Proceedings of the **14th International Congress of Speleology**

21-28 August 2005, Athens, Kalamos, Hellas

Volume 1

INTERNATIONAL UNION
OF SPELEOLOGY (UIS)

ΥΠΟΥΡΓΕΙΟ ΠΟΛΙΤΙΣΜΟΥ
HELLENIC MINISTRY OF CULTURE

wonderful
Greece   MINISTRY OF TOURISM
GREEK NATIONAL TOURISM ORGANISATION

PROBANK
ΠΡΟΤΥΠΟ ΣΥΝΕΤΑΙΡΙΑΣ

THE NATIONAL CAVING ORGANIZATION OF GREECE

Since 1950

HELLENIC SPELEOLOGICAL SOCIETY

32, Sina str., Athens 10672, Greece / tel. +30 210 3617824
www.speleologicalsociety.gr / e-mail: ellspe@otenet.gr

*Proceedings of the 14th International
Congress of Speleology,
21-28 August 2005, Kalamos, Hellas*

Volume 1

Athens 2005

TABLE OF CONTENTS Vol. 1

TABLE OF CONTENTS Vol. 2

Introduction

14th INTERNATIONAL ATHENS 2005 CONGRESS OF SPELEOLOGY

of the INTERNATIONAL UNION OF SPELEOLOGY (UIS)

21-28 August 2005, Kalamos, Hellas

**WITH THE SPONSORSHIP OF THE
HELLENIC MINISTRY OF CULTURE
AND THE
HELLENIC MINISTRY OF TOURISM DEVELOPMENT
HELLENIC NATIONAL TOURISM ORGANIZATION**

UNDER THE AEGIS OF THE CITY OF ATHENS

**Congress Organization:
HELLENIC SPELEOLOGICAL SOCIETY
HELLENIC FEDERATION OF SPELEOLOGY
In collaboration with the
EPHORATE (DEPARTMENT) OF PALEOANTHROPOLOGY AND SPELEOLOGY,
HELLENIC MINISTRY OF CULTURE**

Cover photos by George Avagianos
Best Speleo Photo Awards
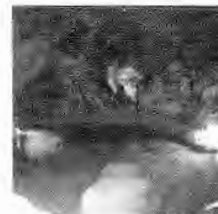
14th INTERNATIONAL ATHENS 2005 CONGRESS OF SPELEOLOGY

of the INTERNATIONAL UNION OF SPELEOLOGY (UIS)

21-28 August 2005, Kalamos, Hellas

WITH THE SPONSORSHIP OF THE
HELLENIC MINISTRY OF CULTURE
AND THE
HELLENIC MINISTRY OF TOURISM DEVELOPMENT
HELLENIC NATIONAL TOURISM ORGANIZATION

UNDER THE AEGIS OF THE CITY OF ATHENS

Congress Organization:
HELLENIC SPELEOLOGICAL SOCIETY
HELLENIC FEDERATION OF SPELEOLOGY
In collaboration with the
EPHORATE (DEPARTMENT) OF PALEOANTHROPOLOGY AND SPELEOLOGY,
HELLENIC MINISTRY OF CULTURE

The 14th International Congress of Speleology was

dedicated to the memory of

John and Anna Petrochilos

who founded the Hellenic Speleological Society and

for more than 50 years worked for the exploration

and recording of more than 8000 caves in Greece

U.I.S. BUREAU 2001-2005			
Honorary Presidents	Paolo FORTI (Italy) Hubert TRIMMEL (Austria)	President	José Ayrton LABEGALINI (Brazil)
UIS Past-Presidents	Arrigo A. CIGNA (Italy) Adolfo ERASO ROMERO (Spain) Derek C. FORD (Canada) Paolo FORTI (Italy) Mrs. Julia Mary JAMES (Australia) Hubert TRIMMEL (Austria)	Vice-Presidents	Andrew James EAVIS (Great Britain) Alexander KLIMCHOUK (Ukraine)
UIS Bureau Honorary Members	Maurice AUDÉTAT (Switzerland) Reno BERNASCONI (Switzerland) Arrigo A. CIGNA (Italy) Adolfo ERASO ROMERO (Spain) Paolo FORTI (Italy) Mrs. Julia Mary JAMES (Australia) Vladimír PANOŠ (Czech Republic) Hubert TRIMMEL (Austria)	Secretary General	Pavel BOSÁK (Czech Republic)
		Secretaries Adjoint	Roman HAPKA (Switzerland) George HUPPERT (USA) deceased 2001 George VENI (USA) from 2002 Andrej MIHEVC (Slovenia) Claude MOURET (France) Fadi NADER (Lebanon) Armstrong OSBORNE (Australia) Linhua SONG (China P.R.) Abel VALE (Puerto Rico)

Introduction by Andrew J. Eavis, President UIS

It is with great pleasure and an element of relief that I introduce these Proceedings for the 14th International Congress of Speleology. The Congress took place exactly in the same manner as the Olympic Games, the previous year; the Congress was very successful in almost every respect other than it was rather short of delegates. Those 500 or so speleologists from the entire world who did attend had an excellent time and there have been very few complaints.

The Programme of lectures was extensive as you will read in the Proceedings; particular highlights for me were landmark papers on Speleo-Paleo History, particularly on Speleothems and films and reports on some of the sport's most dangerous and difficult expeditions including, of course, the discovery of the first 2000m deep cave, Krubera.

Social events during the Congress were as ever very successful and all with an excellent informal atmosphere, which is always the trademark of speleological parties.

Andy Eavis

CONGRESS PREPARATION

The decision for the organization of the 14th International Congress of Speleology in Greece was voted at the 13th Congress in Brazil in 2001. The Organizing Committee was then formed and the process of the preparation of the Congress started; a series of meetings with the UIS Bureau members took place to discuss the various aspects of the organization.
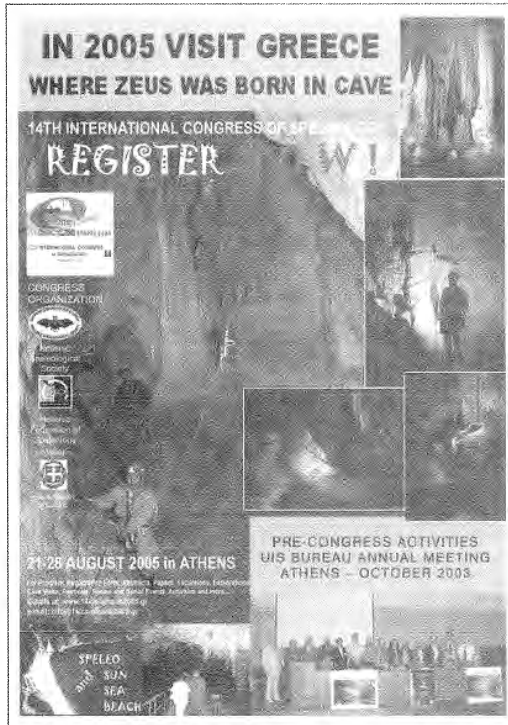
The venue for the 14th ICS was eventually selected to be the small seaside resort town of Kalamos, a short distance north of Athens, in Attica.

The Congress accommodation hotels were either on the beach or very near, and a camping / dormitory facility was nearby.

LEFT: One of the first posters announcing the 14th International Congress of Speleology

ORGANIZING COMMITTEE of the 14th U.I.S. International Congress of Speleology	
President	Dr Petros **THEMELIS**, Professor of Classical Archaeology, University of Crete, Former Director of the Palaeoanthropology and Speleology Ephorate, Hellenic Ministry of Culture, current President of the Scientific Society for Messinian Studies
1st Vice-President	Dr Elias **MARIOLAKOS**, Em. Professor of Geology, Athens University, President of the Hellenic Geological Society, Member of the Central Archaeological Council of the Hellenic Ministry of Culture, Foreign Member of the Russian Academy of Natural Sciences
2nd Vice-President	Dr Athina **ZAMANI (Mrs.)**, Em. Professor of Geography, Athens University, President of the Hellenic Geographical Society
General Secretary	Christos **PETREAS**, MBA (USA), Business and Tourism Economist, SME and Tourism Development Consultant, EU Expert, Vice-President of the Hellenic Speleological Society
Treasurer	Evangelos **TSIMBANIS** : Mathematician, Educator, Gen. Secretary of the Hellenic Speleological Society
Members	Dr George Antonopoulos, Medical Doctor, Head Director of the Gynecological Dept. of the Oncological Hospital of the Institute of National Insurance, President of the Hellenic Speleological Society
	Konstantinos Zoupis, President of the Hellenic Federation of Speleology, Vice-President of the Balkan Speleological Union
	Iakovos Karakostanoglou, (MSc Geology), Physicist, Educator, Special Secretary of the Hellenic Federation of Speleology
	Dr Nick Symeonidis, Em. Professor of Palaeontology, Athens University, Former President of the Hellenic Speleological Society, Chairman of the Scientific Committee
	Ex officio: **Stavroula Samartzidou (Mrs.)**, Archaeologist, Director of the Paleanthropology and Speleology Ephorate, Ministry of Culture
UIS Bureau	Ex officio: Andrew James Eavis, Senior UIS Vice President

With more than 10,000 recorded caves, Greece still has many unexplored that are awaiting eager speleologists. All types of karst are found throughout the mainland and islands. Caves are precious archives of nature that provide valuable information. Caves in Greece are especially known as rich archaeological and palaeontological sites, as well as for some outstandingly beautiful show caves. Speleology in Greece started with the first recorded exploration in 1841. Modern Greek Speleology has its roots in the 1950 founding of the Hellenic Speleological Society and has been continuously developing since, with the founding of the Hellenic Speleological Federation in 2001 and the Balkan Speleological Union in 2002.

The **3rd SYMPOSIUM on CAVE ARCHAEOLOGY, GEOLOGY & PALAEONTOLOGY -**
"New perspectives in Archaeological, Geological and Palaeontological research in Caves", *took place in Athens in October 2003. The Symposium was well attended by more than 100 participants, while about 50 papers were presented.*
The Symposium was an opportunity for UIS Bureau members to meet with various representatives of Greek speleo groups. The Symposium was also attended by Mr. Roman Hapka, UIS Bureau member and President of the Archeology and Paleontology in Caves Commission.

In the previous Symposium photo standing from left to right

Gen Secretary, Mr. Evangelos Tsimbanis HSS Gen. Secretary and Treasurer 14th ICS Org. Committee, Prof. Hubert Trimmel (Austria) UIS Bureau, former President, Mr. Linhua Song (China) UIS Bureau, Dr. George Veni (USA) UIS Bureau, Dr. Andrej Mihevc (Slovenia) UIS bureau, Mr. Pavel Bosák (Czech Republic) General Secretary UIS, Mrs. Stavroula Samartzidou - Archaeologist, Director of the Paleanthropology and Speleology Ephorate - Hellenic Ministry of Culture, Dr. Petros Themelis - Professor of Classical Archaeology, Former Director of the Palaeoanthropology and Speleology Ephorate - President 14th ICS Org. Committee & Symposium President, Mr. Costas Zoupis - President of the Hellenic Federation of Speleology (HFS), Mr. Jose Labagalini - President of UIS, Dr. George Antonopoulos HSS President, Mr. Andy Eavis Vice-President of UIS.

SPELEO NATIONS EXHIBIT during Athens Olympic Games 2004

*Following a proposal by the Organizing Committee, a number of speleologists volunteered for putting together the **"Speleo Nations Exhibit"** which was displayed at the Olympic Townships of Alimos and Palaio Faliro during the 2004 Olympic Games. Even though all the countries were invited to send posters, only a few responded within the deadline.*
The Exhibit poster-panels (2 ½ m. high) were set-up on the boardwalk near the beach access of the two townships; and in one case next to the tramway station. All the countries that responded to the call were presented. HSS put together an "Exhibition Team" whose members mounted the display panels and setup the exhibition at the two coastal sites.
The 14th ICS Organizing Committee thanks all the participating countries and speleological organizations for their response.

The Poster of Great Britain

The Poster of Korea

The Poster of Samcheok City

The Poster of Croatia

The Poster of Japan

The Poster of Austria

The Poster of Jeju Island

The Poster of Romania

The Poster of Poland
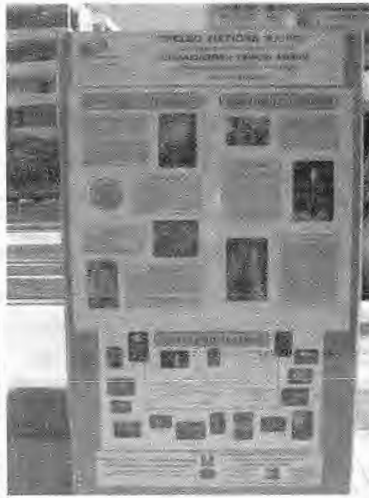
The Poster of HSS   The Poster of Ireland   The USA Poster
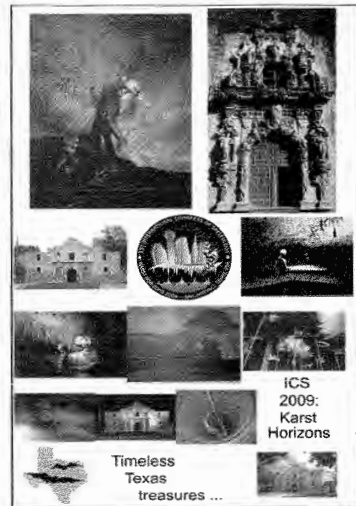
The Speleo Exhibit at night next to the Tramway Station was a point of focus of the passengers coming for the beach and the coastal area facilities, both during daytime and at night

"WHAT IS THE UIS" by Jose Labegalini, UIS President 2001-2005 (extract from the Congress Circular)

The acronym UIS stands for the Union Internationale de Spéléologie, in the original French. The UIS is a non-profit, non-governmental organization which promotes interaction between academic and more technical speleologists of a wide range of nationalities to encourage and facilitate the coordination of international speleology and promote its development, whether scientific, technical or cultural.

Speleology only took its first steps towards becoming a recognized science at the end of the 19th century. In the mid-1900′s, the international speleological community, mostly Europeans, had the idea to hold an international speleological congress, and the first was organized in Paris, France, in 1953. Since then, international speleological congresses have been held in Italy (Bari-1958), Austria (Wien-1961), Yugoslavia (Ljubljana-Postojna-1965), Germany (Stuttgart-1969), Czechoslovakia (Olomouc-1973), Great Britain (Sheffield-1977), USA (Bowling Green - 1981), Spain (Barcelona-1986), Hungary (Budapest-1989), China (Beijing-1993), Switzerland (La Chaux-des-Fonds-1997), and Brazil (Brasilia, 2001).

The initiative of some of the speleologists at the 1965 congress led to the proposal of the creation of an international entity to unite speleologists from all over the world and coordinate their activities. The UIS was then founded on September 16, 1965, during the closing session in the Festival Room of the Postojna Cave during the 4th International Congress of Speleology. The first statutes were approved, and the first board of officers elected: Bernard Gezè (France) as President, Gordon T. Warwick (England) as Vice-President, Stjepan Mikulec (Yugoslavia) as second Vice-President, and Albert Anavy (Lebanon) as General Secretary.

In order to supervise the work of exploration and international expeditions, the UIS instituted a Code of Ethics. This code, although it does not have the force of law, provides ethical guidelines for such activities to promote the development of speleology, increase our knowledge about international speleological heritage, and foster interactions between speleological communities.

THE CONGRESS

AUGUST 2005 IN GREECE:
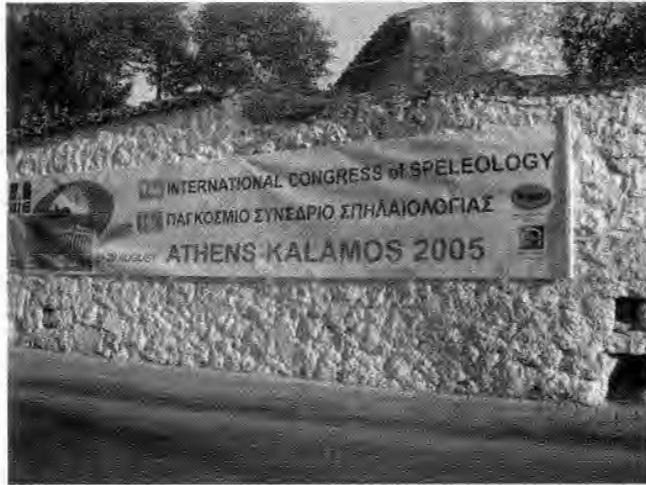
539 registered participants coming from 51 countries, set the background for a productive Congress, in excellent weather, at the peaceful resort of Kalamos, in the outskirts of Athens on the beach.

14th UIS INTERNATIONAL CONGRESS OF SPELEOLOGY PROGRAMME	
12-20th August 2005	Pre-Congress excursions (start dates will vary but all will end in Athens on 21 August 2005)
Sunday 21st August 2005	First day – registrations Opening Reception
Monday 22nd August 2005	Sessions – meetings – Congress activities Opening of Photo Exhibit and "Speleo Stands"
Tuesday 23rd August 2005	Sessions – meetings – Congress activities Organizational assemblies / meetings
Wednesday 24th August 2005	Relaxation day: Day trip, Show cave visit Peloponnese
Thursday 25th August 2005	Sessions – meetings – Congress activities Evening Festival – Greek night
Friday 26th August 2005	Sessions – meetings – Congress activities Organizational assemblies / meetings Gala Dinner
Saturday 27th August 2005	Sessions – meetings – Congress activities Congress closing
Sunday 28th August 2005	Post-Congress excursions – Participants' departures

COUNTRY	No.
ALGERIA	2
ARGENTINA	2
ARMENIA	17
AUSTRALIA	12
AUSTRIA	1
BELGIUM	18
BOSNIA	1
BRAZIL	10
BULGARIA	5
CANADA	6
CROATIA	3
CZECH REPUBLIC	8
FRANCE	39
GERMANY	11
GHANA	4
GREECE	45
HUNGARY	10
IRAN	5
ISRAEL	1
ITALY	34
JAPAN	8
JORDAN	1
LEBANON	19
LUXEMBOURG	2
MEXICO	6
NEW ZEALAND	2
NIGERIA	2
NORWAY	15
P. R. CHINA	3
POLAND	6
PORTUGAL	13
PUERTO RICO	5
REP. DEM. CONGO	1
ROMANIA	12
RUSSIA	11
SERBIA & MONTENEGRO	5
FYROM	1
SLOVAKIA	7
SLOVENIA	12
SOUTH KOREA	9
SPAIN	17
SWEDEN	9
SWITZERLAND	8
TANZANIA	2
THE NETHERLANDS	3
TOGO	2
TURKEY	10
UNITED KINGDOM	24
UKRAINE	5
USA	64
VENEZUELA	2
Undeclared	17

33

14th INTERNATIONAL CONGRESS OF SPELEOLOGY

OPENING CEREMONY
MONDAY 22 AUGUST 2005

09:00	Arrival of congress participants Speleological photo show
10:00	Arrival of Deputy Minister for Tourism H.E. Mr. A. Liaskos
	Receiving the Deputy Minister and other political officials: Prof. Petros Themelis, President of the Organizing Committee Mr. Christos Petreas, General Secretary of the Organizing Committee Mr. Jose Labegalini, President of UIS – Union Internationale de Spéléologie Mr. Andrew James Eavis, Senior Vice-President of UIS – Union Internationale de Spéléologie & Ex-Officio Member of the Organizing Committee Mr. George Antonopoulos MD, President of the Hellenic Speleological Society Mr. Konstantinos Zoupis, President of the Hellenic Federation of Speleology
10:30	Opening Ceremony of 14th International Congress of Speleology Masters of Ceremony: Mr. Andrew Eavis & Mr. Christos Petreas

	Official Introduction / Welcome	Prof. Elias Mariolakos, Organizing Committee 1st Vice-President
	Official Opening of Congress	H.E. Mr. Anastasios Liaskos Deputy Minister for Tourism
	Welcome from the Ministry of Culture	Mrs. N. Kyparissi, Director of Prehistoric and Classical Antiquities, Ministry of Culture
	Welcome from the Organizers	Mr. George Antonopoulos, President of the Hellenic Speleological Society Mr. Konstantinos Zoupis, President of the Hellenic Federation of Speleology
	Welcome from the UIS - Union Internationale de Speleologie	Mr. Jose Labegalini, UIS Bureau President
11:00	Official inauguration of Exhibits and Stands International Speleological Photo Exhibit and Special Photo Exhibit of HSS Cave Exploration in Evia Island Exhibit Stands by National Associations, Clubs, Organizations, and Speleo Groups	H.E. Mr. Anastasios Liaskos Deputy Minister for Tourism Mr. J. Labegalini, UIS President, Mr. Andrew Eavis, UIS Senior Vice President, Prof. E. Marilakos, 1st Vice President, and Mr. Christos Petreas General Secretary, 14th ICS Organizing Committee, Mr. George Antonopoulos, President of the Hellenic Speleological Society Mr. Konstantinos Zoupis, President of the Hellenic Federation of Speleology other UIS, international and Greek officials
11:30	Press Interview by Deputy Minister, UIS and Greek officials	

SPELEO AWARDS

14th ICS ATHENS 2005 – SPELEO AWARDS	
Publications Awards	Special Prize: *The Encyclopedia of Caves* Edited by David C. Culver and William B. White, Published by Elsevier, 2005
	Special Prize: *Encyclopedia of Caves and Karst Science* Edited by John Gunn, Published by Fitzroy Dearborn, 2003.
	1st) *Speleo-karstologie et environnement en Chine*, Publisher: FFS & Association Française de Karstologie, 2004, Authors: Richard Maire, Jean-Pierre Barbary, Zhang Shouyue, Nathalie Vanara, Jean Bottazzi
	2nd) *Die St. Beatus-Hohlen*, Publisher - Speleo Projects, 2004, Editor - Philipp Hauselmann
	2nd) *Beneath the Cloud Forest - A History of Cave Exploration in Papua New Guinea*, Publisher - Speleo Projects, 2003, Author - Howard M. Beck.
Best Film Awards	1st) International Cave exploration team - CaveX Team and film studio (Krylia Rossii) "Speleology: a Journey to the Centre of Earth": The exploration of the 2080 m deep Voronia- Krubera Cave in summer 2003.
	2nd) N. Chalkiopoulous and K. Adamopoulos, "Anogeia 2002 - Caving expedition in Crete".
	3rd) Ian Ellis Chandler, "In Sight of Light".
Best Posters Awards	1st) "Origin and diagenesis of cave corals in the lava tubes of Jeju Island, Korea" K.C. Lee, D.W. Choi and K.S. Woo.
	2nd) "Conservation of Ballet cave, Brazil", H. David
	2nd) "The Svarthammar project", North Norway, S. E. Lauritzen, L. Baastad and J. Bjorlier.
Best Pictures Awards	1st) Robbie Shone, "Titan taken from roof dome 145 meters above floor level showing the breakthrough window where the surface shaft connects"
	2nd) George Avagianos, "Cave of Lakes"
	3rd) George Avagianos, "Reflecting drops"
Best Portfolio Awards	1st) George Avagianos, "Caves of Greece"
	2nd) Michael Queen, Stuart Kogod & Jack Soman, "Guadalupian images by Karst Features"
Best Discovery and Exploration Awards	1st) The "Krubera Cave", Abkhazie, in Georgia -2080 m deep; the first cave situated deeper than 2km Expedition "The Call of the Abyss" group of the Ukrainian Speleological Society
	Honour prize: The exploration of "L'Ardèche souterraine", France. More than 60 km of submerged galleries had been connected

35

Former UIS President Prof. Mrs. Julia James made the award presentations. In her speech to the participants and the awardees, she stated (in summary):

It is with great pleasure and I'm very honoured to be able to present both the speleomedia and the UIS prizes. It's been a novel experience for me and for all categories we had an international team of judges.

First we will start with the films and there is no doubt that the film made of the history of the exploration of Cuba is one of the most important events of the new millennium and this period of UIS history.

There were many novel and new attempts of making films and here I'd like to mention that the Lebanese are rather novel and surprising entry.

The next prize was very-very difficult, for both slides and pictures and prints. We had to judge them together and it was very hard because we would have awarded two gold, if we had two gold prizes; but we feel the pictures of Titan shaft by Robby Shone of the U.K. were in fact fantastic and very fitting for an expedition theme, so we awarded the gold to these.

For George Avagianos we would like to give the second and third prize, the pictures were magnificent; without doubt they are the best slides I've seen in a long time. George also presented a fantastic portfolio and not that many of you were there to see the pictures of Greek caves which are superb.

And the second prize goes to the "Guadalupian images by karst features".

If there is anything more fun than actually taking the pictures it's having a chance to share them with people who enjoy them. All I want to say is that speleology is also an art as well as a science.

I think the speleomedia revealed quite clearly that caving is a cooperative sport and to produce anything is a great cooperative effort. We, as UIS, would like to make two special awards, in this Congress, we would like to honour the "Encyclopedia of Caves", which has been edited by David Culver and William White and it has many excellent articles.

Everybody knows that this has been a real active period in book publishing and we would like also to honour John Gunn as editor of the "Encyclopedia of Caves and Karst Science". I assure you they are not the same. Both books are very valuable contributions to science and we, as UIS, are happy to honour these publications.

Now, you all know that there is a UIS book prize. We must recognize that the prizes really are to encourage groups to publish; judging this time has been exceptionally difficult, because in the period 2001 to 2005 there have been many excellent publications. We have however an outstanding winner which both covers karst and environmental science. But there are other books that we feel deserve honourable mention.

Next we have the prize for the best poster and they were a great team effort to organize and to count the votes. Again it was a very difficult task; however they were three outstanding entries that got an average of a hundred and fifty votes each, that's very good.

Finally we come to the discovery prize. The hottest prize of all because in 2001 in Brazil the prize was awarded to the same cave, during this period it is beating its own record and gone even deeper: it is the first over two kilometer deep cave. When I was president I requested that the cave team to go out and find me at two thousand meter deep cave, they are a bit late but I can still make the award.

We felt that something that was a very late entry and in fact was entered as a film, was an exploration which was equally difficult; we felt very much that the under water explorations connecting scientifically and by diving, the passages of the Ardèche River, merited a prize.

This major job is over, so I can hand back to the Organizing Committee, but I may first of all acknowledge the help I've had from a small group of persons, the international experts that have judged with me, and I think we should always include in the final general assembly a celebration like this.

CONGRESS CLOSING

*The 14th Congress also was the scene for the change of the UIS Presidency from Latin America to Europe. **Andrew James Eavis**, until now Senior Vice President, was unanimously elected the new President of UIS. The new President is a well known British explorer and avid speleologist.*

The two UIS Presidents

Acceptance Speech by new UIS President Mr. Andrew J. Eavis (Extracts)

Ladies and Gentlemen,

It is with enormous pleasure that I accept the post of UIS President. I am particularly pleased to be taking over from a President who has handled it so well for the last four years and left many things – particularly the necessary bureaucracy – in a very good state.

In addition, I am delighted that we have such a wonderful team to be steering the UIS over the next four years. It is with some sadness that we see Pavel Bosak reduce his role but it is great to know that the job is being taken by a very capable and energetic youngster, Fadi Nader. Pavel has promised to continue helping from the sidelines.

In addition the choice of the USA for the next Congress – under the leadership of George Veni – gives me a great deal of confidence for the future and I am sure will be as good as this Athens/Kalamos Congress, but attended by rather more people. The Americans have assured us that they will do everything within their powers to improve the situation regarding visas and travel. We must all hope that there are no political incidents before July 2009!

Many thanks again to the organizers of this Congress. I think it has been one of the most enjoyable ever with some of the best science ever. Thanks particularly to all the persons involved who worked as a team, and pulled it all together on the day! We must not, of course, forget the input of the Hellenic

Speleological Society and the Hellenic Speleological Federation. On a personal level, I should like to thank George Antonopoulos, Christos Petreas, Kostas Adamopoulos and Kostas Zoupis who along with other members of the Society and Federation have given me so much support and help during my numerous visits to Greece over the last two years.

I look forward to visiting Greece on holiday – maybe next year – to spend some quality vacation time in the country!

I look forward immensely to the four years ahead. A final thanks to everyone who has supported me in the past.

Andy Eavis
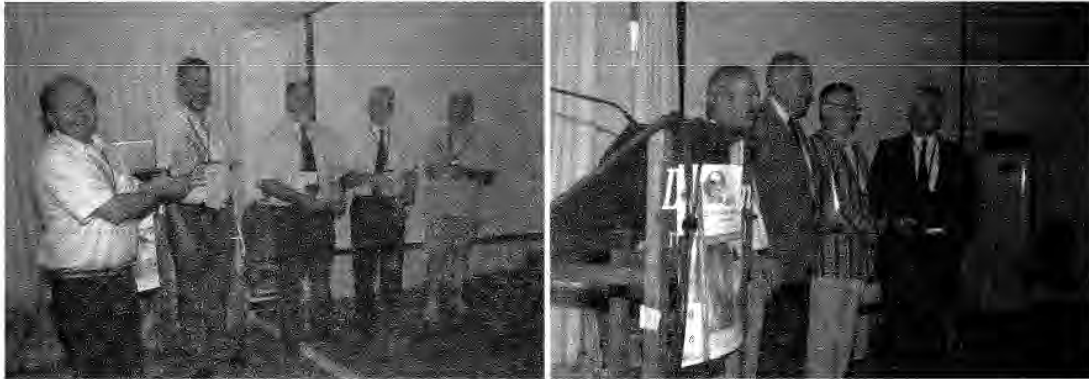
The Congress Organizers made special presentations to UIS Bureau members.
Making the presentations Dr. Antonopoulos President of HSS and Mr. Zoupis President of HFS.
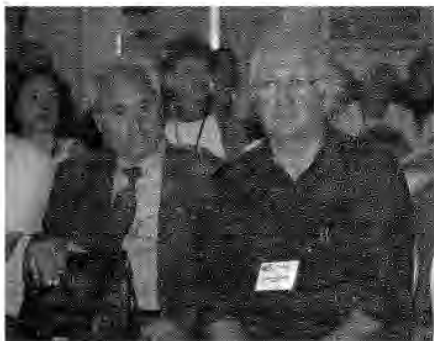
RIGHT: President of the Organizing Committee Prof. Themelis exchanging views with former French Federation of Speleology FFS President, Philippe Brunet

LEFT: 14 ICS Organizing Committee President and Vice President follow the proceedings

An important aspect of each "ending General Assembly" is the voting for the next Congress. In this case there was one candidate, the USA, whose senior representative, Dr. George Veni – Member of the UIS Bureau, made a very descriptive presentation, following which, the official voting representatives, unanimously selected the USA for the organization of the 15th International Congress of Speleology.

The logo of the next 15th ICS in the USA

Many UIS Officials together

O-1

Study of karst development and possible leakage from the sazbon dam, Iran

Raeisi, E., Aghdam, J., Zare, M, and Karimi, H.

Department of Geological Science, Shiraz University, Shiraz, Iran

Abstract

The Sazbon Dam site is located on Seymareh River in the upper parts of Karkheh Basin, Ilam province, west of Iran. The dam will be constructed on karstified Asmari Formation and part of the reservoir will be in direct contact with this formation. The Asmari Formation is sandwiched between the two impermeable marly formations of Pabdeh-Gurpi and Gachsaran. In 18 piezometers constructed for this purpose, the water level was measured daily during the wet season and once per week in the dry season for a period of 10 months. The major ions, electrical conductivity and temperature were measured six times in all the piezometers, springs and six locations within the Seymareh River. Based on the water level in piezometers, the direction of flow is determined to be from the dam abutments towards the Seymareh River. The piezometers were classified based on the geochemistry and permeability. Ten kilograms of uranine were injected in a 200 meter deep borehole in the right abutment and inside the reservoir. This borehole, constructed in the Upper Asmari Formation, had very high permeability. All the piezometers, springs and the six locations of Seymareh River were sampled for five months. The dye concentration was measured by a Schimadzo Spectrofluorometer. Dye was detected in four boreholes on the left abutment, two of them downstream the dam site. The dye tracing revealed that the water flows against the dip of the Lower and Upper Asmari Formations. The dye velocity was in the range indicative of a diffuse regime. Two alternative schematic models of flow direction and karst development were proposed based on the dye tracing results. One of the models was selected as the most probable alternative based on dye tracing, water table level, electrical conductivity, permeability, and geological setting. The karst aquifer in the Sazbon Dam area may still have a conduit system in spite of the dye tracing results. The low gradient of ground water level, valley development by Seymareh River, high permeability of boreholes, lack of specific discharge points, limited information from only one dye tracing, combination of diffuse and conduit flow in the flow route, and characteristics of the Asmari Formation in other regions of Zagros are collective evidences of possible conduit flow in the Sazbon Dam site.

Introduction

Leakage from dam reservoirs in karst terrains has been reported for many dams all over the world. The prerequisite to a safe and reliable dam reservoir is the proper understanding of the aquifer characteristics and the karst conduit system. The Sazbon Dam will be constructed in the west of Iran, with a height of 152 m and a reservoir capacity of 1.6 billion cubic meters. The reservoir will extensively be in direct contact with the karstic Asmari Formation. The objective of this study is to determine the flow regime(s) (diffuse and/or conduit) and to present a schematic model for flow direction in the karstic formation of Sazbon Dam, using sodium fluorescein dye tracer.

Hydrogeology of the Study Area

The study area, the Lina Anticline, is located in the Zagros Simply Folded Zone, Ilam Province, west of Iran. The exposed core of the Lina Anticline in decreasing order of age is made of Tertiary Pabdeh-Gurpi

(marl and shale), Tertiary Asmari Formation (karstified limestone), Tertiary Gachsaran Formation (gypsum and marl) and Pliocene Conglomerate (Fig. 1). The Asmari Formation is divided into the Lower and Upper Asmari (Mohab Ghods, 1996). The more extensive surface karst features and massive thickness of the Upper Asmari imply that it is more capable of karst development than the Lower Asmari. The Seymareh River flows on the surface of the Gachsaran Formation, and through a narrow valley in the Asmari Formation (Fig. 1). The Sazbon Dam will be constructed on the Lower Asmari Formation of the northern flank of Lina Anticline. The reservoir water will extensively be in direct contact with the Asmari Formation and may thus leak via the possibly existing small conduits in the Asmai Formation, and consequently to the downstream sections of the Seymareh River.
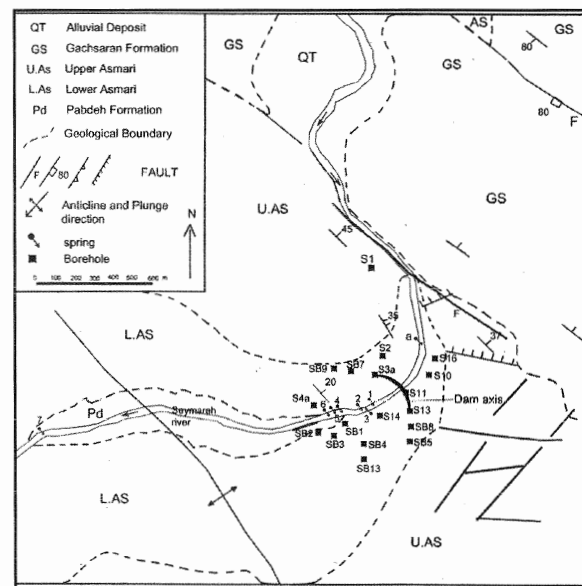
Figure 1. Geological map of the study area

Method of Study

The major ions, electrical conductivity (EC) and temperature were measured six times in all piezometers, springs and six locations within the Seymareh River. The water level in 28 piezometers was measured daily during the wet season and once per week in the dry season for ten months. An injection borehole (S_1), with a depth of 200 m, was constructed inside the reservoir on the Upper Asmari (Fig. 1). The depth to water table was about 120 m in this borehole. The permeability of S_1 was more than 100 lugeon in most parts. Ten kilograms of sodium fluorescein were injected into the S_1 borehole. Injection of water into the borehole at a rate of 1 l/s was continued for 20 days in order to push the dye into the conduit system. Water samples were collected from 14 boreholes, 7 springs, and 7 sections of the Seymareh River (Fig. 1) for a period of five months. Bags of activated charcoal were placed in all the resurgences. The sodium fluorescein concentration was measured in all water samples by a Schimadzu spectroflurometer (model RF 5000) with a detection limit of 0.001 ppb.
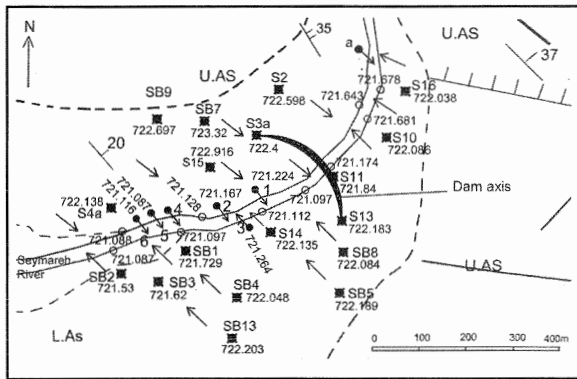
Figure 2. Piezometer's water level above mean sea level and flow direction in the study area (Aug. 24. 2004)
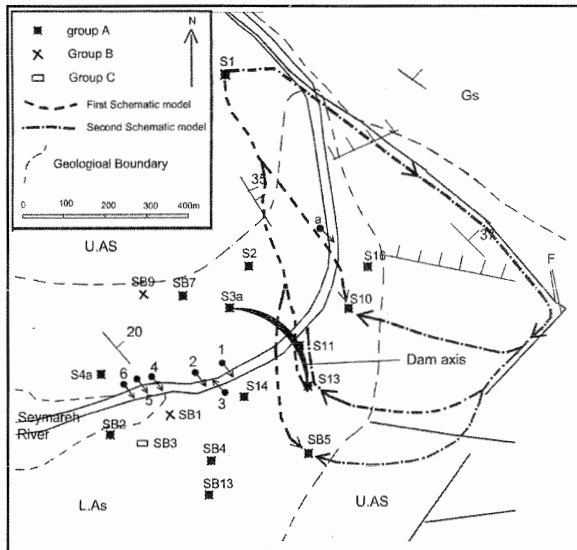
Figure 3. Schematic model of flow direction and classification of boreholes in the study area
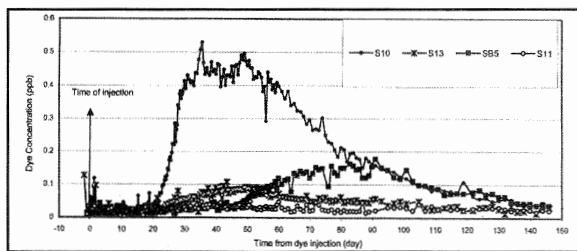
Figure 4. Dye concentration versus time in the S_{10}, S_{13}, S_{11} and SB_5 boreholes

Result and Discussion

The water level in the piezometers shows that the flow direction in the dam site is towards the river with a hydraulic gradient of 0.001 (Fig. 2). EC increases towards the river, but the EC of the river itself is lower than the EC of the boreholes near the river, implying that river-water does not flow into the adjacent aquifer. Based on the dominant permeability, the boreholes are classified to three groups (Fig. 3), A (50 to 100 Lugeon), B (10 to 50 lugeon), and C (less than 10 Lugeon). Group C includes only SB_3 and Group B includes SB_1 and SB_9. SB_3 and SB_1 are located in the Pabdeh-Gurpi Formations and SB_9 far from the river. The high permeability of most of the boreholes is indicative of possible karst developments in the damsite. The Seymareh River discharge is more than 150 m³/s in the wet season, which decreases to 50 m³/s in the dry season. No dye was detected in any of the sampling sites except for the S_{10}, S_{13}, S_{11} and SB_5 boreholes. These boreholes are located in the left side of the Seymareh River (Fig. 1). The dye concentration curves of the boreholes are presented in Figure 4. The maximum dye concentration was 0.529 ppb in borehole S_{10}.

The dye was injected in the right side of the Seymareh River, but it was detected in the left side, so it must be flowing below the Seymareh River. Two alternative models of flow direction are proposed (Fig 3). In model A, water from the injected borehole flows from the Upper Asmari to the Lower Asmari in the left side of Seymareh River (Fig 5). Part of the water joins the Seymareh River and a part flows below the Seymareh River towards the right side of the river, being detected in the S_{10}, S_{13}, S_{11}, and SB_5 boreholes.
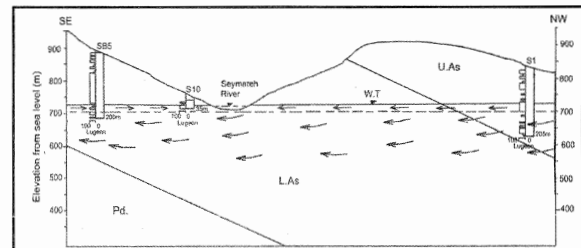
Figure 5. Schematic flow direction in model A (flow direction ®)

The dye was not detected in the Seymareh River, because it was diluted by the high flow of the Seymareh River to values below the detection limit by the spectrofluorometer. The flow velocity of this model ranged from 1.15 to 2.03 m/h based on the first appearance of dye in the boreholes, and 0.67 to 0.97 m/h based on time to peak dye concentration, assuming a tortuosity of 1.5. The isopotential map shows that the direction of flow is from the left side of the Seymareh River towards the river while the dye flows beneath the river, being observed in the boreholes on left side of Seymareh River (Fig.5). The flow of groundwater in two different directions is hydraulically possible (Freeze and Cherry1979), but it requires discharging points for each direction. This seems to be an unlikely model for the following reasons:

1. The S_2 borehole is located near the path of this model, therefore the dye is expected to be detected in this borehole, at least as a result of dispersion.

2. The groundwater must have a discharging point after flowing beneath the Seymareh River. No discharging points can be determined for this model.

3. The flow route is mainly through the Lower Asmari Formation, which is less karstified than the Upper Asmari Formation.

In the second model (B), the water of the injected borehole flows towards the left side of Seymareh River in the upstream region (Fig. 3). Part of the water joins the Seymareh River and part flows below the river. The dye was not detected in this part of the river because the flow of Seymareh River reduced the dye concentration below its detection limit by the spectrofluorometer. The water then moves against the dip of the Upper Asmari Formation parallel to the Seymareh River. Small fractures transfer

the water to the area of the S_{10}, S_{13}, S_{11}, and SB_5 boreholes and finally to the river itself. This model is based on the following reasonings:

1. Water flows in the Upper Asmari Formation in most parts of its route. This formation is more capable of karst development than the Lower Asmari.

2. The direction of water from the right side to the left side corresponds with bedding planes and a fault.

3. Several small faults perpendicular to the dip of the Upper Asmari Formation increase the chance of a water route in this direction.

4. The water table level and EC maps confirm the flow direction of the proposed model in the region of the damsite on the left side of Seymareh River.

5. The discharging points are the Seymareh River, but the dye cannot be detected in the river because of high Seymareh River flow rates.

In model B, the flow velocity in all the boreholes varies from 1.7 to 3.27 m/h based on the first appearance of the dye, and from 0.94 to 1.64 m/h based on the time to peak dye concentration. What follows justifies a diffuse flow regime in the dam site area based on the dye tracing results:

1. Flow velocities through karst conduits for straight lines of more than 10 km range from 4.5 to 1450 m/h (Aley, 1973; Bakalowicz, 1973; Kruse, 1980; and Williams, 1977). Millanovic (1981) reports that from 281 dye tests carried out in Dinaric karst, flow velocities varied over a range of 7.2 to 1880 m/h. Velocities less than 18 m/h involve long underground retentions (Ford and Williams, 1989). The maximum velocities of both models are less than 3.27 m/h based on the first appearance of dye, and less than 1.64 m/h based on the time of peak dye concentration, therefore it may be concluded that the type of flow is mainly diffuse.

2. No cavities were observed in any of the boreholes.

3. No sinkholes were evident on the Asmari Formation outcrops.

Determination of the flow type is mainly based on the results of dye tracing, but other criteria suggest that a conduit system may well exist in the study area:

1. The valley has developed by the action of the Seymareh River. This river was in direct contact with the different sections of Asmari Formation for a long period, and the river water flowed inside the joints and bedding planes, especially during high floods, making possible the development of a conduit system.

2. The slope of water table on both sides of the Seymareh River is about 0.001, which denotes the development of karst above the water table. The Seymareh River acts as a base of erosion, therefore the recharge water must be discharged in the Seymareh River.

3. The dye tracing results are only applicable below the water table. The permeabilities of most of the boreholes above the water table are in the range of 50 to 120 Lugeon which imply a possible conduit flow above the water table.

4. The injected borehole may be located in a region of diffuse flow, taking the dye a long time to reach the main conduit. The dye-detected boreholes may not be intersected with the main conduit, but the water diverts to the boreholes via small fissures, increasing the dye travel time. In other words, the dye route may be a combination of diffuse and conduit flow, but the longer travel time of a diffuse flow system reduces the average velocity to the range typical of diffuse flow.

5. The detection of dye in a specific discharge point such as a spring is the most reliable method to determine the type of flow regime.

The discharge points are most probably beneath the surface of Seymareh River. The absence of a distinguishable discharge point reduces the credibility of the calculated velocity.

6. Big springs emerge from the Asmari Formation in other regions of Iran, suggesting that this formation has the potential of conduit development (Raeisi et al., 1999; Karimi et al., 2003; and Raeisi, 2004) but the high flow rate and depth of the Seymareh River conceals the springs.

7. The entrance of fossil caves are most probably filled by sediment washes on the steep slopes of anticlines in the Zagros (Raeisi and Laumanns, 2003), therefore, the absence of big caves on the steep slopes of Lina Anticline is not necessarily a proof of diffuse flow in the region.

Dye tracing presents the characteristics of a karst aquifer from the injected boreholes to the dye-detected boreholes. Therefore, it is not capable of determining karst characteristics above the water table and in regions outside of the dye route. It may be concluded that the results of the present study are not conclusive enough to determine the type of flow and degree of karstification in the study area, and consequently, the dimensions of the grout curtain. A short grout curtain may increase the leakage from the reservoir and a long one is very expensive. An extensive study on karst hydrogeology, including hourly variations of water table in boreholes and river level during the wet season, distribution map of surface karst features, valley evolution, water balance of Lina Anticline, geomorphology, and geophysics is required to give a deep insight of the study area. One dye tracing test does not provide enough information to determine the karst hydrogeology of the study area. It is recommended that at least two dye tracings be done on both abutments of the damsite. The dye injected borehole should be located in front of the proposed grout curtain, as close as possible to the dam, thus allowing the determination of karst development before and after the proposed grout curtain.

Conclusions

The future Sazbon dam abutments and part of the reservoir are in direct contact with the karstic Asmari Formation. Dye was injected into a borehole inside the reservoir of this future dam. The dye was detected at low concentrations in four boreholes on the left side of Seymareh River. The dye velocity was in the range of diffuse flow. The most probable schematic flow model is proposed considering the dye tracing results. Based on this model, the water flow path is from the right side to the left side of the Seymareh River in the bedding plane of the Asmari Formation, then it changes its direction perpendicular to the dip of the Asmari Formation. The small fissures transfer the water to dye-detected boreholes and finally to the Seymareh River. The karst aquifer in the Sazbon Dam region may have a conduit system in spite of the dye tracing results. The low gradient of groundwater level, valley development by Seymareh River, high permeability of boreholes, lack of information of specific discharge points, limited information from only one dye tracing, combination of diffuse and conduit flow in the flow route, and characteristics of the Asmari Formation in other regions of the Zagros are collective evidences of possible conduit flow in the Sazbom Dam site. Extensive karst hydrogeological studies and at least two more dye tracings are recommended to determine the possible conduit system in the study area.

search, by the Power and Water Resources Development Company of Iran. Thanks are also due to Shiraz University for providing the facilities and leave-time to work on this research.

References

Aley, T. 1975. A predictive hydrological model for evaluating the effect of land use on the quantity and quality of water from Ozark Spring. Ozark Laboratory, Missouri.

Bakalowicz, M. 1973. Les Grandes manifestations hydrologiques des karsts dans le monde. Spelunca 2. 38-40.

Freeze, R. A. and J. A. Cherry. 1979. Groundwater. Englwood Cliffs, Prentice-Hall, Inc., 604pp.

Ford, D. and P. Williams. 1989. Karst geomorphology and hydrology. Unwin Hymam, London. 601pp.

Karimi, H, E. Raeisi and M. Zare. 2003. Hydrodynamic Behavior of the Gilan Karst Spring, West of the Zagros, Iran. Journal of Cave and Karst Science. Vol. 30, No. 1, pp 15-22.

Kruse, P. B.1980. Karst investigation of Maligne basin Jasper National Park, Alberta. MSc Thesis , University of Alberta, Canada.

Millanovic, P. T. 1981. Karst hydrogeology. Colorado Water Resources Publication.

Mohab Ghods Consulting Engineers. 1999. Engineering Geology Report of the Sazbon Dam. Power and Water Resources Development Company of Iran.

Raeisi, E., M. Zare and P. Eftekhari.1999 . Application of dye tracing for determining characteristics of Sheshpeer karst spring. Theoretical and Applied Karstology, Vol. 11-12, pp. 109-118.

Raeisi, E., and M. Laumanns. 2003. Cave Directory of Iran. Berliner Hohlenkundliche Berichte, ISSN 1617-8572, Berlin.

Raeisi, E. 2004. Iran cave and karst in Encyclopedia of Cave and Karst, Editor John Gunn, Fitzroy Dearborn, New York.

Williams, P. W. 1977. Hydrology of the Waikoropupu Springs: a major tidal karst resurgence in northwest Nelson (New Zealand). Journal of Hydrology, 35, 73-92.

42

O-2

Karst surface symbols: Proposition of a standard symbol set

Philipp Häuselmann

Institut für Bodenkultur, Peter Jordan Strasse 70, 1190 Wien, Austria, praezis@geo.unibe.ch

Introduction

After the successful installation of a standardized cave symbol set in 1999, the idea to standardize also the surface karst symbols was born. In the last five years, the list presented below was created, mostly based on the works of Bini et al. (1986) and Joly (1997). Since symbols at the surface are not only of importance to cavers (and thus to the UIS), the International Geographical Union IGU (John Gunn) as well as the International Association of Hydrogeologists (Heinz Hoötzl) were iinformed and asked for collaboration.

The present list

The list presented below (Figs. 1-3) is the result of a rather long and tedius work involving three iinternational bodies. Most of the ideas that were presented were taken into account, and thus the list is near completion. The presentation here in Greece is thought to give a last opportunity to other input before the list is voted by the national delegates that are represented in the UISIC "Topography and mapping" working group. Any country not having a delegate yet is kindly asked to get in touch with me (address below) in order to be heard.

The list concetrates itself on karst features, and it is meant to be "open". This means that features not covered by the present list may be added (of course it is expected that they be accompanied by a legend!).

The final aim of the list is that karst surface maps have a common and internationally understandable set of symbols.

The future?

After presentation of the list in Athens, eventual ideas and suggestions will be considered. After that, the UIS delegates will vote on the finalised list. Parallel to that the IGU will consult the list. The final vote is expected to be in early spring 2006.
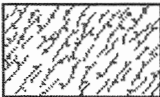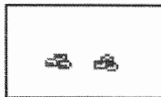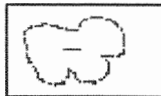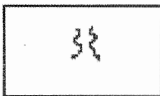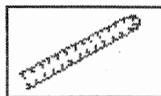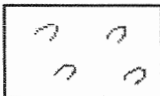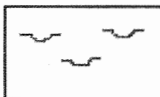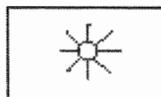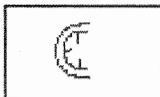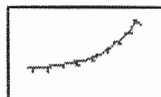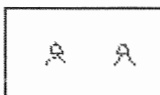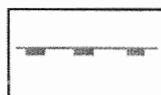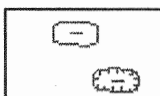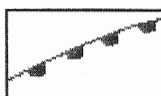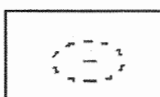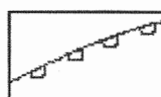
Then, the "Topography and mapping" working group will have to consider another of the many tasks awaiting. Everyone having a question or an idea is welcomed to contact the working group (address of the author).

Bibliography

Bini, A., Meneghel, M. & Sauro, U. (1986): Proposta di legenda per una cartografia geomorfologica delle aree carsiche. - Atti e memorie della Comm. Grotte "E. Boegan" 25, 21-59.

Joly, F. (1997): Glossaire de géomorphologie: base de données sémiologiques pour la cartographie. - Armand Colin, Paris, 325 pp.

Karst surface symbols - conventional signs 1

Karren field		partly eroded doline	
spitzkarren field		field of dolines	
roundkarren field		Uvala	
covered karren field		Uvala with diffuse edge	
Rinnenkarren		Bogaz	
Heel-print karren Trittkarren		whaleback	
Grikes / Crevasses		Chicot	
kamenitsas		cone hill hum, mogote	
nivokarstic niche		small scarp	
Perched blocks		Schichttreppenkarst	
Doline doline with steep slopes		rim of active polje	
Doline rim not well defined		rim of inactive polje	

43

Karst surface symbols - conventional signs 2

Symbol	Description
	undef. rim of act. polje
	undef. rim of inactive polje
	fluviokarstic canyon
	dry valley (V)
	dry valley (U)
	blind valley
	pocket valley
	vertical (vauclusian) spring (penetrable)
	vertical ponor (cave penetrable)
	vertical dry cave
	snow pit
	estavelle (vert./horiz./imp.)

Symbol	Description
	horizontal spring (cave penetrable)
	horizontal ponor (cave penetrable)
	horizontal dry cave
	Limit of underground catchment area
	captured spring (imp.)
	imp. spring (arrow as shown in pocket valley optional)
	ponor (impenetrable)
	stream
	temporary stream
	inactive valley floor talweg
	underground river connection
	cave (underground)

44

Karst surface symbols - conventional signs 3

	roofless cave
	shelter
	natural arch, bridge
	karstic infillings
	speleothems (not tufa)
	tufa
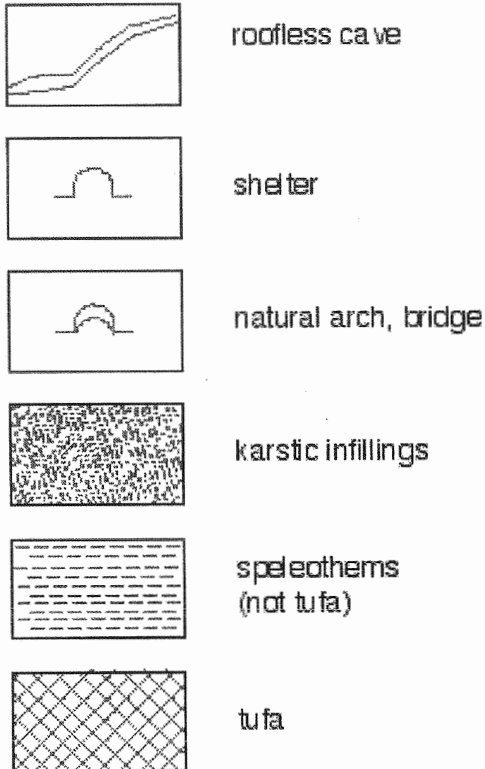
O-3

Factors, conditions and main development stages of the associated paleokarst - kaolin deposits system in northeastern Bulgaria

T.I. Krastev

Abstract

The associated system of paleokarst-kaolin deposits in Northeastern Bulgaria represents a geomorphologic phenomenon which is unique not only for the territory of Bulgaria, but also for the World. The surface morphological complex of paleokarst occupies an area of 3,600 square kilometers. Tectonically this region belongs to the Moesian platform and occupies the nortwestern wing of large first order structure, known as the North Bulgarian Dome. The rocks making it lie almost horizontally, slightly sloping (3-4o, rarly 5-7o) to the North and Northeast. There are no surface tectonic breaches. The major lithostratigraphic units of natural outcrop in studied region relate to karst genesis and are of wide geomorphological range: Lower Cretaceous (Hauterivian, Barremian, Aptian and Albian), Paleogene (Eocene) and Neogene (Sarmatian-Romanian), up to Quaternary (Plio-Pleistocene, Pleistocene and Holocene). The widely spread limestones of the Rousse formation (Upper Hauterivian - Barremian - Lower Aptian) have been subject to intensive and continious karstification. The fossilized paleokarst morphology includes as small dish-like slumps of isometric form sized 50x50, or 100x100 m, so some huge looping slumping forms covering areas from 0,3-0,6 up to 8-12 sq.km, which dominate in the paleokarst topography. Among them some separate limestone swellings bulge (typical "hums"). A great depth characterizes the paleokarst surface morphological complex running down to 140-170 m. The morphology and morphogenesis of the paleokarst indicate, that its has been modeled in the conditions of tropical climate, about 117-118 Ma BP (Late Aptian - Lower Albian). Based on data from complex investigations the main stages of paleogeographic development on the studied territory have been identified.

O-4

The Speleogenesis of the Caves in Crnopac Mt. Area

Mladen Kuhta & Andrej Stroj

Institute of Geology, Sachsova 2, Hr-10000 Zagreb, Croatia, E-mail: kuhta@igi.hr; astroj@igi.hr

Abstract

Velebit Mt. is the longest (145 km) mountain range of Croatia. The Velebit region is the part of Dinaric karst that cover≠s southern half of Croatian territory. Its strikes in the NW-SE direction along the Adriatic coast, and although the distance from the sea is only several km, the region of Velebit Mt. has a mountain climate type.

Crnopac Mt. is located on the most southern part of the Velebit massif. As a morphological barrier (up to 1403 m a.s.l.) between the Lika region (550 m a.s.l.) in the north, and the Krupa and Zrmanja River valleys that lie close to the sea level, in the south, the area of Crnopac Mt. was exposed to intensive karstification processes. Its surface geomorphology indicates an advanced karstification which is even more stressed in the underground. Up to date 119 caves were discovered and explored.

Due to the complexity of natural conditions including, horizontal groundwater flow through the massif from the sinking zone in the Lika polje (550 m .a.s.l.) to the discharge area along Krupa and Zrmanja River valleys, and simultaneous vertical circulation through a deep unsaturated zone, different types of caves were formed. The speleogenesis of the most important caves was analysed in respect to the lithological characteristics of rocks, geological structure, hydrographic network, and hydrogeological relations.

Introduction

The Velebit region is the part of Dinaric karst that covers southern half of Croatian territory. It strikes in the NW-SE direction along the Adriatic coast in length of 145 km. Crnopac Mt. is located on the most southern part of the Velebit massif and it forms the morphological barrier (up to 1403 m a.s.l.) between the Gra_a_ko polje (547-560 m a.s.l.) in the north, and the Zrmanja and Krupa River valleys which lie close to the sea level (0-150 m a.s.l.) in the south. According to its geomorphologic and hydrogeological characteristics, the Gra_a_ko polje is a classical example of a karstic field covering the area of about 10 km2. The Otu_a River flows along the field (medium annual flow …m3/s) which sinks underground along its southern border, i.e. at the foot of steep northern slopes of Crnopac Mt. Despite the fact that average annual precipitations in the Crnopac area reach around 2500 mm, mountain area is entirely waterless. Extreme indentedness, in which numerous and frequently rather deep dolinas often occur, indicates an advanced karstification which is even more stressed in the underground. Up to date 119 caves were discovered and explored in the area of about 40 km2.

Review of exploration

First speleological explorations of this area date from the beginning of 20th century (Poljak, 1929) but they were primarily connected to the discovery of Cerova_ke Caves (in 1912 during the construction of the railroad) and to explorations of smaller objects in its surroundings. Detailed speleological explorations of mentioned caves started in 1948. Besides significant length; Gornja (Upper) Cerovac Cave about 1200 m, Donja (Lower) Cerovac Cave about 2000 m, paleontological explorations pointed out that these caves are a significant Paleolithic locality. Both caves belong to the group of typical "Bear Caves". Furthermore, descriptions of the first findings of Upper Paleolithic man in the Dinaric Karst originate from the Upper Cave (Malez, 1956).

First Speleological explorations in the higher parts of Crnopac Mt. started in 1978 and lasted till 1990 (JAL_I_, 1984; LUKI_ 1991; KUHTA, 1992). During that period about 50 caves were explored including Burinka (-295 m) and Muni_aba (-448 m). A new phase of explorations has initiated during the year 2000 and up to date it resulted in a discovery of 64 new caves (KUHTA, 2003; KUHTA et al., 2004; BOROVEC, 2005).
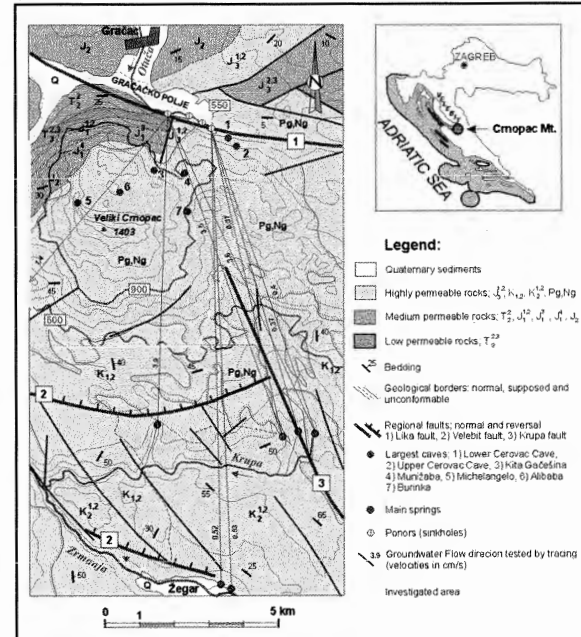
Fig. 1 Simplified hydrogeological map of the investigated area (geology after: IVANOVI_ et al., 1973 and PAVI_I_, 1995)

Geological and Hydrogeological settings

The oldest rocks in the area of the Crnopac massif are dolomites and limestones originating from the Middle and Upper Triassic (T22, T32,3) which cover NW slopes from the level of the Gra_a_ko polje to around 850 m above sea level. On the Triassic sediments continuously follow Jurassic carbonate development (dolomites and limestones) in the stratigraphic range from Lower Lias (J11,2) to Middle Malm (J31,2). Outcrops of Jurassic sediments are noticeable along NW slopes, all the way from the very massif bottom to maximum 1100 m a.s.l.. Cretaceous sediments built up the southern slopes of Crnopac and valleys of the Zrmanja and the Krupa rivers. They are represented by carbonate breccias (K1,2) in the lower part and limestones from Upper Cretaceous Age (K21,2). Central parts of the massif, and a part of NE slopes all the way to the level of the Gra_a_ko polje, are constructed of Tertiary carbonate breccias (Pg,Ng) also known as Jelar-deposits. As the youngest lithostratigraphic member, they lied down unconformably on all older sediments. The largest number of explored speleological objects was formed precisely in these sediments.

The investigated area, as well as the whole Velebit Mt., is situated within structural complex of the Dinaric carbonate platform along its contact zone with Adriatic carbonate platform (HERAK, 1986). The recent geological structure is a consequence of two main periods of tectonic activity. During the Tertiary tectonic cycle, which lasted from Eocene to the end of Miocene, compressive movements oriented NE-SW reached their cumulative maximum with orogenesis of the Dinarides. As a consequence of the mentioned regional tangential stress, the deep nappa structures, folds and regional faults have been formed. Beside that, the formation of carbonate clastic Jelar-deposits is to be considered as the process accompa-

nying the rupture deformations caused by mentioned orogenic movements (BAHUN, 1974). During the later, Neotectonic period, the main stress changed to N-S, resulting in further uplift and transpressive deformation of older structures, which were broken in the smaller structural units and tectonic blocks. In the area of Crnopac Mt. the summary amplitudes of vertical neotectonic movements were estimated to the more than 900 m (PRELOGOVI_ et al., 1979).

Although the considered area is entirely made of carbonate sediments, they can be classified into three categories (Fig. 1) concerning their permeability to water and hydrogeological characteristics. The largest part of the terrain is built up of highly permeable and intensively karstified Cretaceous breccias and limestones (K1,2, K21,2), and especially Tertiary carbonate breccias (Pg, Ng). In the same category belongs Upper Jurassic limestones (J31,2) too. The sediments of the Middle Triassic Age (T22), Lower (J11,2, J14) and Upper Jurassic Age (J2) go into the category of the rocks of medium permeability. The permeability of these sediments depends on the share of dolomites. Precisely due to a bigger presence of dolomites in relation to limestones, Upper Triassic sediments (T32,3) belong to the group of rocks of low permeability. Hydrogeological relations are defined by the position of the massif between the Gra_a_ko polje (547-560 m a.s.l.) in the north, and the Zrmanja and Krupa River valleys that lie close to the sea level (0-150 m a.s.l.) in the south. Results of groundwater tracings showed a connection of the River Otu_a ponors (sinkholes) to springs in the valleys of the Krupa and Zrmanja. The groundwater flow velocities range from 0,37 to 3,85 cm/s, depending on hydrologic conditions at the time of tracing.

Cave geomorphology and genesis

As already mentioned up to date 119 speleological objects have been explored in the Crnopac area. Concerning their depth and length, they are classified into 4 categories shown in Table 1. The smaller caves with depth or length below 50 m prevail in this area. The most significant speleological objects are Muni_aba (-448 m, 3700 m), Kita Ga_e_ina (-338 m, 1002 m), Burinka (-290 m, 325 m), Michelangelo (-274 m, 65 m) Alibaba`s Jama/Pit (-212 m, 250 m), Gornja Cerova_ka Cave (-42 m, 2682 m) and Donja Cerova_ka Cave (-22 m, 1295 m). We also have to mention that explorations of Muni_aba i Kita Ga_e_ina have not yet been finished.

Table 1 Review of speleological objects by their dimensions

Depth category	Number of Caves	Length category	Number of Caves
< 50 m	75	<50 m	83
50-100 m	26	50-100 m	20
100-200 m	13	100-500 m	12
>200 m	5	>500 m	4
Total	119	Total	119
Total depth (m)	6691	Total length (m)	13565
Average depth (m)	56	Average length (m)	114

In a geomorphologic sense, the explored area can be divided into two zones. The area of side slopes spreads from 550 m a.s.l. (the sea level of the Gra_a_ko polje) to approximately 900 m a.s.l. The area above 900 m a.s.l. all the way to the very top (Veliki Crnopac, 1403 m a.s.l.) can be considered the peak part of the massif. Although the karstic plateau spreading in the area of the Krupa and Zrmanja canyons can be also put among the massif slopes, this area was not taken into consideration here.

The researches have not been finished and it is expected that further objects will be discovered; however, the existing sample can be representative enough for a basic statistical analysis. In the area of the massif slopes, only 20 caves were explored (17 %). The total depth of those objects is 1170 m, and the total ground-plan length is 5970 m. This evidences that mostly horizontal speleological objects are present in this area. The fact that Upper and Lower Cerova_ka Cave (all together 3977 m long) are

situated in this area certainly contributes strongly to such results. Based on the stated data, the relation of the vertical and horizontal karstification component was calculated to 1:5,1. In the peak massif part (>900 m a.s.l.) there are entrances into 99 objects (83 %). Although pit-type objects prevail here, the total depth of the explored objects is 5521 m while their total ground-plan length is 7595 m. The relation of the vertical and horizontal karstification component is 1:1,4. The mentioned length of underground channels, i.e. the horizontal karstification component, is a consequence of the large length of Muni_aba (-448 m, 3700 m) and Kita Ga_e_ina (-338 m, 1002 m). Concerning the fact that entrances into these two caves are rather low, i.e. at 915 and 940 m a.s.l., their horizontal parts are entirely developed in a lower hypsometric zone. If the total length of channels in the peak zone decreased for their length, and is added to the length of channels in the area from 550 to 900 m a.s.l., the relation of the vertical and horizontal karstification component in the peak zone changes to 2:1, and in the lower (slope) zone to 1:9,1. Ratios of the vertical and horizontal karstification component calculated in this way, fit rather well in the essential frame of the genesis of speleological objects in the Crnopac area.

Recent studies performed in the Dinaric karst terrain indicate that the present landscape is very young. The majority of the most important and most developed morphological features were created during the Pleistocene and Holocene (FRITZ, 1992).

In the explored area the general karstification processes were directed by the position of local erosion basis i.e., the Gra_a_ko polje (550 m a.s.l.) in the north and Zrmanja and Krupa River valleys (0-150 m a.≠s.l.) in the south. Under such circumstances, as a morphological barrier Crnopac Mt. has a very important role and controls the groundwater conditions and underground discharge from Gra_a_ko polje toward south. At the same time, the underground of Crnopac Mt. was exposed to strong karstification. Constant tectonic uplift of Velebit Mt contributed to the development of such strong karstification processes in the studied area. As it was already mentioned, the summary amplitude of Neotectonic movements for Crnopac area is estimated to more than 900 m. Simultaneously, the Gra_a_ko polje north of the Lika fault, as well as Krupa and Zrmanja valleys south of the Velebit fault, represent relatively descended blocks. The groundwater flows through the carbonate massif from the Gra_a_ko polje toward the spring zone along the Krupa and Zrmanja valleys tended to compensate these movements and thus it developed a network of deep underground channels and the cave systems. The described mechanism took important part in development of largest explored caves.

The Cerovac Caves that lie on 624 and 671 m a.s.l. represent old ponors (sinkholes) of the Otu_a River. Recent, permanently or temporally active, ponors developed along the south border of the Gra_a_ko polje (550 m a.s.l.). Their entrances are choked up by deposited matter thus making speleological explorations impossible. In spite the fact that the entrances elevation of the two large caves Muni_aba (915 m a.s.l.) and Kita Ga_e_ina (940 m a.s.l.) belong to the higher morphological unit (zone), their development should be related to the same genesis pattern, as well as the activity of sinking waters from the Gra_a_ko polje. Namely, the largest parts of mentioned caves represents generally horizontal channels which developed within altitude range from 500 to 650 m a.s.l. Lower channels characterised by large dimensions have been developed by strong and concentrated underground flow. Recently discovered entrance vertical shafts should be considered the youngest parts. The lowest point in Muni_aba reached the elevation of 467 m a.s.l., that is about 80 meters below the altitude of Gra_a_ko polje, but there is still no evidence of any active groundwater circulation.

The speleological and cave-diving explorations in the discharge area, both in the Krupa and Zrmanja River valleys, pointed out the existence of several permanently or temporally active spring caves. The caves are up to several hundred meters long.

The genesis of the caves in the higher zone (900-1400 m a.s.l.) is related to dominantly vertical circulation through a deep unsaturated zone. The

large number and density of caves is the consequence of a favourable lithology. Namely, the uppermost part of terrain built up the massive calcareous breccias that are very liable to karstification. The results of cave exploration conducted in same deposits on other parts of Velebit Mt prove the mentioned fact (KUHTA & BAK_I_, 2001). The largest pits Michelangelo (-274 m) and Alibaba`s Pit (-212 m) are located on altitudes of 1283, i.e. 1080 m a.s.l. and they are too shallow to reach even the zone of ancient horizontal circulation.

Conclusions

Although difficult access and movement along the terrain as well as the lack of potable water makes explorations significantly difficult, the area of Crnopac Mt. is very attractive for speleological explorations. Central parts of Crnopac are built up of Neogenic carbonate breccias, also known as Jelar deposits. Lower parts of the mountain northern slopes are composed of Triassic and Jurassic carbonate rocks while the Cretaceous sediments are in the south. Their common hydrogeological characteristic is a good permeability which has enabled underground discharge of surface flows from the Gra_a_ko polje (Otu_a River) towards the springs in the Krupa and Zrmanja River valleys. In these circumstances significant horizontal speleological objects have been formed in the border, hypsometricaly lower parts of the massif while jamas/pits prevail in the higher parts of the terrain, i.e. in the zone of emphatically vertical circulation. Although the zone of active underground flow for the time being has not been reached anywhere, such enterprise would result in an extremely deep (and probably also a very long) object. Taking into account the fact that peak parts of the massif go as high as 1400 meters above sea level and that the spring zones of the Krupa and Zrmanja valley are situated at elevations from 70 to 150 meters above sea level, the depth potential of Crnopac is up to 1000 meters.

References

BAHUN, S. 1974: The tectogenesis of Mt. Velebit and the formation of Jelar deposits. Geolo_ki vjesnik 27, Zagreb : 35-51.

BOROVEC, M. 2005: Alibaba,s Jama on the Crnopac Mountain. Speleolog 52, Zagreb : 18-22.

FRITZ, F. 1992: Effect of recent sea level change on the development of Karst phenomena. Proceedings of the International Symposium "Geomorphology and Sea". Mali Lo_inj : 85-92.

HERAK, M. 1986: A new concept of geotectonics of the Dinarides. Acta geologica 16/1, Zagreb : 42 p.

IVANOVI_, A., SAKA_, K., MARKOVI_, B., SOKA_, B., _U_NJAR, M., NIKLER, L. & _U_NJARA, A. 1973: Basic Geological Map, scale 1:100 000, sheet Obrovac, State Geological Survey, Beograd.

JAL_I_, B. 1984: Bezdanka kod _abri_a on Velebit Mt. Na_e planine 11-12, Zagreb.

KUHTA, M. 1992: Caving explorations of the Crnopac area in the Velebit Mt. Speleolog 38/39, Zagreb : 25-28.

KUHTA, M. & BAK_I_, D. 2001: Karstification Dynamics and Development of the Deep Caves on the North Velebit Mt. - Croatia. 13 International Congress of Speleology, Proceedings, Brasilia.

KUHTA, M. 2003: Some recent results of speleological exploration on Mt. Crnopac. Speleolog 48/49, Zagreb : 36-44.

KUHTA, M., BOROVEC, M. & BOSNER, N. 2004: Cpeleological explorations of Crnopac from 2002 and 2003. Speleolog 50/51, Zagreb : 48-55.

LUKI_, O. 1991: Speleological explorations of the Crnopac area on the Velebit Mt.. Speleolog 36/37, Zagreb : 14-26.

MALEZ, M. 1956: Erster Found des oberdiluvialen Menschen im dinarichen Karst. Bull. sci. Cons. Acad. Yougosl. 3/2, Zagreb : 47-48.

PAVI_I_, A. 1995: Hydrogeological conditions for the construction of reservoirs in the Velebit Mt. hinterland. Unpublished. Ph.D. Thesis, University of Zagreb, Croatia, 124 p.

POLJAK, J. 1929: Mountaineering Guidebook on Velebit Mt. Zagreb.

PRELOGOVI_, E. 1979: Seismotectonic activity in the area of the Zrmanja valley. Geolo_ki vjesnik 31, Zagreb : 123-136.

48

O-5

Sediments and groundwater in the Baradla and Béke caves, Hungary

J. Berényi Üveges, G. Vid, I. Berényi Üveges

Plant Protection and Soil Conservation Service, Budapest, Budaörsi, Hungary

Several studies were carried out on the genesis of Baradla and Béke caves but no reliable information was available on the composition and characteristics of the sediments filling the bottom of these caves. The aim of our research was to gain basic information on these sediments. Sampling was carried out by drilling. Particle size distribution and plasticity index were determined as the first step. The majority of the sediments are loam, sandy loam and clay loam. The samples from the Béke cave and the upper part of the Baradla borehole are coarser and the bottom part of the Baradla borehole is finer. Groundwater was found in both caves in the boreholes. A water level observation well was constructed in the borehole in the Baradla cave. The groundwater level varied between 236 and 295 cm. The hydraulical characteristics were tested by pumping test and inverse pumping test. The water percolation is very slow, the well was not refilled within 24 hours. The basic chemical parameters of the water in both holes were analyzed. They were related to the analytical data measured in the springs related to the two cave systems (Josva, Komlos, and Rövid-also springs). The statistical method was cluster analysis and multidimensional scaling. The presence of groundwater influences the hydrological characteristics of these caves.

O-6

The Stratigraphy of the Kabwe Cave of Rhodesian Man

A. Bartsiokas

Univ. of Thrace, Komotini, Greece

Abstract

The Stratigraphy of the Kabwe Cave of Rhodesian Man by Antonis Bartsiokas Here, a reconstruction of the stratigraphy and speleogenesis of the Kabwe Cave is provided based on the descriptions of the cave and the known mineralogy of lead-zinc deposits found elsewhere. The taphonomy of Kabwe (Rhodesian) man is also provided. The lead-zinc ore of the cave has been formed 650-800 million years ago. The upper part has been opened in sandstone and the lower part in limestone. The two parts (bedrocks) of the steeply dipping cave were separated by a water table. It appears that lead and zinc would have been originated from the limestone itself or the nearby Post Palaeozoic shales and deposited as galena and sphalerite in the cavities or the cave was formed during the dolomitization of the limestone. It is concluded that in Broken Hill, where the Kabwe Cave was formed, the protore of galena-sphalerite-pyrite core was oxidized into cerussite - that occupied mainly the lower part of the cave - as well as hemimorphite and limonite respectively - that occupied mainly the upper part of the cave. Therefore, the stratigraphy of the cave from top to bottom has as follows: Smithsonite and hemimorphite, relict galena, cerussite, and finally sphalerite with galena. The whitish colour of cerussite and the yellowish colour of limonite have stained the bones of the cave accordingly. Because the endocranium of the skull of the Rhodesian man is covered by hemimorphite it follows that the skull was originally deposited in the upper cave and soon after it was transported in to the lower cave where it was finally found. The water of the cave was responsible for the lead poisoning of the Rhodesian man and the accumulation of the cultural and bone material.

O-7

The stratigraphy from the Loutra Aridéas Bear-cave (Pella, Macedonia, Greece) with Emphasis on two new chambers

Katerina Chatzopoulou

Geology School, Aristotle University, GR-54124 Thessaloniki, Greece

Abstract

The Loutra Aridéas Bear-Cave (Northern Greece) yielded a rich Late Pleistocene fauna including large and small mammals. In the present study, the stratigraphy of all excavated chambers is presented and revised. The supply of the sediments and the possibility of a correlation between the stratigraphical columns are also discussed. Two new stratigraphical columns are added to the previous ones; a new square (R2) in the third chamber of the cave (LAC III) and a new grid in the chamber of gours (LAC Ic). The excavation project is still in progress.

Introduction

The cave-site of Loutra (LAC: Loutra Aridéas Caves) is located in North Greece on the slopes of Voras mountain (2524 m), very close to the former Yugoslavian border, about 2km from Loutraki village and 120km north-west of Thessaloniki (Fig.1). A system of caves has been developed mainly in the north side of the V-shaped Rema Nicolaou gorge. The broader area is situated near the geological boundary between Almopia zone to the east and Pelagonian zone to the west (MERCIER 1968, MOUNTRAKIS 1976) and it consists of Mesozoic metamorphic and sedimentary rocks. The Rema Nicolaou gorge consists of Maestrichtian limestone (Pelagonian zone) with intense karstik phenomena caused by the Tertiary faulting of the area. A NW-SE striking ore-bearing fault zone and the ENE-WSW striking Loutraki fault of 10 km length dominate the wider area (PAVLIDES et al. 1990). Furthermore, several thermal springs and travertine deposits that occur in the area are also attributed to the neotectonic activity of the Loutraki fault (MOUNTRAKIS 1976, ELEFTHERIADES 1977). The gorge of Loutra has a depth of 150 m, through which Thermopotamos stream flows. The fact that the whole area has been uplifted due to the intense neotectonic activity of the Loutraki fault, could possibly explain the intense erosion.

The investigation of this area started in 1990 due to the great palaeontological interest. Eleven systematic excavation circles including micromammalian research, took place in 1992-1994, 1996, 1999-2005 by Geology School of Aristotle University in cooperation with the Ephoria of Palaeoanthropology and Speleology, Ministry of Culture and the Vienna University. At first, there were three excavation-blocks of squares in three chambers (LAC I, LAC II and LAC Ib) of the cave. During the excavation in 2000, 2001 and 2005 a new grid was opened in the chamber LAC III and another one was excavated in the chamber LAC Ic during 2002, 2003, 2004 and 2005 in order to add data to the study. The aim of the research is the sediments as well as the palaeontological material of all chambers to be correlated. The research is still in progress.
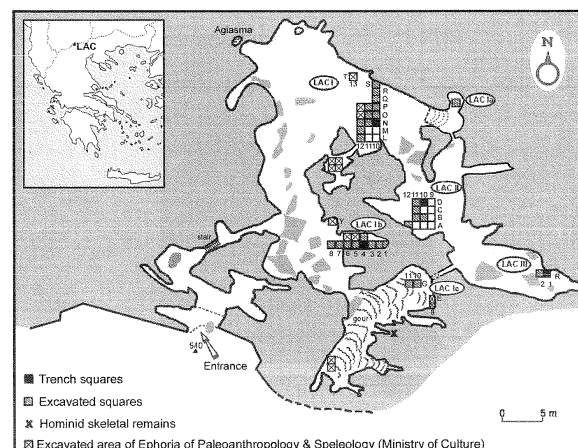
Figure 1. Bear-cave LAC, location and ground plan. On the ground plan the excavated trench squares are shown.

Palaeontology

More than 15.000 ursid remains, that are described and analyzed from five blocks of squares, are determined as Ursus ingressus. Other large mammalian fauna remains found in association with cave-bears, confer to: Vulpes vulpes, Crocuta crocuta spelaea, Panthera pardus, Panthera leo spelaea, Bos primigenius, Capra ibex, Dama dama (TSOUKALA 1994, 1996, TSOUKALA et al. 2001, TSOUKALA & RABEDER 2005).

The micromammalian fauna shows a remarkable diversity of taxa (22 species belonging to 10 families) and a great abundance of bones and

teeth remains. All taxa excluding chiropters that have been recorded up to now from the excavations from LAC I, Ib, II, III are: Erinaceus cf. europaeus, Sorex sp. (S. araneus group), Sorex cf. minutus, Crocidura sp., Spermophilus sp., Arvicola terrestris, Microtus arvalis, M. agrestis, M. nivalis, M. (Pitymys) cf. multiplex, Clethrionomys sp., Apodemus aff. mystacinus, A. sylvaticus, A. flavicollis, Cricetulus migratorius, Mesocricetus newtoni, Glis glis, Dryomys nitedula, Muscardinus cf. avellanarius, Sicista subtilis, Spalax leucodon and Lepus cf. europaeus (CHATZOPOULOU et al. 2001, CHATZOPOULOU 2003, 2005).

Stratigraphy

During the excavating progress, the stratigraphical data were recorded and samples of the sediments were collected. Some of the stratigraphical columns were discussed in previous studies (CHATZOPOULOU 2001, 2003, 2005). In this paper two new square-trenches are presented with emphasis on the third chamber of the cave (LAC III) and the chamber of gours (LAC Ic). The previous reported columns (chambers LAC Ib, LAC I, LAC II and LAC III) are being revised.

Chamber LAC Ic. The chamber of gours is situated very close to the today's entrance of the cave. The floor is covered with gour structures and is situated at the highest level among all chambers. The reddish and gray sterile sediments overlie the fossiliferous beds (Fig.2). The fossiliferous layer appears to be very thick in this square (~140 cm) although the fossil material is relatively poor. A great number of pebbles were observed throughout the brownish layer although there are fewer and smaller to the bottom. The external surface of the stones of the lower fossiliferous beds shows an alteration probably due to weathering. A sequence of thin calc-crust layers with gray sand underlies the fossiliferous layer. All beds show a SW inclination towards the center of the chamber. All the sediments of this chamber are bored by plant roots due to its closeness to the open-air slope of the gorge.
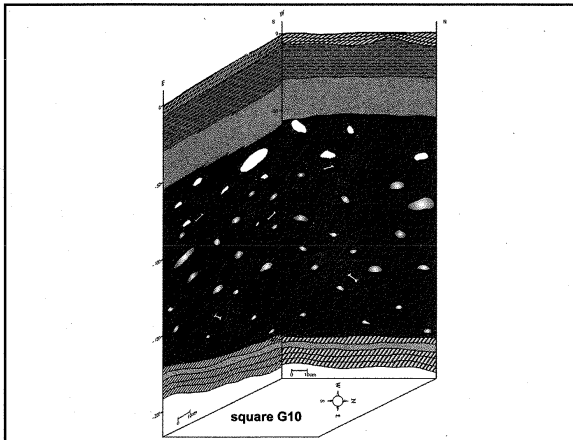
Figure 2. Stratigraphical sections of square G10 (LAC Ic). The depth in the sections is considered from the reference-zero point of the cave and it is counted in cm. The fossiliferous layer appears to be very thick in this square (~140 cm) although the fossil material is relatively poor.

Chamber LAC Ib. This is a very small chamber. Actually it is a sinuosity of the main chamber showing a great palaeontological interest regarding the abundance of large mammal bone remains (Fig.1). The sedimentation in V4 is basically clastic. All beds display the maximum thickness at V4 and are wedging out towards the walls of the cave and the connection to the main chamber (LAC I). The reddish and gray sediments overlying the fossiliferous beds are similar to those of LAC Ic (square G10). At the superior beds of the fossiliferous layer in V4 a great accumulation of large

stones and pebbles was observed (Fig.4). The lithological composition of the pebbles represents the rocks of the broader area (limestones, dolomites, ophiolites, phyllites). The fossiliferous layer is relatively thin (~40cm). Thick gray sterile micaceus sand underlies the fossiliferous layer.

Chamber LAC I. The central chamber is the wider one, while the level of the floor is the lowest in the cave. The diversity of sediments is the most remarkable of all chambers. In trench-square N10, the clastic material dominates, although there are four thin calc-crust layers interposed (Fig.4). The sediments are mainly brownish and small grained (clay and silt). Below 250cm from the reference-zero point sandy beds with many pebbles seems to be the deepest layer of the entire cave. The fossiliferous layer is very close to the surface (<20cm). It is thin (~25 cm) and the upper beds are consolidated to crust, sometimes with enclosed fossils.

Chamber LAC II. The accumulation of sediments in Bear-cave was in cyclic intervals. The alternation of clastic and chemical sediments is more evident in D10. The calc-crust layers (Fig.4, oblique stripes) were deposited during warm and humid intervals, while the clastic sediments (sand, clay, silt) were accumulated during colder periods. The study of the small grain size of the clastic sedimentation of the floor of the Bear-cave is an evidence of slow water flow in the deposition site. This is the result of the surface increase of water mass flowing inside the cave, as well as of probable climate changes from wet to dry (TSIRAMBIDIS 1998). The surface beds (Fig. 4, above the dotted line) are disturbed by unauthorized diggings, resulting in an unequal thickness (25-60 cm) to the fossiliferous layer.

Chamber LAC III. This chamber is the deepest area of the cave, although there is a passage that links LAC III with the gour chamber (LAC Ic) (Fig.1). At first, square R1 was excavated. The sedimentation is basically clastic and rather monotonous. The fossiliferous layer appears to be very thick (~120cm). It is mainly brownish sandy clay dotted with white calcareous pebbles and gravels. Some blackish lenses appear close to the surface of the column. The fossiliferous layer ends on the limestone of the floor of the cave. The small mammals in this square are very abundant while the remains of large mammals are scarce and not well-preserved. The excavation of R2 added new data when a series of layers were revealed. All beds show a SW inclination (dip angle 30°) and are wedging out towards the walls of the cave. That is expected since the layers are thicker towards the center of the third chamber. The fossiliferous layer is less extended, ending on a calc-crust. This crust must have been a palaeo-floor of the cave since a stalagmite in situ (consolidated to the upper part of the crust) is preserved (Fig.3). The fossiliferous beds must have filled this part of the cave afterwards. The gray and reddish sterile sediments underlying the fossiliferous beds show no similarity to those of other chambers. Sedimentation ends on the limestone of the floor of the cave.
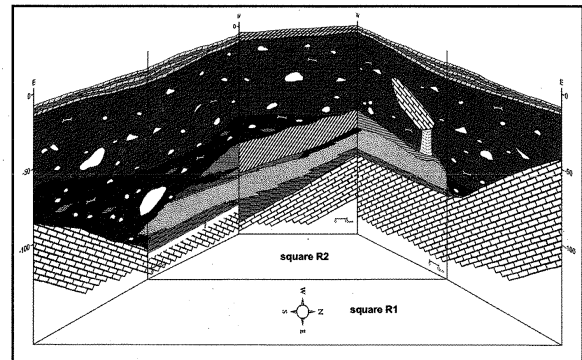
Figure 3. Stratigraphical sections of squares R1 and R2 (LAC III). The depth in all the sections is considered from the reference-zero point of the cave and it is counted in cm. The fossiliferous layer appears to be thicker in south-eastern part of the squares. All Discussions—Conclusions *are wedging out towards the walls of the cave.*

Five stratigraphical columns are presented from the five square-trenches G10, V4, N10, D10 and R2 of the chambers LAC Ic, LAC Ib, LAC I, LAC II and LAC III respectively (Fig.4). The only safe chronological and sedimentological correlation of the five trenches is the fossiliferous layer that is characterized by the presence of Ursus ingressus (TSOUKALA & RABEDER 2005). Despite the distinctly different sedimentation in the five square-trenches and the deviation in thickness, it is obvious that the fossiliferous layer is placed at the same depth (-130cm) in the cave.

The mammalian fauna of the cave indicates a Late Pleistocene age. Two dating projects of the sediments are in progress concerning trench-square N10, one in cooperation with Vienna University (C14-AMS method-Centre for Isotope Research, University of Groningen) and the second by the Laboratory of Archaeometry of "Demokritos", Athens (ESR method). The age of the paleofauna is measured by C14-AMS method about 37.000 years B.P. (dating of a bone sample from LAC I) (RABEDER et al. in press). The ESR-absolute dating of the crust underlying the fossiliferous layer indicated an age more recent than 20.000 years (KAMBOUROGLOU et al. 2006).

The best-preserved and abundant remains of large mammals are excavated from the center of the cave (LAC Ib, I & II), while in LAC Ic & LAC III the material is scarcer. On the contrary, the abundance of small mammals is remarkable in LAC III and is reduced towards the today's entrance of the cave (material from LAC Ic has not been studied yet). Moreover, some teeth and bones of both macro and micromammals show traces of transportation by water. These features could be the result of the surface increase of water mass flowing inside the cave. During Late Pleistocene the Thermopotamos stream was probably flowing 80m higher than its today's level. The lithological composition of the pebbles as well as the small-grained depositions of the cave represents the eroded rocks of the broader area. It is likely that during floods of the river, micro and macromammalian remains were scattered inside the cave or entered the cave like the sediments. Heavier material (long bones, skulls and large pebbles) was deposited close to the supply of the sediments in the cave, while lighter fine-grained assemblages (sediments and micromammalian remains) were transported into deeper parts of the cave.

References

CHATZOPOULOU, K., VASILEIADOU, A., KOLIADIMOU, K., TSOUKALA, E., RABEDER, G. & NAGEL, D., 2001 - Preliminary report on the Late Pleistocene small mammal fauna from Loutraki Bear-cave (Pella, Macedonia, Greece).-Cadernos Lab. Xeolóxico de Laxe, 26: 485-495, Coruña.

CHATZOPOULOU, K. 2001 - Contribution to the study of Quaternary micromammals and the stratigraphy of the Cave A from Loutra Aridéas (Pella, Macedonia, Greece). - Postgraduate thesis (unpublished). Aristotle University, Thessaloniki (in Greek).

CHATZOPOULOU, K. 2003 - The Late Pleistocene small mammal fauna from the Loutra Aridéa Bear-cave (Pella, Macedonia, Greece) - Additional data. -Atti Mus. Civ. Stor. Nat., 49 (suppl.): 35-45, Trieste.

CHATZOPOULOU, K., 2005 - The small mammal fauna from the Loutra Aridéa Bear-Cave (Pella, Macedonia, Greece) with Emphasis on the Third chamber. -In: "Neue Forschungen zum Höhlenbären in Europa" eds. Ambros, D., Gropp, C., Hilpert, B. & Kaulich, B. - Naturhistorische Gesellschaft Nürnberg, Abh. 45/2005: 57-64, Nürnberg.

ELEFTHERIADES, G., 1977 - Study of the volcanic rocks in South Almopia. Thesis Dissert. Aristotle University, 1-173, Thessaloniki.

KAMBOUROGLOU E., BASSIAKOS, I. & BOUZAS, D., 2006 - The Cave A' in the Aridaia-Loutraki Area. - Proceedings of the annual Archaeological Meeting "Archaeological Works in Macedonia and Thrace 18, 2004" eds. Adam-Veleni P. & Tzanavari K.: 573-589, Thessaloniki (in Greek).

MERCIER, J., 1968 - Étude géologique des zones internes des Hellénides en Macédoine centrale (Gréce). -Annales Géologiques des Pays Helléniques, 20:1-792, Athens.

MOUNTRAKIS, D., 1976 - Geological study of the Pelagonien and Vardar Zone boundary in the Almopia area (North Macedonia). Thesis Dissert. Aristotle University, 1-164, Thessaloniki.

PAVLIDES, S., MOUNTRAKIS, D., KILIAS, A., TRANOS, M., 1990 - The role of strike-slip movements in the extensional area of Northern Aegean (Greece). A case of transtensional tectonics. - Annales Tectonicae, Special issue, 4 (2): 196-211.

TSIRAMBIDIS, A., 1998 - Study of floor sediments from the Agiasma Cave of Loutraki, Pella (Macedonia, Greece). -Bulletin of the Geological Society of Greece, 34: 339-349, Patra (in Greek).

TSOUKALA E., 1994 - Bärenreste aus Loutraki (Macedonien, Griechenland)-"Ursus spelaeus". -2nd Höhlenbären Symposium (Corvara, 15-18 September), Italy.

TSOUKALA E., 1996 - Comparative study of ursid remains from the Quaternary of Greece, Turkey and Israel. -Acta Zool.Cracov., 39 (1): 571-576, Kraków.

TSOUKALA E., RABEDER, G. & VERGINIS, S., 2001 - Ursus spelaeus and Late Pleistocene associated faunal remains from Loutraki (Pella, Macedonia, Greece)-Excavations of 1999. -Cadernos Lab. Xeolóxico de Laxe, 26: 441-446, Coruña.

TSOUKALA E. & RABEDER, G., 2005 - Cavebears and Late Pleistocene associated faunal remains from Loutra Arideas (Pella, Macedonia, Greece). 15 years of research. -In: "Neue Forschungen zum Höhlenbären in Europa" eds. Ambros, D., Gropp, C., Hilpert, B. & Kaulich, B. - Naturhistorische Gesellschaft Nürnberg, Abh. 45/2005: 225-236, Nürnberg.

RABEDER, G., TSOUKALA, E. & KAVCIK, N., (in press) - Chronological and systematic position of cave bears from Loutrá Aridéas (Macedonia, Greece) - Proceedings of 12th International Cave Bear Symposium (Aridéa/Loutrá, 2-5 November 2006), Greece.

51
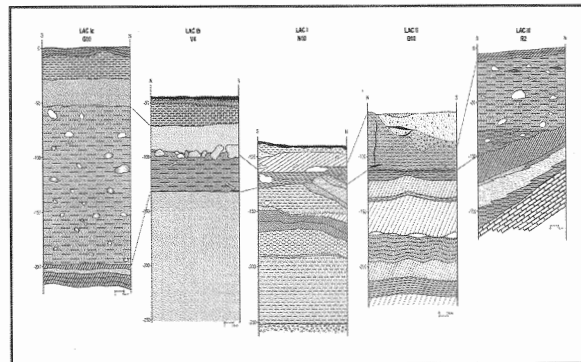
Figure 4. Stratigraphical sections of trench square G10 (LAC Ic), V4 (LAC Ib), N10 (LAC I), D10 (LAC II), and R2 (LAC III). The depth in all the sections is considered from the reference-zero point of the cave and it is counted in cm. The fossiliferous layer appears to be thicker in G10 (~140cm). Despite the distinctly different sedimentation in the five square-trenches and the deviation in thickness, it is obvious that the fossiliferous layer is placed at the same depth (-130cm) in the cave.

O-8

Palaeontological remains from the Manga Larga Cave (Santo António plateau, Porto de Mós, Portugal) Panthera pardus (L., 1758) and Felis sylvestris Schreber, 1777 - a case study between speleology and palaeontology

Frederico Tátá Regala* & João Luís Cardoso**

Abstract

During a speleological survey at the Manga Larga Cave, a photographic record made at the time shows photographs of an incomplete mammal skeleton laying nearly 100 meters below the entrance of the cave. Analysis of the photographs revealed the identity of the skull – its morphology and size showed that it belonged to a large felid, probably a leopard. This identification was subsequently confirmed by the osteometric data obtained from the analysis of the specimen. After they were retrieved from the site and studied, the skull showed some uncommon morphological features. The complete palaeontological study was carried out under the scientific supervision of J. L. Cardoso. It is briefly described in this paper and will be the subject of a detailed forthcoming edition.

The presence of this and other palaeontological remains, namely from wild cat, in a profound and inaccessible area of the cave, reveals the existence of unexplored galleries leading out. Comprehensive considerations concerning the taphonomic processes determining the deposition of the remains of the leopard are also discussed.

Location and brief description of the cave

Located on the western border of the Santo António plateau (Porto de Mós), the Manga Larga Cave is a karst cavity developed in the Jurassic limestone. The only known entrance opens at the altitude of 468 meters above Sea Level, on a slope over the Mendiga polje. The geographic co-ordinates for the site are: 29 514622 E; 4 37 4672 N (UTM – European *Datum*). The cave is formed by successive vertical pits and inclined galleries, with a vertical entrance shaft measuring 55 meters deep. The bottom of this shaft leads on to an ascending gallery and to a small tunnel followed by a series of four other pits, each of less than ten meters in depth. These are followed by a narrow corridor opening into the gallery where the bone remains of the leopard were found, consisting of a sloping meander of fourteen meters with a general south-north orientation, narrowing abruptly into a crevice. The walls, covered with flowstone and fragile subaerial coralloids, converge gradually toward the top. The proximal third of the ground is composed of diverse sized blocks revealing two distinct collapse moments in its history. First, a base layer of larger blocks covered with flowstone cemented to each other and to the walls, and an upper layer of free smaller stones, without any flowstone, resulting from a later collapse. Beyond this area of collapsed stones the ground is covered with flowstone.

The cave continues to the southwest ascending irregularly and down again into new pits and galleries. However, describing the remainder of the cave must remain outside the scope of this paper. According to the topographic mapping taken by SAGA – Sociedade dos Amigos das Grutas e Algares – it reaches to a depth of 185 meters below the level of the entrance.

Historical data

Discovered by the SPE (Sociedade Portuguesa de Espeleologia), this cave was the object of several explorations and obstruction removal works, involving several speleologists and speleological societies, being published by C. THOMAS (1985). The bone remains that constitute the object of the present paper were known to previous explorers who referred to them as belonging to the skeleton a dog.

In January 2003 a speleological team from AESDA (Rui Luís, Valter Luís and Bruno Oliveira) carried out a recognition survey of the site. The photographic record obtained includes some images of the skeletal remains that allowed the subsequent observation of the general morphological features of the skull. The possibility that it may have belonged to a large felid species, demanded a new visit to the site in order to determine the specific taxonomical identification of the specimen. The significance and rarity of the remains justified their immediate record and collection.

Site characteristics

The incomplete skeleton was deposited over a thin layer of reddish-brown clay that covered part of the base rock and the flowstone coating. Some of the bones were partially inlayed into the clay with the exposed surfaces clean of sediment except for some inner spaces, cracks and orifices.

The bones belong to the same individual, and despite the generalised calcite coating along the surfaces of the cave and part of the stones, they show no carbonate deposition, except in a small area of the skull. While the cranium and some

* *Instituto Português do Património Arquitectónico (IPPAR) and founding member and General Secretary of the Associação de Estudos Subterrâneos e Defesa do Ambiente.*

** *Professor. Universidade Aberta (Lisbon); Coordinator of the Centro de Estudos Arqueológicos do Concelho de Oeiras (CMO).*

of the neck bones and front legs were found disarticulated, the positioning of the metacarpals was nearly in correct anatomical order.

However, the recorded location of some of the parts does not mach their original distribution because of consecutive handling by other cave explorers. Nevertheless, according to information given by the first discoverer, João Neves (SAGA), the bones remained in the original area where they were first seen. The skull, initially found in a passage, was carefully moved to a lateral point near the other bones.

Collection of the remains

Regarding the specimen's obvious fragility, adequate measures were taken to prevent further deterioration. When extracting the bone material from the environment that preserved it, special attention was taken concerning variations of temperature and humidity levels, besides the necessary protection against vibration during carriage.

The bone elements were individually wrapped with consecutive layers of pneumatic plastic (with air bubbles) and packed in a stiff plastic box. Empty spaces in the box were filled with the same soft material to improve physical protection. No foam or cotton was used to avoid sudden dehydration. After collection, the remains were kept for a 24-hour rest period before unwrapping so that temperature could gradually reach equilibrium with exterior environment levels. Drying occurred naturally in a dark indoor environment.

Collection, carriage and temperature/humidity adequacy, were performed successfully, resulting in no visible damage to the remains.

The remains of *P. pardus* in the Manga Larga Cave

Description and brief comparative discussion

All the visible bones were collected, except part of an extremely damaged long bone, small vertebrae fragments and unidentifiable splinters. They are deeply lixiviated and friable, exhibiting porosity and fissures along the surface. Jugal dentition and the incisor teeth show good preservation levels. Upper and lower canine teeth are considerably more deteriorated, with broken crowns and deep fissures.

The collected parts consist of: skull, mandible, cervical vertebrae, right humerus (incomplete) and left metacarpal bones (metacarpals II, III and IV). The third metacarpal kept its integrity, but the other two lack their distal extremities. Exhaustive osteometric comparative study goes beyond the scope of this paper, being the object of a forthcoming publication.

A summary of the data concerning the skull and the dentition are here given:

Skull – considerably well preserved, with loss of some bone and dental material; it shows fractures that affect mainly the buccal/nasal and occipital/parietal regions, and the zygomatic arches.

Skull sutures are not visible and the dentition is fully developed showing no relevant dental wear, indicating an adult but not senile individual.

The dimensions of the skull are generically close to the lowest sizes recorded for *Panthera pardus*. In spite of the reduced longitudinal size of the skull, transversal measurements of anatomical configurations reveal considerable differences over the proportions, when compared with the other analysed fossil and living specimens. Manga Larga's leopard skull is in fact the smallest of the fossil specimens known, with a snout wide and short, broad and high forehead with spaced eyes. One of the most striking characteristics is the reduced condylobasal length proportionally compared with the breadth features, responsible for the notoriously convex appearance of the skull's profile.

Dentition – All the measurements fit within the variation amplitudes recorded for *P. pardus* by SCHMID (1940). When compared with other fossil specimens, most tooth sizes are below average, around the average values obtained for living leopards. The upper rows are slightly above the actual size averages, particularly the canine and third premolar. Contrarily, the lower row has most of the odontometric values slightly under the corresponding averages, with the remarkable exception of the quite smaller fourth premolar.

Chronological consideration

There are no archaeological materials or stratigraphy suitable to establish a chronology for the remains found. Making use of a small fragment extracted from the diaphysis of the humerus, an AMS radiocarbon dating was considered, unfortunately without success since there wasn't enough collagen present.

Under the circumstances a comparative chronological framework will have to be established with other known remains found throughout Europe, especially in the Iberian Peninsula.

It is generally accepted that the most ancient remains of *P. pardus* known from Europe until now, date back to Cromerian times. This is the case with the specimens from Mauer (SCHÜTT, 1969; KURTÉN, 1968) and Voigstedt (KOTSAKIS & PALOMBO, 1979). There is, however, the possibility that some of the specimens go further back in time, such as those from Hundsheim and Valonnet. According to BONIFAY (1971), because the ancestral forms of the leopard are not known, its origins may have been outside the European continent.

The expansion of the European leopard attained its peak by the end of Middle Pleistocene, reaching the south of England and the Alps of Transylvania by the beginning of the Upper Pleistocene (KURTÉN, 1968). Climatic deterioration during Würm seems to be responsible for the extinction of the leopard in Europe, not surviving beyond the Aurignacian outside the Iberian Peninsula. In fact, Iberia appears to have been the last refuge of the European leopard according to some Portuguese and Spanish archaeological contexts that included remains of this species. In this region, most of the remains are reported to the Aurignacian (ALTUNA & MARIEZKURRENA, 1984), but they also occur later. This is the situation of other Portuguese specimens found in Solutrean levels of Gruta do Caldeirão, and in a deposit dated to 22 730 ± 880; 790 BP from Gruta das Fontaínhas, (ANTUNES *et al.*, 1989; CARDOSO, 1993). In Spain, at Bolinkoba (Biscay), more recent leopard bones were collected from the Lower Magdalenian level III (CASTAÑOS, 1987). ALTUNA (1972), quoting Vega del Sella, mentions the presence of leopard in the Azilian context of La Riera cave, suggesting cautiously the possibility that this species survived in that region until the Mesolithic.

Attending to the above, a time span of 700 thousand years is considered, with hardly defined limits, through the Middle and Upper Pleistocene. Consequently, we can only think of a probable chronology, with most leopard remains from Portuguese and Spanish sites dating from the end of Upper Pleistocene, especially during the Aurignacian period. This would allow us to accept, with caution, that the leopard from the Manga Larga Cave may possibly be dated between 20 000 to 35 000 years BP.

On the presence of the leopard in the Manga Larga Cave

The leopard is characterised by expressive versatility, adapting to diverse habitats and food regimens. It inhabits wide areas of Africa and Asia, through diverse environments varying from savannah to forest, plain to mountain, hot climate to sub-zero temperatures. His presence in the Santo António Plateau and its surroundings is therefore not a surprise.

Subterranean cavities are frequently used as shelters by females during the first stages of parental care. It is also natural that, in the pursuit of prey, a leopard runs into a gallery or falls accidentally into a natural pit. On the other hand, the skeleton that forms the subject of this study was found in a very deep and inaccessible gallery, raising questions about the causes of such an apparently improbable occurrence. Actually, it's not probable that a leopard would manage to go through all the pits, corridors and passages that lead into the place of deposition, starting by the known entrance. His fall into the first 55 meters of the shaft wouldn't be surprising but the same can't be said about the possibility of surviving to such a violent fall, in order to reach the next pit of eight meters, fall again, and repeat that feat three more times in the following three vertical shafts, connected by irregular corridors. He would have to move by his own means after each fall, to reach the spot where he was actually found. For that reason we accept that this animal got into the cave through another entrance, still to be found.

The gallery with the remains ends to the north into an unsurpassable narrow crack. Yet, it's narrowing was formed by the gradual thickening of the parietal flowstone deposition, so it would have been somewhat larger in previous times. On the opposite side, the cave goes on forming a tortuous gallery with vertical and sub-vertical unlevelling, forming a laborious progression for the speleologist and absolutely insurmountable for a leopard lost in total darkness. This gallery leads to another vertical shaft reaching new lower levels of galleries. One of these extends southwest until it gets too narrow for speleological progression, but may communicate or has once communicated with the outside. Such is probable considering the presence there of two wild-cat skeletons, one of them laying in anatomical connection in mid gallery and the other dispersed over the area where human progression becomes very difficult. It would be possible for an animal with the constitution of a small leopard to eventually enter through this passage, but it excludes the hypothesis of reaching the superior spaces for the obvious reasons of inaccessibility. Nevertheless, this occurrence shows that in a deeper area of the cavity, animal remains from the outside are still present, indicating the existence of unregistered galleries that communicate with the exterior.

The observation of the bone parts allows deducing that this feline's death didn't occur in the place where the remains were found. In fact, most of the interior and interstitial spaces of the bones are filled with clay, showing that they were once totally or partially embedded in sediment and suffered posterior anataxic phenomena. The infill of spaces in the cancellous bone of the humerus indicates that the fracture occurred in the past, possibly being contemporary with the

primary deposition. The absence of most parts of the skeleton and its anatomical disconnection denote also the intervention of post-depositional factors. Moreover, the bone surfaces are washed and lixiviated, a situation that indicates exposure to water. This is corroborated by the traces related to the evacuation of sediment from inside the skull, forming drainage channels coincident with the natural orifices. Thin fissures in the bone surface, caused by long exposure to the cave's aerial or sub-aerial environment, are not filled with sediment, meaning that they formed after the secondary deposition.

The existence of smashed bones with clean fractures may have been caused by a violent episode related with the final deposition, or posterior to that. Same of the fractures could be recent, eventually caused by previous cavers, but simple handling would not be responsible for such an intense fragmentation, and the location of the smashed bones is near the wall, not on the passage area. Furthermore, no clear signs of trampling where found and vandalism is excluded because it would certainly fall upon the most significant parts.
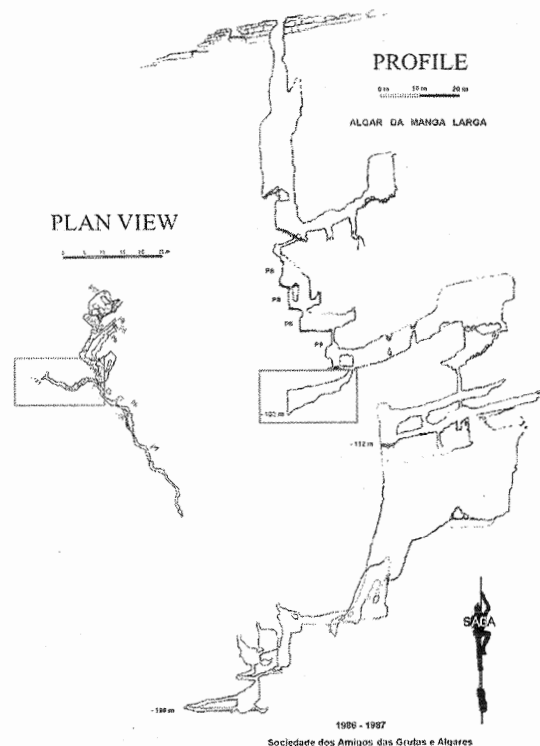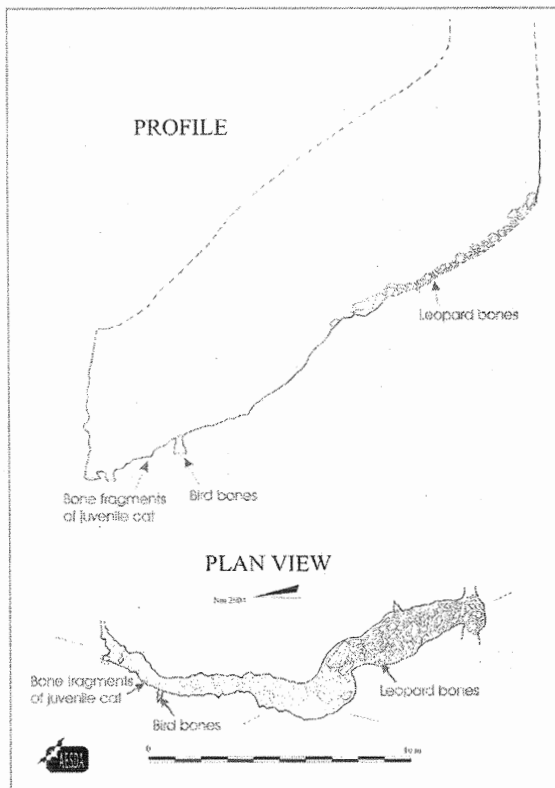
Another factor that substantiates the idea of a natural violent occurrence involving the remains is the fact that the destroyed bones were found in a restrict area combined with a thin layer of clay. The collapse of clastic and clay material over a part of these would explain them being smashed, but their origin remains unexplained. Consequently, it's sustainable that the bones were incorporated among the materials that collapsed, which would explain the existence of a small part of the skeleton, merely from the animal's anterior portion, anatomically displaced. It's possible that some bone elements contained in a clay volume, or on top of it, could suffer no significant damage during subsidence, and others, caught by an impact zone, would be totally smashed. In the mean time, water flow may have removed most of the clay material, only a small part retained in cavities of the bones and irregularities on the rock, especially in the area of collision, together with the smashed bones. If the explained hypothesis is correct there must exist a gallery above that area, with access to the exterior. In it, the thanatic phase of the process occurred as well as the primary deposition, whose deposit collapsed partially, forming the secondary deposition under study.

Attempts were made to find the upper gallery from where the materials proceeded. The speleologists Rui Luís, Hugo Pelerito and Bruno Oliveira performed a climbing and discovered an unrecorded overlapping gallery with no signs of paleontological vestiges. On a higher level, 13,5 meters above the top of the collapsed stones, they found another opening, too narrow for speleological progression due to the amount of flowstone. However, according to information given by Rui Luís, there was an air flow and a scent usually felt in subterranean spaces connected with the surface, with large amounts of humus. No osteological remains are visible there. However, it is possible that carbonate deposits may

have covered them completely. If the bone remains originate from that area, we have no conclusive evidence for that yet.

Another aspect to consider is the location and development of the cave itself. It must be noted that the cave was formed in a slope. Although the referred gallery reaches more than 100 meters above the entrance, that doesn't mean that this is the shortest distance to the exterior. It is possible that other karst openings connect or have once connected in a more direct way to the vicinity of that place. Other faunal remains found in this cave demonstrate the validity of this idea. In the same gallery were found a few skull fragments of a juvenile cat and the complete skeleton of a bird, probably a chough. As referred already, in a deeper gallery, to the south, two more wild-cat skeletons were discovered (see topography). Note that most of these faults are crevice-shaped, forming high chimneys of obviously difficult exploration and undefined highs.

Conclusion

The leopard discovered in the Manga Larga Cave shows very peculiar osteometric characteristics but their representativeness is diminished by the polymorphic tendency of the species. This is further evidenced by the number of described subspecies. Besides the reduced dimensions of the specimen, the most remarkable morphological feature is the proportion between the length and breadth of the skull, particularly the anterior region. It belongs to a small leopard with broad head and short snout. The features that distinguish Manga Larga's *P. pardus* strengthens the conjecture proposed by HEMMER (1974) and sustained by CARDOSO (1993: 452), that southern Europe could have functioned as a refuge area for distinct population groups of diverse geographical provenience, pushed by glaciation transgressions.

The presence of the remains in an inaccessible zone of the cave must be evaluated against the background of dynamic phenomena involved in the modification of the cave itself. Taking into account that this animal lived several thousands of years ago, one must consider the effects of seismic events, hydric regimen modifications and carbonate deposition. In fact, once open galleries may have become narrowed or obstructed through the formation of thick flowstone layers. The absence of most of the skeleton, the distribution of the remains and even their location, indicate the participation of post-depositional factors, suggesting that the bones came from a subterranean upper level, during a subsidence event. Despite de speleological survey preformed, the specific location of the primary deposition is yet to be found.

Bibliography

ALTUNA, J. (1972) — Fauna de mamíferos de los yacimientos prehistoricos de Guipuzcoa. *Munibe,* 24 (1/4): 464 p.

ALTUNA, J. & MARIEZKURRENA, K. (1984) — Bases de subsistência de origem animal de Ekain. *In El yacimiento prehistórico de Ia cueva de Ekain* (Deba, Guipúzcoa) p. 211-280. Sociedad de Estudios Vascos. Guipúzcoa.

ANTUNES, M.T.; CABRAL J.M.P.; CARDOSO, J.L.; PAIS, J. & SOARES, A.M. (1989) — Paleolítico médio e superior em Portugal: datas 14C, estado actual dos conhecimentos, síntese e discussão. *Ciências da Terra* (UNL), 10: 127-138.

BONIFAY, M.-F. (1971) — Carnivores quaternaires du Sud-Est de La France. *Mém. Mus. Nat. Hlist. Nat.,* N.S.(C), 21 (2), 43-377.

CARDOSO, J. L. (1993) – *Contribuição para o conhecimento dos grandes mamíferos do Plistocénico superior de Portugal.* (dissertação de doutoramento apresentada à Universidade Nova de Lisboa), Câmara Municipal de Oeiras.

CASTAÑOS, P. (1987) — Los carnivoros prehistoricos de Vizcaya. *Kobie,* 16:7-76.

GUERIN, C. & PATHOU-MATHIS, M. (1996) – *Les grands mammifères Plio-Pléistocènes d'Europe.* Masson.

HEMMER, H. (1974) — Zur Kenntnis pleistozäner mitteleuropäischer Leoparden (*Panthera pardus*). *N. Jb. Geol. Paläont. Abh.,* 138 (1): 15-36.

KOTSAKIS, T. & PALOMBO, M.R. (1979) — Un cranio di *Panthera pardus* (L.) del Pleistocene médio superiore di Monte Sacro (Roma). *Geologica Rom.,* 18:137-155.

KURTÉN. B. (1968) — *Pleistocene mammals of Europe,* 303 p. Weidenfeld & Nicolson. Londres.

SCHMID, E. (1940) — Variationsstatistische Untersuchungen am Gebis pleistozäner und rezenter Leoparden und anderer Feliden. *Zeitschrift für Säugetierkunde.,* 15 (I), 179 p.

SCHÜTT, G. (1969) — *Panthera pardus sickenbergi* n. subsp. aus den Mauerer Sanden. *N. Jb. Geol. Palaont., Mh.,* Hf. 5:299-310.

STROGANOV, S. U. (1962) – *Carnivorous Mammals of Siberia.* Moskva (versão traduzida: Israel Program for Scientific Translations).

THOMAS, C. (1985) – *Grottes et Algares du Portugal.* 230 p. Lisboa.

O-9

Caves in the Odyssey

David N. Brison

8 rue d'Alsace Lorraine 92100 Boulogne sur Seine, France

Down through the centuries Homeric scholars, explorers, and navigators have debated if the places Odysseus visited could ever be located. Two schools of thought developed for interpreting the events described in Homer's epic poem. The literary scholar's approach claims that all the incidents following the moment when Odysseus passed Cape Malea must be purely mythical and imaginary. Whereas the historic geographer's approach sees plenty of evidence that whole sections of this work incorporate ancient Phoenician pilot's instructions for known coastlines and tales based on authentic experiences of those ancient mariners. By careful study of The Odyssey text, the latter school has put forward many theories as to where to look in the Mediterranean area for the nine caves that Homer described.

In 1624 Philipp Clüver, a professor in Leiden, Holland, published one of the earliest studies on the route of Odysseus and he put Calypso's Ogygia Island in Malta. (Wolf 1968) In the centuries that followed many others published their own confused theories, some of which were so far-fetched as to put Odysseus in the Caspian Sea, or the Black Sea, or as far north as Norway, and even in Iceland. In the last decade of the 19th century, one of the first serious researchers working in the field was Samuel Butler who located the Cyclops Cave of Polyphemus near Trapani in Sicily. Between 1906 and 1912, Victor Bérard did much to advance the research, although some of his sites do not conform well with the text. In the early 1920s, Richard Halliburton traced his own logical route. Then in the 1950s, Lewis Pocock placed most of the landfalls in or near Sicily and Gaetano Baglio proposed yet another route. One of the most consistently reliable geographers, Ernle Bradford, sailed to all his proposed sites during the 1950s. Around 1963, Attilio

Route of Odysseus suggested by Bradford - 1963
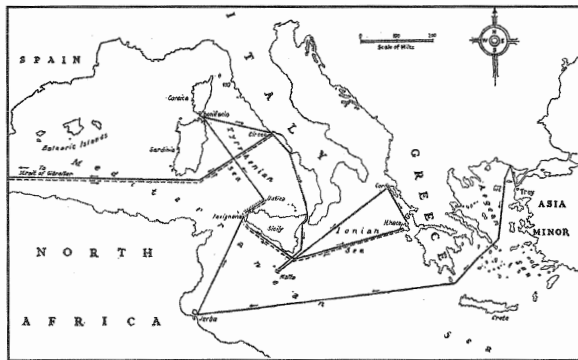
Gaudio visited the landfalls indicated by Bérard. Tim Severin sailed a route in 1985 to establish that Odysseus must have encountered the Cyclops in Crete and then sailed up the west coast of Greece, right past his homeland of Ithaca. Recently, at the turn of the century, Jean Cuisenier, summed up some of the earlier theories and sailed to many of his own chosen sites.

Each author seemed intent on promoting their own original ideas regarding the routes followed by Odysseus, ignoring most of the previous research. Frequently researchers would lock onto one seemingly accurate landfall and then build the entire route around that. Homer's text is cited when it nicely corroborates their theories, but Homer's troublesome little details are systematically omitted when they do not conform to a chosen landfall.
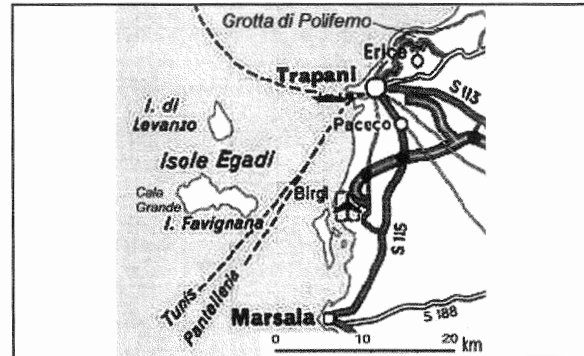
The text tells us that, after the leaving the land of the Lotus-Eaters (probably in Tunisia), his squadron of twelve warships arrived in the land of the Cyclops in a "thick fog" and beached on the shores of a "luxuriant island" located "not very far from the harbor of their coast, and not so near either…which was the home of innumerable goats." Many writers on Homeric geography, intent on tracing the route of Odysseus, have skipped over and neglected to locate this Goat Island or have found some island off a likely coast but found that it lacks a landing beach. Bradford tells us that the Isle of Favignana, off the northwest coast of Sicily was called "Aegusa" or Goat Island in classical times, and, that when approaching it from the south with the south winds blowing, one often finds these islands enveloped in fog. At the head of the harbor on this island, Homer writes "there is a stream of fresh water, running out of a cave in a grove of popular trees." Bradford noted that at Cala Grande on the southwest coast here there was a shelving sand beach where Greek warships coming from the south could easily land. The Italian Touring Club guidebook lists seven caves for Favignana Island, some of which were found to contain either Paleolithic or Neolithic remains.(del Salvio et al. 1989) Any cave near Cala Grande that shows signs of a discharge point aught to meet the requirements.

Seeing the smoke from the fires in the neighboring land of the Cyclops, Odysseus decided to take his ship and investigate. Sailing "no great distance to the mainland coast …as we approached its nearest point, we made out a cave there, close to the sea, with a high entrance overhung by laurels. Here large flocks of sheep and goats were penned at night, and round the mouth a yard had been built with a great wall of stones." Various extravagant ideas have been put forward to localize the Cave of Polyphemus, some even as improbable as the Canary Islands. Bérard puts the cave at Posillipo near Naples, but this is an entirely artificial tunnel dating to Roman times and never visible from the sea. Several researchers, starting with Butler in 1897, locate this cave not far from Favignana Island, about five kilometers north of Trapani near Pizzolungo Point. Halliburton hiked out there in the 1920s and took shelter from the rain in a walled-in sheep pen cave near the coast called Grotta di Polifemo, which he estimated to be fifty feet (17 meters) square and thirty feet (10 meters) high. Thirty years later Bradford checked out this same cave and agreed that "a band of men could easily be trapped" here.

After loosing the rest of his fleet to the cannibal Laestrygonians, Odysseus arrived on his ship at Aeaea Island, the home of the goddess-sorceress, Circe. He climbed a crag to reconnoiter and found that the island was "for the most part low-lying, as all round it in a ring I saw the sea stretching away to the horizon." Later Circe tells Odysseus "to drag your ship onto dry land and stow your belongings and all the ship's tackle in

57

a cave," and then come and stay as her guests. They would need to hide the oars, rigging, and plundered treasures from local thieves. The ancient Greek geographer, Strabo, situated Circe's home at Monte Circeo in Italy and numerous Homeric geographers since have agreed. This 540-meter-high promontory is attached to the continent by flat marshlands today, but in the Late Bronze Age the sea may have covered this lowland. Over 30 marine caves run around the base of this limestone mount and many of them could have served as a boat storage cave. Bérard proposed the Grotta delle Capre which he measured at 36 meters long, 25 meters wide, and 10 meters high. Today tourists are shown a large marine cave, Grotta Azzurra della Maga Circe, but the text clearly states that Circe lived in "a well-built castle of dressed stone." Among other likely locations for Circe's Island, Gaudio has proposed the low-lying, volcanic Isle of Ponza (27 kilometers south of Mount Circeo) as fitting the island's description more suitably and Pocock proposed the Isle of Ustica (70 kilometers northwest of Palermo) with its Grotta della Barche, where boat tackle is stored even today.

Next Odysseus must visit Hades, the Underground-Cavern of the Dead and Circe tells him that the North wind will blow him to a "wild coast and to Persephone's Grove." Homer puts the entrance to Hades' Kingdom where "the River of Flaming Fire and the River of Lamentation, which is a branch of the Styx, unite around a pinnacle of rock to pour their thundering streams into Acheron." Traditionally there are at least four entrances to Hades: two in Greece and two in Italy. At the southernmost point of Greece, in the ancient Tenarian settlement on the tip of the Mani peninsula in the Peloponnese is a marine cave entrance that Orpheus used when he went to bring Eurydice from the Underworld. In Epirus of northwestern Greece at the confluence of the Acheron and the Cocytus, the River of Woe and the River of Wailing, is a rock where another entrance can be found. In central Sicily, near Enna, a cave on the south shore of Lake Pergusa is where Hades came out of the Underworld, kidnapped Persephone, and took her back underground to be his bride.(del Salvio et al. 1989) But the traditional location in Italy, for consulting the oracle of the dead and entering Hades, was at the Lake Avernus, north of Baiae and west of Naples. Many think that the latter location is where Odysseus went to dig a trench and offer sacrifice so as to be able to converse with the dead spirits that came forth to meet him. But, as Severin points out, the entrance to Hades in Epirus fits better with the directions given in Homer.

Returning to Circe's Island, Odysseus is given precise sailing instructions that will get him back to his home in Ithaca. After safely passing the Sirens at the Galli Islands, he continues south and must pass through the Strait of Messina. Now the early Phoenician mariners knew the whirlpools of Charybdis on the Sicilian side and the headland at Scilla in Calabria. The strait is from three to four kilometers wide, but in Mycenaean times the dangerous currents and whirlpools of Charybdis must have been quite formidable for a war galley. So Circe warns him to hug closely the high rock promontory of Scylla and beware that, "halfway up the crag there is a misty cavern, facing the west and running down to Erebus, past which, my lord Odysseus, you must steer your ship. The strongest bowman could not reach the gaping mouth of the cave with an arrow shot from the ship below. It is the home of Scylla, the creature with the dreadful bark…she has twelve feet, all dangling in the air, and six long necks, each ending in a grisly head with triple rows of teeth." The monster could well be a hybrid mythical creature composed of elements of giant squid, dog's heads, and shark's teeth. The 18th-century Italian natural historian, Lazzaro Spallanzani, reported that several small caves and a large one called, Dragara, could be found at the base of this 75-meter-high limestone headland and that the waves crashing into these caves produced strange sounds. In 1912, Bérard spotted a retaining wall, halfway up the rock, that seemed to conceal a fissure cave entrance and he tried to explore it but was stopped by the Italian Coast Guard. Several observers have surmised that the earthquake of 1783 destroyed any cave that was there.

After losing six men to the monster, a violent storm came up and Od-

ysseus was persuaded by his men to land on Thrinakia Island. Thrinakia means "Island of the Trident," but the name commonly given to Sicily in classical times was "Trinakria," meaning "Three-Angled Island," for its shape is an almost equilateral triangle. So, the text says, "we beached our ship and dragged her up into the shelter of a cave, a pleasant spot which the Nymphs used as a dancing-ground and meeting-place." Bérard tried to locate this littoral cave at a cape marked "La Grotta," not far from the strait, north of Messina, but all he found under the remains of a church destroyed by an earthquake was the collapsed ceiling of a cave with a spring. Bradford calculated that the ship should have sailed further down the coast in a day's time and would have reached the cove where Taormina is now located. He writes, "there are still caves in plenty in this cove, as well as two or three small beaches."

Later his ship and all his men are lost in a storm, but Odysseus survived by tying the mast and keel together. For nine days he drifted on the sea and reached the "lonely" Isle of Ogygia, "far away in the middle of the seas," where the goddess, Calypso, welcomed him. Her "cave was sheltered by a verdant copse of alders, aspens, and fragrant cypresses…Trailing round the very mouth of the cavern, a garden vine ran riot, with great bunches of ripe grapes; while four separate but neighboring springs four crystal rivulets were trained to run this way and that; and in soft meadows on either side the iris and the parsley flourished." More than any other, this landfall has generated considerable speculation by Homeric geographers. In 1624, Philip Cluver proposed the Isle of Malta for Ogygia and later, both Baglio in 1958 and Bradford in 1963 followed suit. In 1897, Butler suggested the Isle of Pantellaria, located southwest of Sicily.

Calypso was the daughter of Atlas, who "with his own shoulders supports the great columns that hold the earth and sky apart." The Atlas Mountains are in Morocco and the "great columns" are the Rock of Gibraltar on one side and Mount Acho on the other, so Bérard searched along the Moroccan coast and found Perejil Island, whose name means "parsley." There he discovered a "vaulted cave" some 50 meters long and, over on the African mainland, another cave with four springs. Throughout his investigation Bérard persists in ignoring that Perejil Island is situated close to the mainland, not in "the middle of the seas," and it is far too distant, almost 2000 kilometers, from the Strait of Messina for someone drifting on a mast-keel raft, with a speed of at best one knot, to be able to reach in nine days.

As early as the 3rd century B.C., the director of the library at Alexandria, Callimaque, had proposed the Isle of Gozo, just northwest of Malta, as Calypso's Ogygia Island. An old engraving shows this cave as an

arched opening at the north end of a limestone escarpment above Ramla Bay. In the 1920s, Halliburton estimated the cave at thirty feet (10 m) square and ten feet (3 m) high and "hung with beautifully shaped stalactites." There were "signs of the chisel everywhere," indicating that some portions of the cave were artificial. Later massive collapse occurred due to local quarrying near and over the cave. In 1952, Shaw wrote that "the interior of the cave consists of a series of low crawlways between shattered chambers floored with angular fragments of rock." While visiting this cave in 1986, I found it much the same.

After seven years, Odysseus built a raft, sailed east for seventeen days, and reached Scheria (modern-day Corfu) where the Phaeacians heard his tale and escorted him south to his homeland of Ithaca. He landed there in the cove of Phorcys and hid the treasures he had received from the Phaeacians in a nearby cave. The text reads, "At the head of the cove grows a long-leafed olive tree and nearby is a cavern that offers welcome shade and is sacred to the Nymphs whom we call Naiads. This cave contains a number of stone basins and two-handed jars, which are used by the bees as their hives; also great looms of stone where the Nymphs weave marvelous fabrics of sea-purple; and there are springs whose water never fails. It has two mouths. The one that looks north is the way down for men. The other, facing south, is meant for the gods; and as immortals come in by this way it is not used by men at all." Nearly all Homeric geographers
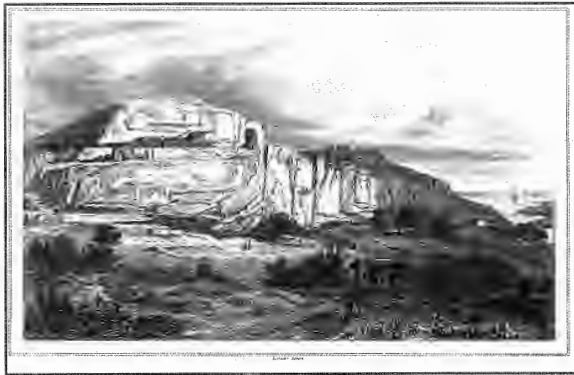
and scholars are in agreement that this cave is Marmarospilia or the Cave of the Nymphs, located south of Dexia Bay near Vathy. Its entrance faces northwest and a second skylight entrance is 80 meters to the northeast. Ancient terracotta lamps and figurines were recovered there which are on exhibit at the Vathy Archeological Museum. Much vandalism of the "looms of stone" has occurred and broken stalactites have become sad ornaments on the terraces above the entrance.

From this cave, Odysseus followed a path to Eumaeus' hut at the Raven's Crag in the southern part of Ithaca, where he stayed until returning to his home to fight the suitors. The swine herder, Eumaeus, watered his pigs at the Spring of Arethusa, just below these cliffs. This discharge point is in a shelter cave of thin-bedded limestone in a small gorge that occasionally carries surface water from the cliff. Homer tells us that, while Odysseus slept at the hut, Eumaeus "went off to pass the night where the white-tusked porkers slept, under an overhanging rock sheltered from the northerly winds." This rock shelter is either the one at the base of the Raven's Crag or the one I noticed further north across the slope. Homer's vague descriptions of distant Mediterranean landfalls were probably gained from oral tradition and mariner's tales, but some feel that his accurate mastery of the geography of Ithaca was based on a personal knowledge of that island.

At Polis Bay in the northern part of Ithaca in 1873, a local man found a bronze sword and a tripod-cauldron under the remains of the collapsed Louizos Cave. Following this lead, Sylvia Benton, working for the British School at Athens in 1932, found in this cave shrine twelve more bronze tripod-cauldrons, dated from the tenth to early eighth century B.C.(Benton 1938) Now the number of bronze tripods that Odysseus had been given as parting gifts by the rulers in Scheria was thirteen according to Homer. So the tantalizing question remains: did Homer know about these thirteen tripods in the cave at Polis Bay and decide to work them into his epic poem? (Luce 1998) Benton also dug up a fragment of a terracotta mask dating from the second or first century B.C. and bearing the words, "Votive offering to Odysseus." This was clear proof that the cult of the hero Odysseus had been associated with this cave in the Hellenistic period.

Thanks to The Odyssey we know more about Odysseus than about Homer himself. Never an adventure seeker, "Odysseus of the nimble wits" used his intelligence to conquer obstacles, which were placed in his path. He had all the makings of a great caver - prudent, ingenious, perseverant, and courageous. He showed that the true power of a man or woman lies not in their muscles or their technical knowledge, but in their ability to think.

All this debate about the different landfalls is not terribly important. What is essential is Homer's Odyssey - one of the first true classics of Western literature. If cavers - both science and sport cavers - would only develop the cultural side of their education, maybe we could all better spread the message of how beautiful caves are and how important it is to protect them. This epic poem has shown all generations for almost three thousand years the beauty of nature and the weakness of man in face of

that nature.

References:

Baglio, Gaetano 1958, Odisseo nel Mare Mediterraneo centrale, L'Erma di Bretschneiser, Rome

Benton, Sylvia 1938, Excavations in Ithaca, III, The Annual of the British School at Athens, n. 35, 1934-

35, Macmillan, London, p. 45-74

Bérard, Victor 1927-1929, Les navigations d'Ulysse:

Ithaque et la Grèce des Achéens, vol. 1, 1927, Armand Colin, Paris

Calypso et la mer de l'Atlantide, vol. 3, 1929, Armand Colin, Paris

Nausicca et le retour d'Ulysse, vol. 4, 1929, Armand Colin, Paris

Bérard, Victor & Boissonnas, Frédéric 1933, Dans le sillage d'Ulysse, Armand Colin, Paris

Blanc, Albert 1940, The Fossil Man of Circe's Mountain, Natural History, v. 45. n.5, May 1940, p.280-281

Bradford, Ernle 1963 (2004), Ulysses Found, Hodder & Stoughton, London

Butler, Samuel 1897, The Authoress of the Odyssey, Jonathan Cape, London

Casteret, Norbert 1954, Exploration, Perrin, Paris, p. 184-192

Cuisenier, Jean 2003, *Le périple d'Ulysse*, Fayard, Paris

Cuisenier, Jean 2004, Dans le sillage d'un héros de fiction, *Geo-Hors Série*, Nov. 2004, p. 22-25

Gauci, Anthony 1966, Gozo, St. Joseph's Home Printing Press, Malta, p. 73

Gaudio, Attilio 1964-65, Dans le sillage d'Ulysse, Sciences et Voyages, Août 1964; Déc. 1964; Janv. 1965;

Mars 1965; Avr. 1965; & Mai 1965

Grosvenor, Melville 1973, Homeward with Ulysses, National Geographic, v. 144, n. 1, July 1973, p. 1-11

Halliburton, Richard 1927, The Glorious Adventure, Garden City Pub. Co., New York, p.196-204, 230,

282, 326-331

Homer, *L'Odyssée*, Tome 1-3, (Translated by Victor Bérard, 1924), Les Belles Lettres, Paris

Homer, The Odyssey, (Translated by E.V. Rieu, 1946), Penguin Clas-

sics, London

Luce, J.V. 1998, Celebrating Homer's Landscapes, Yale Univ. Press, New Haven, Conn., p.191-204,

224-230

Petrocheilou, Anna 1984, The Greek Caves, Ekdotike Athenon, Athens, p. 64-65

Pocock, Lewis 1957, The Sicilian Origin of the Odyssey, Wellington, New Zealand

del Salvio, Elena; Ferrari-Bravo, Anna; & Lissoni, Marco 1989 (2000), Sicilia, Guida d'Italia, Touring

Club Italiano, Milan, p. 295-296, 503

Severin, Tim 1987, The Ulysses Voyage, Guild Pub., London, p. 158-167, 224-234

Shaw, T.R., The Caves of Malta, The American Caver, NSS Bull. n.14, Sept.1952, p. 39

Spallanzani, Lazzaro 1792-1797 (Translated from Latin by Angelo Fabroni, 1825), Viaggi alle due Sicilie e

in alcune parti dell'Appenino, Tomo II, Milan, p. 443-444; (Translated into French by G. Toscan, 1797)

Voyage dans les deux Siciles, Tome IV, Maradan, Paris, p. 113-114

Steinhart, Matthias & Wirbelauer 2002, Aus der Heimat des Odysseus, Philipp von Zabern, Mainz, p. 72-77

Wolf, Hans-Helmut & Armin 1968, Der Weg des Odysseus, E. Wasmuth, Tübingen, p. 48-49, 124-125

O-10

PARFUM DE GRECE

Par Catherine et Jean-Carlo FAIT

Spéléo-club de La Ciotat - La Salamandre • 7, Les Ombelles III Avenue Guillaume Dulac 13600 La Ciotat (1980 - 2004)

Villa jujube 19, chemin de Fardeloup 13600 La Ciotat (2005) • Tel/Fax: 04 42 08 56 31 e-mail: jcfait@mairie-laciotat.fr

Résumé:

Catherine et Jean-Carlo FAIT, sont membres fondateurs du Spéléo-club de La Ciotat (Bouches du Rhône - France) qu'ils dirigent de main de maître depuis 25 ans.

Jean-Carlo FAIT possède à son actif l'exploration de plus de 1500 grottes, a écrit de nombreux ouvrages et réalisé des films sur les cavernes et les falaises de La Ciotat, dont il est le spécialiste incontournable. En décembre 1989 il crée l'Institut du Monde Minéral. Né d'un père Italien et d'une mère française il possède la double nationalité et est né à Karditsa, en Grèce, le 5 décembre 1959.

Après avoir été pendant longtemps trésorière du Spéléo-club de La Ciotat, Catherine REGNAULT-FAIT est aujourd'hui présidente de la Maison des Falaises, créée en 1993, pour gérer et valoriser le site naturel classé des plus hautes falaises maritimes d'Europe.

Au mois de septembre 1987 Catherine et Jean-Carlo ont organisé un voyage en Grèce en compagnie de sa mère Rosette Tommasi et « Jo » son beau-père. Ce voyage initiatique d'un mois est pour Jean-Carlo un pèlerinage sur sa terre de naissance: d'abord sur les traces des bergers du plateau d'Astraka où s'ouvre le mythique « Abîme de la Provatina », l'une des plus grandes verticales souterraines du monde, mais aussi à Karditsa, à quelques kilomètres des « Météores », région centrale de la Grèce et dont les conglomérats rappellent étrangement ceux du Bec de l'Aigle à La Ciotat. Un voyage de 6000 km à travers l'Italie et l'ex Yougoslavie, à la rencontre de l'origine de la civilisation, de la Grèce antique: Delphes, Athènes, Mycène, Olympe, sans oublier le « canal de Corinthe » qui vibre sur un air de Sirtaki.

Président-fondateur du Spéléo-club de La Ciotat, fondé en 1980, photographe et cinéaste, Jean-Carlo FAIT, Catherine son épouse et leurs deux enfants souhaitent profiter de l'organisation à Athènes du 14 congrès international de spéléologie au mois d'Août 2005 pour redécouvrir ce « Parfum de Grèce » et promouvoir leur regard nouveau sur la spéléologie à l'heure ciotadenne à travers la présentation d'un film sur la « Grotte du Grand Draïoun ».

Cette communication est dédiée à mes parents, Silvio FAIT et Rosette FAIT, née TOMMASI, décédés brutalement début 2004 ; et à Marcelle REGNAULT, née Grégeois, qui vient de nous quitter en ce début d'avril 2005.

Abstract

In La Ciotat, Jean-Carlo and Catherine Fait founded , in 1980, the Speleo-club "La Salamandre", then in 1993 the Cliffs-House , with a main aim : to give the opportunity to discover and add value to this natural site of the highest sea cliffs in Europe. The Mineral World Institute was finally created in 1999.

Jean-Carlo Fait explored more than 1500 caves, wrote different books and realised films on La Ciotat's cliffs and cavities, that he is nowadays the most respected specialist of them.

The dynamic support of his wife relayed his activity in the field, in cooperation with local actors of the sportive and associative life in La Ciotat, and with nature lovers. The couple has 30 years of practice in organisation of various kinds of events, outings and courses for all ages and types of groups. And their activity strengthened the speleology in La Ciotat area. Therefore, they are extremely interested in participating in this congress and transmitting their experience, since Jean-Carlo, born greek of an Italian father and a French mother, took his wife and his mother back to his roots, eighteen years ago, on the Astraka table-land where the mythical Provatina abyss opens, with a great enthusiasm .

Now, with an increased motivation, they wish to take advantage of this 14th congress to take their children with them and transmit them the "perfume of Greece" and bring together the speleological interest of La Ciotat through the presentation of the film on the Draïoun Cavity, the most important of Calanques.

Ici Commence L'aventure

Je suis né à Karditsa, en Thessalie, à quelques kilomètres des célèbres « Météores », le 5 décembre 1959 au matin. Le premier air que j'ai respiré en venant au monde est donc « le parfum de la Grèce ! », mon pays natal. Mon père, Silvio Fait, italien de nationalité, a quitté son tyrol natal en

1956 pour venir travailler aux Chantiers Navals de La Ciotat en tant que manœuvre puis soudeur.

Il raconte dans son cahier-journal: « Ragazzi ! quella *laggiù è La Ciotat, la cittadina che ci porterà fortuna o che finirà di rovinarci ! ».* En compagnie d'une dizaine d'italien entre vingt et vingt cinq ans, c'était ajoute-t-il: « la prima volta che andavamo all'estero »… Son travail le conduira à travers toute la France, puis en Grèce où, pendant un an il sera soudeur hautement spécialisé, et contribuera à la mise en place des conduites forcées qui alimentent la centrale hydroélectrique de Karditsa, où ma mère, née à La Ciotat de parents émigrés de Toscane, me mettra au monde.

A ma naissance impossible de bouger. Les Grecs m'avaient « ficelé » dans des bandelettes, comme une « momie » et lorsque ma mère me sortait pour « aller promener » les passants me « crachaient » dessus pour, dit-on, éloigner le mauvais œil. J'ai oublié le nom du docteur qui m'a mis au monde, mais ma mère me racontait souvent les problèmes de compréhension dus à la différence de langue, qui se terminaient souvent par un fou rire. Ainsi, un jour où j'étais malade elle fit appel au docteur qui m'a mis au monde:

- « J'ai mis du miel dans son biberon.

- Non, Madame,

- Si, j'en ai mis… vous dis-je !

- *Mais non, ne vous inquiétez pas il n'a pas l'anémie !* »

J'ai donc commencé à explorer le monde en Crèce, sur des bases d'incompréhension. Et, il me faudra attendre 28 ans pour retourner dans « mon » pays natal en compagnie de ma mère, Rosette. Un prénom prédestiné qui rappelle celui de la fameuse « Pierre de Rosette » déchiffrée par Champollion !

C'est le compte rendu inédit de ce « Voyage en Grèce - septembre 1987» que je voulais publier en mémoire de mes parents à l'occasion de ce 14ème congrès international de spéléologie. Avec Cathy nous avons préféré faire un bulletin spécial « La Salamandre », en le complétant de notre expérience de 2005.

Je ne donnerais donc ici que les grandes lignes de notre périple… de 1987 ! Et je remercie d'avance nos collègues spéléologues Grecs pour leur accueil à l'occasion de ce congrès qui est une occasion inespérée, pour moi-même et toute ma famille, de retrouver mes racines non sans une certaine émotion.

Ainsi je puis dire que depuis 45 ans, je suis Grec de naissance, italien par le sang et français par l'esprit. On ne saurait rêver meilleur lien pour sceller une solide amitié « européenne ».

Récit d'un « Voyage en Grèce, septembre 1987 » par Catherine REGNAULT-FAIT

Samedi 12 septembre 1987, 8 h.

Enfin le départ tant attendu de La Ciotat (Bouches du Rhône - France). Un périple de près de 10 000 kilomètres, longuement préparé. N'avons-nous rien oublié, tout est-il dans la voiture ? Les bagages sont-ils bien arrimés sur le porte-bagage chargé à craquer ? En effet, nous emportons 200 mètres de corde et tout le matériel d'exploration pour descendre dans la « Provatina » qui hante nos rêves. Dernières vérifications du sac à main: les cartes d'identités, les sous, tout y est, nous pouvons partir, mais pour se faire, il ne faut pas oublier les cartes routières de la Yougoslavie et de la Grèce.

Pour aller en Italie, pas besoin d'indications nous connaissons le chemin… depuis le temps que nous circulons entre Toscane et Trentino à l'occasion des vacances. Mais la Grèce nous paraît bien lointaine, isolée par la barrière géographique de la Yougoslavie, où nous n'avons jamais mis les pieds. Que de rêves, que d'espoir, que de retrouvaille dans cette Grèce antique, berceau de notre civilisation !

« Après un parcours autoroutier sans encombre nous débarquons, samedi vers 20 h, chez beau papa, à Saltaria, près de Rovereto (TN) ouf ! Je suis un peu fatiguée et dire que 7000 Kms (aller-retour), nous attendent ; là, dans la vieille maison familiale nous établirons l'itinéraire que nous ne suivrons que de très loin. Tout d'abord la Yougoslavie, pays de désolation, de tristesse, les gens sont pressés, les enfants courent pour aller à l'école de peur d'être en retard ; il fait bon, mais les femmes sont habillés de robe, de chandail et portent des bas ; pas un sourire sur les lèvres, seulement la tristesse. Les enfants 5 à 6 ans (comment leur donner un âge ?) viennent mendier trois sous, trois bonbons tandis qu'un petit vieux, fatigué de sa longue marche, vient se rafraîchir à la fontaine où nous nous sommes arrêtés pour nous désaltérer… et d'un pas leste, s'évanouit dans la forêt, où va-t-il ainsi, combien de kilomètres lui reste t-il à parcourir ?

Notre premier objectif touristique en Yougoslavie sera la **grotte de Postumia.** Magnifique, grandiose mais trop touristique à mon goût. Je préfère beaucoup **Sokjean** Jame, plus pittoresque et mystérieuse avec son torrent souterrain qui gronde sous des voûtes de cent mètres de hauteur. Nous ne quitterons pas ce pays sans aller voir les **lacs de Plitvice.**

Un petit train vous dépose dans un grand parc réserve naturelle, où les lacs abondent. Trente six paraît-il, de droite et de gauche, les lacs, les cascades de tuf se succèdent aussi étincelantes les unes que les autres. Nous aurons peu de temps pour la visite aussi nous ne ferons que le trajet le plus court. Quel dommage, il faudrait passer des jours entiers dans ce lieux enchanté et romanesque.

Notre séjour n'est que de trois semaines et nous n'avons pas le temps de nous attarder. Nous poursuivrons notre périple vers la Grèce, où l'histoire et la mythologie nous attendent.

Arrivée en Grèce.

Nous commencerons par le **plateau d'Astraka.** Nous installerons nos tentes dans un petit village, des plus pittoresques. Notre but est clair à Jean et moi: aller voir **l'Abîme de la Provatina,** sur le très haut plateau d'Astraka, mais le temps est à la pluie. Et après 10 heures de marche lourdement chargés (200 m de cordes plus le barda du parfait spéléologue) nous rebrousserons chemin au grand désespoir de Jean, dans la nuit et sous les hurlements des chiens qui gardent les troupeaux dans la montagne.

Dans la plaine de Thessalie, les « **Météores** », rochers de grès et poudingues où s'accrochent de splendides monastères nous redonnent de l'espoir. Il faudrait là aussi rester des semaines, en admiration devant ces beautés de la nature et des hommes. On se demande comment les prêtres, les sémites à l'époque ont pu construire leurs monastères là haut, près du ciel. Je crois que de tout ce que j'allais voir de la Grèce, c'est l'endroit qui m'a le plus frappé.

Puis nous irons à **Karditsa**, ville où Jean est né, le 5 décembre 1959. A la grande stupéfaction de ma belle-mère, Rosette, la maison où elle était logée (rue kolokotroni) est toujours là, à l'abandon ! 28 ans se sont écoulés… tout est en place, comme si le temps avait été suspendu. Hasard ou signe du destin ? Jean prend quelques photos. Il n'y a là, rien de particulier dans cette petite ville. Le soir, vers 18 h, sur la place principale les gens défilent dans un sens puis dans l'autre sans arrêt jusque tard dans la nuit ; même les boutiques ouvrent-leur portes.

Avant de continuer, nous irons voir la conduite forcée qui descend de la montagne à **Mitropolis**. C'est là que mon beau-père, Silvio FAIT, travaillait comme soudeur hautement qualifié lors de son séjour d'un an en Grèce. »

A **kastania**, au bord du lac artificiel, nous rencontrons un vieil homme moustachu et ridé, assez fort, qui nous dit avoir travaillé à la construction du barrage entre 1952 et 1965, époque où mon père était donc sur place.

- « Le barrage fait 83 m de haut pour 220 m de long », nous précisera-t-il.

« Puis nous arriverons à **Delphes**, site archéologique majeur. Merveilleux: il faut «gravir» la montagne, passer entre les temples (enfin ce qu'il en reste) pour atteindre le stade, immense et bien plat presque inimaginable au milieu des montagnes.

Enfin nous visiterons **ATHENES**, la capitale. Je fus très déçue par cette ville, rien n'y est particulier, les gens sont pressés, les magasins identiques à ceux que nous avons vus. Bien sûr il y à le **Parthénon**, comme posé sur un piédestal de grès, mais par rapport à certain site que nous avons visité je ne crois pas que ce soit le plus beau, surtout avec tous ces échafaudages… qui créent un « barrière visuelle ». En revanche **les cariatides** sont elles magnifiques de souplesse et de fragilité.

Nous franchirons le **canal de Corinthe,** dont je garde une forte impression sur un fond de Sirtaki. Les boutiques sont nombreuses et nous achetons quelques cassettes audio qui égrènerons les longues heures de notre voyage de retour. »

Faute de temps, notre périple dans le Péloponèse se limitera à Mycène et Olympe... et il nous faudra attendre dix huit ans pour partir enfin à sa découverte.

LE JOURNAL DETAILLE DE NOTRE VOYAGE en 1987 et de celui de 2005 SERA PUBLIE DANS LA SALAMANDRE N° 75 à notre retour de voyage.

2 photos Astraka, 2 photos Météores, Athènes et coucher de soleil sur la baie de Vougliagmeni.

QUEQUES SPECIALITES GREQUES QUI NOUS ONT MARQUEES EN 1987

Au cours de notre séjour en Grèce nous avons découvert des spécialités et us et coutumes locales:

Boissons:

Vin au fort goût de résine:	RETSINA
Apéritif goût d'anis:	« OUZO »
Tarama:	mousse aux œuf de cabillaud
Tzatziki:	yaourt au concombre et à l'ail
Salade Grecque:	concombre, tomate, féta, olives,
Souvlaki:	brochettes
Marchants Ambulants:	« Donner » = polpete + brochette

Risotto in Cavroman viande de mouton, artichauts à la grecque
Fromage local de chèvre: la féta

Pâtisseries:

baclavas à base de miel,

kovmos:	crème au citron
lokoum	
kataïfi, loukoumades.	
Gâteau « tiropito »:	riz + œuf + crème

Spécialités grecques:

Moussakà:	ragoût de viande hachée, tomates + béchamel, verdure frite, fromage
Dolmates:	feuille de vignes
	froid en entrée: riz, oignons, feuilles de menthes
	chaud, plat de résistance: riz + fromage ou viande hachée + œuf

Le Dîner	vers 10 h le soir
Night/cabarets:	Athènes et littoral du Pirée à Vouliagmeni
Monnaie:	Le drachme

1 drachme = 100 leptas / 1 F = 10 drachme = 4,95 prix à diviser par 20 environ

Chèques non acceptés   Banques: Ouverture de 8 h à 14 h 30

1 h de décalage par rapport à la France (+ 1h)

GRANDS GOUFFRES et GROTTES DE GRECE

La revue « Spelunca » de la Fédération Française de Spéléologie avait publié deux articles en 1976 et 1977 sur deux des principales verticales souterraines grecques, situées sur le plateau d'Astraka:

1) **La Provatina** (grèce): pindhos oros, loaninna,
Plateau d'Astraka qui domine le village de Papigon.
Bibliographie: Spelunca 1977, n°4 p 159. 160
*Accès: Canyon raide (quelques passages d'escalades ou sentier au Nord Ouest qui contourne le*s falaises). Descente - 6m spit + crochet ; 2ième spit 3m sous le palier - 177m

2) Le gouffre **Mavro Skiadi**
Spelunca 1976 n° 4 p155 - 158
Grottes: Perama (Perama, loaninna, Ipeiros), développement 1700 m.
Vlyhada ou Glyphada (Diros, Lakonie, Peloponnisos, développement 3400 m.
grotte touristique au bord de mer.

Curiosités: Cote de Vouliagmeni, prés d'Athènes, piscine naturelle d'eau douce.

Yougoslavie, près de Lubljana, pont naturel et gorge du RAK REKA, prés du village de Skocjan - gouffre.

14ème congrès international de spéléologie à Athènes - Août 2005.
Depuis ma naissance ceci est mon troisième séjour en Grèce:

- 5/12/1959: Naissance à Karditsa. Mes parents sont arrivés en Grèce en août, pour un an.
- Septembre 1987: Retour sur mon lieu de naissance et découverte de la Grèce antique.
- Août 2005: Congrès de spéléologie et découverte du milieu souterrain Grec avec ma famille.

Un seul regret, ne pas l'avoir fait avec mon père décédé le 28 février 2004. Aussi était-il normal que je lui dédie une partie de mon œuvre de spéléologue qui s'inscrit dans le grès et le poudingue des plus hautes falaises maritimes d'Europe, à La Ciotat ; mais aussi dans le marbre de Toscane et dans les dolomies du Trentin.

Désormais, un triangle sacré s'est formé entre le Tyrol du Sud, la France et la Grèce, en passant par la Toscane ; un hymen invisible unira pour moi et pour l'éternité ses lieux chargés d'histoire. Après tout mon nom, FAIT ne dérive-t-il pas de l'allemand Veit, en italien Vito, nom qui signifie « vie éternelle ».

Au sommet du Bec de l'Aigle, rocher de poudingue caractéristique qui protège depuis des temps immémoriaux la ville de La Ciotat, existe un petit abri rocheux caché par des oliviers d'où le regard scrute la mer vers l'Est à la recherche de quelque navire venu de Grèce. N'est-ce pas au pied de ce monolithe de poudingue roux, qui semble déployer les ailes d'un rapace flottant sur les eaux turquoises que les premiers Grecs vinrent jeter

l'ancre dans l'Anse du pré qui deviendra, bien plus tard, La Ciotat, escale inévitable sur la route maritime de MASSALIA ?

Je dédie donc la petite grotte au sommet de cette « pierre », à Rosette ma mère, et le pas d'accès depuis le Belvédère du large (parc du Mugel) à mon père Silvio. Et j'invite nos amis Grecs, spéléologues ou non, à venir nombreux découvrir les plus hautes falaises maritimes d'Europe, sur les traces de leurs ancêtres venus s'installer à Massalia (Marseille), et surtout à faire l'ascension du Bec de l'Aigle, dont le poudingue n'est pas sans rappeler les célèbres « Météores » de Thessalie. Hasard ou correspondance ?

A UN AN DE LA TRAGEDIE

Il y a plus d'un an, au décès de mes parents j'ai décidé de leur dédier une partie de mon travail d'exploration et de mise en sécurité des sites naturels de La Ciotat, notamment la création des « Randonnées du vertiges ». Au cours de l'été 2004 j'ai déposé une plaque de marbre et cette inscription au sommet du Bec de l'Aigle:

Je dédie cette pierre à Rosette, ma mère
Soutien fidèle de mes plus hardies pérégrinations.
Je dédie le « Passo Silvio », à mon père
Qui, bien avant moi a gravi

Le Bec de l'Aigle et les montagnes
De son Tyrol natal
Je dédie cet abri « de la mante religieuse »
Aux artisans méconnus qui ont ouvert la voie…
Des « randonnées du vertige » à La Ciotat.
Et baptise les rappels qui suivent
Au nom du Père, du fils et du Saint Esprit
Incarnés dans les rochers des « Trois Secs »,
ABRACADABRA.
Une chanson les représente comme « trois filles », « trois Maries ».
Un véritable cimetière marin repose au pied de ce mirador.
Depuis l'île verte, ce monolithe rocheux vu de profil
Peut faire penser à un rapace, animal vénéré par les Egyptiens.
Les Grecs et les Romains ont été impressionnés par
Sa splendeur immortelle et sa majesté.
Gageons que ceux qui suivront nos pas sauront le respecter !

Jean-Carlo FAIT
(Fils éploré - 28 février et 6 mars 2004)
Photo Bec de l'Aigle à La Ciotat.

O-11

Precise Measurement of Surveying-Sections Using Image Processing Techniques

Selçuk Canbek*, Nihat Adar*

elcuk@ogu.edu.tr, nadar@ogu.edu.tr

* Osmangazi University Computer Engineering Department, Eskişehir, Turkey

In this research, a method for surveying of cave, tunnel, and closed volumes is developed. In traditional methods, section height and width is estimated or measured manually. Approximated 3-D map of volume can be produced connecting those sections. In order to get more precise map, operator shall measure sections with many points that is very time consuming process. In this study, measurement process is automated by taking pictures of sections and those pictures are post processed using image processing techniques to produce precise cutting contours of measured sections. This method called Photo-Survey.

Photo-Survey uses a specially modified light source (battery operated light source with 180-degree view angle). Operator uses this lamp to illuminate the section and to obtain sharp shadow edges at measurement locations. Then, a digital photograph of illuminated section is taken. On the back of the light source, an object (circle picture) with known size is attached. These pictures are processed as following, afterwards. First, a median filter is applied to eliminate noise and reflections. In order to produce shadow contours of section, edge detection methods are used on pictures. Having shadow contours, measurement can be applied on these pictures if they satisfy two criteria. The first one is that camera should be perpendicularly positioned to sections surface. In other words, camera should be located on the normal axis of section surface. If one knows angle between section surface normal and camera, picture taken with any angle can be used for measurement. A method to find normal axis of a circle in a picture is developed. Thus, the picture can be corrected using affine transform methods using calculated angle. Second criteria, camera used in this method should be inserted far enough so that perspective distortion is negligible. However, this is not a proper restriction to follow in caves, because, we do not enough space in caves to get pictures from far away. The camera used in Photo-Survey method is calibrated and a method is devised so that its pictures can be transformed from perspective to parallel projection allowing us to take pictures closer to measured sections.

Photo-Survey method allows users to take pictures freely and fast.

Next, these pictures are post processed to make measurements precisely. This lets operators to spend less time for measurement in caves or tunnels (only time to take pictures for each measured section).

Having precise cutting contours of each measured section one can produce 3-D map of volume.

1. Introduction

Cave studies are made by researchers from different disciplines. Geologists, archeologists, biologists, speleologists and others use similar research methods in cave studies. While some researchers study rocks and underground water, others only might interest intersects, flora in caves. In order for them to make research in caves, cave maps must exist. Cave maps can serve many uses in an investigation; depend upon what is being attempted. Some disciplines uses cave map to find their ways in caves, some others tries to point the location where they picked the samples. Speleologists need to know how far and deep they reached in caves. Traditional maps give rough information about shape and distances in the caves. When researchers use cave maps for volume calculation or distance measurement, map's precision becomes important [YAMAC 03, TASKIRAN 03, ARIKAN 03, PANCARCI 03].

The standard survey technique consists of the measurement of azimuth and distance between consecutive survey stations and depth, width, and height at each station. Survey stations were established at turns in the guideline and at junctions between cave passages. Once the survey data has been collected, checked, and tabulated, the next step in the mapping process was to convert the data into a Cartesian coordinate system such that the data could be plotted and compared to other forms of spatial data. Numerous computerized cave mapping programs are available that will automatically generate cave maps. Some of the more popular programs include Compass2, Survex3, and WinKarst4. Some of the available programs are capable of three-dimensional plotting and statistical analysis of

survey data [BTOPCU 05]. Most programs, however, are tailored for survey data that manually collected. In this research, we proposed a method that automates the survey data collection.

People preparing cave maps have to study with light and a few equipments because the measurement process is hard and very time-consuming work. Thus, maps prepared by these traditional methods give information about shape and rough distances in the caves and most of the details are not included (Readings taken from a navigational compass can be considered accurate to within +/- 1°; Distance measurements taken can be considered accurate up to +/- 1meter). Because of the lack of the precision, to make surface or volume calculations using traditional maps is not possible. Techniques used in traditional cave mapping methods are main cause of this precision problem. In traditional mapping methods, distance between measurement stations and direction information's precision is important. However, precise cutting contours of the measurement section at stations have no much importance. They usually measure height and width of the section and the shape of the section contours are roughly hand drawn. Most of the time, the height of the section at stations is estimated. As a result, maps prepared using traditional methods cannot be used for precise calculations of the cave distances and volumes. A method to produce precise cutting contours of the sections, called section-cut, is proposed. Thus, precise 3-D maps of the caves can be constructed using section-cuts produced by our method.

2. Photo-Survey Method

In traditional mapping methods, section-cuts are measured using right, left, top, and bottom distances at stations and section-cut shape is hand drawn roughly on to papers (Figure 1). Since this processes handled by the person who stands at station location, most of the details are lost in these hand drawn section-cuts.
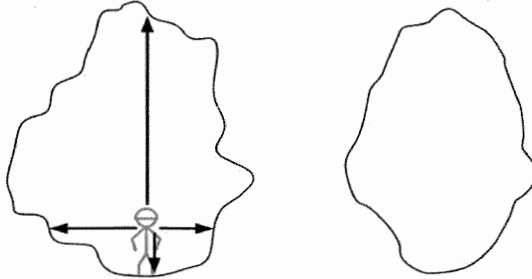
Figure 1: Traditional section-cut measurement method. Actual contour of the section and distances measured on the left. A typical hand drawn approximation of the same section on the right.

In Photo-Survey method, neither distance measurements nor hand drawing the contour of the section are needed. Only a picture of the section is taken and then post processed. These post processed pictures than can be used to make distance measurements and produce precise contour of the section (Figure 2).
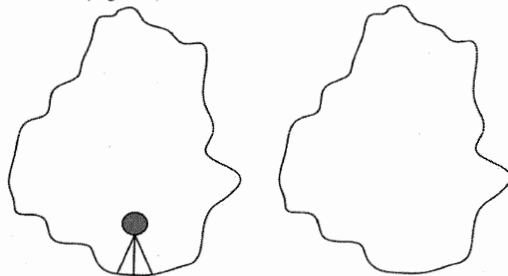
Figure 2: The Photo Survey Method. Picture of the section with light source on the left, the contour of the section after post processing on the right.

2.1. Material and Method

In this method, a camera for taking pictures and a point light source that lightens the half sphere are needed.

2.1.1. **Camera:** A digital camera with fixed lens can be used. In this study, Canon EOS 10D-photo camera with 20 mm fixed lens is being used. Cameras with zooming lenses cannot be used because lens distortions are corrected with software techniques and these techniques cannot be applied to zooming lenses. While taking pictures, camera is fixed using a standard tripod. Using higher resolution camera increases the measurement precision. Our camera's resolution is 6.5 pixels. Its picture, taken 5 meter away from camera, can be used to calculate distances with ±5 mm tolerances.

2.1.2. **Light source:** The light source should be small and have high intensity in order to create sharp shadow contours. In this application, 55W halogen light bulb is used. Since light source should lighten half sphere homogenously, we inserted the light bulb into one side open cylindrical cover (Figure 3). The cylindrical cover is positioned using a tripod at stations. On the back of the cylindrical bulb cover a circle with known radius is drawn. This circle is being used as reference object in pictures.

Front view   Left view   Rear view
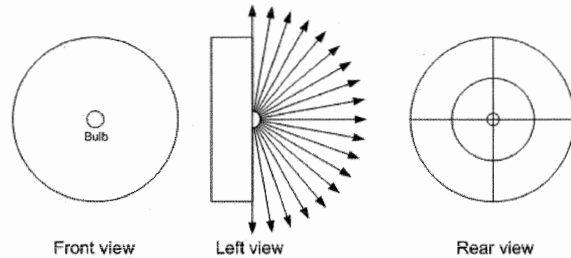
Figure 3: The front, side and rear views of the light source

2.2. Taking Pictures

The light source is located at station where the contour of the section is needed. Camera is positioned at some distance (distance registered for later use) so that it can get the picture of the whole section (Figure 4). Light source lightens the section away from camera.
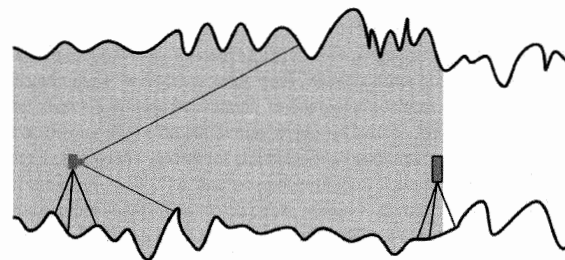
Figure 4: Taking section picture

In the picture the contours of the section is marked by shadow edges (Figure 5).

Additionally, traditional mapping measurements, using DistPro laser range finder, are taken at every section and compared with Photo-Survey method results.

2.3. Post Processing

In order to use the picture, taken from survey location, it has to be post processed by image processing techniques. The post processing operations are handled at several stages as shown in Figure 6.
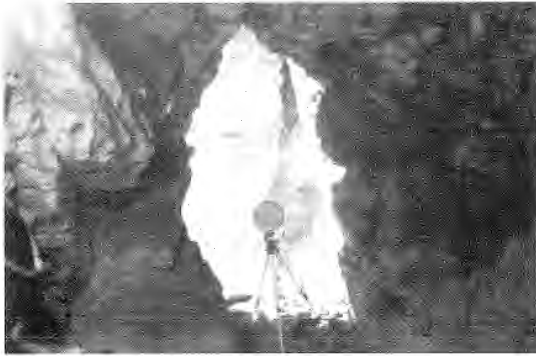
Figure 5: A sample section picture
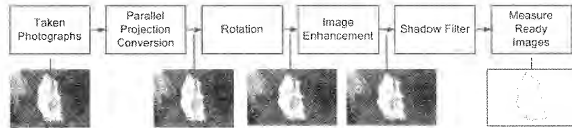
Figure 6: Post Processing Operations

2.3.1. **Perspective to Parallel Conversion:** The light rays of the object go through camera lenses and poses camera sensors. Camera lenses and detectors cause's distortions near the picture frame borders. Taking picture further away from the section alleviates the distortion problem however caves are small places. Most of the time, pictures has to be taken in short distances. In addition, lenses with wide angles (24 mm) have more distortion. In order to make measurements on the pictures, this distortion has to be corrected. For this purpose, a picture of the test image (black and white 16x16-checker board picture) has taken and a correction filter is constructed by software. A correction filter for each lens has to be constructed.

2.3.2. **Rotation:** Another criterion to meet in order to make measurements on a picture is that the camera should be perpendicularly positioned to sections surface. However, this is not an easy task to achieve especially in caves. A method to find normal axis of a circle in a picture is developed so that camera can be positioned with any angle to section surface. After taking pictures, using circle on the back of the light source, the angle between section surface normal and camera direction is calculated. Thus, knowing the angle, the rotated picture, that is same as the picture taken with a camera that located on the normal axis of the section surface, is reproduced by affine transforms [CANBEK 04]. After rotation process, measurement on the picture using pixel counts can be achieved. The unit distance a pixel represents can be calculated by the radius of the circle drawn on the back of the light source.

2.3.3. **Image Enhancement:** Cave's environmental conditions do not allow us to take picture with same quality all the time. Noise and unnecessary details should be filtered away from the picture. In this stage, a median filter is used.

2.3.4. **Shadow Filter:** The contour of the section is produced by shadow edges in the picture. In this stage, shadow edges are sharpened

and detected to use as a contour of the section. As a result, each section picture is post processed and the precise contours of the sections are produced (Figure 7).

Figure 7: Section picture on the left. The contour of the section produced on the right

3. Results and Discussion

Photo-Survey method allows users to take pictures freely and fast. Next, these pictures are post processed to make measurements. This lets operators spend less time and effort for measurements in caves or tunnels (only time to take pictures for each measured section). Using a standard camera and a light source, ±5 mm tolerances are easily achieved. Once the precise cutting contours of each measured section, section-cut, is collected, the next step in the 3-D mapping process is to connect section-cuts to generate three-dimensional plot of the cave. In order to produce 3-D cave maps, connecting the section-cuts of the Photo-Survey method is being studied currently. In this research, each stage of the post processing is done by different software modules. Our next goal is to produce a single software module so that image-processing phase can be handled faster.

4. References

[CANBEK 04]   Canbek S., Adar N., Aksoy E., "Yüzey Yönlenmelerinin Belirlenmesinde Çemberdeki Biçim Bozulmasının Kullanımı", Havacılıkta İleri Teknolojiler ve Uygulamaları Sempozyumu, pp 537-540, 9-10 December 2004, Istanbul, Turkey.

[YAMAC 03]   Yamaç M., "Biology of Caves (Biospeology)", Conservation of the Cave Ecosystem and Cave Use in Turkey, pp 33-44, 6-7 December 2003, Antalya, Turkey.

[TASKIRAN 03] Taşkıran H., "The Importance of Caves From the Point of View of Prehistoric Archaelogy", Conservation of the Cave Ecosystem and Cave Use in Turkey, pp 77-82, 6-7 December 2003, Antalya, Turkey.

[ARIKAN 03]   Arıkan N., Evci D., Caves, "Tourism, Human and Environmental Health", Conservation of the Cave Ecosystem and Cave Use in Turkey, pp 83-89, 6-7 December 2003, Antalya, Turkey.

[PANCARCI 03] Pancarci M., Ünlü P., "Sportive Usage of Caves", Conservation of the Cave Ecosystem and Cave Use in Turkey, pp 103-114, 6-7 December 2003, Antalya, Turkey.

[BTOPCU 05]   Büyüktopçu F., "AutoCAD ile Fotoğraflardan En Kesit ve 3 Boyutlu Görüntünün Elde Edilmesi", speleoTURK-Karst and Cave Explorations Periodical, pp 28-34, Vol 2, 2005, Turkey

65

O-12

URBAN STORM WATER MANAGEMENT FOR CITIES BUILT UPON KARST:
BOWLING GREEN, KENTUCKY, USA

Gina Lee Cesin* • **Nicholas C. Crawford**
Center for Cave and Karst Studies, Applied Research and Technology Program of Distinction
Department of Geography and Geology, Western Kentucky University
Bowling Green, Kentucky USA

Abstract

Cities built upon well-developed karst have serious problems associated with storm water management, such as, sinkhole flooding, groundwater contamination from storm water runoff, spills of toxic chemicals, and storm water induced regolith collapse sinkholes. Bowling Green, Kentucky, with a population of about 60,000, is a city located entirely upon a sinkhole plain with virtually all storm water runoff flowing into the cave streams that drain the city. This paper discusses sinkhole flooding problems, regolith collapse sinkholes induced by storm water runoff and storm water quality issues. The Center for Cave and Karst Studies (CCKS) has assisted the city of Bowling Green and Warren County with its karst environmental problems since it was established within the Department of Geography and Geology in 1978. Research discussed in this paper includes the use of dye traces combined with water table measurements to determine the general flow routes of cave streams that drain the karst aquifer beneath the city. The CCKS has also mapped the accessible caves under the city and located the general route of other caves by using the geophysical techniques of microgravity and electrical resistivity. The CCKS has prepared a GIS map showing springs, karst windows, caves and other karst features. The map also shows the general flow routes taken by cave streams as determined by over 100 dye tracer tests. It also shows the contours for the water table surface beneath the city and the groundwater basin catchment area boundaries for the major springs. The paper discusses the storm water management plan enacted by the Bowling Green - Warren County Planning Commission in 1976 that prohibits construction within sinkhole flood plains and requires storm water retention basins. Two case studies are presented where the CCKS has assisted the city with sinkhole flooding problems and the removal of contaminants from storm water runoff.

Sinkhole Flood Plains

Bowling Green, Kentucky is located entirely upon a sinkhole plain with virtually all of the storm water runoff flowing into the cave streams that drain the city. Virtually all of the city is located on the Mississippian Ste. Genevieve Limestone which is characterized by large, shallow sinkhole basins with large catchment areas for storm water runoff. This low relief sinkhole plain has resulted in serious sinkhole flooding problems throughout much of the city. Just to the east of the city the underlying St. Louis Limestone outcrops and is characterized by numerous large, deep sinkholes. This high relief sinkhole plain has few problems associated with sinkhole flooding because the catchment areas are smaller, and the bottoms of the sinkholes are obvious. Therefore, people have not built houses or buildings in the sinkhole flood plain, and this area is presently characterized by low-density, suburban development or farmland.

The sinkhole flooding problem within the city was addressed by the Bowling Green - Warren County Planning Commission when they enacted their Storm Water Management Plan in 1976. This plan requires that any time there is a land use change within the County, an engineering consulting firm must prepare a storm water management plan that delimits the sinkhole flood plain elevation for all the sinkholes that would be impacted by the land use change. The sinkhole flood plain is defined as the flood elevation in each sinkhole that would result from a 100-year probability three-hour storm event. This is equal to 10.2 cm (4 in) of precipitation

falling in three hours. No consideration is given for any drainage out of the sinkhole in calculating the sinkhole flood plain elevation even though many sinkholes have open throats or cave entrances and therefore do not flood. No permanent structures are permitted within 0.3 m (1 ft) of the sinkhole flood plain elevation. If the land use change is to occur on property that does not drain into a sinkhole but rather flows onto adjacent property, then the land owner is required to construct a storm water retention basin capable of holding the increased runoff resulting from the land use change. The storm water management plan has greatly decreased sinkhole flooding in areas that have been developed since 1976. However, the older part of the city still has serious problems, so much so that the people with homes and buildings located in twenty sinkholes are eligible for federally subsidized flood insurance. Also, the city has obtained several grants from the Federal Emergency Management Agency (FEMA) to purchase and remove homes that are located in designated sinkhole flood plains.

Drilled Drainage Wells

For many years Bowling Green has attempted to alleviate sinkhole flooding by drilling storm water drainage wells to permit storm water to drain down into the karst aquifer. The U.S. Environmental Protection Agency (USEPA) considers these wells to be Class V Storm Water Injection Wells. There are now over 1,000 such wells within the urban area, and new ones are continuing to be installed. The wells are typically 20-25 cm (8-10 in) in diameter and are only cased to bedrock. They then extend as open boreholes down into the limestone. Although these wells rarely intersect caves, the great majority do intersect solutionally-enlarged bedding plane partings that direct the runoff into the network of cave streams beneath the city. These wells typically do not have the capacity to prevent sinkhole flooding in sinkholes with large catchment areas although they do facilitate drainage into the karst aquifer and reduce the sinkhole flood duration time. Many do have the capacity to reduce or eliminate sinkhole flooding in sinkholes with small catchment areas.

Constructed Drainage Wells

Increased storm water runoff due to urban development often results in induced regolith collapse sinkholes (cover collapse sinkholes). These sinkhole collapses tend to occur during flood events in places where increased storm water sinks through the regolith into a vertical crevice in the underlying limestone. These bedrock crevices are places where regolith water sinks down into the karst aquifer. The water table is typically about 18 m (60 ft) above the top of bedrock. There is usually a regolith arch or dome over the top of these bedrock crevices, and these tend to be stable until land use changes increase the amount of water percolating downward above the arch, causing the arch to collapse. If the arch collapses all the way to the surface, it results in a steep-sided hole typically 3.7 m (12 ft) wide and 3.7 m (12 ft) deep. The high clay content of the regolith in the Bowling Green area often results in the vertical walls observed in the sinkhole collapses. In areas where depth to bedrock is shallow, numerous small diameter collapses tend to occur. In areas where the depth to bedrock is deep, there tends to be fewer, but larger diameter collapses. In the Bowling Green area, even the largest collapses are rarely more than 10.7 m (35 ft) in diameter. Most of the collapses tend to occur along ditches

66

and in the bottoms of bowl-shaped sinkholes where water stands after hard rains. Although the regolith collapse sinkholes are numerous, they rarely occur under homes or buildings in the Bowling Green area. Sometimes the ones that occur along ditches do impact the adjacent highway. Since the great majority of the collapses tend to occur near the bottoms of bowl-shaped sinkholes and along ditches, they are often used to direct storm water into the karst aquifer. The collapse identifies an open vertical crevice down into the karst aquifer. These collapses are, therefore, often excavated to bedrock to expose the crevice, and a well is then constructed, sometimes several meters (feet) in diameter, to direct storm water runoff into the vertical crevice.

Caves and Open Throat Sinkholes

Since Bowling Green is built entirely upon a sinkhole plain, virtually all storm water runoff sinks directly into the karst aquifer at thousands of locations. At some of these locations, the city has directed additional storm water runoff into cave entrances and open throat sinkholes.

Storm Water Quality

In the well-developed karst of Kentucky, cave streams are quite comparable to surface streams. Storm water runoff flows directly into caves at swallets and at numerous open throat sinkholes on the sinkhole plain. Therefore, the cave streams function as storm sewers just as surface streams also function as storm sewers in non-karst areas. Cities over 100,000 population have been required for several years by USEPA to test, and if need be, to treat storm water runoff in an attempt to increase the water quality of surface streams. Two years ago, USEPA extended these regulations to all towns within the U.S. with populations of 10,000 or more. Therefore, Bowling Green, with a population of approximately 60,000, is now required to meet USEPA Phase II Storm Water Management Plan regulations. The city has recently passed a tax increase and hired five people just to deal with storm water quality. The USEPA is still permitting the direct injection of storm water runoff into the karst aquifer beneath the city, but like other towns with more than 10,000 population, Bowling Green must now test its water quality and take steps to improve the quality of storm water runoff. The Center for Cave and Karst Studies (CCKS) has assisted the city and county with sinkhole flooding problems, sinkhole collapses and groundwater quality issues since it was founded in 1978. The faculty and professional staff and students associated with the CCKS are now actively involved in assisting the city to meet the USEPA Phase II Storm Water Management Plan regulations.

Groundwater Flow Map of Bowling Green

A GIS map showing the approximate groundwater flow routes within the karst aquifer in the vicinity of Bowling Green was prepared based upon: 1) dye traces, 2) cave maps, 3) caves located by microgravity and electrical resistivity, and 4) water table measurements. This map represents research performed by the faculty, professional staff and students of the CCKS since 1978. The numerous dye traces are shown as red lines on the map. Water table elevation contours as estimated from measurements taken at: 1) open borehole water wells, 2) storm water drainage wells that extend below the water table, 3) cave streams, 4) springs, and 5) surface streams are shown as blue lines. The approximate groundwater basin catchment boundaries based upon the dye traces and water table elevations are shown as dashed green lines. The map identifies the approximate groundwater flow routes to springs for the following major groundwater basin catchment areas: 1) Lost River, 2) Graham Springs, 3) Hobson Grove Springs, 4) Double Springs, 5) Mt. Ayr Blue Hole and Bluff Springs, and 6) Harris Spring. Included on the map are dye trace and

water table contours northeast of Barren River performed by Dr. James Quinlan and Mr. Joe Ray (1981, revised 1989). This compilation of karst groundwater data onto one map was prepared to assist the City of Bowling Green in meeting the USEPA Phase II Storm Water Management Plan requirements and to assist Bowling Green with emergency response to any future spills of hazardous liquids. A poster paper authored by Brewer and Crawford (2005), entitled, "Groundwater Basin Delineation by Dye Tracing, Water Table Mapping, Cave Mapping, and Geophysical Techniques: Bowling Green, Kentucky, USA", is presented at this conference.

Case Study: Egypt Parking Lot

One serious sinkhole flooding problem occurred in the vicinity of the Egypt Parking Lot at Western Kentucky University. After heavy rains, the sinkhole flooding covered not only the Egypt Parking Lot but also a major highway. This sinkhole has flooded repeatedly over the past 50 years, and during the last large flood, over eighty cars were inundated. Two storm water drainage wells had been drilled in the past in an attempt to alleviate the flooding. The wells did not help, and they actually resulted in increased contamination of the karst aquifer by receiving the first flush of storm water during every storm event. The CCKS investigated the problem for the University, the city of Bowling Green, and the Kentucky Department of Transportation. Dye tracer tests and water table mapping indicated that the large Lost River Cave was located near the vicinity of the flooding problem. Microgravity and electrical resistivity traverses were made perpendicular to the hypothesized route of Lost River Cave (Crawford, Fryer and Calkins, 2000). Exploratory borings were made into prominent low-gravity, high-resistivity anomalies. These borings intersected the large Lost River Cave. With the cave location established at one location, other traverses were performed in a "leapfrog" fashion to map the location of the cave as it extended under the Egypt Parking Lot (Crawford, Lewis and Webster, 1999). A boring into a low-gravity, high resistivity anomaly under the Egypt Lot intersection the Lost River Cave stream at a depth of 12 m (40 ft) (Figure 1). A downhole camera was used to investigate the cave, and dye traces were used to confirm that the cave stream was, in fact, the large Lost River. The flooding problem was mitigated by drilling four, 1.22m (4 ft) diameter wells directly into the cave stream. Contamination by first flush water was mitigated by plugging existing drainage wells and the installation of four VortechsR storm water treatment units (Figure 2). These units separate oil and grease and suspended sediment before the storm water flows into the cave stream. This project was the first attempt to remove contaminants from urban storm water runoff previous to its flowing into the karst aquifer beneath the city. Similar systems are now being built at various locations throughout Bowling Green.

The four VortechsR storm water treatment systems installed at Egypt Parking Lot are the largest built by the Vortechnics Company and are highly efficient in the treatment of storm water (Vortechnics, 2004). Each of these units is designed to remove oil and grease and suspended sediments for about 2.84 m³/s (100.5 cfs). These units not only treat the first flush but also the entire flow of storm water previous to its being discharged into the Lost River. The treatment system is designed to work at three levels of storm intensity (low, medium, and high) using three unique chambers (grit chamber, floatable baffle wall, and low/high flow control) that are each designed for a specific function. The grit chamber separates the floating and sinking pollutants that first enter the system by a gentle swirling motion. The gravitational separation allows the settleable solids to conically pile on the chamber floor. Over time, as storm intensities vary, the grit chamber increases the swirling action appropriately to maintain a high removal rate of sediments. The floatable baffle wall stops floating pollutants, such as, debris and hydrocarbons from flowing through the system while allowing the debris-free water to flow beneath the wall and into the final chamber. The final chamber's low/high function is to control the discharge rate at varying storm intensities. During low inten-
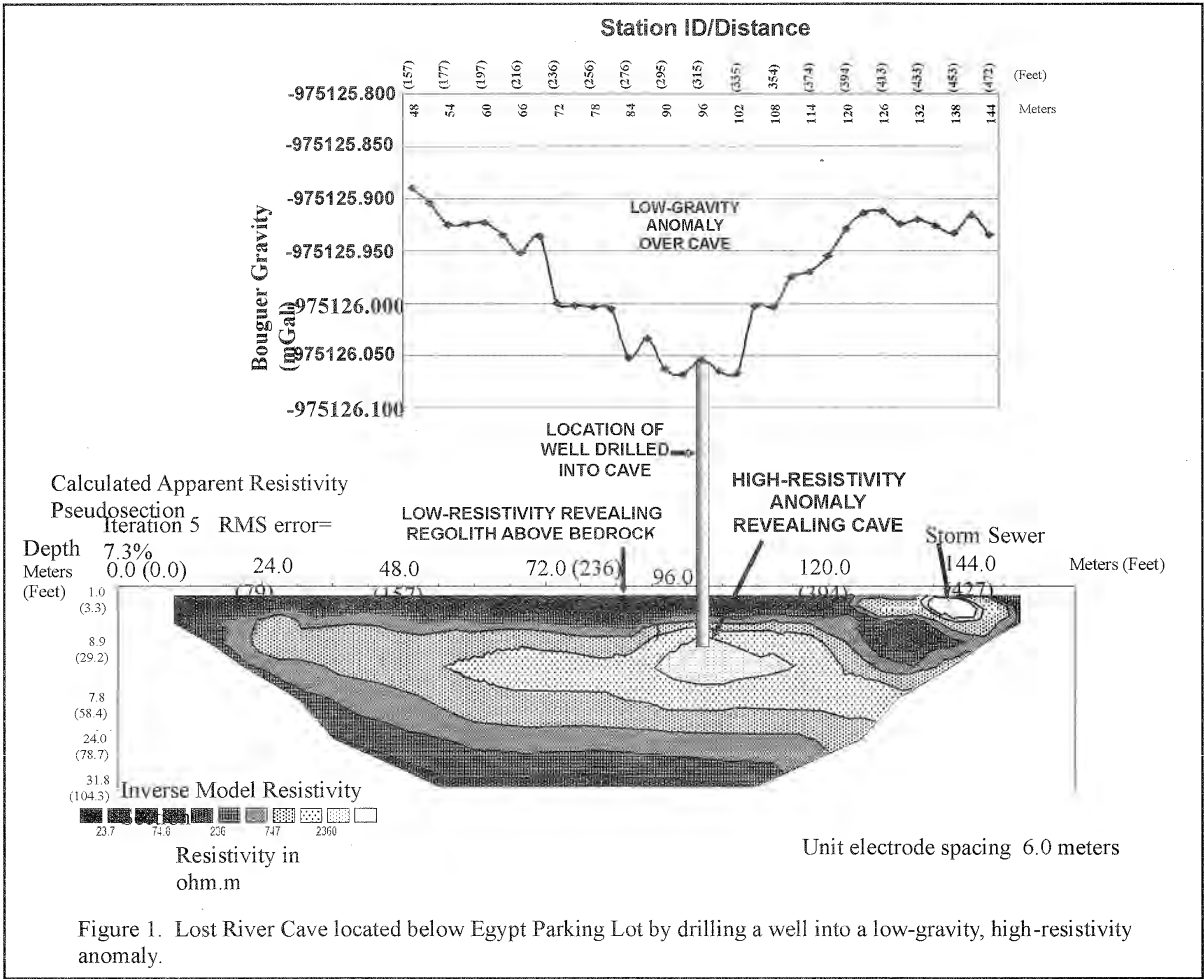
Figure 1. Lost River Cave located below Egypt Parking Lot by drilling a well into a low-gravity, high-resistivity anomaly.

Figure 1. Lost River Cave located below Egypt Parking Lot by drilling a well into a low-gravity, high-resistivity anomaly.

Figure 2. Aerial view of 4 Vortechs. units being installed to treat storm water runoff before it is discharge into the Lost River through four 1.22 m (4 ft) diameter wells. Photography courtesy of Vortechnics, Inc.

sity storms, the low flow control will manage the discharge rate, while at medium intensity storms, the high flow control will begin to operate. Finally, a high intensity storm completely inundates the low flow control, forcing the high flow control to operate at full capacity. These unique chambers require periodic maintenance and inspections to guarantee their efficiency. In order to provide easier access for maintenance, Vortechnics has designed these chambers to be placed below a manhole cover. A vacuum truck is used to periodically remove the oil and grease and sediments from the units.

Case Study: Kentucky Trimodal Transpark

The Kentucky Trimodal Transpark is a new industrial park being built in Bowling Green above the Graham Springs Groundwater Basin. The CCKS under a grant to Western Kentucky University from the Inter-Modal Transportation Authority, performed the hydrogeologic investigation of the site (Crawford, 2003). Crawford recommended in the final report that extraordinary steps be taken to prevent sinkhole flooding and regolith collapse sinkholes and to protect the water quality of the Graham Springs karst aquifer. A storm water management system was proposed that would treat all storm water runoff from the roads, parking lots and buildings at the site while also providing emergency containment in the event of an accidental spill or leak of hazardous liquids. The recommended system included curbed streets and parking lots with storm sewers that would direct all storm water runoff into a treatment system that would separate oil and grease and settleable solids. The treated storm water runoff would then flow into a surface impoundment capable of holding the entire volume of runoff from a three-hour, 100-year storm. It was recommended that a synthetic liner be placed under the surface impoundment to prevent possible regolith collapse sinkholes. The surface impoundment would also serve to allow additional suspended sediments to settle out, thus providing secondary treatment for the storm water runoff since most contaminants are attached to suspended solids. Crawford also recommended that the water from the surface impoundment be spray irrigated either onto the green spaces required for the industrial park and/or adjacent farmland. This would allow the water to infiltrate and slowly percolate down through the soil into the karst aquifer and thereby be treated by soil treatment. Soil treatment is the method by which surface water is naturally cleaned as it percolates down to the water table throughout the world. The storm water treatment system would prevent direct recharge into the karst aquifer through sinkholes, and storm water would be treated by a three-phase system to remove contaminants before it percolated down into the karst aquifer. This system was designed by Mayes, Sudderth and Etheredge, Inc. and the proposed storm water treatment system was included in the binding elements for all impervious areas at the Transpark location (Figure 3).This system far exceeds what is required by government regulations. Hopefully, it will set an example for rigorous protection of groundwater quality for development upon both karst and porous media aquifers.
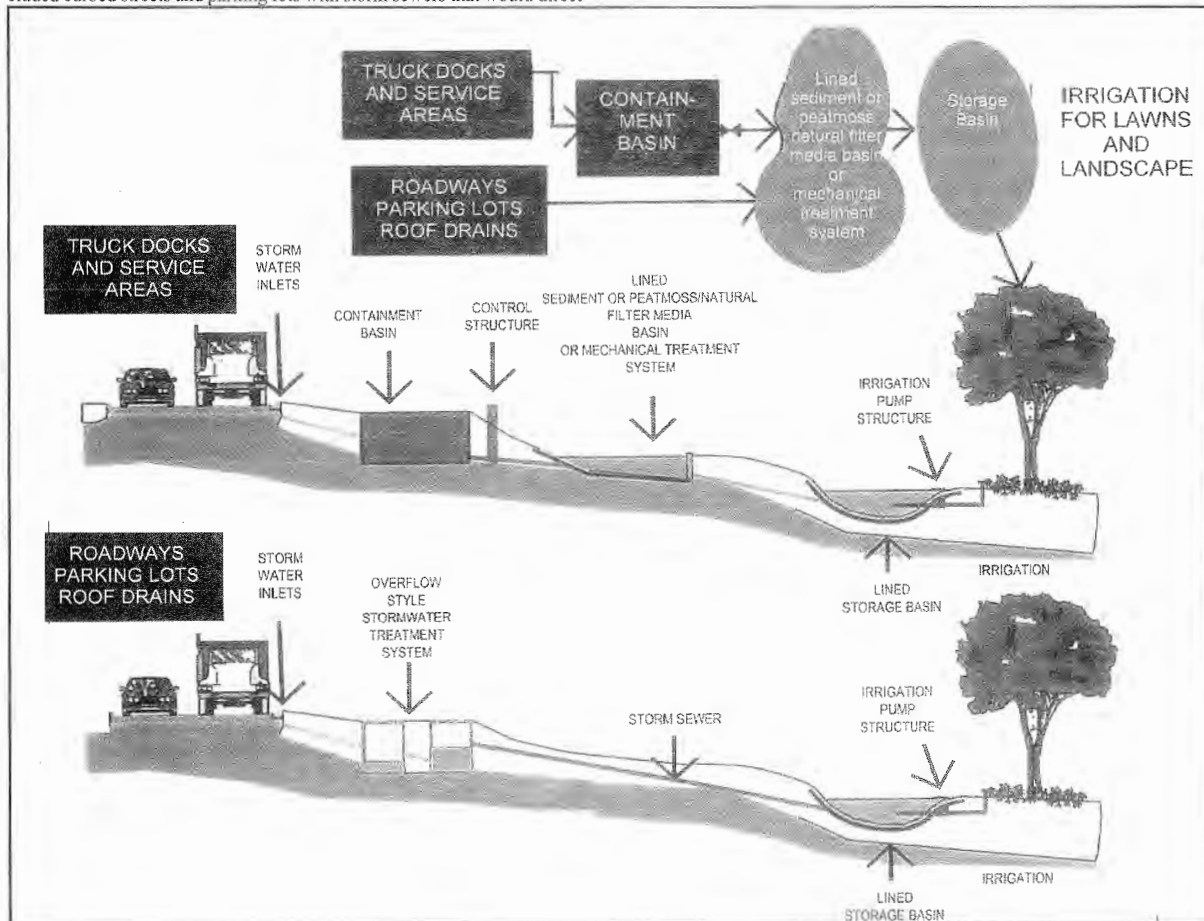
Figure 3. Required storm water runoff system for Transpark. Designed to: 1) provide tertiary treatment of storm water runoff, 2) contain spills of hazardous chemicals, 3) prevent sinkhole flooding, and 4) prevent storm water induced regolith collapse sinkholes. Design by: Mayes, Sudderth, and Etheredge, Inc.

References

Brewer, J.D. and Crawford, N.C. (2005). "Groundwater basin delineation by dye tracing, water table mapping, cave mapping, and geophysical techniques: Bowling Green, Kentucky, U.S.A.", Proceedings of the 14th International Congress of Speleology, Athens, Greece.

Crawford, N.C. (1984). "Sinkhole flooding associated with urban development upon karst terrain: Bowling Green, Kentucky" in Beck (ed.), Sinkholes, Their Geology, Engineering and Environmental Impact, Rotterdam, Netherlands, A.A. Balkema Publishers, pp.283-292.

Crawford, N.C. (1988). Karst Hydrogeologic Problems of South-central Kentucky: Groundwater Contamination, Sinkhole Flooding, and Sinkhole Collapse, Guidebook for Second Conference on Environmental Problems in Karst Terranes and Their Solutions, sponsored by Association of Ground Water Scientists and Engineers, National Water Well Association, Nashville, Tennessee, U.S.A., 107 p.

Crawford, N.C. (2003). "Karst hydrogeologic investigation for proposed Kentucky Trimodal Transpark", in Beck (ed.), Sinkholes and the Engineering and Environmental Impacts of Karst, Technical Publication #122, American Society of Civil Engineers, pp. 404-414.

Crawford, N.C., Fryer, S.E. and Calkins, C.A. (2000). "Geophysical techniques for locating and mapping caves from the ground surface: microgravity subsurface investigation of Egypt Parking Lot, Western Kentucky University", Proceedings of Mammoth Cave National Park's Eighth Science Conference, Mammoth Cave Nat'l Park, pp. 25-36.

Crawford, N.C., Lewis, M.A. and Webster, J.A. (1999). "Microgravity techniques for subsurface investigations of sinkhole collapses and for detection of groundwater flow paths through karst aquifers", in Beck, Pettit and Herring (eds.), Hydrogeology and Engineering Geology of Sinkholes and Karst, Balkema, Rotterdam, pp. 203-218.

Vortechnics (2004) "Where the earth meets the sky: storm water treatment in a karst environment", Project Profile by Vortechnics, Inc., 4 p.

O-13

Experimental research using Thermography to locate heat signatures from caves

Jim Thompson

1 Jim Thompson Way, Blackwell, MO 63626 USA, Portland, disasterjim@aol.com, (800) 839-6789

Murray Marvin

621 S.W. Alder Street Suite 200, Portland, Oregon 97205 USA, murray@murraymarvin.com, (800) 247-5404

Abstract

Thermal differences between cave entrances and the surrounding landscape have long been known. Cavers traditionally ridge walked in cave-likely temperate regions in cold mid-winter with a falling barometer in order to visually detect 'fog-plumes' of escaping subterranean air from crevices in order to locate caves. We are experimenting with a high-technology solution to this cave detection method by applying infrared thermography, a useful tool in fire detection, human body location and other building examination remote sensing to the surface of the earth. Early trials during the spring of 2005 with a Therma CAM™ B20 HSV infrared (IR) camera, even under foliage-filled and warm atmospheric conditions, produced promising results in initial trials in New Mexico, Missouri and West Virginia. Further research is underway at Fisher Cave, Franklin County, Missouri.

This research began by documenting temperatures of cave openings and surrounding substrates. Atmospheric, ambient conditions (temperature, relative humidity, specific humidity and dew point) were recorded inside the cave, at the entrance and at intervals up to 183 meters. Normal images were contrasted with thermograms that showed full temperature gradients of the openings. At 118 meters, the opening could no longer be seen with the naked eye. The thermograms showed distinct images of cave openings. Trials continued to 388 meters. In excess of 300 meters, thermograms showed the distinct cave opening of Fisher Cave. At 388 meters, the thermograms showed signatures that could be that of a cave entrance. The initial results indicate that individual cave entrances have separate and unique temperature gradients. Thus, individual cave thermograms are a "fingerprint" or signature of that cave. Thermograms can be used to isolate and identify caves entrances from surrounding terrain. Once standardized procedures are established, thermograms may become an important tool for cave location and exploration.

Introduction

Thermography is a type of infrared imaging. Thermographic cameras detect radiation in the infrared range of the electromagnetic spectrum and produce images of that radiation. Since infrared radiation is emitted by all objects at ambient temperature, thermography makes it possible to "see" ones environment with or without visible illumination. The amount of radiation emitted by an object increases with temperature. Thermography allows visualization of variations in temperature. With a thermographic camera warm objects stand out well against cooler backgrounds.

Thermographic technology has advanced considerably in the last few years. Current uses include building-energy audits, building diagnosis, medical applications, fire detection, military night vision, computer heat scans, industry, surveillance and other utilitarian uses where heat production and dissipation are a factor. We hypothesize this technology can be used under the correct conditions to locate potential caves by taking thermograms of land masses such as hillsides and valleys while looking for heat signature changes in the images which would reveal cave openings, swallets, seeps and other karst features.

Overview of Theoretic Thermography.[3]

There are three methods by which heat flows from one object to another-radiation, convection and conduction. IR viewers are concerned with radiation effects, but the others cannot be neglected. In radiation, electromagnetic energy is actually emitted by an object or gas.[2]

Heat measurement devices are either contact or non-contact devices. Infrared Imagers observe and measure heat without being in contact with the source and rely largely on radiation. The infrared camera used in this experiment generates a digital false-color image of the view being examined using IR sensors in the place of normal visual-range detectors. Thermography makes use of the infrared spectral band. At short-wavelength end the boundary lies at the limit of visual perception, in the deep red. At the long-wavelength end it merges with the microwave radio wavelengths. The unit relationship between the different wavelength measurements is: $10\,000\ \text{Å} = 1\,000\ \text{nm} = 1\ \mu = 1\ \mu\text{m}$.

The Infrared Spectrum

Every animate or inanimate body that exists emits infrared energy from its surface. This energy is emitted in the form of electromagnetic waves that travel with the velocity of light through a vacuum, air, or any other conductive medium. Whenever waves fall on another body, which is not transparent to the eye, they are observed and their energy is reconverted into heat. The difference between a cold or hot body is the level at which it both emits and absorbs energy. If the body absorbs more energy than it radiates, it can be considered cold. If the body tends to emit more energy than it absorbs, it is considered hot. The state of being hot or cold is a dynamic state. If a body is allowed to equilibrate with its surroundings, the emission and absorption will become equal and the body will be neither hot nor cold.

Measurement Principles

All materials above absolute zero emit infrared energy. Infrared radiation is part of the electromagnetic spectrum and occupies frequencies between visible light and radio waves. The infrared part of the spectrum spans wavelengths from 0.7 micrometers to 1000 micrometers (microns). Within this wave band, only frequencies of 0.7 microns to 20 microns are used for practical, everyday temperature measurement.

Though IR radiation is not visible to the human eye, it is helpful to imagine it as being visible when dealing with the principles of measurement and when considering applications. In many respects, IR and visible light are similar. IR energy travels in straight lines from the source and can be reflected and absorbed by material surfaces in its path. In the case of most solid objects that are opaque to the human eye, part of the IR energy striking the object's surface will be absorbed and part will be reflected. Of the energy absorbed by the object, a portion will be re-emitted and part will be reflected internally. This also applies to materials that are transparent to the eye, such as glass, gases and thin, clear plastics, but some of their IR energy will also pass through the object. These phenomena contribute to what is referred to as the emissivity of the object or material.

Materials that do not reflect or transmit any IR energy are know as "blackbodies" and are not known to exist naturally. However, for the purpose of theoretical calculation, a true blackbody is given a value of 1.0. The closest approximation to a blackbody emissivity of 1.0, which can be achieved in real life is an IR opaque, spherical cavity with a small tubular entry. The inner surface of such a sphere will have an emissivity of 0.998.

Different materials and gases have different emissivities, and emit IR at different intensities for a given temperature.

Theoretical Basis for IR Temperature Measurement

Thermography (infrared thermal scans) uses specially designed infrared video or still cameras to make images (called thermograms) that show surface heat variations.

The formulas upon which infrared temperature measurement is based are old, established and well proven. Theoretic physical laws invoked by thermography include:

1.   **Planck's Equation:** Describes the relationship between spectral emissivity, temperature and radiant energy.

$$W_{\lambda.b.} = \frac{2\pi hc^3}{\lambda^5 \left(e^{hc/\lambda k T} - 1 \right)} x \ 10^{-6} \left[Watt/m^2 \mu m \right] \qquad \text{(Eq. 1)}$$

where: $W_{\lambda b}$ is the blackbody spectral radiant emittance at wavelength λ, c is the speed of light, h is Planck's constant, k is Boltzmann's constant,

T is the absolute temperature (K) of a blackbody and λ is the wavelength in μm.

2.   **Stephan Boltzmann Law:** The hotter an object becomes the more infrared energy it emits.

$$W_b = \sigma T^4 \ [Watt/m^2] \qquad \text{(Eq. 2)}$$

where the total radiant emittance is integrated from $\lambda = 0$ to $\lambda = \infty$.

3.   **Wien's Displacement Law:** The wavelength at which the maximum amount of energy is emitted becomes shorter as the temperature increases.

$$\lambda_{max} = \frac{2898}{T} [\mu m] \qquad \text{(Eq. 3)}$$

4.   **Kirchoff's Law:** When an object is at thermal equilibrium, the amount of absorption will equal the amount of emission.

$$\alpha = \varepsilon \qquad \text{(Eq. 4)}$$

The theoretic functioning of the thermographic camera is best explained by the following diagram[2]:
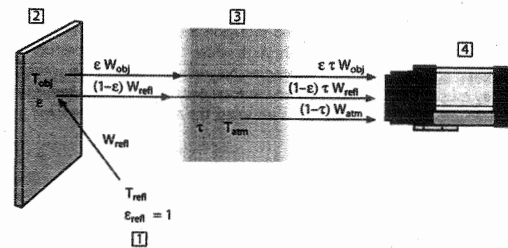
Figure 1. Schematic showing a generic thermographic imaging situation. 1: Surroundings; 2: Object; 3: Atmosphere; 4: Camera.

Assume that received radiation power W from a blackbody source of temperature T_{source} on short distance

Generates a camera output signal U_{source} that is proportional to the power output (power linear camera). We can then write Equation 5:

$$U_{obj} = \frac{1}{\varepsilon T} U_{vol} - \frac{1-\varepsilon}{\varepsilon} U_{refl} - \frac{1-T}{\varepsilon T} U_{atm} \qquad \text{(Eq. 5)}$$

Where the operator has to supply values for object emittance ε, relative humidity, T_{atm}, object distance (D_{obj}), the effective temperature of the object surroundings, or the reflected ambient temperature T_{refl} and the temperature of the atmosphere T_{atm}.[2]

Speleology and Thermography

The natural meteorological conditions of temperate latitude caves make infrared thermographic investigation possible. Differences in temperature and humidity make cave entrances discrete from the surface, and visible to thermography. As the inside of the cave maintains a constant temperature and the outside ambient temperature fluctuates with the seasons the cave entrance temperatures are normally different then outside conditions. It is this premise that directs this research. Moore and Sullivan put this most succinctly:

"The air in most caves is nearly saturated with water vapor - in other words, the relative humidity is close to 100 percent. This is so because seeping water moistens the ceilings, wall, and floor and that the air must pass by as it moves slowly through the cave. The constant temperature of the inner part of the cave permits this high humidity to be maintained indefinitely.

Near the entrances to caves, however the humidity may be lower, partly because the outside humidity is usually lower, and partly because the cave temperature differs from the outside temperature.

In the summer, warm air entering a cool cave soon becomes saturated without absorbing water from the cave walls. In the winter the air becomes warmer as it enters the cave, and for a short distance its relative humidity falls."[4]

Research assumptions:

1. Cave entrance substrate temperatures are normally different from other outside substrate temperatures. The air blowing from a cave or into a cave is at a different temperature and humidity level than the outside ambient temperature and humidity.

2. Cave humidity alters moisture on cave entrance substrates compared to other surface substrates.

3. An infrared camera measures and images the emitted infrared radiation from an object. Since radiation is a function of object surface temperature it is possible for the camera to calculate and display this temperature.

4. Cave entrances can have their surface temperatures displayed by thermo imaging infrared camera.

Trial Location

Fisher Cave is a lantern-toured show cave located in Meramec State Park, Franklin County, Missouri, USA. The cave entrance is approximately 3 m high by 11 m wide, gated, and easily accessible. This wide mouthed cave entrance allows ample atmospheric exchange. The cave entrance is at a slightly oblique angle to its containing bluff, making it 'vanish' visually within a short distance, despite proximity to a parking lot. These factors selected it as our experimental site. One set of thermogram/normal photos is included from the mouth of Carlsbad Caverns for comparison.

Materials

The camera used for this research is the Therma CAM™ B20 HSV, which is the most sophisticated of the infrared-thermographic image cameras made by the FLIR Company. A steady tripod was necessary to get accurate signatures.

Nikon D1X Camera and lenses.

Delmhorst HT 3000 A Thermo Hygrometer & Dickson TH 550 Thermo Hygrometer to measure temperature, humidity and dew point at cave entrances and distances from the entrance.

Data Log Recorders (HOBO brand: timed temp, dew point, relative and specific humidity at prescribed intervals and distances from the entrance.)

Fluke 52 II Thermometer and Thermocoupler to measure temperature readings of the substrates at cave entrances and stream water temperatures.

Methods

Radiation measured by the IR camera not only depends on the temperature of the object but is also a function of emissivity. Radiation also originates from the surroundings and is reflected by the object. Radiation from the object and the reflected radiation will also be altered by atmospheric adsorption. We consulted C. Warren Campbell on our methods. [1]

To measure temperature accurately, one must compensate for the effects of different radiation sources. This is done electronically and automatically by camera. The following parameters must be supplied for the camera:

- The emissivity of the object
- The reflected temperature
- The distance between the object and the camera
- The relative humidity

These parameters were established for the IR camera with the use of handheld thermo hygrometers at the cave entrances. Data loggers were then set up to ensure accurate monitoring during the thermography, and to provide data for the FLIR camera manufacturer, which is in process of establishing standard emissivity tables for limestone based on this research.

Results

Measurements at the entrances of known caves for temperature, relative humidity and dew point were taken at different distances from the entrance for the caves and locations. The data were used to calibrate the B20 HSV. A tripod was required for steady images as the B20 HSV does not have a fast "shutter speed."

On May 11, 2005 with a cloudy sky and recent light rain, Fisher Cave had a entrance temperature of 16.4 C (61.6 F) with Relative Humidity (RH) of 66.8%, Dew Point (DP) 10 C (50.2 F) with a substrate at entrance temperature of 19.2 C(66.5F). Ambient conditions at 15.2 m (50 ft.) from the entrance-were 15. 6C (60.1 F), RH of 62.4% DP C (46.2 F). At 182.9 meters from the entrance (600 ft.): Temperature 26.4 C (79.5 F) RH 20 DP (68 F)

At 118 meters, the opening could no longer be seen with the naked eye. The thermograms showed distinct images of cave openings. Trials continued to 388 meters. In excess of 300 meters, thermograms showed the distinct cave opening of Fisher Cave. At 388 meters, the thermograms showed signatures that could be that of a cave entrance

Thus, individual cave thermograms are a "fingerprint" or signature of that cave. Thermograms can be used to isolate and identify caves entrances from surrounding terrain. We found taking the thermograms was easier if the remote control was removed from the camera and used to adjust the setting and take the shots, as it helped reduced camera shake. The resulting thermograms and corresponding visual images are reproduced in Appendix I.

We found we will need to compensate for the following conditions in future trials: a) Shooting thermograms through tree foliage will pick up reflective signatures off the leaves. b) Shadows on hills do not show the same temp gradient as actual cave openings. c) Images without a tripod are susceptible to camera shake thereby altering the image result.

Analysis of the Results

We believe thermography shows great promise as a cave entrance location method. Thermograms will expedite field work in locating cave sites, especially in temperate climates, where the mean annual temperature (and therefore the temperature of the cave air) is stable but local surface atmospheric conditions reflect wide seasonal variation. The ability of a thermogram to penetrate vegetative cover (once we learn to norm for

reflective signatures) may turn ridge walking into a year round activity, not one confined to late fall through early spring. Thermographic imaging may be useful in recording cave entrance meteorological data as it relates to monitoring trogloxene and troglophile species.

Conclusion

Thermography can be applied when seeking unknown caves by photographing larger land mass areas such as hillsides and aerial perspectives. This paper documents fundamental field research done to demonstrate this technology is a viable tool to assist scientists in finding caves and other karst features. As this technology and its field use improves, so will its efficiency. As an ongoing project our fieldwork is establishing baseline standards for professional use.

References

1) Campbell, C. Warren. "Application of Thermography to Karst Hydrology." Journal of Cave and Karst Studies. 58 (3); 163-167.

2) FLIR Systems Handbook for the "Therma CAM™ B20 HSV Camera".

3) Sierra Pacific Innovations. http://www.x20.org/thermal 2005

4) Sullivan, G. N. and G.W. Moore. Speleology: The Study of Caves. Cave Books, St. Louis, MO 1978, 150 p.

Appendix I - Sample photo/thermogram pairs showing cave detection abilities of the technique.
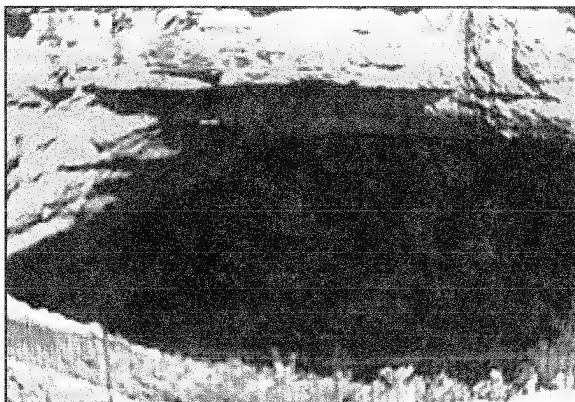
Carlsbad Caverns, New Mexico
+/-75 ft +/-22.9 m

Carlsbad Caverns, New Mexico
+/-75 ft +/-22.9 m

Fisher Cave Meramec S.P., Missouri
600 ft 182.9 m

Fisher Cave Meramec S.P., Missouri
600 ft 182.9 m

Fisher Cave Meramec S.P., Missouri
1,000 ft 304.8 m

Fisher Cave Meramec S.P., Missouri
1,000 ft 304.8 m

O-14

PRELIMINARY DATA RECORDED BY A MONITORING STATION TO SUDY THE HYPOGEAN CLIMATE IN A ICE CAVE: THE LO LC 1650 ICE CAVE "ABISSO SUL MARGINE DELL'ALTO BREGAI" (GRIGNA SETTENTRIONALE, LECCO - ITALY)

Turri S.[1], Citterio M.[1], Bini A.[1], Maggi V.[2], Favaron M.[3], Fraternali D.[3], Alberici A.[3], Borghi S.[4], Colombo M.[4], Gottardi R.[4], Zappalà D.[4]

[1] *Earth Sciences Dept. "Ardito Desio", University of Milano. Via Mangiagalli 34, 20133 Milano. Italy. E-mail: stefano.turri@unimi.it*

[2] *Environmental and Territorial Sciences Dept., University of Milano - Bicocca. P.zza della Scienza 1, 20121 Milano. Italy.*

[3] *S.T. Servizi Teritorio S.r.l. Via Garibaldi, 21, 20092 Cinisello Balsamo. Italy*

[4] *Osservatorio Meteorologico di Milano Duomo, Piazza del Duomo 21, 20121 Milano. Italy*

74

Abstract

In November 2004, to study the hypogean climatic conditions a monitoring station is installed at the LO LC 1650 ice cave. The ice cave is locate at Moncodeno, Grigna Settentrionale (Lecco). The climatic study of ice caves is one aspect of a wider multidisciplinary project. The climatic studies are supported by glaciological studies, aimed to understand the factors controlling the conservation, ablation of ice deposits in caves. The monitoring system is composed of a meteorological station to record epigean data and two hypogean stations. The meteorological station collects solar radiation, air temperature, humidity, wind direction and velocity. The two hypogean stations collect air temperature and humidity in many points of the cave, rock temperature at different depths and ice temperature. Hypogean air direction and velocity are measured by an ultrasonic anemometer. Some preliminary data after the first short period of measurement are presented here.

Introduction

Studies of ice caves is attracting more researchers in the last few years (e.g., Racoviţă & Onac, 2000; Perroux , 2001; Borreguero & Pahud, 2001; Turri et al., 2003; Piasecki et al., 2004; Strug et al., 2004; Luetscher & Jeannin, 2004; Borsato et al., 2004; Mavlyudov & Kadebskaya, 2004; Szczuciński & Rachlewicz, 2004). Since 1999 studies of glaciology and climatology are conducted in some ice caves of Moncodeno (Grigna Settentrionale, Northern Italy). A preliminary and small data logger network was installed in 2000 both in the hypogean and the epogean environments (Turri et al., 2004). The earlier temperature data collected were so interesting that successive monitoring systems project were setup to measure epigean meteorological parameters and various hypogean parameters.

Geographic background

The Moncodeno site is nearly rectangular amphitheatre occupying an area of less than 2 km^2 at the northern flank of mount Grigna. This karst forming high mountain zone has developed a high density of caves that appear on the surface as depressions (dolinas) and shafts. Due to the high altitude and the high quantity of snow precipitation, during the cold seasons thick deposits of ice are preserved for long time in some of the caves. The studied cave for this task is LO LC 1650 "Abisso sul margine dell'Alto Bregai", where its entrance is located at 2030 m, forming a shaft of 30 m in diameter (Fig.1A). The shaft is connected with an ice deposit that is recharged directly by meteoric snow. The cave meanders downwards (Fig. 1B) leading to a wide and 50 metres deep shaft that is also capped by ice, which is the focal point of this study (Fig. 1C). Therefore, this ice deposit is not directly connected with the meteoric ice, but should have descended following a tunnel that was formed by the circulating hypogean air and the tunnel terminates in a 25 metres deep shaft located at a lower level (Fig.1D). The later shaft is bounded by an ice and detritic deposits (Fig. 1E).

Monitoring system

There are clear relations between epigean and hypogean temperatures. In each cave the significant variations are related to seasonal variations, depending on the snow cover of the entrances. Moreover, the internal parts of a cave could show constant or seasonal variations irrespective of other hypogean environmental conditions where communication is controlled by the morphological development of the cave and dynamics of the ice and snow deposits. In addition to the effects of the particular conditions of a cave, temperature data indicate that the circulating air, which

is the principal media of heat exchange between the internal and external parts, is variably influenced by the highly complex structure of the karstic system. In here, we propose a simple schematic model to show the internal - external climatic relation by understanding their working systems.

Considering the complexity of the study, the unique way to resolve the set of unknown variables is to install various sensors in different stations all along the internal morphology of the hypogean cave. This will allow to collect necessary data to understand and establish the hypogean micro-climatic conditions.
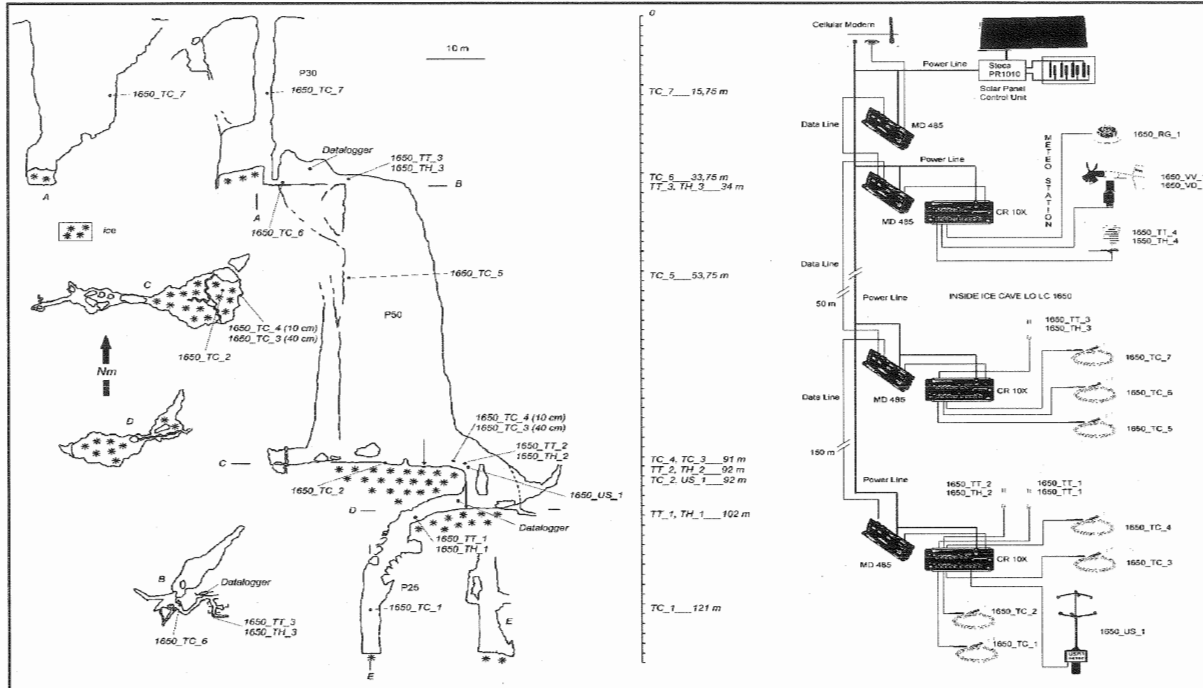
Fig.1 - Map of the LO LC 1650 cave. A) The 30 m deep shaft at the entrance of the cave. B) Meandering tunnel. C) Top of the ice deposit. D) Map of tunnel of the ice deposit. E) The 25 m. deep shaft. Locations of the monitoring system sensors that are described in the text are indicated with their relative depth. On the right side the monitoring system plan is sketched.

Abbreviation	Parameter	Instrument	Data range	Accuracy	Resolution
VD	Wind direction	Anemometer RM Young 05103 Wind Monitor	0...360° mechanical, 355° electrical (5° open)	± 3°	-
VV	Wind speed	Anemometer RM Young 05103 Wind Monitor	0...134 mph (0...60 m s^{-1})	± 0.6 mph (± 0.3 m s^{-1})	-
RG	Global radiation G	Starpyranometer Schenk 8101	0...1500 Wm^{-2}	-	<1 Wm^{-2}
TT	Air temperature	Rotronic Hygroclip S3	-40°C...+60°C	At 23°C ± 0.2°C	-
TH	Air humidity	Rotronic Hygroclip S3	0...100 %RH	At 23°C ± 1.5 %RH	-
TC	Air, rock, ice temperature	Campbell TC 105T thermocouple probe	-73°C...50°C	-73°C ± 0.365°C 20°C ± 0.1°C 50°C ± 0.25°C	-
US	Hypogean air direction and speed	Metek ultrasonic wind sensor USA-1	0...45 m/s	-	0.01 m/s

Fig.2 - Table that shows symbols utilized to identify the monitoring stations with some of their technical characteristics.

To compare the hypogean with the epogean climatic conditions, a meteorological stations is installed near the entrance of LO LC 1650, at an altitude of 2030 m.

Installation of the meteorological station has permitted to measure;

- the air temperature and humidity with the Rotronic Hygroclip S3 termohygrometer,
- global solar radiation with a Schenk 8101 global radiometer,
- wind direction and velocity with an RM anemometer. Measured data are collected by a data logger Campbell CR10X 2M.

The monitoring system sensors in the internal part of the cave are systematically distributed to establish a network so that a complete data could be collected from the surface to the depth of 121 m. The acquired data are registered by two data loggers Campbell CR10 2M, located at the meandering tunnel, -31 m. and the tunnel deposit at -99 m (Fig.1). Air temperature is measured at 7 positions with 4 Campbell TC 105T thermocouples and 3 Rotronic Hygroclip S3 thermohygrometres that measures also air humidity. Rock temperature is measured by 2 Campbell TC 105T thermocouples inserted in to the rock at a depth of 10 cm and 40 cm. Temperature of the ice deposit is measured with one Campbell TC 105T thermocouple that is fixed at the surface of the deposit. Wind direction and velocity are measured using the Metek USA-1 ultrasonic anemometer.

A general map of the LO LC 1650 cave is shown on Figure 1, with the locations of the installed instruments, both in vertical section and planar view. The main aim of the distribution of these instruments is to measure the microclimatic conditions at various parts of the cave and to identify their respective climatic variation with the external climatic changes. Sensors network around the ice deposit is quite dense, hence climatic conditions that preserve the ice deposit could be better monitored. The thermocouple installed in the rock measures the thermal gradients of the

rocks near the ice deposit. This permits to evaluate quantitatively the events that are manifested and to identify the major agents that affect the ice deposit The principal role of the thermocouple that is installed on the surface of the ice deposit is to control the periods of ablation, conservation and accumulation

of the ice deposit. Abbreviated words and letters representing the installed measurement stations are listed together with some of their technical characteristics in the table of Figure 2.

Initial data collected during the first cold season

In this preliminary phase, we limit our study to the analysis of the air temperature, air humidity, rock temperature and surface of the ice deposit temperature. Diagrams in Figures 3a through 3f show the air temperature variation registered at various hypogean stations (TC_7, TC_6, TC_5, TT_2, TT_1 e TC_1) in comparison to the meteorological station (TT4). Plots of the two curves in comparison have different scales to show clearly the hypogean trend. Scales on the right side of the graph correspond to the hypogean and on the left side to the epigean temperatures.

It can be noted that graphs of 3a and 3b have the same scale that is utilized in the epigean temperature plot. In fact, at TC_7 and TC_6 stations, that are located at 15.75 m and 33.75 m down from the entrance, were significantly affected by the epigean temperature, as it can be observed from the intensity and the time overlap. Hypogean temperature variations should be attentively observed during the end of a cold season when the epigean temperatures start to rise. The mild increase of the hypogean temperature should be related to the water of the melting ice that enter in to the cave, in fact the tendency is to equilibrate at about 0°C.
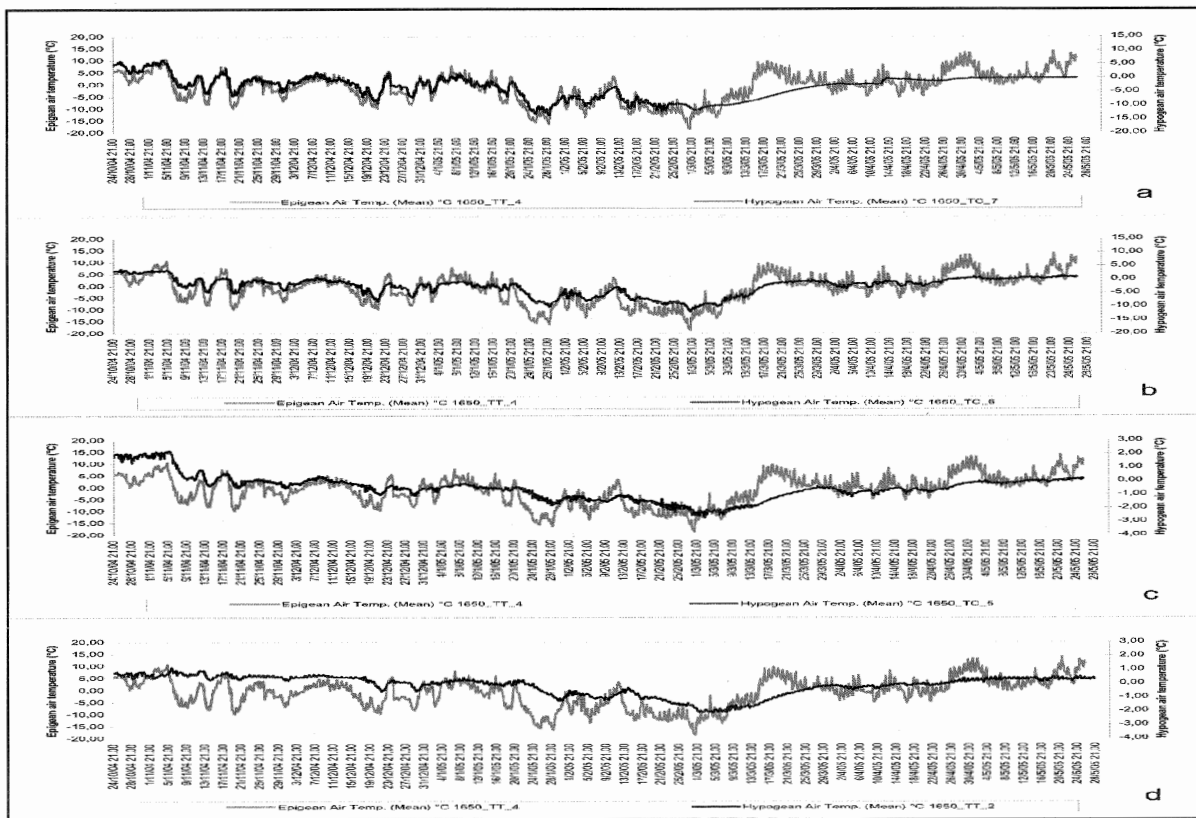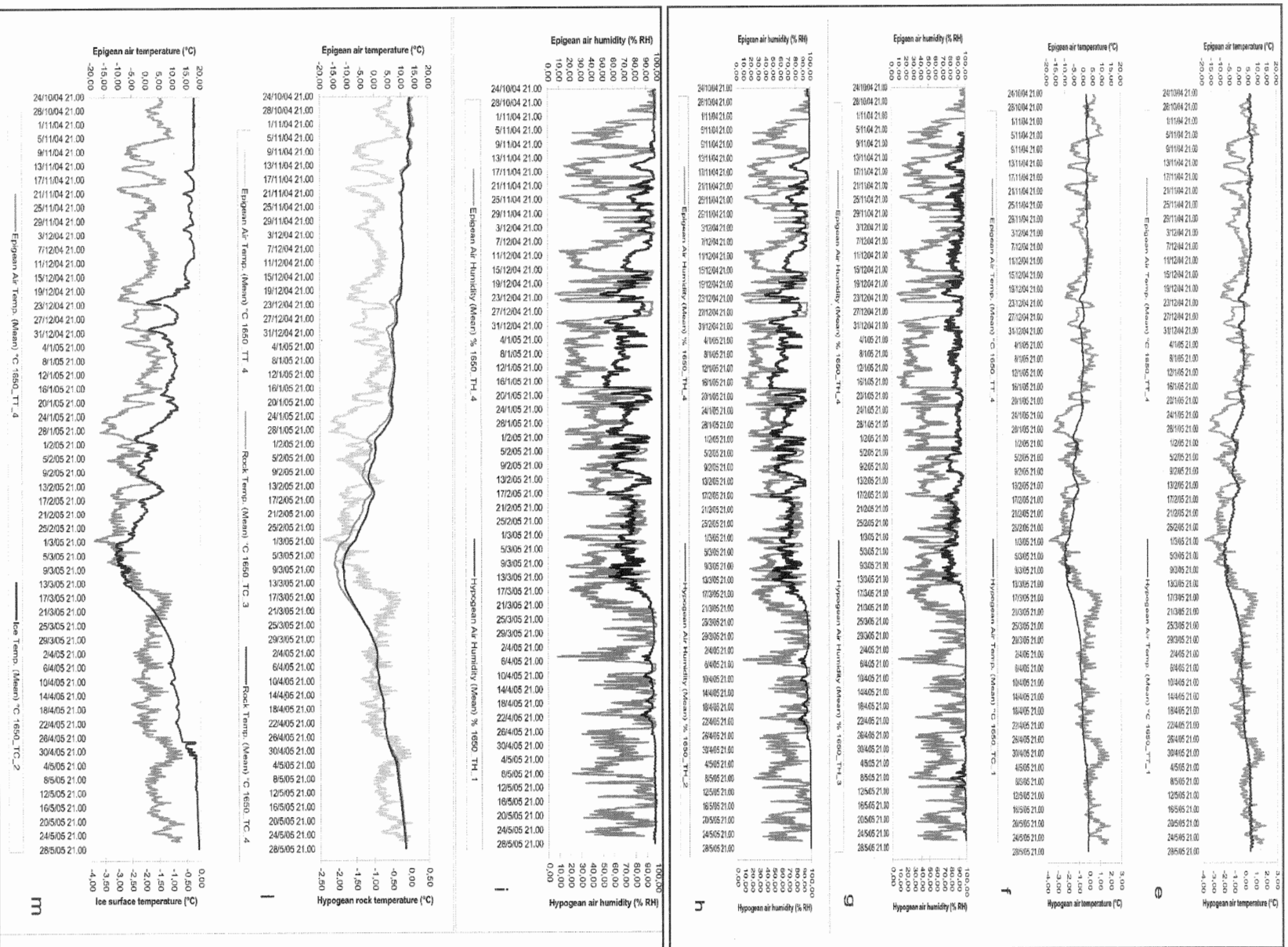
Fig.3 - Initial temperature and humidity data collected during the first cold season.
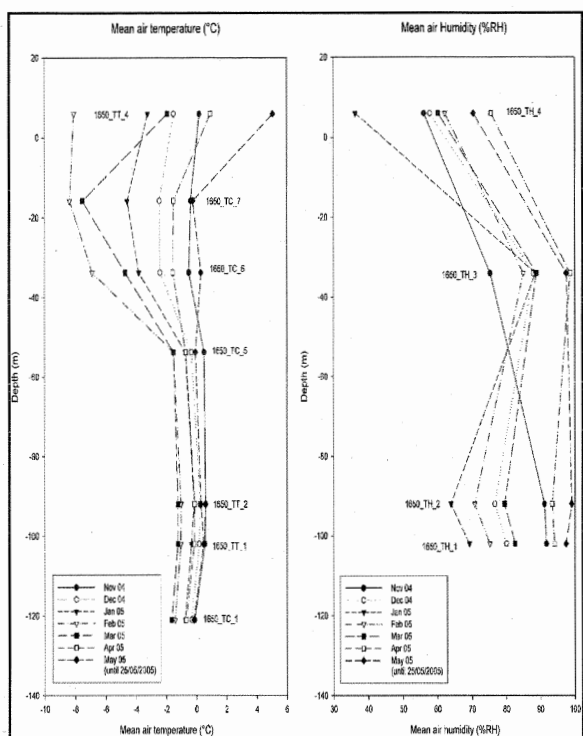
Fig.4 - Air temperatures and humidity trends in vertical profiles. Each line represents average temperature, monthly mean humidity value with increase of depth of various stations.

Station TC_5 is located at a depth of 53.75 m, within the 50 m deep shaft after the meandering tunnel shown in Figure 1. Trend of the temperature shows these environmental variations and hence the reference scale is also changed (Fig. 3c). Epigean "cold" temperatures could be still sensed, although there are some delay. The slightly increasing trend of the hypogean temperature at the end of the cold season is appreciable.

Temperature variations registered at the station of TT_2, located at a depth of 92 m near the ice deposit, are shown in Figure 3. "Cold" epigean events can be still observed although the effects are more delayed. Temperature increase during the cold season are less marked as compared to that of TC_5 station, this is due the presence a nearby ice deposit. On Figures 3e and 3f, plots of TT_1 and TC_1 are shown, that are located under the ice deposit at a depth of 102 m and 121 m respectively. On these plots it can be only effects of only the important "cold" epigean events can be observed, and delays of some days are again appreciated in this case. The first thermal profiles are shown in Figure 4, that were measured during the cold season. Plots represent mean monthly temperature in respect to the depth of the cave. The first points of every plot at the depth of 6 m. belong to the mean temperatures of epigean station. Each station shows different thermal characteristics with depth and variable environmental conditions. In fact along the meandering tunnel, as shown on Figure 3, effects of the epigean temperatures are reflected both in their intensity and temporal overlap. The shaft of 50 m depth reacts differently to the epigean events, that is, intensity decrease and major delay of "cold" impulses. At the base of the shaft, the ice deposit has created a new environment that is conditioned by the ice itself. Hence below the level of the ice deposit, the monthly mean data show a zone with a different trend. Profile of the month of March is particularly interesting. The mean epigean temperature shows a moderate increase indicating the beginning of the end of the cold season. Where as the mean monthly temperature at the station of TC_1 at a depth of 121 m, shows the lowest mean temperature of the season.

Diagrams of Figures 3g, 3h, and 3i show the relative humidity trend registered at the stations of TH_3, TH_2 and TH_1 at the depths of 34 m, 92 m, and 102 m, respectively. All the plots are made in comparison to the meteorological station (TH_4). Evaluating the 3 diagrams, it can be noted that, like during the cold season, the relative hypogean humidity is also affected by the epigean humidity. In fact, during the end of the cold season values increase due to the percolating water into the cave melting from the surface ice. The low relative humidity value registered at the stations of TH_1 and TH_2 as compared to that of TH_3, are indicators of sublimation condition that take place near the ice deposit by either the direct contact of the ice itself or the cave wall near the ice deposit.

The above situation could be better observed in Figure 4, where diagrams show the vertical profile trends of the air humidity. Each plot represents the mean monthly air humidity in relation to the depth of various stations.

In Figure 3l rock temperatures at depths of 10 and 40 cm are plotted against the epigean temperature variations. As it can be noted from the diagram, during the "cold" events the rock is affected by the air temperature at least in the first 40 cm. Studies are on progress to evaluate the rates of delay, considering the above mentioned stations and the nearest station TT_2.

The variation diagram of Figure 3m shows the temperature fluctuations on the surface of the ice deposit. This trend is compared to the epigean temperature variations. This station is particularly interesting since it may indicate the periods of ablation of the ice deposit. We have limited data of the cold season, but some indications are obtained. The deposit has suffered from many "cold" events with delayed manifestations (typical of its environment). A mild increase towards the end of the cold season, different from the other heating trends registered during the cold season, may indicate a progressive melting of the surface ice and percolation in to the ice cave deposit. The short interruptions of this trend may create favourable condition for the formation of new ice.

References

Borreguero M. & Pahud A., 2001 - *Mesures de température dans la grotte des Pingouins, (Saviése, VS), premiers résultat*s. Cavernes, 2-2001, 7-17

Borsato A., Miorandi R. & Onelio F., 2004 - Age and evolution of two cave ice deposits in the Brenta Dolomites (Italian Alps). In: Citterio M. & Turri S. (ed.) Volume of abstracts of the 1st International Workshop on Ice Caves, Căpuş, Romania, 29th February - 3rd March 2004, p. 14

Luetscher M. & Jeannin P.-Y., 2004 - What heat flux must be considered at the base of an ice cave ? In: Citterio M. & Turri S. (ed.) Volume of abstracts of the 1st International Workshop on Ice Caves, Căpuş, Romania, 29th February - 3rd March 2004, p. 21.

Mavlyudov B. R. & Kadebskaya O. I., 2004 - About degradation of glaciation in Kungur cave and possible ways of its restoration. In: Citterio M. & Turri S. (ed.) Volume of abstracts of the 1st International Workshop on Ice Caves, Căpuş, Romania, 29th February - 3rd March 2004, p. 23.

Perroux A.-S., 2001 - *Etude du fonctionnement d'une cavité englacée durant un cyc*le climatique. Karstologia n°37 - 1/2001, 41-46

Piasecki J., Zelinka J., Pflitsch A. & Sawiński T., 2004 - *Structure of air flow in the upper parts of the Dobšinská ice cave.* In: Bella P. (ed.) Výskum, využívanie a ochrana jaskýň, 4. vedecká konferencia s medzinárodnou účasťou, 5-8 októbra 2003, Tále, 113-124

Racoviţă G. & Onac B., 2000 - Scărişoara Glacier Cave; Monographic study. Editura Carpatica, Cluj Napoca, Romania. 139 pag.

Strug K., Piasecki J., Sawiński T. & Zelinka J., 2004 - The ice crystals d*eposit in the Dobšinská ice cave.* In: Bella P. (ed.) Výskum, vyuţívanie a ochrana jaskýň, 4. vedecká konferencia s medzinárodnou účasťou, 5-8 októbra 2003, Tále, 125-133.

Szczuciński W. & Rachlewicz G., 2004 - Seasonal, annual and decadal ice mass balance changes in Jaskinia Ladowa w Ciemniaku (ice cave in Ciemniak, Tatry, Poland). In: Citterio M. & Turri S. (ed.) Volume of abstracts of the 1st International Workshop on Ice Caves, Căpuş, Romania,

29th February - 3rd March 2004, p. 27.

Turri S., Citterio M., Bini A., Maggi V., Udisti R. & Stenni B., 2003 - *Etude glaciologique et climatologique des cavités glacées du Moncodeno. (Grigna septentrionale, province de Lecco, Lombardie).* Karstologia n°42 - 2/2003. 37-44

Turri S., Citterio M., Bini A. & Maggi V. 2004 in press - Preliminary analyses of the avaible hypogean and epigean temperature recordings in Moncodeno (Grigna Settentrionale, Lecco, Italy). Theoretical and Applied Karstology (Special Issue on Ice Caves) n. 17.

O-15

THE PROPAGATION OF THE SEASONAL HEAT WAVE INTO CRYSTAL AND FANTASY CAVES (Bermuda)

Arrigo A. Cigna, SSI, Fraz. Tuffo

I-14023, COCCONATO (Asti), Italy

Abstract

Crystal and Fantasy caves were monitored since some years both for air and water temperature. Such temperatures vary along the year due to the influence of the seasonal changes outside. Here the results of a study on the propagation of the heat wave from the surface sea water to the pools of water inside the caves are reported.

Keywords: Bermuda, show caves, environment, heat wave

Introduction

Some boys, who found a hole in the ground, discovered Crystal Cave in March 1905. A couple of year later the owner of the land visited the cave and decided to develop it. On January 8th, 1908 the cave was opened to the public who could walk on a pontoon bridge. Four year s later, a tunnel was excavated in order to have an easier access to the cave.

In 1907 another cave was discovered in the vicinity of Crystal cave and was opened to the public in 1912 only intermittently, as Wonderland cave until 1931. The cave was reopened on June 30th, 2001 as Fantasy cave after its redevelopment involving the replacement of the lighting plant and the improvement of the original staircase and trails.
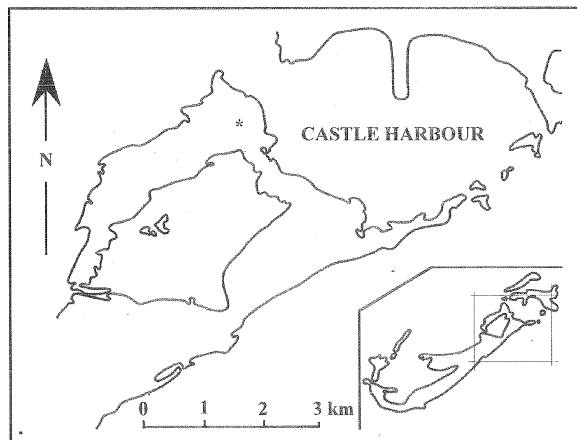
Fig. 1 - Map of Bermuda showing the location (*) of the Crystal and Fantasy Caves.

Temperature Measurements

Air and water temperatures were measured weekly, in Crystal cave since October 1998 and in Fantasy cave since November 2001. Notwithstanding the large error affecting each measurement because the

thermometers have a scale divided in degree Fahrenheit where the values may be estimated with an uncertainty of about 0.5°C, the long series of data allowed the achievement of some interesting results.

Bermuda Weather Service kindly supplied air and surface seawater temperatures. According to the actual data, the information was transformed from the original °F into °C. A sinusoidal best fit was calculated for each series of values with the FitSin Programme (Giorcelli, 1998). The generic equation of a sinusoid being:

$$y=A+B*sin(2\pi(x+\varphi)/T)$$

where y is the temperature (°C), A is the average temperature, B is a coefficient equivalent to one half the amplitude of the sinusoid, x is the time (days), φ is the phase delay with respect to x = 0 (1st January 1998) and T is the period (= 365 days).
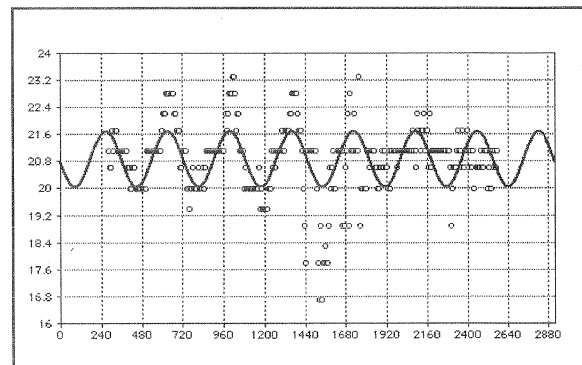
Fig. 2 - Water temperatures (°C) measured in Crystal Cave vz. days form Jan. 1st, 1998. A sinusoidal best fit is reported.
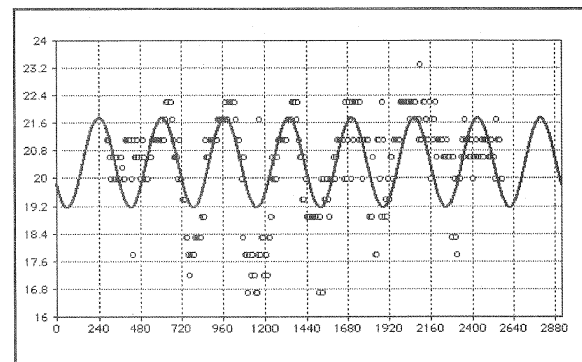
Fig. 3 - Air temperatures (°C) measured in Crystal Cave vz. days form Jan. 1st, 1998. A sinusoidal best fit is reported.

Obviously the temperature wave, originated outside by the seasonal variation, propagates into the cave through different mechanisms (water, air) with a delay and attenuation depending on the mechanisms involved for each station. In Fig. 1 and 2 the diagrams of water and air in Crystal cave are reported.

Table 1 - Delays of the heat wave between outside and the caves

Station	Date of Max (days from 1/1/1998)	Date of Max (day of the year)	Delay
Outside, surface seawater	225	August 13th	-
Outside, air	224	August 12th	-
Crystal Cave, water	268	August 13th	43
Crystal Cave, air	244	September 1st	20
Fantasy Cave, water	265	September 22nd	40
Fantasy Cave, air	230	August 18th	5

In Table 1 the delays of the heat wave between outside and the caves are reported. The date of the "summer" peak and the delay with respect to the outside peak are given both as days from January 1st, 1998 and as days of the year. A first examination of these data shows that the temperatures of the surface seawater and air outside vary synchronously. Water temperatures in both caves varies with a delay of about 40 days, i.e. this is the times required by the heat wave to propagate from the outside sea into the caves through the anchialine environment.

For the air temperature, it takes 20 days of delay with respect to outside to have the summer maximum in Crystal Cave while only 5 days are found for Fantasy Cave. This means that air temperature inside the caves depends mainly on the air exchanges along the access to the caves. The air circulation in Crystal Cave is dominated by a two entrances system, consisting in the long tunnel descending into the cave and the original entrance. In fact an air current is evident in the region immediately below the natural entrance, while the rest of the cave, occupied by a tidal lake remains relatively isolated. For Fantasy Cave, on the other hand, the delay is shorter on account of a minor thickness of the rock layer above the cave and an immediate connection with outside.

Conclusion

Notwithstanding the very poor quality of the thermometers used for the measurements into the caves, and therefore a relatively great uncertainty of each measurement, it was possible to calculate a sinusoidal best fit, which allowed the estimation of the delay of the propagation of the heat wave. This delay, which was practically the same for both caves, supports the hypothesis of rather similar connection between the caves and the sea.

On the other hand the evaluation of the attenuation of the heat wave was not possible, as it is evident from the distribution of temperature values in Fig. 1 and 2. In fact there are frequently clusters of such values, in correspondence of integers of the thermometer scale. The attenuation of the heat wave would have supplied another piece of information on the cave climatology as it was obtained, e.g., in Kartchner Caverns, Arizona, US (Cigna, 2001)

The new monitoring systems operating in both caves since March 2005 with data loggers, will ensure better records of temperature (and CO_2 concentration in Crystal Cave) both from the point of view of continuity as well as the smaller error associate to each measurements. Therefore in the next future more reliable evaluations of the cave environment will be drawn.

References

Cigna A.A., 2001 - Evaluation of the tourist impact in the Kartchner Caverns (Arizona, USA). Proc. 13th Int. Congr. of Speleology, Brasilia July 15-22, 2001, Speleo Brazil 2001, 2: 188-192.

Giorcelli F., 1998 - FitSin 2.1. Personal communication.

O-16
The caves of Thrace region (Northwestern Turkey)
K. Tork, L. Nazik, K. Tuncer, E. Ozel

Abstract

The karstic rocks are mounded in the certain areas on the Thrace Region. The karstification is denser on the Yıldız (Istranca) Mountains through the Black Sea cost of the Thrace Region. The karstic belt stretches out with in the Paleozoic and Jurassic marbles and in the Eocene limestone that cover the marbles from the western and southern of the region. The Eocene age of limestone continues through the NW-SE direction and have more caves than the marbles. The litostratigraphic, tectonic properties, the Quaternary rejuvenation and erosion-karstic base level relation are effective on the karstification of the area. The Thrace caves have been at the base of the paleo polje and uvala (polycyclic) of Pliocene epoch and the base and the hillside of the Quaternary epoch. The extension of the most of the caves are horizontal and through the limestone-schist contact on the area. That's why the karstification is limited with the Eocene age of limestone thickness (100-150 m). The Pabuç and Kazan Rivers have been effective fluvial systems on the karstification of the Eocene age of limestone at the eastern of the basin. The hydrological system in the caves is controlled by these two rivers. The caves have one layer in spite of the polycyclic development processes at the Eocene age of limestone. But the caves of the older rocks as Jurassic and Triassic marbles have more layers. And the Pliocene relief systems are widespread on the explored 25 caves at The Yıldız (Istranca) Mountain and close area.

O-17

The effect of the relief systems of the Beyşehir lake and the Kembos Polje basins on the cave development of the area

L. Nazik, K. Tork, K. Tuncer, E. Ozel

Abstract

The Beyşehir Lake and the Kembos Polje Basins are located at the northern part of the Central Taurus Region. The area geologically consists of the naps, autochthonous and the metamorphic complexes. The geomorphologic and the hydrological properties of the area formed with the tectonic lines on the N-S and NE-SW directions. The each of the basins have no outlet from the surface to the main drainage system. They connect to the Manavgat River Basin with the cave and the conduit systems. The Beyşehir Lake and Kembos Polje Basins contain the relief systems of Middle-Upper Miocene, Pliocene and the Pleistocene Epoch. These relief systems that have been on different altitudes are separated to each other with certain borders. The very dense and the polycyclic karstification developed according to the primary (origin) and the secondary (shaping) factors of the area. The investigated 80 caves divided to the three zones according to the relief systems. The relief system of the Miocene epoch represented with the 1600-1750 m and the upper altitudes (western of Beyşehir Lake, Anamas-Dedegöl Mountains, Seyran Mountain and İpeler Mountain). Through the tectonic lines the vados vertical pits and the sinkholes developed at the bottom and the edge of the paleokarstic depressions of the Miocene surface. The most of the caves are on the altitude range between 1250-1400 meters in the Pliocene relief systems. The caves of the Pliocene relief system mostly extend on the semi horizontal-horizontal directions and describe the polycyclic development with the more than one cave layer. These caves that totally fossilised on the upper layers are hydro logically sinkhole and spring situated. The Eocene flysch and the faults had been effective on the caves that developed according to the Beyşehir Lake Basin. The youngest caves of the area located at the range of 1150-1250 meters where the morphological and karst base levels have been closed to each other in the Pleistocene relief system. The mechanical erosion of the rivers had been effective on the development of the active and semi active caves that are line as one layer (monocyclic development).

O-18

The geological and morphological origine and distribution

L. Nazik, K. Tork, K. Tuncer, E. Ozel

Abstract

Turkey had been formed with different tecto-genetic units and 1/3 of Turkey covered with the soluble carbonate rocks (limestone, dolomitic limestone and dolomite) and sulfate (gips). The karstic regions and caves were formed according to the parameters which changes at close distance between regions at the above of the rocks which are as certaine belts. The initial parameters (chemical contents of the rock, stratigraphic position, petrographic and structural properties and climate) and the formative secondary factors (geomorphological, hydrological and hydrogeological properties and vegitation) have been effective for the development of the caves. The caves of Turkey grouped at five karst region according to the theire forming and developing properties and inner cave formation. 1. The caves of Taurus Mountain Belt a. The caves of Western Taurus karst region b. The caves of Central Taurus karst region c. The caves of Eastern Taurus karst region 2. The caves of Central Anatolia karst region 3. The caves of Southeastern Anatolia karst region 4. The caves of Western Anatolia and Thrace karst region 5. The caves of Blacksea mountains karst region a. The caves of Western Blacksea karst region b. The caves of Central and Eastern Blacksea karst region The Taurus Mountain Belt has the most continiuty and evidenty karst region betveen these regions. That's why it is the most dense place for the cave developing. The caves in this region have polycycle development properties and have the caves deeper than 1000 m and longer than 10 km. and for these reasons called as holokarst region. The other karst regions which are Western Anatolia and Thrace, Blacksea Mountains, Southeastern Anatolia and Central Anatolia called as shallow karst regions because of to have the carbonate rocks deposits as a lens betveen the impermeable rocks.

O-19

Karst and rock Phantoms (fantômes de roche) in the Netherlands

Herman de Swart

Speleo Nederland, Scientific Commission • Koolstraat 56, NL 2312 PT Leiden, the Netherlands
*tel: **31 71 5236580 • e-mail: hermandeswart@casema.nl*

Abstract

Although in the Netherlands very little karst and only a few natural caves are present, because of the fact that the 98% of the country is covered with soft Pleistocene or Holocene sediments, in the southern part, in the Cretaceous chalk, a great number of rock phantoms (fantômes de roche (Quinif, 1998)) can be observed and studied. These phenomena precede the actual formation of karst, and play an important role in cave-formation, in older rocks too.

98% of the Netherlands consists of Pleistocene and Holocene sediments: gravel, sand, clay and bog. A large part of the country is formed by 'polders' or diked land. In two rather small areas we find older rocks (Carboniferous and Cretaceous) and even some karst: subterranean drainage, dolines, limestone pavements and karren, swallow holes and springs, and some little caves, the longest 140 metres in length (de Swart, 1996 and 2001, and references herein).

In the province of Limburg, south of the line Maastricht/Heerlen/Aken in the most southern part of the Netherlands and continuing to the west in Belgium, Cretaceous limestone was deposited, a calcarenite, locally inaccurately called 'marl'. The Maestrichtian formation (Upper Cretaceous) has here its type locality (Felder & Bosch, 2000). This limestone is very soft and can thereby be quarried away easily. This has been done since the Middle Ages, in large underground and surface quarries. In this area these underground quarries are called 'marl caves'. The limestone is used as blocks for building purposes, in the cement industry, and as agricul-

tural lime. In this way large underground systems were formed. A recent inventory (Orbons, 2005) describes 287 underground quarries, with 556 entrances, with a total surface of 386 hectares, and an estimated length of 600 kilometres!

Recent studies (De Swart, 2005, Willems, 2004), following an extensive underground reconnaissance - that is still in progress - show that these several hundreds kilometres of underground quarries, as well as several of the open air limestone quarries, contain a relatively large number of so called rock phantoms or *'fantômes de roche'*, an isovolumic chemical (biochemical or bacteriological?) alteration of the limestone, preceding the formation of caves and other karst phenomena (Quinif, 1999, Quinif & Quinif, 2002). And although the number of caves in the Netherlands, discovered in these artificial 'caves' is very small, due to the fact that the limestone is very soft and consequently caves formed in these rocks quickly 'collapse' through crumbling of the ceiling and walls, a large number of rock phantoms was discovered. Some were naturally emptied when the quarries were dug (and so form caves), but the majority is still intact and shows the change in chemical composition of the rock and consequent change in colour of the quarry walls. The 'marl caves' therefore give us an opportunity, on several millions of square meters, to study the first stages of cave formation!

References:

DE SWART, HERMAN (1996) Karst in the Netherlands In: Karren Landforms, Universitat de les Illes Baleares, Palma (Balears), p. 335-341

DE SWART, HERMAN (2001) *Le Karst néerlandais* In: Actes des Journées de Spéléologie scientifique Han-sur-Lesse 1997 à 2000. Geological Survey of Belgium, Professional Paper 2001/3, N. 295, Bruxelles, p. 92-7

DE SWART, HERMAN (2005) Karst en fantomen in Limburg, in press

FELDER, W.M. & BOSCH P.W. (2000) Krijt van Zuid-Limburg, Geologie van Nederland, deel 5 Nederlands Instituut voor Toegepaste Geowetenschappen TNO, Delft/Utrecht

ORBONS, JOEP (2005) Inventarisatie van de ingangen van onderaardse kalksteengroeven in Nederland 2002-2004 Uitgave Studiegroep Onderaardse Kalksteengroeven van het Natuurhistorisch Genootschap in Limburg (SOK)/ Stichting Instandhouding Kleine Landschapselementen in Limburg (IKL)/Stichting ir. D.C. van Schaïk, Maastricht

QUINIF, YVES (1999) *Fantômisation, cryptoaltération et altération sur roche nue, le tryptique de la karstification* Etudes de Géographie physique, Travaux 1999, suppl. XXVIII, CAGEP, Université de Provence, p. 159-164

QUINIF, YVES ET GILLES (2002) *Méthodes et éléments de cartographie d'un paléokarst, l'exemple de la Carrière du Clyptot* (Hainot, Belgique) Karstologia 39, p. 1-8

WILLEMS, L. (2004) *Recherches sur les karsts de la Montagne Saint-Pierre, Basse-Meuse liégeoise* In: Journées 2004 de Spéléologie Scientifique Han-sur-Lesse, Centre Belge d'Etudes Karstologiques F.N.R.S./ Union Belge de Spéléologie (abstract)

O-20

Karsts and caves of the Shan Plateau Myanmar (Ex-burma)

By Claude MOURET

claude.mouret@wanadoo.fr • La Tamanie F-87380 Magnac - Bourg

Résumé

Le plateau Shan occupe environ 600 x 500 km dans l'est du Myanmar. Situé au-dessus de 1000 mètres d'altitude, il est largement constitué de carbonates paléozoïques et mésozoïques, parmi lesquels se trouve une grosse proportion de dolomie secondaire. Dolomie et calcaire donnent lieu à des paysages karstiques très différents. La dolomie produit des reliefs arrondis en creux et en bosse, drainé par un système fluvio-karstique. Le calcaire montre les formes classiques de ces régions, avec de nombreuses dolines. L'escarpement du plateau donne lieu à des vallées qui s'approfondissent en gorges, avec parfois de gigantesques chutes d'eau précipitant des travertins.

Les cavités sont encore modérément connues malgré plusieurs campagnes d'exploration. La plus longue, Mundewa Guh, développe 1770 m explorés. La profondeur maximale atteinte est de -70 m.

Abstract

The Shan Plateau is approximately 600 x 500 km large. Located at an elevation in excess of 1000 m a.s.l., it is largely made up of Paleozoic and Mesozoic carbonate, including a larger part of secondary dolomite. Dolomite displays round-shaped landscapes in a fluvio-karst setting. Limestone shows a characteristic morphology with numerous dolines. The scarps around the Plateau determine high waterfalls -with common travertines- along progressively deepening and narrowing valleys. Caves are moderately known despite several exploration campaigns. The longest explored cave is Mundewa Guh and it is 1770 m long. The deepest cave is -70 m.

In 1995, the author and his wife restarted cave exploration in the Union of Myanmar and, until august 1998 (around 25 caves mapped), investigated regions as diverse as the Hpa-an and Mawlamyine (Moulmein, NB-traditional names are between brackets) areas in northern Thanintharyi (Tenasserim), the southern part of the Rakine (Arakan) Mountains, the Central Plains (man-dug caves in Bagan (Pagan) and near Monywa), the edge of the Shan Plateau from the north of Mandalay to the region of Kyaukse, the Mogok region, and the Shan Plateau. On the Plateau, were explored the areas around the cities of Pyin-Oo-Lwin (Maymyo), Lashio, Muse, Kalaw and Taunggyi, and a number of other, spotty, areas (Fig. 1).

During the late part of 1998, another exploration campaign was conducted by Philippe Bence, Florence Guillot and Stéphane Maifret, based among others on information provided by the author. In this sense, the two series of work are fully in the continuity of each other.

General setting

The Shan Plateau is approximately 600 x 500 km large and located in the eastern part of Myanmar. It is mainly made up of Proterozoic to Mesozoic formations with local Late Cenozoic to Quaternary deposits. Its surface morphology evolved at least during Cenozoic to Quaternary times, over tens of million years. This evolution resulted in a likely significant eroded thickness on the Plateau. Himalayan movements related to the collision of Greater India with mainland Asia resulted in its uplift and the formation of deep incisions by the rivers. The longest canyon on Earth is on the Shan Plateau, along the Thanlwin (Salween) River. While longest canyons trend North to South in the central part of the Plateau, more radial patterns are present along the Shan scarp to the West and the Northern edge around Mogok.

The plateau ranges above 1000 m a.s.l., up to 1500 m in average. However, it reaches 2641 m near the Chinese border. 6 peaks rise above 2500 m a.s.l. and 39 above 2000 m. Besides, the Central Plains are at around

100 to 200 m only. So, the Shan Scarp is like a wall at the edge of the plains. Rivers commonly show deep falls and gorges behind the scarp and along the incised part of their upstream valleys (as around Pyin-Oo-Lwin for instance).
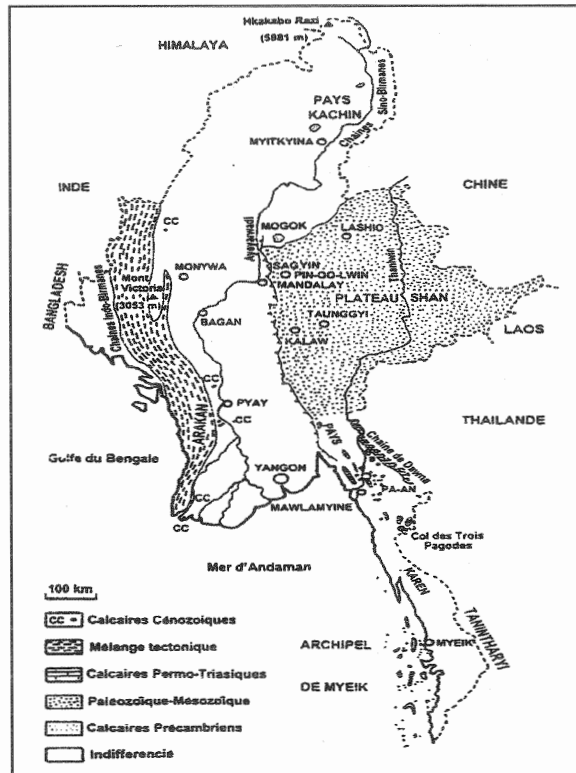
Fig. 1: Location map of the Shan Plateau in Myanmar (Mouret, 1998; Mouret et Lebreton, 2003)

Climate

The climate seems to be known at a limited number of measuring stations. Accessible data is scarce, though it is sufficient to characterise the Shan Plateau at the edge of the dry belt of the Central Plains. The Plateau has a dry season from November to May, which is cool up to mid-march then hot up to May The rainy season lasts the rest of the year, with an intermediate temperature which is due to the large degree of cloudiness.

Two stations can be used to illustrate climate characteristics in the studied area, i.e. on the western part of the Plateau. At Taunggyi, the average yearly rainfall depth is 1518 mm, to be compared on one hand to the 2677mm at Yangon (Rangoon) near the coast close to the Ayeyarwady (Irrawaddy) delta or to the 4759 mm at Mauwlamyine (Moulmein) on the rainy coast line of Andaman Sea, and on the other hand to the 600-700 mm in the dry belt of the Central Plains. Temperature can drop down to a few degrees Celsius, even zero, during the night from December to February, though it can reach 25°C during the day. In April, it can rise up to 35°C but it does not drop below 20°C at night.

At Kalaw, rainfall depth is in average 1323 mm per year (min. = 942 mm; max = 2083 mm; standard-deviation = 273 mm). For temperature, equivalent figures are 24.5, 15.1,32.9 et 3.0 °C.

Wind regime is known at Mandalay, a city at the foot of the Shan Scarp. Wind comes from the North and Northeast from November to January, South-Southeast and Southeast from February to October (Do-bby,1950).

Geology

The sedimentary formations of the Shan Plateau start with Upper Cambrian strata overlying metamorphic rocks (gneiss with cipolinos and micaschists formed under high pressure conditions). Carbonates are present in the Ordovician and some shaly limestone exists in the Silurian. However, the bulk of the carbonate on the Plateau is made up of pervasive dolomite that cuts through Devonian to Triassic carbonate, with some isolated limestone remnants. Its thickness may be several kilometres thick, according to some authors (Bender, 1962); at least, it is very thick. In the studied area, the Permo-Triassic alone is more than 1000 m thick. This carbonate is named Shan Dolomite Group, but the dolomite is less abundant in the upper part. Its internal structure is poorly known and non-carbonate lateral equivalents may be present at places. Internal unconformities are reported but poorly documented. Some Jurassic carbonate is reported (Bender, 1984).

Undated Cretaceous is present as red beds. Its distinction with terra rossa sensu lato remains to be clarified. Mesozoic formations participate in the folds present in, at least, the western part of the Plateau. A very long stratigraphic gap lasts up to the Late(st ?) Cenozoic to Quaternary times, during which fluvial and lacustrine sediments were deposited in tectonic lows, e.g. in the Lake Inle area.

Tectonics of the Shan Plateau are related to successive microplate collisions in the Paleozoic and the Triassic. In the Late Triassic, occurred the Indosinian collision, after which Asia is made up of one sutured set of plates. The main deformation is related to the India-Asia collision in the Cenozoic, specially in the Neogene and to the associated right-lateral motion of India vs. Asia in front of the Shan Plateau.

Late right-lateral North-South trending normal faults affect the plateau, as along the pull-apart basin which contains the world-famous Lake Inle. These faults are possibly responsible for the high CO_2 contents in Mundewa Cave, which opens along the graben edge.

Old chemical analyses (in Cchibber,1934) confirm the abundance of $MgCO_3$, with a content commonly reaching 29 to 45%. However, genuine limestone is proved with $MgCO_3$ values of 1.37% for example.

Density measurements have shown values of 2.72 to 2.84, which cover most of the range between pure limestone (d = 2.71 if no porosity) and true dolomites (d = 2.85 if no porosity).

Karst morphology

Karst morphology does not cover the whole Shan Plateau, because carbonate does not cover it entirely. Except the cipolino areas in Mogok region (Mouret, 1998) which exhibit some spectacular karst morphology (lapies with pinnacles up to 8 m high, crypto-lapies with rundkarren, large dolines), which is indeed out of the Shan Plateau proper, and some areas in Ordovician carbonate, where karst morphology is probably not well developed (by comparison with Northern Thailand), the nearly entire karst morphology is related to the Shan Dolomite Group.

Dolomite karst is dominant in the landscape, but it cannot be separated from smaller inliers of limestone with a typical polygonal tropical karst, which are commonly protruding in the morphology. These two morphologies, quite different at first sight, are indeed fully complementary and make the Shan Plateau an especially interesting karst area.

The morphology is overall a fluvio-karst, and limestone areas integrated in the whole pattern. Along the main rivers and over the whole of the region the valleys progressively deepen downstreamward. Cliffs and gorges develop as in the Gogteik Gorge between Pyin-Oo-Lwin and Lashio. The base level for the plateau is set by the Central Plains at the edge of the famous Shan Scarp, which is around several hundred to more than 1000 metres high, and by the Thanlwin (Salween) River gorge, said to be the longest gorge in the world.

83

Dolomite karst

Dolomite karst itself determines the fluvio-karst. The morphology is largely characteristic, smooth, rounded hills and rounded valleys. Local scarps are present on the hills. Such a landscape is related to rock properties. Dolomite is made up of dolomite crystals, rhomboedra, which are shedding a significant intergranular porosity. Disintegration of often poorly cemented crystals near the surface is a more powerful phenomenon than dissolution. Dolomitic sand formation is the result, a classical fact. Progression of the disintegration front is irregular, as it depends on lithological heterogeneity, such as crystals size, degree of cementation and cement dissolution or even, at a more local scale, tectonic crushing of the rock formation, proved by slickenslides often observed by geologists. Progression front is clear in quarries, where dolomitic sand is exploited "by hand", as workers leave harder parts untouched, which protrude across the sand. These crypto-pinnacles are commonly squat; they often reach several metres high and are rarely coalescent. However, they cannot resist weathering for long, as we observe many more crypto-pinnacles in quarries than exhumed pinnacles at surface.

Such features and especially the sandy nature of weathered dolomite preclude the formation of the usual karst morphology, typical of limestone which do not disintegrate. Karren and pinnacles may be present, but they are usually much less typical in dolomite and restricted to the best cemented (or where the cement has selectively been less dissolved) areas.

However, cliffs along valleys or on slopes (in this case, they usually have a limited lateral extent) are the main locii for rock exposure. Sand initially on top of the cliff has commonly been washed away, so rocks on the lower part of upper slopes directly connect cliff tops.

Fluvio-karstic valleys are usually very wide in the upstream part and display the concave, rounded, cross-section already mentioned. Hill tops themselves are shaped as surbased rounded cupolas. Further downstream, valleys get progressively deeper and lateral cliffs start appearing. They progressively get higher as the valley goes, together as the valley section becomes more squared.

Underground drainage may exist nevertheless, as observed examples prove it, but it is less developed than in limestone, because dolomitic sand is choking passages, if possibilities of export are limited: in these passages, karst permeability is partly or entirely replaced by a porous type permeability which allows only a lower flow velocity and flow yield. Erosion rate is severely decreased in this way. Karst passages are better open where dolomitic sand can be exported to the outside, as near springs and in through caves. Most of known caves are related to conditions favourable to sand export out of endokarst. However, large river sinks with large flows may exert a stronger dissolution in the upstream parts of massifs, where CO_2 of biological origin is abundant.

The dolomitic sand blanket at surface is obviously favourable to infiltration and surface vegetation is rather sparse. Infiltration water can dissolve rock but what power of dissolution remains below the sand ? How laterally continuous is the sand ? The existence of large voids is so far not proved, for instance by large collapse areas already known. Probably, dolomitic sands are able to hide the smaller collapses.

Vauclusian springs are known to exist, probably in dolomite, but the access to them is currently forbidden.

Polygonal karst in limestone. Relations with dolomite karst

Limestone areas show polygonal karst, a fact already put in evidence by Dunkley et al (1989). Such karst landforms are often choked at surface by shaly sediments, but they are water absorption zones, with vadose features. The way of restitution of water is still unknown. Some sectors at least, as to the West of Pindaya, correspond with anticlines and are morphologically higher than dolomite lands. Underground drainage is necessarily directed towards the dolomite, either laterally or by vertical to oblique infiltration. Either springs exist in the valleys or there is a feeding of the dolomite aquifer. On the edge of the Shan Plateau, because of the higher hydraulic gradient, anticline flanks are prone to karst units with a major difference in elevation.

In small limestone units surrounded by dolomite, limestone drainage can be only towards the dolomite aquifer, because dolomite porosity is not favourable to karst springs at the contact between the two rocks (stratigraphic barrier).

Caves

Around 20 caves were explored and surveyed on the Shan Plateau. The longest is Mundewa Guh (guh means cave) near Taunggyi, with 1770 m surveyed (Fig. 2) and the second is Leikte Guh near Kalaw, with a 960 m length (Bence et al, 1998), then we find the main cave at Padah Lin with 450 m (Mouret, 1998), Peik Kyin Myaung Guh (in Pyin-Oo-Lwin region) with 447 m (Bence et al, 1998) and Myinmethu Guh with 330 m (Dunkley et al, 1989). So far explored cave depths are not so deep: Leikte Guh is the deepest and it reaches a -70 m depth.

Mundewa Guh (near Taunggyi) is a system with a dry passage level which opens in the cliff along the fault bounding to the East the graben of Lake Inle (Mouret, 1998) and an active one with a small stream (Bence et al, 1998). The outlet of the stream is located some 25 m lower than the dry entrance. The whole cave system is high above the lake level. In the upstream part of the stream, there is the very high CO_2 content in the air already mentioned (exploration was stopped because of it). It was observed just after the end of the rainy season, in November 1998.

Leikte Guh (close to Kalaw) is a river sink. There is a main passage around 6 to 10 metres wide and two smaller choked side passages. One of them is a polluted tributary and the other one a passage oriented towards the upstream. The end of the cave is a sump at - 70 m (Bence et al, 1998).

Padah Lin main cave is a fossil passage located at a relatively low elevation on the flank of the Shan Plateau, at an elevation around 400 metres, 50 km to the SE of the small city of Kyaukse. It is an overall wide passage, but it shows a succession of narrower part, several metres large, and of chambers 20 to 30 m wide and high, with some openings to the sky (Mouret, 1998).

Peik Kyin Myaung Guh is a spring cave with a significant flow rate, located at the base of a cliff. The river originates from a boulder choke in a side passage and connects the main passage , whereas the main passage itself continues up to a narrow passage.

Myinmethu Guh (to the SE of Kalaw, South of Aungban) is a through cave collecting in a vertical sink a small, temporary flowing, surface stream. Passage size is several metres wide.

So far explored caves are either fossil caves at high relative elevations (Pindaya Cave, north of Kalaw) or lower on the slopes (Mundewa Cave). Some are sinks (Leikte Cave) or springs (Peik-Kyin-Myaung). Entrance deep shafts have not yet been explored. There are also famous travertine caves in the Gogteik Gorge (Cchibber, 1934). Close to the Shan Scarp, there are also caves, as Dattaw Cave near Kyaukse which is a top side collapse of a large chamber, or the fossil Shwemale Cave in the remnant hill among the foothills to the North of Mandalay.

Prehistoric paintings are present in Padah Lin I Cave, one of the Padah Lin Caves. It is the only case so far known in the country.

Caves in Mogok are dug out for rubies and sapphires (Mouret, 1998). Caves of the Shan Plateau are widely used, commonly for religious purposes, but also for tourism, some for guano or nitrate exploitation and occasionally for various purposes.

As in all parts of Myanmar, caves are commonly used as Buddhist shrines. The most spectacular is Pindaya Cave with its thousands of Buddha statues of all shapes and sizes, its gilded or painted pagodas and the

84

rêt sur CO₂

Fig. 2: *MUNDEWA GUH*
Dev. = 1770 m
Taunggyi, Shan Plateau, Myanmar.
Map by Ph. Bence, Fl. Guillot,
S. Maifret, Shan 1998

- 19 m

siphon   P 8

Plan

P 15

siphons   siphon

- 15 m

Nm nov. 98

stupa

entrée

0   30 m

exurgence

85
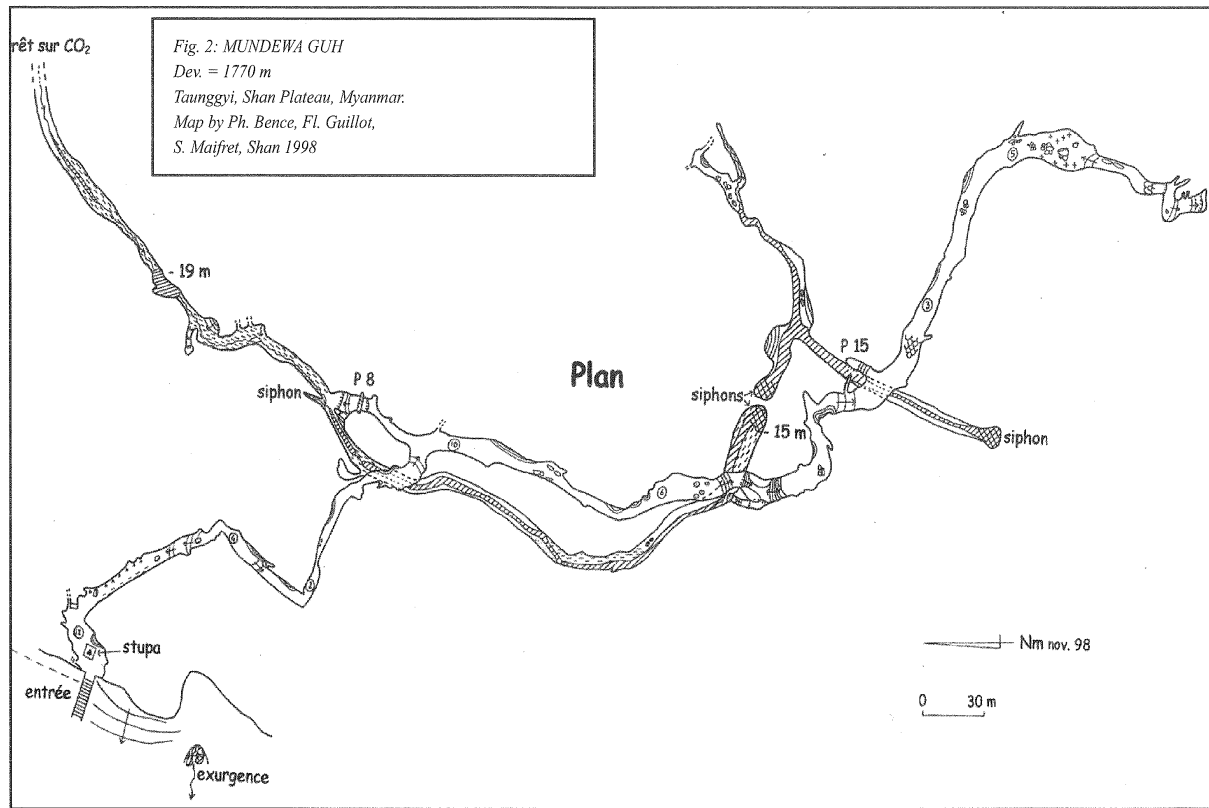
abundant use of gold leaf. Very spectacular also is Peik Kyin Myaung Guh with statues displayed over several hundred metres, gilded pagodas and, at the end part of the main passage, so many copies of Lord Buddha's boddhi tree: there is like a forest in the cave. There are also Shwe-Ohn-Min Cave near Kalaw, Schwemale, Dattaw (Mouret et al, 2003), Myinmethu and so many others shedding lot of Buddha statues and shrines of many kinds..

Bibliography

BENCE, Ph., GUILLOT, F., MAIFRET, S. 1998. **Shan 98. Expédition spéléo en Birmanie**. French Federation of Speleology (DDS), report to CREI, 45 p.

BENCE, Ph., GUILLOT, F., MAIFRET, S. 1999. Myanmar. Shan 98. Spelunca Bull., n°74, pp 8-10

BENCE, Ph., GUILLOT, F., MAIFRET, S. 1999. **Les cavités topographiées en Birmanie**. Spelunca Bull., n°74, p. 10

BENDER, F. 1984. Geology of Burma. Berlin,-Stuttgart, Gebrüder-Borntraeger, 260p. + plates

DOBBY, E.H.J. 1950. South-East Asia. London

CHHIBBBER, H.L. 1934. Geology of Burma. London, MacMillan and Co, 538 p.

DUNKLEY, J.R., SEFTON, M., NICHTERLIN, D., TAYLOR, J. 1989. Karst and caves of Burma (Myanmar). Cave Science, 16, 3, pp 123-131

MOURET, C. 1994. Wake-related formation of runnels in carbonate and silici-clastic rocks along major Asian rivers: Chindwin in Myanmar (ex-Burma) and Yangze in China. Beijing, Academia Sinica, Proceed. XI Internat. Congr. Speleology, Beijing August 1993, Supplement, p. 44

MOURET, C. 1997. Speleology in Australasia and Oceania. Spelunca Mém. n°23, Contributions to Speleology, p 204

MOURET, C. 1997. Myanmar. Spelunca Mém. n° 23, Contributions to Speleology, pp 190-191

MOURET, C. 1997. **Human use of caves in Myanmar.** Switzerland, La Chaux-de-Fonds, Proc. 12th Internat. Congr. Speleo., UIS, Vol. 6, pp 61-63

MOURET, C. 1998. **Les karsts à rubis et saphirs de la région de Mogok, Nord du Plateau** Shan, Myanmar (ex-Birmanie). Spéléo-Club de Paris publ., Proc. 8th Rencontre d'Octobre, Avignon 1998, pp 58-62

MOURET, C. 2003. Interactions entre les colonies de chauves-souris tropicales des grottes d'Asie et leur environnement naturel et humain. Spelunca Mém., n°26, pp 77-91

MOURET, C. 2004. Karsts of Southeast Asia. Routledge, Dearborn et Fitzerald, Encyclopedia of Speleology, John Gunn ed.

MOURET, C., LEBRETON, B. 2003. Myanmar (ex-Birmanie). Encyclopaedia Biospeologica, Vol. 3, pp 1935-1942

MOURET, C., MOURET, L. 2003. Dattaw Cave, Birmanie. Paris, Flammarion, Merveilles du Monde Souterrain., pp 88-89 (+versions in Italian and in English).

O-21

About processes governing speleogenesis in the rocks

By Claude MOURET

claude.mouret@wanadoo.fr • La Tamanie F-87380 Magnac - Bourg

Résumé

La plupart des roches peuvent recéler des grottes, qu'elles soient, sédimentaires, ignées ou métamorphiques. Toutefois, la taille et le développement des grottes varient beaucoup d'un type de roche à l'autre. Nous présentons ici les trois facteurs principaux de creusement spéléogénétique, de façon générale: dissolution/ corrosion, altération géochimique et désintégration granulaire/ érosion. Ces trois facteurs de creusement nécessitent la présence d'un export des matériaux dont le départ est nécessaire pour que le vide se développe et apparaisse en tant que tel: export en solution, par entraînement de grains ou par effet mécanique gravitaire. Dans la quasi totalité des cas, la présence de l'eau est nécessaire à quelque degré, soit pour la destruction de la roche, l'export ou les deux. Même les effets gravitaires et ceux du vent sont accentués, sinon largement préparés, par la présence d'eau.

De nombreux facteurs géologiques interviennent,outre ceux tectoniques et hydrogéologiques bien connus, comme les alternances de bancs de résistance contrastée, les expositions aériennes interrompant momentanément la sédimentation, la diagenèse classique, les effets hydrothermaux lors des phases d'enfouissement.

Abstract

Most of rocks may host caves, whatever they are sedimentary, igneous or even metamorphic. However, the size and overall length of caves largely differ from a type of rock to an other. We comment here three main factors of rock destruction, which are dissolution/corrosion, geochemical weathering and grain disintegration / erosion. Rock export is necessary and it occurs as mineral solutions, grain transport or gravity effect. In most of cases, water is necessary to some extent. Even gravity and wind effects are accentuated and even largely prepared par water.

Any geological factors also play a role, in addition to the well known tectonic and hydrogeological ones, such as alternation of beds, or intervals, of contrasted resistance, aerial exposures during short interruptions of sedimentation (relative sea level falls), classical diagenesis or deep burial effects.

Most of the rocks (sedimentary, igneous and metamorphic) may have caves, but the related passage developments vary significantly. In a given rock, the number, the size and the location of the caves depend on rock nature and fabric, and on the geological, geomorphologic and climatic settings.

Water is nearly always necessary to speleogenesis, even with regard to a number of gravity-driven processes. Even the wind, under arid conditions, cannot fully exert its action if the rock has not previously or sub-contemporaneously been weakened by some weathering-related and capillary phenomena.

1. Rock destruction and rock export

Both destruction and export are necessary to cave formation. Rock destruction mainly includes rock dissolution and corrosion, rock geochemical weathering and erosion-grain disintegration.

Export by water and/ or gravity processes (sliding, solifluction, fall, undermining…) may enhance or in some cases slow down rock destruction, depending on climate and morphology. Wind plays a role in carrying arenas or other kinds of particles and small grains away from small caves.

1.1. Rock destruction

Rock dissolution/ corrosion by acidic water (whatever acidity originates from CO_2 dissolution in the soil, organic acids, bacteria action, volcanic gases, oil-related or hydrothermal solutions), is active at a significant scale on a limited number of rocks:

- carbonates, with significant differences from limestone to dolomite, siderite, etc.,
- metamorphic carbonates, such as marble and cipolino,
- evaporites, which are highly soluble.
- largely calcite-cemented sandstones and conglomerates with non-carbonate grains or elements.

Nevertheless, corrosion by organic acids also occurs, but at a very limited scale, with siliceous minerals such as quartz and feldspars.

Geochemical weathering includes a minor amount of pure dissolution, and mainly a lixiviation/ geochemical transformation of weaker minerals in non carbonate, non evaporitic, rocks which can be sedimentary (sandstone, conglomerate), metamorphic (micaschist, gneiss…), igneous either crystallised at depth (granite, diorite, syenite, gabbro, pegmatite, etc.) or volcanic (basalt, andesite, dacite, rhyolite, etc.). As weathering depends on water availability, it depends on climate and seasonal effects and on regional morphology as well. Rainy paleoclimates are important especially in arid regions, where rock weathering was more developed a few millennia ago. Weathering is facilitated when rock drainage is poor, as in flat and low lands, while aprons, plateaus edges or pitons are not so weathered.

Usually, feldspars (and certain rock fragments in sandstones and conglomerates) are the weak components of the rocks (sandstones, igneous rocks, volcanic and metamorphic rocks), but ferro-magnesian minerals are weak as well. Dissolution and weathering may lead to a neoformation of clay minerals (variable according to drainage conditions) and mineral destruction starts and accompanies rock weakening. Geochemical weathering action interacts with mechanical weakening. Acidic solutions penetrate the rock better where grain contacts are loosened and where microfracturing occurs. There is always a balance between discontinuities opening and weathering, because water must penetrate the rock but it must also remain a sufficient time for chemical reactions are effective.

Salt migration in the rock commonly creates mechanical exfoliation which results in void enlargement, specially near surface. Capillary effects needs only a small quantity of water and largely weaken the rock, preparing a ground for rock disintegration and desquamation

Bacteria may exert an additional destructive action through corrosion or more complex interactions with the host rock.

Rock disintegration concerns crystals or grains. It depends on the nature of rock, on the size of the crystals (dacites often have large crystals of biotite or hornblend and in this case disintegrate much more than basalts or rhyolites) and on the pattern they form with other minerals. It facilitates water penetration into the rock and may have a direct impact on weathering. Too small-grained rocks usually do not show significant grain disintegration. Thermal action (alternations of cold and hot, frost…) is able to enlarge already existing voids (for instance in some granite caves). Rock overburden leads to generate rock shelters, as in siltstones and shales interbedded below massive sandstones.

Erosion is directly linked to grain disintegration and freed crystals or grains can be easily carried away, provided there is available space for that (connected fenestrae, conduits, open fractures, open stratification surfaces, outside slope, etc.). Erosion probably occurs in karst conduits to a higher extent than it is usually thought. In passages behind river sinks,
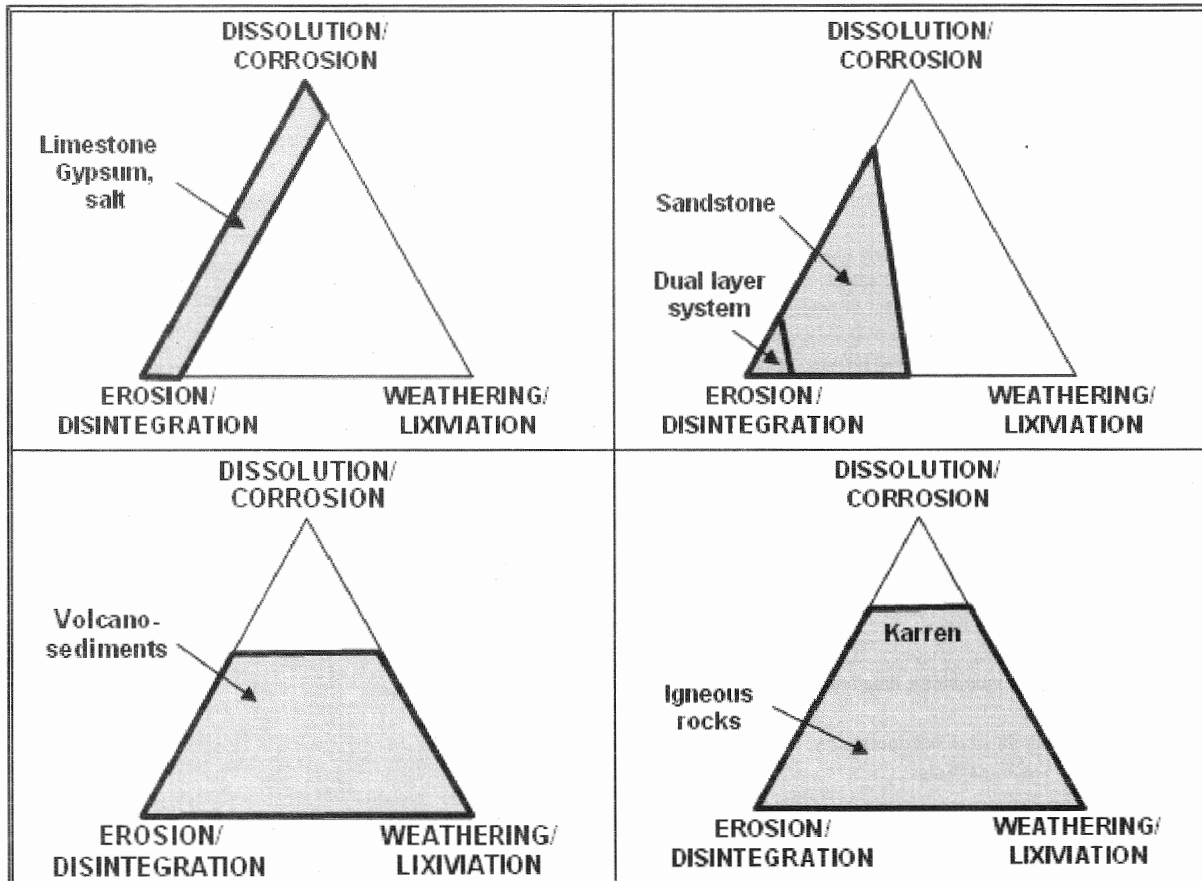
Fig. 1: Rock destruction processes in speleogenesis

transportation of solid particles by water may erode cave walls and the fine-sized particles generated in this way are subsequently more easily dissolved. Near the outlets, erosion (if conditions for it are encountered) is enhanced by stronger current; eroded particles are easily exported. The water breakthrough and specially the cave breakthrough between sink points and outlets lead to a well developed passage association able to generate long cave systems.

Rock massifs existing as topographic highs can be affected by gravity deformation leading to deep open cracks within them, which form sometimes long caves.

1.2. Rock export

Rock export is made as a mineral solution or by the way of particle transportation. Dissolution is predominant in carbonates and evaporites. Grain disintegration and particle export is dominant in sandstones. Weathering and capillary effects dominate in metamorphic and igneous rocks and liberate particles which can be exported by water and gravity over a commonly short distance (before it is reworked and exported at long distance. Small caves in grained rocks form more easily along fractures if gravity-related export processes are present.

At a large scale, geometric setting plays a large role in grain export, specially if it is associated with a favourable geological pattern: e.g. strata surfaces in a sandstone gently sloping towards the local hydraulic base level. Rock export occurs downstream at first and progressively moves upstreamward. In the sub-basaltic caves in Western Borneo, such an export is the major reason why caves have formed in silici-clastic beds below basaltic andesites.

2. Other factors of cave formation

Many factors play a role with respect with cave formation, which is classically established. However, we would like to review here some factors which have been less studied. They are reviewed, for sedimentary rocks, from sedimentation to diagenesis and deformation, and for other rocks mainly under the aspect of lithological contrasts.

Beds succession may enhance speleogenesis, whenever a harder, thicker, more resistant bed (or interval) overlies a less resistant one. For instance, roofs of large chambers and even of large passages may be made up of the thicker beds of a thickening up sedimentary sequence in carbonate, or made up of a more cemented carbonate lithology or of a different carbonate (siderite beds interbedded with some limestone series for example).

In non carbonate environments, caves often form because there is a stronger bed above easily erodible rocks. It is the case in volcanic and volcano-sedimentary environments (basalt above sandstone or above sandstone-shale alternations, welded breccias above sandy volcano-sediments...), in sedimentary silici-clastic settings (cemented thick sandstone above thinner, finer-grained, less cemented one), in laterite profiles (caves formed below the iron crust), etc.

Speleogenesis also occurs where a formation concentrates water towards peculiar points or areas of weaker strata, as a poorly porous, fractured, sandstone above an underlying fractured carbonate. Structural conditions may enhance this.

Harder beds also play a role as potential barriers to horizontal flows along their non fissured or faulted parts. Water is forced to follow them until it meets a fracture or a sedimentary or diagenetic wedge which allow

it to go deeper in the rock massif, according to the hydraulic gradient.

Longer periods of temporary exposure during relative sea level falls (temporarily interrupting sedimentation in higher areas) are more prone to initial cave development, because they allow slow processes to take place in a significant way. Once the secondary voids, including caves, have developed, they are usually sufficiently preserved (if their fill is not too highly cemented during deep burial) to influence subsequent karstification and speleogenesis. Therefore, depositional sequence boundaries are prone to subsequent karst development.

Diagenesis of sedimentary rocks is a very important factor: in carbonates, karstification and speleogenesis are completely different when the degree of rock cementing and the amount of porosity vary. Poorly cemented, porous, limestones with a low mechanical resistance lead to often smaller caves and to a dual porosity system (matrix + karst) with complex mutual relations. Hard, tight, highly cemented limestones will bear longer caves, sometimes very long, with large passages and chambers; they will also show more contrasted, much steeper, outside morphology.

Dissolution and/ or rock alteration under deep burial conditions are probably more common than it is presently thought, not only in carbonates but also in sandstones for instance, though it is much more subtle to spot.

Cave filling plays an opposite role as it slows down or stops cave enlargement (it may be generated by changes in the conditions of cave evolution). It takes place as a response to local or more regional conditions and even to relative sea level fluctuations.

Many karsts are subsequently onlapped by marine formations and may become more or less completely filled with sediments. Larger parts are likely to collapse progressively with burial, and this will be more developed if the rock has no good mechanic resistance.

Cave fills may be allochthonous or simply autochthonous (e.g. exfoliation sheets in granite caves) and may slow down cave formation because they decrease the possibility of export, in the case of non solution export.

Obviously, tectonic conditions play a classically known role and the hydraulic conditions as well. It is not here our purpose to be exhaustive, but we wish to draw attention on some less known factors which are conditioning speleogenesis. We also wish to highlight, if necessary, the extraordinary variety of rocks and rock formations in which caves can form.

O-22

The Maronia cave in the nummulitic limestone (Thrace, Greece).

Geology & Paleontology

S. Pavlides[1], E. Tsoukala[1], A. Chatzipetros[1], A. Chatzopoulou[1], V. Melfos[1], A. Vasileiadou[1],

G. Lazarides[1], M. Vaxevanopoulos[1].

1. Department of Geology, Aristotle University, GR-54124 Thessaloniki (pavlides@geo.auth.gr)

Abstract

The Maronia Cave (Thrace, Greece) is a cavern with great geological, palaeontological and archaeological interest. The tectonics, morphology and the speleothems of the cave are being described. In the present study the invertebrate and vertebrate remains are presented.

Geological structure of Maronia cave

Maronia cave is located at the Koufoplati hill (2 km NW of the Maronia village) and is developed in a relatively thin layer of eroded Nummulitic limestones of Middle Eocene age (Kouris 1980, Papadopoulos 1982). These Nummulitic limestones have been unconformably deposited on top of the underlying greenschists of Makri and Drymos-Melia Units (Circum Rhodope geotectonic zone), and are spread over a wide area, covering today the top of the region hills. Limestones are slightly inclined towards the west and contain several species of fossilized Foraminifera, Algae, corals, sea urchins, bivalves and Bryozoa. A basal clastic series partly defines the contact between limestones and greenschists. It comprises mainly of conglomerate and sandstone. It is considered to be the regression series marking the beginning of limestone deposition. The greenschists of the Makri and Drymos-Melia Units are a complex of Jurassic - Lower Cretaceous metavolcanic rocks (lavas and tuffs) of low metamorphic grade. The Mesozoic metamorphic rocks and the Eocene limestones are intruded by Oligocene volcanic rocks, which are represented mainly by altered andesites alternating with bedded and partly unbedded tuffs (Melfos 1995).

The cave is formed along two main tectonic lines (faults): the primary one is trending NW - SE and forms the main cave chambers, while the secondary one is trending ENE - WSW and forms the secondary chambers. These lines are in good agreement with surface microtectonic analysis. Two main sets of joints are observed: the primary one (D1) is striking S20°E to S30°E and comprises of long (>10 m) and quite sparsely (ca. 0.5

m) developed joints, while the secondary one (D2) is striking N60°E and comprises of shorter joints. The coincidence in strike between the two main joint systems, the cave chamber orientation and the tectonic lines of the near area, lead to the conclusion that the cave was formed along three main tectonic zones. Surface water circulation has played an important role during the speleogenesis procedure (fig.1).

Τεκτονική Μαρώνειας (όλα τα στοιχεία)
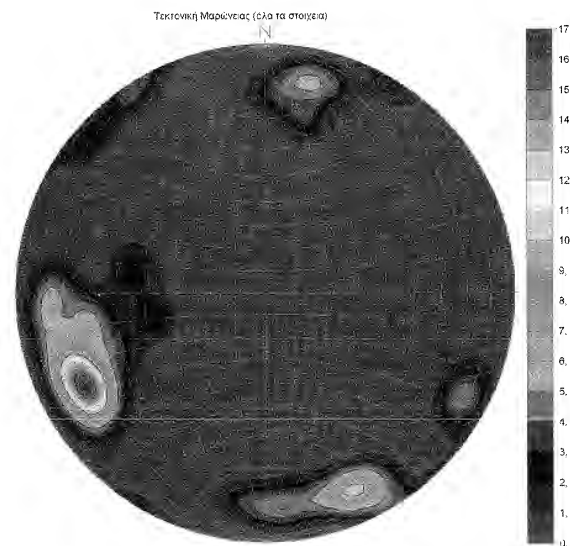
Figure 1. Stereographic projection (lower hemisphere) of faults and joints (density diagram) showing the two main directions NW-SE and ENE-WSW.

The Maronia Cave presents a total passage length of approximately 2000 metres and expands 10000 square metres. There are two natural entrances to the cave, both on the eastern slope of the Koufoplati hill. Most of the floor surface is covered with calc-crust flowstone. The southern part of the cave comprises large chambers. It has great biological interest due to the presence of 11 different species of bats and 31 species of invertebrates. 1/3 of this fauna consists of endemic species (Paragamian 2004). This can be interpreted by the early cracking of the Eocenic Nummulitic limestone cover that resulted isolated cave faunas. The southern part of Maronia Cave shows remarkable diversity of speleothems. The most spectacular forms are the shields, (e.g. Hill & Forti 1997), such the huge shield (diameter 2m)(Photo 1), which was observed in one of the deepest rooms of the cave.

The northern part of the cave is rather small. The two entrances control the microclimate of this part of the cave. Temperature and humidity are not stable throughout the year. This effects the bat populations regarding moving and hibernating. Curtains and enormous columns create mazy paths. The scarlet hue of the speleothems is dashing (Photo 2). The solution process of percolating water is intense only in few areas. Chambers of the northern part are relatively dry and the speleothems are under corrosion. The stalactites of the ceiling of some chambers have been collapsed (e.g. Klimchouk et al. 2000).

The decoration of the cave presents a great variability. Some of the speleothems are rare and impressive. Among them, there are stalactites that are shorter than the stalagmites almost in all cases, columns, draperies, helictites (Photo 3), conulites, flowstones, gours, pool spars, cave pearls and corrals, and shields or discs as well. Mushroom-like (Photo 4) and curved stalagmites and the discs are the most characteristic features of the Maronia cave. The stalactites and stalagmites follow the tectonic lines of the cave. In some chambers, mainly in the southern part of the cave, chemical corrosion caused great damage to the speleothems. This may be due to the affection of the CO_2 released from the guano of the bats that covers most of the floor of the cave. In certain places small lakes have been formed and small potholes as well.

Palaeontological findings

The Paleontology of the cave presents great interest. There are invertebrates in the limestone of the cave surroundings including sea urchins, giant ostreas, hexacoralls, lamellibranchia (mainly Pectenidae and Cardiidae), and foraminifers (mainly nummulites) (Photo 5) of Eocene age. The nummulites characterized the Intertidal and Neritic environment. They are also of great stratigraphical importance since they are index fossils of Eocene (Dermitzakis & Georgiades-Dikeoulia 1986).

Photo 1. Shield of diameter 2m. The most characteristic form of speleothems of the Maronia Cave.
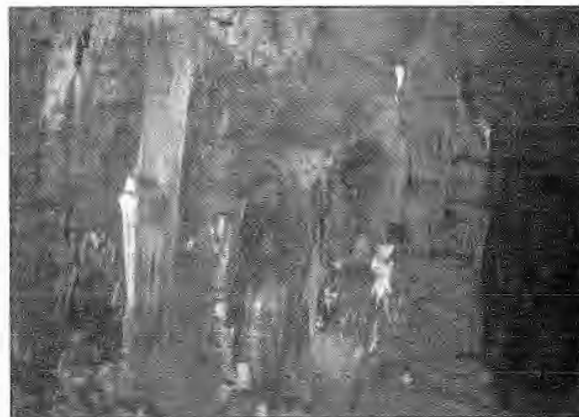
Photo 2. Spectacular red columns due to iron oxide.
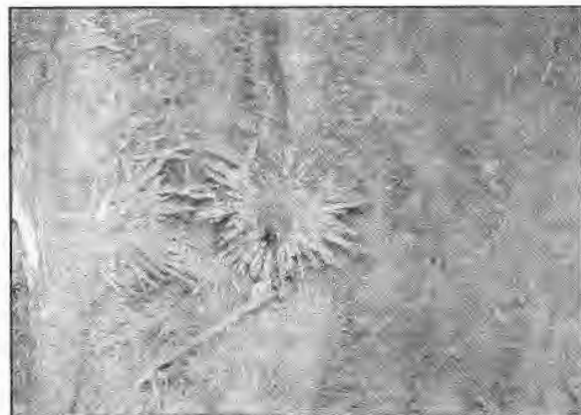
Photo 3. Helictites

Photo 4. Huge mushroom-like stalagmite

Next to the entrance of the cave, in a small recess of the bedrock, a cohesive bone breccia (Photo 6) is being preserved. The initial examination gave interesting results (Bartsiokas 2000). Of the vertebrates found in the breccia from the additional material, the fossilized bones and teeth can be attributed to Crocuta crocuta spelaea (Photo 7), Coelodonta antiquitatis, Elephantidae? Bos primigenius, Equus caballus, Dama dama of the Late Pleistocene age.

Further more, recent bones have been observed on the floor of the cave. These can be attributed to Capra/Ovis, Equus caballus, Sus scrofa scrofa, Homo sapiens, Martes martes, Canis familiaris. Small mammals were also identified: Leporidae, Chiroptera, Erinaceus sp. Crocidura sp., Apodemus mystacinus, A. sylvaticus, Rattus rattus, Microtus arvalis and M. agrestis. Few remains confer to small reptiles and birds. Many of these bones have been covered by stalagmite.

Photo 5. Detail of a nummulite. Scale 1cm
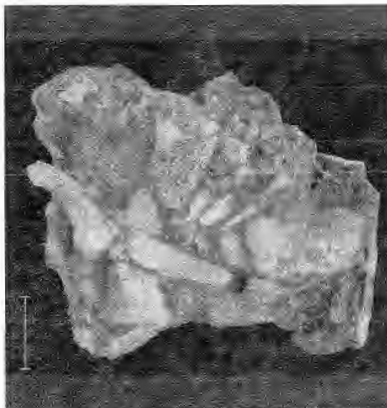
Photo 6. Part of the cohesive bone breccia. Scale 5cm
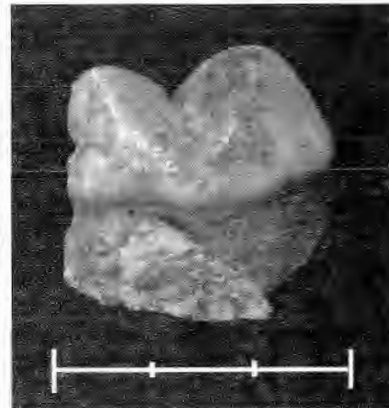
Photo 7. First molar of Crocuta crocuta spelaea. Scale 3cm

Archaeological Importance

The Maronia Cave has a great archaeological interest. Excavations have shown that the cave was inhabited in the Neolithic and Bronze Age, while in the Archaic and Byzantine periods it was a place of refuge in times of hardship or a place of worship (Petrochilou 1985; Bakirtzis &Triantaphyllos 1988). In traditional tales it has been identified with the cave of the Homeric hero Plyphemus, the Cyclops who was blinded by Odysseus, after intoxicating him with the Maron's wine. The cultural importance of the cave is related with the significant archaeological sites, which are spread around the whole region. Maronia was a considerable trade and cultural centre in Northern Aegean Sea, for more than 2.500 years and many monuments and buildings are still preserved, making the area a huge open-air museum. Ismara inhabited by the Thracian Cicones is documented by the acropolis, the city walls with a gate and a sanctuary (Photo 8). In the neighbouring Maronia the colonisers from Chios constructed the city walls, a theatre, sanctuaries, houses with mosaics and a harbour, all still preserved today.

Photo 8.A gate and the city walls of ancient Ismara inhabited by the Thracian Cicones.

References

BAKIRTZIS C, TRIANTAPHYLLOS D (1988) Thrace. Cultural Foundation ETBA, Athens, pp 80.

BARTSIOKAS, A., 2000. The myth of Cyclops Polyphemus and the paleontological reality in the Cave of Cyclops, Maronia, Greece. -18th International Congress of Zoology, Athens (28/8-2/9/2000)

DERMITZAKIS, M.D. & GEORGIADES-DIKEOULIA, E., 1986. Introduction to the Marine Micropaleontology, Part A, p. 720, Athens.

HILL, C. & FORTI, P., 1997. "Cave Minerals of the World". 2nd edition, National Speleological Society. Huntsville, Alabama, USA.

KLIMCHOUK, B. A., FORD, C. D. & PALMER, N. A. 2000. Speleogenesis. Evolution of karst aquifers. Wolfwang Deybrodt Editors, Huntsville, Alabama, U.S.A. 2000, p 526.

KOURIS, Ch., 1980. Geologic map of Greece, Mesi-Xylagani sheet, scale 1:50.000. Inst Geol Miner. Expl, Athens

MELFOS, B., 1995. PhD Thesis, Aristotle University of Thessaloniki, School of Geology, p. 289 (in Greek)

PAPADOPOULOS, P., 1982. Geologic map of Greece, Maronia sheet, scale 1:50.000. Inst Geol Miner Expl, Athens, Greece

PARAGAMIAN, K., 2004. Research project: Biological-Environmental Study of the Maronia Cave. Part A. Institute of Speleological Research in Greece, p. 112.

PETROCHILOU, A., 1985. Caves of Greece. p. 160, Athens.

O-23

From 2001 to 2004: paleontological excavations in the Grotta inferiore dei Covoli di Velo (Veneto - Italy)

Roberto Zorzin*, Fabio Bona* *, Massimo Accordini*

(* Museo Civico di Storia Naturale di Verona, **Università degli Studi di Milano*)

The cave bear

The cave bear (Fig. 1) had its origin from the kind Ursus etruscus mostly spread in Eurasia during the middle-superior Villafranchian. From this progenitor, in fact, two phylogenetic lines are evolved: one in Europe have gave origin to U. spelaeus in the middle Pleistocene (around 350.000 years ago), passing through the kind U. deningeri, and the other one in Asia to U. arctos (the actual brown bear), which has spread then also in Europe and in America (Kurten, 1968).

This animal, very diffused during the superior Pleistocene, from a geographical point of view, can be considered a limited kind to the European continent. Its area of distribution extended him from the south of England as northern limit, to central Italy as southern limit, while to the west it reached the north of Spain and to the east the Caspian Sea (Kurten, 1972). From the point of view of the altimetric distribution, the kind Ursus spelaeus has been found up to the quota of 2800 meters altitude, really in Italy, in the cave of the Conturines.
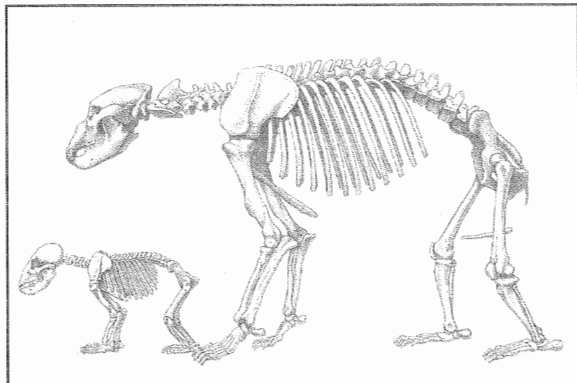
Figure 1 - Pup and adult cave bear skeletons (Kurten, 1972).

The cave bears introduced a notable but variable ransom: the forms suited for glacial periods, in fact, middly possessed superior dimensions in comparison to the forms of the interglacials periods; besides, evident was also the difference of ransom among males, which were bigger than females. A fundamental characteristic of this animal was the specialization of the teeth for a predominantly vegetarian diet.

The forms of cave bear were spread in forest environments of lowland during the glacial periods while in the interglacials, in which the temperature was milder, they could climb to tall quota in hollow of mountain or to more elevated latitudes. In these karst caves they looked for shelter during the winter lethargy, then they went out and wandered freely during the spring with the purpose to get themselves the necessary resources to face the cold following winter. The almost totality of belonging rests to Ursus spelaeus has been recovered really in these hollow, where the bones of the dead bears during the winter period are preserved until today. Interesting seems to be the fact that in some caves the number of the males could overcome a lots that of the females while in others could happen the contrary. This could be interpreted as test of the existence of hollow mostly frequented primarily by the females with pups and populated hollow by the males. According to Kurten, the males for example, preferred ampler caves, while the females small and sheltered caves, which constituted a sure shelter for pups.

The cave bear probably extinguished in western Europe before the moment of maximum aridity of the last glaciation (around between the 20.000 and the 18.000 years ago). One of the hypotheses on the causes of the disappearance of U. spelaeus is that this kind had already reached the last glaciation with few exemplary and that the strong stiffening of the climate and the consequent environmental changes made the retrieval of food extremely problematic and hindered the meetings among the individuals (Kurten, 1976).

Covoli Di Velo - Grotta Inferiore

The zone where the karst system of the Covoli di Velo finds is one of the most interesting of the center oriental Lessini Veronesi, both from the geologic and paleontological point of view. These hollow are situated in the so-called Valle del Covolo, tributary of the deep incision of the Valle di Progno di Illasi, among the excavations of Velo Veronese and Selva di Progno.

The karst system of the Covoli di Velo (Fig. 2) is formed of three prin-
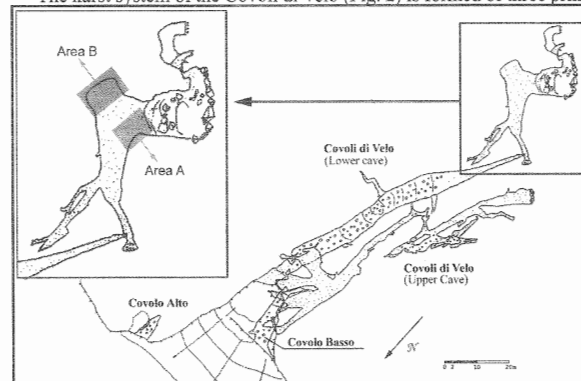
Figure 2 - Planimetry of the karst system of the Covoli di Velo with excavation sectors in the terminal room (details G. Rossi and R. Zorzin).

cipal hollows ("Grotta superiore", "Grotta inferiore" or "Grotta dell'orso" and "Covolo dell'Acqua") and of some smaller hollows. The caves, that primarily introduce an horizontal course, develop to an altitude which is almost between the 860 and the 890 ms s.l.m., inside the calcarenitis oolitiche in benches, locally also intensely dolomitizzate, lumachelle to ostreidi, rolled micriti and micriti with clayey interleavings, belonging to the formation of the "Grey Limestones of Noriglio" (Jurassic inferior).

Overall around 545 meters of karst system, of which 364 ms belong to the system of the Grotta superiore-Grotta inferiore, 65 ms to the Covolo dell'Acqua, 40 ms to the Covolo dell'Atrio and the remainders 75 ms to the smaller hollows, has been explored.

The hollows are rich of alluvial sediments and they are all inactive hydrologically, except the Covolo dell'Acqua, characterized by a perennial water circulation with strong variations of course. The accessible parts of the complex and the presumable connections among hollows are limited from the huge alluvial deposits and that of collapse, that clog the galleries in various and discontinuous way (Rossi and Zorzin, 1999).

The hollow has a total development of 195 ms, to a large extent computable to the principal branch, being entirely the secondary ramifications. Few over the entrance, besides very narrow, the gallery, in light descent, assumes a very ample rectangular section. In this line the paleontological deposit has been removed reaching an underlying sterile level constituted from materials of collapse.

91

Progressively, the dimensions of the gallery are reduced until a narrowing, determined by the contact of the deposit with the vault, overcome only in 60' with a binding work of disobstruction (Benetti and Cristoferi, 1968). The cave continues widening itself with typical circular sections until an ample room, partly busy and delimited by an imposing landslide to big blocks. The principal gallery is presumably buried under the alluvial deposit, while from the room two secondary ramifications develop.

On the vault of the room some speleologists of the C.A.I. have reached with a climb of about ten meters a rolling mill, that shortly tightens, because of the fillings, in impracticable channels of vault. The strong ventilation suggests that this ramification can bring, with an opportune disobstruction, to wide unexplored parts of such karst system.

History of the searches on this karst system

The karst complex of the Covoli di Velo didn't pass unnoticed: since the end of the XVIII century it's was object of interest for illustrious characters and naturalists. The first certain news goes up again at the end of 1700 when the abbot Fortis expressed the opinion that the present bones in these caves were rests of "amfibj" similar to the seals. Few years later Serafino Volta, denied the Fortis' opinions, showing as these bones, in reality, represented the rests of terrestrial animals (Benetti, 1973).

After Volta any other naturalist was interested in these caverns until 1844, when Catullo visited them and published a work, in which Avoni, who accompanied him, dealt with the description of the superior cavern. In this work the presence of a lot of fossil bones is underlined.

Figure 3 - Massalongo's plate illustrating some bones of Ursus spelaeus found in the Upper Cave (Massalongo, 1851).

Abramo Massalongo (1851) studied more carefully both the caverns and the finds picked up by Avoni and others picked up by himself. His description is much more detailed and includes both the caves, the superior and the inferior ones. Massalongo does in his work a lot of hypotheses about the genesis of the caves and the bony finds, accompanied by tables and valuable illustrations (Fig. 3); these hypotheses, even if are partly wrong, make his essay the first true scientific work on the Covoli di Velo.

In 1875 an important memory regarding these caves was published by Giorgio Omboni. In this work some paletnological finds are described

and illustrated in tables, without however to neglect the paleontological aspects. In the first ones, the most important finds studied by Omboni are represented by ceramics, worked flints (knives and scrapers), a point of arrow with fins, worked bones (awls and strikers) and a hammer fact with a piece of horn of buck.

Omboni (1875), besides, was the first one who signalled the problem of the lack of searches and excavations performed with a scientific method in these caves, risking, in this wave, to lose all the knowledges on the position and on the history of the finds contained. The same Omboni always signalled the problem of the unauthorized excavations that defaced the paleontological patrimony of these hollow from about ten years.

In fact, while these naturalists picked up this important material, the inhabitants of the outskirtses tried to get profits at all costs from what the deposits of the two caves offered. The skulls, the jaws and the canine teeth were picked up to be subsequently sold to the collectors.

Also in the writings of Attilio Benetti (1968) it can be read as the inhabitants of the place drew profit selling the sediments of the caves as soil and the entire or ground bones as good fertilizers. Therefore the extraction of the finds was prevented by the hollow. Despite this fact the unauthorized excavations continued due to collectors and especially dealers.

After all these stories, took place foot among the naturalists the opinion that the deposits of the Covolis, stunned and made more and more sterile from the excavations and from the removals of these last three centuries, could not offer anymore finds worthy to be studied. The caves were neglected and left to the mercy of the unauthorized ones.

In 1970 the discovery of a new room made by the speleologists of the C.R.I.S.V. (Hydrological and Speleological Center Searches in Verona) showed that the excavation of these virgin deposits and the exploration of the galleries was still far from the conclusion. Just for this reason, the group of speleologists that year tried to close the Grotta inferiore; however it was reopened by the unauthorized burrowers.

The new paleontological-stratigraphical excavations in the grotta inferiore

Since August 2001, the entrance of the Grotta inferiore of the Covoli di Velo, hollow that still contains unmolested portions of the layer, has been closed to the "curious" to safeguard the deposit from the unauthorized excavations. The closing of the hollow has been realized by the Parco Naturale Regionale della Lessinia, on project of the Speleological Committee in Verona.

Since October 2001 the Section of Geology and Paleontology of the Civic Museum of Natural History in Verona has begun a series of excavations (2001, 2002, 2003, 2004) inside the Grotta inferiore that have primarily brought to the recovery of over a thousand of bony finds belonging to the kind Ursus spelaeus.

The excavations have been realized in the terminal room of this cave, set to around 150 ms from the entrance, and they have interested two small portions of the ground, one along the west side, denominated sector A, and the other one along the east side, denominated sector B (Fig. 4).

Stratigraphy of the sector A

The sector A, in which it was worked in 2001 and partly in 2002, is represented by an area of 12 ms², divided in squares; each of them introduces a surface of 1 m² and it is initialed with at least a letter followed by a number (AA1, AA2, AA3, A1, A2, A3, B1, B2, B3, C1, C2, C3). At the end of the excavation has been reached the depth of around 2,80 ms from the zero of the cave.

The followings levels have been shown, proceeding from the surface of stamping:

92
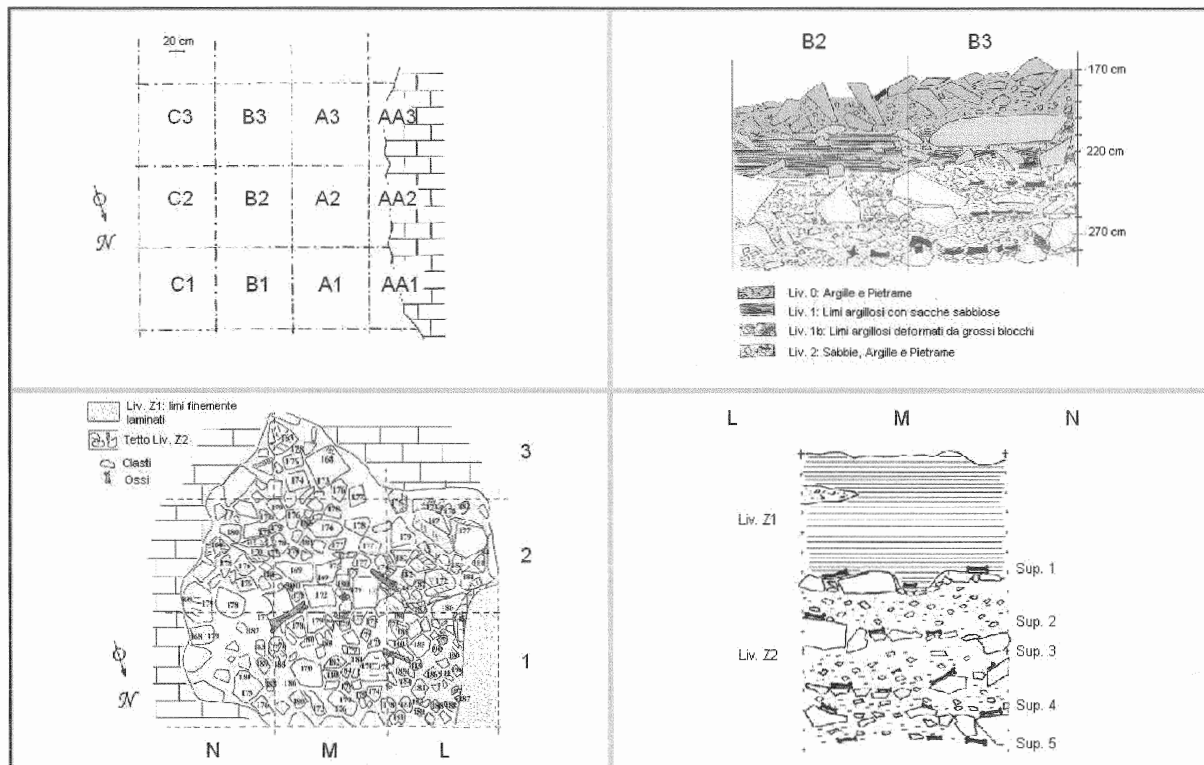
Figure 4 - Up on the left, planimetry of sector A; up on the right, vertical section of sector A in relation to squares B2 and B3; down on the left, planimetry of sector B on the roof of level Z2; down on the right, vertical section of sector B in relation to square M (figures by F. Bona).

Liv. 0   it is the most superficial level, primarily constituted by a big body of landslide, with angular pebbles of various dimensions, very big too. The matrix among the pebbles is clayey of brown color. This level reaches a maximum depth of 90 cms. Here few bones are been recovered, between them we signal some finds of ibex, important for the paleoenvironmental interpretations.

Liv. 1   it is composed from clayey slime, finely rolled. Alternated to foils of maximum thickness of a millimeter, of yellow color and constituted in bigger slime part, there are others black, probably due to accumulation of organic substance in a moment of stasis depositional in calm waters. Besides, lenses of sand which included pebbles of some mms of diameter are present. The thickness of the level 1 reaches the 40 cms. This level is entirely sterile from the macropaleontological point of view.

Liv. 1b   it is characterized by shreds of clayey slime stratified and mixed between big blocks of landslide of non inferior dimensions to the 50 cms and pebbles of smaller dimensions. It can be interpreted therefore as the liv. 1, but in which the foils of clayey slime have been deformed by the blocks coming from the overhanging landslipe. Also its thickness is of around 40 cms. This level results to be extremely poor of paleontological finds.

Liv. 2   it results constituted by angular pebbles of eterometric dimensions. The matrix is clayey of dark brown color. The pebbles are prepared in an horizontal way, in order to create some separate plains. To the actual state of the searches, three principal "paleo-surfaces of stamping" have been individualized, characterized, in addition to pebbles, also from the presence of bones, set, they too, in horizontal position, and from an in-

crease of the sandy fraction and clayey aggregate. Where these plains are recognizable, the matrix, in addition to be composed of sand and clayey aggregate, shows a blackish coloration, with a certain probability, due to the accumulation of organic substance coming from the decomposition of the soft parts of the dead animals. Alternated to these surfaces there are slow of clayey slime with foils of maximum thickness of a millimeter. This level is the richest from the paleontological point of view. On the three "surfaces" individualized, in fact, numerous long bones have been recovered and also a big fragment of skull belonging to Ursus spelaeus, further to a metatarsus of wolf (Zorzin and Bona, 2002).

Stratigraphy of the sector B

Instead since 2002 and in the two following paleontological excavations (2003 and 2004) was dug in the other area, sector B. Here 9 ms² of earth have been considered, these too separated as those of the sector A in squares of 1 m², initialed with letters and numbers (L1, L2, L3, M1, M2, M3, N1, N2, N3), and around 2,70 ms depth has reached.

The stratigraphical levels envoy in light till now with the excavation are two:

Liv. Z1   it is an horizon constituted by finely rolled clayey slime. The foils, of maximum thickness of a millimeter, of yellow color and constituted from slime, are probably formed for accumulation of fine material, transported by a course of water and settled in calm waters. Alternated to these, there are other black foils, due to accumulation of organic substance in a moment of depositional stasis in calm waters. Besides, the presence of a thick granulometric lens, constituted from gravelly
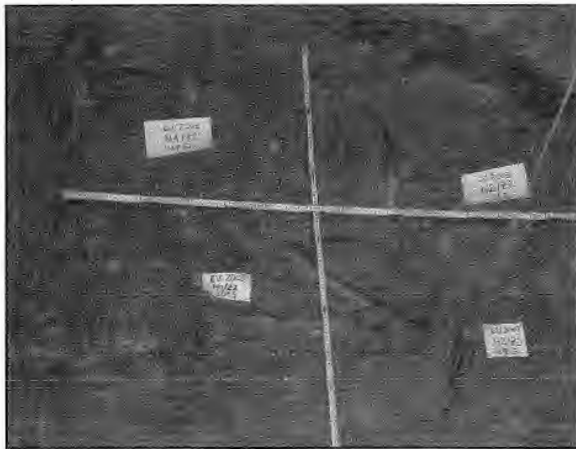
Figure 5 - Particular of surface.5 with accumulation of bones arranged in horizontal position (photo F. Bona).

Figure 6 - Some cave bear skulls found in the Grotta inferiore during the excavations (photo M. Accordini).

material and sand, has been found. In addition to this, other smaller lenses of sand, which are a few wide ten centimetres, are verifiable in the level Z1. This level reaches a general thickness of about 90 cms. Here the presence of bony rests scarce.

Liv. Z2 as in the level 2 of the sector A, here too more distinguished plans have been found, exactly five, constituted by pebbles of eterometric dimensions with angular borders and bones prepared in horizontal way (Fig. 5). The matrix is clayey of dark brown color. Where these plains are verifiable, the matrix, in addition to be composed of sand and clayey aggregate, shows a blackish coloration, probably, due to the accumulation of organic substance coming from the decomposition of the soft parts of the dead animals. Among these paleo-surfaces there are lenses of clayey slime with foils of maximum thickness of a millimeter. This level results very rich from the paleontological point of view. In fact, on all the surfaces a lot of bones have been recovered, also of big dimensions, belonging to Ursus spelaeus, and among them some almost complete skulls or however big portions of skull. Besides, in the level Z2 some bones of ibex and a femur of wolf have been recovered (Zorzin, Bona & Accordini, in press).

The evident stratigraphical similarity of the levels 1 and 2 of the sector A respectively with the levels Z1 and Z2 of the sector B makes us to be entirely almost sure of the depositional uniformity of the levels of the two areas of excavation. However until now they have been encoded with different names, until the union of the two sectors through a transept to verify their real equality. Instead it is still not clear if the "paleo-surfaces" found in the levels 2 and Z2 have to be considered separated levels or surfaces belonging to the same level. This problem will be surely clarified widening and subsequently deepening the excavation.

Finds recovered in the grotta inferiore of the covoli di velo

During the four excavations effected in this cave about 1500 finds have been recovered, some suits and in a good state of maintenance, others in a good state but fragmentary. Obviously we have to exclude from the general number of the classified finds all those whose determination is made impossible from their fragmentariety; otherwise the total number of the pieces would be notably bigger.

Passing to the analysis of the paleontological content of the four excavations, from a first and careful morphological study, it is evident that almost all the finds can be attributed to the kind Ursus spelaeus.
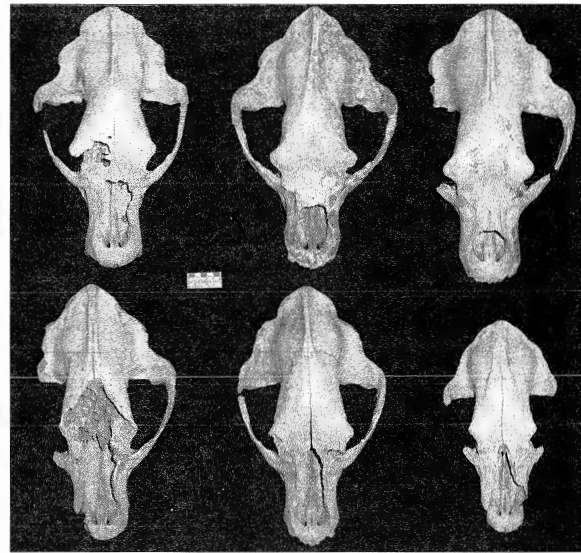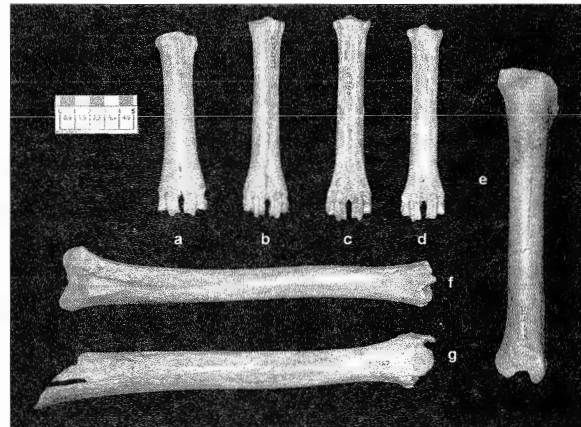
Figure 7 - Bones of ibex found in the excavations: a- Metacarpus sx.; b- Metatarsus sx.; c- Metatarsus dx.; d- Metatarsus dx.; e- Femur sx.; g- Tibia sx.; Tibia dx. (photo M. Accordini).

Between the most meaningful finds belonging to this kind we can count 8 skulls. Between these, only one has been recovered in the level 2 of the sector A, the others in the level Z2 of the sector B. These skulls are almost complete and in a good state of maintenance (Fig. 6). In fact, in the most of the cases only the nasal bones and the zigomatic arcades miss; only the find recovered in the sector A and another one of the sector B result strongly incomplete. Some of these skulls also preserve all the molars and someone still has the canine tooth. In addition to the skulls, good is also the number of the other bones which compose the skeleton of this kind (teeth, emimandibles, long bones, metapodials, vertebrae, shoulder blades, ribs, fragments of basin) recovered in the Grotta inferiore. All these bony finds belong to cave bears in different stadiums of growth. For example, observing the recovered emimandibles, those juvenile, more numerous, are fragmentary and consistent only in parts of the horizontal branch, while those of the adults are better preserved, sometimes introducing all the teeth, if the incisive ones are excepted. Also in the case of the numerous long bones recovered in the excavations, the major part of them belongs to pups and young cave bears, in which the

94

epifisis are not still settled completely to the diafisis. If we consider those of adults, in which the epifisis are usually melted perfectly to the diafisis, in reality, we see how a good part lacks of the extremities. Many teeth have emerged from the excavations of the Covoli di Velo, the major part of them is perfectly preserved; only in some cases they miss some root or even more they rarely show a crown and cusps consumed. A thought, must be made particularly on the canine tooth some of which introduce some notable dimensions.

Few are, instead, the finds belonging to other kinds (Fig. 7). In 2001 a first premolar of cave hyena (Crocuta crocuta spelaea), a fourth left metatarsus of wolf (Canis lupus), two right metatarsus and a right tibia of ibex (Capra ibex) have been recovered; in 2002 an incisive, a molar, a fragment of basin, a left tibia, a left femur and a left metatarsus of ibex have been discovered; in 2003 a right femur of wolf has been found while in the last excavation only a strong left metacarpus of ibex has been identified.

To these rests we have to add different rests of micro-mammals belonging to some kinds of rodents and bats, now in phase of study and recovered through a job of sifting on samples of earth picked in the sector A and in the sector B during the excavations. Particularly, till now, the levels 1 and 2 some area A and the level Z1 of the B have been investigated.

Preliminary results on the population of ursus spelaeus of the covoli di velo

The morphological characteristics and the morfometric analysis of the recovered finds (Accordini, 2003-2004) confirm the exclusive presence, among the kinds belonging to the kind Ursus, of the kind Ursus spelaeus Rosenmüller & Heinroth. For the specific determination and the measurement of the finds various texts have been used and different authors have been consulted (Hue, 1907; Schmid, 1972; Torres, 1988; Von den Driesch, 1976; Perego, 1993). The measures drawn by the finds of the Covoli have been compared at first with the data concerning the Spanish populations of U. spelaeus published by Torres (1988). From the comparison the result is that the dimensions of the bears of the Covoli are inclusive inside the maximum and least values typical of this kind. Particularly, as bony elements for the morfometric study, for the comparison with other populations and for the construction of graphs we have used the long bones. Comparing the long bones, we notice how the least values of these ones are much more inferior than the Spanish ones. This can be explained by the fact that in the charts of the Covoli di Velo the measures of all the finds of the excavation have been inserted, considering not only the adults but also pups and young cave bears, that lower notably the average, while Torres has entirely used for its data only adults. If only the data of the adults are compared also the least measures, they reenter in the interval of the Spanish values. Besides we have to consider, to one side, the specific variability and, to the other side, the fact that Torres has cropped and envoyed together the measures of a lot of Spanish populations of Ursus spelaeus: so, the average and the specific variability result very ampler in comparison to those of a single population.

Minimum number of individuals

Thanks to the femurs, the type of more abundant bone in the excavation, we have calculated the least number of individuals that makes us suppose has populated the cave: this results to overcome the 80 individuals, value that, of course refers to the levels till now investigated. The method used to calculate this value is that of Krantz (1968): considering the bone found with more frequency, the least number of individuals is given by the sum of the number of pairs of this bone recognized as belonging to the same animal adding all those separated lefts and rights.
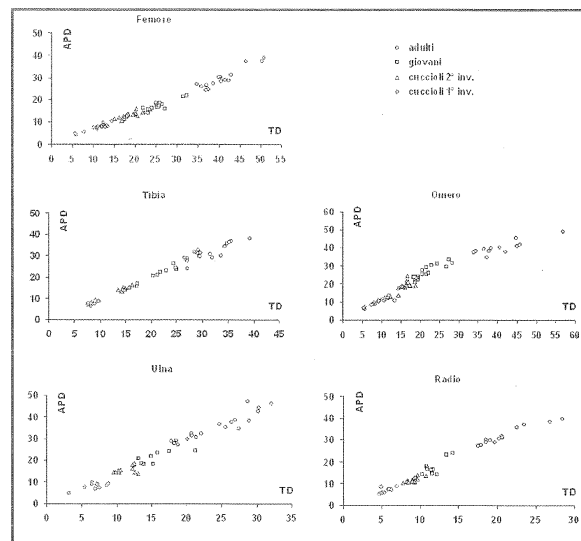
Figure 8 - Dispersal diagrams explaining the distribution of the individuals in the four considered age classes (1ST winter cubes, 2ND winter cubes, youngs, adults) with long bones (femur, tibia, humerus, ulna and radius). The antero-posterior diameter of diaphysis is collocated on ordinate axis, the transversal diameter on abscissa axis.

Classes of age

During the excavation we have recognized bears belonging to different stadiums of development. We have tried to divide the bony elements in groups corresponding to different phases of development (Bona, 2004), recognizable qualitatively for the followings osteological characteristics: dimensions, porosity and degree of calcification, welding of the epifisis with the diafisis. Four classes of age for our subdivision have been considered:

1. first winter pups: it coincides with the animal's birth; bones are very small, calcification is only sketched, degree of porosity is very elevated and epifisis are only sketched;

2. second winter pups: the aspect of bones is similar to that of the preceding class but their dimensions are bigger, they introduce a bigger degree of calcification and porosity, epifisis are not settled;

3. youngs: bones can reach the dimensions of the adults but the epifisis are still not completely fused to the diafisis;

4. adults: bones have the epifisis completely settled to the diafisis.

The most of the long bones recovered during the excavation are fragmentary, mainly missing some epifisis. This is above all due to the fact that the most of them belongs to pups and young cave bears, in which the epifisis are not settled to the diafisis yet. As consequence, only the transversal diameter and the antero-back diameter of the diafisis of the most of our finds have been measured. Just using these two parameters we were able to build some graphs (one for every type of considered bone) which show the distribution of the individuals of the Grotta inferiore in the four classes previously described (Fig. 8).

At this point we have calculated the percentages of the individuals belonging to the various classes of age identified in the whole excavation. According to the femurs and the humeruses, the most abundant bones in the excavation, we have reached the followings data: 30,3% pups first winter; 27,7% second winter pups; 22,9% youngs; 19,1% adults. As we can see, the major part of the bears is constituted by pups which have not overcome the first winter of life (from been just born up to few months of age) and so they have never gone out to the outside of the cave, and by pups which have died during the second winter passed in cave (from few

less to few more than one year). Good is also the percentage of the young individuals while scarcer is that of the adults. So, if we consider overall the pups, we can notice a rate of bigger mortality among these in comparison to the youngs and much more in comparison to the adults: in fact, we note as the general percentage of the pups is higher in comparison to those of the youngs and adults, reaching 58%.

In general, however, the percentages point out a mortality distributed in almost similar proportions between the four classes of age in which it was decided to divide the studied individuals.

It is done, besides, an attempt to see if mortality had suffered some variation among the surfaces of the Z2, considering that the bones, due to their horizontal position, had not been remixed during the time, but that they belonged indeed to those surfaces. In effects, a certain diminution of the mortality of the adult individuals and an increase of the pups was noticed passing from the surface 5 to the 1. It is difficult, however, to explain if this increase of the childish mortality was caused by some climatic changes or something else.
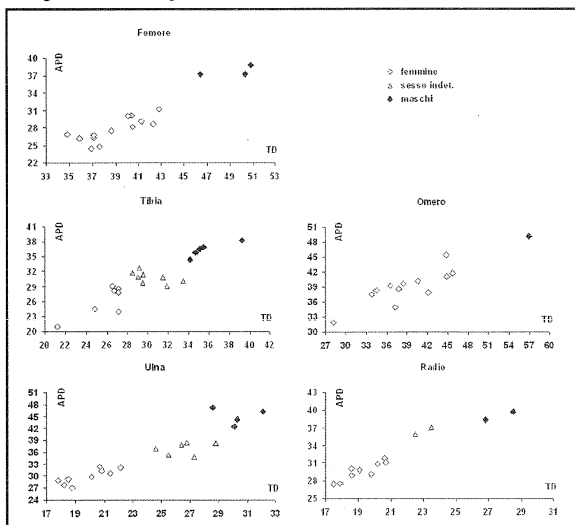
Figure 9 - Dispersal diagrams explaining the sexual dimorphism with long bones (femur, tibia, humerus, ulna and radius). The antero-posterior diameter of diaphysis is collocated on ordinate axis, the transversal diameter on abscissa axis.

Sexual dimorfism

The sexual dimorfism in the cave bear is evident especially in some parts of the skeleton as the skull, the long bones and, concerns to teeth, the canine tooth. The males are bigger than the females of the same age.

Still considering the long bones, already used for the division of the individuals in classes of age, it has been possible to get important information on the quantity of males and females, that have frequented the cave. Obviously this quantity is related to the levels investigated till now. The graphs of dispersion built before on the base of the transversal and antero-back diameters of the long bones have also been used again in the study of the dimorfism. In such context, however, they have been considered only the adult individuals (Fig. 9).

If we observe the diagrams, we can almost always notice a division of the finds into two principal groups: a group down to the left constituted by a series of values distributed in a more homogeneous way, probably attributable to females, and a group up to the right formed by few finds of bigger dimensions, and separated by the precedents, attributable to males. This separation can be seen well in the graph of the femurs and the humeruses, while it is less clear in the other graphs where few other finds, hardly attributable to a sex, put in the middle of the two groups mentioned,

can be counted. Even, in the diagram of the tibias and the ulnas it is very difficult to distinguish the female group from the masculine one, because of the homogeneous distribution of the values. From the data that we have available till now, however, we can affirm as the general number of female individuals is higher than the masculine one. Calculating the percentages of the males and the females according to the femurs (since they seem to be the clearest example) we can get the following data: 81,3% females and 18,7% males.

Conclusive considerations and future perspectives

The stratigraphical excavations effected in 2001, 2002, 2003 and 2004 showed the potentialities from the paleontological point of view of the Covoli di Velo, a karst system that in past, before the razzies made by unauthorized burrowers, had to contain, a big quantity of finds, as testified in the writings of many authors.

The four paleontological excavations have interested two sectors of the terminal room of the cave: the sector A, next to the west side of the room and the sector B, along the east side. Through the granulometric analysis, the stratigraphy of the two areas of excavation was established, distinguishing the levels 0, 1, 1b and 2, for the sector A and the levels Z1 and Z2, for the sector B.

The determination of around 1500 skeletal rests has not shown a big variety of the material recovered by the excavations: a morphological and morfometric analysis of the finds, in fact, has permitted to establish that almost of of all them belongs to the kind U. spelaeus.

The fauna of macro-mammals that has been recognized in the Grotta inferiore of the Covoli di Velo is composed, besides the cave bear, also from Canis iupus, Capra ibex and Crocuta crocuta spelaea. These kinds unfortunately are represented by few skeletal elements.

If the carnivores are excluded, that are generally little indicative from the point of view paleoenvironmental, the presence of the ibex, instead, could be enough meaningful, pointing out some particular paleoenviromental conditions, with a cold and arid climate in the open zones. Particularly, one sprout of interesting reflection is furnished by the recovery of this animal (liv. 0, 1b, Z2 sup.1, Z2 sup.3) to an altitude of 880 ms s.l.m. This results to be very low, knowing that this kind today lives in rocky zones above the limit of the wood, to an altitude between the 1.600 and the 3.000 ms s.l.m., hardly recognizables with the actual environmental conditions of the Covoli di Velo, surrounded by the forest. However, the expressed considerations about the presence of the ibex refer exclusively to the rests found to the roof of the Z2, since the levels 0 and 1b of the sector A, from first observations on the field, they would seem to be, at least partly, rehandled and so not entirely reliable.

It was previously mentioned to the analyses of the micro-mammals, that we know they're very useful to furnish us information for possible paleoenvironmental and paleoclimatic reconstructions. Just for this reason in the last excavation for every square and level of the Z2 we picked samples of ground that will be analyzed soon to esteeming if there are micro-mammals, already found in the level Z1 with similar analysis on picked samples of earth in 2003. If these analyses had to have positive result, that is, if it had to be confirm the recovery of micro-mammals in good quantity in the investigated levels, after an accurate determination of the present kinds and the percentages related to such kinds in the sector B, we could get perhaps interesting news on the cave.

Another interesting initiative that we have decided to undertake is to develop some pollen analyses: three samples of ground have been picked in the sector B to three different depths to sound the presence of pollens in the levels of the area of excavation and eventually to clarify of what type of pollens are. In fact, the granules of pollen, remaining stuck to the fur, were transported in cave by the bears and, when they had died, these pollens could keep in the muddy sediments of the karst hollow. The vari-

ous types of pollen granules could reveal us something on the vegetation and on the paleoenvironment of the Covoli, besides giving us some news on the diet of the cave bears. Besides the samples of sediment we have preserved bony fragments to make radiometric datings with the method of the radio-carbon, so that to get more precise information on the age of the animals that have populated the cave and, therefore, to date the levels of the two areas of excavation. Not being available radiometric datings that can give us a precise age of the stratigraphical levels investigated till now, currently, the only certainty that we have is that the constant presence in the fauna of the Grotta inferiore of the U. spelaeus lets report our levels to a last glacial period. In fact, this kind reached its maximum development and diffusion during the last big Würm glaciation, probably extinguishing itself approximately around the 20.000 years ago. An important consideration has to be done on the sector B: during the operations of excavation long the east side, more precisely in the squares M3 and N3, we noticed that the wall, to level of the surfaces 4-5 of the Z2, curtains to form a niche. Particularly, in the square N3 an enough deep niche, that seems to become still deeper in the wall, has been dug,. Just in this niche the three skulls exhumed in the last paleontological excavation together to other bones of notable dimensions have been found (Fig. 10). This makes us hope to be able to recover many other finds of a certain consistence and paleontological importance in that point.

Waiting for the results of the analyses in progress (on the micro-mammals, on the pollens and on the age of the levels and the finds), between the purposes of the next paleontological excavation in the Grotta inferiore, that will be effected in 2005, there is that to widen the sector B and to dig inside the niche found in the squares M3 and N3; besides this, there is the wish, already expressed the preceding years to connect the two areas of excavation A and B with the purpose to find some stratigraphical correlations.

Figure 10 - Particolar of sector B explaining the shell excavated in surfaces 4-5 (photo F. Bona).

Bibliography

ACCORDINI M. (2003-2004) - Studi stratigrafici e faunistici del deposito pleistocenico della Grotta inferiore dei Covoli di Velo. Tesi di laurea. Università degli Studi di Padova.

BENETTI A. (1973) - La distruzione dei depositi quaternari dei "Covoli di Velo" nei Monti Lessini Veronesi. Natura Alpina, 24 (1): 27-37.

BENETTI A. & CRISTOFERI W. (1968) - La grotta del "Monte Gaole" e i " Covoli di Velo" nei Lessini Veronesi. Studi Trentini di Scienze Naturali, B, 45: 270-283.

BENETTI A. & SAURO F. (1999) - Storia delle ricerche sul complesso carsico dei Covoli di Velo. Atti della Tavola Rotonda "Un importante sistema carsico dei Monti Lessini: i Covoli di Velo". Verona-Camposilvano, 16-17 aprile 1999: 5-12.

BONA F. (2004) - Preliminary analysis on Ursus spelaeus Rosenmüller and Heinroth 1794 populations from "Caverna Generosa" (Lombardy - Italy). "Cahiers scientifiques". Centre de Conservation et d'Etude des collections (Museum de Lyon).

HUE E. (1907) - Osteometrie des Mammiferes. C. Reinwald, Paris, 50 pp. e 186 tavv.

KRANTZ G.S. (1968) - A new method of counting mammal bones. American Journal Archeology 72: 285-288.

KURTEN B. (1968) - Pleistocene mammals of Europe. Weindfeld and Nicolson, London, 317 pp.

KURTEN B. (1972) - L'orso delle caverne. Le Scienze, 46: 73-80.

KURTEN B. (1976) - The cave bear story: Life and Death of a Vanished Animal. Columbia University Press, New York, 163 pp.

MASSALONGO O. (1851) - Osteologia degli Orsi fossili nel Veronese, con un saggio sopra le principali caverne del Distretto di Tregnago. Naturwissenschaftliche Abhandlungen, 4: 31-86.

OMBONI G. (1875) - Di alcuni oggetti preistorici delle caverne di Velo Veronese. Atti della Società Italiana di Scienze Naturali, 18: 69-82.

PEREGO R. (1993) - Ursus spelaeus Osteometrie. Presentation des mesures considerees dans l'etude des restes de la Grotte Fontana marella (Campo dei Fiori, Varese, Italy). Borse de Perfectionnement au Musee d'Histoire Naturelle et a l'Universitè Claude Bernard - Lyon I. Lyon.

SCHMID E. (1972) - Atlas of animal bones. Elsevier Publishing Company, Amsterdam, 159 pp.

TORRES PEREZ H. (1988) - Osos (Mammalia, carnivore, Ursidae) del Pleistocene ibericos (U. deningeri Von Reichenau, U. spelaeus Rosenmüller-Heinroth, U. arctos Linneo). I Filogenia; Distribucion estratigrafica y geografica. Estudio anatomico y metrico del craneo. Boletin Geologico y minero, 909: 3-46. II Estudio anatomico y metrico de la mandibula, hioides atlas y axis. Boletin Geologico y minero, 909: 220-249. III Estudio anatomico y metrico del miembro toracico, carpo y metacarpo. Boletin Geologico y minero, 909: 356-412. IV Estudio anatomico y metrico del miembro pelvico, tarso metatarsa y dedos. Boletin Geologico y minero, 909: 516-577. V Denticion decidual, formula dentaria y denticion superior. Boletin Geologico y minero, 909: 660-714. VI Denticion inferior. Boletin Geologico y minero, 909: 886-940.

VON DEN DRIESCH A. (1976) - A guide to the misurement of animal bones from archaeological sites. Peabody Museum Bulletin, 1, Harvard University Press, Cambridge, 136 pp.

ZORZIN R. & BONA F. (2002) - Covoli di Velo (VR). Prima campagna paleontologica: risultati preliminari. Bollettino del Museo Civico di Storia Naturale di Verona, Geologia Paleontologia Preistoria, 26: 43-46.

ZORZIN R., BONA F. & ACCORDINI M. - L'orso delle caverne dei Covoli di Velo. Primi studi sulla popolazione di Ursus spelaeus della Grotta inferiore (VR - Italy). Bollettino del Museo Civico di Storia Naturale di Verona, Geologia Paleontologia Preistoria. In stampa.

ZORZIN R. & ROSSI G. (1999) - Il sistema carsico dei Covoli di Velo. Atti della Tavola Rotonda "Un importante sistema carsico dei Monti Lessini: i Covoli di Velo". Verona-Camposilvano, 16-17 aprile 1999: 13-22.

The authors' address

Roberto ZORZIN - Civic Museum of Natural History in Verona, Section of Geology and Paleontology, Lungadige Porta Victoria, 9 - 37129 Verona (Italy).

Fabio BONA - Department of Sciences of the Earth, University of the Studies in Milan, 34, Mangiagalli street -20133 Milan (Italy).

Massimo ACCORDINI - Civic Museum of Natural History in Verona, Section of Geology and Paleontology, Lungadige Porta Victoria, 9 - 37129 Verona (Italy).

97

O-24

Milk teeth of Quaternary carnivores
from Northern Greek Caves

Preliminary Report by Spyridoula PAPPA[1], Evangelia TSOUKALA[1], Georgios LAZARIDIS[1] & Gernot RABEDER[2]

1. School of Geology, Aristotle University, 54124 Thessaloniki, Macedonia, Greece

2. Institute of Paleontology, University of Vienna, Althanstrasse 14, A-1090, Vienna, Austria

Abstract

From extensional studies on Quaternary faunas it is concluded that certain caves were habited by animals (carnivores). The habitation is established by the presence of milk teeth and bones with infused epiphyses, the food remains and the coprolites. The most important site of Greece with abundant material of fossilized milk teeth, in spite of their fragility, is the Late Pleistocene Loutra Arideas (Pella, Macedonia) Bear-cave. Thousands of isolated deciduous teeth - very few in situ- have been collected from the systematic excavations that were carried out in the cave. In Middle Pleistocene Petralona cave, even though there is abundant ursid material, the presence of milk teeth is rather rare. On the other hand, there are hyaenid mandibles with milk teeth belonging to the Middle Pleistocene Crocuta spelaea intermedia and Pliohyaena perrieri as well. These milk teeth are compared with those of the Late Pleistocene Crocuta crocuta spelaea from Agios Georgios cave (a typical hyaenid den in Kilkis, Macedonia). The evolutionary stage of these animals is preliminarily under discussion.

Introduction

Three caves of Macedonia (N. Greece) with milk teeth are referred in the present study: The Petralona cave (PEC), 45Km SE, the Agios Georgios-Kilkis (SGK), 45Km NNW and the Loutra Arideas Bear-Cave (LAC), 120 Km NW of Thessaloniki (Fig. 1). The Petralona material of juveniles comes from the "old excavation" and surface collections by professors of the Thessaloniki University, which was found in association with the famous homi-

nid skull. The milk teeth are very few in contrast to the rest findings that are thousands of well preserved specimens, representing 22 different species of Middle Pleistocene large mammals (TSOUKALA, 1989/1991). The Agios Georgios-Kilkis cave is the unique up to now, exclusively hyaenid den of Greece of Latest Pleistocene, as the most specialized scavenger, the real cave hyaena, lived in. The presence of the milk teeth, the coprolites and the food remains establish the habitation. The juveniles are represented either by milk teeth or by post cranial skeleton (TSOUKALA, 1992a,b). The investigation in the Loutra Arideas area started in 1990 and the first excavation circle in the Bear Cave started in 1992. The sieving process and the systematic collection of the milk teeth started in 1993 up to now. Ten systematic excavation circles, under strictly archaeological rules, including micromammalian research took place. All the sediments of the 189 levels (about 5 cm of thickness each) have been washed into a system of double sieves, one for micromammals CHATZOPOULOU, (this volume) with a mesh of 0.8 mm and the other of 3 mm for large mammalian remains, both with milk teeth. Then the material was dried out, conserved and recorded for further study. Additionally few bigger specimens were numbered and collected in place with their coordinates during the excavation (TSOUKALA 1994, 1996, TSOUKALA et al. 1998, 2001, PAPPA, 2004). All the material above is stored in the Paleontological Museum of Aristotle University of Thessaloniki.

Paleontology

a) Petralona Cave, Middle Pleistocene

Taxonomy

Order: CARNIVORA BOWDISH, 1821

Sub-order: Canoidea SIMPSON, 1931/ Arctoidea FLOWER, 1969

Family: Ursidae GRAY, 1825

Genus: Ursus LINNAEUS, 1758

U. deningeri v. REICHENAU, 1906

Material: dC PEC 1028, dI^3 PEC 1040 dex, D^4 PEC 1020 dex

Description: The milk canine is little worn and the root is broken, the third upper milk incisor is slightly worn and most of the root is preserved. The upper milk carnassial is well preserved (D^4, fig. 2a) as only little part
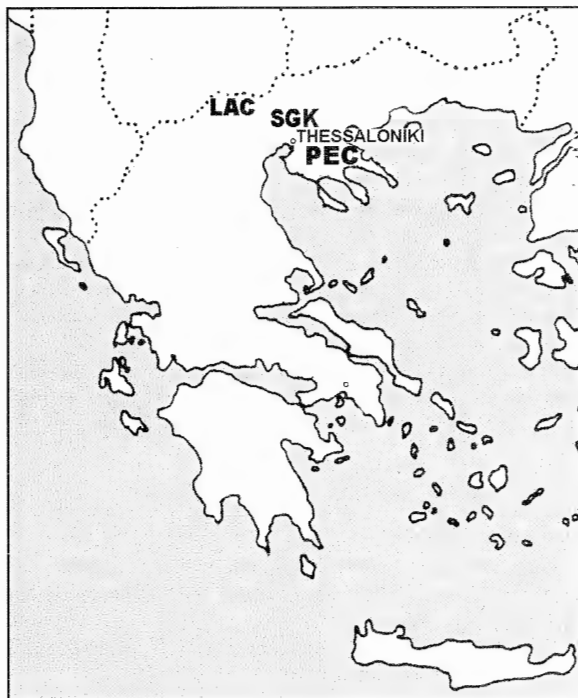
Figure 1. Map of Greece with the three localities (PEC: Petralona Cave, SGK: Agios Georgios-Kilkis Cave, LAC: Loutra Arideas Cave) depicted.
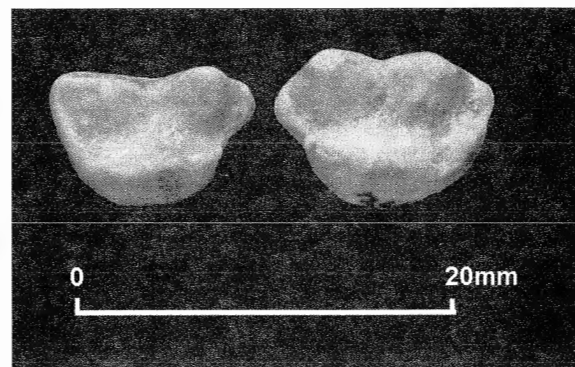
Figure 2. D^4 occlusal view: a) Left, Petralona cave, U. deningeri PEC 1020 dex and b) Right, Loutra Arideas Bear cave, U. ingressus LAC 12557 sin.

98

of the roots is missing. The external cones are pointed and straight on their labial side, the paracone is well developed and the metacone bears longitudinal palatinal crest. There is a small parastyle, while there is trace of a cingulum like metastyle. The morphotype seems to be a simple one.

Sub-order Feloidea SIMPSON, 1931

Family: Hyaenidae GRAY, 1869

1) Genus: Crocuta KAUP, 1828

Crocuta spelaea intermedia M. de SERRES, 1828

Material: Mandible fragment with D_3 - D_4 PEC 15 dex.

Description: Of the brachygnath mandible most part is preserved with the D_3 and D_4 both slightly worn (fig. 4.1). Of the D_3 the protoconid is intense, and there are an anterior and two posterior small accessory cuspids. Of the milk carnassial, the paraconid and protoconid are pointed, the metaconid is absent and the large talonid is bicuspid as the hypoconid is reduced, but well developed the entoconid and hypoconulid. The M_1 is unerupted.

2) Genus: Pliohyaena KRETZOI, 1938

Pliohyaena perrieri CROIZET & JOBERT, 1828

Material: Cranium with dC^s sin, D^2 - D^4 sin+dex, P^4 dex, M^1 sin PEC 28, 2 mandible fragments with D_2 - D_4, M_1 PEC 14 dex and 13 sin, D_3 PEC 35 sin, D_4 PEC 44 sin.

Description: The skull is almost well preserved and it bears almost all the slightly worn milk teeth and the unerupted left carnassial and the right M^1 as well. The I^2 dex and the C^s sin are under eruption (fig. 3). The milk canine is slender, with an intense posterior and an anteropalatinal crests with a well developed cingulum on the base of the latter. There are only the alveoli of the single root D^1. The D^2 is elongated and its longitudinal axis is directed palatinal. There are a small anterior and a well distinguished posterior accessory cuspid and an intense palatinal cingulum. The D^3 is the largest tooth with well separated parastyle, long metastyle and a very low protocone in the middle. On the basis of the amphicone there is an intense triangular cuspid. The molar like D^4 is small, triangular, transversally developed.

Of the hypsognath mandible, most part is preserved with the slightly worn D_2, D_3 and D_4 (fig. 4.2,3). Of the long D_3 the protoconid is intense and posterior inclined, and there are anterior and posterior accessory cuspids. Of the milk carnassial D_4 that is clearly distinguished the paraconid and protoconid are less pointed, the metaconid is present and the large talonid is tricuspid as the hypoconid, hypoconulid and entoconid are well developed, with the latter one being the most strong. The M_1 is unerupted, with the metaconid well distinguished. It must be noted that in all milk teeth there is an intense labial cingulum. Only two isolated well preserved teeth have been found (fig. 5.5,6). The dimensions of the specimens are given in tab. 1.

Table 1. Pliohyaena perrieri - Crocuta spelaea intermedia PEC
Measurements of milk teeth (in mm)

Pliohyaena perrieri									
Cranium	PEC 28		PEC 35						
LdC^s	8.12	LD_3	16.99						
BdC^s	5.90	BD_3	7.35						
LD^1alv.	6.50	PEC 44							
BD^1alv.	6.40	LD_4	19.89						
LD^2	16.00	BD_4	8.82						
BD^2	7.54	LD_4tr^d	15.15						
LD^3	25.50	LD_4ta^d	4.61						
BD^3	14.00	HD_4crown	10.82						
LD^4	9.60	Md PEC14, PEC13	n	x^-	min	max	s	v	
BD^4	15.64	LD_2-D_4	2	50.00	49.50	50.50	-		
LM^1	7.40	LD_2	2	13.65	13.60	13.70	-		
BM^1	14.17	BD_2	2	6.25	6.20	6.30	-		
Ldiastema	2.87	LD_3	3	17.20	16.90	17.60	0.35	2.03	
LD^1alv.-D^4	52.00	BD_3	3	7.56	7.50	7.70	0.11	1.46	
LdC^sant.-M^1post.	85.00	LD_4	3	20.50	19.90	21.00	0.56	2.73	
LdC-D^4	67.49	BD_4	3	8.47	8.40	8.60	0.12	1.43	
LD^2-D^4	42.76	Crocuta spelaea intermedia							
LD^2	16.00		PEC15						
BD^2	7.83	LD_2-D_4	43.00						
LD^3	25.70	LD_2	al.9.60						
BD^3	15.53	BD_2	al.5.20						
LD^4	9.68	LD_3	12.90						

99
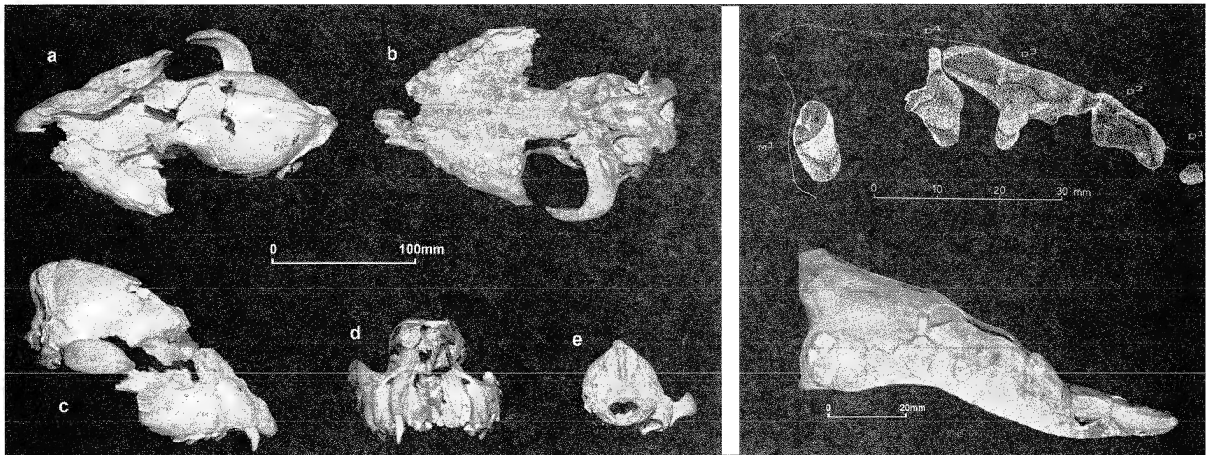
Figure 3. Pliohyaena perrieri, Cranium with dC, D² - D⁴, M¹ PEC 28, Left: a) dorsal, b) basal, c) right lateral, d) anterior and e) posterior (occipital region) view. Right: Detail of the right tooth-row, occlusal view.
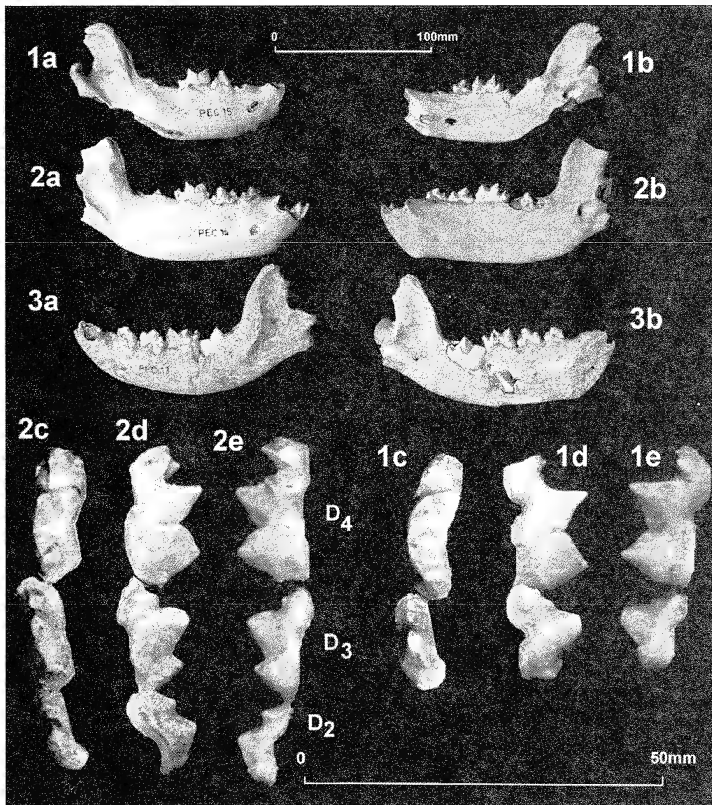
Figure 4. Crocuta spelaea intermedia: 1) mandible fragment with D₃ - D₄ PEC 15 dex, Pliohyaena perrieri, 2) mandible fragment with D₂ - D₄, M₁ PEC 14 dex and 3) mandible fragments with PEC 13 sin. a,d) labial, b,e) lingual, c) occlusal view
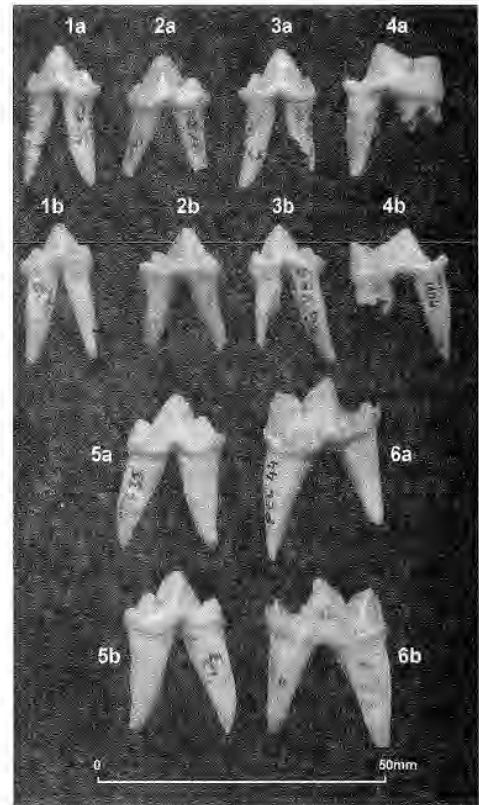
Figure 5. Crocuta crocuta spelaea: D₃ 1) SGK 97 dex, 2) SGK 1067 sin, 3) SGK 96 dex, 4) D₄ SGK 1104 dex. Pliohyaena perrieri: 5) D₃ PEC 35 sin, 6) D₄ PEC 44 sin a) labial, b) lingual view.

b) Agios Georgios (Kilkis) cave

3) Crocuta crocuta spelaea (GOLDFUSS, 1832)

Material: Mandible fragment with D₄ SGK 90 sin, 3 D₃ SGK 96, 97 dex, 1067 sin, D₄ SGK 1104 dex, 2 D₄ fragm. SGK 689, 690 dex.

Description: Of the mandible only the posterior part with condylus, the processus coronoideus as well as the lower slightly worn milk carnassial are preserved (fig. 6). There are also isolated teeth, D₃ and D₄, very well preserved (fig. 5.1-4). Of the D₃ the protoconid is intense, and there are anterior and posterior accessory cuspids. Of the milk carnassial, the paraconid and protoconid are less pointed, the metaconid is absent and on the large talonid not well distinguished cuspids were observed. The dimensions of the specimens are given in tab. 2. Further more, post cranial bones with infused epiphyses were found.
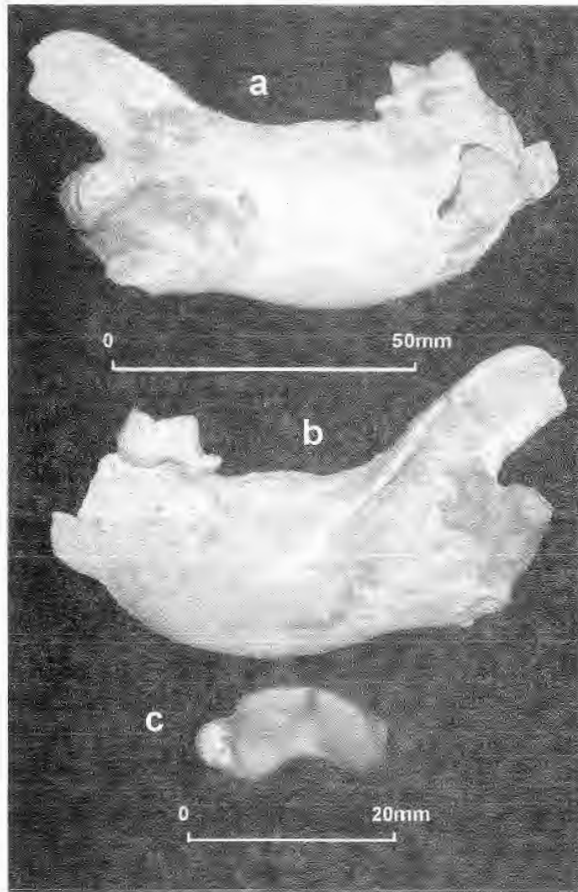
Figure 6. Crocuta crocuta spelaea: SGK 90. a) lingual, b) labial, c) D₄ occlusal view

Table 2. Crocuta crocuta spelaea SGK:
measurements of milk teeth (in mm)

LdC	SGK 906 6.47		
BdC	4.79		
LD₃	SGK 96 13.95	SGK 97 13.30	SGK1067 14.66
BD₃	6.57	6.58	7.09
LD₄	SGK 1104 18.10	SGK 689 -	SGK 690 -
BD₄	7.92	7.04	6.72
Md	SGK 90		
LD₄	17.62		
BD₄	8.11		
H md D₄ post.	28.78		
H md proc.coron.	44.19		
H md cond	12.16		
Abbreviations: see tab.1 and H=height, proc.coron.=processus coronoideus, cond.=condylus			

c) Loutra Arideas Bear cave

Ursus ingressus RABEDER, 2004

Material: Mandible fragment with dC₁, D₄, M₁ unerupted LAC 1389 dex, 12 dI¹, 105 dI², 695 dI³, 6 D², 26 D³, 240 D⁴, 52 dI₁, 29 dI₂, 180 dI₃, 7 D₂, 62 D₃, 285 D₄, 1600 dC,

Description: In spite of the abundance of the milk teeth, among of which 3.259 are studied and measured (tab. 3) the mandibles are extremely rare, as only one is almost well preserved. The dC is slightly worn, as well as the lower milk carnassial; on the other hand the M₁ is germ and unerupted (fig. 7). The mandible with I₃, C, M₁, M₂ and M₃ unerupted LAC 4114 belongs to a sixteen months bear (after Dittrich in ANDREWS & TURNER, 1992) (fig. 8). The dI¹ is a small and slender tooth. There is a palatinal well developed cingulum and the root is elongated, slightly curved and conical. The dI² is much stronger than the first one, and also bears a well developed palatinal cingulum. The crown is curved and the root is conical and anterior flattened. The dI³ is the largest upper milk incisor that is similar with the milk canine, except the more convex crown and the intense palatinal cingulum. This tooth seems to be the most abundant among the LAC material. The D² is the smallest of the cheek milk teeth, the less differentiated. The root is small and conical. The D³ is more differentiated with developed talon and two roots. The upper milk carnassial D⁴ is the most important tooth because it contributes to the study of the evolutionary stage according to its morphotype (RABEDER, 1983, 1991, 1999). It is molar like and has one palatinal and two labial roots. The occlusal shape is rounded and sometimes there is a palatinal cuspid-like cingulum (fig.9).

The dI₁ is very small tooth, with small crown and cylindrical root, the end of which is slightly convex. The dI₂ is much stronger than the first one, with triangular crown and elongated root. The dI₃ is the largest lower milk incisor with triangular crown and well developed root. There are two lingual accessory cuspids, jointed with a small cingulum.

The D₂ is the smallest of the cheek milk teeth and the less differentiated. It grows inclined, with no root. The D₃ are of elongated crown and have two roots that are well separated or fused in some specimens RADULESCU & SAMSON (1959). The lower carnassials D₄ are much more various than that of the maxillar one, with crown bearing at least 5 cusps and two roots (fig.9).

The milk canines are large and abundant, but difficult to be distinguished in maxillars and mandibulars, thus both are described as long and flattened teeth (fig. 10).

Figure 9. Ursus ingressus LAC: Representative material of the milk carnassials showing the variability of the morphotype.

Left: Two upper the D⁴ and two lower rows the D₄. Right: First upper and second row lower milk teeth

Figure 10. Ursus ingressus LAC. Deciduous canines.

Figure 11. Ursus ingressus LAC. Various categories of deciduous canines (KURTEN 1976). a) Germs, b) Full teeth with root showing resumptions marks, c) Full teeth, d) Shed canines.
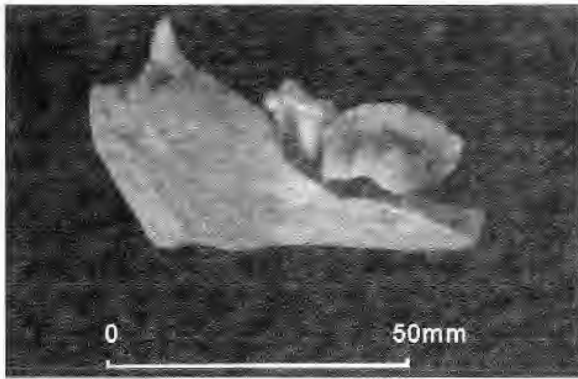
Figure 7. *Ursus ingressus LAC. Mandible fragment with dC, D₄, M₁ unerupted LAC 1389 dex*

Figure 8. *Ursus ingressus LAC Mandible with I₃, C, M₁, M₂ and M₃ unerupted LAC 4114.*
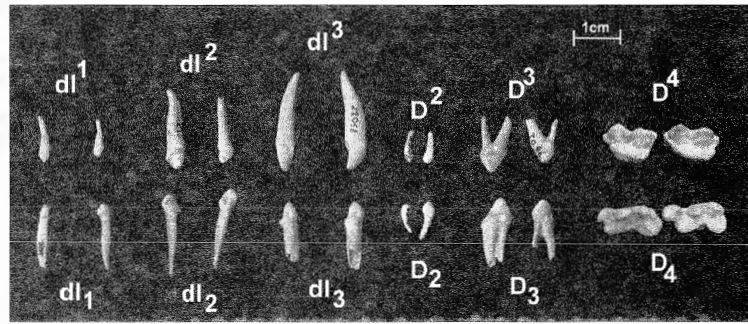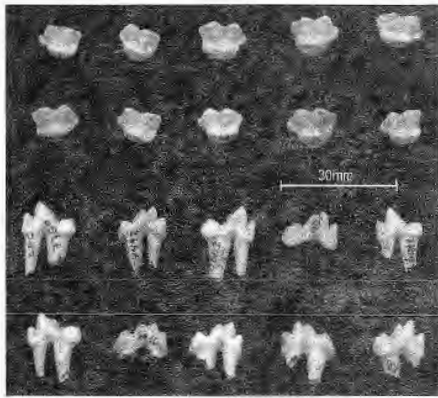
Figure 9. *Ursus ingressus LAC: Representative material of the milk carnassials showing the variability of the morphotype. Left: Two upper the D⁴ and two lower rows the D₄ Right: First upper and second row lower milk teeth*

Table 3. Ursus ingressus LAC: Measurements of the milk teeth (in mm)

	n	min - max	x	s_{n-1}	v
LdI^1	12	1.77-2.95	2.44	0.32	13.15
BdI^1	12	1.57-2.68	2.21	0.35	15.58
LdI^2	103	3.02-4.63	3.85	0.32	9.46
BdI^2	103	2.72-4.97	3.35	0.32	8.24
LdI^3	671	4.03-6.62	5.23	0.38	7.30
BdI^3	671	4.01-6.77	5.05	0.42	8.31
LdC	1507	5.08-9.58	7.31	0.60	8.23
BdC	1507	3.96-7.25	5.52	0.45	8.23
LD^2	6	2.10-2.76	2.40	0.25	10.60
BD^2	6	1.99-2.65	2.25	0.26	11.75
LD^3	26	3.97-7.30	6.21	0.62	9.96
BD^3	26	3.07-4.17	3.72	0.26	7.04
LD^4	124	9.20-12.85	11.13	0.74	6.69
BD^4	124	6.42-11.60	7.56	0.64	8.43
LdI_1	52	1.45-2.73	2.17	0.29	13.54
BdI_1	52	1.21-2.09	1.73	0.21	11.87
LdI_2	27	3.50-4.76	4.02	0.29	7.25
BdI_2	27	2.42-3.83	2.94	0.36	12.32
LdI_3	173	4.10-6.32	5.21	0.47	9.12
BdI_3	173	3.02-5.33	4.05	0.37	9.23
LD_2	6	2.12-2.82	2.43	0.29	11.80
BD_2	6	2.12-2.57	2.29	0.18	7.97
LD_3	59	2.98-6.49	4.98	0.94	18.94
BD_3	59	2.38-4.02	3.29	0.38	11.69
LD_4	242	10.21-14.98	12.76	0.77	5.10
BD_4	242	5.03-9.70	6.31	0.58	9.17

Figure 10. Ursus ingressus LAC. deciduous canines.
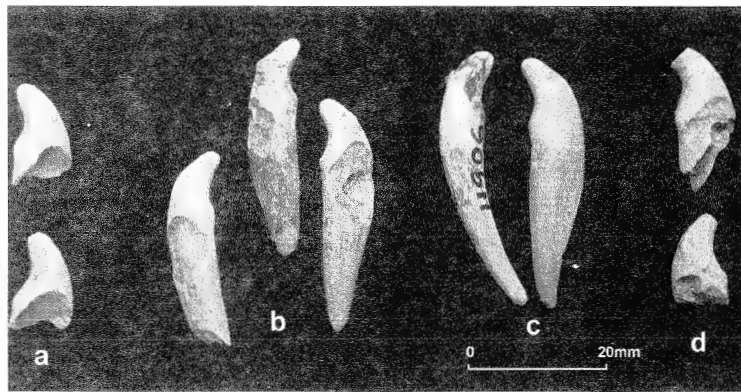
Figure 11. Ursus ingressus LAC. Various categories of deciduous canines (KURTEN 1976). a) Germs, b) Full teeth with root showing resumptions marks, c) Full teeth, d) shed canines.
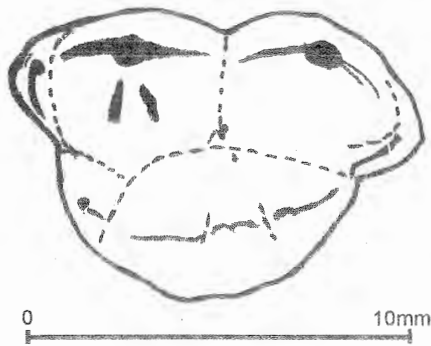
Figure 13. Ursus ingressus D⁴ LAC 12557 sin, occlusal with the morphotype
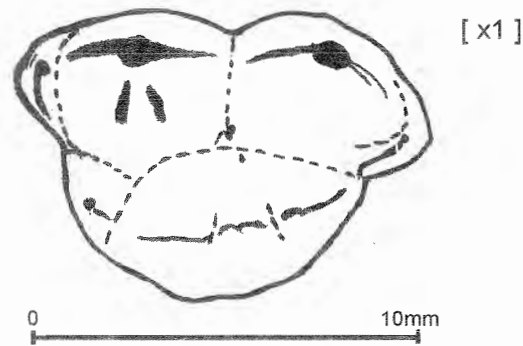
Figure 14. Ursus ingressus D₄LAC 12560 sin, occlusal, with the morphotype.

103

Nordmann was the first who studied the bear milk teeth in 1858, Schlosser in 1909, Kormos in1916, Pohle in1923, Ehrenberg in 1931, Friant & Stehlin in 1933, Mottl in 1934, 1939, Zapfe in 1946, KOBY (1952), ERDBRINK (1953), RADULESCU & SAMSON (1959), EHRENBERG (1964), KURTEN (1968), TERZEA (1969), TORRES (1988), AN-DREWS & TURNER (1992), DEBELJIAK, 1996, 1997 etc .

The study of the milk teeth and bones showed the presence even more of unborned bears. On the other hand, completely worn milk teeth were also observed, thus there was difficulty in chewing so the individuals could not survive a long winter, as this last glacial period of Würm. These animals died exhausted at the end of the winter, even though they could survive more (KURTEN 1968, 1976). The milk carnassials D⁴ and D₄ are the most important deciduous teeth as the study of the morphotype can give evidence for their evolutionary stage (RABEDER, 1983). The D⁴ LAC is molar like with one palatinal and two labial roots. The occlusal shape is rounded and sometimes there is a palatinal cuspid-like cingulum. The Paracone is well developed and the metacone bears longitudinal palatinal crest. There is small parastyle while there is a trace of cingulum like metastyle. Finally there is hypocone crest like. It is similar to the Gamssulzenhöhle (Austria) morphotype (fig. 13). The lower carnassials D₄ LAC are much more variable than those of the upper ones, with crown bearing at least 5 cuspids. Paraconid, metaconid and protoconid are well developed. There is a small hypoconid and endoconid. Apart from some differences D₄ is similar to the Gamssulzenhöhle as well (fig. 14).

Concerning the milk canines, the material can be attributed to categories (KURTEN, 1976) (tab. 4): (A) by few germs - milk canines consisting by an enamel cap and a root that has barely started to form (fig. 11a), (B)

by few complete teeth with unworn occlusal and fully formed roots (fig. 11c), (C) by complete teeth with root showing resumptions marks (fig. 11b). This is a preliminary stage to the tooth being shed and as the root is gradually dissolved by the osteoclast (KOBY 1952). There is a very large crop of shed milk canines (D) in which the root has dissolved completely (fig. 11d). The (E) category includes the heavy wear stage of deciduous. Finally the (F) includes worn deciduous canines with resorbed root.

Table 4. Ursus ingressus LAC: Wear stages of cave-bear deciduous canines

Wear stage (dC)	Description		Number of specimens LAC	Westbury ANDREWS & TURNER 1992	Odessa KURTEN 1976
A	Unerupted	Neonates	132	22	13
B	Erupted		500	10	26
C	Unworn		83	32	
D	Slightly wear	Yearl-ings	130	39	165
E	Heavy wear		600	80	
F	Worn with resorbed root		155	8	

Unerupted, when the crown is formed but the root is not; erupting, when some root development has taken place; unworn, when the root is fully formed but the crown has no wear; slight to moderate wear; heavy wear.

From the distinction of the dI³, D⁴ and D₄ in rights and lefts the MNI (minimum number of individuals) can be calculated to 355 individuals based on dI³ (the left ones) and 400 (not reliable, based on milk canines with the total 1600 rights and lefts plus uppers and lowers divided to 4)(tab. 5).

Table 5. Ursus ingressus LAC: Distinction of the dI³, D⁴ and D₄ in rights (dex) and lefts (sin) for calculation of the minimum number of individuals (MNI).

Category of Teeth	Number of lefts (sin)	Number of rights (dex)
dI³	355	340
D⁴	120	120
D₄	139	146

Discussion, Conclusions

- Three caves of northern Greece present the most important milk teeth material of Pleistocene: the Petralona cave (PEC) with hyaenids and bears, the Agios Georgios, Kilkis cave (SGK) with hyaenids and Loutra Arideas Bear-cave (LAC) with bears.
- The most important remarks are preliminarily shown in table 6, as the research is in progress.
- In Middle Pleistocene Petralona Cave, the material representing the hyaenids comprises well preserved skull with almost all the slightly worn milk teeth and the unerupted left carnassial and the right M¹ as well as mandibles with the milk cheek teeth that give evidence, parallel to adults, the two genera crocuta and hyaena to be distinguished. For example the presence (Pliohyaena) or not (Crocuta) of the metaconid in the lower carnassials M₁ follows the milk carnassials D₄ respectively. For the bears only the upper carnassial can be compared with that of LAC and the main remark is that the morphotype is more complicated in LAC specimens than that from PEC.

- The Agios Georgios-Kilkis cave is the unique, up to now, exclusively hyaenid den of Greece, as the most specialized scavenger - Crocuta crocuta spelaea- the real cave hyaena, lived in. The presence of the milk teeth, the coprolites and the food remains establish the habitation. In other caves with Quaternary faunas, the presence of the most common cave-bear is notable. A sample of hyaena tooth (upper carnassial) enamel was ESR dated giving an age in the range 12.2±2,5 Kyr BP. This indicates Greece as a refugee for the hyaenas, when they were largely excluded from northern and central Europe during last glacial. Further more, post cranial bones with infused epiphyses were found.
- The Late Pleistocene Loutra Arideas bear-cave is very rich in paleontological material of ursid milk teeth. Thus the site can be considered as the unique place of Greece where so abundant and well stratified deciduous teeth from 189 excavated layers (5cm of thickness each) have been collected.

The abundance of the milk teeth, in spite their fragility, is very remarkable.

The majority of the tooth and bone remains belong to juveniles and sub-adults, while very few belong to very old individuals and few to adults.

Among the material there are specimens such as skull and mandibles with deciduous teeth and postcranial bones, especially metapodials with the distal epiphysis infused. Therefore all ages from juvenile to senate individuals are represented. The majority of the tooth and bone remains belong to juveniles and sub-adults, while very few belong to very old individuals and few to adults, indicating thus an extremely high incidence of young and neonate mortality.

The study of the milk teeth proved the presence either of unborn bears.

There are many bear carcasses as a result of death during hibernation. All this evidence establishes the inhabitation. On the other hand, many milk teeth must have been brought into the cave with the sediments.

The morphotype of the milk carnassials from Loutraki is similar to those from Gamssulzenhöhle (Austria).

Table 6. Some morphological characters on milk teeth of Pleistocene carnivores from Greek caves for comparison

\	U. deningeri	Crocuta spelaea intermedia	Pliohyaena perrieri	Crocuta crocuta spelaea	Ursus ingressus
		Petralona Middle Pleistocene		Agios Georgios, Kilkis Latest Pleistocene	Loutra Arideas Bear-cave Late Pleistocene
Mandible		brachygnath	hypsognath		
D⁴ occlusal	More squarish				More rounded
paracone-metacone	More pointed and diverged				Lesser pointed and lesser diverged
Morphotype	Lesser complicated				More complicated
D₃ protoconid		Lesser intense More erect	More intense Inclined posterior	Lesser intense More erect	
Accessory cuspid		Anterior and two posteriors, all small	Anterior and posterior, clearly more developed	Anterior and two posterior small clearly lesser developed	
D₄ paraconid and protoconid		Pointed Open angle	Pointed ·Lesser open angle	Lesser pointed More open angle	
metaconid		absent	present	absent	
talonid		Bicuspid: hypoconid reduced, but entoconid & hypoconulid well developed	Tricuspid All well developed	Not developed	
cingulum			labial intense in all milk teeth		
Morphotype	Lesser complicated				More complicated

References

ANDREWS, P. & TURNER, A., 1992. Life and death of the Westbury bears. - Ann. Zool. Fennici, 28: 139-149, Helsinki.

CHATZOPOULOU (this volume). The small mammal fauna from the Loutra Arideas Bear-Cave (Pella, Macedonia, Greece) with emphasis on the third chamber.

DEBELJIAK, I., 1996. Ontogenetic development of dentition in the cave bear. - Geologija, 39: 13-77, Ljubljana.

DEBELJIAK, I., 1997. Age composition of the cave bear population from the Divje babe I Cave. - Int. Meeting on Man and Bear, Auberives - Pont en Royans (Vercors - Isère).

EHRENBERG, K. 1964. Ein Jungenbärenskelett und andere Höhlenbärenreste aus der Bärenhöhle im Hartlesgraben bei Hiflau (Steiermark).- Ann. Naturhistor. Mus. Wien, 67: 189-252.

ERDBRING, D. P., 1953. A review of fossil and recent bears of the old world. 1-2. Jan de Lang, Deventer

KOBY, F.-Ed., 1952. La dentition lacteale d' Ursus spelaeus. - Rev. Suisse Zool., Geneve. 59(27): 511-541.

KURTÉN, B., 1968. Pleistocene Mammals of Europe. Aldine Publishing Company, Chicago: 1 - 317.

KURTEN, B., 1976. The cave bear story. Life and death of a vanished animal.- Columbia University Press, 1-163, New York.

PAPPA, S., 2004. Study on the milk teeth of the cave bear from the excavational research in Loutra Arideas Cave.- Diplomatic work with unpublished data submitted to the School of Geology, Aristotle University, 1-81, Thessaloniki

RABEDER, G., 1983. Neues vom Höhlenbären. Zur Morphogenetik der Backenzähne. Die Höhle, H. 2(34): 67-85, Wien.

RABEDER, G., 1991. Die höhlenbären der Counturines.- Verlagsanstalt Athesia, 1-124, Bozen.

RABEDER, G., 1999. Die Evolution des Höhlenbärengebisses.- Mitt. Kom. Quartärforch. Östrerreich. Akad. Wiss. 11: 1-102, Wien.

RADULESCU, C. & SAMSON, P., 1959. Contribution a la connaissance de la dentition lacteale d'Ursus spelaeus. Eiszetalter und Gegenwart, 10: 205-216, Ohringen.

TERZEA, E., 1969. Nouvelles données sur la dentition lacteale de l'Ursus spelaeus.-Act. IV. Congr. Int. Speleaol. 4-5: 383-389.

TORRES PEREZ-HIDALGO, T.J., 1988. Osos (Mammalia, Carnivora, Ursidae) del Pleistoceno de la Peninsula Iberica. Boletin Geologico y Minero, Madrid (publ. espec.), 1-4: 1-316.

TSOUKALA, E., 1989. Contribution to the study of the Pleistocene fauna of large mammals (CARNIVORA, PERISSODACTYLA, ARTIODACTYLA) from Petralona Cave (Chalkidiki, N. Greece). Doctorate Thesis, Aristotle University of Thessaloniki, Sci. Ann., School of Geology, 1(8): 1-360, 124 fig., 64 tabl., 62. pl., summary in English. - C.R.A.S. Paris 312 (II): 331-336, 1991.

TSOUKALA, E., 1992a. The Pleistocene large mammals from the Agios Georgios Cave, Kilkis (Macedonia, N. Greece). - Geobios, 25 (3): 415-433, Lyon.

TSOUKALA, E., 1992b. Quaternary faunas of Greece- Courier Forsch. - Inst. Seckenberg, 153: 79-92, Frankfurt a.M.

TSOUKALA E. 1994. Bärenreste aus Loutraki (Mazed., Griechen.) - "Ursus spelaeus": 2nd Höhlenbären Sympos. (Corvara, 15-18/9/94), Italy.

TSOUKALA, E. 1996. Comparative study of ursid remains from the Quaternary of Greece, Turkey & Israel. - Acta Zool. Cracoviensa., 39(1): 571-576.

TSOUKALA, E., RABEDER, G. & VERGINIS, S., 1998. "Ursus spelaeus and associated faunal remains from Loutraki (Pella, Macedonia, Greece) - Excavations of 1996. Geological and geomorphological approach".- 4th International Höhlenbären Symposium, 17-19/9/98, Velenje, Slovenia.

TSOUKALA, E., RABEDER, G. & †VERGINIS, S., 2001. Ursus spelaeus and Late Pleistocene associated faunal remains from Loutraki (Pella, Macedonia, Greece). Excavations of 1999. - Cadernos Lab. Xeolóxico de Laxe, 26: 441-446, Coruña.

105

O-25

Paleontological research in Pella cave bears and late pleistocene associated faunal remains from Loutrá Aridéas (Macedonia, Greece) preliminary report

Spyridoula PAPPA[1], Evangelia TSOUKALA1, Georgios LAZARIDIS[1] & Gernot RABEDER[2]

1. School of Geology, Aristotle University, 54124 Thessaloniki, Macedonia, Greece

2. Institute of Paleontology, University of Vienna, Althanstrasse 14, A-1090, Vienna, Austria

Abstract: From extensional studies on Quaternary faunas it is concluded that certain caves in Greece were habited by animals (carnivores). The habitation is established by the presence of milk teeth and bones with infused epiphyses, the food remains and the coprolites. The most important site of Greece with abundant material of fossilized milk teeth, in spite of their fragility, is the Late Pleistocene Loutrá Arideas (Pella, Macedonia) Bear-cave. Thousands of isolated deciduous teeth – very few *in situ*-which have been collected from the systematic excavations are described and discussed here. The study of the morphotypes may show their evolutionary stage, such as those of the fourth premolars.

Introduction

The investigation in the Loutrá Arideas area, that is located 100 km northwest of Thessaloniki (fig.1), started in 1990 and the first excavation circle in the Bear Cave started in 1992. The Bear Cave is part of a block of caves that have been developed in the limestone of the Almopia Speleopark (LAZARIDIS, 2005). The sieving process and the systematic collection of the milk teeth started in 1993 up to now. Eleven systematic excavation circles, under strictly archaeological rules, including micro-mammalian research took place. All the sediments of the 204 levels (about 5 cm of thickness each) have been washed into a system of double sieves, one for micromammals (CHATZOPOULOU, 2005) with a mesh of 0.8 mm and the other of 3 mm for large mammalian remains, both with milk teeth. Then the material was dried out, conserved and recorded for further study. Additionally few bigger specimens were numbered and collected in place with their coordinates during the excavation (TSOUKALA, 1994, 1996, TSOUKALA *et al.*, 1998, 2001, TSOUKALA & RABEDER, 2005, PAPPA *et al.*, 2005). All the material above is stored in the Paleontological Museum of Thessaloniki Aristotle University and Aridéa Museum.

Figure 1. Map of Greece with the most important locality (LAC: Loutrá Arideas Cave) depicted, where abundant cave bear milk teeth have been found.

Paleontology

Taxonomy

Order: CARNIVORA BOWDISH, 1821
   Sub-order: Canoidea SIMPSON, 1931/ Arctoidea FLOWER, 1969
      Family: Ursidae GRAY, 1825
         Genus: *Ursus* LINNAEUS, 1758
           Ursus ingressus RABEDER *et al.*, 2004

<u>Material</u>: Mandible fragment with dC_i, D_4, M_1 unerupted LAC 1389 dex, mandible with I_3, C_i, M_1, M_2 and M_3 LAC 4114 dex, mandible fragment with unerupted C_i LAC 9203sin and LAC 1351 sin, mandible with no teeth LAC 4007 dex, mandible with unerupted M_2 LAC 11335 dex, mandibles fragments with no teeth LAC 5399 dex, LAC 11329 sin, LAC 9312 dex, LAC 9151sin, mandibles very fragments with no teeth LAC 5470 dex, LAC5361 dex, LAC 552II, 12 dI^1, 105 dI^2, 695 dI^3, 6 D^2, 26 D^3, 240 D^4, 52 dI_1, 29 dI_2, 180 dI_3, 7 D_2, 62 D_3, 285 D_4, 1600 dC. (Yearling cubs included).

<u>Description</u>: Among the abundant material, 3.259 milk teeth were studied and measured (tab. 1). Complete maxillas and mandibles are extremely rare, as only one mandible is almost well preserved (LAC 1389, fig. 2). The dC is slightly worn, as well as the lower milk carnassial; on the other hand the M_1 is germ and unerupted. The mandible LAC 4114 (fig. 3) belongs to a sixteen months bear (after Dittrich in ANDREWS & TURNER, 1992). On the mandible fragments (LAC 9203 and 1351) there are unerupted C_i, while the mandible with no teeth (LAC 4007) has a thin and well presented condylus, and the mandible (LAC 11335) has a well distinguished processus angularis, sort and thick condylus and the distal corpus is intensely curved beneath M_2. The rest mandibles have are small in size, fragmented with no teeth (fig 4).

Figure 2. *Ursus ingressus*. Mandible fragment with dC$_i$, D$_4$, M$_1$ unerupted, LAC 1389 dex.

Figure 3. *Ursus ingressus*. Mandible with I$_3$, C, M$_1$, M$_2$ and M$_3$ unerupted, LAC 4114.
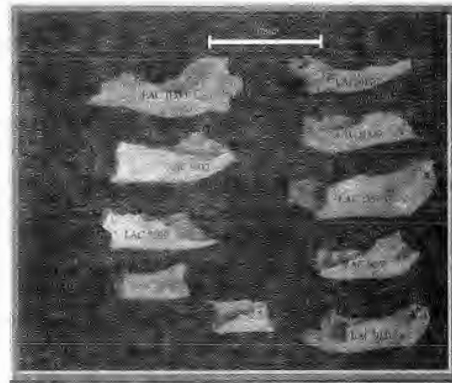
Figure 4. *Ursus ingressus* LAC. Mandibles of juveniles. Left: Labial view. Right: lingual view.

107

The first milk incisors are the smallest teeth of the milk incisors (fig. 5). The dI^1 is a small and slender tooth. There is a palatinal well developed cingulum and the root is conical, elongated and slightly curved. The dI$_1$ has short crown and long cylindrical root, the end of which is slightly curved.
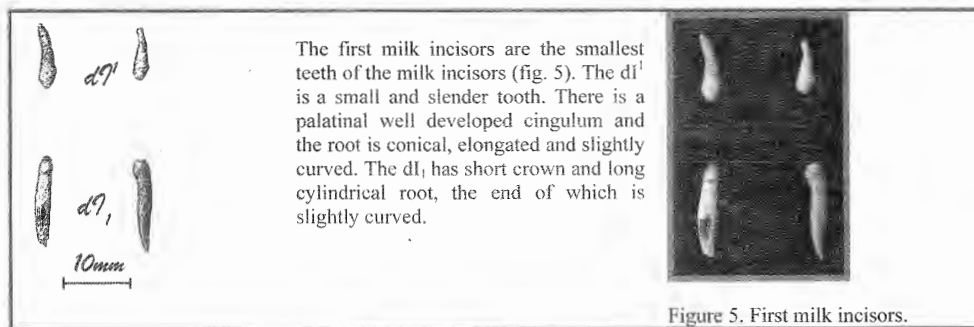
Figure 5. First milk incisors.

Figure 6. Second milk incisors.

The dI^2 is much stronger than the previous one, and also bears a well developed palatinal cingulum. The crown is curved, the root is conical and anterior flattened. The dI$_2$ is much stronger than the first one, with triangular crown and elongated root (fig. 6).

The third milk incisors are the strongest teeth of the milk incisors (fig. 7).The dI^3 is similar with the milk canine, except the shorter and more curved crown and the intense palatinal cingulum. This tooth seems to be the most abundant among the LAC milk material. The dI$_3$ has triangular crown and well developed root. There are two lingual accessory cuspids, connected with a small cingulum.
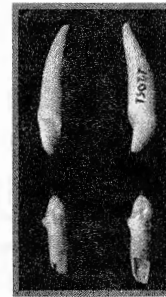
Figure 7. Third milk incisors.

The upper and lower second milk premolars are both the smallest milk teeth and the less differentiated (fig. 8). Between them, the eruption is different, therefore is easier to be distinguished while they are in situ. The upper erupts more straightly than the lower one. They are quite similar with minor differences. The root of D^2 is small and conical. The D$_2$ grows inclined, more often with no root. When this root exists, it is more curved than the upper's one.

Figure 8. Second milk premolars.
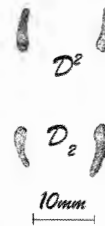
The D^3 is more differentiated with developed talon and two roots. The crown of D$_3$ is elongated and has two roots that are either separated or fused in some specimens (RADULESCU & SAMSON, 1959) (fig. 9).

Figure 9. Third milk premolars

The most important milk carnassials contribute to the study of the evolutionary stage according to their morphotype (RABEDER, 1983, 1991, 1999). The D^4 is molar like and has one palatinal and two labial roots. The occlusal shape is rounded and sometimes there is a palatinal cuspid-like cingulum. The lower carnassial D$_4$ are much more variable than the upper one, with crown bearing at least 5 cusps and two roots (fig.10).

The milk canines are abundant, long, flattened and relatively large teeth. It is difficult to be distinguished in upper and lower ones, thus are both described here unitedly (fig. 11).

Table 1. *Ursus ingressus* LAC: Measurements of the milk teeth (in mm) (L=length, B=breadth)

	n	min - max	x	s_{n-1}	v
LdI^1	12	1.77-2.95	2.44	0.32	13.15
BdI^1	12	1.57-2.68	2.21	0.35	15.58
LdI^2	103	3.02-4.63	3.85	0.32	9.46
BdI^2	103	2.72-4.97	3.35	0.32	8.24
LdI^3	671	4.03-6.62	5.23	0.38	7.30
BdI^3	671	4.01-6.77	5.05	0.42	8.31
LdC	1507	5.08-9.58	7.31	0.60	8.23
BdC	1507	3.96-7.25	5.52	0.45	8.23
LD^2	6	2.10-2.76	2.40	0.25	10.60
BD^2	6	1.99-2.65	2.25	0.26	11.75
LD^3	26	3.97-7.30	6.21	0.62	9.96
BD^3	26	3.07-4.17	3.72	0.26	7.04
LD^4	124	9.20-12.85	11.13	0.74	6.69
BD^4	124	6.42-11.60	7.56	0.64	8.43
LdI_1	52	1.45-2.73	2.17	0.29	13.54
BdI_1	52	1.21-2.09	1.73	0.21	11.87
LdI_2	27	3.50-4.76	4.02	0.29	7.25
BdI_2	27	2.42-3.83	2.94	0.36	12.32
LdI_3	173	4.10-6.32	5.21	0.47	9.12
BdI_3	173	3.02-5.33	4.05	0.37	9.23
LD_2	6	2.12-2.82	2.43	0.29	11.80
BD_2	6	2.12-2.57	2.29	0.18	7.97
LD_3	59	2.98-6.49	4.98	0.94	18.94
BD_3	59	2.38-4.02	3.29	0.38	11.69
LD_4	242	10.21-14.98	12.76	0.77	5.10
BD_4	242	5.03-9.70	6.31	0.58	9.17
LD_4tr^d	252	5.67-9.85	8.47	0.62	7.36
LD_4tl^d	252	2.83-5.91	4.60	0.53	11.58
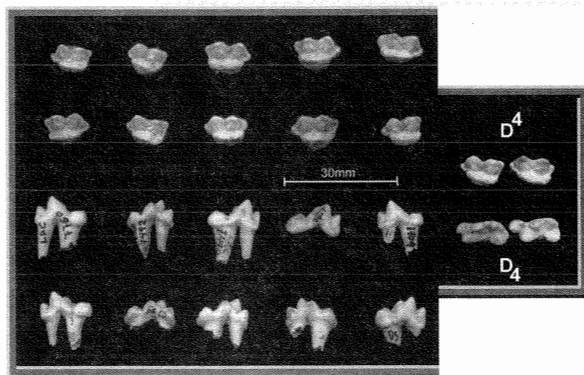
109

Figure 10. *Ursus ingressus* LAC: Representative material of the milk carnassials showing the variability of their morphotype.

Left: Two upper rows: D^4 occlusals, and two lower rows: D_4 lingual and labial views.
Right: occlusals of the upper and lower carnassials
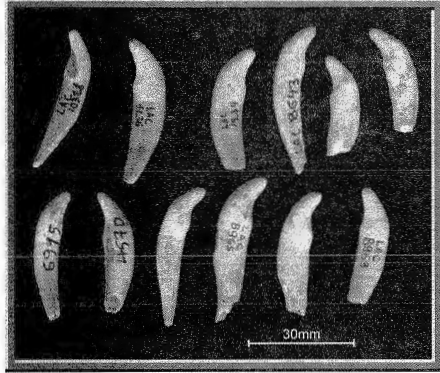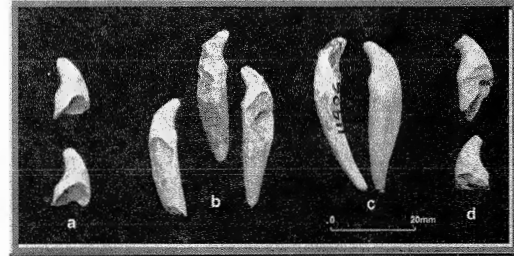
Figure 12. *Ursus ingressus* LAC. Various categories of deciduous canines (KURTEN, 1976). a) Germs, b) Full teeth with root showing resumptions marks, c) Full teeth, d) Shed canines.

Figure 11. *Ursus ingressus* LAC. Deciduous canines.

Discussion

Nordmann was the first who studied the bear milk teeth in 1858, Schlosser in 1909, Kormos in 1916, Pohle in 1923, Ehrenberg in 1931, Friant & Stehlin in 1933, Mottl in 1934, 1939, Zapfe in 1946, KOBY (1952), ERDBRINK (1953), RADULESCU & SAMSON (1959), EHRENBERG (1964), KURTEN (1968), TERZEA (1969), TORRES (1988), ANDREWS & TURNER (1992), DEBELJIAK, (1996, 1997) etc .

The study of the milk teeth and bones showed the presence even more of unborn bears. On the other hand, completely worn milk teeth were also observed, thus there was difficulty in chewing so the individuals could not survive a long winter, as this last glacial period of Würm. These animals died exhausted at the end of the winter, even though they could survive more (KURTEN 1968, 1976). Concerning the milk canines, the material can be attributed to categories (KURTEN, 1976) (tab. 2): (A) by few germs – milk canines consisting by an enamel cap and a root that has barely started to form (fig. 12a), (B) by few complete teeth with unworn occlusal and fully formed roots (fig. 12c), (C) by complete teeth with root showing resumptions marks (fig. 12b). This is a preliminary stage to the tooth being shed and as the root is gradually dissolved by the osteoclast (KOBY 1952). There is a very large crop of shed milk canines (D) in which the root has dissolved completely (fig. 12d). The (E) category includes the heavy wear stage of deciduous. Finally the (F) includes worn deciduous canines with resorbed root.

The milk carnassials D^4 and D_4 are the most important deciduous teeth as the study of the morphotype can give evidence for their evolutionary stage (RABEDER, 1983). The D^4 LAC is molar like with one palatinal and two labial roots. The occlusal shape is rounded and sometimes there is a palatinal cuspid-like cingulum. The paracone is well developed and the metacone bears longitudinal palatinal crest. There is small parastyle while there is a trace of cingulum like metastyle. Finally there is crest like hypocone. It is similar to the Gamssulzenhöhle (Austria) morphotype (fig. 13a,b). The lower carnassials D_4 LAC are much more variable than those of the upper ones, with crown bearing at least 5 cuspids. Paraconid, metaconid and protoconid are well developed. There is a small hypoconid and endoconid. Apart from some differences, the morphotype of D_4 is similar to that of Gamssulzenhöhle (fig. 14a,b).
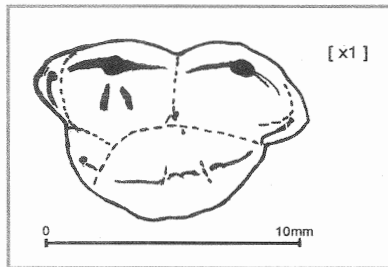
Figure 13a. *Ursus ingressus,* Loutrá Arideas Bear Cave: D⁴ LAC 12557 sin, with the occlusal morphology.
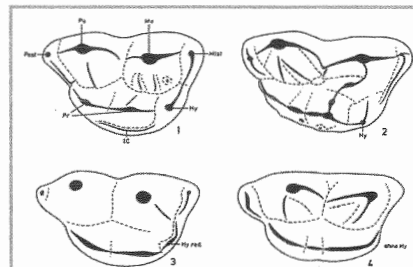
Figure 13b.   D⁴ sin with the occlusal morphology from Repolusthöhle (1), Conturineshöhle (2), Gamssulzenhöhle(3) and Nixloch (4). Abb.: Hy: hypocone, lC: lingual cingulum, Me: metacone, Mtst: metastyle, Pa: paracone, Past: parastyle, Pr: protocone (RABEDER, 1983).
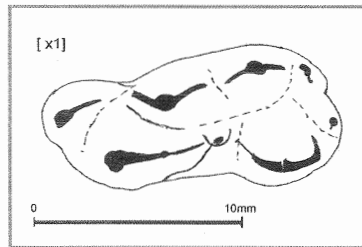
Figure 14a. *Ursus ingressus,* Loutrá Arideas Bear Cave: D₄ LAC 12560 sin, with the occlusal morphology.
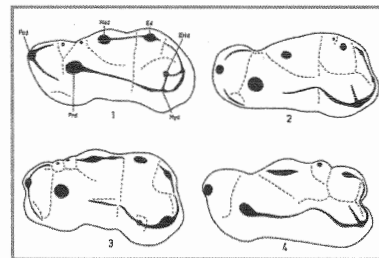
Figure 14b. D₄ sin with the occlusal morphology from Repolusthöhle (1), Conturineshöhle (2), Gams-sulzenhöhle(3) and Nixloch (4). Abb.: Ed: entoconid, EHd: enthypoconid, Hyd: hypoconid, Med: metaconid, Pad: paraconid, Prd: protoconid (RABEDER, 1983).

Table 2. *Ursus ingressus* LAC: Wear stages of cave-bear deciduous canines

Wear stage (dC)	Description		Number of specimens LAC	Westbury ANDREWS & TURNER 1992	Odessa KURTEN 1976
A	Unerupted	Neo nates	132	22	13
B	Erupted		500	10	26
C	Unworn		83	32	
D	Slightly wear	Yearlings	130	39	165
E	Heavy wear		600	80	
F	Worn with resorbed root		155	8	
Unerupted, when the crown is formed but the root is not; erupting, when some root development has taken place; unworn, when the root is fully formed but the crown has no wear; slight to moderate wear; heavy wear.					

111

From the distinction of the dI^3, D^4 and D_4 in rights and lefts the MNI (minimum number of individuals) can be calculated to 355 individuals based on dI^3 (the left ones) (tab. 3).

Table 3. *Ursus ingressus* LAC: Distinction of the dI^3, D^4 and D_4 in rights (dex) and lefts (sin) for calculation of the minimum number of individuals (MNI).

Category of Teeth	Number of lefts (sin)	Number of rights (dex)
dI^3	355	340
D^4	120	120
D_4	139	146

The following scatter diagrams of length and width of the milk teeth accomplish the distinction between upper and lower jaw (Fig. 15-18) that is better shown on the milk carnassials.
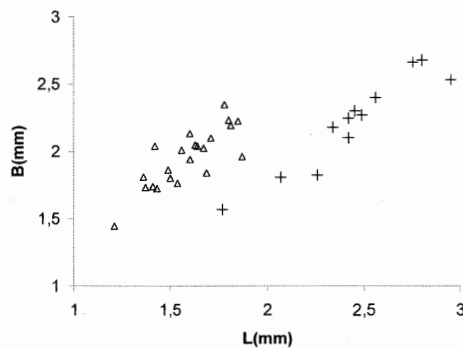
Figure 15. Scatter diagram of L=length and B=breadth of the dI^1, dI_1, which shows the distinction between upper (+) and lower (Δ) first deciduous incisors.
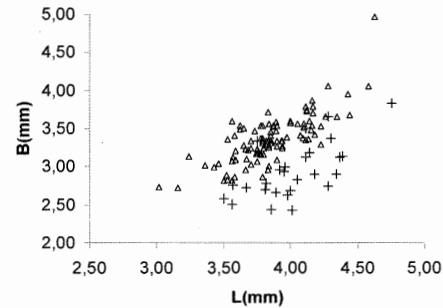
Figure 16. Scatter diagram of L=length and B=breadth of the dI^2, dI_2, which shows less the distinction between upper (Δ) and lower (+) second deciduous incisors.
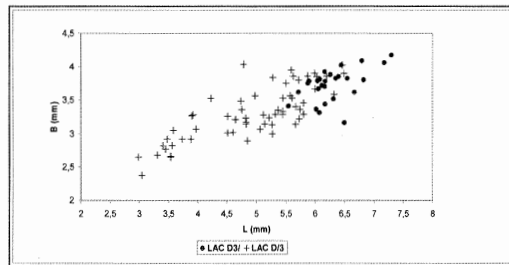
Figure 17. Scatter diagram of L=length and B=breadth of the D^3, D_3 which shows the distinction between upper (●) and lower (+) third milk premolars.
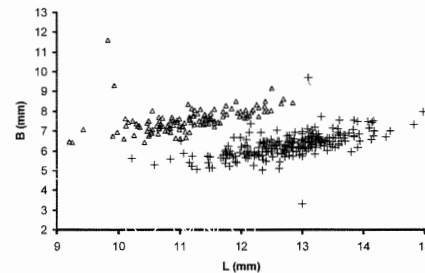
Figure 18. Scatter diagram of L=length and B=breadth of the D^4, D_4 which shows clearly the separation between the upper (Δ) and lower (+) milk carnassials.

Conclusions

- The Late Pleistocene Loutrá Arideas bear-cave is very rich in paleontological material of ursid milk teeth. Thus the site can be considered as the unique place of Greece where so abundant and well stratified deciduous teeth from 204 excavated layers (5cm of thickness each) have been collected.
- The abundance of the milk teeth, in spite their fragility, is remarkable.
- Among the material there are many postcranial bones, including metapodials, with their epiphysis infused. Therefore all ages from juvenile to senate individuals are present.

112

- The majority of the tooth and bone remains belong to juveniles and sub-adults, while very few belong to very old individuals and few to adults, indicating thus an extremely high incidence of young and neonate mortality.
- The study of the milk teeth showed the presence either of unborn bears.
- There are many bear carcasses as a result of death during hibernation. All this evidence establishes the inhabitation. On the other hand, many milk teeth ware brought into the cave within the sediments.
- The morphotype of the milk carnassials from Loutrá Arideas Bear Cave is more similar to that from Gamssulzenhöhle (Austria) than that from Conturineshöhle (RABEDER, 1995).
- Finally only 3 caves of northern Greece present significant carnivore milk teeth material of Pleistocene: the most important Late Pleistocene Loutrá Arideas Bear-cave (LAC) with bears between latest Pleistocene and Middle Pleistocene, the Middle Pleistocene Petralona cave with hyaenids bears and the latest Pleistocene Agios Georgios, Kilkis cave with exclusively hyaenid remains (TSOUKALA 1989, 1992a, b, 1994, 1996, TSOUKALA et al. 1998, 2001, TSOUKALA & RABEDER 2005).

References
ANDREWS, P. & TURNER, A., 1992. Life and death of the Westbury bears. - Ann. Zool. Fennici, **28**: 139-149, Helsinki.
CHATZOPOULOU, K. 2005 - The small mammal fauna from the Loutra Aridea Bear-cave (Pella, Macedonia, Greece) with emphasis on the Third Chamber. –Naturhistorische Gesellschaft Nürnberg, **45**: 57-64, Nürnberg.
DEBELJIAK, I., 1996. Ontogenetic development of dentition in the cave bear. – Geologija, **39**: 13-77, Ljubljana.
DEBELJIAK, I., 1997. Age composition of the cave bear population from the Divje babe I Cave. – Int. Meeting on Man and Bear, Auberives - Pont en Royans (Vercors – Isère).
EHRENBERG, K. 1964. Ein Jungenbärenskelett und andere Höhlenbärenreste aus der Bärenhöhle im Hartlesgraben bei Hiflau (Steiermark).- Ann. Naturhistor. Mus. Wien, **67**: 189-252.
ERDBRING, D. P., 1953. A review of fossil and recent bears of the old world. 1-2. Jan de Lang, Deventer
KOBY, F.-Ed., 1952. La dentition lacteale *d' Ursus spelaeus*. - Rev. Suisse Zool., Geneve. **59**(27): 511-541.
KURTÉN, B., 1968. Pleistocene Mammals of Europe. Aldine Publishing Company, Chicago: 1 – 317.
KURTEN, B., 1976. The cave bear story. Life and death of a vanished animal.- Columbia University Press, 1-163, N. York.
LAZARIDIS. G. (2005): Speleological research in the Loutra Arideas area (Macedonia, Greece). –Naturhistorische Gesellschaft Nürnberg, **45**: 155-162, Nürnberg.
PAPPA, S., TSOUKALA, E., LAZARIDIS. G., RABEDER, G. (2005): Milk teeth of Quaternary carnivores from Northern Greek Caves. –Naturhistorische Gesellschaft Nürnberg, **45**: 169-182, Nürnberg.
RABEDER, G., 1983. Neues vom Höhlenbären. Zur Morphogenetik der Backenzähne. *Die Höhle*, H. **2**(34): 67-85, Wien.
RABEDER, G., 1991. Die höhlenbären der Counturines.- Verlagsanstalt Athesia, 1-124, Bozen.
RABEDER, G., 1995. Die Gamssulzehöhle im Toten Gebirge.- Mitt. Kom. Quartärforch. Österreich. Akad. Wiss. **9**: 1-133, Wien.
RABEDER, G., 1999. Die Evolution des Höhlenbärengebisses.- Mitt. Kom. Quartärforch. Österreich. Akad. Wiss. **11**: 1-102, Wien.
RABEDER, G., HOFREITER, M., NAGEL, D. & WITHALM G. (2004): New taxa of Alpine Cave Bears (ursidae, Carnivora).- Cahiers Scientifiques, 2:49-67, Dept. Du Rhone, Museum Lyon.
RABEDER G. & HOFREITER, M., 2004: Der neue Stammbaum der alpinen Höhlenbären.- Die Höhle, H. **55**(1-4): 58-77, Wien.
RADULESCU, C. & SAMSON, P., 1959. Contribution a la connaissance de la dentition lacteale d'*Ursus spelaeus*. Eiszetalter und Gegenwart, **10**: 205-216, Ohringen.
TERZEA, E., 1969. Nouvelles données sur la dentition lacteale de l'*Ursus spelaeus*.-Act. IV. Congr. Int. Speleaol. **4-5**: 383-389.
TORRES PEREZ-HIDALGO, T.J., 1988. Osos (Mammalia, Carnivora, Ursidae) del Pleistoceno de la Península Iberica. Boletin Geologico y Minero, Madrid (publ. espec.), **1-4**: 1-316.
TSOUKALA, E., 1989. Contribution to the study of the Pleistocene fauna of large mammals (CARNIVORA, PERISSODACTYLA, ARTIODACTYLA) from Petralona Cave (Chalkidiki, N. Greece). *Doctorate Thesis*, Aristotle University of Thessaloniki, Sci. Ann., School of Geology, **1**(8): 1-360, 124 fig., 64 tabl., 62. pl., summary in English. - C.R.A.S. Paris **312 (II)**: 331-336, 1991.
TSOUKALA, E., 1992a. The Pleistocene large mammals from the Agios Georgios Cave, Kilkis (Macedonia, N. Greece). – Geobios, **25 (3)**: 415-433, Lyon.
TSOUKALA, E., 1992b. Quaternary faunas of Greece- Courier Forsch. - Inst. Seckenberg, **153**: 79-92, Frankfurt a.M.
TSOUKALA E. 1994. Bärenreste aus Loutraki (Mazed., Griechen.) -"*Ursus spelaeus*": 2nd Höhlenbären Sympos. (Corvara, 15-18/9/94), Italy.
TSOUKALA, E. 1996. Comparative study of ursid remains from the Quaternary of Greece, Turkey & Israel. – Acta Zool. Cracoviensa., **39**(1): 571-576.
TSOUKALA, E., RABEDER, G. & VERGINIS, S., 1998. "*Ursus spelaeus* and associated faunal remains from Loutraki (Pella, Macedonia, Greece) - Excavations of 1996. Geological and geomorphological approach".- 4th International Höhlenbären Symposium, 17-19/9/98, Velenje, Slovenia.
TSOUKALA, E., RABEDER, G. & †VERGINIS, S., 2001. *Ursus spelaeus* and Late Pleistocene associated faunal remains from Loutraki (Pella, Macedonia, Greece). Excavations of 1999. – Cadernos Lab. Xeolóxico de Laxe, **26**: 441-446, Coruña.
TSOUKALA E. & RABEDER, G., 2005 – Cave bears and Late Pleistocene associated faunal remains from Loutrá Arideas (Pella, Macedonia, Greece). 15 years of research. –Naturhistorische Gesellschaft Nürnberg, **45**: 225-236, Nürnberg.

O-26

The pursuit of elephants in Grevena (W. Macedonia, Greece)

Evangelia Tsoukala

School of Geology, Aristotle University, 54124 Thessaloniki, Macedonia, Greece

The paleontological research in Grevena (fig. 1) started in 1990, when a student discovered elephant remains in an old stream, in a building plot close to his house. After preliminary visits for reconnaissance, three substantial field seasons, in 1992, 1994 and 1995 were devoted to systematic excavation of the site.

Fig. 1. Map of Greece with the Grevena Prefecture and the localities with the proboscidean remains depicted. GRE: Ambelia locality, Grevena town. MIL: Milia area and SGP: Priporos, Agios Georgios

Fig. 2. Complete view of the excavated area with remains of *Elephas (Palaeoloxodon) antiquus* in the Ambelia locality (GRE)

These resulted in abundant fossilized elephant remains, apparently all pertaining to a single skeleton. The excavated area, in which the elephant was discovered, is situated on the outskirts of Grevena town, in "Ambelia"(GRE), 585m of altitude above the sea level, which is the metropolitan center of Grevena Prefecture, in western Macedonia, 190 km west of Thessaloniki. A partial skeleton of straight-tusked elephant, *Elephas (Palaeoloxodon) antiquus* FALCONER & CAUTLEY (1847) was excavated from Pleistocene

deposits (TSOUKALA & LISTER 1998). The material was found in unconsolidated sands, close to the surface, so the remains are in a rather poor state of preservation, because of the waters, but mainly of the roots of the plants that penetrated the fossils and resulted in great damage. Very few, mainly the metapodials, were well preserved. Only two other fossils were found in association with the elephant: two teeth- an upper ($M^{1,2}$) and a lower molar $M_{1,2}$ of a large bovid. This skeleton included substantial portions of the skull, mandible, vertebral column, ribs, the two scapulas, fibula, carpals, tarsals, metapodials and phalanges (fig. 2) represent a large, adult male of about 40 years. Three samples of elephant tooth enamel were ESR-dated (by Dr. Y. Bassiakos- Nuclear Center for Scientific Research, N.C.S.R. "DEMOKRITOS", Attiki), giving an age in the range 160-170 ± 25 Ky. BP, i.e. Oxygen Isotope Stage 6. This is very important because indicates Greece as a refugee for temperate, woodland-adapted large mammal species at a time when they were largely excluded from northern and central Europe.

Fig. 3. Complete view of the excavated area with fossil findings of the mastodont *Mammut borsoni* in the Milia locality (MIL 1)

The second excavated area, in which the mastodont *Mammut borsoni* HAYS, 1834 (Proboscidea) was discovered, is situated on the outskirts of Milia village, 15 km northeast of Grevena town. The excavations in the Milia locality (MIL) (fig. 1) brought to light proboscidean partial skeleton of the mastodont material (fig. 3), which was found in unconsolidated sands of the Aliakmon river Pliocene deposits, close to the surface, so the remains are in a rather poor state of preservation.

114

Research in the Milia area started in 1996, when the excavating team of Aristotle University of Thessaloniki trying to evaluate some information given by local villagers, discovered a complete right humerus and part of a tusk. One year later, systematic excavations took place in the area and two complete tusks more of the humerus, and part of skull with two molars *in situ* were brought to light. The transportation of the complex of very heavy fossils was very difficult, as the tusks were found in crosswise position. The restoration of the broken tusks- in many pieces, because of natural causes (plant roots, earthquakes and erosion) - completed in 1997. In 1998 the excavations were continued with additional very interesting findings, such as the complete mandible that gave evidence for the paleontological study, right tibia and left ulna, as well as ribs. Finally, in 1999, as the excavations in this area have been completed, additional material, such as the right ulna, thoracic vertebras, as well as ribs were found.

The skeleton includes substantial portions of the skull - maxillary area - with left and right molar series (M^2+M^3); with the longest upper tusks ever found in Greece, in Europe (AGUSTI & ANTON 2002) and probably in the world (4.39m!); The two approximately straight tusks are rather slender and asymmetrical, as the right one is more curved and torsioned (about 115^0). They have approximately circular transverse section but more oval at the tips. The greatest diameter of the tusk MIL 101, at a distance of 10cm from the tip, is 88.5mm, the smallest 65mm, and the circumference is 250mm; at a distance of 4m from the root these measurements are: 116, 101 and

Fig. 4. *Mammut borsoni* MIL. Mandibles with left and right molar series (M_2+M_3) a) Left: MIL 1(male), b) right: MIL 2 (probably female).
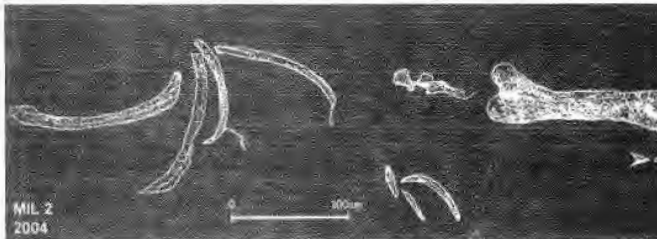
Fig. 5. Complete view of the excavation of 2004 in MIL 2 locality with ribs, occipital region of a cranium fragment and a complete femur of 1.5m of height.

350mm respectively; at a distance of 3m from the root, these measurements are: 149, 144 and 475mm respectively; at a distance of 2m these are: 171, 164 and 540mm respectively; at 1m 184.5, 174.5, 570mm, and at the root they are: 178, 163, 580mm respectively. The most complete mandible with left and right molar series (M_2+M_3) and two lower incisor
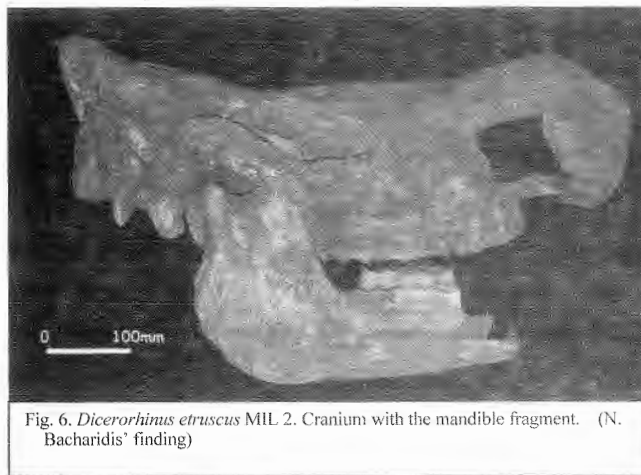
Fig. 6. *Dicerorhinus etruscus* MIL 2. Cranium with the mandible fragment. (N. Bacharidis' finding)

tusks (fig. 4a), as well as bones of the post-cranial skeleton (humerus, left and right radius, tibia, vertebras and rib fragments) were found. Concerning the lower molars, these are low and broad with variable enamel thickness. The M_2 is typically trilophodon and little worn and the axis of the ridge-crests are sub-perpendicular to the sagittal axis of the tooth. The M_3 is tetralophodon with well marked talonid and the longitudinal axis of the tooth is slightly bend so that the end of the tooth are somewhat turned to the labial side. There are two, nearly complete and well distinguished, cingula anterior and posterior. It represents a very large adult of about 40 years, perhaps one of the latest representatives of this species in Greece and in Europe as well, and its geological age is considered as Middle Pliocene (TSOUKALA 2000).

Only a tooth of a large bovine was found in association with the proboscidean material. As the excavations are still in progress, many other rhino and mastodon remains were found (2001-2004) in the broader area of Milia. In the new locality MIL 2, close to the hill of the first locality MIL 1, remains of another mastodont, about the same biological and geological age with the first one, were found. They are: a humerus (the robustness index of which may show a female individual, a pelvis fragment, a mandible fragment with left and right molar series (M_2+M_3) (fig. 4b) of the same wear stage with the MIL 1 mandible of the male mastodont. In 2004 a cranium fragment with the occipital region and the condyles, ribs and a femur of 1.50m of length were brought to light (fig. 5).
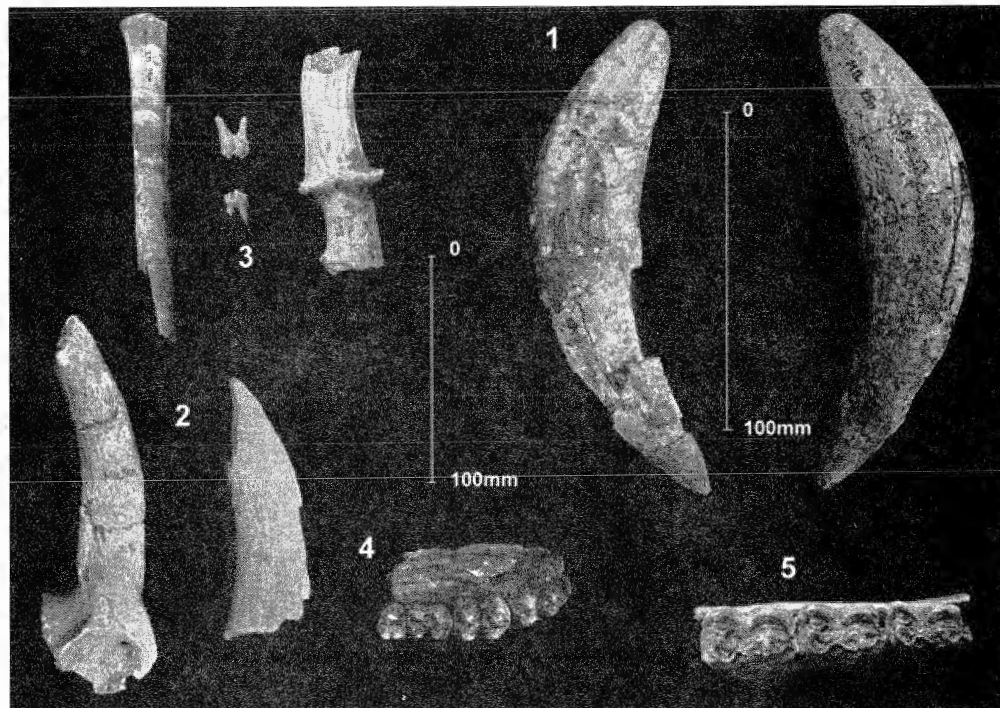
Fig. 7. Milia Grevena area, the associated with *Mammut borsoni* remains: *Homotherium* sp. Upper canine, 2. cf. *Gazella borbonica* horn fragments, 3. cf. *Croizetoceros ramosus*: Metapodial (Mc 3+4), teeth ($M_{1,2}$, P_4), antler fragment, 4. Suid: maxilla with teeth (P^4, M^1, M^2, M^3), 5. *Hipparion* sp. mandible with teeth (P_4, M_1, M_2)
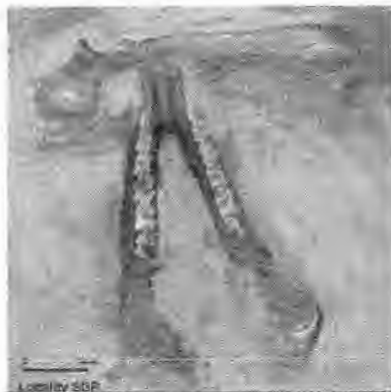
Fig. 8 *Dicerorhinus etruscus* SGP. Mandible and ulna found in Priporos, Agios Georgios village

Very important material attributed to *Dicerorhinus etruscus* (FALCONER, 1859) was also found in many localities round Milia. In MIL 2 an almost complete skull with teeth and about half of the mandible (fig. 6) were brought to light as well as mandibles and postcranial remains were found in the broader area of the sand quarry of Milia, Kokkinia village etc.

In the broader area, fossils including machairodont (an upper canine of a cf. *Homotherium* sp.) (fig. 7.1), bovid (horn fragments of cf. *Gazella borbonica*) (fig. 7.2), cervid (a metapodial (Mc 3+4), teeth ($M_{1,2}$, P_4), antler fragment of cf. *Croizetoceros ramosus*)(fig. 7.3), cf. *Sus arvernensis* (maxilla with P^4, M^1, M^2 and M^3) (fig. 7.4), hipparion (mandible with P_4, M_1, M_2 of *Hipparion* sp.) (fig. 7.5),

In 2000, in Priporos area (SGP, fig. 1), between the Milia and Agios Georgios villages, a very well preserved complete mandible and ulna of a rhino (*Dicerorhinus etruscus*) have been found also in these Pliocene sand deposits (fig. 8).

The Grevena Prefecture has financed the excavations, as well as the dating projects, and the mayors of Grevena town and Herakleoton as well.

The fossils are stored now in the Municipal Museum of Grevena (the elephant), and in the Public Building of the Milia village (the mastodont) (Fig. 9).

Fig. 9. Left: Municipal Museum of Grevena with the elephant remains of 200.000 years. Right: Museum of Natural History of Milia, Herakleoton Municipality, with mastodon remains of 3.000.000 years.

Conclusions
-Grevena area is very important paleontological site as the proboscidean material gives evidence for:
-*Elephas (Palaeoloxodon) antiquus* FALCONER & CAUTLEY, excavated from Pleistocene deposits of Grevena town (Ambelia locality), of age 160-170 Ky. BP, i.e. Oxygen Isotope Stage 6, indicating Greece as a refugee for temperate, woodland-adapted large mammal species at a time when they were largely excluded from northern and central Europe.
-*Mammut borsoni* HAYS, 1834 that belongs to progressive form of the *Zygolophodon-Mammut* group with very long (may be the longest in the world of this species), straight, or upturned upper incisors without enamel and rudimentary/subfunctional lower incisors, with very few primitive characteristics (e.g. no cement in the cynclines of the molars). The morphology of the Milia specimen (mainly its large size that shows gigantism) may have been response to favorable environment for this browsing adapted animal.
-The abundance of the rhino material give evidence the "pursuit" to be continued in the Grevena area
-The following fauna has preliminarily been determined: *Mammut borsoni, Dicerorhinus etruscus, Homotherium* sp., *cf. Gazella borbonica,* cf. *Croizetoceros ramosus,* cf. *Sus arvernensis,* Bovidae, *Hipparion* sp.
The age is calculated of Middle Pliocene and further study will give evidence for the completeness of the paleoecology and paleoenveronment of the area as the research and excavation are still in progress.

References
AGUSTI J. & ANTON, M. 2002.- Mammoths, Sabertooths and hominids, 65 million years of Mammalian Evolution in Europe. Columbia University press, N. York.
TSOUKALA E. 2000. Remains of a Pliocene *Mammut borsoni* (HAYS 1834), from Milia (Grevena, W. Macedonia, Greece). Annales de Paléontologie, 86(3): 165-191, Paris
TSOUKALA E. & LISTER A. 1998. Remains of straight-tusked elephant *Elephas (Palaeoloxodon) antiquus* FALC. & CAUT. 1847, ESR-dated to oxygen isotope stage 6 from Grevena (W. Macedonia, Greece). Bolletino della Società Paleontologica Italiana, 37(1): 117-139, Modena.

117

O-27

Mineralogy of the hybrid Kiinyugawa-dam Cave, Kii Peninsula, Central Japan

Naruhiko Kashima, Emeritus Professor, Ehime University, 10-13 Dogo-Himata, Matsuyama, 790-8577 Japan

Kunihiko Hisatomi, Department of Geology, Faculty of Education, Wakayama University, 930 Sakaedani, Wakayama, 640-8510 Japan

Abstract

The hybrid Kiinyugawa-dam Cave is situated in the Kii Peninsula of Honshu Island, about 10km southeast of Hashimoto City in Wakayama Prefecture and rediscovered in 2001. The cave is developed into the black slate and mafic volcanic rocks of the Upper Cretaceous System, Hidakagawa Group of the Shimanto terrane. It is the peculiarly hybrid cave system which linked the closed mine cave and the natural tectonic cave. Mineralogical identification was made by X-ray powder diffraction method and revealed nine minerals five classes as follows ; Carbonates (aragonite, calcite), Oxide (goethite), Silicates (clinochlore, illite), Sulfates (brochantite, glaucocerinite, gypsum) and Sulfide (pyrite).

The closed mine cave was well mineralized by the leaching which derived from the cupriferous iron sulfide ore deposits. And the natural tectonic cave was decorated with the carbonate minerals. Brochantite, clinochlore, glaucocerinite and pyrite are reported as new findings from the cave environment in Japan.

Zusammenfassung

Die hybride Kiinyugawa-damm Höhle wird in der Kii Halbinsel von Honshu Insel, etwa 10km Südosten von der Hashimoto Stadt in der Wakayama Präfektur aufgestellt und die Wiederentdeckt 2001.

Diese Höhle wird in der schwarzen Schiefer und in die mafisches vulkanischen Felsen der Oberen Kreide System Hanazono Formation, Hidakagawa Gruppe, Shimanto terrane entwickelt. Es ist das eigenartig hybride Höhlensystem, das geschlossene Grube Höhle mit der natürlichen tektonische Höhle verband.

Die Mineralogische Kennzeichnung wurde durch die Röntgenstrahlpuder-Beugungmethode gebildet und die neun Mineralien der fünf Kategorien aufdeckte, wie folgt ; Karbonates (Aragonit, Calcit), Oxide (Goethit), Silicates (Clinochlore, Illit), Sulates (Brochantit, Glaucocerinit, Gyps) und Sulfide (Pyrit).

Die geschlossene Grube Höhle wurde gut durch das Auslaugen mineralisiert, das von den kupferhaltigen Eisensulfid-Erzablagerungen ableitete. Und die natürliche tektonische Höhle wurde mit den
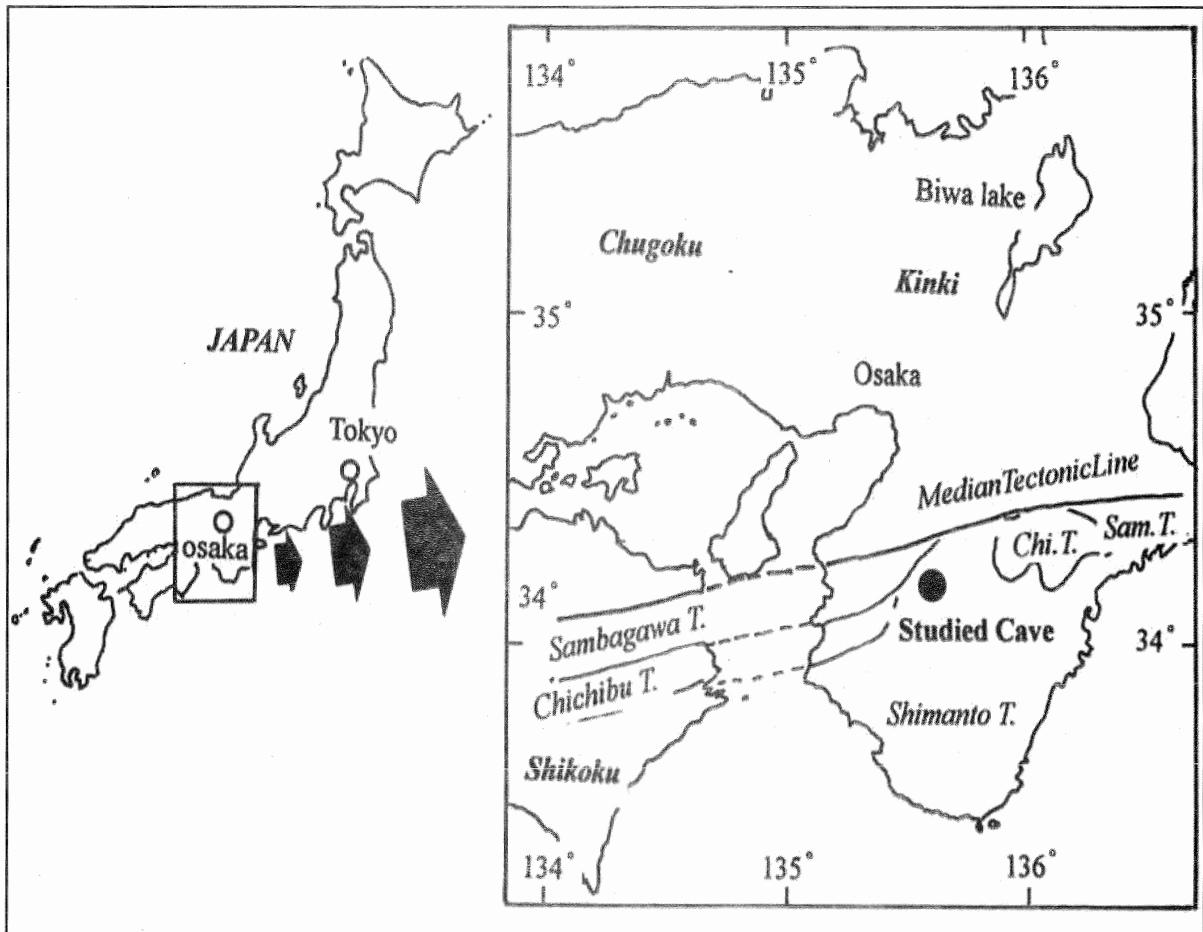
Fig. 1. Location map of the hybrid Kiinyugawa-dam Cave, Japan.

Karbonatmineralien verziert. Brochantit, Clinochlore, Glaucocerinit und Pyrit werden als neue Entdeckungen vom das Höhleklima in Japan berichtet.

Introduction

The hybrid Kiinyugawa-dam Cave is located in the Kii Peninsula of Honshu Island, Central Japan. It lies within the Hiko valley, a southern tributary of the Kiinyugawa-River, neighboring dam construction site, about 10km southwest of Hashimoto City in Wakayama Prefecture (Fig. 1).

The cave is first mentioned to a document in 1935 for the "stalactite cave" by the Research Group of the Historic remains, Scenic beauty spots and Natural monuments in Wakayama Prefecture. However up to this day, the speleological investigation has not been conducted. Systematic reexploration of the cave was conducted by Kiinyugawa-dam Investigation Office of the Kinki Regional Department Bureau at 1998-2001 and with the resulted that report for details of the speleological fields. The authors were carried out an investigation of the geological and mineralogical parts in this project. The hybrid Kiinyugawa-dam Cave is relatively short, with only 250m passages, but it consists of a complex network of the closed mining passages (artificial "cave", Hill et al., 1997) and the entranceless natural tectonic cave. The study has resulted in the identification of hybrid cave units and its mineralogical data of heretofore undiscovered in Japan.

Geological Settings

Geologically the hybrid Kiinyugawa-dam Cave region belongs to the Hanazono Formation of the Shimanto terrane, which is composed predominantly of black slate, with some intercalation of sandstone, mafic volcanic rocks(greenstones), chert, red slate, acidic tuff and limestone (Kurimoto, 1982). The greenstones are occasionally containing bedded cupriferous iron sulfide deposits. In Kiinyugawa-River district, the cupriferous iron sulfide deposits were mined from the mid-eighteen century to 1924(?). The Hanazono Formation has the general strike of NE-SW, dipping 30 to 70 degrees to north and south and showing complexly folded structure. And the upper Cretaceous (Coniacian~Campanian) radiolarian fossils have been reported from chert beds.

Cave description

The hybrid Kiinyugawa-dam cave is measured at total length of about 250m and height of 40m, with width ranging from 0.5m to maximum of 6m. The main entrance(No.1)-about 0.8m wide and 0.7m high- located at the altitude of about 290m above sea level of the right bank of Hiko valley, and the other entrances(No.2 and No.3-both 1-2m long and 1m wide) located at the altitude of about 330m a.s.l. on the same slope on the hill.

In plan view, the closed mine complex sequence of adits exhibit a hook shaped rectilinear pattern of two main directions. The main mining adits belong to two entrances(No.2 and No.3) stretched the strike direction ore beds(ENE-WSW) about 65m in greenstones and the other adit which dug in the search for ore beds which has shown cross at right angle in black slate(NNE-SSW) about 55m from the entrance No.1. The entranceless natural tectonic cave located parallel to the strike direction of main mining adits and connected with NNE-SSW adit at the point of about 30m from the entrance No.1.

In cross section, the cave consists of three levels. The closed mine adits consists of two levels, the lower horizontal adit(at an altitude of 293m-297m a.s.l.) and the upper network adits(at an altitude of 318m-328m a.s.l.) and they are connects with vertical shaft. The entranceless natural tectonic cave(at an altitude of about 301m-308m a.s.l.) occupies the middle level and the vertical shaft of closed mine directly penetrates its east part of cave passages (Fig. 2).

The entranceless natural tectonic cave embedded in the intensely folded black slate, about 45m long, width 1m and 6m~20m deep wedge or lens shaped cross section. Isoclinal fold has axial plain paralleled to bedding plane of black slate. The surface shape of the ceiling and floor of the natural cave passage indicates that the space of passage was emplaced by spread out bedding plain of black slate. There is a large possibility that the black slate in this area was subjected to stresses resulting in the creep type landslide and leading the entranceless open space (natural tectonic cave) in black slate bed.

Speleothems

The lower level adit continued from the entrance No1, tunneling in black slate, partially covered by flowstone and cave corals of the fine white calcite. On the middle level of cave which the entranceless natural tectonic cave, various speleothems are recognizable on the walls ; such as flowstone, soda-straw, stalactite, column, curtain, helictite and acicular crystals.
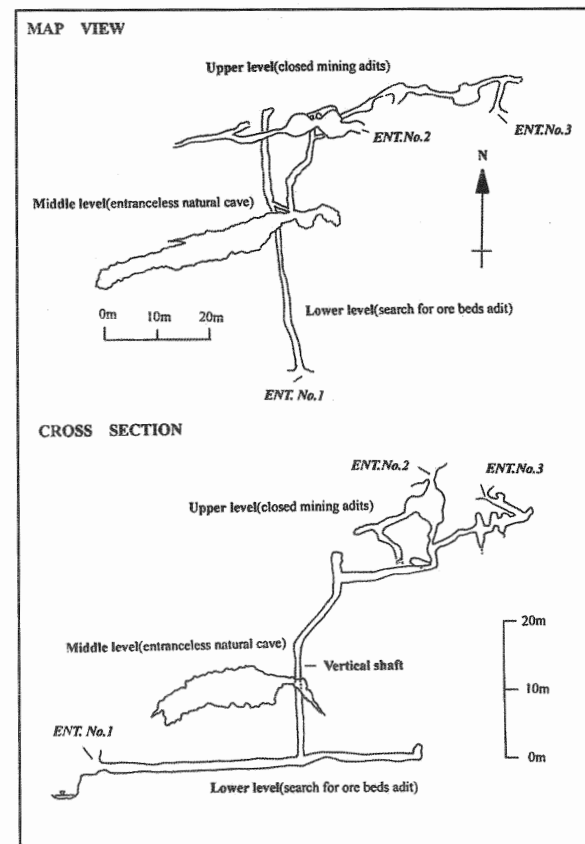
Fig. 2. Map of the Kiinyugawa-dam Cave, Japan.

Brown and greenish blue colored speleothems; such as flowstone, curtain and microgour are distributed on the walls about 10m south from the Entrance No.2. Near by, an ore-rocks were dug out and dumped up to outside of the passage.

Inside the closed mine, the point of about 20m west from the entrance No.3, it is still now possible to see outcrop of the bedded cupriferous iron sulfide deposit at greenstones walls and the brown and blue colored flowstones are found at the walls.

Mineralogy

Samples were collected from the entranseless natural tectonic cave and the closed mine cave (artificial cave). Mineral assemblages were established using X-ray powder diffraction method and revealed nine minerals belong five classes.

Two different geneses of the unusual minerals of the hybrid Kiinyugawa-dam Cave are related to the normal-true cave and an artificial cave speleogeneses.

Minerals derived from black slate (natural-true cave) are containing normal speleogenetic Carbonates (aragonite and calcite). Minerals derived from ore-rocks (artificial cave), Oxide (goethite), Silicates (clinochlore, illite), sulfates (brochantite, glaucocerinite, gypsum) and sufate (pyrite) have been identified. Table 1 lists all the speleominerals identified, chemical composition and occurrences.

Table 1. Identified minerals in the hybrid Kiinyugawa-dam Cave.

Minerals	Chemical composition	Occurrence
(Carbonates)		
Aragonite	$CaCO_3$	white colored helictite and acicular crystals
Calcite	$CaCO_3$	white colored flowstone, soda-straw, stalactite, column and cave coral
(Oxide)		
Goethite	$FeO(OH)$	brown colored coating and crust
(Silicates)		
Clinochlore	$(Mg,Fe)_5Al(Si_3Al)O_{10}(OH)_8$	bluish green crystal
Illite	$(K,H_2O)(AL,Mg,Fe)_2(Si,Al)_4O_{10}((OH)_2,H2O))$	pale brown and brown colored crust and clay
(Sulfates)		
Brochantite	$Cu_4SO_4(OH)_6$	greenish blue and brown colored flowstone, curtain and microgour
Glaucocerinite	$CuAl_2SO_4(OH)_{12} \cdot 3H_2O$	greenish blue and brown colored flowstone, curtain
and microgour		
Gypsum	$CaSO_4 \cdot 2H_2O$	transparent tabular crystal
(sulfide)		
Pyrite	FeS_2	greenish blue and brown colored flowstone

Conclusive Remarks

The hybrid Kiinyuugawa-dam Cave is peculiarly hybrid cave system in Japan which linked with the closed mine cave (artificial cave) and the entraceless natural tectonic (creep type landslide) cave.

The natural tectonic cave contains normal speleogenic carbonate minerals (aragonite and calcite) originate from meteoric water and calcite veins in the black slate. The entranceless closed mine cave (artificial cave) speleogenesis that oxide (goethite), silicates (clinochlore and illite), sulfates (Brochantite, glaucocerinite and gypsum) and sulfide (pyrite) minerals resulted from the action of ore leachate on the walls of greenstones.

References

Hill. C. A. and Forti, P., 1997, Cave minerals of the World, Second Edition. 463p. National Speleological Society. Hunsvile.

Kashima, N. and Hisatomi, K., 2002, Speleominerals in Kiinyugawa-dam Cave, Wakayama Prefecture. Proceedings of the Nishini-hon Branch Geological Society Japan, 121, 13. (In Japanese)

Kurimoto, C., 1982, "Chichibu System" in the area southwest of Koyasan, Wakayama Prefecture-Upper Cretaceous Hanazono Formation-. Jou. Geol. Soc. Japan, 88, 901-914.

Nakazawa, K., Ichikawa, K. and Ichihara, M. eds., 1987, Regional Geology of Japan. Part 6. Kinki. Kyoritsu Shuppan Co. Ltd. Tokyo. (In Japanese)

O-28

Activators of Luminescence of Speleothems- Organic versus inorganic.

Y. Y. Shopov

Faculty of Physics, University of Sofia, James Bourchier 5, Sofia 1164, Bulgaria • E-mail: YYShopov@Phys.Uni-Sofia.BG

Abstract

This work summarizes main results of the operation of the International Program "Luminescence of Cave Minerals" of the commission on Physical Chemistry and Hydrogeology of Karst of UIS of UNESCO in the field of activators of speleothem luminescence. It discusses Activators of Luminescence in Speleothems as a source of major mistakes in the interpretation of luminescent paleoclimatic records. It demonstrates existence of 6 types of luminescence of speleothems and cave minerals in dependence of the type of the luminescence center and its incorporation in the mineral. 24 different activators of photoluminescence of speleothem calcite and 11 of aragonite are studied. This paper demonstrates that it is impossible to produce reliable Paleotemperature or Past Precipitation records from luminescence of speleothem without establishing the organic origin of the entire luminescence of the particular sample.

Introduction

Absorption of excitation energy by a mineral leads to rising of electrons from ground state to an excited level. Sooner or later these electrons falls down to a lower level while emitting light. If the emission proceeds only during the excitation than it is called "fluorescence", if it proceeds later (usually seconds or minutes) than it is called "phosphorescence". In the later case falling of electrons from the excited state proceeds through intermediate levels (thus taking more time), so the energy of the emitted light is less than the energy of fluorescence (i.e. colour of the emitted light is shifted to the red). Some luminescent centers produce only fluorescence, but other both fluorescence and phosphorescence of minerals.

The type of luminescent centers determines the colour of luminescence. Colour may vary with changes of the excitation sources, because they may excite different luminescent centers existing in the mineral. Every luminescent center has its own excitation spectra Shopov, 1986), temperature dependence and conditions of excitation. One colour of luminescence sometimes may be produced by a single luminescent center or by a combination of two or several centers. The decay rate of luminescence (time for visible disappearance of the luminescence afterglow after switching off the excitation source) may vary from virtual zero for fluorescence to minutes or hours for phosphorescence. It is also characteristic for every luminescent center. Brilliance (brightness) of luminescence is function of the concentration of luminescence centers. It is almost linearly proportional to concentration of luminescent centers in transparent or white calcite, but can be substantially decreased by light absorption in colour centers of clay and other coloured inclusions or colour admixture ions in less-pure calcite.

Easiest and the most efficient method of excitation is irradiation by UV light sources producing photoluminescence and when luminescence is usually spoken about it is with this kind of excitation in mind. Phosphorescence of speleothems in caves can be seen by irradiating of speleothems with a photographic flash with closed eyes, with following rapid opening of the eyes after flashing. This simple technique is useful for the previous diagnostics of cave mineral and the selection of samples for laboratory analysis. Such "Visual Luminescent Analysis" (VLA) has been widely used in caves (TARCUS, 1981), usually with a photographic flash but also with other simple devices such as portable UV lamps with short wave UV (SWUV) and long wave UV (LWUV). However data obtained by the VLA method are subjective and the determination of luminescence activators is not possible. In fact attempts to determine activators of the luminescence with VLA and chemical analysis leads to incorrect results.

It is known that almost 50 cave minerals have the capacity for exhibit-ing luminescence, but only 17 had been actually observed to be luminescent in speleothems so far (Shopov, 1997).

This paper summarizes main results of operation of the operation of the International Program "Luminescence of Cave Minerals" of the commission on Physical Chemistry and Hydrogeology of Karst of UIS of UNESCO in the field of activators of speleothem luminescence (Shopov 1989a).

Origin of luminescence of Speleothems

Many speleothems exhibit luminescence when exposed to ultraviolet (UV) or other light sources. In dependence of the type of the luminescence center and its incorporation in the mineral we distinguish following types of luminescence of speleothems and cave minerals:

1. Luminescence of electron defects of the crystal lattice:

Such type is the luminescence of CO_3^{3-} ion in speleothem calcite under UV or electron beam excitation (Ugumory & Ikeya, 1980). It probably exists in any speleothem, but have lower quantum gain than the other types of luminescence in speleothems, so can be observed only in their absence. In cathodoluminescence petrography it is called "background luminescence". It is as intensive as older is calcite (Ugumory & Ikeya, 1980), because this center is produced only by ionising radiation from decomposition of natural radio- nuclides and have lifetime of millions of years. In ion crystals (such as chloride, fluorite or sulphide minerals) luminescence of this type is produced by admixtures of metal ions substituting the cations in the crystal lattice of the minerals. In this case the admixture cation must have different valency than the structural cations (Marfunin, 1979), so it cause compensation of the charge by trapping of free electrons or traps (which are activators of the luminescence of ion crystals).

2. Luminescence of admixture ions substituting structural ions in the crystal lattice or incorporated in cavities of this lattice:

Such type is the luminescence of most known luminescent centres in calcite, which are inorganic ions: Mn^{2+}, Fe^{3+}, Pr^{3+}, Tb^{3+}, Er^{3+}, Dy^{3+}, Eu^{2+}, Eu^{3+}, Sm^{3+} and Ce^{3+} (Tarashtan, 1978, Marfunin, 1979, Gorobets, 1981, Shopov, 1986, Shopov et al., 1988, Richter et al., 2003). This type of luminescence increases its intensity with decreasing of the temperature. This kind of luminescence exhibits strong quenching by Fe^{2+}, Ni and Cu-ions substituting structural cations in the crystal lattice, which adsorb the luminescence emission and re- emit it in the infrared region of the spectra (Marfunin, 1979).

3. Sensitizes luminescence of admixture ions substituting structural ions in the crystal lattice:

Pb^{2+} have UV luminescence in calcite with no visible emission but it sensitizes the luminescence of Mn^{2+}, which produce short-time orange-red phosphorescence in hydrothermal calcites (Marfunin, 1979, Shopov, 1997). Such sensitized luminescence of these ions can be observed only if both they substitute a structural cation in the crystal lattice. Mn^{2+} in calcite does not have strong absorption lines in UV, so it does not exhibit luminescence in infiltration calcites. Pb^{2+} have very strong UV- absorption lines in calcite and transfer its excitation energy to Mn^{2+} through the crystal lattice. It produces strong orange-red phosphorescence of Mn^{2+} in calcite. This type of luminescence decreases its intensity with decreasing of the temperature, due to the reduction of the energy transfer through the temperature vibrations of the crystal lattice.

4. Luminescence of molecules, ions or radicals adsorbed inside of the lattice:

Such luminescence can be produced both by:

a. inorganic (like uranil ion- UO_2^{2+}) or

b. organic molecules (Tarashtan, 1978, Shopov, 1986, Shopov et al., 1988, White and Brennan, 1989, Shopov, 1997, 2002). In some cases they both produce luminescence of the same speleothem (fig.1).

This type of luminescence decreases its intensity with decreasing of the temperature, because energy transfer through the crystal lattice became impossible at low temperatures.

Usually luminescence of organics in speleothems is attributed to fulvic and humic acids (White and Brennan, 1989) but free acids could not exist in the alkaline karst environment. They react with the limestone producing their calcium salts in which form they exist in speleothems. The process of their chemical extraction from speleothems in order to study them converts them in free fulvic and humic acids.

Luminescence organics in speleothems can be divided to 4 types:- (1) Calcium salts of Fulvic acids, (2) Calcium salts of humic acids, (3) Calcium salts of huminomelanic acids (Shopov, 1997) and (4) Organic esters (Gilson et al., 1954). All these four types are usually present in a single speleothem with hundreds of chemical compounds with similar chemical behavior, but of different molecular weights. Concentration distribution of these compounds (and their luminescence spectra) depends on type of soils and plants over the cave, so the study of luminescent spectra of these organic compounds can give information about paleosoils and plants in the past (White, Brennan, 1989). Changes in visible colour of luminescence of speleothems suggesting major changes of plants society are observed very rare.

5. Luminescence of inclusions of other minerals:

Inclusions of other luminescent minerals can produce luminescence inside calcite speleothems. Most frequently these are inclusions of moon milk minerals. Such is also the green-yellow luminescence of magursilite clusters (Tarashtan, 1978) in speleothem calcite (Shopov, 1989b).

6. Luminescence of fluid or gas inclusions- Gas inclusions containing oil and gas products (hydrocarbons) had been observed to produce blue fluorescence and phosphorescence in speleothem calcites from Gaudalupe Mts., USA under SWUV or flash excitation (Shopov, 2001), but orange fluorescence under LWUV excitation.

All six types of luminescence centers are observed to produce luminescence of speleothem calcites under UV excitation.

Different types of excitation may excite different luminescent centers. Some or all of them may luminesce in a single speleothem (Shopov, 1997, 2001, Richter et al., 2003).

Activators of Luminescence as Source of Mistakes in Interpretation of Luminescent Paleoclimatic Records

Recently some researchers attribute all luminescence in calcite speleothems to organics (e.g. Baker et al, 1993) without any reason to do so. But 14 (58% of all known) activators of speleothem luminescence are inorganic. Minerals are not pure chemical substances and contain many admixtures. Usually several centres activate luminescence of one sample (table 1) and the measured spectrum is a sum of the spectra of two or more of them (fig.1). Luminescence of minerals formed at normal cave temperatures (below 40° C) is usually (but far not always) due mainly to molecular ions and absorbed organic molecules. Luminescence of uranil- ion (UO_2^{2+}) is also very common (fig.1) in such speleothems (Shopov, 2001). Luminescence of other inorganic ions sometimes dominate luminescence spectrum of speleothems.

Before 1983 all luminescence in calcite speleothems was attributed to inorganic ions (Kropachev et al. 1971, Mitsaki, 1973, Slacik, 1977,

Turnbull, 1977, Ugumory & Ikeya, 1980, Rogers and Williams 1982, Hill and Forti, 1986)

All paleoenvironmental luminescence (paleoluminescence) methods (Shopov, 2004) use only luminescence of organics in Speleothems. Therefore it is necessary to determine that all luminescence of the sample is due to organics before using a speleothem for any paleoenvironmental work. Detailed spectral measurements of the luminescence are absolutely necessary to determine luminescent compounds in any speleothem. This requires the use of a luminescence spectrometer, plus an Electron Spin Resonance (ESR) spectrometer or chromatograph (Shopov, 1989a,b). Lasers and Raman spectrometers used for measurements of luminescent spectra allow also determination of the luminescent mineral or inclusion in the speleothem, because the narrow Raman lines appearing in luminescence spectra at high resolution scanning are characteristic for different minerals.
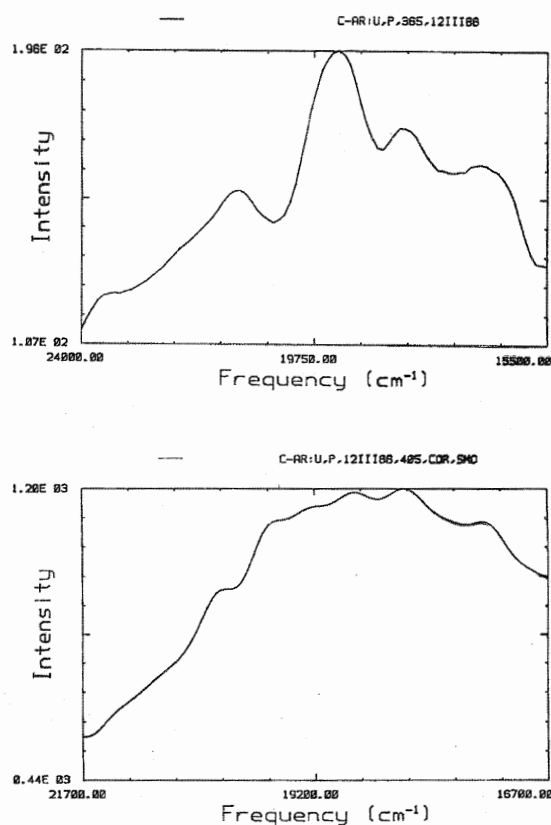
Figure 1. Luminescence of speleothem calcite under excitation by 365 nm (up) and 405 nm (down) lines of Hg- lamp. The narrow lines of luminescence in both spectra are produced by uranil- ion (UO_2^{2+}) while the broadband luminescence is due to organics. UV excitation of UO_2^{2+} is far more efficient than this of organics so it predominates in the spectra at 365 nm excitation.

In many calcite speleothems all or a significant part of the luminescence is produced by inorganic ions (Shopov, 1986, Shopov et al., 1988). Sometimes they even have annual banding (photo 1) due to variations of acidity of the karst waters, causing variations of the solubility of some inorganic luminophores (Shopov, 1997). Uranium compounds have such migration behavior. We found some speleothems demonstrating fine fluorescence banding produced by uranium impurities in the speleothem

(photo 1) under short-wave UV light (Shopov, 2002). Fine fluorescence banding under long-wave UV light is produced by rare earth elements in the same sample. This banding can be annual or even sub- annual. Such luminescence banding is usually considered to be annual (if produced by organics) and have a number of paleoclimatic and dating applications (Shopov et al., 1997). Phosphorescence of this sample (not shown) suggests that there are no any luminescent organics in the middle (darker) part of the speleothem, but there are some in the outer part of the sample.

Statements that Sr causes violet luminescence of carbonate speleothems (e.g. Kropachev et al. 1971), Zn greenish- white luminescence of calcite stalactites (Turnbull, 1977) and Cu- causes pale-green and blue luminescence of calcite and aragonite (e.g. Rogers and Williams 1982) are in error. Sr and Zn- ions do not have electron transitions in the visible region of the spectra and therefore cannot activate luminescence in carbonates, but Cu is known to cause quenching (reduction of luminescence) induced by other cations (Tarashtan 1978). Cu^{2+} can excite only infrared luminescence of some sulfides. Also, interpretations of the visible luminescence of calcite as Pb- activated (Slacik, 1977) are not correct, because Pb in calcite emits only UV light (Tarashtan 1978, Shopov et al. 1988). Such wrong interpretations had been obtained by correlation of the intensity of luminescence with the concentration of these elements in speleothems without proper measurements of spectra of their luminescence.

Luminescence of the high- temperature hydrothermal minerals is due mainly to cations because molecular ions and molecules destruct at high temperatures. The orange-red luminescence of Mn^{2+} in calcite (table 1) sensitized by Pb^{2+} can be observed only in hydrothermal calcite, because Pb^{2+} has very big ion radius and can substitute Ca^{2+} in the crystal lattice of calcite only at high temperatures, so it can be used as an indicator of the hydrothermal origin of the cave mineral (Shopov, 1989 a, b). Therefore, if calcite has only orange-red, short time phosphorescence, it is sure to have

formed in high-temperature, hydrothermal solutions (>300° C). But if it has long-time phosphorescence in addition to the red- orange one, then it is a low-temperature hydrothermal calcite (Shopov, 1989a,b). Calcites formed by low-temperature hydrothermal solutions have fluorescence or short-life phosphorescence due to cations and long phosphorescence due to molecular ions (Gorobets, 1981). Minimal temperature of appearance of this orange- red luminescence was estimated to be of about 40^0C by Dublyansky (in press) by fluid inclusion analysis in hydrothermal cave calcites, but our direct measurements of luminescence of calcites in hot springs shows that even at 46^0C such luminescence do not appear (Petrusenko et al., 1999). It probably appears at over 60^0C. Luminescence of hydrothermal calcite formed at lower temperatures looks similar to usual speleothem luminescence (photo 1). Such luminescence data visualize the changes of the temperature of mineral forming solutions and are comparable with the stable isotope data used conventionally for this purpose (Bakalowicz et. al., 1987, Ford et al., 1993).

Conclusions

Before using of any speleothem for paleoenvironmental luminescence measurements it is necessary to determine that all luminescence of the sample is due to organics. Otherwise interpretation of the data can be completely wrong and there is no way to prove or disapprove it without further measurements on the same sample to establish the organic nature of all its luminescence.

Acknowledgements

123

Table 1. Activators of Luminescence of Speleothems

Luminescence activator	Excitation	Emission color	After glow	Origin	Reference
Calcite:					
1.Esters	Hg-lamp	blue	long	infiltration	Gilson et al. (1954)
2.Organics,	N_2-Laser	blue	long	infiltration	Shopov et al. (1983)
3.Calcium salts of Fulvic & humic acids	Ar-L., Xe	yellow-green	long	infiltration	Shopov et al. (1989)
4.Fulvic& humic acids	SWUV	blue-green	long	infiltration	White, Brennan (1989)
5.Organics	Ar-L., Xe -lamp	blue-green	long	infiltration	Shopov (1989b)
6.Organics	N_2-Laser	yellow-green	long	infiltration	Shopov (1989b)
7.Organics	LWUV, Hg	yellow	long	infiltration	Shopov (1989b)
8.Organics	SWUV, LWUV	yellow-orange	long	infiltration	White, Brennan (1989)
9. CO_3^{3-}	N_2-Laser	blue		infiltration	Ugumory, Ikeya (1980)
10.UO_2^{2+}	SWUV	green	no	infiltration	White, Brennan (1989)
11.UO_2^{2+}	N_2-L., Hg -lamp	green	no	infiltration	Shopov (1989b)
12.$UO2^{2+}$ (magursilite?)*	N_2-L., Hg -lamp	green- yellow	no	infiltration	Shopov (1989b)
13.Organics	Hg, Xe -lamp	bluish	<15s	hydrothermal	Shopov et al. (1996)
14. *Mn^{2+}	Ar-L, N_2-L., Xe	orange-red	0.1s	h-t.hydrothermal	Mitsaki,1973;White,1974
15. *Hydrocarbons	Xe -flash lamp	violet	long	epithermal	Shopov et al (1996)

16.Fe^{3+}	Ar- Laser	dark- red		? hydrothermal	Shopov, 1988
17.Pb^{2+}	SWUV	UV		hydrothermal	Shopov, 1985
18-24*. Rare Earth Elements $^{3+}$-ions	LWUV, SWUV electrons	various		?	Shopov, 1985, 1988 Richter (2002)
Aragonite:					
25.Organics	Hg-lamp	blue	long	infiltration	Shopov (1989b)
26.Organics	Hg-lamp	blue-green	long	infiltration	Shopov (1989b)
27.Organics	N_2-Laser	blue-green	long	infiltration	Shopov (1989b)
28.Organics	N_2-Laser	green	long	infiltration	Shopov (1989b)
29.Organics	Hg-lamp	yellow	long	infiltration	Shopov (1989b)
30.Organics	SWUV, LWUV	blue-green	long	infiltration	White, Brennan (1989)
31. UO_2^{2+}	SWUV	green	no	infiltration	White, Brennan (1989)
32. ?	Hg (LWUV)	orange	?	?	White, Brennan (1989)
33.Mn^{2+}	LWUV, e-beam	yellow-green	short	?	Shopov, 1988
34.Sm^{3+}	LWUV, e-beam	red		?	Shopov, 1985
35.Eu^{2+}	LWUV, e-beam	blue		?	Shopov, 1988

Comments to table 1:

* - luminescence of Rare Earth elements in calcite is well described in (Tarashtan, 1978, Shopov, 1986, Shopov et al., 1988, Richter, 2002), so is not included in the table

*12- Tarashtan (1978) attributed this spectrum of luminescence to luminescence of clusters of the mineral magursilite adsorbed in calcite;

*14- also in (Shopov et al., 1988, White and Brennan 1989)

*15- hydrocarbons present only in fluid inclusions in calcite, formed 1 km below the surface by waters heated by Earth thermal gradient (epithermal solutions) in a cave in Carlsbad Caverns region. Guadeloupe Mts., New Mexico, US (Shopov et al., 1996)

124

References

BAKALOVICZ M., FORD D.C., MILLER T.E., A.N. PALMER M..V. PALMER. 1987 Thermal genesis of dissolution cave from Black Hills, South Dakota.- GSA Bulletin, 99: 729-738.

BAKER,A.,SMART, P.L., EDWARDS, R.L., RICHARDS, D.A, 1993, Annual Growth banding in a cave stalagmite. Nature, 304: 518-520.

DUBLYANSKY Y.V. (in press) Luminescence of calcite from Buda Hill caves

FORD D.C., BAKALOVICZ M., MILLER T.E., A.N.PALMER M..V. PALMER (1987) Uranium series dating of the draining of an aquifer: an example of Wind cave Black Hills, South Dakota.- GSA Bulletin, v.105, pp. 241- 250.

GILSON, R.J., AND MACARTHNEY, E. 1954 Luminescence of speleothems from Devon, U.K.: The presence of organic activators: Ashford Speleological Society Journal, 6:8.(abstr.)

GOROBETS B.S. 1981 Atlas of Spectra of Luminescence of Minerals. VIMS, Moskow. (in Russian)

HILL C., FORTI P. 1986 Cave Minerals of the World., 1-edition, NSS, Huntswille, Alabama, USA, 238p.

KROPACHEV A.M., GORBUNOVA K.A., TZIKIN V.Y. 1971 Metachromatism and luminescence of the carbonate speleothems from the caves of Bashkiriya form Krasnoyarks region- Peshtery, 10-11:74-80. In Russian

MARFUNIN A. S. 1979 Spectroscopy Luminescence and Radiation Centers in Minerals. Berlin, Springer-Verlag, 352 pages.

MITSAKI V. 1973 Geochemical study of some spesimens of stalactites from Tourkovonia cave, Athens. Deltio, v.12, 3: 90-95

PETRUSENKO S., SHOPOV Y., A. KUNOV 1999 Micromorphologic Peculiarities and Typomorphic Luminescence of Calcites from Bulgarian Deposits of Various Genesis.- Proceedings of The National Scientific Conference on New Achievements and Actual Problems of Karstology and Speleology in Bulgaria, March 25- 28, 1999, Sofia, pp. 75- 81.

RICHTER D.K., GOETTE TH., NIGGEMANN S., WURTH G. 2003 Cathodoluminescence of Carbonate Speleothems: State of the Art In: Karst and Environment. Carrasco F., Duran J.J., Andreo B. (Eds.), 381- 387.

ROGERS B.W., WILLIAMS K.M. 1982 Mineralogy of Lilburn cave, Kings Cannion National Park, California. NSS- Bulletin, v.44, 2: 23-31

SHOPOV Y.Y., SPASOV V.A. 1983 Speleological Applications of Physical Methods for analysis of solids.- Abstracts of the First National Congress of the Physicists in Bulgaria (Sofia, 28 IX- 1 X 1983): 193.

SHOPOV Y.Y. 1986 Applications of photoluminescence in Speleology.- Bulgarian Caves, 4: 38-45.

SHOPOV Y.Y., IVANOV G.I.,KOSTOV R.I. 1988 Phase Analysis of the Polymorphic modifications of $CaCO_3$ by spectra of its photo- luminescence. In: Spectral Methods for solving of Problems of the Solid State Physics, Scientific Commission on "Atomic and Molecular Spectroscopy" of Academy of Sciences of USSR, Acad. Sci. Press, 1988, Moskow, pp.191-201 (in Russian).

SHOPOV Y.Y. 1989a Bases and Structure of the International Programme "Luminescence of Cave Minerals" of the Commission of Physical Chemistry and Hydrogeology of Karst of UIS.-Exped. Annual of Sofia University, 3/4:111- 127.

SHOPOV Y.Y. 1989-b Spectra of Luminescence of Cave Minerals. Expedition Annual of Sofia University, 3/4:80-85.

SHOPOV Y.Y., L.TSANKOV, M. BUCK, D.C. FORD 1996 Time Resolved Photography of Phosphorescence- A New Technique for Study of Thermal History and Uplift of Thermal Caves.- Extended abstracts of Int. Conference on "Climatic Change- the Karst Record", 1- 4 August 1996,

Bergen, Norway. Karst Waters Institute Special Publication 2: 154.

SHOPOV Y.Y. 1997 Luminescence of Cave Minerals: 244-248 In: C.HILL, P. FORTI (Eds.)- Cave Minerals of the world, second edition, NSS, Huntsville, Alabama, USA

SHOPOV Y.Y. 2001 Luminescence of Cave Minerals. - Boletín de la Sociedad Venezolana de Espeleología. N° 35, pp.27-33.

SHOPOV Y. 2002 Influence of the Solar Luminosity on the Glaciations, Earthquakes and Sea Level Changes.- 4th International Cave Symposium on "The Sustainable Development of Cave: Academic and Policy Implications", Samcheok, Korea: 65-73 (in English): 195- 203 (in Korean)

SHOPOV Y. 2004 20 Years of Speleothem Paleoluminescence Records of Environmental Changes: An Overview- in the same volume.

SLACIK, J. 1977. Luminescence analysis in speleology. Proc. 7th Int. Cong. Speleol. Sheffield: 31-36.

TARASHTAN A.N., 1978, Luminescence of minerals. Naukova Dumka, Kiev (in Russian)

TARCUS-CSSR 1981 Bibliography of working groop of the CSS ZO 1-O5 GEOSPELEOS for 1973-1980. Prague CSS, 31 pp.

TURNBULL I. C. 1977 Zinc: an activator of fluorescence in cave calcite. Fluorescent. Min. Soc. Jour., v.6, p. 58- 60.

UGUMORI, T.,IKEYA M. 1980, Luminescence of $CaCO_3$ under N_2- Laser excitation and application to archaeological dating: Japanese J.Appl.Physics, v.19(3): 459-65.

WHITE, W.B. 1974. Determination of Speleothem growth mechanism by luminescence spectrography. Geo^2, 3(3): 37.

WHITE W.B, BRENNAN E.S. 1989 Luminescence of speleothems due to fulvic acid and other activators.- Proceedings of 10th International Congress of Speleology, 13-20 August 1989, Budapest, 1: 212- 214.
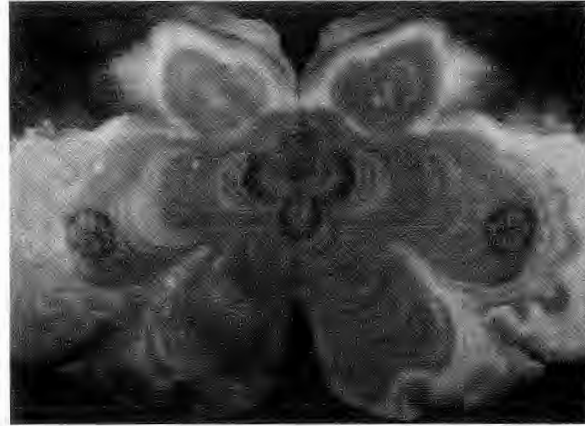
Foto 1. Annual (?) banding of luminescence of uranil- ion and rare earth elements in a calcite flowstone due to variations in pH of the water (Luminescence of a section of a calcite coralloid from a cave near Irkutsk, Russia). Fine fluorescence banding under short-wave UV light (left) is produced by uranium impurities (UO_2^{2+}) in the speleothem. Fine fluorescence banding under long-wave UV light (right) is produced by rare earth elements in the same sample (right and left images are mirror images of the same sample).
Photo by Yavor Shopov.

O-29

An introduction to genetic mineralogy and the concept of "ontogeny of cave minerals"

CHARLES A. SELF
4 Tyne Street, Bristol, BS2 9UA, England; self@globalnet.co.uk
CAROL A. HILL
17 El Arco Drive, Albuquerque, NM 87123, USA; carolannhill@aol.com

Abstract

The "ontogeny of minerals" is the study of individual crystals and their aggregates as physical bodies rather than as mineral species. The genetic approach to mineralogy has been developed in Russia over the last 80 years, but is poorly understood (if at all) in the West. Although ontogeny as a subject had its origins in the Russian mining industry, caves prove to be ideal settings for ontogeny studies because, while there are few common mineral species in caves (mainly calcite, aragonite, and gypsum), there is a great variety in the speleothem forms that these minerals can take. This paper introduces the basic principles of minerals ontogeny and explains a hierarchy classification scheme whereby mineral bodies can be studied as crystal individuals, aggregates of individuals, association of aggregates (termed koras by the Russians), and as sequences of koras (ensembles). The importance of minerals ontogeny is that, just by looking at the physical organization of a simple minieral body, its environment of deposition can often be deduced.

Introduction

The study of the origin and evolution of mineral bodies is termed genetic mineralogy and includes nucleation, initiation (on a growth surface), development, alteration, and disintegration. Genetic mineralogy was formulated in Russia as a separate field of study within mineralogy during the 1920s (Fersman, 1935), and by the 1950s Grigor'ev (1961) had divided genetic mineralogy into two separate branches: ontogeny and phylogeny (these terms are familiar from biology and are used in a broadly similar sense by Russian mineralogists). Ontogeny is the study of individual crystals (mineral individuals), how these crystals combine as aggregates, and their development as physical bodies ("minor mineral bodies"). Phylogeny is the study of mineral species and their paragenesis (i.e., their association with contemporaneous mineral species). Phylogeny closely corresponds to the Western view of genetic mineralogy, whereas ontogeny (and even the term itself) is unfamiliar to most Western mineralogists. However, this line of study has become a well-established science in Russia.

Ontogeny as a concept is important to mineralogy because the same mineral species can display different physical forms, depending on the specific environment in which growth occurs. In caves, it is possible to study the different forms of speleothems together with their depositional environments. This has resulted in a large number of mainly descriptive mineralogy texts, such as Cave Minerals of the World (Hill and Forti, 1997). It is now necessary to study cave mineralogy from a genetic perspective. Ontogeny explains not only how speleothems grow, but why different speleothem types exist.

Hierarchy of minor mineral bodies

Minor mineral bodies (MMBs) are simple enough to be studied purely by mineralogic techniques. They are classified according to their complexity of structure and texture. However, the hierarchy scheme of MMBs is not the same as the classification of speleothems into types and subtypes as was done by Hill and Forti (1997). "Speleothem" is a descriptive term and can only be used to indicate the morphology of a MMB. The hierarchy scheme for MMBs is outlined in Table 1.

Only the most important of these MMBs are discussed herein; for a more detailed discussion of this topic refer to Self and Hill (2003). In Table 1, the term level is used when MMBs of one level are built from MMBs of a previous level or levels.

Order is used as a subdivision within a level and shows the level of complexity of the MMBs. Second-order MMBs are built from MMBs of the previous level, but in a more complicated manner than first-order MMBs. For example, multiaggregates (level 2, second order) are not built from aggregates (level 2, first order); they are built from individuals (level 1, either first or second order), but in a more complicated manner.

(0) ZERO LEVEL: Subindividuals. The fundamental building block for all minor mineral bodies is the mineral individual (level 1). Simple (first-order) individuals are single crystals having no structure other than a crystallographic network. More complex (second-order) individuals, on the other hand, are composed of a number of different crystalline units known as *subindividuals*. Subindividuals also have no structure except for their crystallographic network, but they are at least partly separated by free space or a line of dislocation from neighboring crystal blocks. Inasmuch as subindividuals do not exist independently from each other, they are ascribed to a hypothetical "zero level" in the MMB hierarchy. A zero level is needed because complex (second-order) MMBs of the first level must be formed from MMBs of a previous level, not from first-order MMBs of the same level. Subindividuals (in the sense used here) are termed *crystallites* by some mineralogists, but in ontogeny the preferred use of this term is for the initial stage of crystallization of mineral individuals.

1.(1) FIRST LEVEL: Mineral Individuals. Individuals are mineral bodies that grow from a single crystal nucleus or embryo (crystallite), during one phase of crystallization, and which have a "through" crystallographic structure (Godovikov et al., 1989). Crystallites are minute crystal grains that represent the initial stage of crystallization, and which act as seeds for further crystal growth. When crystallites are widely separated from each other, they grow freely into separate first-level mineral individuals. But when they grow close together, there is competition for growth space and a second-level MMB (a mineral aggregate) is formed. It should be emphasized that mineral individuals are not speleothems (except in a few special cases): they are the building blocks from which speleothems are made.

(1.1) First-Order Individuals. In the simplest case, mineral individuals are single crystals having no other structure except a standard crystallographic network, which is determined by the mineral species itself. First-order individuals can be described by their isometric, columnar, acicular, filamentary, or tabular habit, or by their euhedral, subhedral, or anhedral form. An example in a cave would be an individual calcite spar (non-druse) crystal.

(1.2) Second-Order Individuals. Second-order individuals are single crystals that subdivide or split into a number of subindividuals, single crystals that have their growth inhibited on some crystal faces or edges, single crystals that incorporate crystallites into their crystal lattice, or single crystals that are twinned (Shafranovskiy, 1961). In some cases second-order individuals can look as if there is a co-growth of several crystals, but this is an illusion. Subindividuals of second-order individuals are not separate from each other: they grow from the same nucleus and have a joined crystallographic network (Fig. 1). Second-order individuals grow

in response to certain environmental conditions, particularly oversaturation - a common occurrence in caves due both to $CO2$ loss and evaporation of thin films.

(1.2.1) Split Crystals. When a crystal individual splits apart during growth, it forms a number of subindividuals, a sheaf-like structure, or in its final form, a spherulitic structure (Fig. 2). Different minerals have a different "splitting ability" depending on their crystal structure. Aragonite has a higher splitting ability than calcite under usual cave conditions, and therefore it is almost always found in caves as split acicular crystals. Splitting may be due to a crystal receiving extra molecules in its layers (mechanical splitting), or to when certain ions (e.g., Mg as well as Ca) are present in the parent solution (chemical splitting) (Grigor'ev, 1961). According to the level of supersaturation or impurity concentration (which can change during growth), splitting will take on different grades, which results in a number of subforms for split crystals.

(1.2.1A) Spherulites. Spherulites are second-order individuals having either a radial or curving radial structure due to the splitting of crystals. If growing in free space, they are spherical in form; if nucleated on a substrate, they grow as hemispheres. Spherulites are composed of straight subindividuals, but often the subindividuals themselves continue to split. If part of the growth surface becomes mechanically blocked, the unobstructed "rays" will continue their growth in the form of a new spherulite. This composite body is still a mineral individual, not an aggregate.

Spherulites are widespread in caves as components from which many speleothems are built.

(1.2.1B) Spherulite Bunches. Spherulite bunches are composed of subindividuals that grow from a single nucleus to form a stalk (a well connected bunch) or a splay of crystals (a poorly connected bunch). This shape depends on the growth speed of crystals: slow growth results in well connected bunches, fast growth in poorly connected splaying bunches. Examples of speleothems built from spherulite bunches are most kinds of helictites and some kinds of anthodites and frostwork. Spathites and beaded helictites are sequences of spherulite bunch splays, with new bunches growing from subindividual "rays" of the previous bunch in the manner of a daisy chain.

(1.2.1C) Discospherulites. Discospherulites are spherulites that have preferred crystal growth in two, rather than three, dimensions. Some kinds of cave rafts display discospherulitic growth, where the surface of a cave pool confines crystal growth to a plane and supersaturation allows for split growth.

(1.2.1D) Spheroidalites. Spheroidalites are spherulites with nonsymmetrical structure (Godovikov et al., 1989). They have elongated and curved subindividuals, whereas spherulites have straight subindividuals. Most coralloids display spheroidalitic growth.

(1.2.1E) Spherocrystals. Spherocrystals are chemically split second-order individuals, so perfectly split that boundaries between subindividuals are at a molecular level, and physical properties (such as cleavage) become generalized across the whole crystal (Shubnikov, 1935). This results in growth surfaces that are smooth and bright in appearance (e.g., botryoidal malachite or chalcedony; Fig.3). Although spherocrystals are composed of subindividuals, the separate fibers are not visible even under microscopic examination. However under crossed nicols (polarizers), spherocrystals display a "Maltese cross" extinction.

2.(2) SECOND LEVEL: Mineral Aggregates. Mineral individuals very seldom occur singly; they grow multiply over a substrate surface as mineral aggregates. Aggregates are much more than simply a group of individuals of the same mineral species growing together: interaction between individuals directly affects and limits the growth of each crystal. During such "group" or "common" growth, there is competition between the mineral individuals constituting the aggregate. Most speleothems are mineral aggregates.

Most aggregates form where growing individuals compete for space

126

by physically contacting one another. In such a situation, contact faces develop between neighboring individuals, leaving a group growth front comprised of the crystallographic terminations of many individuals. However, aggregates do not necessarily have to be in direct physical contact for competition to occur. An example of indirect competition for the supply solution is when growth is in a plastic substrate such as porous clay, where interaction between crystals is due to the closure of feeding pores in the clay as a result of crystallization pressure. When growth is in a capillary film environment, there is competition for the loss of solvent molecules and interaction is by convection of water vapor and CO2 between individuals. The mineral individuals constituting an aggregate have contact faces when they are in direct competition, but display true crystal faces when they are in indirect competition.

Competitive growth on a substrate surface normally leads to a reduction in the number of individuals constituting the aggregate, a situation called selection. The most influential process during the early stages of crystal growth is geometric selection. The crucial elements of geometric selection are (Fig. 4): (1) initiation of separate centers of crystallite growth, (2) the beginning of competition of these crystal individuals for growth space, (3) selection and a reduction in the number of competing individuals according to a geometric rule, and (4) continued growth with no further selection. There are several geometric rules for selection, but perpendicularity to the substrate is the most common. This rule applies to most mineral veins and to many common varieties of speleothems (e.g., dripstone, flowstone, pool spar).

(2.1) First-Order Aggregates. In ontogeny, first-order aggregates are simply termed aggregates, while second-order aggregates are termed multiaggregates. Aggregates can be defined as intergrowths or co-growths of individuals (either first- or second-order) of the same mineral species, which develop simultaneously on a common growth surface and which possess a homogeneous texture. Texture is the distinctive pattern of crystal boundaries that is produced by competitive growth. Aggregates are subdivided according to their texture.

(2.1.1) Parallel-Columnar Aggregates. Examples of parallel-columnar texture, sometimes known in the West as "palisade fabric" (Folk, 1965), dominate the collections of amateur mineralogists. Mostly these are groups of crystals with well-formed terminations, taken from vugs in simple mineral veins. If visible to the naked eye, these crystal aggregates are called druses, where each crystal is a mineral individual within a composite aggregate of crystals. These individuals only have crystallographic faces on their end terminations, with their sides being contact surfaces with other individuals (Fig. 4). Each druse crystal has had to compete with other individuals, and is a survivor of geometric selection at the aggregate druse growth front.

(2.1.2) Spherulitic Aggregates. Spherulitic texture is a variant of parallel-columnar texture whereby the substrate, instead of being flat or slightly irregular, is sharply convex. Geometric selection produces crystals growing perpendicular to the substrate, but the curvature of this substrate produces a radiating fan of crystals rather than a roughly parallel growth of crystals. Cave pearls are a common type of spherulitic (core) aggregate.

(2.1.3) Radial-Fibrous Aggregates. Radial-fibrous aggregates are an important variation on both parallel-columnar

and spherulitic aggregates where some (or all) of the individuals have begun to split. They make up the texture of many speleothem types, including flowstone and dripstone. Commonly they are interlayered with parallel-columnar (or spherulitic) aggregate crystals in these speleothems (Fig. 5). The change to radial-fibrous texture is due to a decrease in solution supply in a capillary thin-film environment. If the solution supply decreases further, radial-fibrous texture may lead to interruptions in growth and/or contamination of the growth surface.

(2.1.4) Branching Aggregates. A great variety of aggregates grow by evaporation in a capillary film environment. These include corallites, crystallictites, and many intermediate forms. Branching aggregates are aggregates of crystals displaying a compound branching form. The competition in the case of branching aggregates is indirect and includes competition between nearby branches on the same bush. Molecules of solvent (water vapor and CO2) leaving one branch adhere to neighboring branches, thus slowing their growth. For this reason, competing branches never touch each other and the strongest growth is always out towards the open void of the cave (Fig. 6). For a single aggregate, there is competition between individuals but not selection. The situation changes when these aggregates grow together in close proximity. Substrate selection very strongly favors growth from protrusions, and aggregates situated there develop rapidly.

3. Less favorably situated aggregates find it increasingly difficult to lose solvent molecules, and their growth is suppressed or distorted away from nearby large bushes.

(2.1.4A) Corallites. Corallites are the product of thin capillary water films that have a condensation origin or appear because of the slow spread of water due to very weak trickling. Prime examples of corallites are thin-film-generated varieties of coralloids (popcorn and cave coral). (Note that corallite is an ontogeny term and should not be confused with the speleothem type "coralloid" of Hill and Forti, 1997.)

(2.1.4B) Crystallictites. Crystallictites are branching aggregates built from faced crystals (Serban et al., 1961; Moroshkin, 1976). They form in a capillary film environment as an analog of corallites, but without the splitting of individuals that is characteristic of corallites. The branching of crystallictites is usually noncrystallographic - it is due to branching of the aggregates themselves. A full range of intermediate forms exists between corallites and crystallictites, where different degrees of crystal splitting are displayed. Aragonite frostwork is a prime example of a crystallictite (Fig. 6).

(2.1.5) Fibrous Aggregates. Fibrous aggregates are built from filamentary individuals and grow from a porous substrate that may be solid (such as the cave walls or breakdown blocks within a cave) or plastic (such as cave sediments, particularly clays). Fibrous aggregates are always composed of soluble minerals such as gypsum, epsomite, mirabilite, or halite. The reason why no calcite "flowers" and "needles" exist is because carbonate solutions simply do not carry enough solute. The growth mechanism of fibrous aggregates is purely by evaporation of the solvent and takes place close to the ends of pores in the substrate. The unique feature of fibrous aggregates is that they grow from the base, with new growth pushing the previous growth out into the cave void. This growth mechanism means that selection between individuals is impossible and there is only competition between pores. For growth from a solid substrate, the pores feeding the center of an aggregate often have a stronger supply than those feeding the periphery, leading to different growth rates. For well connected aggregates such as gypsum flowers, this causes the aggregate to burst into separate curving "petals". For loosely connected aggregates such as hair, the fibers may become tangled so as to form "cotton". For growth from a plastic substrate such as cave clay, competition between pores leads to a very different situation. The capillary pressure and the crystallization pressure together press the substrate, causing only certain favorable pores to remain open while other surrounding pores collapse. This is a very specific type of selection for plastic substrates and explains the wide separation between individuals (e.g., selenite needles) in this environment compared with growth from a solid substrate.

(2.2) Multiaggregates. Multiaggregates are an intergrowth or co-growth of different types of aggregates that form simultaneously and syngenetically in the same crystallization environment. They can be either polymineral or polytextural, as compared to simple aggregates, which are always monomineral and texturally homogeneous. A common polymineral multiaggregate found in many caves is calcite popcorn from which grows aragonite frostwork that is often tipped with a magnesium-rich

mineral such as hydromagnesite. All three mineral species form simultaneously from the same capillary solution and in the same crystallization environment. Stalactites are a polytextural multiaggregate comprised of a monocrystalline tube with a crown of skeleton crystals, plus a spherulitic aggregate outer layer.

(2.3) Pseudoaggregates. Some speleothems are disordered and have no "through" structure. They cannot be considered as true aggregates and do not fit into the hierarchy of MMB. However, these anomalous mineral bodies can take part in the formation of higher levels of the MMB hierarchy (koras and ensembles), and so behave as if they were some form of aggregate. Such anomalous mineral bodies are called pseudoaggregates. A consistent feature of pseudoaggregates is that the original place of nucleation of any crystal individual is different from its final resting place on a substrate. This produces a chaotic arrangement of crystals, for which no "through" structure can exist. For tufaceous deposits and some types of moonmilk, the crystallization displacement is usually quite small. But in the case of cave cones, where sunken cave rafts accumulate at the bottom of a pool, this distance can be measured in meters.

(3) THIRD LEVEL: Assemblages of Aggregates. Above the level of aggregate, there seemed to be a class of MMB that had the same sense of texture as an aggregate, but lacking the structure of an aggregate. This new and more complicated type of MMB was given the name kora by Russian speleologists. A kora is an assemblage of texturally similar aggregates, growing together at the same time and in the same crystallization space, and forming under the same environmental conditions. An example is the "stalactite-stalagmite kora" where different forms of stalactites, stalagmites, draperies and flowstones grow together and simultaneously in a dripping water environment.

(4) FOURTH LEVEL: Assemblages of Koras. On the fourth hierarchy level is an ensemble. The ensemble concept is fundamentally different from that of other terms used in MMB hierarchy: it involves a cycle of regular changes through time 4.that takes place in the crystallization environment as a whole (Stepanov, 1971). An ensemble is usually described as a "diagnostic set" of minerals or speleothems or as the "mineralogic landscape" of a cave or cave passage. Each cave or cave system has only a limited number of ensembles.

References:

Fersman, A. E., 1935, Achievements of Soviet mineralogy and geochemistry during recent years, 1929-1934: Moscow-Leningrad, Izdatel'stvo A.N. SSSR. In Russian.

Folk, R. L., 1965, Some aspects of recrystallization in ancient limestones, in Pray, L. C., & Murray, R. C. (eds.), Dolomitization and limestone diagenesis: Soc. Economic Paleontologists and Mineralogists Special Publ. 13, p. 14-48.

Godovikov, A. A., Ripenen, O. I., & Stepanov, V., I., 1989, Spherolites, spherocrystals and spheroidalites: New data on minerals, "Nauka", Moscow, v. 36, p. 82-89. In Russian.

Grigor'ev, D. P., 1961, Ontogeny of minerals: Lvov, Izdatel'stvo L'vovskogo Univ. In Russian. English translation 1965, Israel Program for Scientific Translations, 250 p.

Hill, C. A., & Forti, P., 1997, Cave minerals of the world (2 nd ed.): National Speleological Society, Huntsville, AL, 463 p.

Kantor, B. Z., 1997, Besedi o mineralakh (Discussions about minerals): Nazran, Astrel, 136 p. In Russian. Republished in English 2003, as Crystal growth and development interpreted from a mineral's present form: Mineralog. Almanac, v. 6.

Moroshkin, V. V., 1976, On genesis of crystallictite types of aggregates: Novye Dannye o Mineralakh SSSR, v. 25, "Nauka", Moscow. In Russian.

Polyak, V. J., 1992, The mineralogy, petrography, and diagenesis of carbonate speleothems from caves in the Guadalupe Mountains, New Mexico: Unpublished MS thesis, Texas Tech University, Lubbock, 165 p.

Self, C. A., and Hill, C. A., 2003, How speleothems grow: An introduction to the ontogeny of cave minerals: Journal of Cave and Karst Studies, v. 65, no. 2, p. 130-151.

Serban, M., Viehmann, I., & Coman, D., 1961, Caves of Romania. Meridiane, Bucharest. Romanian, Russian, French, and German eds.

Shafranovskiy, I. I., 1961, Crystals of minerals: curved-faced, skeletal and granular forms: "Gosgeoltekhizdrt", Moscow, 230 p. In Russian.

Shubnikov, A. V, 1935, How crystals grow: Izdatel'stvo AN SSSR, Moscow-Leningrad. In Russian.

Stepanov, V. I., 1971, Crystallization processes periodicity in karst caves: Trudy Mineralogicheskogo Muzeya imini A.E. Fersmana,

Moscow, n. 20, p. 198-206. In Russian. English translation, 1999, Cave Geology, v. 2, no. 4, p. 209-220.

Table 1. Hierarchy of Minerals Ontogeny

(0) ZERO LEVEL: Subindividuals	(2.1.2B) Irregular spherulites
(1) FIRST LEVEL: Mineral individuals	(2.1.3) Radial-fibrous aggregates
(1.1) First-order individuals	(2.1.4) Branching aggregates
(1.2) Second-order individuals	(2.1.4A) Corallites
(1.2.1) Split crystals	(2.1.4B) Crystallictites
(1.2.1A) Spherulites	(2.1.5) Fibrous aggregates
(1.2.1B) Spherulite bunches	(2.1.6) Interactive aggregates
(1.2.1C) Discospherulites	(2.1.7) Other aggregates
(1.2.1D) Spheroidalites	(2.2) Multiaggregates
(1.2.1E) Spherocrystals	(2.2.1) Polymineral multiaggregates
(1.2.2) Skeleton crystals	(2.2.2) Polytextural multiaggregates
(1.2.3) Twin crystals	(2.2.3) Hybrid multiaggregates
(1.2.4) Screw crystals	(2.3) Pseudoaggregates
(1.2.5) Block crystals	(2.3.1) Tufaceous mineral bodies
(1.2.6) Complex	(2.3.2) Moonmilk
(2) SECOND LEVEL: Assemblages of individuals	(3) THIRD LEVEL: Assemblages of aggregates
(2.1) Aggregates	(3.1) Koras
(2.1.1) Parallel-columnar aggregates	(4) FOURTH LEVEL: Assemblages of koras
(2.1.2) Spherulitic aggregates	(4.1) Ensembles
(2.1.2A) Core spherulites	
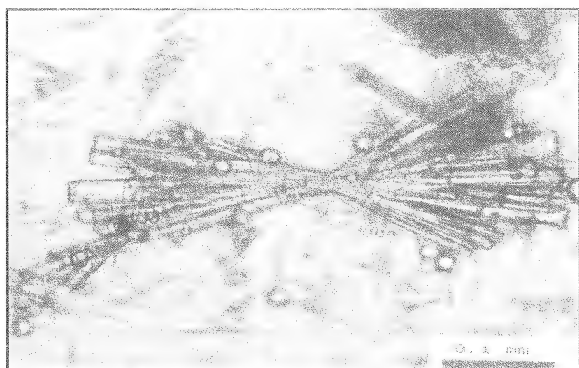
Figure 1. Thin-section photomicrograph of a split crystal of aragonite grown from a single nucleus under laboratory conditions. From Polyak (1992).
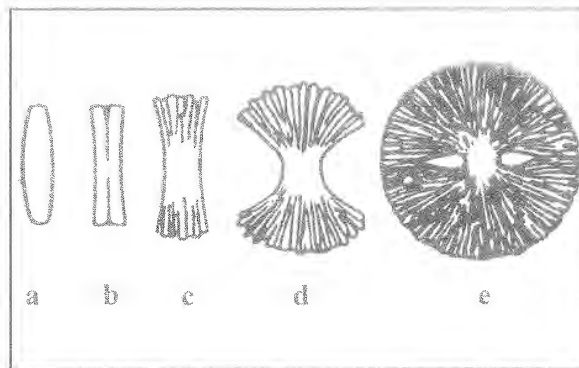
Figure 2. Drawing of successive stages of splitting during crystal growth: a = no splitting, b and c = simple splitting, d = "sheaf" structure, e = spherulite. From Grigor'ev (1961).

Figure 3. The smooth, bright surface of malachite, which is composed of several spherocrystals (not a cave photo). From Kantor (1997).
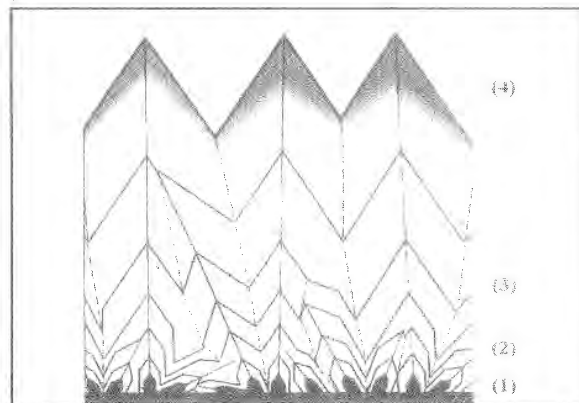
Figure 4. Geometric selection on a flat growth surface showing competition between crystals and selection. Numbers correspond to those in the text. From Kantor (1997).

129
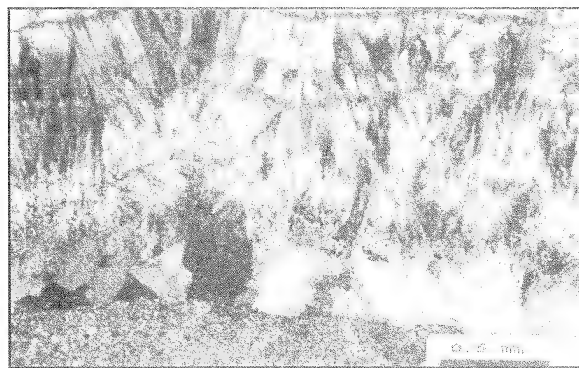
Figure 5. Thin-section photomicrograph of parallel- columnar texture (spar crystals at growth surface) changing to radial-fibrous texture ("felted" or "coconut- meat" crystals overlying spar). The "lines" may be due to interruptions of growth or contamination of the growth surface. From Polyak (1992).
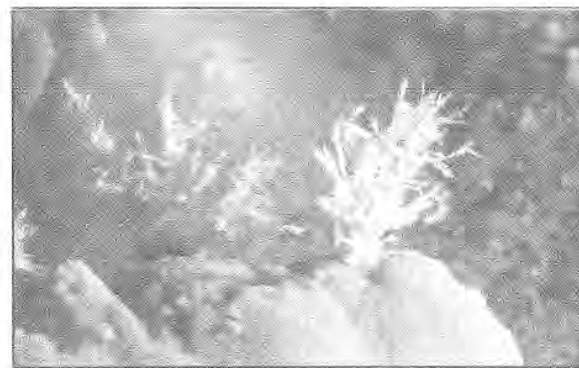
Figure 6. Aragonite frostwork growing from a stalagmitic floor crust, Cueva del Nacimiento, Spain. Note that the separate branches of the crystallictite do not touch each other. Also note that when competition is indirect, as in this case due to interaction by convection of water vapor and CO2, true crystal faces (but no contact surfaces) are displayed. Photo by C. Self.

O-30

Identification of Cave Minerals by Raman Spectroscopy: New Technology for Non-Destructive Analysis

William B. White

Materials Research Institute and Department of Geosciences, The Pennsylvania State University, University Park, PA 16802 USA

Introduction

The identification of minerals from caves poses some unique problems. Some, such as calcite and gypsum, are common, occur as large crystal grains, and can often be identified from visual inspection. Others are fine-grained, nondescript powders that require instrumental analysis. Some cave minerals are not stable when removed from the cave. Their stability demands the cool, damp cave environment and they readily decompose into other compounds when brought into the warm, dry surface environment. For many delicate speleothems, specimens should not be removed from the cave at all, or if samples are removed, they become scientifically valuable specimens that should be analyzed in the least destructive way possible so that the specimens can be preserved for possible future study.

Beyond visual inspection and examination by binocular microscope, the analytical tool of choice is powder X-ray diffraction. X-ray powder patterns provide unique fingerprints that can be matched against catalogs of standards. X-ray powder diffraction has the drawback that samples must be ground to a fine powder for measurement. Grains, which may consist of different minerals, are mixed together. Possible decomposition in the ambient atmosphere is enhanced. A further limitation of X-ray powder diffraction is that there is no easily interpreted relationship between the diffraction lines and the chemical composition of the sample. The patterns can be calculated from the crystal structure of the mineral but the calculation proceeds from the known structure to the diffraction pattern, not the reverse. Other characterization tools such as the scanning electron microscope and energy dispersive X-ray spectroscopy have important uses but there remains a need for additional tools for cave mineral investigations.

The purpose of the present paper is to describe the application of Raman spectroscopy to cave mineral investigations and to point out certain special features that address some of the shortcomings described above.
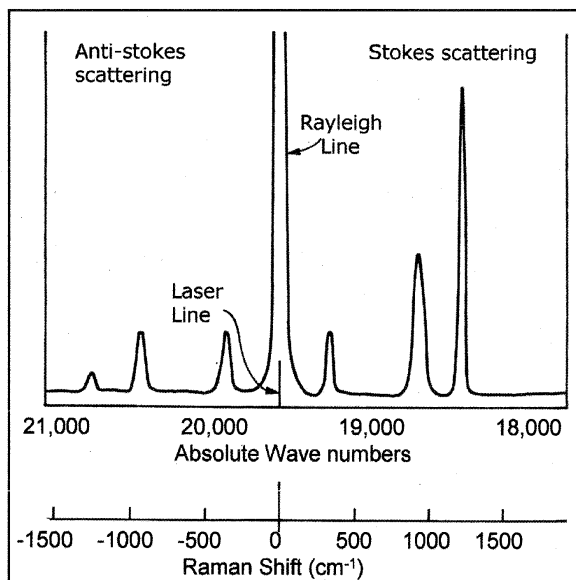
Fig. 1 Schematic Raman spectrum. Note that Raman lines appear at both higher and lower wavenumbers from the exciting (Rayleigh) line. Usually, only the low wavenumber side is displayed, with the wavenumber of the exciting line set equal to zero.

Principles of Raman Spectroscopy

Raman spectroscopy is an inelastic light scattering experiment. If a transparent specimen is illuminated with an intense, monochromatic light source such as a laser, light is scattered from the specimen in all directions. For many specimens, the scattering will be due to flaws, inclusions, and other sources of cloudiness. If the sample is truly transparent the intensity of the light scattered perpendicular to the beam will be extremely weak but not zero. Most of the scattered light, called Rayleigh scattering, will have the same wavelength as the incident laser beam. However, a very small fraction of the scattered light will interact with the specimen, set its molecular structure into vibration, and appear in the scattered light as a weak component with shifted wavelengths. The wavelength shifts are a measure of the vibrational frequencies of the chemical bonds in the specimen. This weak component is the Raman effect. If the scattered light is passed through a monochromator to display the component wavelengths, the Raman scattered light appears as side bands on the much more intense central peak of the Rayleigh scattering (Fig. 1). The usual convention is for Raman spectra to be plotted in units of wavenumbers, cm-1, the inverse of the wavelength in units of centimeters measured from the wavenumber of the exciting laser line taken as zero. In these units, the wavenumbers of the Raman bands are proportional to the frequencies of the vibrations of the molecules or crystals.

Although the Raman effect was discovered in 1928 it did not at once produce a new analytical technique. The problem is that the Raman effect is extremely weak; Raman scattered intensities are on the order of 10-10 of the intensity of the exciting source. The Raman signal is easily lost in stray light and measurement on other than perfectly transparent samples was impossible. Two inventions were made in the 1960's: the laser as an ultra-intense excitation source and double (or triple) monochromator optics to extract the desired signal from the stray light. With these improvements, routine spectra could be measured on cloudy crystals, colored crystals, and even opaque crystals, exactly what was needed for the analysis of minerals. A number of further extensions of the technology have been made, two of which are discussed in this paper.
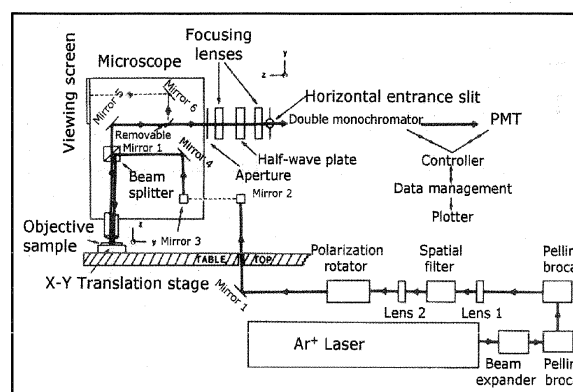
Fig. 2. The optical system of a microfocus Raman spectrometer. Only the laser steering optics and the beam-splitting arrangement within the microscope are shown. The double monochromator, the detector (PMT = photomultiplier tube), and computer system are only roughly indicated.

The number, wavenumber, and intensity of the Raman bands are determined by the symmetry and arrangement of the atoms within the unit cell and by the strength of the bonds that hold them together. Raman spectra, therefore, are closely related to infrared spectra. The physics of these interactions is complex but well known (Wilson, Decius and Cross, 1955; Long, 1977). For present discussion, the Raman spectrum can be considered a fingerprint with no need to be concerned with the underlying physics.

Microfocus Raman Spectroscopy

Because Raman spectra are measured with visible light lasers, it is possible to bring the exciting beam through the optics of an ordinary microscope, extract the scattered beam back through the microscope, and thus make measurements on individual crystal grains to the resolution of the microscope - about 2 μm (Fig. 2). For speleothems, this means that the mineralogy of multimineralic speleothems can be examined one grain at a time without damage to the specimen itself. Alternatively, one could prepare thin sections of speleothems for examination under the polarizing light microscope and also for grain-by-grain mineral identification by Raman spectroscopy.

Some stalactites in cross-section show alternating bands of calcite and aragonite. The appearance of both minerals in this relationship has important climatic implications but if the banding is on a fine scale, band-by-band mineral identification is difficult. By placing a section of stalactite on the microscope stage, the laser beam can be focused on the individual layers and the mineral identified.

The Raman spectra of calcite and aragonite are shown in Fig. 3. Note that the high wavenumber features are very similar but the low wavenumber features are different. The high wavenumber bands are the internal vibrations of the carbonate ion which is an essential part of both calcite and aragonite structure. The low wavenumber bands arise from vibrations of the ionic arrangement within the crystal so these are distinct and allow the identification of calcite, aragonite, or a mixture of both. A full theoretical analysis of the calcite and aragonite spectra is given by White (1974). It should be noted that Raman spectroscopy is not useful for distinguishing calcite from dolomite. These two minerals have, except for the ordering of Ca^{2+} and Mg^{2+} ions in dolomite, the same crystal structure and thus essentially identical spectra.

Because the samples to be measured are simply placed on a microscope stage, the microfocus Raman spectrometer allows the possibility of using a water-immersion lens so that crystals can be measured immersed in an aqueous solution. Mirabilite, $Na_2SO_4.10H_2O$ is a commonly occurring sulfate mineral. It is stable in a saturated solution but unstable in the ambient surface atmosphere where it decomposes to anhydrous Na_2SO_4, the mineral thenardite. With the water immersion lens, it was possible to obtained a good quality spectrum of mirabilite immersed in its own saturated solution (Fig. 4).

Fiber Optic Raman Spectroscopy and Portable Spectrometers

The most recent improvement in technology, and the one that inspired the present paper, is the fiber optic Raman spectrometer. The essence of the device (Fig. 5) is a laser source (a solid state laser operating at 785 nm), a set of optics based on an Echelle grating and a charge coupled device (CCD) array as a detector.

The result is an instrument that produces a plot of scattered intensity as a function of wavenumber with no moving parts. Instead of a microscope and fixed sample chamber, this spectrometer uses fiber optic cable to connect the laser, the sample probe, and the spectrograph. The probe contains a highly efficient narrow band-pass filter that eliminates the need for a second monochromator to discriminate the Raman signal from stray light. The spatial resolution of the probe is less than that of the microscope but has the advantage of being flexible so that spectra can be measured from any object regardless of its size. Further, because the instrument is small, has no moving parts, requires no cooling water for the laser, has modest power requirements, and has no delicate focusing optics, it can be adapted for field use. It would not be impossible to transport the instrument into a cave for in-situ measurements.

The quality of signal obtained from the fiber optic probe spectrograph is illustrated with the spectrum of gypsum (Fig. 5). The peaks are sharp and in agreement with single crystal measurements (Berenblut et al., 1971). The intense peak at 1008 cm-1 is the symmetric stretching mode of the SO_4^{2-} tetrahedron. Although this peak is similar to the 1084 cm-1 band in calcite, the wavenumber shift is significant and represents the distinction between a tetrahedral molecular unit and a triangular one. The high wavenumber modes are characteristics of the specific molecular anion. One could identify an unknown mineral as a carbonate or a sulfate even in the absence of reference spectra for the identification of the specific mineral.

An additional capability of the fiber optic probe is illustrated in Figure 6. Epsomite, $MgSO_4.7H_2O$, is stable in closed containers but tends to dehydrate to hexahydrate, $MgSO_4.6H_2O$ under ambient conditions. The Raman probe has a working distance of 5 mm. It can be focused on a chip of epsomite contained in a glass vial. The broad feature near 1400 cm-1 is

131
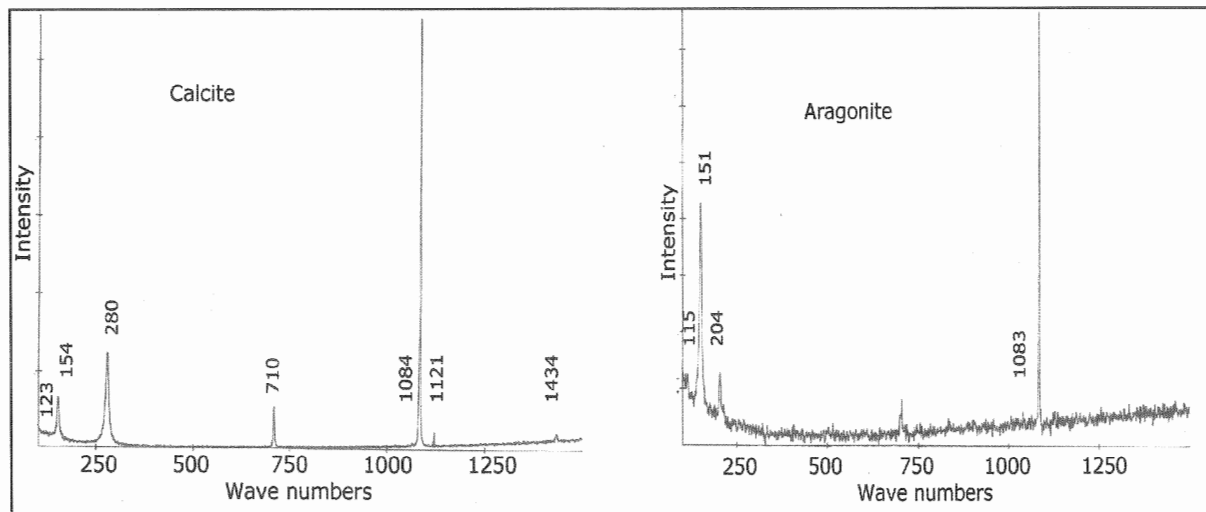
Fig. 3. Raman spectra of calcite and aragonite.
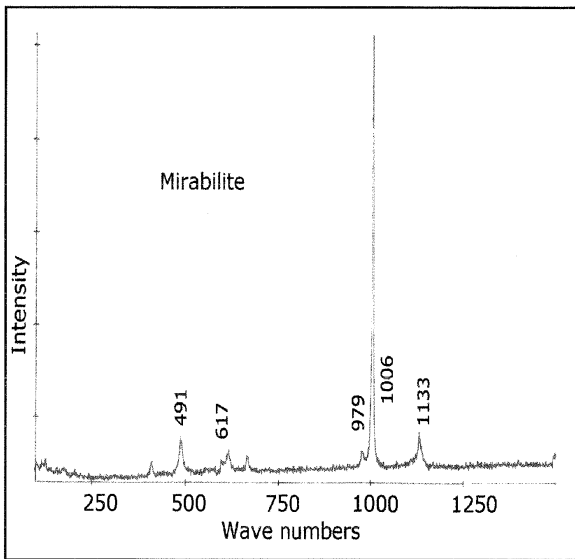
Fig. 4. Raman spectrum of mirabilite crystal in Na2SO4-saturated water.
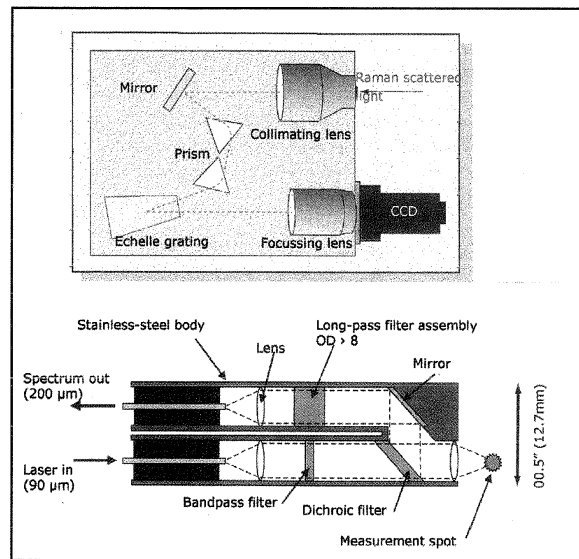
Fig. 5. (A) Spectrograph showing internal optical system. (B) Internal optics of the probe. Not shown are the laser and the optical fibers that connect laser, probe, and spectrograph.

related to the glass as confirmed by focusing the probe on the glass itself.

Conclusions

The purpose of this paper was to call attention to the cave and karst community of new possibilities for the analysis of cave materials. It has been demonstrated that both the microfocus Raman spectrometer and the new fiber-optic probe Raman spectrometer are useful devices for the determination of speleothem mineralogy. Although the probe device has not yet been taken into a cave, it's weight, compactness, lack of need for cooling water, and low power consumption bring in-cave analyses to the threshold of possibility.

The Raman spectrum serves two purposes. First, the pattern of Raman bands can be used purely as a fingerprint. Minerals can be identified by simply matching the observed spectrum against a catalog of reference spectra. In this sense, Raman spectra are used in the same way as powder X-ray diffraction patterns. However, the bands of a Raman spectrum relate directly to the bond strengths and atomic masses of the sample. Thus, molecular groups such as the carbonate ion, the sulfate ion, the hydroxyl ion, and water of crystallization can be recognized directly even if no reference spectra are available.

References

Berenblut, B.J., P. Dawson and G.R. Wilkinson (1971) The Raman spectrum of gypsum. Spectrochimica Acta 27A, 1849-1863.

Long, D.A. (1977) Raman Spectroscopy. McGraw-Hill, New York, 276 pp.

White, W.B. (1974) The carbonate minerals. Chap. 12 in The Infrared Spectra of Minerals, V.C. Farmer, Ed., Mineralogical Society of London, pp. 227-284.

Wilson, E.B., Jr., J.C. Decius and P.C. Cross (1955) Molecular Vibrations: The Theory of Infrared and Raman Vibrational Spectra. McGraw-Hill, New York, 388 pp.
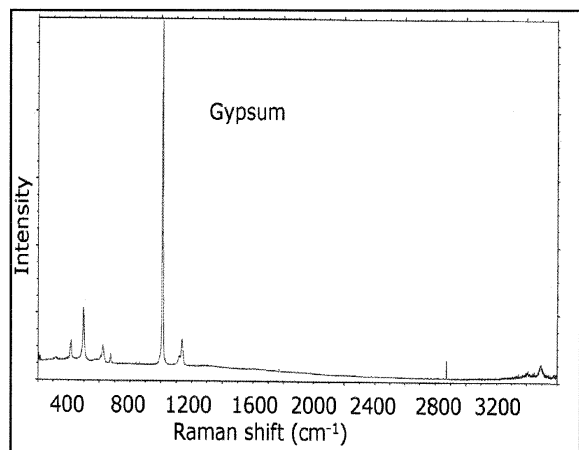
Fig. 6. Raman spectrum of gypsum. Note bands near 3400 cm-1 which are due to the waters of hydration.
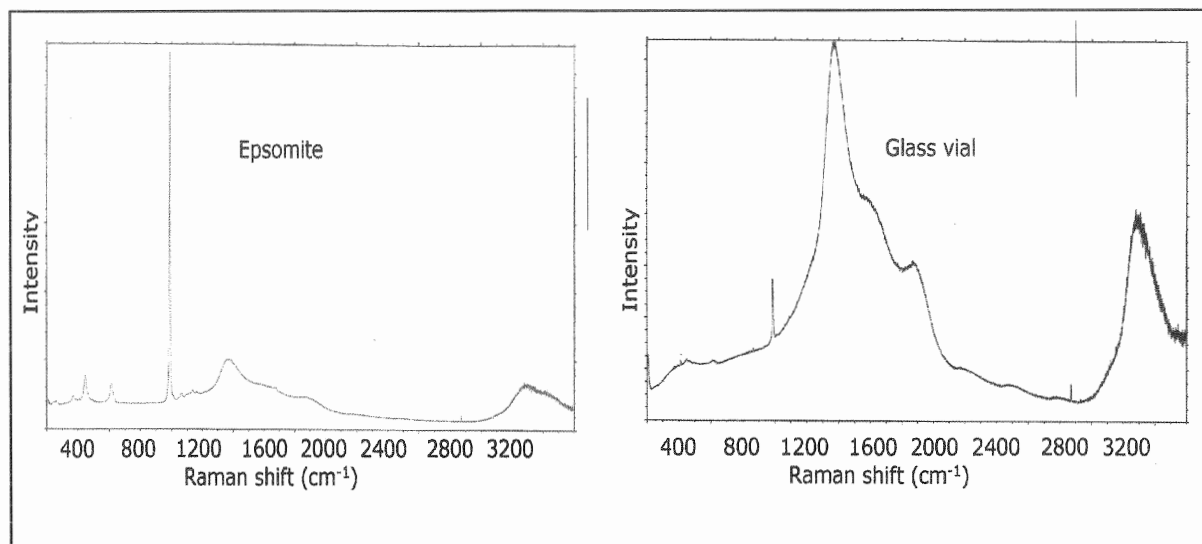
Fig. 7 (A) Raman spectrum of epsomite taken through the glass wall of a shell vial. (B) the spectrum obtained when the probe was focused on the glass.

O-31

Vashegyite from the Gaura cu Musca Cave (Locvei Mountains, Romania): a new and rare phosphate occurrence

B.P. Onac, J. Kearns, L. Zaharia

Dept. of Mineralogy, University of Cluj & "E. Racoviţă" Institute of Speleology, Cluj, Romania; Materials Research Institute, The Pennsylvania State University, University Park, U.S.A.

Vashegyite, ideally Al11 (PO4) 9 (OH) 6 • 38H2O or Al6(PO4)5(OH)3•23H2O, occurs as dull (chalky) white irregular nodules up to 1.5-2.5 cm in diameter within the fresh guano deposit from the Gaura cu Muscă Cave (Locvei Mountains, SW Romania). It is friable and usually covered by a millimeter-size sandy clay film. It was characterized by means of X-ray diffraction, thermal, scanning electron microscope (SEM-EDS), infrared spectroscopy, and by chemical analysis. Under SEM, vashegyite shows m across) flattened on (001) with?euhedral and subhedral crystals (up to 10 {010} and {001} being the prominent forms. An EDS inspection of the vashegyite crystals surface indicate the presence of the following elements: Al, P, Si, S, radiation)?and Fe. Indexing of the X-ray powder pattern (Philips X-pert, CuK gave orthorhombic symmetry with the following calculated parameters are a = 10.75(6), b = 15.029(9), c = 22.444(5) Å, and V = 3626.433(4) Å3; strongest lines are 11.21 (100, 002), 7.52 (77, 020), 6.9 (28, 112), 6,25 (72, 022), 3.297 (40, 312), 2.909 (60, 330), and 2.44 (15, 062). Vashegyite IR absorption bands are comparable in position and relative intensity to bands in the spectra of other Al phosphates (variscite, wavellite, etc.). The most important absorption bands (cm-1) are at 3400 and 3200 (H2O, OH stretching), 1635 (H2O bend), 1384 3, antisymmetric stretching), 729 (Al-OH2 mode?), 1165, 1115, 1007 (PO4: ?(OH 4, in-plane bending). The Raman?or OH out-of-plane band), 603, 525, 482 (PO4: spectrum of vashegyite displays The TGA curve indicates major losses between 40 and 200°C corresponding to the removal of water molecules (endothermic peaks at 56, 82, and 128°C on the DTA curve). Although the TGA curve do not shows any significant weight loss, the DTA curve displays an endothermic effect at 860°C suggests the expulsion of OH groups and recrystallization responsible for formation of AlPO4. The mineral occurs with some clay minerals, crandallite and ardealite. When the study of vashegyite will be completed, a sample of the type material will be deposited in the Mineralogical Museum of the "Babeş-Bolyai" University in Cluj, Romania.

O-32

CAVE MINERALS OF SOME LIMESTONE CAVES OF SAUDI ARABIA[1]

Paolo FORTI[2], Ermanno GALLI[3], Antonio ROSSI[3], John PINT[4], Susana PINT[4]

[1] Research made within the MIUR 2002 Project "Morphological and Mineralogical Study of speleothems to reconstruct peculiar karst environments" Resp. Prof. P.Forti

[2] Italian Institute of Speleology, University of Bologna, Italy

[3] Department of Earth Sciences, University of Modena and Reggio Emilia, Italy

[4] Saudi Geological Survey, Jeddah, Saudi Arabia

Abstract

This is a preliminary study on cave minerals of a few limestone caves in Saudi Arabia. Despite the paucity of analyzed samples, 14 different cave minerals have been detected. Among them Palygorskite seems to be rather common in the desert caves and in one of them (B31 Cave) there is perhaps the best display of this mineral inside a natural cavity. The same cave also hosts a deposit of sideronatrite, which has been herewith reported for the first time as a cave mineral. Finally Murubbeh cave, a supposed thermal cave, hosts large calcite crystals and widespread cave rafts together with two uncommon organic compounds (wedellite and whewellite).

Keywords: Cave minerals, limestone caves, Saudi Arabia

Introduction

The exploration of natural caves in Saudi Arabia started only some decades ago (Pint, 2003) and it is still in progress. A few karst areas are now rather well known, one of these being the As Sulb Plateau north of Riyadh (Fig. 1), which consists of a subhorizontal stony desert with pockets of sand within small depressions. Outcropping rocks consist of limestones of the Um er Raduma formation (Paleocene-lower Eocene) (Schifsma E., 1978).
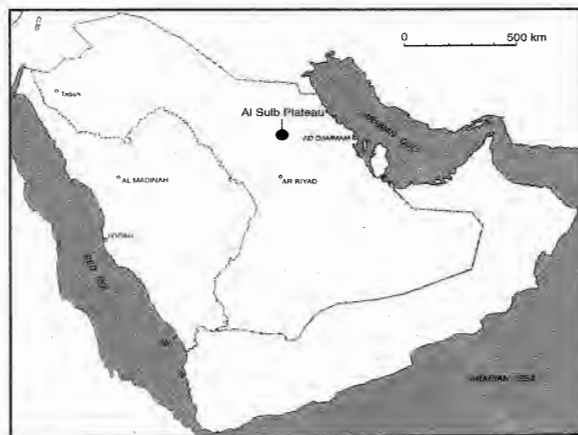
Fig.1- Schematic map of Saudi Arabia with the location of the karst area of the As Sulb Plateau

The area is perforated by hundreds of subcircular pits from 20 cm to 2 m in diameter, only a few of which have been explored or even located. Presently the known caves are about 100 but there should be two orders of magnitude more caves.

Following an invitation from the Saudi Geological Survey, we had the possibility to make a preliminary study of cave minerals in this area. Karst cavities in the desert of the As Sulb Plateau are rather small and often less than 15 meters deep. Today, most of them have no water inside but it is clear that in the past they were partially flooded by groundwater.

During our visit we had the chance to explore and sample only four caves but we think that they are sufficiently representative of the karst of that area. The caves of the As Sulb Plateau present noticeable interest from the climatic and minerogenetic point of view: climatic aspects have been already discussed (Forti et Al. 2005), while the present paper focuses on the mineralogical aspects.

B31 Cave (Forti 2003) consists of 3 subcircular rooms with an average diameter of 5-7 meters. Its walls are highly friable due to weathering processes which allow the deposition of crusts and flowers while other kind of speleothems are completely lacking.

Friendly and Surprise Caves are characterized by subcircular entrance pits at the bottom of which start sub-horizontal galleries with an average diameter of 3-4 m, developed in phreatic conditions and with rather steady water. Almost all the calcite speleothems were dated over 400.000 yr BP (Fleitmann et al, 2005).

The most common still growing speleothems consist of gypsum, which develops thin millimetric crusts or even small flowers and monocrystalline stalactites in most of Al Sulb Plateau caves. Some large gypsum formations were found, among which a tray (Fig. 2) and a hollow stalagmite from Surprise cave are worthy of mention.

Murubbeh cave was the last visited: it consists of a huge chamber (150x80x50 m) with a relatively small entrance (10x3 m) at the bottom of a small collapse doline. The bottom of the cave is about 40 meters below the surface, therefore this cave is far deeper than all the others. All its speleothems are epiphreatic or phreatic: no stalactites and stalagmites are present but only boxwork, cave clouds, digits and folia (Hill & Forti, 1997) and most of the floor is covered by a thick deposit (from 10 to 100 cm) of cave rafts. In the deepest part of the cave there are druses of large calcite crystals, which suggests a thermal origin of the cave.

Experimental

A detailed analysis of all the samples by the stereoscopic microscope was performed to distinguish and to separate the different mineralogical phases eventually present in each sample. Then the single phases were analysed by a powder diffractometer (Philips PW 1050/25), when the material was quantitatively sufficient and homogeneous, or by a Gandolfi camera ($\emptyset$: 114.6 mm, exposition: 24/36 hrs), when the material was scarce or inhomogeneous. The experimental conditions were always: 40Kv e 20 mA tube, CuKα Ni filtered radiation (λ = 1.5418 Å). The same samples analyzed in the Gandolfi camera were later used to obtain images and chemical qualitative analyses through an electron scanning microscope (SEM Philips XL40) with an electronic microprobe

Fig. 2 - The gypsum tray of Surprise cave
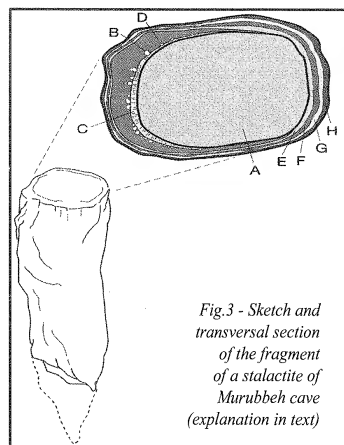
Fig.3 - Sketch and transversal section of the fragment of a stalactite of Murubbeh cave (explanation in text)

(EDS - EDAX 9900) at the "Centro Interdipartimentale Grandi Strumenti" of the Modena and Reggio Emilia University.

Investigated samples

B31 Cave - the sample was taken from the cave roof: it consists of fragments (from 1 cm to less than a mm in size) from milky white to hazel brown or brick red calcareous speleothems. The identified minerals are: calcite, celestine, glauberite, gypsum, halite, palygorskite, quartz, sideronatrite and thenardite. The Na sulphates are peculiar of very arid regions, but they were found only in this cave because its internal climate was completely controlled by the external one.

Friendly Cave - Heterogeneous earthy alteration material (from 1 cm to less than 1 mm in size) with color ranging from white to pale pink. The largest fragment consists of vitrous hemi-transparent material covered on a side by a thin aggregate of acicular crystals, and the other side by a layer of banded, translucent to transparent, tabular prismatic cristals often cemented to each other. The smaller fragment consists of a thin aggregate of acicular crystals incorporating spherical grains of quartz. The identified minerals are: gypsum, halite, palygorskite and quartz.

Surprise Cave - Alteration material consisting of 3 types, different in size and color: the largest (Ø > 5 cm) is milky white, very light and is characterized by euhedral, transparent, calcite crystals, with some brick-red earthy powder. The intermediate sized material consists of a pale yellow earthy material mixed with aggregates of semi-transparent rounded grains covered by a thin reddish film. The smallest materials (Ø > 1 mm) consist of heterogeneous grains sometimes fairly resinous and dark grey. The identified minerals are: calcite, dolomite, halite, hydroxylapatite, palygorskite and quartz.

In this sample there is also a small stalactite (Ø maximum 2.4 cm and 5 cm in length, see Fig. 3): this stalactite consists of an inner micritic core 1.7 mm in diameter (A); half of the circumference of the inner core is covered by a thin crust of transparent aggregates of calcite crystals (0.7 mm) (C) covered by a film of rounded quartz grains (B); then there is a 3 mm layer of micritic calcite (D), and finally the external 2 mm layer consists of several films (E,F,G,H) made by compenetrated calcite crystals, the maximum dimension of which is 0.5 mm.

Murubbeh Cave - Fragment of a speleothem collected under a layer of organic material: the sample is very light, stratified, pale hazel brown to reddish on surface and milky white to pale hazel brown inside; the external surface is partially covered by a thin layer of white fibrous material. The identified minerals are: gypsum, palygorskite, quartz, weddellite and whewellite.

Description of the detected minerals

Calcite (CaCO3) - Is by far the dominant cave mineral. In Surprise cave are present some euhedral, sometime twinned, vitreous transparent scalenohedral crystals (Fig. 4 A); in B31 cave perfect rombohedral micrometric crystals have been observed. By far the best display of large calcite

crystals, probably of thermal origin, is at the bottom of Murubbeh cave.

Celestine (SrSO4) - It has been detected only inside B31 Cave, where it is present as radial aggregates of thin elongated tabular fibres (Fig. 4 B), or as prismatic, euhedral crystals. Often this mineral gives rise to small aggregates of rounded elements.

Dolomite [CaMg(CO3)2] - It has been detected only by means of X Ray diffraction in the detritic material of Surprise cave.

Glauberite [Na2Ca(SO4)] - This sodium and calcium sulfate (Palache et al., 1951a) has been frequently observed as aggregates of tabular monoclinic prismatic crystals (Fig. 4 C), white grey or pale yellowish in color, or more frequently colorless. Sometimes it is present as subspherical crystals with rounded edges.

Gypsum (CaSO4·2H2O) - Normally associated with calcite and quartz; in most of the samples it consist of grains with rounded edges; in one occurrence it gave rise to a thin crust of elongated vitreous to transparent elements randomly oriented.

Halite (NaCl) - It has been observed in all the caves and it is strictly associated with calcite (Fig. 4 D), quartz and palygorskite, giving rise to small crusts with rounded elements or aggregates of vitreous semi-transparent crystals with rounded edges.

Hydroxylapatite [Ca5(PO4)3(OH)] - It has been identified only in Surprise Cave where it is present as aggregates of small elongated thin tabular crystals (Fig. 4 E).

Palyygorskite (Mg,Al)2Si4O10(OH)·4H2O] - Beside calcite, it is the most common cave mineral in all the analysed cavities. It is present as light milky white cotton tufts consisting of elongated and banded fibers. Sometimes it is present as acicular milky white crystals on the walls of the small voids within the halite crystals (Fig. 4 F, 5 A).

Quartz (SiO2) - It is often present as a detritic (residual) component but sometime it also occurs as a true cave mineral. In this case it forms thin colorless crusts and aggregates characterized by a graphic texture (Fig. 5 B): at high magnification it is evident that they consist of a thick maze of tabular fibres cemented each other.

Sideronatrite Na2Fe(SO4)2(OH)·3H2O] -this is the first cave record of this hydrated basic sulfate of sodium and ferric iron (Palache et al., 1951b): it has been observed, as glauberite and thenardite, only in B31 Cave. It consists of earthy to pulverulent, transparent to grayish-white nodular masses or tabular crusts (Fig. 5 C).

Thenardite (Na2SO4) - Among the most frequent phases inside the B31 Cave, this sodium sulphate (Palache et al., 1951c) is present as micrometric tabular prismatic crystals {010}, sometimes with rounded edges (Fig.5 D).

Weddellite (CaC2O4·2H2O) and *Whewellite* (CaC2O4·H2O) - Both these minerals have been observed only in Murubbeh Cave and their presence was proved only by X ray analyses. It was impossible to define their habit by SEM because they are strictly embedded within the carbonate matrix. These minerals are surely strictly related to the guano overlying the sample

Discussion and final remarks

Despite the scarcity of analysed samples, 13 different cave minerals have been detected (Tab. I): two of which were found in all of the studied caves (calcite and quartz).

From the mineralogical point of view the most interesting cave is B31 hosting 9 of the 13 cave minerals detected in that area. Moreover sideronatrite from this cavity has been reported for the first time as a cave mineral.
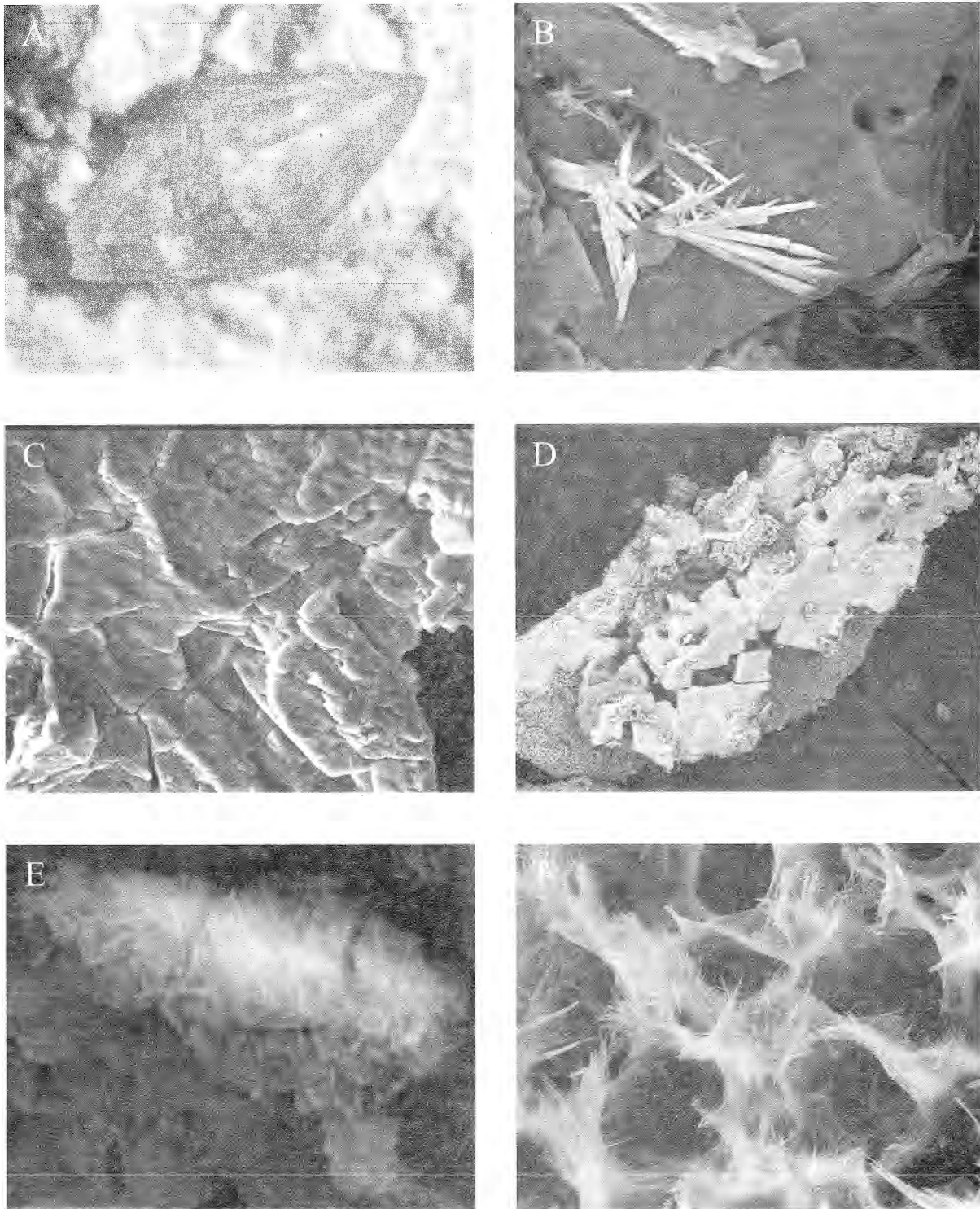
Fig. 4 - A) stereo-microscope photo of a transparent calcite scalenohedron from Surprise Cave; SEM images of: B) a tuft of acicular celestite crystals over quartz with a rombic crystal of glauberite in the upper part (B31 cave); C) tabular aggregate of glauberite crystals (B31 cave); D) crust of halite crystals over calcite (B31 cave); E) aggregate of thin blades of hydroxylapatite (Surprise Cave); F) tuft of thin fibers of palygorskite (Surprise Cave).
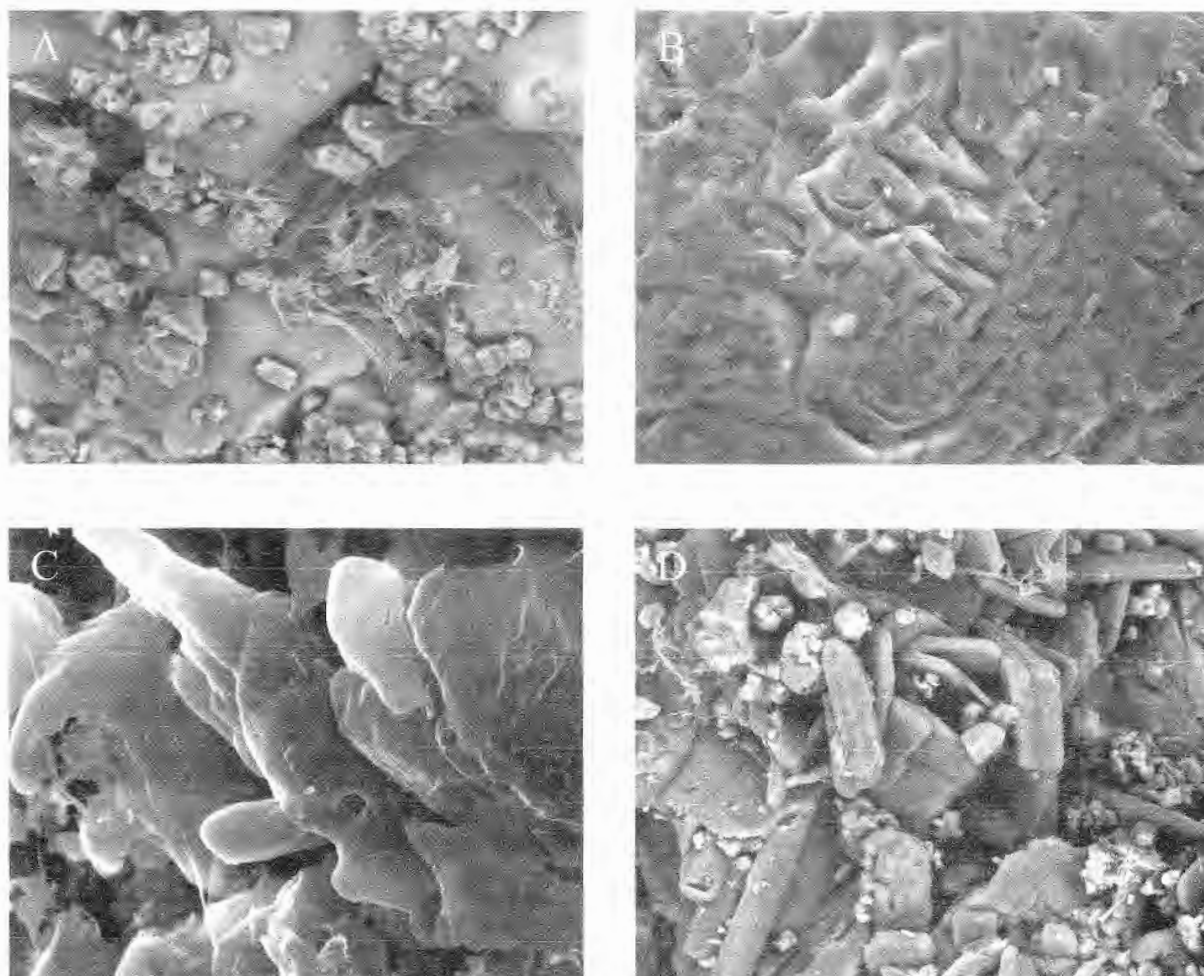
Fig.5 - SEM images of: A) tuft of palygorskite with calcite over globular halite crystals (B31 Cave); B) quartz aggregate with "graphic" texture on the surface (B31 Cave); C) small lens-shaped masses of sideronatrite (B31 Cave); D) thenardite tabular prismatic crystals (B31 Cave).

Tab. I - Identified minerals and their distribution: B - B31 Cave; F - Friendly Cave; M - Murubbeh Cave; S - Surprise Cave.

Cave	Mineral	Formula	System	Occurrence
B, F, M, S	Calcite	$CaCO_3$	Trigonal	Saccaroidal aggregates, vitreous schalenoedrons, micrometric rombohedrons
B	Celestine	$SrSO_4$	Orthorhombic	Tufts of acicular tabular crystals, small masses of rounded grains
S	Dolomite	$CaMg(CO_3)_2$	Trigonal	Earthy grains
B	Glauberite	$Na_2Ca(SO_4)_2$	Monoclinic	Aggregates of tabular primatic crystals
B, F, S	Gypsum	$CaSO_4 2H_2O$	Monoclinic	Rounded grains or thin vitreous crusts of transparent, elonged crystals
B, F, S	Halite	$NaCl$	Cubic	Crusts or aggregates of rounded crystals
S	Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	Hexagonal	Elonged aggregates of thin, bladed crystals
B, F, S	Palygorskite	$(Mg,Al)_2Si_4O_{10}(OH)\cdot 4H_2O$	Orthorhombic Monoclinic	Tufts of thin, banded, shining white fibers
B, F, M, S	Quartz	SiO_2	Trigonal	Colorless crusts or aggregates with a "graphic" structure surface
B	Sideronatrite*	$Na_2Fe(SO_4)_2(OH)\cdot 3H_2O$	Orthorhombic	Colorless to grayish-white nodular masses or tabular crusts
B	Thenardite	Na_2SO_4	Orthorhombic	Micrometric tabular prismatic crystals, sometimes with rounded edges
M	Weddellite	$CaC_2O_4\cdot 2H_2O$	Tetragonal	Embedded within calcareous matrix
M	Whewellite	$CaC_2O_4\cdot H_2O$	Monoclinic	Embedded within calcareous matrix

* reported as cave mineral for the first time

The contemporaneous and restricted presence in this cavity of glauberite, sideronatrite and thenardite, sulfates normally found in arid regions along the west coast of South America, notably in Chile, of North America and Europe (Palanche et al, 1951) may be easily explained by the peculiar shape of the cave. In fact B31 cave is characterized by a wide entrance and two large chambers and therefore the climate inside it is completely controlled by the desert outside, while all the other studied caves have small inlet holes if compared with the underground development and therefore their internal average humidity constantly exceeds the equilibrium value for the development of such minerals.

The two organic compounds weddellite and whewellite observed only in Murubbeh cave are surely related to the presence in the cave floor of a high quantity of organic remains (bones, excrement): it is difficult to say if they are by-products of human activities (people using the cave for a picnic and leaving all the remains inside) or if they were produced by the mineralization processes of guano and remains of wild animals which normally utilize the cavity as shelter. It is worthy of mention that palygorskite has been detected in all the studied caves, where it was often associated with halite. This mineral was recently described in detail for the Ghar Al Hibashi lava tube in Saudi Arabia (Forti et al., 2004).

Palygorskite is characterized by an open crystal structure (Artioli et al., 1994), which allow ionic exchange (Bridley, 1981). It is present in several different environments, from marine and lacustrine to soils and paleosoils and to carbabonate crusts, but it is rather rare in cavern environments (Hill & Forti 1997).

On the contrary Palygoskite is worthy of mention, because it appears rather common in the desert caves of Saudi Arabia and in one of them (B31 Cave) there is perhaps the best display of this mineral inside a natural cavity.

This first and short overview on the cave minerals of limestone caves of Saudi Arabia put in evidence that the desert caves of the As Sulb Plateau are a really interesting minerogenetic environment: in fact, despite the paucity of analyzed samples, 14 different cave minerals have been detected, some of which are rare for the cavern environment and one (sideronatrite) has been here reported for the first time as a cave mineral.

A more detailed study will surely increase the number of cave minerals and perhaps some new cave minerals will be detected: but the problem is that presently it is not sure that these caves will last for enought time to be studied.

In fact it must be stressed that the caves of As Sulb Plateau are really endangered by both natural processes and anthropic actions. Presently the more dangerous are the natural processes: in fact the desert sand is rapidly entering many caves, some of which have been filled up in the last few years.

But the vandalism carried out by visitors (actually limited to a few horizontal caves) has undergone a rapid increase in the last few years: for this reason the Saudi Geological survey is planning to gate some of the most important caves of the As Sulb Plateau in order to preserve the speleothems and other interesting things therein, for future research and study.

References

Artioli A., Galli E., Burattini E., Cappuccio G., Simeoni S. (1994) - Palygorskite from Bolca, Italy: a characterization by high-resolution syncrotron radiation powder diffraction and computer modeling. N. Jb. Miner. Mh., 1994 H.5, 217-229.

Brindley G.W. (1981) - Clays, clay minerals in The Encyclopedia of Mineralogy, Keith Frye Ed. (Encyclopedia of Earth Sciences, Vol. IV B), Hutchinson Rob Publishing Company, Strousburg, Pennsylvania, 69-80.

Fleitmann D., Matter A., Pint J., Al-Shanti M. (2005) The speleothem record of climate change in saudi arabia, SGS Jeddah

Forti P. (2003) - Le grotte sotto il deserto: note a margine di una spedizione in Arabia Saudita. Sottoterra 114, 34-43.

Forti P., Galli E., Rossi A., Pint J., Pint S. (2004) - Ghar Al Hibashi lava tube: the richest site in Saudi Arabia for cave minerals. Acta Carsol., 33/2, 190-205.

Forti P., Pint J., Al-Shanti M. A., Al-Juaid A. J., Al-Amoudi S. A., Pint S. 2005 Potenzialità turistiche delle grotte nei deserti dell'Arabia Saudita Convegno di Fabosa Soprana, 2003, in press.

Hill C.A., Forti P. (1997) - Cave Minerals of the world. Nat. Spel. Soc., Huntsville, USA, 464 pp.

Pint J., (2003) - The Desert Caves of Saudi Arabia. Stacey International, London, 120 pp.

Palache C., Berman H., Frondel C. (1951) - Dana's System of Mineralogy - The System of Mineralogy - VII Edition, Vol II., John Wiley and Sons, Inc., New York, London: a) 431-433; b) 604-605; c) 404-407.

Schyfsma E. (1978) - As Sulb Plateau, General geology in Al-Sayari S.S., Zötl J.G. (Eds.) Quaternary period in Saudi Arabia. Spring-Verlag, New York, 164 pp.

138

O-33

New approach of the karstic evolution of the canyon of the Peruacu river

(Januária - Itacarambi, Minas Gerais, Brazil)

Joël Rodet[1] , Maria Jacqueline Rodet[2] , Daniel F. Mariano[3] , Luc Willems[4] , André Pouclet[5]

[1] EuReKarst, UMR 6143 CNRS, Continental and Coastal Morphodynamics, Laboratory of Geology, University of Rouen, 76821 Mont Saint Aignan Cedex, France, joel.rodet@univ-rouen.fr

[2] PhD student in Archaeology, University of Paris-X, brazilian CNPq grant holder, France,

[3] Graduate in Geology, UFMG, Belo Horizonte, Brazil,

[4] EuReKarst, Laboratory of Sedimentology, Dpt. Geology Petrology Geochimistry, B20, University of Liege, 4000 Liege, Belgium,

[5] EuReKarst, ISTO, Earth Sciences Institute, University of Orleans, France.

Abstract:

Tributary of the left side of the São Francisco river, the Rio Peruaçu Basin is an important site for archaeological and geomorphological studies in the Central Brazil. From its springs in the sandy detritic layers of the São Francisco-Cochá border, the Peruaçu River flows out to its confluence with the main river, 100 km farther. In its middle watercourse, it has dug a very impressive karstic relief with canyon into the limestone layers. Resulting in these magestic epikarst and endokarst forms the complex evolution begins to be understood. The morphological observation of this great canyon and of the associated forms (caves, sediment deposits, landforms, ...) has placed in a prominent position various complex elements, revealing several phases of the karst evolution. From this, appear two great digging phases stored in 50 m and separated by a complex stage of inundations attributed to the roof collapsing of the great gallery which opened the canyon and the Terra Brava polje too. Consequently i) testimonies of a first drainage stage (Janelão I) are hanging and detached of the current geomorphological context, and ii) adapted forms to inundation phases (Terra Brava) iii) or/and water level lowering (Janelão II) can be identified. The karst system evolution during the Cenozoic is explained in a conceptual model which can be extended to other karst systems of the São Francisco middle stream, showing the regional value of the agents responsible for this evolution.

Introduction

The River Peruaçu Basin develops on the left margin of the Rio São Francisco (fig.1), north of the Minas Gerais state (Brazil). In its lesser course, the river cross through the Bambuí limestones, of Proterozoic age, lying over the basement of the São Francisco craton, opening an impressive karst landscape with very deep collapse dolinas over a fluvio-karst drainage (fig.2). For over 17 km, it develops a large canyon interrupted by great tunnel caves [Piló & Kohler, 1991]. Always local people was attracted by these features, from early aboriginal tribes to archaeologists

Fig. 1: Location of the Peruaçu River Basin, in Minas Gerais state (Brazil).

and tourists [Prous, 1992]. Geomorphological study is recent with the early research of Piló [1997]. At the end of the nineteen nineties, we realised a multi-field approach [Rodet et al., 2002] reaching to a new proposal for the karst evolution of this area [Rodet & Rodet, 2001].

Most of the Central Brazil develops in the São Francisco Craton formed during the Pre-Cambrian [Almeida & Hasui, 1984]. In Minas Gerais state, it is including the carbonated sequences of the Bambuí group formed at least 580 My ago [Dardenne, 1978]. Over these unities, the detritic Urucuia Formation (upper Cretaceous) was occasionally deposited after a hiatus of few hundreds millions of years [Projeto RadamBrasil, 1982]. The basement only points to the surface in the middle basin area where the erosion cut off the sandy cretaceous covering layer. The canyon develops into the limestones, in the lesser part of the Peruaçu Basin, between the middle basin with basement rocks and the junction with the main valley of the São Francisco River [Piló, 1997]. Basin, in Minas Gerais state (Brazil). During 17 km, the river has dug into the limestone layers a 200 m deep canyon with vertical walls. Six times, the river sinks into galleries, resulting in impressive arches or great tunnels developing several kilometres. The biggest caves are the 'Lapa do Brejal' and over all the 'Lapa do Janelão', with a 100 m high roof in a gallery of over 50 m wide.
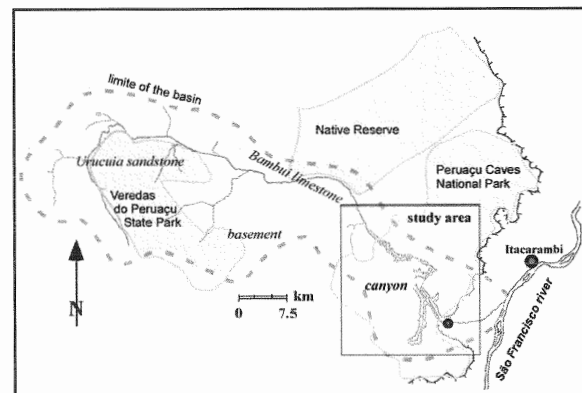
Fig. 2: the Peruaçu River Basin and the Canyon Compartment.

1. Two main karst opening stages: Janelão I and Janelão II

Upstream, the river cross first through the Brejal cave for several hundred metres. Near the resurgence, the cross section shows (fig. 3): i) a roof half-tube, ii) an hanged residual old river deposit at the base of the roof channel, iii) a large basal gallery with a small river. That demonstrates at least two stages of gallery excavation, the upper one being the most recent [Rodet et al., 2004b]. Downstream, the river cross through the Janelão gallery, the largest cave of the Peruaçu karst (fig. 4). The present sinkhole is a small gallery of about few metres diameter, dug fifty metres under the upper entrance. This fossil entrance is bigger, around fifty metres diameter. Few tens metres after the entrance, the two passages joint into a
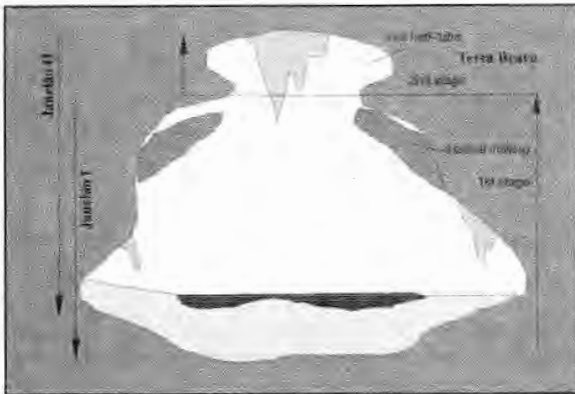
Figure 3: cross section of the Brejal cave

Fig. 4: cross section of the Janelão cave, near the current sinkhole.

Fig. 5: The polje of Terra Brava with its two main sedimentary surfaces. View from the Falso Janelão cave.

the peripheric cliffs near the current Troncos cave, altitudinal similarities in cave drainages and/or in terrigenous terraces, wall speleothems without their wall support in the Bichos cave (fig. 6), and so on.

3. A five stage karst regional evolution

The evolution of the karst area can be resumed in five stages [Rodet & Rodet, 2001]. The river crossed through the carbonated compartment protected by the impermeable covering formations, and joined the São Francisco depression (fig. 7.1 - ante-karst stage), until the limestone substrate emerged in the upstream part of the compartment (fig. 7.2 - incipient karst stage). Superficial water began to penetrate underground and formed

Fig. 6: The massive speleothem in the Bichos' cave showing its internal structure: its terrigenous support has been removed by the water drainage.

large gallery of about one hundred metres high. These two entrances illustrate two different stages of the cave evolution, separated by fifty metres [Rodet et al., 2004a]. Between these two caves, the Peruaçu river shows several rapids, indicating a present dynamic stage of the river flow.

Near the São Francisco main valley, the Peruaçu canyon is very strait and linear. Both border cliffs contain relict tunnel caves, fifty meter over the current river. We suppose that this part of the canyon is modern and is imposed over the ancient topography, cutting the old features, like the residual bench near the Bichos' cave, on its way [Rodet et al., 2003].

2. One karst infilling complex stage: Terra Brava

Around the great depression called Terra Brava (fig. 5), a lot of elements demonstrates large phases of inundation at various levels: a gravel-stone terrace near the Janelão upper entrance, a ten metres deep clay terrace lying over a basal peeble conglomerat, with superficial drainage channels, relationed with the landscape features (flat areas, foot notch in

Fig. 7: five evolution stages of the karst of the Peruaçu Basin.

a large karst network which joined the alluvial plain, while concentrating on its course, several tributaries. resulting from losses into cover layers. Little by little these layers have been involved into the powerful underground drainage (fig. 7.3 - juvenile karst stage). A filling of the main drainage between Terra Brava and the São Francisco valley is responsible for a complex stage of overflood surface allowing the development of the polje of Terra Brava (fig. 7.4 - mature karst stage). Then an underground capture of this area by a small river allows the re-opening of the drainage network and the return of an effective erosive incision (palaeo terraces of the river Peruaçu).

The covering layers continue to creep into the endokarst within collapses which punctuate the larger drains, at the origin of the digging of a great number of gullies or voçorocas contributing to the dismantling of the cover and carving incisions into the carbonated substrate (fig. 7.5 - rejuvenated karst stage), resulting in a ruiniform evolution of the karst landscape

(pitons and towers, hums, ...). Tectonics is of an high importance in this evolution but the numerous faults are not indicated to not complicate too much the scheme. It results to a fluvio karst drainage favourable to the human implantation with very numerous rock shelters in slope and clift, and with a lot of lodgings of mineral resources used for stone tools, illustrating a perfect integration of primitive human groups in a karst region [Rodet et al., 2002].

4. Theoritical karst evolution model

The theoretical model of the karst evolution in the Peruaçu Basin [Rodet et al., 2003, 2004a, 2004b] can be presented in three main stages (fig. 8).

1 - Janelão I: former water level, identified in the upper part of the
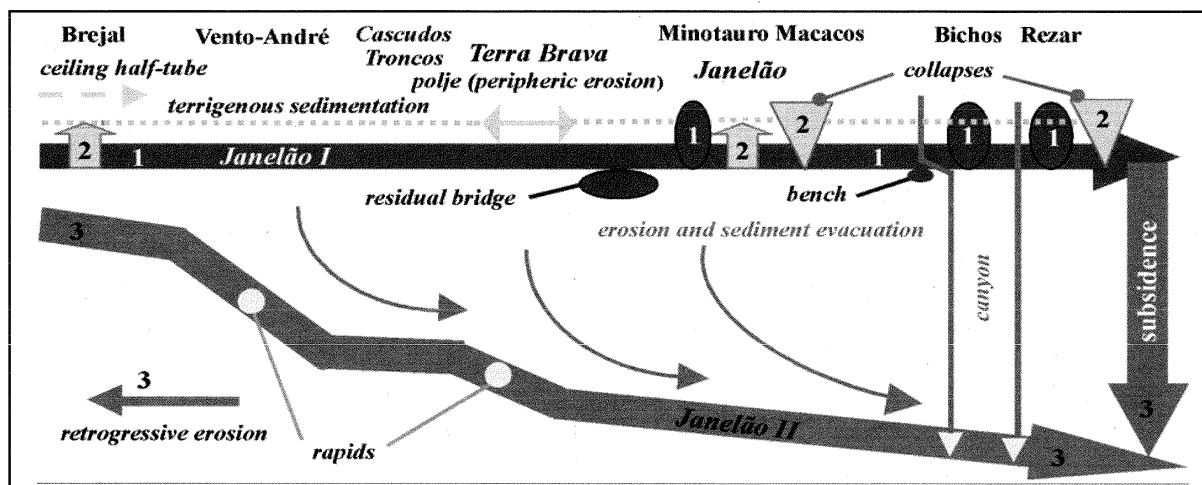
Fig. 8: theoretical evolution model of the Peruaçu River Karst

main conduit of the Janelão cave, in connexion with the Minotauro gallery and the Bichos' cave and the Rezar's cave. It seems that a former Troncos cave was excaved on the right merge of the River Peruaçu, later transformed into a canyon. The current Troncos cave has been opened during the third evolution stage (Janelão II).

2 - Terra Brava: damming of the drainage by several collapses of the cave roof between the Janelão main gallery and the confluence to the main valley (São Francisco), giving the great dolina dos Macacos's shafts, infilling all the caves connected on the river drainage from the Rezar to the Brejal, opening a multiphased polje in the Terra Brava site, and digging a ceiling half-tube in the roof of the Brejal's cave. The elevation of this half-tube is similar to water infill testimonies in the Arco do André cave (Piló, pers. comm.).

3 - Janelão II: important subsidence of the water level (over 50 m), digging out the lower part of the canyon (residual bench), cutting the connexion between Bichos and Rezar. The river retrogressive erosion opens the lower part of the Janelão's gallery, taking away elements of the collapse and infillings, and leaving a residual bridge out. Around the Terra Brava polje, caves as Bonita, Suspiro and Indio are definitely deconnected out of the drainage, hanging over the depression with piping effects into their terrigenous infills. Upstream, the Troncos cave has been opened as its lateral canyon fossilised. The Brejal cave is dug down again, hanging a part of its filling over the basal gallery. The river profile is cut by several rapid zones, illustrating that this third stage is always working on today.

Conclusion

The karst of the Peruaçu offers a complex and old evolution, directed by three main stages. The first period, Janelão I, concerns the genesis and the development of the karst network. The second period illustrates the passage from the karst drainage to the fluvio-karst drainage, when caves open and give the impressive canyon. The resulting great collapses are responsible for several cave damming phases and surface drainage adaptations, like lake with peripheric corrosion (Terra Brava polje) and underground adaptations (Brejal ceiling half-tube). An important regional subsidence influence the water base level and all the karst system in the São Francisco valley from Bahia state to Minas Gerais state [Bitencourt, 1998 ; Bitencourt & Rodet, 2001]. This neotectonics was attribute to the Cenozoic Period, and is identified as responsible of the rejuvenated karst period, illustrated by the second digging stage of the Peruaçu karst (Janelão II). Further studies will been realized to refine the chronology, and to try to date the main events.

References:

Almeida F. & Hasui Y. - 1984. O pré-Cambriano do Brasil. Edg. Blücher, São Paulo, 378 p.

Bitencourt A.L. V. - 1998. Morphogenèse, Quaternaire et archéologie en milieu karstique : le site du Morro

Furado, Serra do Ramalho (Bahia) - Brésil. Thèse de l'Université de Caen, Centre de Géomorphologie du

Fig. 9: Peebles of a paleo-terrace in the Terra Brava polje, near the former Janelão sinkhole.

CNRS : 212 p.

Bitencourt A.L. V. & Rodet J. - 2001. Premiers éléments d'évolution karstique sous contrôle tectonique d'un

massif calcaire : la Serra do Ramalho (Bahia, Brésil). Geologica Belgica, 2001, 4 (3-4): 251-261.

Dardenne M.A. - 1978. Síntese sobre a estratigrafia do Grupo Bambuí no Brasil Central. 30° Congresso

Brasileiro de Geologia, Recife, vol. 2 : 597-610.

Piló L.B. - 1989. A morfologia cárstica do baixo curso do rio Peruaçu, Januária/Itacarambi, MG. Departamento

de Geografia do Instituto de Geociências da UFMG, monografia de graduação/ bacharelado em Geografia

Física : 97 p.

Piló L.B. - 1997. Caracterização regional do carste do Vale do Rio Peruaçu. O-Carste, 9 (2) : 22-29.

Piló L.B. & Köhler H.C. - 1991. Do Vale do Peruaçu ao São Francisco : uma viagem ao interior da terra. Anais

do III Congresso da Associação Brasileira do Estudo do Quaternário, Belo Horizonte, 2 : 57-73.

Projeto RadamBrasil - 1982. Folha SD.23 : Brasília. Ministério das Minas e Energia, Rio de Janeiro,

Levantamento de recursos naturais, vol. 29 : 644 p.

Prous A. - 1992. Arqueologia brasileira. Editora UnB, Brasília: 613 p.

Rodet J. & Rodet M.J. - 2001. Evolution karstique et ressources lithiques archéologiques. L'exemple du Rio

Peruaçu (Januária - Itacarambi, Minas Gerais, Brésil). Actes du XIème Congrès National de Spéléologie,

Genève (Switzerland), 14-16 september 2001: 129-134.

Rodet J., Mariano D.F., Rodet M.J., Pouclet A., Piló L.B., Willems L. - 2003. Evolução cárstica do vale do rio

Peruaçu (Minas Gerais): uma nova abordagem. XIIe Simpósio de Geologia de Minas Gerais, Ouro Preto

(Brazil), 4-8 november 2003, resumo: 97.

Rodet J., Rodet M.J., Mariano D.F., Do Nacimento S.P., Huguet Y. - 2004a. La grotte du Janelão, élément-clé

de l'évolution géomorphologique de la vallée karstique du Peruaçu (Januária-Itacarambi, Minas Gerais,

Brésil) - the Janelão cave, key-element of the geomorphological evolution of the karst of the Peruaçu Basin

(Januária-Itacarambi, Minas Gerais, Brazil). Proceedings of the 2003 AFK European Meeting, Rouen

(France), 10-12 september 2003: 62-63.

Rodet J., Rodet M.J., Mariano D.F., Willems L., Pouclet A., Piló L.B. - 2004b. Do Brejal ao Janelão, uma

historia geomorfologica do Terra Brava. Carste-2004, Belo Horizonte (Brazil), 27-31 july 2004, Caderno de

Resumos: 23.

Rodet M.J., Rodet J., Do Nascimento S.P., Mariano D.F., Huguet Y., Silva J.R. - 2002. Metodologia de

prospecções geoarqueológicas dentro de uma bacia (exemplo da bacia do Rio Peruaçu, Minas Gerais, Brasil).

Revista do Museu de Arqueologia e Etnologia da Universidade de São Paulo, 12 : 25-41.

143

O-34

Explorations and Geomorphology of the Velebita-Dva Javora Cave System on North Velebit Mt. in Croatia - World's Deepest Subterranean Shaft

Darko Bakšić[1], Andrej Stroj[2] & Mladen Kuhta[2]

[1] Faculty of Forestry, Svetošimunska 25, Hr-10000 Zagreb, Croatia

[2] Institute of Geology, Sachsova 2, Hr-10000 Zagreb, Croatia

E-mail: baksa@hazu.hr; astroj@igi.hr; kuhta@igi.hr

Abstract

The North Velebit massif according to the recent exploration results is speleologicaly the most important Dinaric karst region. Over the last 14 years about 300 caves were discovered and explored. The system Lukina jama - Trojama (-1392 m) and Slovačka jama (-1301 m) are the deepest caves in Croatia and rank as 16th and 21st deepest caves in the world. Furthermore, significant depths were reached in the Meduza (-679 m), Patkov gušt (-553 m), Ledena jama (-536 m) and Jama Olimp (-531 m) caves. The karstification processes are dominantly controlled by vertical groundwater circulation through the deep unsaturated zone built up of fractured carbonate rocks. As the result about 97 % of explored caves may be classified as pits with long vertical sections as their major morphological characteristic. For instance, the 553 m deep pit Patkov gušt practically consists of one vertical shaft, the final part of Meduza represents a 390 m deep vertical shaft. Vertical sections longer than 200 m can be found in almost all deeper caves.

The intense vertical karstification processes and genesis of extremely deep speleological objects in this area are confirmed by the last explorations in the Velebita pit. This 580 m deep cave system morphologically has a 513 m subterranean (internal) vertical section, which is the world's deepest known subterranean shaft.

Introduction

The discovery of the cave Lukina jama in 1992 in the North Velebit Mt. area started off intensive speleological researches. In the period from 1992 to 2004 more than 250 caves were explored in this area. The cave system Lukina jama - Trojama (-1392 m) and cave Slovačka jama (-1320 m) are the deepest speleological objects in Croatia and are the 16th and 21st deepest cave in the world. Another 5 caves deeper than 500 m were explored; Meduza (-679 m), Patkov Gušt (-553 m), Ledena Jama (-536 m), Olimp (-531 m) and Lubuška Jama (-521 m). During the Croatian-
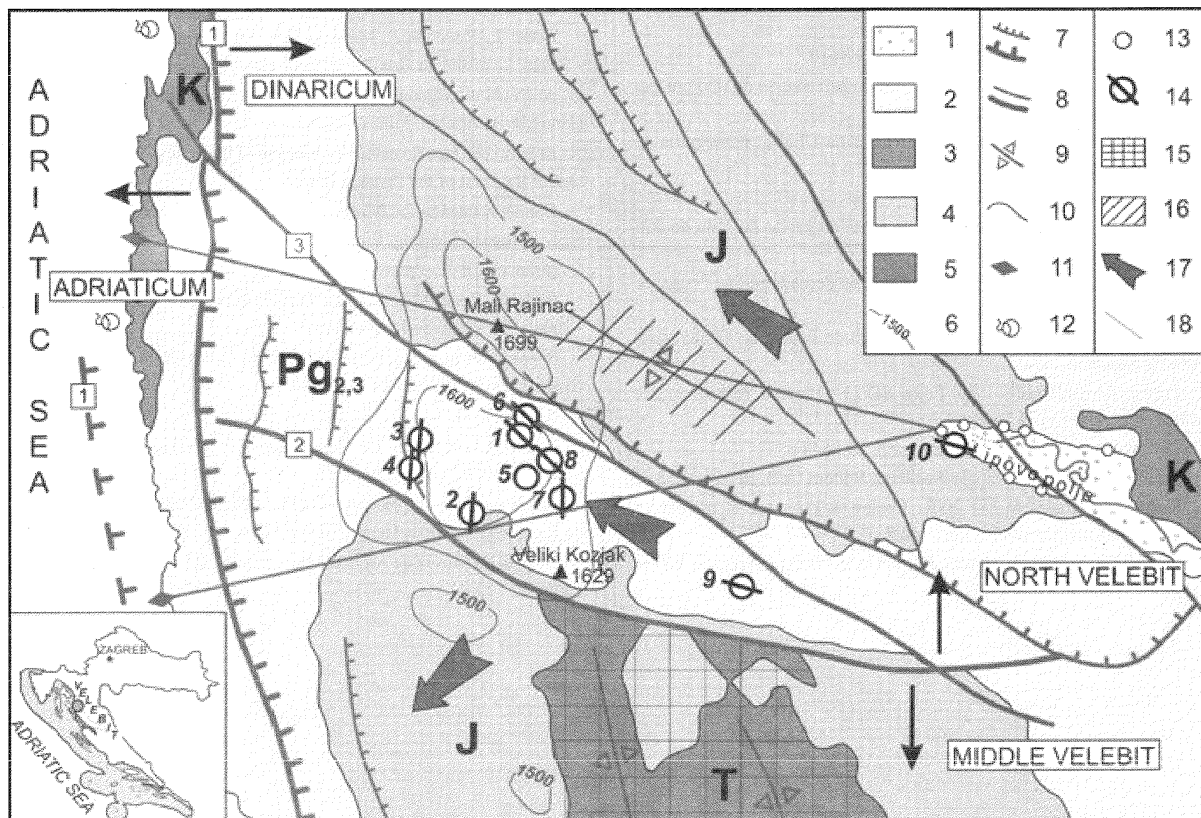
Fig. 1 Simplified geological map of the North Velebit area. Legend: 1) alluvium deposits; 2) calcareous breccias of Upper Palaeogene; 3) Cretaceous carbonate rocks; 4) Jurassic carbonate rocks; 5) Triassic carbonate and clastic rocks; 6) summary amplitudes of vertical neotectonic movements (in metres); 7) reverse faults, (1) Velebit fault; 8) normal faults, (2) Bakovac fault, (3) Lomska duliba fault; 9) anticline axis; 10) geological boundary; 11) coastal spring; 12) submarine spring (vrulja); 13) sinkhole; 14) deep caves, (1) Lukina jama, (2) Slovačka jama, (3)Meduza, (4) Velebita, (5) Patkov gušt, (6) Ledena jama, (7) Olimp, (8) Lubuška, (9) Paž, (10) Markov ponor; 15) area of Velebit complex barrier; 16) relative barrier; 17) general groundwater flow direction; 18) groundwater flow direction tested by tracing.

French expedition, the aim of which was to continue the explorations in cave Meduza, members of the speleological department of the mountaineering society "Velebit" found the entrance into cave Velebita, called after the society and the mountain range where the cave is situated. The cave was explored to the depth of -376 m in that same year. The explorations continued in August 2004 and went to the depth of -580 m. The second entrance into the cave (cave "Dva Javora") was also found and explored.

Geological, hydrogeologic and geomorphologic setting of the terrain

North Velebit Mountain is built of rocks dating from the Jurassic period to Palaeogene. The Jurassic period is represented by carbonate sediments in which limestone predominate but there are also dolomites in them. The Cretaceous sediments have been arranged on the border parts of North Velebit Mt. in the direction of the Lika region (hinterland of the massif) and in the coastal part too. They consist of limestone, carbonate breccias and dolomites. In hydrogeologic sense, rocks from the Jurassic and the Cretaceous period are highly permeable.

Palaeogene is represented by "Jelar" carbonate breccias widely spread in northern and western parts of Velebit. In the southern part of North Velebit Mt. these sediments cover the entire profile from sea coast on the west to the Lika region on the east side of the mountain. Jelar breccias are very significant due to their singular submissiveness to karstification processes, KUHTA (2001). Areas having the most intensively developed karstic morphology, as well as entrances into all deepest objects on North Velebit, are found in the area built of these rocks. It also frequently happens that shafts or entire caves stop on the point of the contact of Jelar sediments and Jurassic carbonate rocks; thus the bottom of the big shaft in cave Velebita is rather close to this contact. The data on the thickness of Jelar sediments up to 300 m are mentioned in Literature, BAHUN (1974), although during explorations of cave Velebita the contact of Jelar breccias and Jurassic rocks was identified on the depth larger than 500 m.

Geological structure of North Velebit Mt. also conditions hydrogeologic situation inside the massif. Since low permeable rocks, which are found on the very surface in the Middle and Southern Velebit, are much deeper here, the sea level becomes the erosion base of karstification. As a consequence of such situation there is present a deep unsaturated zone with dominantly vertical water flows in north Velebit massif. Only two deepest caves Lukina jama and Slovačka jama in their bottom parts reach recent and sub-recent levels of saturated zone where systems of horizontal channels occur. When waters which fall on a permeable terrain as precipitations reach the saturated zone, they join the waters form the River Gacka and the River Lika. These two rivers sink underground next to east borders of north Velebit and their waters spring on the numerous coastal springs and vruljas along the western border of a Velebit massif.

As a consequence of such situation, the most singular feature of speleological objects in the area of north Velebit is their verticality. Thus cave Patkov Gušt is a 553 m deep shaft from its top to the bottom which makes it the second deepest shaft in the world. The 513 m deep shaft "Divke Gromovnice" in the cave system Velebit - Dva Javora is the deepest known shaft in the world having no outside entrance. We should also mention 390 m deep shaft "Bojim, bojim" in the cave Meduza. Shafts deeper than 200 m can be found in majority of more significant caves on North Velebit. Precisely these characteristics make area of the North Velebit Mt. unique in the world.

Morphology of the Velebita - Dva javora cave system

The entrance into the cave Velebita is located on steep western slopes of the central part of the North Velebit Mt. It is hidden by collapsed rock blocks and it is hardly noticeable. A narrow passage leads into the first

shaft 35 m deep. On its bottom, there is another narrow passage, called "Striborov Prolaz", leading into the second 25 m deep shaft. The system becomes rather indented in this part. Meanders prevail, out of which some end in narrowings (Palčičev Meandar), and some in shafts (Malikova Igrarija, Perunov Meandar). Besides the shaft "Divke Gromovnice", these shafts terminate on depths between 110 and 150 m. A narrow meander continues from the shaft "Perunov Odvojak" to the depth of around -160 meters and terminate with a narrowing. Perunov Meander provides the entrance into the shaft "Divke Gromovnice".

The higher entrance into the shaft "Divke Gromovnice" can be reached from cave Dva Javora. The entrance into cave Dva Javora is located around 65 m north-west and 7 m lower than the entrance into Velebita cave. Cave Dva Javora is also morphologically complicated. Narrow meanders and shafts alternate. On the depth of -55 m meander "Žrekova Prečka" is separating from the 80 m deep shaft; the higher entrance into the shaft "Divke Gromovnice" is reached by traversing this meander. In the opposite direction, the cave continues with narrow meanders and smaller shafts all the way to a hall on the depth of around -120 m. This hall provides the entrance into the final 98 m deep shaft.

The shaft "Divke Gromovnice" in about first hundred meters has an elliptic diameter of an average size 8 m by 3 m. On the depth of -210 m from the entrance into the Velebita cave several smaller shafts join together into a single shaft with approximate size 40m by 15 m. After that part the shaft has a similar form all the way to its bottom on the depth of -580 m. The bottom is slanting and is covered in big stone blocks.

Geological and hydrogeological features of the cave system

The Velebita - Dva javora cave system is almost entirely developed in Palaeogene Jelar carbonate breccias. The contact between Jelar breccias and Jurassic limestone is found to be at approximately 530 m of depth. The bottom part of the cave is developed in well bedded Jurassic limestone and the very bottom is covered with Jelar breccias blocks which were transported by gravity from upper parts of the shaft.

Jelar breccias have massive structure, and the discontinuities in them are connected exclusively to faults and joints. The dominant stretching orientation of fractures is NNE-SSW and less distinctive E-W. Dip angles are mostly between 70 and 90°. Discontinuities mostly have relaxation character with compact walls and without fractured zones. Precisely such discontinuities character enables the creation and the stability of big underground spaces in the cave. The mentioned discontinuities are connected to a younger neotectonic straining phase.

During explorations, larger groundwater flows were not noticed in the cave. Water flows are present in the form of dripping water and a thin water film on the walls of shafts. In the hall on the bottom of shaft "Divke Gromovnice" there is a concentrated small capacity groundwater flow which is sinking further among stone blocks. During heavy precipitations larger groundwater flows having mostly vertical character probably occur in the cave. Their occurrence and duration are directly connected to outside precipitations or periods of intensive snow melting.

According to the analogy with Lukina and Slovačka caves, the level of a phreatic zone under Velebita cave is located on between 50 and 100 m above sea level. Taking into consideration this presumption, there is a perspective of reaching the depth of around 1500 m in the cave.

The cave genesis

The genesis of the cave system Velebita - Dva javora is connected to a vertical water flows in a vadose zone through karstification prone carbonate rocks. The bottom of the cave is situated high above phreatic zone. The massive structure and a steep to vertical angle of the main discontinuities

Velebita cave system

North Velebit Mt., Croatia

Dva javora entrance
▽ 1550

Velebita entrance
▽ 1557

0 m

Striborov prolaz

50 m

Žrekova prečka

Malikova igrarija

Palčićev meandar

Perunov meandar

100 m

Palčićev meandar

Perunov odvojak

Depth: -580 m
Lenght: 452 m
Poligon lenght: 1445 m

200 m

Explore: SO PDS Velebit, SO HPD Dubovac, SO HPD Mosor
Komisija za speleologiju Hrvatskog planinarskog saveza

Topo: Matija Čepelak, Dalibor Paar, Ronald Železnjak, Darko Bakšić,
Lovro Čepelak, Tihana Dasović, Vesna Hrdlička

P 513

300 m

Measure: Darko Bakšić, Ronald Železnjak, Tihana Dasović, Matija Čepelak,
Marinko Malenica, Jana Bedek, Marin Glušević, Marko Lukić

Compile and digitalization: Darko Bakšić, Lovro Čepelak

Vertikala Divke Gromovnice

400 m

500 m

-580 m

600 m

Fig. 3 Shaft "Divke Gromovnice" in its wider part.

in Jelar breccias are, together with a vertically directed water pressure gradient, main reasons of the non-existence of horizontal channels in the cave.

The water which falls through precipitations on the terrain surface quickly enters into the upper epikarstic zone. The water from this zone is strained in the direction of the most permeable discontinuities in the rock mass and it also widens them to the dimensions of meanders and shafts by its corrosive effect. This process of the widening of underground spaces is active until hydrological conditions are changed or until the enlargement of the cavity causes instability and collapsing.

Groundwater flows concentrate with depth and usually the indentedness of caves decreases. Thus in the cave system Velebita - Dva javora the lower wider part of the big shaft was created by joining of several smaller shafts into a single one and the cave is the most indented by the depth of around 150 m.

In the initial stage of the genesis of shafts, the water which flows as a thin film on the walls of widened fractures has the main role. Since fractures become wider and wider dripping water gets more and more important role, BARON (2002). The water that drops is suddenly enriched with CO_2 through its falling through the CO_2 rich cave atmosphere; thus its aggressiveness grows while the water flowing on walls of fractures gets saturated with $CaCO_3$ and loses dissolution capacity. On the places where water drops fall, the corrosion is the most intense and the vertical growth is the fastest. Thanks to this mechanism it is possible to explain the phenomenon of almost flat bottom of big shafts in the continuation of which water further flows through narrow passages. If fractures are not vertical but leaned under a certain angle, typical triangle shapes of shafts are created having one wall slanting and the other vertical (Perunov Odvojak). The slanting wall of the vertical is connected to the position of primary fracture, while the vertical wall was created due to a corrosive effect of the dripping water. Channels of step-like shapes can be formed by simultaneous growth of more shafts all connected to the same fracture. Passages connecting such shafts are frequently narrow and developed along primary fracture (Striborov Prolaz). Intersections of several fractures can also speed up processes of the creation of shafts.

The creation of narrow passages and meanders is connected to water flow in the form of a thin film on walls of vertical discontinuities. Due to a slower dissolution dynamics, channels get their characteristic shape extended along the stretching of the primary fracture. The majority of underground spaces was created by a combination of water film and

Fig. 2 Topographic plan of the Cave system Velebita-Dva javora

dripping water action and narrow meanders frequently turn into shafts and vice-versa (Perunov Meander, Malikova Igrarija, Perunov Odvojak). The collapsing processes also have an important role in the shaping of underground spaces, and they result in a decrease or total burying of some channels.

In the Velebita - Dva javora cave system, the same as in the majority of other caves in North Velebit area, the corrosion processes are still active, with an almost total lack of speleothem sedimentation.

Conclusions

The genesis and the morphology of the cave system Velebita - Dva javora are a consequence of geological, hydro-geological and hydrological features of the surrounding terrain. The object was developed in massive and karstification prone Jelar carbonate breccias. The bottom of the deepest shaft in the system is located close to the contact of Jelar breccias and Jurassic limestone. The most important morphological characteristic of the cave are the alternations of spacious shafts with narrow passages and meanders. The cave is rather indented in its upper parts, while on the depth of around -100 m turns into a shaft more than 500 m deep, the deepest known underground shaft in the world. Morphology of the cave is are a consequence of a dominantly vertical water flow in a deep vadose zone along vertical and sub-vertical fractures. With regards to the presumed groundwater level, there is a perspective that the maximum depth of the cave could reach around 1500 m.

147

References:

BAKŠIĆ, D. 2004: Cave system Velebita-Dva Javora. Subterranea croatica, 3, Karlovac: 2-6.

KUHTA, M. I BAKŠIĆ, D. 2001: Karstification dynamics and development of the deep caves on the north Velebit Mt. - Croatia. - Proceedings to 13th Speleological Congress, Brazil.

PAVIČIĆ, A. 1995: Hydrogeological conditions for the construction of reservoirs in the Velebit Mt. hinterland. Unpublished. Ph. D. Thesis, University of Zagreb, Croatia, 124 p.

PRELOGOVIĆ, E. 1989: Neotectonic movements in the Northern part of Mt. Velebit and a part of Lika (SW Croatia). Geološki vjesnik, 42, Zagreb: 133-147.

BAHUN, S. 1974: The tectogenesis of Mt. Velebit and the formation of Jelar deposits. Geološki vjesnik, 27, Zagreb: 35-51.

BAHUN, S. 1984: The tectonic and hydrogeologic significance of the areas composed of the Jelar formation. Krš Jugoslavije, 11/1, Zagreb: 1-11.

WHITE, W. B. 2000: Speleogenesis of vertical shafts in the eastern United States. Speleogenesis, Nat. Spel. Soc., Alabama: 378-381.

BARON, I. 2002: Speleogenesis along sub-vertical joints: A model of plateau karst shaft development: A case study: the Dolny Vrch Plateau (Slovak Republic). Cave & Karst Science, 29 (1), 5-12.

O-35

The 'karstic delta' concept, as a morphological expression of climatic variations of the base level in coastal areas - the example of the Eastern English Channel region (Normandy, France)

Joël Rodet, Benoît Laignel, Nicolas Massei, Matthieu Fournier, Jean-Paul Dupont

UMR 6143 CNRS, Laboratoire de Géologie, Université de Rouen, 76821 Mont Saint Aignan Cédex, France, joel.rodet@univ-rouen.fr

Abstract:

Coastal output karst systems offer a very well developed network of galleries with a complex organization resulting of the hydrological base level variations. In the Eastern English Channel, the lower Seine river valley has been successively and cyclically from the middle Pleistocene, bay bottom, estuary and river. Consequently, numerous base level variations were recorded by functionnal karst systems, as the Caumont karst network: its exacerbeted gallery development results directly from the underground drainage adaptation to the altitudinal and lateral constraints of these variations.

Introduction

The 'karst delta' is a concept introduced for the first time, at least in the french karst research, by Rodet [1982], in his study of the chalk karst on the littoral area of Normandy (France), and developed by the same author in 1992. This concept is about dissolutional caves on the sea border, not about true sea caves [Bunnell, 2004]. The Normandy coast offerts numerous dissolutional sea caves (Rodet, 1992a), ones of them with a very complex network organization [Rodet & Lautridou, 2003].

Normandy is a particular region in which the impressive spatial development of the karstic forms and system organisations formed under the influence of the Quaternary sea-level changes, can be seen. The plateaux of the Lower Seine limit the depth of incision of the great valley, between the confluence of the River Andelle and the estuary in the English Channel (fig. 1). The Quaternary evolution is complex and recorded in karst development. The upper part of the valley always was a river (ter-restrial environment) when the downstream part, more or less important, was included in the estuary, or even marine during transgression, or a river environment during regression. This was dependent on global sea-level fluctuations [Lautridou et al., 1999]. These changes resulted in large modifications of the hydrological base-level and in consequence of the karstic drainage. This study contributes to the chronological reconstruction of the Quaternary evolution in the Lower Seine.

In this way, the Caumont area, 120 km distant from the coastal zone along the River Seine, at an elevation of only 4 m, is under the direct influence of the tidal zone (fig. 3). The geomorphological study of quite 8 km of galleries ought to define the function and the chronology of each conduit and to propose a genesis sketch of a complex output karst network. It presents different drain levels and drainage diffluences in a diachronic functioning of a three dimensional delta scheme, fixing the 'karst delta' concept. Regressive periods incite to the spring outflow, responsible for regressive downward incision in the substratum.

Upstream to downstream, forms follow from the filling erosion to the new gallery opening, through drawing-off and ground incisions opening a 'key-hole' section. In relation with the downward velocity, it opens a wide gallery (slow descent) or a strait gallery (quick descent), with morphology of a 'canyon' and direction linked to the structure (tectonics), and vertical slope when the direction changes suddenly.

Transgressive periods involve an alluvial infilling with dam effect responsible for the spring overflow, with submersion of the palaeoconduits and roof equilibrium domes and intrakarst sedimentary stocking [Fourni-

Figure 1 - Location of the studied area. Caumont is located near the Orival valley, south-west of Rouen.

shoreline (Cap Fagnet) where the destruction of an old karstic network can results in the complex morphology of an indented coastal area (Etretat - photo. 6).

Conclusion

In fact, it is possible to distinguish the 'littoral', a geomorphological zone where the sea and the continent confront each other, and the 'littorality', a temporal concept of a conflict between marine and continental processes, that migrates in relatively space with the temporal evolution of the relative mean sea-level during the Quaternary. In this way, a continental cave can be seen on the coastline never retouched by the sea. It can also be seen far away from the modern coast, in the side of a deeply incised valley like the Lower Seine, there a karst network wholly subjected to Quaternary fluctuations of the sea-level. This is why it is very important to distinguish the present coastal zone from that influenced by previous Quaternary sea-level changes. The 'karstic delta' concept can be extended to all the regions under influence of important sea level variations (climatic and tectonic origins) like in the Mediterranean Sea during the Cenozoic, and where the present transgression is responsible for the reservoir submersion (Fontaine de Vaucluse, greek Almyros, etc.).

References

Bunnell D. - 2004. Littoral caves. *Encyclopedia of caves and karst science*, J. Dunn ed., Fitzroy Dearborn: 491- 492.

Fournier M. - 2004. Structure et fonctionnement du système karstique du Hannetot replace dans le contexte géomorphologique de la basse vallée de Seine. Actes des Journées Européennes de l'AFK 2003, Rouen: 106-116.

Lautridou J.-P., Auffret J.-P., Baltzer A., Clet M., Lécolle F., Lefebvre D., Lericolais G., Roblin-Jouve A., Balescu S., Carpentier G., J.C. D., Ochietti S. & Rousseau D.-D., 1999. Le fleuve Seine, le fleuve Manche. *Bulletin de la Société Géologique de France*, 170 (4) : 545-558.

Rodet J. - 1982. *Contribution à l'étude du karst de la craie : l'exemple normand et quelques comparaisons*. PhD thesis, Géographie Physique, Université de Paris I "Panthéon - Sorbonne": 427 p.

Rodet J. - 1992a. *La craie et ses karsts*. Ed. CNEK & Groupe Seine, Centre de Géomorphologie du CNRS, Caen: 560 p.

Rodet J. - 1992b. Le karst dans l'évolution quaternaire de la Basse Seine (Normandie, France). *Karsts et évolutions climatiques*, J.-N. Salomon & R. Maire eds., Presses Universitaires de Bordeaux: 363-382.

Rodet J. - 2004. Karst et craie en Normandie : une approche géographique - chalk and karst in Normandy : a

geographical approach. Actes des Journées Européennes de l'AFK 2003, Rouen: 16-31.

Rodet J. & Lautridou J.-P. - 2003. Contrôle du karst quaternaire sur la genèse et l'évolution du trait de côte d'une région crayeuse de la Manche (Pays de Caux, Normandie, France). *Quaternaire*, **14** (1) : 31-42.

Rodet J., Massei N., Laignel B., Dupont J.-P. - 2003. The karstic delta as a morphological consequence of base level variations. Example of a chalk karst system in the western Paris Basin (Normandie, France). Climate Changes : the karst record III, Montpellier, 11-14 may 2003, abstract: 139-140.

Rodet J., Massei N., Laignel B., Dupont J.-P. - 2004. The karstic delta as a morphological consequence of base level variations. Example of a chalk karst system in the western Paris Basin (Normandy, France) - le delta karstique, expression des variations climatiques du niveau de base. Exemple d'un système karstique de la craie de l'Ouest du bassin de Paris (Normandie, France). Actes des Journées Européennes de l'AFK 2003, Rouen: 64-65.

Figure 2 - The deltaic karst network of Fagnet Cape. 1- high level at 8 m NGF; 2- medium level at + 6m; 3- base level at 3 m; 4- lower level at 0 m. This karst system adapted during the eemian transgression, from its base level at +3 m, to two upper levels (+6 and +8 m), before to be deconnected suddenly by the weichselian regression effect (lower level at 0 m).

er, 2004]. Diffluences demonstrate the karst adaptation to the drainage area evolution, more specifically near springs. They can happen as during transgression phases (high base level) than during regressive ones (low base level).

The distance from its origin reduces the pertubation on the network functioning and morphology. Upstream, bigger phases only appear, whereas downstream morphological adaptations of minor phases are registred. That places in a prominent position the notion of 'encasing'; a bigger form upstream divided in various smaller forms downstream, valid as for conduit stages than for gallery diffluences.

The large underground network, known to exceed 7 km, includes a number of different conduits, with several connections, developed in a complex organisation scheme. This results from the adaptation of underground drainage to the various variations of the hydrological base-level (fig. 4) rather than from the geomorphological variations of its hydrological basin (fig. 5). In fact, the considerable distance of this network from the sea-cliff erosion, protected the Caumont underground system, with its rich evidence of complex Quaternary evolution. This explains why the modern coastal zone, subjected to the erosional effect of a rejuvenated shore-line, does not provide such impressive karst examples (Cap Fagnet - fig. 2) like those at Caumont (fig. 3), which is protected by its upper estuarian location [Rodet, 2004].

A 'karstic delta' needs of an important and stable flood to hold the connexion between the conduits against the ruptures resulting of the base level variations. It needs too of a place protected of the sea border erosion to conserve the different phase testimonies. A location in a deep coastal valley like the Lower Seine (Caumont) is a better protection than on the

Photo. 1 - original water base level. *A paleo gallery flooded by the submersion water level. The small river opens its way through the filling (terraces on walls), showing an adaptation morphology. Robots (Caumont).*

Photo. 2 - small rising of the water level. *A dual conduit resulting of the low elevation of the water level (Jacqueline cave, Caumont). The former gallery was totally infilled by sediments, when above it a new gallery opened a way to the drainage. It results two opposite morphologies on wall: the upper gallery (the most recent) presents small scallops resulting of a low water dynamics (dynamic siphon), as the lower gallery (the former one) offers coalescent deep scallops with terrigenous infill demonstrating the very low water dynamic (phreatic siphon). Photo. 4 - submerged gallery with sediment filling **and a fossil evolution evidence.** A submerged gallery, ten metres under the current water level. The morphology demonstrates a polyphased evolution, with a ceiling half-tube and an impressive terrigenous filling. The front of the deposit shows clay polyedrics (dry period) eroded by the anthropic pumping of the Water Supply (Siphon of Les Varras, Caumont karst system).*

Photo. 4 - submerged gallery with sediment filling and a fossil evolution evidence. *A submerged gallery, ten metres under the current water level. The morphology demonstrates a polyphased evolution, with a ceiling half-tube and an impressive terrigenous filling. The front of the deposit shows clay polyedrics (dry period) eroded by the anthropic pumping of the Water Supply (Siphon of Les Varras, Caumont karst system).*
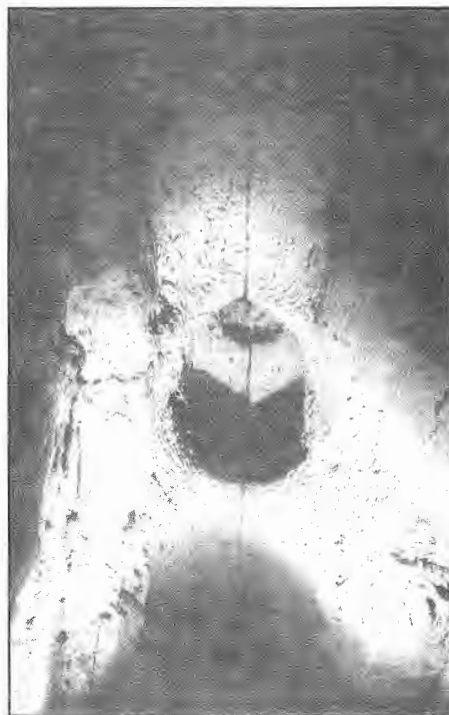
Photo. 3 - phreatic uplift passage. *Developed on tectonic ceiling dome works like an equilibrium chimney during transgressive periods (Jacqueline's cave, Caumont karst system). Photo. 5 - palaeo conduit cutting the modern **water level surface**. A descending gallery is submerged by the current water level, resulting of the flandrian transgression into the ria of the Seine Valley. Le Pylône cave (Caumont karst system).*

Photo. 5 - palaeo conduit cutting the modern water level surface. *A descending gallery is submerged by the current water level, resulting of the flandrian transgression into the ria of the Seine Valley. Le Pylône cave (Caumont karst system).*

150
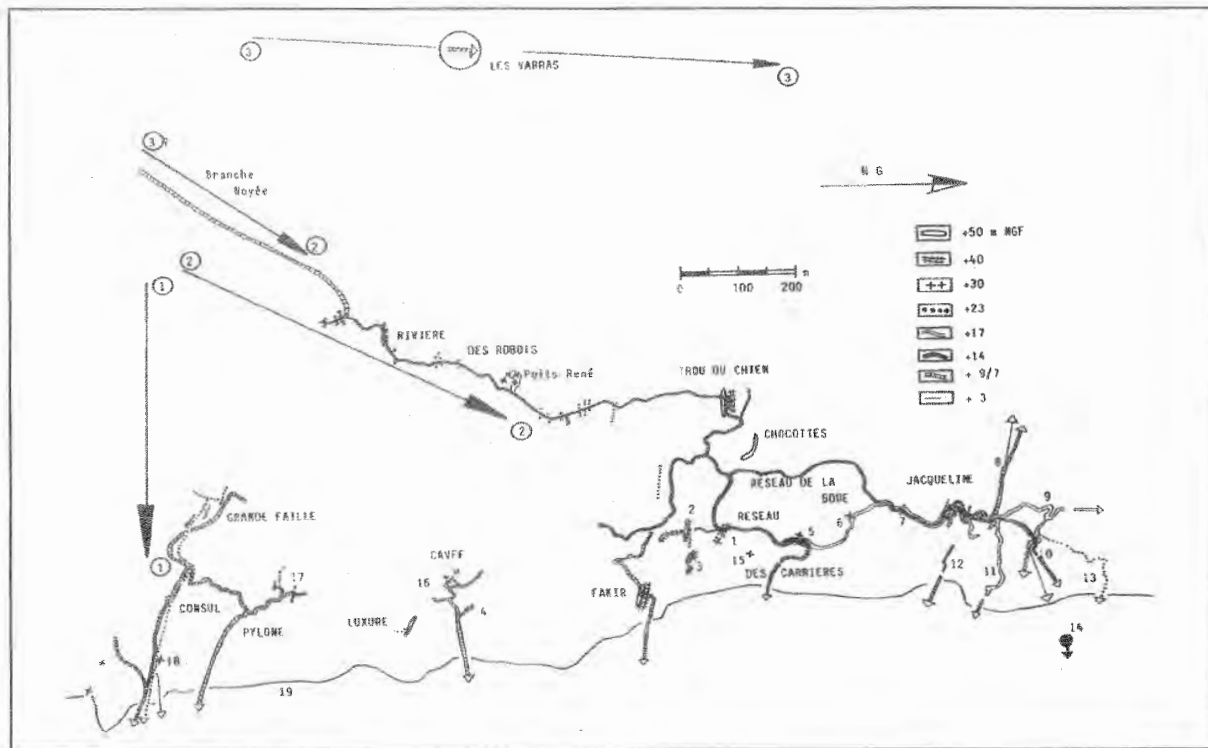
Figure 3 - the karstic delta network of Caumont with its three drainage axis (1- early, 2- medium, 3- current). Every karst element is located with its altitude class: +50 m, +40 m, +30 m, +23 m, +17 m, +14 m, +9/7 m, +3 m. All altitudes are explained in NGF (French General Levelling).

Photo. 6 - the complex morphology of an indented area : the sea cliffs of Etretat contain various elements of an old karstic delta network [Rodet, 1992a].
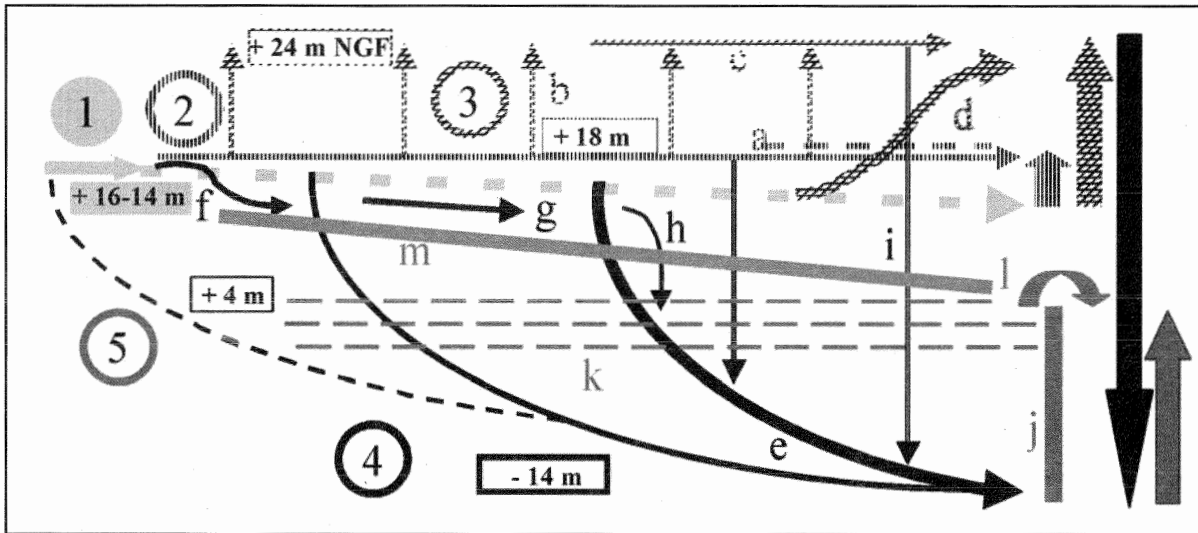
Fig. 4 - Vertical organization of a karstic delta network [after Rodet et al., 2004]. **1** : original water base level at + 16 (upstream) /+ 14 m NGF (downstream) - **photo** 1. **2** : small rising of the water level up to 18 m with downstream (a) the duplication of the main conduit - **photo** 2. **3** : great rising of the water level up to 24 m, giving development of (b) phreatic lifting passages - **photo** 3, and on the top the development of (c) small galleries. Downstream, the uplift of the basal drainage results in a (d) vauclusian spring. **4** : the quick and important fall down of the water table to - 14 m (over 38 m deep) is responsible for a new equilibrium profile with a retrogressive erosion dynamic into the karstic drainage, underlined from upstream to downstream, by a (f) cutting passage into the gallery sediments, then the (g) filling withdrawing till a (h) water fall. Near the exsurgence, (i) shafts are common. **5** : the ultimate rising to + 4 m due to the flandrian transgression, by effect of a (j) karstic damming, is responsible for the storage of water in a (k) great underground reservoir with alluvial infilling - **photo** 4. A new (l) spring level floods over the dam, and a new (m) equilibrium profile is realised between the original drainage (1) and the modern spring level - **photo** 5.
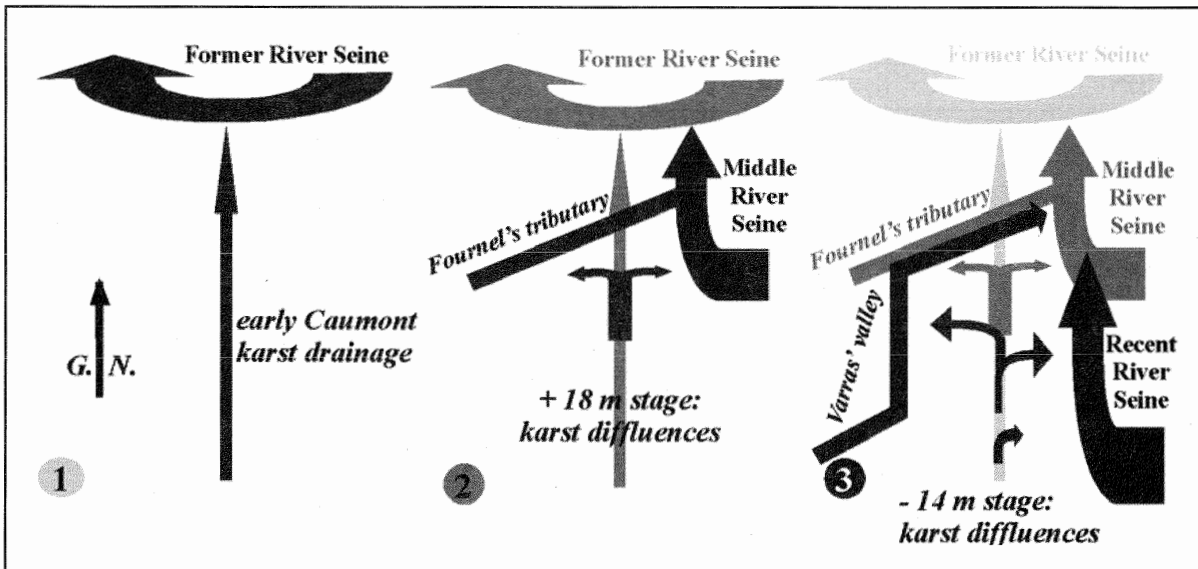
Figure 5 - Karst diffluences as an underground drainage adaptation to the geomorphological evolution [after Rodet et al., 2003]. Only three successive stages of several are shown. Ur/Th dating performed at the CERAK (Mons, Belgium) using speleothems mainly calcite flowstones, allows to consider that karstic delta functioning started in the middle Pleistocene (235.6 ky + inf./-75) until present days (74.5 ky +19.7/-16.6 ; 37 ky +13.9/-11.8 ; 16.4 ky +111.1/-16.4 ; 0 ky).

O-36

Genesis of a karst system in the Lower Meuse chalk district (Belgian-Dutch border)

Luc Willems[1] , Joël Rodet[2], Matthieu Fournier[2], Nicolas Massei[2], Benoît Laignel[2], Ludivine Dussart-Baptista[2], Jean-Christophe Schyns[3], Michiel Dusar[4], David Lagrou[5], Camille Ek[1]

[1] *EuReKarst, Laboratory of Sedimentology, Dept. Geology Petrology Geochemistry, B20, University of Liege, B-4000 Liege, Belgium,*

[2] *EuReKarst, UMR 6143 CNRS, Continental and Coastal Morphodynamics, Laboratory of Geology, University of Rouen, F-76821 Mont Saint Aignan Cedex, France,*

[3] *EuReKarst, Laboratory of Geomorphology and Teledetection, Dept. Physical Geography and Quaternary, Allée du 6 août, 2, University of Liege, B-4000 Liege 1, Belgium,*

[4] *Geological Survey of Belgium, Jennerstraat 13, B-1000 Brussels, Belgium.*

[5] *VITO - Flemish Institute for Technological Research, Boeretang 200, B-2400 Mol, België*

Abstract:

Different karst phenomena were intersected by underground and open-air quarries in Cretaceous chalks of the Belgian-Dutch border zone along the Meuse river. Dolines and more than one thousand solution pipes were observed. Solution pipes can attain a depth of sixty meters. These may intersect endokarst features: sub-horizontal galleries developed along joints, round galleries without visible fissure and sponge networks. Occasionally, surfaces sculpted by cupolas and arched cavities stopping upwards were observed. At deeper levels, pluridecametric nodes of weathered chalk are developed under the base water level. All these karst features indicate a three stage genesis for the karstic system. The first stage occurred in the phreatic zone, independent of the surface climate. Weathered nodes, generally in relation with fissures, develop and may lead to opening conduits. The second stage is related to valley incision and the emersion of a karst system above the piezometric level. Locally, this 'primokarst' can initiate subhorizontal cave features as axis of drainage. In the same time, a vertical input karst (solution pipes or 'organ pipes') develops and often intersects the caves at deeper levels. Waterflood is affecting these drainage axis, and fine sediments can fill the cave galleries. The third stage is the disconnection of the different forms, raised above the base level. Only input by infiltration waters is controlling the further evolution of these forms.

Introduction

At the Belgo-Dutch border (Fig. 1) near the city of Maastricht, a series of surface quarries and artificial caves have exploited chalk and calcarenites of Maastrichtian to Campanian age (Upper Cretaceous). These have intersected typical karst, features like caves, alveoli, solution pipes, ceiling pockets, nodes of weathering. Their study enables to reconstruct the genesis of a polyphased karst system. Drains within the chalk prove that

Fig. 1: Localisation of the studied area

underground drains, hence karst can develop in a rock type characterised by a very high porosity.

1. Physical environment

The studied area in East Belgium and South Netherlands (Dutch Limburg) is characterised by a rolling plateau on deeply drained Cretaceous chalks under loess cover. Saint Peter's Mountain (Montagne Saint Pierre, Sint Pietersberg) is a separate part of the Hesbaye plateau isolated between the incised valleys of the Geer and Meuse rivers, due south of their confluence in the city of Maastricht. The altitude of the plateau lies between 153 and 100 m above sea level, up to 70 m above the alluvial plains.

The studied forms develop in the Gulpen and Maastricht Formations (Campanian to Maastrichtian age), exposed over 100 m. The upper unit (Maastricht Formation) consists of macroporous calcarenites, subdivided by hardgrounds. Flint nodules already appear in the Maastricht Formation. The lower unit (Gulpen Formation) consists of very fine calcarenites grading into chalk with many flint beds in its upper part (Lanaye and Lixhe Members) overlying more pure chalks with and without small flints in its lower part (Vijlen and Zevenwegen Members). The ENCI quarry exposes all these strata. Impervious marls of the Vaals Formation separate the chalk from deeply weathered and kaolinised Carboniferous limestones (Felder & Bosch, 1998, 2000).

Young Paleocene carbonates and continental deposits are not preserved on Saint Peter's Mountain. The next deposit consists of Oligocene, marine Tongrian sands (St Huibrechts Hern Formation) were deposited on the area. On Saint Peter's Mountain they are mainly preserved within dolines. From the Pliocene, the Meuse river drainage system came into existence and progressively incised down to its actual level, as testified by peneplanation levels and gravel terraces. The high terrace of the Meuse river covers the older formations with an alluvial gravel during the Middle Pleistocene. These coarse and loamy river deposits armour the underlying Cretaceous chalk and lead to a local relief inversion. During the Weichselian glaciation, about ten meters of loess were deposited, burying the pre-existing landscape.

Underground quarries extensively exploited the middle part of the Maastricht Formation (Nekum and Emael Members), where most observations of endokarsts and roots of solution pipes were made. Our study focuses on the three main Belgian quarries (lower Petit-Lanaye, upper Petit-Lanaye, Caster). They are located between the Albert Canal and the Dutch border. Additional observations are made in the ENCI quarry, to the north of these caves on Dutch territory. The underground passages are about 6 m wide for 10 m high (Fig. 2). Their form a network exceeding 100 km of galleries. The quarries of lower Petit- Lanaye and Caster are located 10 to 25 m under the plateau surface. In the quarry of upper Petit-Lanaye, part of the ceilings is only some meters below the plateau surface. The ENCI quarry allows observation of the basement of Saint Peter's Mountain. The floor of the excavation is 30 m below the Meuse river (5 m above sea level). All these places present a privileged three-dimensional observation of the described karst phenomena.
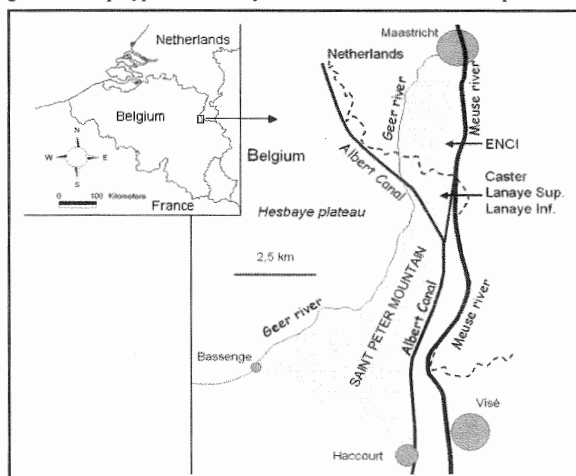
2. Exokarst

2.1 Dolines

The surface of Saint Peter's Mountain is pitted by tens of depressions which can exceed 20 m in diameter and 10 m in depth. Some of them are identified dolines developed in the top of the Cretaceous formations. Part of their deepening could result from piping inside the underground galleries.

2.2 Solution pipes or "organ pipes"

In many cases, the bottom of the dolines is extended by tubular solution pipes whose lenthg may exceed 60 m (Figs. 3 & 4). These local name is «organ pipes». They have a quite regular section and their diameter can vary between a few centimetres to several meters. Mathieu (1813)

Fig. 4: Network of solution pipes in top of a gallery in the Caster underground quarry (Rodet, 2004).
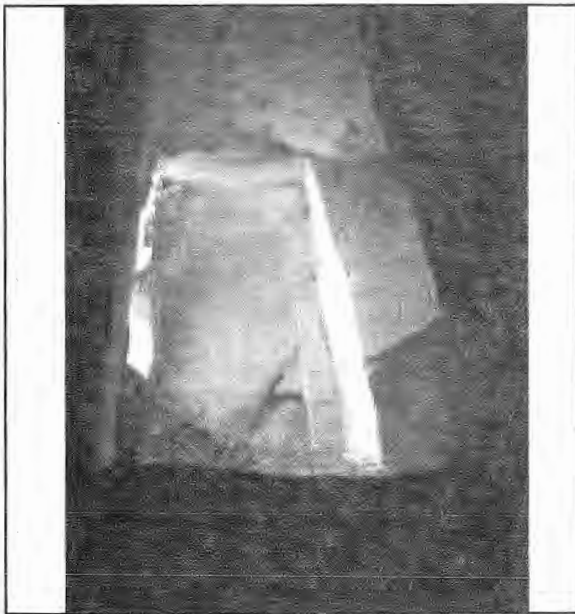
Fig. 2: Example of gallery inside the upper Petit-Lanaye (Klein-Ternaaien) underground quarry (Willems, 2004)

already imputed their formation to infiltration of seepage water. The aver-
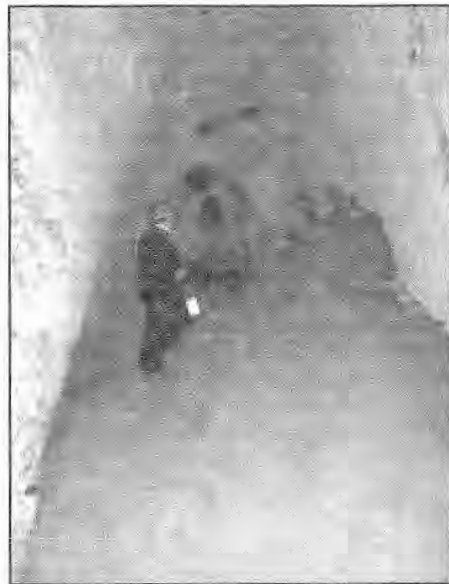
Fig. 5: Fan-talus from a solution pipe inside the Caster underground quarry (Willems, 2003).

Fig. 3: Cross-section of solution pipes on the left bank of the Albert Canal. The larger solution pipes reach more then 50 m (Willems, 2004).

age density of these solution pipes is greater than 16/ha. The underground quarries have destabilized some of them: Tongrian sands and fluvial deposits are swept inside the galleries forming fan-talus (Fig. 5) which can block passages.

The walls of the solution pipes are pierced by alveoli. Weathering fronts are highlighted by iron oxide staining of the bed rock surrounding the solution pipes.

Fig. 6: Sponge network in the lower Petit-Lanaye underground quarry (Rodet, 2004)

154

The widening may result from the coalescence of smaller ones. For Juvigné (1992), their genesis could be connected to the irregularity of the terrace deposits. Locally, these may be more coarse-grained and permeable, and could have initiated a punctual water infiltration.

3. Endokarst

3.1 Sponge networks and ceiling pockets

Several sponge networks (Fig. 6) are noted on the walls

of the underground galleries. The alveoli, centimetric to decimetric, are developed in all directions. By coalescence, they could form bigger alveoli or small conduits (Figs. 7). Generally, there appears no direct connection with fractures or stratification. This is also the case of ceiling pockets, found in a part of the quarry of lower Petit-Lanaye quary where the bed rock is particularly weathered.
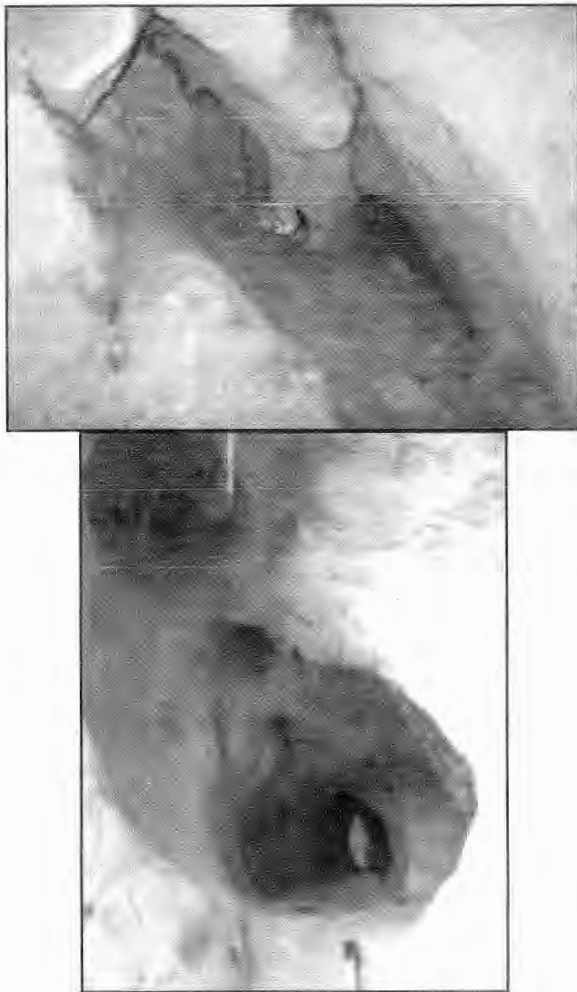
Figs. 7: Small conduits generated by weathering of oblique fracture (Caster, Rodet, 2004 - Crypte quarry near Caster, Willems, 2005)

3.2 Caves

Natural caves were first reported in the 19 th century (Clere, 1814). Two cave types are observed. The first one is developed on fractures. It begins with a lateral weathering of the fracture on the top of an aquifer.

Iso-weathering takes place and could be transformed into allo-weathering by collapse and aeration of the bed rock or by genesis of alveoli. At this stage, preferential water circulation can be generated.

The residual clay found inside the vertical fractures of small conduits could be the product of the same mechanism. Some of these conduits could be upgraded into axis of drainage with more important sediment transport and deposits. Sometimes they form true caves like the CRSOA gallery (Fig. 8) which has length of 39 m for an average width and height of 1 m. A part of this cave is filled by Tongrian sands and clayey sands. Characteristic sedimentary figures attest a low energy flow.

A second type of caves does not show any connection to visible fracture (Fig. 9). Their shape is characterised by rounded plurimetric rooms. Locally, small alveoli pit the main walls.
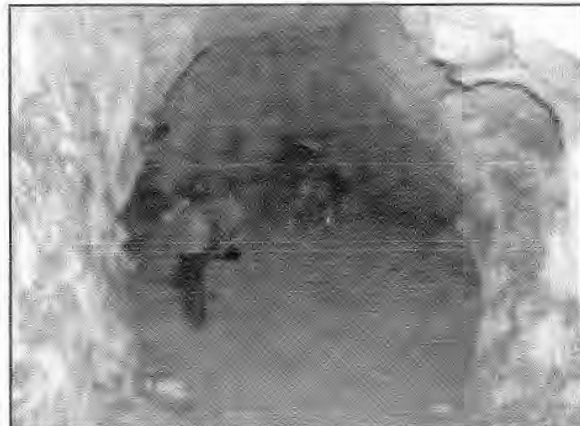
Fig. 8: View of the south side of the CRSOA gallery - example of a natural cave develops on subvertical fracture - lower Petit-Lanaye quarry (L. Willems, 2004).
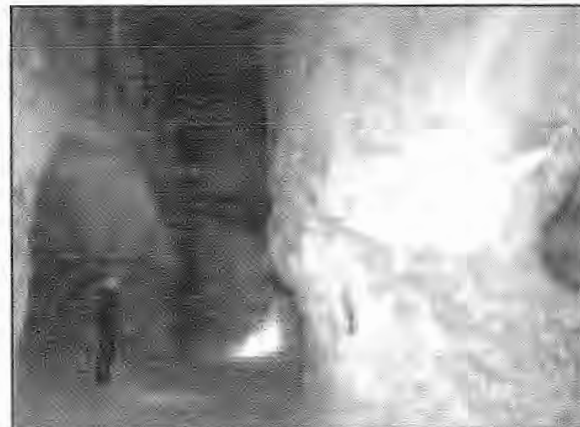
Fig. 9: Remants of a natural cave without visible fracture - lower Petit-Lanaye quarry (L. Willems, 2004)

An other type of caves could exist like those found in 1970 in the right bank of Albert canal and today destroyed. "During excavation operations alongside the Canal Albert near Caster in 1970, a big horizontal karst-gallery was found more than 20 m long, 11-20 m wide and 4-8 m high. It was partly filled with clayey material containing > 30% iron-hydroxide. An impervious silex-layer in the chalks probably caused a semi-horizontal groundwater-flow for some distance, resulting in solution-phenomena with a horizontal direction" (Felder, 1974).

Others cavities quite similar to those described above are found in the underground quarries close to Maastricht (Smitshuijsen, 1983; Didden, 1996; Rademakers, 1998).

3.3 Nodes of weathered chalk

The different excavation faces of the ENCI quarry have exhumed numerous weathered zones inside the Gulpen chalk. These forms true nodes.

Figs. 10: General view of nodes of weathered chalk in the south excavation face of the ENCI quarry. Details of deep nodes of weathered chalks in the east excavation face of the ENCI quarry with water exsurgence (right side of the picture) (Willems, 2004).

Their size could be bigger than tens of meters long and several meters wide. Some of these nodes are located more than 20 m below the alluvial plain of the Meuse river. They are associated with fractures but have no visible connection with the regolith. Due to the dewatering of the quarry pit, aquifer or seepage waters preferentially resurge at these weathered chalks. The flow erodes the weathered chalks and opens small conduits. When there are flints, these have a constricting influence on the node shapes.

4. Discussion - Karst genesis

The solution pipes and caves developed on fractures are essentially generated by concentrated solution inside chalks, however porous they may be. Dolines and solution pipes are generated by vadose percolation water from the plateau surface. The opening of fractures results in caves at different maturity stages. Some have even evolved into axis of drainage. The genesis of alveoli in all directions and ceiling pockets without fracture, support a dissolution inside a paleoaquifer.

Caves without visible fractures could be old nodes of weathered chalk like those found under the Meuse level, in the ENCI quarry. We assume these were already existing before quarrying exhumed them and reactivat-

ed flow by lowering of the water table, with possibility of partial removal of the weathering residues, further opening the conduits. A comparison can be made with the « ghost rocks » found inside the Carboniferous limestones of Tournaisian in western Belgium. These "ghost rocks" result from isovolumetric weathering of bed rock (e.g. : Vergari, 1992,1998; Quinif et al., 1994).

The regular form of the solution pipes irrespective of depth could be due linked to the progressive lowering of the aquifer in parallel with the incision of the Meuse river. Thus a node of corrosion takes place in the mixing point between the percolation water and the aquifer water (Bögli, 1964). The migration of these mixing points with respect to the lowering of the aquifer calibrates the solution pipes. All of these solution pipes do not reach the same depth. It could be explained by the varying permeability of river deposits on the plateau surface or by heterogeneities inside the chalk (presence of flints, hardgrounds, clayey layers, etc).

All these observations allow us to propose a hypothesis of a poly-phased karst system genesis in four stages :
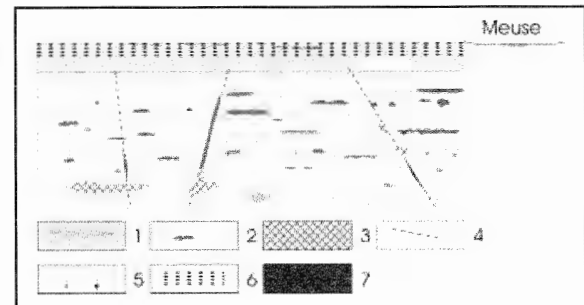
1 River deposits, loess and Tongrian sands; 2 : Cretaceous chalk with flints; 3 : nodes of weathered chalk and solution pipes; 4: fractures; 5: seepage water; 6: aquifer; 7: quarry galleries.

1. Independent of surface conditions, nodes of weathered chalk are created perhaps to several hundred meters of depth. It represents the initiation of a primokarst (first karst phenomena generated) (Rodet, 1992). On the surface, the Meuse river creates its alluvial plain, with a differentiated aggradation related to river dynamics. The river then assumes its vertical erosion. The terrace formed is partially covered with loess and the vertical drainage concentrates in the coarsest and more permeable terrace deposits. Water infiltrates through the surface deposits (Quaternary gravel, Oligocene cover, regolith).
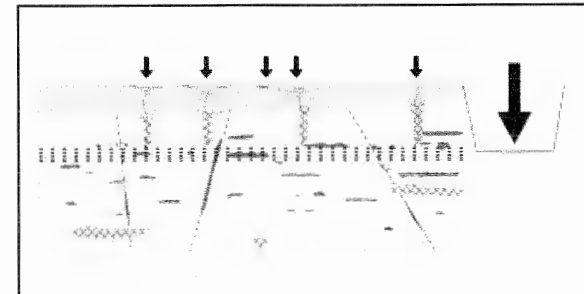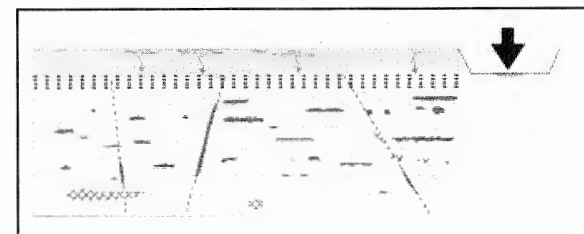
2. Progressively with the lowering of the aquifer, the node of corrosion between vadose and phreatic water progresses downwards. The slow and regular descent of the water table causes a calibration of the solution pipes. The local hydraulic gradient develops. Alveoli, nodes of weathered
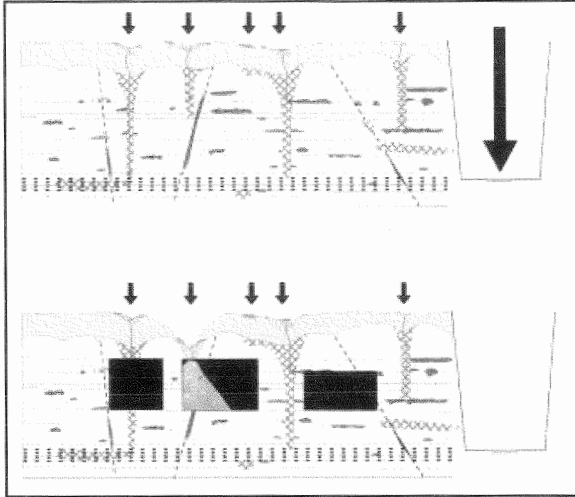
chalk or caves are further expanding.. According to their degree of organisation, they can evolve into drainage systems, able to mobilize the fine elements.

3. The valley continue to incise, followed by the aquifer. The weathering residue emerges above the water table and is not supported any more by hydrostatic pressure. It is compacted and induces further subsidence on the surface.

4. Anthropogenic exploitation of the carbonate rock destabilizes some of the most important karst phenomena, causing mining depressions on the surface of the plateau.

It can be concluded that there exists a high density of karst phenomena in chalk. It influences in a major way the geomorphological evolution of Saint-Peter's Mountain. The study of the various forms clearly points to the genesis of karst phenomena within microporous carbonates, and thus to the development of drains, which could have negative incidence on geological risks and water pollution. Further studies will have to specify the exact conditions of the initiation and distribution of drainage systems identified within the Saint-Peter's Mountain, in particular by comparison with the better documented karst phenomena developed in chalk of Normandy (France) (Rodet, 1992).

Bibliography

- Bögli, A. (1964). Mischungskorrosion, ein Beitrag zum Verkarstungsproblem. Erdkunde 18, 83-92
- Clere, J.F. (1814). Notice géologique sur l'espèce et la nature du terrain des environs de Maëstricht. J. des Mines (Paris), t. 36, n° 214.
- Didden, J.M. (1996). Tektoniek, karst en speleothemen in de kalksteen van het Laat-Maastrichtien van Zuid-Limburg. Natuurhistorisch Maandblad, 85: 72-82.
- Juvigné, E (1992). Les formations cénozoïques de la carrière C.B.R. du Romont (Eben,/Bassenge, Belgique). Ann. Soc. Géol. Belg., 115: 159-165.
- Felder, P.J., 1974. Horizontale karstverschijnselen in de groeve Caster van de E.N.C.I. Natuurhistorisch Maandblad, 6: 112-115.
- Felder, W.M. & Bosch, P.W. (1998). Geologie van de St. Pietersberg bij Maastricht. Grondboor & Hamer, 52: 53-63.
- Felder, W.M. & Bosch, P.W. (2000). Krijt van Zuid-Limburg. Geologie van Nederland, deel 5. NITG Delft/Utrecht, 190 p.
- Rademakers, P.C.M. (1998). Ge ologische orgelpijpen. Grondboor & Hamer, 52: 71-76.
- Mathieu, M.L. (1813). Notice sur les orgues géologiques de la colline Saint-Pierre, près de Maëstricht. J. des Mines (Paris), t. 34, pp. 197-208.
- Quinif, Y., Vergari, A, Doremus, P., Hennebert, M., Charlet, J.M. (1994). Phénomènes karstiques affectant le calcaire du Hainaut. Bull. Soc. Belg. Géol., 102 : 379-384.
- .Rodet, J. (1992). La craie et ses karsts. Ed. CNEK-Groupe Seine, Elbeuf, 560 p.
- Smitshuijsen, E., 1983. Karst in Limburg. S.O.K, N° 2, pp. 13-18.
- Vergari, A. (1992). Etude des paléokarsts dans l'optique de leur incidence dans l'exploitation des roches carbonatées. Travail de Fin d'Etudes, FPMs.
- Vergari, A. (1998). Nouveau regard sur la spéléogenèse: le "pseudo-endokarst" du Tournaisis (Hainaut, Belgique). Karstologia, 31/1: 12-18.

O-37

A GLOBAL DENUDATIONAL MODEL OF CAVE DEVELOPMENT

Augusto S. Auler

CPMTC - Instituto de Geociências, Universidade Federal de Minas Gerais. Av. Antonio Carlos, 6627, Belo Horizonte - MG - 31270-901, Brazil

Peter L. Smart

School of Geographical Sciences, University of Bristol, Bristol, BS8 1SS, England

Abstract

A significant number of caves in the stable cratonic area of eastern Brazil display well-developed "primary" paragenetic features (i.e. features generated during cave phreatic development and not during later sedimentation processes) that indicate that paragenesis was a dominant process of speleogenesis. However, a survey of cave geomorphological studies elsewhere in the world indicate that paragenesis is usually considered to be a relatively minor speleogenetic process, syngenesis being considered as the "normal" type of phreatic cave development.

Paragenesis in eastern Brazil is favoured by a combination of geomorphic and hydrological conditions such as: (i). high rates of pedogenesis under tropical conditions yield thick soil sequences that commonly mantle the karst. Thus, nearly all karst areas contain abundant soil cover that can be eroded towards phreatic conduits; (ii). low elevation terrain and thus very low hydraulic gradients that prevent fine grained sediment to be removed from phreatic cave passages during conduit development; (iii) low denudation rates / uplift rates and thus low water table lowering rates. Any evolving conduit will stay for a prolonged time under phreatic conditions before interception (due to both upward paragenetic ceiling migration and water table lowering) by the water table. Paragenesis may also benefit from deeper initial flow routes.

We propose a model in which, given sediment availability, paragenetic development will be the dominant mode of speleogenesis in tectonically stable areas under slow denudation / uplift rates. Central Brazil and areas of Africa, Australia and parts of Europe are prime candidates for paragenetic caves. Paragenetic caves will tend to be rare or absent in bare karst terrains in tectonically active areas such as in high mountain karst areas in Europe.

1. Introduction

A survey of caves in several Brazilian karst areas, but mostly in the Lagoa Santa, Caatinga and Iraquara areas (Fig. 1), has demonstrated that the majority of caves display features previously recognised as due to paragenetic processes such as:

1. Presence of pendants (Bretz, 1942; Renault, 1968). 2. Presence of anastomoses or half tubes (Bretz, 1942; Renault, 1968). 3. Presence of parasitic wall tubes (Lauritzen and Lauritsen, 1995). 4. Presence of wall grooves (Farrant, 1995). 5. Lack of guiding fracture or bedding plane at ceiling level (Pasini, 1967). 6. Lack of a precursor phreatic tube on the ceiling (Lauritzen and Lauritsen, 1995; Farrant, 1995). 7. Downstream propagation of meanders (Ewers, 1985). 8. Phreatic canyon or triangular passage cross section (Farrant, 1995). 9. Active paragenetic passages in the phreatic zone (Worthington, 1991).

Observations in several karst areas in eastern Brazil have allowed the recognition of the following additional distinctive features of paragenesis:

10. Lack of scallops. The velocity required for scallop length to match passage sinuosity (and thus become indistinguishable) is too slow to allow for sediment removal and should therefore favour paragenesis if there is sediment availability.

11. Meander junctions at ceiling level occur through an ascending meander. This feature demonstrates that water flow was occurring mostly at ceiling level at time of junction.

12. Anastomotic canyons are the predominant type of cave pattern. In low dip situations this should be the prevalent type of paragenetic cave pattern. Variable passage cross section due to changes in sediment volume can keep several passages simultaneously competitive.

13. General absence of joint fed speleothems. When compared with vadose caves, paragenetic caves may exhibit less speleothems due to the general absence of vertical joints at ceiling level. Furthermore, the overall volume of a paragenetic passage spends more time in the phreatic zone and under sediment cover than a typical vadose cave, restricting the chance of speleothem precipitation by water percolating through joints.

The caves located along the stable cratonic area of east central Brazil have shown similar styles of cave development, despite major differences in lithology, hydrology and present climate. Paragenetic processes are evident in the majority of caves examined. It will be proposed that the mode of conduit development after initiation is controlled by large-scale denudation rates which are dependent on the tectonic setting.

2. Controls on paragenetic development
2.1. Sediment availability

The first requisite for paragenesis is the availability of sediment for transport into the cave system. In eastern Brazil, bare bedrock floors are extremely rare, nearly all caves having their floor covered by sediment deposits usually of unknown thickness. There has been no worldwide survey on the frequency and extent of soil cover in karst areas, but covered karst predominates in most of the karst areas in the Americas, especially in eastern United States, northern Mexico, Central America and some islands of the Caribbean such as Cuba, and most of South America. Soil cover predominates in many karst areas of Europe, such as in England, parts of France and Italy, and in most of tropical Asia sites. It seems apparent that sediment derived from the soil is commonly available in most karst areas of the world. Possible exceptions to this situation would be very pure limestones in barren karst areas with very limited sediment supply such as in some alpine settings, mixing zone karst areas, or hypogenic settings where deep flow is not surface derived.

2.2. Depth of conduit initiation

Deep initial flow routes will enable a given conduit to have the necessary vertical amplitude for paragenetic upward ceiling migration. The depth at which a cave will originate below the water table has been subject to considerable debate in the past on conceptual grounds (see review in White, 1988) but even recently few quantitative advances have been made. Folding and faulting may promote deeper ground water routes (Palmer, 1987). For the sake of simplicity, a homogeneous carbonate aquifer, without significant folding or faulting and without impermeable beds that can cause confined and artesian aquifers will be assumed. This is the common situation in eastern Brazil cratonic carbonate areas.

Although there is a number of ways of determining depth of present or past ground water circulation such as water temperature in spring outlets (Worthington and Ford, 1995) or empirical relationships that equate catchment length and dip of the strata (Worthington, 2001) few direct observations have been made. Borehole logging and packer testing frequently show the presence of dissolution openings at depths up to 3000 m (Ford and Williams, 1989), often with capacity for water circulation. Direct observation of flooded passages by cave divers worldwide confirm the common existence of deep flow routes in carbonate systems, to depths well in excess of 100 m below the water table (Farr, 1991). The vertical range of a paragenetic passage provides an alternative method of determining minimum flow depth of cave passages. This is represented by the elevation difference between the bedrock floor of the passage and the ceiling. Considering that some water table lowering must have occurred since the beginning of the paragenetic development, this parameter provides a minimum depth of initiation below the water table. Vertical paragenetic amplitudes up to 50 m have been reported in the literature (Renault, 1968). At Lapa Doce cave in the Iraquara Karst, the vertical paragenetic range is 11 m as measured at several sites with an ultrasonic tape. In the Lagoa Santa Karst, it may exceed 15 m in some caves. According to Worthington (2001) depth of ground water flow in unconfined aquifers is related to $D = 0,18 (L \sin \theta)^{0.79}$ where D is the mean depth of flow in metres below the water table, θ is the dip of the carbonate strata and L is the flow path length in metres. In much of eastern Brazil, low dip (up to 10°) and long flow paths (up to 20 km in a straight line) would translate in depths up to 110 m, but commonly below 50 m, a value that is in general accordance with cave diving reports for the area.

2.3. Rates of upward paragenetic evolution

After breakthrough has been achieved, provided the water table remains above the passage during the period of enlargement, there will be two alternatives for further development of a flooded conduit. In a situation where there is no supply of sediment, or where water velocities are

too high to allow for sediment deposition, a phreatic tube will develop. Such a tube will grow indefinitely until modified by breakdown or drained by water table lowering. Given the existence of flooded passages at great depths (in excess of 100 m) we should expect the common occurrence of very large phreatic tubes. Although White (1988) and Worthington (1991) have acknowledged the existence of phreatic tubes > 40 m in diameter, such very large passages appear to be more the exception than the rule. The second style of development is through paragenesis. Cave divers have commonly reported that phreatic caves normally have a sediment mantled floor (Worthington, 1991). It thus appears that sediment filled passages are at least as common than sediment-free phreatic tubes.

Ground water flow velocities decrease with lower hydraulic gradients. In the subdued relief of eastern Brazil low hydraulic gradients should be expected, resulting in very low conduit velocities, below the threshold for sediment transport. Considering the nearly global availability of sediment in karst systems, the ubiquitous existence of input points linking sediment sources to underground passages, and the slow water flow velocities in subsurface conduits, paragenesis should be a common mode of cave evolution in the phreatic zone.

During paragenesis, the floor of a phreatic passage is armoured by sediment. Dissolution, if it occurs, is unlikely to be significant at the sediment-bedrock interface because it will be limited by replacement of reactant and evacuation of products. The sole sections of bedrock available for conduit enlargement are the upper walls and ceiling. The cave will then evolve upwards towards the water table. Rates of upward conduit migration are an important component in determining the magnitude of vertical paragenetic range, the rate of loop elimination, and possibly the development of flat water table roofs. There has been no previous study of this problem. However, if a paragenetic passage is considered to be a half tube with a sediment floor, the relation of Palmer (1991) can be applied:

$S = 31.56\ Q\ (C- C_0)\ /\ pL\rho_r$; where: S is the rate of paragenetic upward migration; Q is discharge of water through the passage; C is the solute concentration ($C_0 = C$ at upstream end of passage); p is the wetted perimeter; L is the passage length and ρ_r is the rock density

Dreybrodt (1990) has estimated average rates of 100 m/Ma for conduit bedrock removal after breakthrough, but variations of an order of magnitude on either side are possible. Taking into consideration discharges measured at the Lagoa Santa Karst (Auler, 1994) and estimated discharges for springs in the Iraquara Karst, a range between 0.05 - 2 m³/s appears reasonable. Length of underground flow paths should be in the range 1 - 20 km, resulting in Q/L ratios below 20 cm²/s. Following Palmer (1991) these values would represent enlargement rates in the range of 1000 m/Ma. Typical maximum enlargement rates for karst systems averages about 100-1000 m/Ma (Palmer, 1991).

2.4. Water table lowering rates in karst regions

The end of the phreatic regime in a cave system happens when the water table reaches the top of the passage, and dissolution becomes concentrated on the floor. It is thus important to quantify the rates of water table lowering, because these will determine the amount of time available for paragenesis. Water table lowering will be considered as a relative measure in relation to a fixed point in the bedrock (or a cave system within the bedrock). This is because tectonic uplift can rapidly change relative water table positions within the bedrock, while the water table elevation relative to a outside datum (such as sea level) could remain virtually unchanged.

Long-term regional denudation rates in cratonic or low relief areas are reported in Table 1 while denudation rates based on fluvial incision rates in karst are given in Table 2. It is assumed that surface lowering rates are compatible with water table lowering rates. Furthermore, fluvial downcutting rates, together with other techniques of punctual measurements, are assumed to provide reasonable approximation of regional scale water table lowering rates.

The data demonstrate that denudation rates in cratonic or low relief areas are typically in the range 1 - 50 m/Ma, with several areas (mainly in the best studied sites in the plains of Australia) having values below 10 m/Ma. These data demonstrates that denudation rates in stable tectonic settings can be an order of magnitude lower than in mountainous or in tectonically active regions.

3. A denudational model of cave evolution

It has been demonstrated that conduits commonly carry sediment deposits. It has also been shown that ground water velocities, especially in low relief areas with low hydraulic gradients, may fall below the threshold of sediment transport. Under such conditions, the minimum requirements for the initiation of paragenetic development should be present in many if not most karst settings. Two further variables should be taken into account. Because paragenetic passages evolve upwards towards the water table, there should be enough vertical amplitude for a passage to develop, i.e., the deeper the passage is, the more "room" for upward paragenetic development there will be. Areas with steeply dipping carbonate should in theory be more favourable for paragenetic development. However, a major control affecting this opportunity for upward development is the rates of water table lowering. The rate is very slow in eastern Brazil permitting an extended period for paragenesis, despite the shallow dip of the carbonate which limits depth of paragenetic development.

Water table lowering rates in mountainous or tectonically active areas are an order of magnitude higher than in stable cratonic settings. In the latter regions, caves would tend to remain for a much longer time in the phreatic zone. It has also been demonstrated that upward paragenetic migration rates should be at least an order of magnitude higher than water table lowering rates in tectonically stable, low relief areas, but should match these rates in mountainous settings. Fig. 2 illustrates these relationships. For any given initial conduit depth, the time available for upward paragenetic migration would be greatly increased in karst areas with low water table lowering rates. On the other hand in areas with very fast water table lowering rates, such as mountain ranges, the cave passage could be intercepted by the water table before significant paragenetic development had occurred.

From this denudational model of cave development, paragenetic caves should predominate where water table lowering rates are slow, such as in cratonic settings or in low relief continental interiors. Prime candidates are the ancient tablelands of interior South America, Africa and Australia. At the other extreme, areas with very high denudation rates, such as mountain ranges or areas with active tectonics, should show predominantly vadose passages and little paragenetic development. Many karst areas, however, fall between these extremes, and could display both paragenetic and syngenetic development styles, depending on initial flow depth, sediment availability and local geomorphic factors.

The above model, developed at a regional scale of cave systems, is also applicable to individual passages in caves. It has been suggested by Palmer (1991), Worthington (1991), Dreybrodt (1990) and others, that cave passages can play the role of local base levels for tributary conduits, in the same way that major rivers do for large cave systems. It is thus possible that a tributary can evolve paragenetically towards a vadose trunk passage. This is supported by the observation of paragenetic passages within otherwise predominantly vadose caves, such as in Gruta do Padre, Brazil, Ogof Draenen, Wales, among others.

4. References

Atkinson, T.C.; Rowe, P.J. 1992. Applications of dating to denudation chronology and landscape evolution. In Uranium Series Disequilibrium. Applications to Earth, Marine and Environmental Sciences (Ivanovich, M.; Harmon, R.S. ed.). Clarendon Press, p. 669-703.

Auler, A.S. 1994. Hydrogeological and hydrochemical characteriza-

tion of the Matozinhos-Pedro Leopoldo karst. MSc Thesis, Western Kentucky University.

Auler, A.S. 1999. Karst evolution and palaeoclimate in eastern Brazil. PhD Thesis, University of Bristol.

Bretz, J.H. 1942. Vadose and phreatic features of limestone cavernas. Journal of Geology 50: 675-811.

Dreybrodt, W. 1990. The role of dissolution kinetics in the development of karst aquifers in limestone: a model simulation of karst evolution. Journal of Geology 98: 639-655.

Ewers, R.O. 1985. Patterns of cavern development along the Cumberland Escarpment. In Caves and Karst of Kentucky (P.H. Dougherty ed.). Kentucky Geological Survey Special Publication 12: 63-77.

Farr, M. 1991. The darkness beckons. Cave Books.

Farrant, A.R. 1995. Long-term Quaternary chronologies from cave deposits. PhD Thesis, University of Bristol.

Ford, D.C.; Williams, P.W. 1989. Karst geomorphology and hydrology. Unwin Hyman, London.

Lauritzen, S.E.; Lauritsen, A. 1995. Differential diagnosis of paragenetic and vadose canyons. Cave and Karst Science 21: 55-59.

Palmer, A.N. 1987. Cave levels and their interpretation. National Speleological Society Bulletin 49: 50-66.

Palmer, A.N. 1991. Origin and morphology of limestone caves. Geological Society of America Bulletin 103: 1-21.

Pasini, G. 1967. Nota preliminare sul ruolo speleogenetico dell'erosione "antigravitativa". Le Grotte d'Italia 4: 297-322.

Renault, P. 1968. Contribution a l'etude des actions mécaniques et sédimentologiques dans la spéléogenèse. Annales de Spéléologie 23: 529-596.

White, W.B. 1988. Geomorphology and hydrology of karst terrains. Oxford University Press, Oxford.

Worthington, S.R.H. 1991. Karst hydrology of the Canadian Rocky Mountains. PhD thesis, McMaster University.

Worthington, S.R.H. 2001. Depth of conduit flow in unconfined carbonate aquifers. Geology 29: 335-338.

Worthington, S.R.H.; Ford, D.C. 1995. High sulfate concentrations in limestone springs: an important factor in conduit initiation? Environmental Geology 25: 9-15.
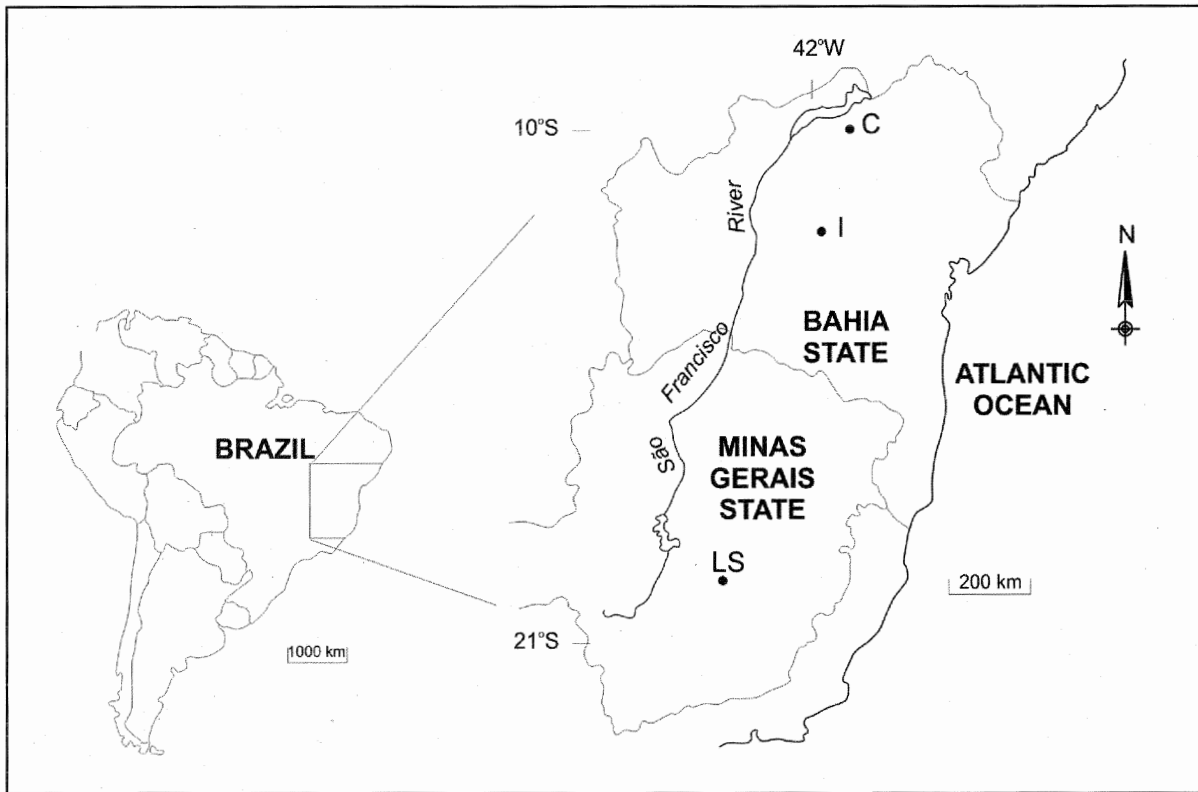
Figure 1. Location of study area. LS - Lagoa Santa Karst; I - Iraquara Karst; C - Caatinga Karst.

Figure 2. Model of cave development in relation to water table lowering rates. Rw = Rate of water table lowering; Rp = Rate of paragenetic upward migration; Hw = Amount of water table lowering between t=0 and t=1; Hp = Paragenetic vertical range.

Table 1. Denudation rates for cratonic and low relief interior settings. Estimates extrapolated over diverse timescales. This list is by no means a complete list. AFTA - Apatite fission track analysis. References in Auler (1999 p. 26).

Location	Method	Rate m/Ma
West Australian Craton	Geomorphological criteria	0.1-0.2
Southeastern Australia	Incision rates	1-10
Guyana Craton	Fluvial geochemistry	10
West African Craton	Cosmogenic	3-8
Mount Roraima, Guyana Craton	Cosmogenic	1
Southeastern Australia, Yilgarn	Weathering rates	1-2
Africa, Lake Chad	Fluvial geochemistry	8
SE Australia, Snowy River	AFTA	15-18
Southeastern Brazil, Paraná	AFTA	8
Guaporé Craton, Brazil	AFTA	15-50
Interior São Francisco Craton	AFTA	20-40
Interior São Francisco Craton	AFTA	18
Global average rate		43
Mountainous areas/highlands		500

Table 2. Compilation of fluvial downcutting rates in karst terrains. Adapted from Atkinson and Rowe (1992) and Farrant (1995). See references in Auler (1999 p.37).

Location	Rate (m/Ma)		Location	Rate (m/Ma)
Cueva del Agua, Spain	c. 300		Arige Valley, France	120-210
Nahanni River, Canada	< 800		Manifold Valley, England	55
Green River, Kentucky	70-90		Derwent Gorge, England	< 190
Matchlight Cave, Tasmania	< 100-200		Mammoth Cave, USA	40
Exit Cave, Tasmania	< 60		Cheat River, USA	56-63
Yorkshire Dales, England	120 / > 50 / < 200		Buchan Karst, Australia	3-4
Elwy Valley, Wales	120		East Fork Obey River, USA	< 20
Creswell Crags, England	65		Wee Jasper, Australia	26
Perlait River, Malaysia	8		Greenbrier River, USA	46
Cheddar Gorge, England	190 / 60 / 200		Santana Cave, Brazil	42
Crowsnest Pass, Canada	115-130		Wyandotte Cave, USA	60
Bearjaw Cave, Canada	290-510		Clearwater Cave, Malaysia	190
Castleguard Cave, Canada	50-130			

O-38
"Folia Drakou" Cave (Potamoi, Drama, Macedonia, Greece)
Geological and Speleological study - Preliminary report

Vaxevanopoulos Markos[1], Lazaridis Georgios[2], Zachariadis Stavros[3], Pennos Christos[2] & Garlaouni Charikleia[2]

[1] Ephoria of Paleoanthropology & Speleology, N. Greece, Ministry of Culture

[2] School of Geology, Aristotle University, 54124 Thessaloniki, Macedonia, Greece

[3] School of History & Archaeology, Aristotle University, 54124 Thessaloniki, Macedonia, Greece

162

Abstract

The "Folia Drakou" cave is situated in the broader area of the Potamoi village, in the Prefecture of Drama (Macedonia, Greece). The region belongs to the Sidironero geological unit of Rhodope massif. The cave has been formed into marbles, sipolines and gneisses. The speleogenesis of the cave and the anthropological findings are first presented. Characteristic shapes of karstic tubes, breakdown formations, human bones (cranium) and ceramics are singularly described.

Introduction

The "Folia Drakou" cave is located in the Despatis basin, close to the Potamoi village of Drama Prefecture, 100km NE from the city of Drama. In the broader area of Potamoi village a number of karstic caves were developed. The most interesting karstic formation is the "Folia Drakou" cave in which archaeological and anthropological findings have been observed. The cave presents passages with characteristic shapes, which are formed along the tectonic and stratigraphic discontinuities as well as breakdown morphology. The first visit for reconnaissance to the cave took place by the archaeologists in 1982. Since 2004 the cave has been explored and mapped twice by members of the Department of Northern Greece of the Hellenic Speleological Society.

Geological Setting

The broader area of the "Folia Dragou" cave belongs to the Rhodope Massif, which is distinguished into the Sidironero and Pangeon Unit, both consisting of metamorphic rocks. The Sidironero complex consists of a Paleozoic sequence mainly filled with gneisses and intercalations of orthogneisses, two-mica paragneisses, augen-gneisses, amphibolites, mylonites and thin embedding layers of marbles, migmatites. Plutonic bodies

have intruded in the area. The cave is formed within marbles and gneisses close to the thrust zone, where the upper Sidironero unit thrusts over Pangeon unit, with a 101° strike and a SW dip following the riverbed of Nestos (Fig. 2, Falalakis, 2004).
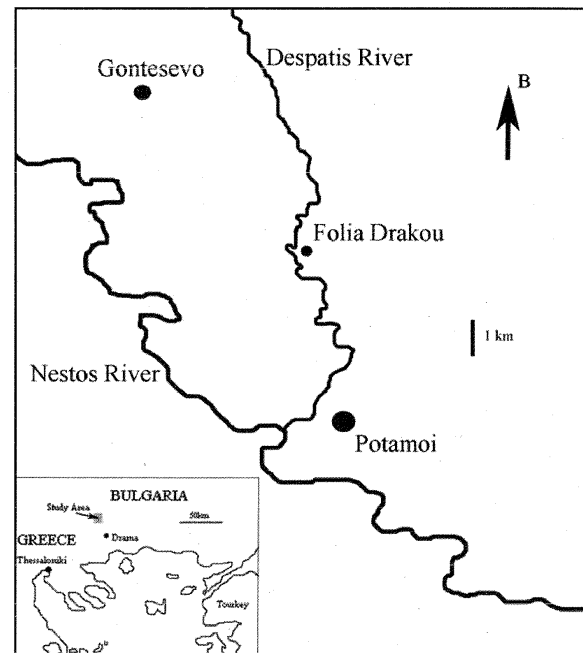
Figure 1. Map of northern Greece with the Drama area, the Potamoi village and the location of the Folia Drakou Cave.
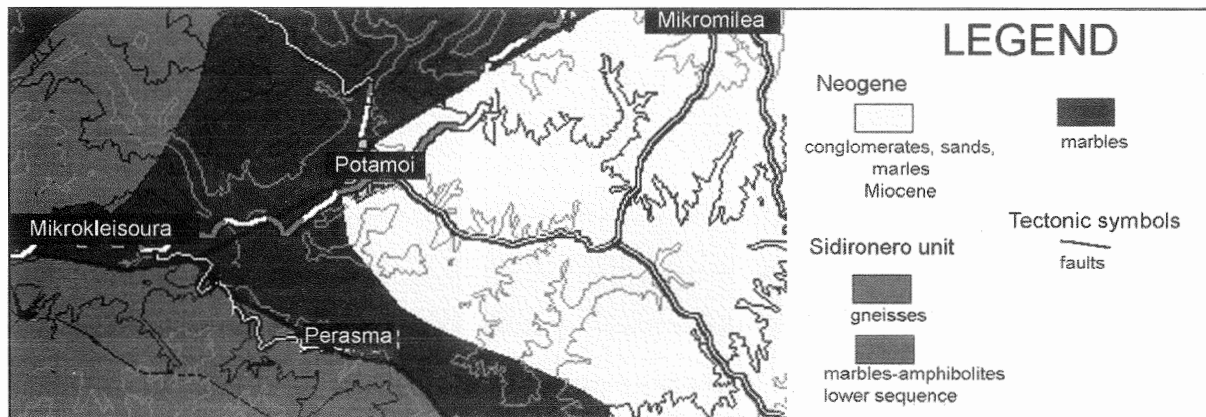
Figure 2. Geological map of the broader area of the Potamoi village (based on Falalakis, 2004).
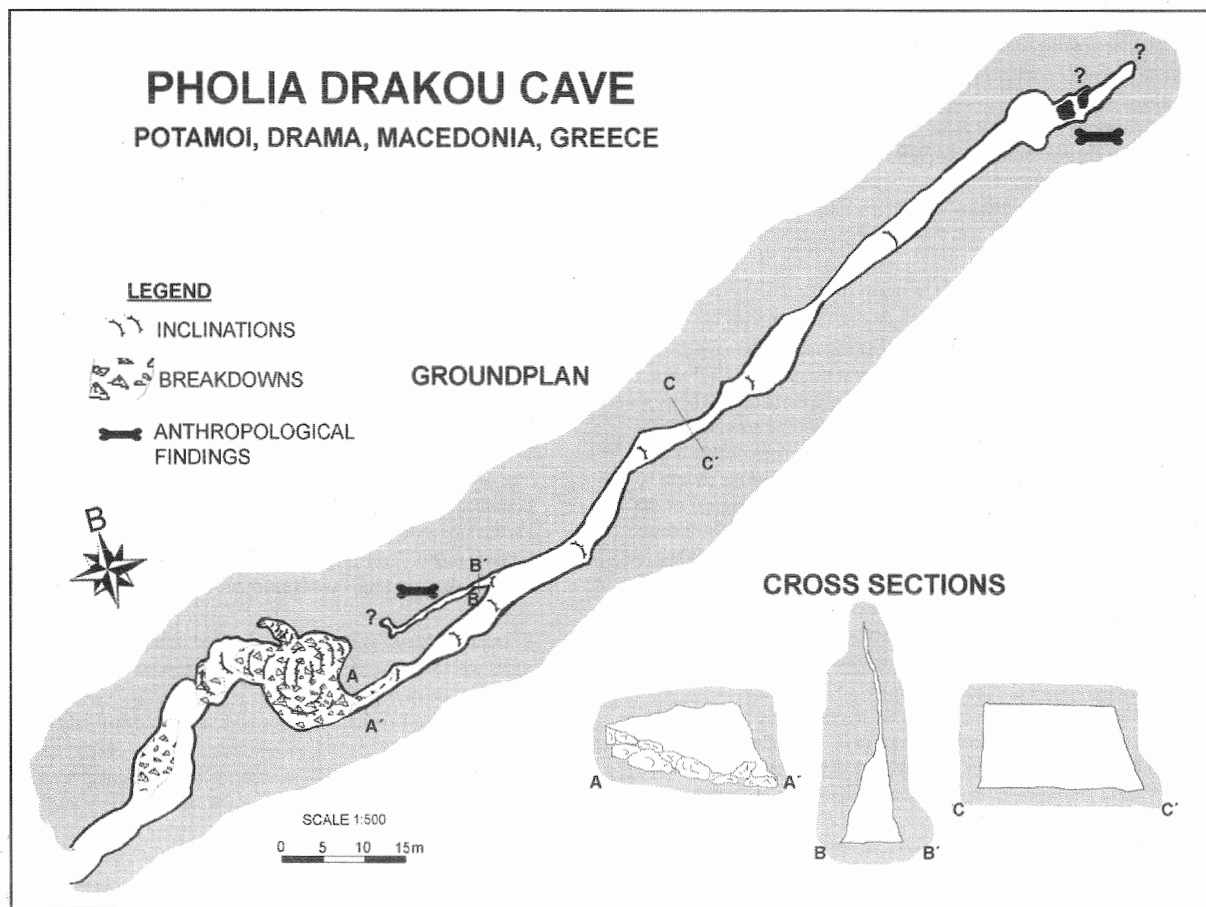
Figure 3. Ground plan and cross sections of the Folia Drakou Cave (Potamoi, Drama, Macedonia, Greece).

There are three phases of folding, including isoclinal folds NE-SW, asymmetric conjugated folds trending from NE-NW to ENE-WNW and open folds trending NW-SE. The second folding event is associated with the development reverse faults striking NE-SW, which predominate in W. Rhodope (Kilias & Mountrakis, 1990). The stress field is nowadays characterized by the maximum tensional axis having a direction from NNW-SSE to NNE-SSW, with the last one being dominant. The seismicity of the area is rather sparse. The tension is characterized as oblique, normal with a dextral component of slip (Mountrakis & Papazachos, 2003).

Archaeological setting

The region of Potamoi has always been a crossroad for different civilizations. Human activity in this area is evident for a very long period. Archaeological research has brought to light findings that date since the prehistoric age up to the Late Roman era (Peristeri, 2002).

Excavations were contacted in the area (Koukouli, 1967, 1976, Peristeri, 2002) by the 18th Ephoria of Classical and Prehistoric Antiquities. The excavations concerned mostly tombs that were dated by numismatic evi-
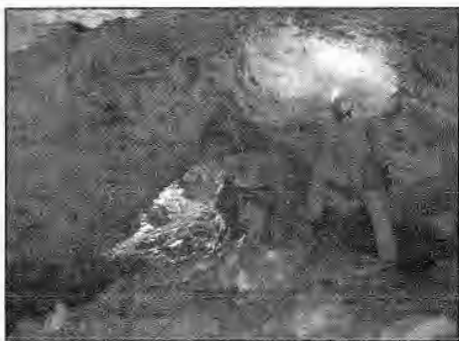
Figure 4. The "Folia Drakou" cave: the greatest chamber close to the entrance, where the breakdown morphology has been observed.

Figure 5. The "Folia Drakou" cave: a passage of a triangular shape.

Figure 6. The "Folia Drakou" cave: a passage of a trapezoid shape.

dence and ceramics in the 1st century A.C. and a tomb of the Late Copper age positioned at the junction of the forest streets Mikromilias - Kourou. In addition a settlement of the Late Copper age was spotted and excavated in the same area at the site known as Eski Borovo.

Inside the cave ceramics of different ages were scattered, possibly due to an illegal excavation. No evidence of inhabitance of the cave by human during the antiquity is present and only a systematic excavation can give evidence how the ceramics were brought into the cave. For the time being there is no clear connection between the human bones found in the cave and its possible use by humans at any time.

Morphology of the cave

The "Folia Drakou" cave is a karstic tube about 200m long, developed in intercalations of marbles and gneisses. The entrance of the cave is 4.0m above Despatis River water level. The height of the cave ranges from 0.5 to 5.0m about, and the breadth varies from 0.5 to 12.0m (Fig. 3). The maximum dimensions of the cave are close to the entrance, where breakdown morphology is observed (Fig. 4). These increasing dimensions are due to successive collapses that resulted in the greatest chamber of the cave to be formed. The almost horizontal foliation contributes to the process of the collapses and the formation of the breakdown morphology. Breakdown facts occur both early and very late to the speleogenetic process (White & White, 2000), the latter one being noted in this cave as well. The floor of the cave is fully covered with fine-grained sediments, flowstones and collapsed blocks. These deposits are mainly autochthonous, originating from the cave interior, while some of them being possibly fluvial.

The speleogenesis took place in a phreatic stage. Phreatic karstic tubes have usually a circular shape when they are developed along the crossing of a joint and the foliation of the rock (Lauritzen & Lundberg, 2000). Despite the fact that a similar crossing leads the development of the "Folia Drakou" Cave, the passages have different shapes. The cross sections of the tube have either triangular or trapezoid shape. The triangular shape is noticed when the water corrosion follows almost vertical joints with the contribution of the foliation being inessential (Fig. 5). The existence of the 2 joints to the sidewalls and the foliation of the ceiling give trapezoid shape to the passages of the cave in cross sections (Fig. 6). These passages had an original circular shape in the beginning that changed to trapezoid due to the collapses. If the collapsed blocks remain in place the shape seems rather triangular.

Concerning speleothemes the "Folia Drakou" Cave presents a great variety. There are stalactites, stalagmites, flowstones, shields, columns, gours, mainly of young age. They are mainly marked to the deepest part of the cave.

Finally, concerning the anthropological findings, the most important calcite-covered skull has been found in the deepest part of the cave, with a

rounded hole on the frontal-parietal area. Further more, post cranial bones such as a femur, a tibia, vertebras, pelvis etc, have been observed in other places of the cave (Figs. 3, 7)

Conclusions

- The "Folia Drakou" Cave is the most interesting cave of the Potamoi region because of the special geological, speleological, archaeological and anthropological interest that presents.

- The cave can be described as a karstic tube is of phreatic origin.
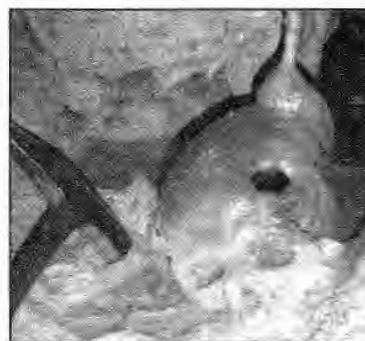
Figure 7. The "Folia Drakou" cave: The human calcite-covered skull, with a rounded hole on the frontal-parietal area, found in the deepest part of the cave.

- The broadening of the cave is associated with successive collapses.

- Triangular shaped passages are observed along almost vertical joints whereas trapezoid ones are developed according to the tectonic features of the rock.

- The presence of ceramic findings adds archaeological interest to the cave.

- A number of human skeleton remains including a skull give an anthropological interest.

Acknowledgments

References

FALALAKIS G., 2004. Kinematic analyses and deformation at the boundary of crystalline Serbomacedonian and Rhodope massifs (Mountains of Kerkini- Vrontou, Makedonia). Thesis Dissert. School of Geology, Aristotle University, p. 1-153, Thessaloniki. (in Greek)

KILIAS, A. & MOUNTRAKIS, D., 1990. Kinematics of the crystalline sequences in the western Rhodope massif. Geologica Rhodopica, 2: 100-115.

KOUKOULI, C., 1967. "Archaeologikon Deltion", chronicles, 22: 427 - 428 (in Greek)

KOUKOULI, C., 1976. "Archaeologikon Deltion", chronicles, 31: 304 (in Greek)

LAURITZEN, S.-E. & LUNDBERG, J., 2000. Solutional and Erosional Morphology. In: "Speleogenesis. Evolution of Karst Aquifers". A. B. Klimchouk, D. C. Ford, A. N. Palmer & W. Deybrodt (eds.) - National Speleological Society: 408-426, Huntsville, Alabama.

MOUNTRAKIS, D. & PAPAZACHOS, K., 2003. Determination of the characteristics and the seismotectonics of the main active faults in North Greece with the use of neotectonic and seismic data. Unpublished final report submitted to the Earthquake Planning & Protection Organization (EPPO, in Greek).

PERISTERI, K., 2002. Excavations of burial tombs at Potamoi of Drama. Archaeological acts in Macedonia and Trace 16: 137 - 144. (in Greek)

WHITE, E. L. & WHITE, W. B., 2000. Breakdown Morphology. In: "Speleogenesis. Evolution of Karst Aquifers". A. B. Klimchouk, D. C. Ford, A. N. Palmer & W. Deybrodt (eds.) - National Speleological Society: 427-429, Huntsville, Alabama.

O-39

Archaeological Excavations in Hourriyeh Cave (Qadisha valley - Lebanon)

F. Beyano, C. Mattar, H. Abdul- Nour

Association Libanaise d'Etudes Spéléologiques (ALES), Beirut, Lebanon

Abstract

The Qadisha Valley located North of Lebanon is listed on UNESCO's world heritage sites for its natural values and the remarkable troglodyte Christian dwellings going back to the Middle Ages. In Marsh 2000 the Lebanese Association for Speleological Studies (ALES), discovered within a cliff in the lower part of the Qadisha Valley, a 22 m sub-horizontal cave accessed by a 5m deep narrow shaft and containing human bones, snail shells and ceramics. The archaeological artifacts and bones that are visible on the surface showed no modern disturbance. A preliminary diagnosis of the ceramic remains showed that it could be dated back to the end of the Early Bronze and beginning of the Middle Bronze Age . This unique discovery in a region already famous for its Christian heritage, and thoroughly disturbed by "treasure hunters", triggered three campaigns of joint archaeological excavations by the General Directorate of Antiquities of Lebanon (DGA) and the ALES Caving Organization, in collaboration with a multidisciplinary committee of scientists, and was able to shed the light on human activities going back to the Neolithic and to the Bronze Age. Typological analysis of the finds and radiocarbon dating revealed three main phases of human use of the cave from the late Neolithic to the Early Middle Bronze period. Occupation layers and two mortuary practices were identified: - The earliest goes back to the late Neolithic with occupation layers including a hearth, a trampled surface and pot fragments. - In the early Bronze Age, the cave was transformed to a burial place where inhumation was practiced and skeletons from children and adults were uncovered. - At the end of the Early Bronze and the beginning of the Middle Bronze Age, a change of mortuary practices was clearly attested with the presence of a great amount of incinerated human bones associated to a large quantity of ceramic vessels. It is important to note that incineration as a mortuary practice going back to the beginning of the Middle Bronze Age, is attested for the first time in Lebanon and rarely mentioned in the neighboring countries; some of the ceramic vessels associated to this period were only attested in the coastal site of Byblos located 40 km southwest

O-40

Cave Explorations on the Islands of Kárpathos and Kásos (South Aegean, Greece)

Thomas Rathgeber - *Staatliches Museum für Naturkunde Stuttgart, Rosenstein Gewann 1, D-70191 Stuttgart, Germany*
Herbert Jantschke - *Höhlenforschungsgruppe Ostalb-Kirchheim, Römerstraße 7, D-72127 Kusterdingen, Germany*

Abstract

During two visits in the years 1983 and 1987 to the islands of Kárpathos and Kásos 13 smaller caves were documented. The explorations included surveys of the caves and the examination of Recent, subfossil and fossil bones found in these caves and also at other places of the area. The results are seen as a contribution for the questions on the formation of the Greek islands. A better knowledge of the faunal and floral development on the islands allows the identification of old land-bridges. A summary of the work is given, including the illustrated and detailed descriptions of two of the more interesting caves.

Introduction

In the south of the Aegean Sea the Greek island of Kár-pathos is situated at a point of interfering influences from Europe and Asia (and Africa as well). The island is 49 km long and 15 km wide. It lies halfway between Crete and Rhodes. Together with Kásos (12 km long, 4 km wide) in the southwest, the nearby Saría (6 km long, 4 km wide) in the north and a number of smaller to tiny costal islands Kárpathos forms the Kárpathos-Archipelago. The three larger islands contain widespread mountaineous areas with some higher peaks, culminating on Kárpathos in the Kalilímni (1213 m), on Kásos in the Megálo Príonas (601 m), and on Saría in the Megálos (660 m). The islands are built up of Cretaceous limestone on Kásos and in the north of Kárpathos and of a series of neritic limestones (Lias-Eocene) and phyllite in the main part of Kárpathos. While the limestones of Kásos are completely autochthonous, the structures of Kárpathos belong to an autochthonous and to four allochthonous series, being displaced from their submarine development area. Due to considerable tectonic movements in the Miocene (20 million years ago), these masses were uplifted, forming a landmass from this time on. According to current know-ledge, there were no land bridges to other larger islands or to the neighbouring continents during the Pleistocene ice ages. This point is significant for a discussion about the younger history of the faunal and floral development on the islands.
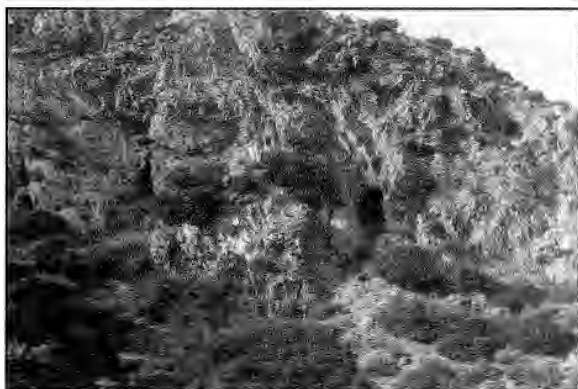
Fig. 1: Entrances of the Bat Cave (Fledermaushöhle - right) and Cricket Cleft (Grillenspalte - left) near Apéri on Kárpathos (photograph: TH. RATHGEBER, 1 st of October 1987).

Politically Kárpathos belongs to the Greek district Do-decanes. The harbour of the capital town Pigádhia con-nects the island to the ferry lines from Crete and Rhodes. A small airport on the island also allows daily flight transfers from Rhodes. The historical development of the islands is quite complex. It is thought that the first settle-ments took place in the Neolithic period about 4600 years b.p. from the northeast. During Bronze Age (about 3500 b.p.) the Minoan culture had greater influences. Around 2500 b.p. four antique prospering villages are known from Kárpathos: Poseidon (Pigádhia), Arkeseia (Arkása), Vrykous (Vrukúnta, see cave description below) and Nissyros (Tá Palátia on the now uninhabited island Saría). After belonging to the Roman Empire in the years before Christ, Kárpathos was governed by Genoa, Veni-ce, Rhodes, Turkey, Italy, Germany and Britain, and it was not until 1948, when it was united with Greece after 654 years of foreign occupation.

In the year 1991 a population of only 5323 inhabitants was living on Kárpathos. Signs of a denser settlement in former times are for example man-made terraces almost everywhere and the occurrence of artificial cave structures even in very remote places. 9 older villages are situated on Kárpathos with Ólimpos in the north and Pigádhia together with Apéri in the south being the greatest. On Kásos, a number of 5 villages exists, but to-day only the harbour town Frí is of greater significance. A network of good roads was built between all the vil-lages on the main islands and it was only in 1981, when a road reached Ólimpos, up to then being the remotest town in Greece, accessible only by trails. Comfortable annual temperatures of 20°C (Pigádhia) and low annual precipi-tations of 464 mm give the islands touristic attractivity. Karst forms are abundant on the islands, but in contrast to Crete and Rhodes they are of minor extension and only of regional significance. Typical for this fact is a region near the summit of the Kalilímni, where corrosive surface features like karren and dolines are formed and the open potholes reach down only to a depth of about 10 m. Big-ger caves are found only in costal regions, related to old sea-levels, mainly around 70 m above the present level.

Summarising it is clear, that on the islands only an "ini-tial karst" is developed. The reason for this might be the small catchment areas for precipitation and the geological disturbance with a lack of a long time constant karst water table inside the limestone. This result of our work supports the theory of a relatively independent develop-ment with no land bridges in the younger history of the earth, especially none during the Pleistocene.

Remarks on the fauna of Kárpathos

From Neogene sediments near the airport DAAMS & VAN DE WEERD (1980) investigated a fauna of small mammals and placed them in the early Pliocene. The sample con-tained teeth of 5 different species. In a quantity of only 20 teeth this comparatively high number is a sign for a diverse continental influence. Hence, the authors came to the conclusion of a high evidence for massive land bridges from Kárpathos over Rhodes to the Asian conti-nent in the early Pliocene.

The Pleistocene mammal fauna is completely reigned by remarkably small endemic cervids. First found 1963 in a cave 700 m to the southeast of Pigádhia, these cervids were placed by KUSS (1975) in a new genus and in the two new species Candiacervus cerigensis and C. pigadi-ensis. Type locality is a cave named Kandilia or, used by the German ornitholo-gists KINZELBACH & MARTENS (1965), Seglergrotte (see Tab. 1). Living in the Middle and Upper Pleistocene, probably even in the early Holo-cene, these deer species held the ecological niche which now is oc-cupied by the domestic goats. Nearly all discoveries of fossil deer bones have taken place in caves or in karst sediments, giving a spotlight on the living circumstances of the animals, seeking for shade and a damp cli-

mate. Beside the deer only remnants of snails, birds, a mouse and a turtle have been found up to date (KUSS 1967, 1973, 1975; WEESIE 1984). Predators are lacking in the Pleistocene fauna. Today, only one wild living Mammalian species of predators exists on the island, the Stone Marten (Martes foina).

Cave descriptions

As examples, two of the more interesting caves of Kár-pathos are

presented, one being an old Christian church and the other one the longest cave of the island known to us.

The cave church Ágios Ioánnis near Avlóna at the north-western part of Kárpathos is probably the most visited underground structure of the whole archipelago. A considerable portion of the underground volume seems to be carved out of the rock in former times and it is diffi-cult to determine natural and artificial parts. The cave lies at the tip of Cape Vrukúnta near the antique town Vry-kous, from which relics of walls and tombs are pre-served. It is very likely that the artificial parts of the cave were formed in

Table 1: Caves on the islands of Kásos und Kárpathos.

No.	Name of the cave	Longitude	Latitude	Altitude	Total length
	Kásos				
1	Stilokamára	E 26°54'27"	N 35°23'26"	255	19 m
2	Ellinokamára	E 26°54'40"	N 35°23'45"	150	20 m
	Kárpathos				
3	Höhlenkirche Ágios Ioánnis bei Avlóna	E 27°10'22"	N 35°47'51"	15	32 m
4	Höhlenkirche Ágios Ioánnis bei Spóa	E 27°09'45"	N 35°37'03"	90	72 m
5	Kuss-Höhle	E 27°05'32"	N 35°34'53"	70	22 m
6	Ziegenhorst	E 27°06'45"	N 35°34'39"	190	23 m
7	Hirschhöhle	E 27°06'56"	N 35°33'18"	70	14 m
8	Achátahöhle	E 27°12'39"	N 35°33'12"	70	56 m
9	Marderhöhle	E 27°12'38"	N 35°33'11"	70	50 m
10	Fledermaushöhle	E 27°11'15"	N 35°31'44"	70	102 m
11	Grillenspalte	E 27°11'14"	N 35°31'44"	70	35 m
12	Pfeilergrotte	E 27°14'28"	N 35°30'02"	5	26 m
13	Seglergrotte	E 27°14'48"	N 35°29'43"	0	98 m

Explanations:

No.	Same number as in fig. 2
Name of the cave	For detailed information see JANTSCHKE & RATHGEBER (2005)
Longitude	According to the Italian topogra- phical maps 1: 25000 (1932-1934)
Latitude	According to the Italian topogra- phical maps 1: 25000 (1932-1934)
Altitude	Floor at the entrance (in metres above sea-level)
Total length	For detailed information see JANTSCHKE & RATHGEBER (2005)

these times and that the church has only been occupied and rearranged in Christian times. Even parts of the trail from Avlóna down to the festival ground above the cave are likely to be very old. As a replacement to a usual chapel tower, a rock cross was erected directly above the cave and the bells hang in a wooden frame nearby. Stairs are leading down to the entrance in the upper third of the steep cliff. A tiny harbour in the neigh-bourhood functions as a transfer point in festival times.

At the entrance, some seating possibilities invite the guests to take a rest.

From the small and white painted entrance some more stairs lead down into an impressive dome with hot, sticky air and the ever lasting smell of incense. The room hosts a shrine, a part of an antique column and a bap-tistry in the form of a cross. This basin is fed, like two similar, but simpler ones, with dripping water from the roof. Candle holders and metal votive panels are installed at the walls. In the southeast corner of the room a tiny shaft drops into the dark, protected by stonewalls and "sealed" with many crosses and candles.

Concerning the foundation of the church a legend exists, saying that in the times of Byzantine emperors the inhabi-tants of Vrykous decided to build a church, but they did not know where. Three times it happened that an icon of Saint John, bound for the new church, vanished from the town

and was found inside the cave. Therefore people followed the will of Saint John and the church was build inside the cave.

The 28 th of August every year, several hundred people from Ólimpos and Diafáni are celebrating a festival in the honour of Saint John the Bap-tist, singing, dancing and staying there for two nights.

The great entrance of the Bat Cave (Fledermaushöhle, Höhle Tsour-laki, Tsoulaki´s Cave, Tzoullaki Spilæon) is situated about 2 km southeast of Apéri and 4 km north-west of Pigádhia. It lies in a little valley about 70 m above sea-level. The cave is developed in Cretaceous Dolomites of the Olonos-Pindos-Series and shows a total length of 102 m. The dolomitic banks of the rock are tectonically deformed into a saddle structure, where the cave follows a series of parallel faults to the north. In the steep north-ward dipping strata the nearly black dolomite contains different layers of whitish grey flintstone, which are now sticking out of the walls as an insoluble com-ponent.

Directly behind the entrance the main room of the cave is 26 m long, 9 m wide und up to 8 m high. On the floor, beneath an only 10 cm thick bed of small stones and earth, fine layered clay points to a formation in quiet wa-ter. Near the western wall of the main room remnants of a building were observed, partly covered with flowstone and therefore of an older age. At the right hand end of the main room, a fissure forms a small, high

167

SARÍA

Árgos

Megálos
▲
660 m

Trístomon

3 ⌒   *Orkhíli*
▲
713 m

Avlóna
○

Dhiafáni

Ólimpos
●

▲ 716 m
*Profítis
Illas*

Kimarás
▲
693 m

Spóa
●

KÁRPATHOS

Ágios Nikólaos
⌒
4

Mesokhóri
●

Lefkós   *Kalilímni*
▲
1213 m

5 ⌒   Mertónas
○
⌒ 6
⌒ 7   Voládha
Óthos   ● Apéri   9 ⌒⌒ 8

Pilés
●

11 ⌒⌒
10

Khómali
685 m ▲   12
⌒ ⌒ 13
Finíki   Pigádhia
Menetés
●

Arkása
●

griech. Festland

Athen
●

Türkei

Peloponnes

ÄGÄIS

Rhodos

Kárpathos

100 km

Kreta

0 2 4 6 8 10 km

ARMÁTHIA

Frí

Príonas
▲

Agía Marína   Panagía 601 m

Póli
⌒⌒
1 2   Arvanitokhóri

▲
Períolas
585 m   KÁSOS

Fig. 2: The Kárpathos-Archipelago with the caves surveyed in 1983 und 1987. The numbers are the same as in Tab. 1 (Altitudes of the mountains as given in the Road Map 1:75000 Karpathos/Kasos by Freytag-Berndt u. Artaria, Wien - Edition 01/99).

passage which runs 20 m upward to the north. There is a good resting place for bats. In the far reaches cave crickets (Dis- coptila kinzelbachi HARZ, 1971) were found. On the western wall of the main room a low gap gives way to a roomy fissure, orientated towards the hillside.
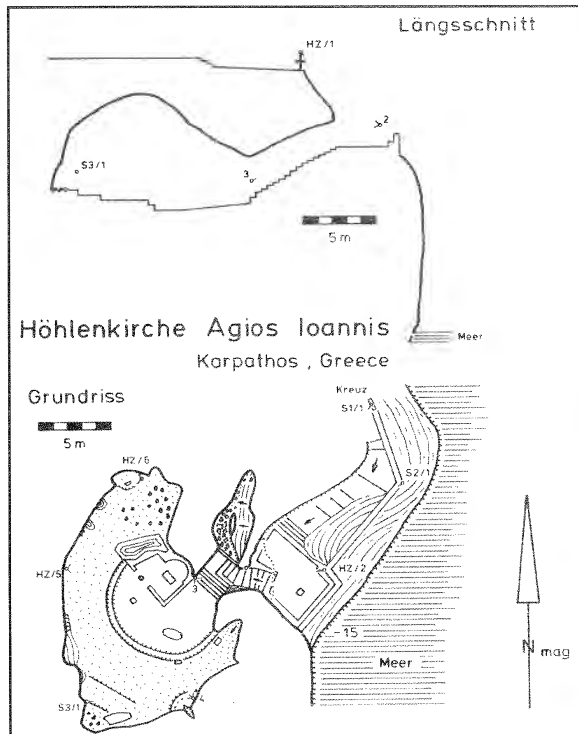
Fig. 3: Cave Church Ágios Ioánnis near Avlóna on Kár-pathos - plan of the cave surveyed and mapped 11 th of October 1987 by H. JANTSCHKE, A. LEHMKUHL and TH. RATHGEBER (drawn by H. JANTSCHKE).

Only few speleothems are found within the cave. In the development of the cave, the highest Pleistocene sea-level during the Tyrrhenic transgression (KINZELBACH & MARTENS 1965) might have played a role. MELAS (1985) reports the discovery of ancient pottery, which he assigned partly to the Neolithic and mainly to the Middle and Late Bronze Age period. West of the entrance, the neighbouring cave Cricket Cleft (Grillenspalte) follows one of the faults mentioned above. The passage goes straight to the north without reaching a connection to the main cave. It forms a narrow fissure and its far end is difficult to access.

Fig. 4: Cave Church Ágios Ioánnis near Avlóna on Kár-pathos - view over the baptistry to the stairs which lead down into the cave (photograph: TH. RATHGEBER, 11 th of October 1987).

Further information

For a detailed description see JANTSCHKE & RATHGEBER (2005), where also a more complete list of literature is given.

Fig. 5: View through the huge portal of the Bat Cave (Fledermaushöhle) down to the ground of the valley (photograph: TH. RATHGEBER, 1 st of October 1987).

References

DAAMS, REMMERT & WEERD, ANNE VAN DE (1980): Early Pliocene small mammals from the Aegean island of Karpathos (Greece) and their palaeogeographic significance. - Geolo-gie en Mijnbouw, 59, p. 327-331, 3 fig., 1 pl.; Den Haag.

JANTSCHKE, HERBERT & RATHGEBER, THOMAS (2005 - in press): Höhlenkundliche Beobach-tungen und Untersuchungen auf dem Kár-pathos- Archipel (Süd-Ägäis, Griechenland). - Materialhefte zur Karst- und Höhlenkunde (MKH), 19; Heidenheim. KINZELBACH, RAGNAR & MARTENS, JOCHEN
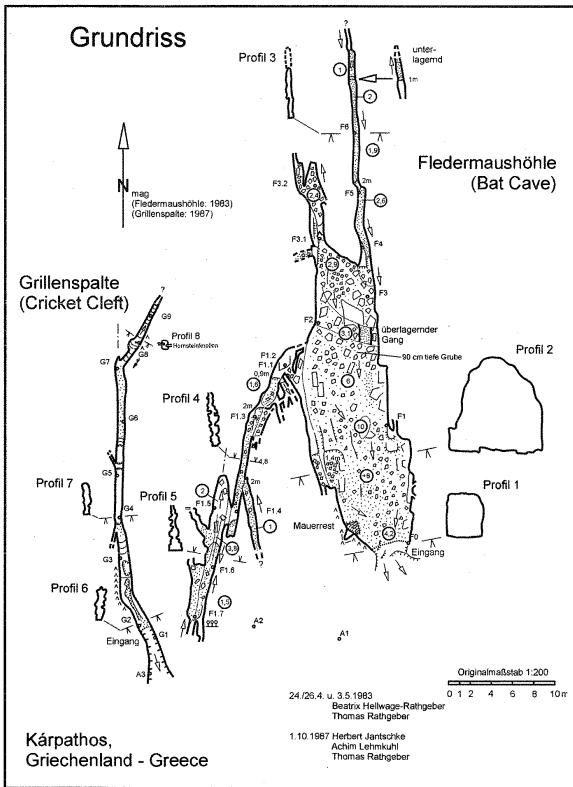
Fig. 6: Map of the Bat Cave (Fledermaushöhle) and the Cricket Cleft (Grillenspalte) near Apéri on Kárpathos - caves surveyed and mapped 24 th and 26 th of April and 3 rd of May 1983 by B. HELLWAGE-RATHGEBER and TH. RATHGEBER, completed 1 st of October 1987 by H. JANTSCHKE and A. LEHMKUHL (drawn by TH. RATHGE-BER and H. JANTSCHKE - sections see fig. 7).
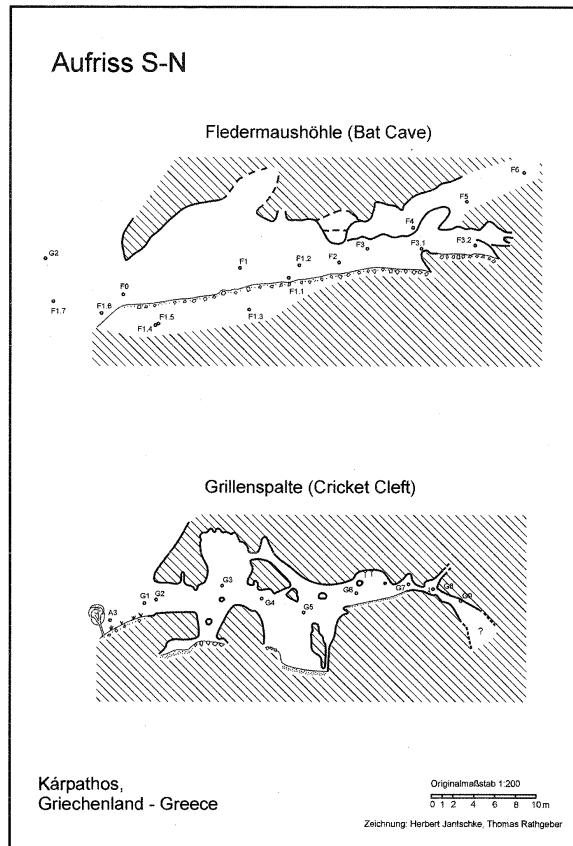
Fig. 7: Sections of the Bat Cave (Fledermaushöhle) and the Cricket Cleft (Grillenspalte) near Apéri on Kárpathos (map see fig. 6). 3 tab., 4 pl.; Freiburg im Breisgau.

(1965): Zur Kenntnis der Vögel von Karpathos (Südliche Ägäis). - Bonner zoologische Bei-träge, 16, p. 50-91, 1 fig.; Bonn.

KUSS, SIEGFRIED E. (1967): Pleistozäne Säuge-tierfunde auf den ostmediterranen Inseln Kythera und Karpathos. - Berichte der Natur-forschenden Gesellschaft zu Freiburg im Breis-gau, 57, p. 207-215, pl. I and II; Freiburg im Breisgau.

KUSS, SIEGFRIED E. (1973): Die pleistozänen Säugetierfaunen der ostmediterranen Inseln. Ihr Alter und ihre Herkunft. - Berichte der Na-turforschenden Gesellschaft zu Freiburg im Breisgau, 63, p. 49-71; Freiburg im Breisgau.

KUSS, SIEGFRIED E. (1975): Die pleistozänen Hirsche der ostmedi-

terranen Inseln Kreta, Kasos, Karpathos und Rhodos (Griechenland). - Berichte der Naturforschenden Gesellschaft zu Freiburg im Breisgau, 65, p. 25-79, 8 fig., 3 tab., 4 pl.; Freiburg im Breisgau.

MELAS, EMMANUEL M. (1985): The Islands of Karpathos, Saros and Kasos in the Neolithic and Bronze Age. - 337 p., 140 fig., 1 tab.; Göteborg (Paul Åströms Förlag). (=Studies in Mediterranean Archaeology, 68).

WEESIE, PETER D. M. (1984): On some Pleisto-cene bird fossils from the south Aegean island of Karpathos (Greece). - Geobios, 17, p. 845- 849, 1 fig.; Lyon.

O-41

REMARKS ON THE PROBLEMS OF THE PALAEOLITHIC TERMINOLOGY

Dr Nickos A. Poulianos

Ministry of Culture, Ephorate of Palaeoanthropology - Speleaology, Ardittou 34b, Athens 11636. Aegean Un., Medit. Studies, Rhodes, Anthropological Association of Greece, 5 Daphnomili, Athens 11471. Greece. E-mail:ww.aee@vip.gr

Abstract

Very often Paleolithic manufacts and tools are found in cave deposits, especially in Europe. The related scientific fields are comparatively recent as they are little more than a century old. Thus the terminology associated with this research is not yet fully established and/or standardized and such an effort still requires further studies. In this paper some terms of primordial importance are discussed. For example, the word "culture" is defined as the sum of the bio-social adaptations to the environment. The need of defining different, contemporaneous or not, distant or mixed cultures and their limits is presented, as well as the meaning of the word "tool". Also discussed is the use of other problematic terms such as: industry, retouch, by-product, sub-product, edge, ridge, flat, linear, bulb, natural flake, simple detached flake, premeditated and/or Levalloisian flake, degree of curvature, chopper, hachoir, bladelet etc.

The development of the Paleolithic scientific discipline is comparatively recent. Ancient philosophers (p. ex. Anaximandros, 610-550) first tried to give an explanation of human origins, expressing the opinion that they might be common along with fishes and other animals. Lucrecius (97-55) supposed that teeth, nails and hands were initially used as tools, while subsequent implements were made of wood, stones and bones. It is only after almost 2,000 years when similar questions appeared on the scientific horizon. Thus, a significant step was made during 19th century by an amateur named Jacques Boucher de Perthes (1788-1868), who unearthed the Achelean Palaeolithic culture in France. Since then however the most important discoveries, offering a possibility of modern interpretations of Palaeolithic period, concern last few decades.

Due to its "young age" Palaeolithic terminology is not yet satisfactorily determined and the present paper is dedicated to promoting a further investigation. First, a commonly accepted definition of culture is needed, which is perhaps best expressed as a sum of bio-social adaptations to the environment. Therefore each culture reflects such adaptations, although the criteria of passing from one culture to another and/or their stages, periods, phases etc, are not yet established in an absolute (i.e. objective) manner. For example: Did North American Indians participate to a single culture, stage etc or to many? At the present time, a mathematical model is almost impossible to provide. Questions abound: What criteria should be used to distinguish one culture from another? Is it for instance satisfactory to set a sum of 10% of changes concerning technological, productive means and spiritual (linguistic, religious etc) factors, as the absolute standard to the passage from one cultural stage to another? Theoretical multidisciplinary analysis accompanied by examination of data even beyond the available bibliographical elements should lead to the answers.

Industry (e.g. the way of transforming row material), culture, civilization (cf. above), tradition (e.g. continuity and evolution of cultural elements), cultural stage, phase etc (e.g. social and technological level of a culture), cultural complex (e.g. combination of traditions and cultural stages within a limited geographical area and time span) are also terms often used arbitrary and a more precise distinction among them is required.

Similar uncertainties are connected to the meaning of the word tool. Many animal classes, as well as humans (contemporary or previous evolutionary stages) use implements without any material preparation and/or flaking. Practically they cannot be distinguished and for this reason the term "handy tool" or "pre-tool" is proposed. Concerning the distinction between human manufacts and tools, not all specialists agree for their terminological use. The word tool usually means an object of the environment that is deliberately detached and shaped for the elaboration of other objects (of living origin or not), known or unknown way of use (i.e. hunting included). Furthermore, such an elaborated object is retouched and must be met in a repeating way and not as an isolated sample in prehistoric sites. Beyond these criteria the words implements or manufacts are used (within which all tools are included). However confusion still remains concerning some tool types, as for example the unretouched choppers and many blades, suggesting that a reconsideration of relative definitions currently used appears necessary.

The same uncertainty is observed for terms such as chips, by-products (e.g. tools produced by chance, not deliberately), debris, etc, to which the term "sub-product" (e.g. a rejuvenation core flake, Kernscheibe) must be probably added. A clarification among natural, simply fabricated, premeditated (note: prepared is a problematic, often misleading term) and/or Levalloisian flakes (perhaps "pholidota" or "folidota", single "pholidoto") is also necessary, since the latter may be due to more or less sophisticated technologies, but not always clearly to which one. Furthermore tool types and technologies appear inconvenient to be based on geographical names. Besides the aforementioned choppers, hachoirs and bladelets need to be defined more precisely. Bladelets that are less than 10 mm wide and less than 40 mm long are proposed to be called "mini-blades" or "nano-blades".

There are nonetheless describing terms of tool parts, which according to the author's opinion, should be rearranged in more details. The word bulb must be abandoned because it is confusing and should be replaced by the word conchoid (since this tool part may even be flat, however never presenting the form of a bulb). Also border retouch must be distinguished from the face retouch of a tool.

The words border, arise, ridge, lip and edge may be used in a synonymous way. However, for practical reasons it is more suitable to use them exclusively in specific cases, i.e. without overlapping terminologically. Thus the following proposals are made: a) "border" to indicate only the implements' margins, b) "arise" to indicate only the ridges (i.e. in between channels) of cores, c) "ridge" to indicate only the flakes' and blades' dorsal edges due to arises, not to retouch, d) "lip" to indicate only the tool's scars borders, and e) "edges" to indicate only working ones.

Many times the words flat and linear are erroneously used, since such features are very rare indeed. It is therefore more appropriate to replace them in most of the cases by terms such as "flattish" and "strait-tending".

Finally, the curvature degree portrayed by the scars of a tool (i.e. fulfill by lines, designing) is proposed according to Figure 1.

Figure 1. The curvature degree of a tool's scars portrayed from 0 to 5+, which correspond to scars' indexes from 1 to 40+ (length x width x depth of scar x 100 divided by tool's volume). These indexes practically show the volume percentage that scars occupy on a manufact. Obviously it is possible to use the intermediate curvature degrees arbitrarily, without any further absolute definition

Reference:

Poulianos A. Nickos (2005) - Introduction to Palaeolithic technology and typology (in Greek). Ed. Kardamitsa. Athens.

O-42

THE ABSOLUTE DATINGS OF PETRALONA CAVE

Dr Nickos A. Poulianos

Ministry of Culture, Ephorate of Palaeoanthropology - Speleaology, Ardittou 34b, Athens 11636. Aegean Un., Medit. Studies, Rhodes, Anthropological Association of Greece, 5 Daphnomili, Athens 11471. Greece. E-mail:ww.aee@vip.gr

Abstract

A long discussion regarding the chronology of the Petralona cave findings (human, animal fossils, manufactures, etc) has been ongoing since the skull of a prehistoric man was found 45 years ago. Both relative and absolute datings have been very controversial among various scholars. The relative datings have suggested that the findings date back to the Early Middle Pleistocene. Absolute datings such as U/Th, ESR, TL, aminoacids, palaeomag, etc have led to several measurable results which are not always concordant. A synthesis of up today efforts and an interpretation of the contradictory results are given herewith.

Stratigraphy and relative datings

On September 16th 1960 a human skull of a male individual was found at Petralona cave covered by stalagmitic sinter. Its age, along with the faunal remains, was initially attributed to the Upper Pleistocene (50,000-70,000 years ago). During 1968 A. Poulianos (1968, 1971) started excavating the site and, according mainly to palaeolithic - stratigraphic data, the age of the Petralona findings were reassessed at about 0,5-0,9 m.y.a. He also founded in 1971 the Anthropological Association of Greece which has taken the initiative of the site's investigation. Summarizing the present evidence, the following picture is obtained: In the northern cave compartment 34 geological layers have being revealed, while in the southern compartment only those beneath the 11th stratum. On the ground surface of the southern compartment, in a chamber named Mausoleum, the Petralona man was found who therefore lived during the formation of the 11th layer (or at most the 14th). Two are the main stalagmitic layers developed in the cave stratigraphy which concern absolute datings: the 1st (upper) and the 10th. The faunal evidence, despite several discordances, confirmed the aforementioned chronology given by A. Poulianos. Note: Because of space limitation in the present paper, palaeolithic, statigraphic and faunal data are not further discussed (for more details see A. Poulianos, 1982a and N. Poulianos, 1989, 1995).

Absolute datings

Specialised laboratories have used different methods in order to achieve the absolute chronology of various materials coming from the Petralona cave sediments. A summary of the up today results follows.

Uranium / Thorium

Sample No. 75022 was the first to be dated with the U-234/Th-230 method, by Prof. H. P. Schwarcz (see A. Poulianos 1977). This sample comes from the 1st stalagmitic layer of Section Alfa and its age was calculated to be of about 0.3 m.y.a. Surprisingly another sample coming from the 10th layer of the same Section was calculated to be at a younger age (~0.2m.y.). The second sample should indicate an elder age compared to the first one. This contradiction is a good example of the difficulties and the limits of the absolute dating methods used for spelaeothems. Regarding the surface stalagmitic material of the Mausoleum, the maximum possible estimation of the method was made, i.e. 0.35 m.y.a.. More material

was subsequently dated to improve the accuracy of the results. Schwarcz et al. (1980) analyzed a number of samples.

A sample collected by H. P. Schwarcz himself, from the lower part of a stalagmitic column of Section Alfa, was dated at 277.000+160.000 or 277.000-70.000 years, containing a concentration of 0.11 ppm of Uranium. Another sample presented a younger age because the analogy between U-234/Th-230 was 0.8 ppm, and a third sample over-passed the equilibrium value indicating an "infinite" age (>350.000 years). A micro-section taken from a higher level of the same stalagmitic column showed to be of a more recent age (69.000 ± 21.000 years), while two other samples, taken from adjacent columns of Section Alfa, presented values extraordinarily high (8.4 and 2.7 ppm). According to Schwarcz et al. (1980), these samples, curiously, did not seem to be chemically disturbed and the uncertainties of the chronological results were attributed to the relatively low Uranium content. The same authors pointed out the large isotopic variation in the samples, despite being only 4 cm apart and coming from the same stalagmitic layer. They concluded that it was impossible to have a precise result for the middle part of the 1st layer, while its lower part indicated an age that reached the limit of the method, i.e. 0.35 m.y.a.

Samples from the 10th layer of Section Alfa indicated again an age of about 0.2 m.y.a. Another sample from the same layer, which contained very low Uranium concentration, corresponded only to 0.14 m.y.a. These results are contradictory with previous findings and thus Schwarcz et al. (1980) considered the estimated age of this layer to not be representative of its actual age. An explanation regarding the results of this stratum must probably lie with the fact that it has been influenced by a more recent sinter flowstone. This flowstone probably followed the limestone wall of the cave in Theophrastus hall, penetrating the empty space that was created between its wall and the sediments in post deposition times, during arid periods when the phenomenon of sediments' subsidence occurred. The travertine floor of the Mausoleum that is mainly composed of two surface stalagmitic layers (i.e. the 1st and the 10th), was found to be of an age between 0.28-0.6 m.y.a. (the later extrapolated), i.e. focusing on a medium of 0.45 m.y.a.

Other results were provided by Henning et al. (1980) for 22 samples, which were mainly dated by the U-234/Th-230 method. The numbering of the samples follows the order in which they were collected. Generally samples coming from the 1st layer showed various chronologies, from 65.000 to more than 350.000 years ago. The latter value also corresponds to the Mausoleum surface. Again these estimations are a compromise between the more recent stalagmitic formation and the limit of the method. The samples 4, 5, 11, 13, and 17 which correspond to the layers 11-16/20, present very similar isotopic analogy indicating their close chronology. This result is in accordance with the biostratigraphical data.

Liritzis (1980) tried to extend the limit of 0.35 m.y.a. by calculating the analogies between Th-230/Th-232 and U-234/U-238. However, extrapolating the datings he indicated that the standard errors might reach even 1-2 sigma (30-60%). Liritzis' (1980) results regarding the chronology and the gamma dosimetry are summarised below:

a) The 1st layer gave an age between 0.075 and >0.35 m.y.a.

b) The intermediate travertine of Section Alfa (10th layer) showed a medium age of about 0.3 m.y.a., presenting an extrapolated maximum estimation of 0.75 m.y.a.

c) The middle-upper portion of the stalagmitic travertine from Mausoleum revealed an age between 154.000 - 250.000 years and the lower one between 400 - 650.000 years. The travertine from the adjacent Mediterranean hall in the upper part was estimated at about 159.000 years and the middle-lower from 350.000 to 600.000 years. Here, the remarkable coincidence of the values of chemical and chronological compositions of both travertine layers of the Mausoleum and the Mediterranean halls must be noted, confirming again the stratigraphical observations.

Liritzis (1980) also noted a vacuum of the calcite formation between 0.2 and 0.35 m.y.a., which was attributed to this period's climatic changes, correlated to the Shackleton & Opdyke (1976) stages 6-10. Furthermore Liritzis (1980) affirmed that the sinter formation of the 1st and the 10th layer proceeded mainly during 0.07, 0.17-0.2, 0.35, 0.45 and 0.6 m.y.a. This result is a very interesting observation for Pleistocene palaeocology, palaeoanthropolgy, as well as palaeontology, because indicating the main world's humid periods during the last half m.y.a.

In respect to the above datings, it is possible to give a hypothetical example regarding the deposition of remains within the various stalagmitic layers: A fossil is just penetrating the surface of a travertine of 0.6 m.y.a. and it is covered by sinter of 0.45-0.2 m.y.a. If the age of the fossil is considered by dating the stalagmitic material that surrounds it with a mean of about 0.3 m.y.a., a wrong chronology would be given. It would be even more wrong if it was dated at 0.2 m.y.a. The correct chronology of the fossil, instead, should be the dating of its deposition at the stratigraphical level, i.e. that of at least 0.6 m.y.a.

Thermoluminescence (TL)

In ideal cases and for materials relatively recent, the standard error of this method is about 10%. Beyond an age of 0.3 m.y.a. the standard error increases considerably.

According to Ikeya (1977), the minimum age obtained by this method for the surface stalagmite of Section Alfa-1 is 0.25 m.y.a. The same method was applied by Liritzis (1979, 1980) on feldspatic sands embedded in burned out argyle from the 4th layer. The results indicated a maximum age of 0.67-0.7 m.y.a. Liritzis (1980, 1986) did not consider these results to be representative of the actual age. Thus, he indicated an age of 0.3-0.35 m.y.a. as more probable because this is the dating usually obtained for the 1st layer as it is closer to the 4th one. The author's opinion though is that for the first time by the absolute datings was revealed that the 4th layer tends to have an age of 0.7 m.y.a.

Fission track detection

Dating the stalagmite of Section Alfa-1 by the fission track method did not provide reliable results (Ikeya 1977). This is again due to the fact that the U-238 concentration is very low (0.12 ppm), a value which is much lower than that obtained by the gamma ray spectroscopy of the Ra-226 (0.57 ppm). M. Ikeya hypothesised that this difference may be due to Radon, which is not derived from Uranium. Ikeya (1977) thus concluded that the Petralona stalagmites could be dated by this method only if it were to have an age of more than 3 m.y.a.

E.S.R. - Electron Spin Resonance

E.S.R., a dating method discovered by Ikeya (1975, 1978a) at Jamaguci University, was first applied to date prehistoric remains from Petralona cave. E.S.R. requires the sample to be exposed to gamma rays. The effects of the rays on the irradiated points are recorded and the spin angles of the out-coming electrons are measured. Its advantages compared to other radiometric methods used in caves are: 1) only a small sample amount is needed (10-20 mg), 2) theoretically its maximum age limit is much higher compare to other methods, and 3) lately, it has been perfected and may also be used as a method which does not destroy the samples.

Initially E.S.R. was applied on a cross section at the base of a stalagmitic column from Section Alfa-1. The central part of the sample presented a white colour, while the rest of it, towards its periphery presented a brown one. Their contact point was calculated to have an age of about 68.000 years and a radial increase of 0.2 micromillimeters/year. Assuming

that the increasing rhythm was stable, a minimum age of 0.25 m.y.a. for the centre of the stalagmite was calculated. Similar results were obtained by Ikeya (1977) on stalagmitic samples from Akiyoshi cave in Japan leading him to conclude that a world-wide simultaneous change of climate humidity occurred.

Precise measurements regarding the radiation per year (annual dose) of the Petralona cave were needed for better estimations of age. This parameter was initially obtained by introducing sensitive capsules of Phosphorum and CaSO4 (Tm) inside the cave sediments. They showed an external dose of 50 mr/year, corresponding to a total annual dose of 200 mr/year (Ikeya 1977). Furthermore, Ikeya (1978b) dated another sample from the surface of Section Alfa, which gave an age of 0.34 m.y.a., on the basis of a total annual dose of 0.2 rad/year and the external dose of 87 ($\pm$ 20) mr/year.

Next, Ikeya & A. Poulianos (1979) presented datings of ashes attached to stalagmitic material coming from the layer 23-24 of the newly excavated Section Gamma (see also A. Poulianos 1980a). The stalagmitic material was probably affected by the same fire that produced the ashes. The archaeological dose (before exposing the samples to radiation) was calculated to be of about 210-230 Krad. Considering the annual dose of 0.2-0.3 rad/y, an absolute dating of 0.7-1 m.y.a. was indicated. However, it was observed that the ashes radiated more than the stalagmites. Thus, the value of the (average) annual dose of 0.2 rad/year could be in fact higher by 0.1 rad/year, or even half (i.e. 0.1 rad/year, see Ikeya & A. Poulianos 1979).

A large variation in the obtained values was again observed within the same sample. This variation, according to Ikeya (1980), is probably due to the variation quantity of the radionucelotides contained inside the samples which influence the values of the annual dose. The eventual carbonate impurity of the stalagmitic material, probably due to a re-crystallisation process and to its porous structure, prompted Ikeya to claim the need of further research. As regards the 10th stalagmitic layer of Section Beta, the same author considered an age of 0.67 m.y.a. as more probable.

More E.S.R. results were presented by Henning et al. (1981b). They used five samples, three of which (b, d, e) had been already dated by the U/Th method (Henning et al. 1980, 1981a), an act criticised by Karakostanoglou (1981a, b) on the level of professional ethics, mainly because they did not previously contact and/or notify the director of the excavations. Since Henning et al. (1981b) did not indicate the precise cave location of the samples (b, d, e), a comparison of the chemical composition between Henning et al. (1980) and Henning et al. (1981b) suggests that they belong to the southern abovementioned cave compartment (Mediterraneum-Mausoleum). The five samples in detail are:

a) Calcite covering the human skull, dated at 0.2 m.y.a., which according to Henning et al. (1981b) indicates the minimum possible age of the Petralona man.

b) Upper level of the stalagmitic floor (Mediterranean - Mausoleum), again at 0.2 m.y.a.

c) Bone fragments of the human skull, which were removed along with stalagmitic material during cleaning, are dated at 127.000 years (between a minimum of 0.1 m.y.a. and a maximum of 0.16 m.y.a.). It must be however noted that unfortunately the quantity of the removed bone fragments is not indicated.

d) A calcite sample taken 3-4 mm below sample (b), was dated at 0.2 m.y.a., which according to Henning et al. (1981b) should indicate the maximum age of the hominid (although no explanation provided). On purely stratigraphical reasoning, this dating indicates instead the minimum age, while for the same reasons the maximum age is obtained from sample (e).

e) Calcite sample taken 30-40 mm below sample (b), dated at 650 $\pm$ 280.000 years.

It is evident that 4 out of 5 datings of Henning et al. (1981b)

173

show more recent chronologies than those suggested by previous researchers (along with those of Henning et al., 1980, 1981a). According to Ikeya (1982) this discrepancy is due to different conclusions of the total annual dose of radioactivity received by the samples; thus p. ex. considering the annual external dose as double, the absolute age falls down to half.

A discussion on the various aspects of these datings was brought up in "Nature":

A. Poulianos (1982b) drew the attention to the stratigraphical and cultural position of the Petralona man, which along with the study of the carnivore remains (see Kurtén & A. Poulianos, 1977, 1981) indicated an age corresponding to the end of the Lower Pleistocene (~0,7 m.y.a.).

Liritzis (1982) noted that he also had discovered more recent ages, but only in the upper and external parts of the Mausoleum concretions.

Ikeya (1982) stated that his E.S.R. method was further perfected beyond the first datings, discussing also the influence of Radon on the samples. The age of 0.6 - 0.7 m.y.a. for the Petralona man (even on the basis of the results obtained for the internal annual dose by Henning et al., 1981b) was indicated as the most representative and very close to that determined for Mauer (see also Ikeya & Miki 1981, Ikeya 1990a, 1990b, 1993).

Kurtén (1982) pointed out that the calcite covering the skull cannot be more ancient than the skull itself, since Henning et al.'s (1981b) sample-a (200,000 years) is indicated to be of an older age than sample-c (127,000 years). After all, it is obvious that a skull may not be "intruded" into elder stalagmitic material in relation to the time the individual was alive.

Henning et al. (1982) in a reply which did not disrespect the above A. Poulianos, Liritzis, Ikeya, Kurtén statements but which was nevertheless misleading, wrote the following in the same volume of "Nature":

1) Henning et al. (1982) claimed to be "the first to date samples of the recent brown calcite's surface".

It is enough to recall the comparison done by Ikeya (1977) of the brown and white regions of the Petralona stalagmite to those of Akiyoshi cave to realise that Ikeya was the first to identify the brown coloured stalagmitic material of 68,000 years old.

2) "The postcranial remains, published by A. Poulianos (1980c), do not belong to a human" (although Henning et al., 1982, never studied them) and they accused A. Poulianos of contradiction, since he "in 1971, stated that the postcranial skeleton was lost for the science".

Here, I would like to note that when the 1977 excavation proceeded in the Mausoleum for the identification of its stratigraphy, to the excavators' amazement many abandoned fossils (although in a bad state and fragmented) were found inside the sediments. These fossils were either free or attached to stalagmitic concretions, enabling A. Poulianos (1980c) to study them. These same bone fragments were further investigated and verified to be human by the medical jurisprudent Jamarellos (see in A. Poulianos, 1981), who had the opportunity to examine them. Among with the damaged fossils, an electric battery of 1960 was also abandoned (belonging to the site's Anthropological Museum collections). This fact verifies the careless way of colleting data during the year of the Petralona man's discovery. According to a statement made in a notary office by the late Christos Sariannidis (i.e. the person who found the skull, also an experienced worker of excavations), several postcranial human bones were initially collected and many were broken in situ during 1960. Therefore it is true that at least for the major part, the postcranial bones are lost for the science while others may appear somehow in the future. Efforts today focus on the recollection of the lost information as much as possible. Besides the above, this specific Henning et al. (1982) reply is misleading because it has little to do with the absolute datings discussion, provoking further confusion on the subject.

3) "The more recent brown coloured (very thin layer of) stalagmitic material (sample a), is in direct contact to the skull, meaning that its age is 0.1-0.16 years".

Such a statement could have merit if the entire skull was covered by similar sinter at the time when Henning et al. (1981b) studied it. Unfortunately after the removal of most of the stalagmitic material (1960-1978), the only part of the skull which remained covered was that of its base. In fact: a) the upper part of the skull was covered by a much thicker sinter formation than at its base (judging from the first photos), and b) the travertine fragments found inside the disturbed Mausoleum soil are composed by both brown (thin) and white (thick) stalagmitic layers. These findings very likely indicate also that the skull was covered by brown and white sinter. Thus, before the subsidence of the cave sediments, since the skull was laying on the ground, the first (white) stalagmitic layer which concretioned it on the sidewall, could only cover its upper part. After the subsidence, the skull remained hanging and stuck on the wall and its base which was no longer laying on the ground, was exposed to the more recent brown sinter. Thus brown sinter could finally cover the skull even at its base (i.e. without any white stalagmitic crust in this part of the skull).

4) "Sickenberg (1964) attributed the Petralona fauna to the age of Riss/Wurm".

In his revision, Sickenberg (1971) corrected his 1964 estimation attributing the Petralona fauna to the Biharian age after the A. Poulianos 1968 excavations. Chosen bibliographical data do not really help anyone understanding the cave's scientific issues.

5) "The dosimetry considered by Ikeya (1977) to obtain the age is different from that of Ikeya (1980)".

Prof. M. Ikeya always indicated two possible values for the annual dose, as well as the need for further measurements and perfection of E.S.R. method.

The difficulties of the dating results have being also summarised by a number of scholars who nevertheless did not analyze the details and/or include all of the available bibliographical data (see Wintle & Jacobs, 1982, Cook et al. 1982 and Grün, 1996).

A study published by Shen Guanjun & Yokoyama (1986) contradicted the results of Henning et al. (1981b). Their main conclusion was that all the cave sediments along with the lower part of the 1st stalagmitic layer have an age not less than 0.35 m.y.a. This study was based on samples taken in 1982 by A. Poulianos, Prof. H. de Lumley and the author.

However, in order to obtain a more precise estimation of the annual dose, in 1983, a few months before a violent and illegal interruption of Poulianos excavations at Petralona, a geophysical team of Thessaloniki University, guided by Prof. S. Charalambous, collaborated with Anthropological Association of Greece. Modern dosimeters were introduced in various cave halls. A year later some of the dosimeters were replaced by new ones for further verification and study (i.e. regarding not only observations of a complete year, but also for even longer periods of time). The Papastefanou et al. (1986) results were quite different from those indicated by Henning et al. (1981b, 1982) and were closer to those determined by Ikeya (1980) and Ikeya & Miki (1981).

Ikeya (1990a, 1990b) noted that the Greek researchers, being polite had not calculated the E.S.R. chronology. Thus, based on their study, M. Ikeya observed the following:

1) The annual dose of 0.1 and 0.2 rad/year as previously determined corresponds to an age of 0.68 and 0.34 m.y.a. respectively. Therefore, it was just enough to verify the exact dose.

2) The most probable dose seems to be that of 100 mrd/y, since the Uranium content is very low and the external dose of the gamma rays was calculated to be 50 mrd/y in Ikeya (1977), 87 mrd/y in Ikeya (1978b) and about 40 mrd/y in Ikeya & Miki (1981). Also,

174

the total dose received by the bones is between 10 Krad/year, for bones of the 16th layer covered by a very thin stalagmitic layer, and 86 Krad/y for bones found in the Mausoleum soil not covered by concretions (Ikeya 1978b).

3) The internal dose of 21-43 mrd/year is observed and accepted by all the authors, Henning et al. (1981b) included, who wrongly estimated the annual dose of 170-190 mrd/year, instead of 100 mrd/year.

4) Papastefanou et al. (1986) measured the external dose of the gamma rays to be of an average of 35 mrd/year for the entire cave and 68 (±5) mrd/year for the surface of the Mausoleum. The above values are close to the 40-50 mrd/year given by Ikeya (1977) and Ikeya & Miki (1981).

Ikeya (1990) concluded that the average rhythm of the annual radiation dose received by the samples at Petralona, in most of the cases, is of about 0.1 rad/year. This value is calculated by using the medium dose of 56 mrd/year, which is obtained by adding 21 mrd/year of the internal dose (from Henning et al., 1981b) to the most probable external dose of 35 mrd/year (from Papastephanou et al., 1986). This gives an age of 745.000 years for the human skull. Since it was however covered by stalagmitic concretions, the dose of 56 mrd/year, absorbed by the skull, needs to be reduced down to 49 mrd/year, resulting in an age of about 590.000 - 675.000 years (see also Ikeya, 1993).

Aminoacid epimerization

Another relatively recently developed method measures the aminoacid content inside fossil remains (see Bada 1971, Bada & Schroeder, 1975). This technique is based on the fact that the aminoacids present in the proteins and the bones of the living organisms are exclusively made as enantiomers in the form of L. During fossilisation the racemization process takes place and gradually they are converted to the corresponding enantiomers of the form D. Thus in the fossils, the enantiomers L and D tends towards 50% equilibrium as their age increases.

This method during the '70s could date materials of an age no more than 0.1-0.2 m.y.a. For this reason such an attempt proceeded by Bada (referred in A. Poulianos, 1980a) on an Ursus mandible fragment was not fruitful. Likewise the related results of Melentis (1980) and Protsch et al. (1982) must also be dismissed. Nonetheless, Protsch (1983, 1986) himself recognized that for its major part the Petralona scientific questions were already solved by A. Poulianos. During the '80s, through the epimerization of isoleucine (see Belluomini & Bada 1985), the dating capabilities of the method were increased to ~1 m.y.a. with a standard error of ~30%

Temperature is the major factor that influences the epimerization process. Consequently, before determining the D/L enantiomeric ratio of a sample, it is very important to verify that it has not been exposed to any heating. Otherwise the samples present a high degree of epimerization and provide inaccurate estimations (i.e. of more recent chronology). Other parameters such as pH and humidity have minimal influence on the velocity of the epimerization reaction. However, it is always best to consider their effects.

For the dating of various Petralona layers, the epimerization method was conducted on enamel samples of animal teeth that did not present any signs of heating. The average surrounding temperature out of the cave, of 16,5° C was used for the dating (on the basis of National Meteorological Service, 1987, Thessaloniki airport), which almost coincides with the inner average cave temperature (A. Poulianos, 1980a). The dating calculation (table 1) was calibrated by isoleucine epimerization measured on elephant teeth from Isernia (Italy), site that is dated by palaeomagnetism, as well as by K/Ar at about 0.7 m.y.a. (Coltorti et al., 1982).

The results from Petralona indicated an age between 0.5 and 0.7 m.y.a., with an average of 0,.6 m.y.a. (Belluomini et al., 1990). However, the calibration of the method still needs some improvement since strata 14-16 appeared slightly younger than the 11th. Also, it is probable that the temperature difference calculated between Petralona and Isernia (~ 4° C) might be a little less, thus approaching even further the age of the two sites. Such a hypothesis is strengthened by the similar faunal composition of the two sites (see N. Poulianos, 1989, 1995).

Table 1: Datings of animal fossil teeth from Petralona and Isernia by the isoleucine epimerization; from Belluomini et al. (1990).

Site	Sample	Layer	Enantiomeric analogy	Age (years x 1000)
Petralona	203D120a - Section Beta	11	0,20	530 - 650
Petralona	M1 (Mausoleum)	11	0,22	600 - 700
Petralona	809 - Section Gamma	14-16	0,18	480 - 600
Isernia	Elephas antiquus		0,15	730

Palaeomagnetism

Earth's change of magnetic polarity is one of the dating methods widely applied in archaeometry. The first two related results arrived by mail in Athens almost at the same time: a) From S. PapamarinoXpoulos in 25-5-1977 (specialised next to Prof. K. Greer in Edinburgh), on samples taken by A. Poulianos, S. Papamarinopoulos and the author from Sections Alfa & Gamma. b) From V. Bucha in 15-5-1978 (Geophysical Institute of Prague), on samples taken by the excavators in Section Beta (see A. Poulianos, 1980d).

Negative (i.e. reversed) palaeomagnetic declinations have been observed mainly in the layers 24/25 of Sections Beta & Gamma. Although not well marked, another appears in the 11th layer of Section Beta. Layer 26 presents again normal polarity.

Papamarinopoulos (1978) for the first 16 layers of Section Alfa did not observe any negative sample and that, according to A. Poulianos (1980d), is probably due to the fact that its layers were excavated many years before sampling (i.e. at 1968). Alternatively, "fresh" samples from the undisturbed soil of the inner Mausoleum (layers 11-16) presented an unstable palaeomagnetism (A. Latham, personal communication, August 1989). These samples were taken by himself and A. Poulianos, and the results were similar to those observed by Bucha for the 11th layer of Section Beta. Another attempt to measure the palaeomagnetism of the layers 1-16 from Section Alfa, by Papamarinopoulos et al. (1987), gave again the same results to those of Papamarinopoulos (1978). Unfortunately it is unknown whether the Papamarinopoulos et al. (1987) samples are the same with those published by Papamarinopoulos (1978) or they are new ones, since the Anthropological Association of Greece was illegally expelled from Petralona cave during the years 1983-1997. It is also unclear why Papamarinopoulos et al. (1987) stopped sampling beneath layer 16 or

175

did not eventually publish the relative results in case that proceeded any further (i.e. beneath layer 16).

The above palaeomagnetic "behaviour" may be interpreted as: a) the layers above the 11th belong to the Brunhes epoch and the unstable unit of layers 11-23 is announcing the beginning of the Matuyama epoch, as it was similarly observed in other sites, p.ex. Stranska Skala (see Kukla, 1975); and b) the unstable unit of layers is only that of 11/16-18. It is very difficult to verify the data coming from the eroded layers 19-23 because of the presence of many sands. If the very humid palaeocological period, re-

flected in the layers 19-23 (Elaeochorian), represents a universal phenomenon, similar interpretative difficulties must be expected in other sites too. According however to data from micromammals, layer 24/25 corresponds to an age of 0,73 m.y.a., fitting well to Brunhes/Matuyama boundary. As far as the normal polarity of the layer 26 is concerned, there is yet one more uncertainty: this evidence indicates either the Jaramillo event (0.9 m.y.a., initially supported by Papamarinopoulos, 1977) or a normal polarity within Matuyama, which had escaped observations at other sites.

Table 2: Summarized dating results of Petralona cave sediments & fossils.

LAYER	LEVEL / FUSED	SECTION	AGE (yrs x 1000)	METHOD
1	SUP.	Alfa	0 - 70	U/TH, ESR
1	MED.	Alfa	250	U/TH, TL, ESR
1	INF.	Alfa	>350	U/TH, E.S.R.
4		Alfa	max. 670	TL
10	(+1?)	Alfa	? 200	U/TH, E.S.R.
10		Beta	>350	U/TH, E.S.R.
10		Beta	670	E.S.R.
10		Beta	350 - 670	U/TH (EXTRAP.), E.S.R.
10	(+1)	MEDITER.	>350	U/TH, E.S.R.
10	(+1)	MAUSOL.	300 - 600	U/TH, E.S.R.
11		Beta	530 - 650	AMINO ACID
11		MAUSOL.	600 - 675	AMINO ACID, ESR, PALAEOMAG
14 -16		Beta	600 - 700	AMINO ACID
24 - 25		Beta, Gamma	730	PALAEOMAG., E.S.R
26		Beta	>730 -?	PALAEOMAG.
28 - 34		Beta	?	-

From the above discussion it is possible to conclude that the absolute datings applied to materials from Petralona cave are between 0.35 m.y.a. and 1

m.y.a., mainly focussing on the time interval of 0.6 and 0.7 m.y.a.. The surface stalagmitic travertines are however influenced by the formation of more recent concretions. The Petralona skull also appears to have an age of about 0.7 m.y.a. These absolute datings are in concordance with recent palaeoanthopological (mainly palaeolithic), palaeocological and palaeontological studies.

More future analyses are greatly anticipated. The help of the Greek Ministry of Culture and the International Scientific Community may be of significant importance. As always, the Anthropological Association of Greece remains welcoming to collaborations with institutions and scholars all over the world.

Bibliography

Bada J. L. (1971) - Kinetics of the non biological decomposition and racemization of amino acids in Hem, Symposium chairman; R.F. Gould, Series Ed.), Advances in Chemistry Series, Vol. 106, pp. 309-331. American Chemical Society, Washington, D.C.

Belluomini G.& Bada J.L.(1985) - Isoleucine epimerization ages of the dwarf elephants of Sicily. Geology, 13: 451-452.

Belluomini G., L. Delitala, A.N. Poulianos & N.A.Poulianos (1988) - Epimerization ages of fossil teeth from Petralona Cave. (Northern Greece). Abstracts of the 2nd Panellenic Congress of Anthropology. May 27-29, Athens 1988. Report published under the title: The Man of Petralona an estimated by amino acid racemization dating. Anthropos 12: 59-64. Athens 1990.

Coltorti M., Cremaschi M., Delitala M.C., Esu D., Fornaseri M., McPherron A., Nicoletti M., Van Otterloo R., Peretto C., Sala B., Schmidt V. & J. Sevink (1982) - Reversed magnetic polarity at an early lower Palaeolithic site in Central Italy. Nature, 300: 173-176.

Cook J., C.B. Stringer, A.R. Currant, H.P. Schwarcz & A.G. Wintle (1982) - A review on the Chronology of the European Middle Pleistocene Hominid Record. Yearbook Phys. Anthropology, 25: 19-65

Grün Reiner (1996) - A re-analysis of electron spin resonance dating results associated with the Petralona hominid. Journal of Human Evolution, 30, 227-241.

Hennig G.J., U. Bangert, W.Herr & A. N. Poulianos (1980) - Uranium Series dating and T L Ages of Spelaeothem from Petralona Cave. Anthropos, 7: 174-214. Athens.

Hennig G.J., U. Bangert, W. Herr & A. N. Poulianos (1981a) - Errata

of "Uranium Series dating and TL Ages of Spelaeothem from Petralona Cave. Anthropos, 7: 174-214". Anthropos, 8: 235. Athens.

Hennig G. J., W. Herr, E. Weber & N. I. Xirotiris (1981b) - ESR dating of the fossil hominid cranium from Petralona Cave. Nature, 292: 533-536.

Hennig G. J. & W. Herr & E. Weber & N. I. Xirotiris (1982) - Letter Nature, 299: 281-282.

Ikeya M. (1975) - Electron Spin Resonance. Nature, 255: 68

Ikeya M. (1977) - Electron Spin Resonance dating and Fission Track Detection of Petralona stalagmite. Athens. Anthropos, 4: 152-168.

Ikeya M.(1978a) - Electron Spin Resonance as a Method of Dating. Archaeomety, 20: 147-158.

Ikeya M. (1978b) - Natural radiation at Petralona Cave. Athens. Anthropos 5: 54-59.

Ikeya M. (1980) - ESR dating of Carbonates at Petralona Cave. Athens. Anthropos, 7: 143-151.

Ikeya M. (1982) - Letter. Nature, 299: 280-281.

Ikeya M. (1990a) - E.S.R. Age of Petralona materials. Proceedings of the 2nd Panellenic Congress of Anthropology. May 27-29, Athens 1988. Published in Anthropos 12: 19-28. Athens 1990.

Ikeya M. (1990b) - E.S.R. Age of Petralona cranium and carbonates. Proceedings of the 2nd Panellenic Congress of Anthropology. May 27-29, Athens 1988. Published in Anthropos 12: 29-35. Athens 1990.

Ikeya M. & T. Miki (1981) - ESR Archaeological Dose of Petralona and Choukoutien bones. Athens. Anthropos, 8: 95-106.

Ikeya M. & A.N. Poulianos (1979) - E.S.R. age of the trace of fire at Petralona. Athens. Anthropos, 6: 44-47.

Karakostanoglou I. (1981a) - Archaeologists, dating and their role in Archaeology. Anthropos, 8: 107-120. Athens.

Karakostanoglou I. (1981b) - Allegation and truth. Anthropos, 8: 121-141. Athens.

Kukla G.J. (1975) - Loess Stratigraphy of Central Europe. After the Australopithecines. Mouton Publ.: 99-188.

Kurtén B. & A. Poulianos (1977) - New Stratigraphic and Faunal material from Petralona Cave - with special reference to the Carnivora. Athens. Anthropos, 4: 47-130.

Kurtén B. & A. Poulianos (1981) - Fossil Carnivora of Petralona Cave: Status 1980. Athens. Anthropos, 8: 9-56.

Liritzis Y. (1980) - U/230 - Th/234 dating of Spelaeothems in Petralona. Anthropos, 7: 215-241. Athens.

Liritzis Y. (1982) - Letter. Nature, 299: 280 - 281.

Liritzis Y. & Poulianos A. N.(1980) - A radiation survey of Petralona Cave. Anthropos, 7: 252-259. Athens.

Melentis (1980) - Newspaper "Thessaloniki", 27 & 28 Febr.

Meteorological National Service - Dep. of Climatology and Statistics (years 1961-1986). Airport of Thessaloniki. Greece.

Papamarinopoulos St.(1977) - The first known European? Bulletin, University of Edinburgh, 13 (10): 1-3. April, 27.

Papamarinopoulos St.(1978) - Limnomagnetic studies on Greek sediments. Ph.D. thesis, University of Edinburgh.

Papamarinopoulos S., Readman P., Maniatis Y. & Simopoulos (1987) - Paleomagnetic and mineral magnetic studies of sediments from Petralona Cave, Greece. Archaeometry, 29 (1):50-59.

Papastefanou C., M. Manolopoulou, E. Savvides & S. Charalambous (1986) - Dose rate measurements in Petralona Cave for Archanthropus dating. The proceedings of the 3rd European and 1st Panhellenic Anthropological Congresses. Anthropos, 11: 41-48. Athina.

Poulianos A. N. (1968) - Finds of 500-900.000 years in Petralona cave. Press, Thessaloniki, 18-4 1968, Athens, 19-4-1968.

Poulianos A. N. (1971) - Petralona: A middle Pleistocene Cave in

Greece. Archaeology, 24: 6-11.

Poulianos A. N. (1977) - Stratigraphy and age of the Petralonian Archanthropus. Anthropos, 4: 37-46. Athens.

Poulianos A. N. (1980a) - Lower and Middle Pleistocene climatic fluctuations at Petralona Cave. Anthropos, 7: 42-80. Athens.

Poulianos A. N. (1980b) - The Archanthropus of Petralona is Autochthonous. Anthropos, 7: 7-11. Athens.

Poulianos A. N. (1980c) - The post-cranial skeleton of the Archanthropus europaeus petraloniensis. Anthropos 7:13-33. Athens.

Poulianos A. N.(1980d) - A new fossilised inion-parietal bone in Petralona Cave. Anthropos, 7: 34-39. Athens.

Poulianos A. N. (1981) - Microhistological and macroscopic investigation of post-cranial bones of the Petralonian Archanthropus. Anthropos, 8: 80-83. Athens.

Poulianos A. N. (1982a) - The Cave of the Petralonian Archanthropinae. Athens-Petralona. Library of AAG. pp.80.

Poulianos A. N. (1982b) - Letter. Nature, 299: 280.

Poulianos A. N. (1983) - On the Stratigraphy and Dating of the Petralonian Man. The proceedings of the 3rd European and 1st Panhellenic Anthropological Congresses. Anthropos, 10: 49-52. Athina.

Poulianos N. A. (1989) - Petralona Cave within Lower-Middle Pleistocene sites. Palaeogeography, Palaeoclimatology, Palaeoecology, 73: 287-294.

Poulianos N. A. (1995) - La Grotta e l'Uomo di Petralona. Edited by Professor Brunetto Chiarelli at the Florence Institute of Anthropology.

Protsch R., N. Xirotiris, W. Henke, G. Henning & M. Schultz (1982) - Petralona. Analysis based on the cleaned splachnocranium and neurocranium. 1er Congress Inter. De Paléontologie Humaine, Résumes des Communications, 16-21 Oct., Nice.

Protsch R. (1983) - Two letters to the Anthr. Ass. of Greece. (23-11-1982), (22-8-1983). The proceedings of the 3rd European and 1st Panhellenic Anthropological Congresses. Athens. Anthropos, 10: 7-11.

Protsch R. (1986) - Letter to Anthr. Ass. of Greece. (27-8-1985). The proceedings of the 3rd European and 1st Panhellenic Anthropological Congress. Athens. Anthropos, 11: 12-13.

Schwarcz H.P., Y. Liritzis & A. Dixon (1980) - Absolute dating of travertines from the Petralona Cave, Chalkidiki Peninsula - Greece. Anthropos, 7: 152-173. Athens.

Shackleton N.J. & N.D. Opdyke (1976) - oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific core V28-239 - Late Pliocene to latest Pleistocene. Geol. Soc. Amer. Mem. 45: 449-464.

Shen Guanjun & Yuji Yokoyama (1986) - Th230/U 234 dating of Petralona spelaeothems. Anthropos, 11: 33-40. Athens.

Sickenberg O. (1964) - Die Saugetierfauna der Hohle Petralona bei Thessaloniki (preliminary report). Athen. Institute for Geology and Subsurface Research, IX(1): 3-16.

Sickenberg O. (1971) - Revision der Wirbeltierfauna der Hohle Petralona (Griechenland). Annales Géologiques des Pays Helléniques, 23: 230-264

Wintle A.G. & J.A. Jacobs (1982) - A Critical Review of the Dating Evidence for Petralona Cave. Journal of Archaeological Science, 9: 39-47.

O-43

The Palaeobotany of Caves in the Aegean

F. Megaloudi

Aeegan University, Departement of Mediterranean Studies, Rhodes Greece

Abstract

Caves are of great importance in Palaeobotany because they provide excellent conditions for the preservation of organic remains. In such environments, macroscopic plant remains may be preserved through desiccation, mineralization, or, more commonly, carbonization, depending on the environment of the cave. In most cases, the anaerobic conditions of cave deposits prevent decay and soft plant remains that are rarely preserved in open-air sites, survive well. These remains provide substantial information about past human use of the sites as well as the surrounding environment. The aim of this presentation is to point out the importance of palaeobotanical research in Caves and Rock shelters This purpose will be illustrated through the example of two case studies: the Palaeobotanical research in Sarakinos Cave (Boiotia) and in Leodari Cave in Attica. The methods, the potential and the limits of Palaeobotany in Cave deposits are presented. A review of the data currently known for the macro-botanical remains retrieved from Caves and Rock-shelters throughout the Aegean region will conclude this presentation.

O-44

Biospeleology of Juxtlahuaca Caves: 20 years later

Gabriela Castaño-Meneses, José G. Palacios-Vargas, Elena Torres-Puga & Marcos Mohar-Fresán.

Laboratorio de Ecología y Sistemática de Microartrópodos, Departamento de Ecología y Recursos Naturales, Facultad de Ciencias, UNAM. Ciudad Universitaria, 04510, México, D. F. E-mail: gcm@hp.fciencias.unam.mx

Abstract

The Cave of Juxtlahuaca is one of the most interesting cave systems in Guerrero State, Mexico. Because of the speleological formations, the archeological ruins in this cave have been used as a tourist attraction and they have many visitors each year, and it has been modified to make the access easier for the tourists.

A total of 99 species (including protozoa, arthropods and mammalian) was recorded from this cave during the studies performed during the 80's. It included 40 new records for the cave and some new species for science.

After this period, the biospeloelogical studies were stopped, and to make the cave access easier for the tourist to visit, several works were done including stairs, masonry and the installations of electric wires to illuminate it. These changes have affected the natural conditions within the cave. Actually the electric installations are not in use any longer, but the wires have been there for the last 15 years.

Because of the bioespeleological importance of the cave and the changes it has had in the last 20 years, we decided to carry out new expeditions and to study the fauna and compare it with the information we have from the previous publications. The result is that this time we recorded 83 taxa from the cave, from which at least 55 are new records for the cave. These include one Nematomorpha (Gordioidea), one species of Schizomida (probably a new genus), one Amblypygi, five of Araneae, two Psocoptera, two Homoptera and one Neuroptera.

When we compare the current results with previous work, we can observe a reduction of the springtails and mites species, the total absence of ticks (Antricola sp.). It is to notice that the number of species of Chiroptera which visit this cave has also been reduced.

Introduction

Subterranean environments, such as caves, caverns and other subterranean formations, have been closely related to the humankind history. This is why they have been of interest for different research projects in different areas such as geology, geochemistry, archaeology, ethnology and biology (Camacho, 1992; Culver et al. 2003; Hapka and Rouvinez 1997; Jennings 1985; Steel 1997).

Due to the peculiar characteristics of these environments, the study of cave fauna is fascinating, and different kinds of studies can be done, such as morphology, physiology and biological adaptations of the animals, which enable them to grow and develop in these places. Despite the development of the speleology at recent times, some authorities estimate that about 90% of the caves have never been used for biological studies. Even more, they claim that there should be about 90% of caves to be discovered as they show no visible entrance or communication to the exterior (Krajick, 2001).

Many caves, in different regions of the world, have an important tourist development and they attract thousands of visitors. More than 1,200 subterranean formations have been recorded in Mexico; some of them represent the deepest cave records in the world (Lazcano, 1985; Arias 2001). Others are frequently visited by tourists, anthropologist, archaeologist, speleologist and biospeleologist, because of their natural formations, humans' remains, ceremonial traditions, and their fauna. Evidences of man occupation in prehispanical times have been found in many caves in Mexico, where rituals were performed and caves were considered as magic places, and there are many human vestiges such as mural paintings, ceramic, buries, etc. (Stone, 1997; Künne & Strecker, 2003).

The Grutas de Juxtlahuaca, in Guerrero state, are a very good example of this kind of caves, they have many beautiful formations, mural paintings of great archeological importance and a very interesting fauna. Therefore, it is one of the most visited caves by tourists, biologist and geologist, and they are still preserved.

The presence of cave paintings, which are from about 900 to 300 years BC, confirm the Olmecs presence in this cave and probably are the most ancient in the New World (Roy, 1974). The first expeditions to this cave were carried out in 1958 by Andrés Ortega. Because of the speleological formations, the archeological ruins in this cave have been used as a tourist attraction and they have many visitors each year, therefore, it has been modified to make the access easier for the tourists.

During the 80's, Hoffmann et al. have begun the biospeleological work in these caves. These contributions were taken for the publication of the "Manual de Bioespeleología", which was issued in 1986, and includes information about several caves from Morelos and Guerrero states, including Juxtlahuaca. A total of 99 species (including protozoa, arthropods and mammalian) was recorded from this cave (Palacios-Vargas et al. 1985). It

included 40 new records for the cave and some new species for science.

After this period, the biospeleological studies were stopped, and to make the cave access easier for the tourist to visit, several works were done including stairs, masonry and the installations of electric wires to illuminate it. These changes have affected the natural conditions within the cave. Actually the electric installation is not in use any longer, but the wires have been there for the last 15 years.

Most recent studies about this cave fauna were done in 2000, but including only the microarthropods living on guano (García, 2000). This information was part of the thesis work by Galicia (2004) which was done to study the bats, in order to evaluate the environment alteration.

Because of the bioespeleological importance of the cave and the changes it has had in the last 20 years, we decided to carry out new expeditions and to study the fauna and compare it with the information we have from the previous publications.

Study area

The Cave of Juxtlahuaca (more than 5,000 m long) is one of the most interesting cave systems in Guerrero State. It is located 59 km SE from Chilpancingo, Guerrero, and 5 km to the NE the village Colotlipa, Municipality of Quechultenango (17°19′N, 99°09′W) at 960 m asl. The main entrance of the cave is 4 - 5 m high, and 6 - 8 m width. About 160 m from the entrance there is a bifurcation that is connected to the Room of the Hell. This room begins with a high of 3 - 4 m and increases toward the end, up to more than 25 m, the average width is about 15 m. In this area there are big bat colonies, whose presence and guano fermentations, and owing to the peculiar topographical conditions of this room, makes the temperature as high as 34°C.

After 610 m from the entrance the Salón del Toro is located (Room of the Bull), with a very wide ceiling and many spelothems. It has a branch to the South of about 570 m long which ends in a second entrance with a depth of 3 m and 2 m diameter. After the main tunnel there are several rooms, such as the Salón de Baile (Dancing Room) and the Batalla del 5 de Mayo (May 5th Battle); to a distance of 1,210 m from the entrance is the Fuente Encantada (Enchanted Fountain) with a 80 cm deep, a length of 40 - 50 m and a maximum width of 20 m. At the end of this pond, and about 1,500 m from the entrance, there is the Jardín de las Rosas de Cristal (Garden of the Crystal Roses) where there are many beautiful excentric formations of Aragonite. This is the end of the tourist area, after this section there are several cave branches with difficult access (Hoffmann, et al., 1986).

Materials and methods

During February and July of 2003, May and July of 2004, several expeditions (during different seasons) to the cave were carried out. The purpose of these expeditions was to take samples of soil and guano. Manual collecting and pitfall traps were done in order to make a new faunistic list and to see the changes.

Collecting was done at the entrance, in the twilight area; at the Hell's room, 200 m from the entrance, where most of the samples were taken. This is the place where most bats are concentrated and a lot of guano is deposited. Other samples were taken in the area known as Batalla del 5 de Mayo, about 350m from the entrance and in the Toro Room (630 m from the entrance) which was dynamited several decades ago, in order to open an easy route to the bottom of the cave. Guano and soil samples were processed by the Berlese funnels. Specimens were isolated to morphospecies under the dissection microscope for further determinations. Slides with Hoyer's solution were done for mites and springtails. The identifications of species were done with the help of keys and confirmations from specialists.

Results

After the study of the specimens from the samples, we have found a total of 83 taxa in the cave. (Table 1). Previous work of Palacios-Vargas et al. (1985) recorded 93 species of terrestrial animals including 11 species of ectoparasite mites from the bats.

Among the arthropods, the best represented group was insect, followed by the mites (Fig. 1A), an interesting difference of what was found in 1985 when the dominant group was the mites followed by the Collembola. (Fig. 1B). In general, the number of species recorded for each group was less in the present study than in previous studies. That was true but for the insects, of which we found 22 more species from what there was recorded before (Fig. 2).

Out of the total, 22 species were recorded 20 years ago (Palacios-Vargas et al. 1985), and five species were recorded in further contributions (Marino, 1989; García, 2000).
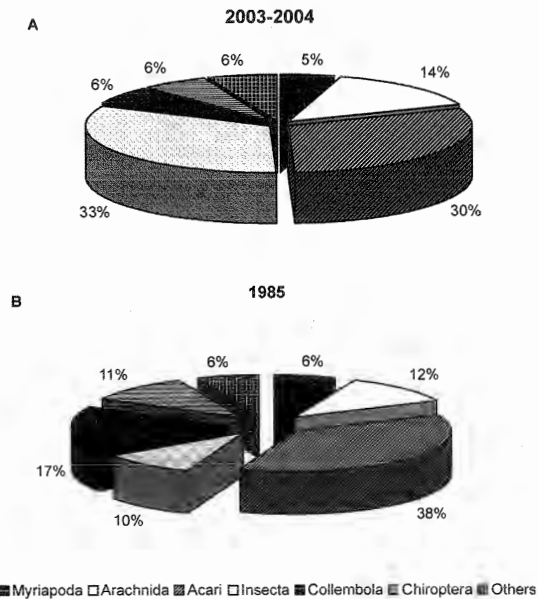
Fig. 1. Percentage of the species found in A) 2003-2004 and B) 1985

It is very important to mention that we have observed almost a total change in the mites and springtails populations of the species found. There are less species now and there is a low similarity of the actual species and the previously recorded. For the rest of the arthropods there was a higher similarity of the taxa found 20 years ago and those that actually are in the cave now.

The total number of species recorded throughout the speleological studies in these caves, including those found in this study is 154, among which 56 are new records. A total of 71 species was no longer found, 22 have been recorded since 1985 and also now, and five species were recorded in 1989 and 2000, they were found in the present study again.

Discussion

It has to been taken in consideration that a high amount of species has been lost in the last 20 years, specially if we consider that most of the species not found in the present study are mites and springtails (31 and 14 species respectively). There is an important difference in the study of 1985, in which bat's ectoparasites were checked; this time only the soil fauna was checked. The total
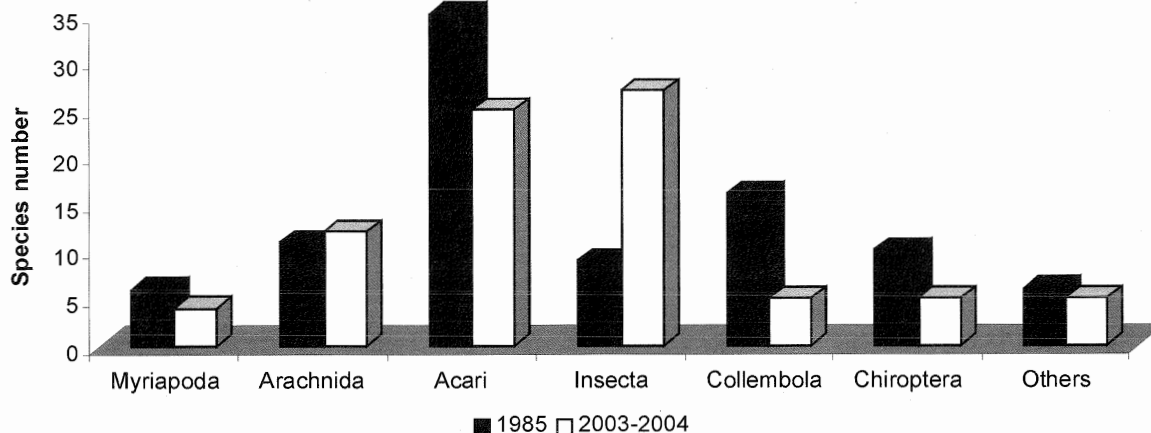
Fig. 2. Species number at this study and relation with the previous records from Juxtlahuaca Cave Guerrero.

number of ectoparasites was 11, however, there were 20 free living species, which were not found again.

This indicates that there was a high rate of change of the species associated to the bat's guano, maybe because of the modifications of the environment of the cave. It is important also to mention that the number of bats recorded in the cave is lower than before, there are only 5 from the 10 species recorded 20 years ago. Nevertheless, our expeditions were done by the main entrance, but there is another entrance no for tourism where other species were collected on 1985 (Galicia, 2004).

Light, CO_2 and relative humidity are factors which affect directly the animals living inside the cave. Probably the work done in 1985 and 1986 for the installation of electric light and the increased number of visitors, have had a direct effect on the guano communities, mainly on the microarthropods from Hell's Room. Alterations of the environmental conditions, mainly because of the light and the tourists, have been demonstrated in several tourist caves, where the tourist action produce a proliferation of the algae and other elements which affect the spelothems. So the conservation of the paintings and the archaeological evidences, and rescue the optimal conditions for the development of troglobites and troglophiles, is very important in order to preserve the biodiversity (Baker & Genty, 1988; Hoyos et al., 1998; Pulido-Bosch et al., 1997).

The conditions inside the cave have been restored. However, there are still some remains of the electric installations since they were never totally removed, even the electric light is not used anymore. The Hell Room, has similar conditions of temperature and humidity (T 26-30°C, HR 60-100%), as it was 20 years ago (T 27-34°, HR up to 97%; Palacios-Vargas et al., 1985), but it has to be noted that the bat species have changed, so there have been some modifications of the guano and the communities that can live in this biotope.

There is a remarkable amount of new records of the insects that can be found now, comparing with the nine species that were previously recorded. Among the new records there are one Staphylinid beetle, one homopteran and two species of Psocoptera (never cited before from caves), families of Hymenoptera as Ichneumonidae (1 species), and Formicidae (6 species), and 5 species of Dipterans. There are other new records in other groups, such as Amblypygi, Symphyla, several Araneae, some mites, 3 isopodan and one Nematomorpha: Gordioidea, among others.

These results show that Juxtlahuaca is one of the best known caves from the view of biospeleology and the study of the modifications that have been experienced by the cave communities give important information to understand the population's dynamics and the energy flows in the caves and the changes in the species, which have undergone. This information can help to plan the adequate use of the cave for a better preservation.

Bibliographic references

Arias, R. 2001. Sótanos de México. Abismos de luz y sombra: México, Secretaría del Medio Ambiente y Recursos Naturales, 139 pp.

Baker, A. & D. Genty. 1998 Environmental pressures on conserving cave speleothems: effects of changing surface land use and increased cave tourism. Journal of Environmental Management 53: 165-175.

Camacho, A. I. (ed.). 1992. The natural history of biospeleology. Museo Nacional de Ciencias Naturales, Madrid, 680 pp.

Culver, D.C., M.C. Christman, W.R. Elliot, H.H. Hobs III & J.R. Reddell. 2003. The North American obligate fauna: Regional patterns. Biodiversity and Conservation, 12:441-468.

Galicia Castillo, R. C. 2004. Diversidad y abundancia de murciélagos en tres cuevas de Guerrero con diferentes niveles de actividad humana. Professional Thesis, Facultad de Ciencias, UNAM. 98 pp.

García, A. 2000. Estudio preliminar de fauna guanobia de tres cuevas de Guerrero, México. In: Stanford, S. G., A. Morales, J. R. Padilla, M. P. Ibarra (eds.) Memorias XXXV Congreso Nacional de Entomología Acapulco, Guerrero, México, pp. 719-724.

Hapka, R. & F. Rouvinez. 1997. Las Ruinas Cave, Cerro Rabón, Oaxaca, Mexico: A mazatec postclassic funerary and ritual site. Journal of Cave and Karst Studies. 59, 22-25.

Hoffmann, A., J.G. Palacios-Vargas & J.B. Morales-Malacara. 1986. Manual de Bioespeleología (Con nuevas aportaciones de Morelos y Guerrero, México). Dirección General de Publicaciones, UNAM, México. 274 pp.

Hoyos, M., V. Soler, J.C. Cañaveras, S. Sánchez-Moral & E. Sanz-Rubio. 1998. Microclimatic characterization of a karstic cave: human impact on microenvironmental parameters of a prehistoric rock art cave (Candamo Cave, Northern Spain). Environmental Geology 33: 231-242.

Jennings, K. 1985. Karst geomorphology. Basil Blackwell Inc.

Krajick, K. 2001. Cave biologists unearth buried treasure. Science, 293: 2378-2381.

Künne, M. & J. Strecker (eds.). 2003. Arte Ruprestre de México Oriental y Centroamérica. Indian Beihfte, 16. Ibero-Amerikanisches Institut Gebr. Mann Verlag, Berlin, Alemania. 357 pp.

Lazcano, C. 1985. México paraíso de la espeleología. Gaceta UNAM 41, 21.

Marino, E. 1989. Primer registro cavernícola de Periplaneta australasiae (Fab.) para México (Insecta: Dyctioptera). Anales del Instituto de Biología, Universidad Nacional Autónoma de México, Serie Zoología, 59: 289-290.

Palacios-Vargas, J. G., I. Vázquez & J. M. Malacara. 1985. Aspectos faunísticos y ecológicos de las grutas de Juxtlahuaca, Gro., México. Mém. Biospéologie, 12:135-142.

Pulido-Bosch, A., W. Martín-Rosales, M. López-Chicano, C.M. Rodríguez-Navarro & A. Vallejos. 1997. Human impact in a tourist karstic cave (Aracena, Spain). Environmental Geology 31:142-149.

Roy, S. 1974. Las Grutas de Juxtlahuaca. Association for Mexican Cave Studies News, 5: 39-42.

Stone, A. 1997. Regional variations in maya cave art. J. Cave & Karst Stud. 59: 33-42.

Steel, J. F. 1997. Cave archaeology in North America and Mesoamerica. J. Cave Karst Stud. 59, 4.

Table 1. Fauna recorded in the Juxtlahuaca Cave during 2004-2005.

NEMATOMORPHA
    GORDIOIDEA
MOLUSCA
    GASTEROPODA
        Subulinidae
            Subulina porrecta
ARTHROPODA
    CHELICERATA
    ARACHNIDA
        ARANEAE
            Clubionidae
            Linyphidae
            Nesticidae
                Nesticus sp.
            Sicariidae
                Loxosceles mixteca
            Pholcidae
                Physocyclus bicornis
            Coriinidae
                Corinna sp.
            Dictynidae
                Dictyna sp.
             Gnaphosidae

        PSEUDOESCORPIONIDA
            Tridenchthoniidae
                Tridenchthonius juxtlahuaca
        AMBLYPYGI
            Phrynidae
                Paraphrynus mexicanus
                Paraphrynus azteca
        SCHIZOMIDA
            Hubbardinae (undeterminated genus)
        ACARIDA
            MESOSTIGMATA
            Ameroseiidae
            Phytoseiidae
                ca. Iphiseius sp.
                undeterminated genus
            Machrochelidae
                Machrocheles sp.
                Glyptholaspis sp.
            Laelapidae
                Geolaelaps sp.
            Polyaspididae

181

Dipolyaspis sp.

Table 1. Cont.

Uropodidae

Trichouropoda sp

METASTIGMATA

Argasidae

Ornithodoros sp.

ASTIGMATA

Guanolichidae

Neoguanolichus sp.

Glycyphagidae

ca. Ctenoglyphus

Undeterminated family

PROSTIGMATA

Cunaxidae

Cunaxoides nicobarensis

Palaeus ca. minutus

Palaeus ca. whartoni

CRYPTOSTIGMATA

Pthiracaridae

Oppiidae

Graptoppia sp.

Ramusella sp.

Malaconothridae

Malaconothrus sp.

Sphaerochthoniidae

Sphaerochthonius sp.

Mesoplophoridae

Mesoplophora sp.

Haplozetidae

Rostrozetes sp.

Scheloribatidae

Scheloribates sp.

Arceremaeidae

Tecteremaeus sp.

Galumnidae

MANDIBULATA

CRUSTACEA

MALACOSTRACA

ISOPODA

Armadillidae

Cubaris sp.

Squamiferidae

Trichorhina sp.

Table 1. Cont.

MYRIAPODA

    CHILOPODA

        SCUTIGEROMORPHA

            Scutigeridae

                Scutigera linceri

    DIPLOPODA

        Pyrgodesmidae

            Myrmecodesmus colotlipa

    Spirostreptida

        Spirostreptidae

            Orthoporus guerreronus

    SYMPHYLA

        Scolopendrellidae

            Symphyllela sp.

INSECTA

    DIPLURA

        Campodeidae

            Juxtlacampa juxtlahuacensis

    COLLEMBOLA

        Entomobryidae

            Seira bipunctata

            Pseudosinella sp.

            Lepidocyrtus sp.

        Paronellidae

            Troglolaphysa sp.

    THYSANURA

        Nicoletiidae

            Anelpistina boneti

    BLATTARIA

        Blaberidae

            Blaberus craniifer

        Blattidae

            Periplaneta australiasae

    ORTHOPTERA

    DERMAPTERA

    PSOCOPTERA

        Psoquillidae

            Psoquilla marginepunctata

        Lachesillidae

            Lachesilla picticeps

Table 1. Cont.

COLEOPTERA
    Carabidae
    Elateridae
    Staphylinidae
        Thoracophorus brevicristatus
    Tenebrionidae
HOMOPTERA
    Cicadelloidea
        Cicadellidae
NEUROPTERA
HYMENOPTERA
    Ichneumonidae

    Formicidae
        Ponerinae
            Cryptopone sp.
        Myrmicinae
            Aphenogaster rudis picea
            Pyramica zeteki
            Cyphomyrmex sp.
            Solenopsis geminata
        Formicinae
            Camponotus sp.
DIPTERA
    Phoridae (two undeterminated genus)
    Trichoceridae
    Cecidomyiidae
    Streblidae
    Psychodidae
CHORDATA
    MAMMALIA
        CHIROPTERA
    Mormoopidae
        Mormoops megalophylla
        Pteronotus parnelli
    Phyllostomatidae
        Glossophaga soricina
        Leptonycteris curasoae
    Natalidae
        Natalus stramineus

O-45

Why Are Cave Animals Colorless? Tyrosinase-Positive Albinism in Cavefish

William R. Jeffery

Department of Biology, University of Maryland, College Park, MD. 20742 U. S. A.

Abstract

Many cave-adapted animals appear to be colorless due to loss of body pigmentation. The developmental mechanisms involved in this evolutionary change are unknown. We have studied pigment cell regression in the teleost Astyanax mexicanus, a single species consisting of a pigmented epigean form (surface fish) and a de-pigmented hypogean form (cavefish). During vertebrate development pigment cells differentiate from migratory neural crest cells, which are derived from surface epithelium at the border of the prospective epidermis and neural plate. As the neural plate becomes the neural tube, neural crest cells leave the epithelium, migrate along specific pathways through the interior of the embryo, and eventually differentiate into many different adult derivatives, including the three types of teleost pigment cells: melanophores (black cells), xanthophores (yellow or orange cells), and iridophores (iridescent cells). All three pigment cell types are present in surface fish. In contrast, cavefish have xanthophores and iridophores but lack melanophores. The deficiency in melanophores could be caused by (1) the development of fewer neural crest cells, (2) the failure of neural crest cells to migrate correctly, (3) the failure of neural crest cells to become melanoblasts, the immediate precursors of melanophores, (4) the unscheduled death of melanophores or their precursors, or (5) the failure of melanoblasts to differentiate into melanophores. We have used several different experimental approaches to test these hypotheses. First, DiI (1,1'-dioctadecyl-3,3,3',3'-tetramethylindocarbocyanine tetramethylindocarbocyanine perchlorate), a lipophilic cell surface marker, was injected into the region where neural crest cells originate and labeled cells were followed during surface fish and cavefish embryonic development. The results showed that cavefish embryos produce as many neural crest cells as surface fish embryos and that these cells migrate properly, discounting hypotheses (1) and (2). Second, analysis by TUNEL, a cell death indicator, showed that most cavefish melanophore precursors survive through development, discounting hypothesis (4). Third, the presence of melanoblasts in cavefish was determined by detection of cells expressing tyrosinase, the enzyme that converts L-DOPA to melanin. The results showed the presence of large numbers of tyrosinase-positive melanoblasts in cavefish embryos and adults. Thus, cavefish neural crest cells are able to develop into melanoblasts, which does not support hypothesis (3). Finally, we tested the ability of cavefish melanoblasts to convert L-tyrosine, the precursor of L-DOPA, into L-DOPA and melanin, a process that normally occurs during their differentiation into melanophores. The results showed that cavefish melanoblasts are unable to convert L-tyrosine to L-DOPA, indicating a deficiency in L-tyrosine uptake or utilization. Therefore, we conclude that cavefish lose body pigmentation because their melanoblasts fail to differentiate into melanophores (hypothesis 5). Cavefish melanoblasts could be diverted into other neural crest-derived cell types, which may confer an adaptive advantage in the cave environment.

Introduction

The amazing phenotypes of cave-adapted animals, including the regression of eyes and pigmentation, have fascinated biologists since the time of Darwin [1]. We study the evolutionary regression of eyes and pigment cells in the teleost Astyanax mexicanus, one of the few cave-adapted vertebrates that exhibit both surface-dwelling (epigean) and conspecific cave-dwelling (hypogean) forms [2]. The epigean form of Astyanax (surface fish) has large eyes and pigmentation, whereas the hypogean form (cavefish) has lost or substantially reduced its eyes and pigmentation (Fig-

ure 1). Actually, 29 different cavefish populations have been identified in the Sierra de El Abra region of northeastern Mexico [2], and there is evidence that some of these populations may have evolved cave specific phenotypes independently [3]. Astyanax surface fish and cavefish diverged from a common ancestor about 10,000 to 100,000 years ago when the progenitors of the hypogean form were trapped in limestone caves [2]. The advantage of the Astyanax system is that the epigean and hypogean forms can be cultivated in the laboratory, where they spawn frequently and are amenable to many types of genetic, developmental, and molecular experiments [4].

Although we are beginning to understand the developmental and evolutionary basis for eye degeneration in cavefish [5-7], much less is known about how and why body pigmentation has disappeared. There are three types of pigment cells in teleosts: iridescent iridophores, yellow or orange xanthophores, and black melanophores. Cavefish have retained iridophores and xanthrophores but melanophores are lacking or present in greatly reduced numbers. Different Asytanax cavefish populations have evolved various degrees of melanophore loss: some populations (e. g. cavefish from the Pachón Cave) contain completely depigmented fishes, whereas others (e. g. cavefish from the Chica, Los Sabinos, Curva, and Tinaja Caves) contain fishes with reduced numbers of melanophores. In contrast to many evolutionary changes in development, which are controlled by multiple genes, a recessive mutation in a single gene is responsible for albinism in Pachón cavefish [8].
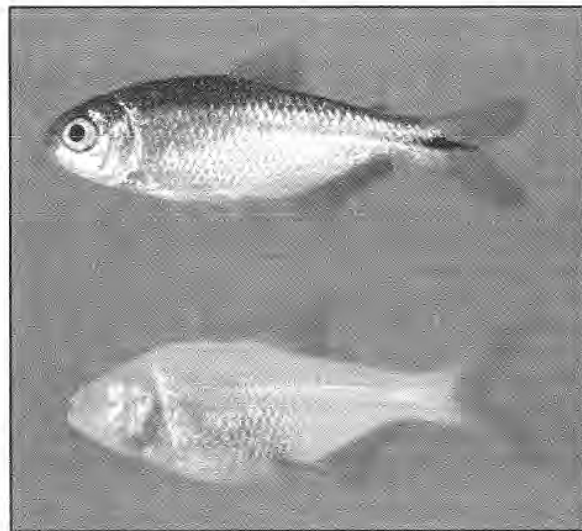
Figure 1. Top: Eyed and pigmented Astyanax surface fish. Bottom: Eyeless and colorless Astyanax cavefish.

All pigment cells arise from the neural crest during vertebrate embryogenesis [9]. Neural crest cells are originally derived from surface epithelium at the border of the prospective epidermis and neural plate. As the neural plate rolls into the neural tube and the latter begins to differentiate into the central nervous system, neural crest cells leave the epithelium and migrate along specific pathways through the interior of the embryo, eventually differentiating into many different adult derivatives, including sensory and sympathetic ganglia, the visceral nervous system, glia, cranial cartilage and bone, and parts of the eye, ear, teeth, and endocrine organs. Obviously, the regression of cavefish melanophores cannot

be attributed to the complete loss of neural crest cells because their absence would be lethal. Instead, the loss or reduction in pigmentation could be caused by the absence of a subset of cavefish neural crest cells devoted to melanophore differentiation, by the failure of neural crest cells to migrate correctly into the epidermis, or by the inability of neural crest cells to complete their differentiation into melanophores. In addition, as exemplified by cavefish embryonic lens cells [5], it is possible that melanophores or their progenitor cells are formed in cavefish embryos but subsequently die, resulting in a colorless adult.

Here we describe the results of experiments that address the mechanism of melanophore loss in Astyanax cavefish embryos. We show that cavefish contain abundant neural crest cells, which migrate properly but do not completely differentiate into functional melanophores because they are unable to convert L-tyrosine to L-DOPA, the precursor of black melanin pigment. Thus, Astyanax cavefish exhibit the same type of albinism that accounts for most human albinisms.

Results

Migratory Neural Crest Cells in Cavefish

To determine whether Pachón cavefish have migratory neural crest cells, we used cell tracing, immunological, and tissue culture methods [10]. First, the lipophilic cell surface marker DiI (1,1'-dioctadecyl-3,3,3',3'-tetramethylindocarbocyanine tetramethylindocarbocyanine perchlorate) was injected into the neural tube, the region where neural crest cells originate, and labeled cells were followed during surface fish and Pachón cavefish embryonic development. We found that cavefish embryos produce as many DiI-positive neural crest cells as surface fish embryos and that these cells migrate properly into the epidermis, where they would normally form melanophores. Second, cavefish embryos were stained with the monoclonal antibody HNK-1, which detects a cell surface lipoprotein that is restricted to migrating neural crest cells in vertebrate embryos [9]. We observed about the same number of HNK-1 positive cells in surface fish and cavefish embryos. Third, the neural tube was dissected from Pachón cavefish embryos and cultured in vitro. We saw cells migrating away from neural tubes in culture that resemble neural crest-derived pigment cells in their morphological and biochemical properties (see below). The results indicate that cavefish embryos produce migratory neural crest cells in similar numbers to their surface fish counterparts.

Cavefish Neural Crest Cells Do Not Show Massive Death

To determine whether the absence of melanophores in cavefish can be attributed to programmed cell death (apoptosis), we assayed cavefish embryos for apoptosis by TUNEL, which detects fragmented nuclear DNA molecules typical of apoptotic cells [5]. As described previously [5], we saw apoptotic cells specifically in the lens and sporadic episodes of cell death throughout the cavefish embryo. However, we were unable to observe more than a few dying neural crest cells in cavefish embryos, which was the same level of programmed cell death as observed in surface fish embryos. These results suggest that melanophores or their progenitor cells do not show massive apoptosis during cavefish embryogenesis.

Tyrosinase-Positive Melanoblasts in Cavefish

Melanophore differentiation involves the initial formation of colorless melanoblasts, which subsequently synthesize black melanin pigment and become functional melanophores. Melanin pigment is synthesized in the melanosome, a membrane bound organelle that can move from place to place in the cytoplasm and is responsible for physiological changes in the intensity of body coloration. The biochemical steps involved in melanin synthesis are well known. First, the essential amino acid L-tyrosine is transported from the cytoplasm into the melanosome, where it is convert-

ed to L-DOPA by the multifunctional enzyme tyrosinase. Next, L-DOPA is converted into melanin within the melanosome by a series of enzymatic reactions, the first of which is also catalyzed by tyrosinase. Most of the subsequent reactions in the pathway are spontaneous.

Oculocutaneous albinism 1 (OCA1), one type of human albinism, is caused by mutations in the tyrosinase gene [11]. Therefore, we asked whether cavefish contain functional tyrosinase. Adding exogenous L-DOPA to fixed specimens and measuring the deposition of black melanin pigment granules was used to assay tyrosinase activity. The results showed that Pachón, Chica, Los Sabinos, Tinaja, and Curva cavefish exhibit active tyrosinase in cells resembling the precursors of melanoblasts in their morphology and location within the embryo (Figure 2). Tyrosinase positive melanoblasts were also observed in adult cavefish. These results indicate that the inability to synthesize melanin is not caused by an inactive or non-functional tyrosinase but must be due to a block in the melanogenic pathway upstream of the tyrosinase dependent steps.
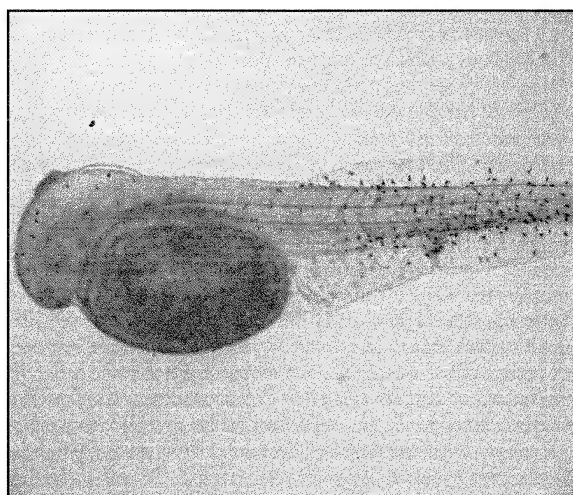
Figure 2. A 30 hr old Pachón cavefish embryo assayed for tyrosinase activity by adding exogenous L-DOPA to form black melanin in tyrosinase-positive cells.

Cavefish Are Unable to Convert L-tyrosine into L-DOPA

The step in melanin synthesis immediately before the L-DOPA dependent reactions is the conversion of L-tyrosine to L-DOPA, which is also catalyzed by tyrosinase. Cavefish must have L-tyrosine itself because it is required for protein synthesis. However, the ability of L-tyrosine to be converted to L-DOPA could be affected in cavefish. We investigated this possibility by providing exogenous L-tyrosine to fixed specimens and assaying for melanin deposition. If cavefish were able to convert L-tyrosine to L-DOPA we would expect to see black pigment deposition in the melanosomes of the same cells that have active tyrosinase. However, even after incubation with an excess of L-tyrosine, melanin deposition could not be detected in any cavefish population we have studied. The results show that cavefish melanoblasts cannot convert L-tyrosine to melanin, although they contain active tyrosinase, suggesting that melanogenesis is blocked at the step in which cytoplasmic L-tyrosine substrate becomes accessible to the enzyme within the melanosome.

Tyrosinase-positive Melanoblasts Are Derived From the Cavefish Neural Crest

Are the tyrosinase-positive cells we have discovered derived from the cavefish neural crest? We addressed this question in two different ways [10]. First, we injected the neural tube of Pachón cavefish embryos with DiI, allowed the DiI labeled cells to migrate into the peripheral regions

of the embryo, and then fixed the injected embryos and assayed them for tyrosinase activity. We observed a subset of the DiI labeled cells that also showed tyrosinase activity. Second, migratory cells that originated from isolated cavefish neural tubes in culture were assayed for tyrosinase activity. We discovered that these cells are tyrosinase positive. The results support the conclusion that tyrosinase-positive melanoblasts are derived from the cavefish neural crest.

Discussion

We conclude that cavefish neural crest cells migrate properly into the epidermis but the melanoblasts they produce cannot convert L-tyrosine to L-DOPA by active tyrosinase and thus do not completely differentiate into melanophores. The reason that L-DOPA cannot be produced from L-tyrosine by active tyrosinase is unknown, although it is likely to be related to a deficiency in transport of the amino acid substrate into the melanosome. Whatever the reason for this deficiency, it has evolved in all of the cavefish populations we have examined, including those that have been derived independently from a surface fish ancestor [3], suggesting extreme biochemical convergence in the evolution of albinism among Astyanax cavefish.

In lacking the ability to convert L-tyrosine to L-DOPA, albinitic cavefish populations resemble the most common type of albinism in humans: oculocutaneous albinism type II (OCA2), a form of tyrosinase-positive albinism [12]. OCA2 tyrosinase-positive albinism is caused by mutations in the oca2 gene, the human homologue of the mouse pink-eyed dilution (p) gene, which encodes a 100 kDa integral membrane protein of the melanosome [13]. Although its precise function is unclear, the OCA2/P protein has been proposed either to facilitate L-tyrosine transport into the melanosome or to generate a proton flux regulating melanosome pH, which is important in melanin synthesis.

As mentioned earlier, tyrosinase-positive albinism is controlled by a recessive mutation in a single cavefish gene [8]. Recently, QTL analysis has indicated that mutations in the oca2 gene are also responsible for tyrosinase-positive albinism in several different Astyanax cavefish populations [14]. Thus, these studies have uncovered molecular convergence between a cavefish trait induced by the dark cave environment and a human syndrome: OCA2 albinism. Cavefish eye degeneration is caused by increased bilateral separation of the eye primordia mediated by Hedgehog signals emanating from the anterior embryonic midline [7]. Interestingly, widely set eyes, similar to the cavefish embryonic eye phenotype, characterize another human syndrome, hypertelorism. The implication is that mutations leading to these phenotypes occur frequently in animal populations, including cavefish and humans. Defects in pigment and eye development that result from these mutations are effectively neutral in the dark cave environment, and thus can be passed from generation to generation without dire consequences.

Although we now have increased insight into the genetic and biochemical basis for cavefish albinism, several important questions remain to be answered that should be a focus for further research on the loss of pigmentation in cave animals. First, do all cave animals show OCA2 tyrosinase-positive albinism or as in humans have different types of albinism, including those equivalent to human OCA1 tyrosinase-negative albinism and OCA3 and OCA4 tyrosinase-positive albinism [12], evolved in the cave environment? Second, assuming that OCA2 tyrosinase-positive albinism is widespread in cave animals, why has this particular step in the melanogenic pathway been selected for modification during repeated episodes of regressive evolution? One possible explanation is that the oca2 gene is particularly sensitive to mutation [15], perhaps because of its large size (345 kb in humans), chromosomal location, or exclusive function in melanogeneis. Another intriguing possibility is that oca2 may be a pleiotropic gene with multiple effects in development. Accordingly, OCA2/P

could function at a pivotal fork in the melanophore development pathway in which a loss of function mutation downregulating pigmentation may reciprocally enhance an unknown adaptive trait(s), which is beneficial to survival in the cave environment.

References

1. Culver, D. (1982). Cave Life. Evolution and Ecology. Harvard Press, Cambridge.

2. Mitchell, R. W., Russell, W. H., and W. R. Elliot (1977). Mexican eyeless characin fishes, genus Astyanax: Environment, distribution, and evolution. Spec. Publ. Mus. Texas Tech Univ. 12: 1-89.

3. Dowling, T. E., Martasian, D. P., and W. R. Jeffery. (2002). Evidence for multiple genetic lineages with similar eyeless phenotypes in the blind cavefish, Astyanax mexicanus. Mol. Biol. Evol. 19: 446-455.

4. Jeffery, W. R. (2001). Cavefish as a model system in evolutionary developmental biology. Dev. Biol. 231: 1-12.

5. Yamamoto, Y., and W. R. Jeffery (2000). Central role for the lens in cave fish eye degeneration. Science 289: 631-633.

6. Yamamoto, Y, Stock, D. W., and W. R. Jeffery (2004). Hedgehog signalling controls eye degeneration in blind cavefish. Nature 431: 844-847.

7. Jeffery, W. R. (2005). Adaptive evolution of eye degeneration in the Mexican blind cavefish. J. Hered. 96: 185-196.

8. Sadoglu, P. (1957). Mendelian inheritance in hybrids between the Mexican blind fish and their overground ancestors. Verh. Dtsch. Zool. Ges. 1957: 432-439.

9. Hall, B. K. (1999). The Neural Crest in Development and Evolution. Springer, New York.

10. McCauley, D. W., Hixon, E., and W. R. Jeffery. (2004). Evolution of pigment cell regression in the cavefish Astyanax: A late step in melanogenesis. Evol. Dev. 6: 209-218.

11. King, R. A., Pietsch, J., Fryer, J. P., Savage, S., Brott, M. J., Russell-Eggitt, I., Summers, C. G., and W. S. Oetting (2003). Tyrosinase gene mutations in oculocutaneous albinism 1 (OCA1): definition of the phenotype. Hum. Genet. 113: 502-513.

12. Oetting, W. S., and R. A. King (1999). Molecular basis of albinism: mutations and polymorphisms of pigmentation genes associated with albinism. Hum. Mutat. 13, 99-115.

13. Rinchik, E. M., Bultman, S. J., Horsthemke, B., Lee, S. T., Strunk, K. M., Spritz, Avidano, K. M., Jong, M. T., and R. D. Nicholls (1993). Nature 361: 72-76.

14. Protas, M., E., Hersey, C., Kochanek, D., Zhou, Y., Wilkens, H., Jeffery, W. R., Zon, L. T., Borowsky, R., and C. J. Tabin (2005). Genetic analysis of cavefish reveals molecular convergence in the evolution of albinism. (in submission).

15. Oetting, W. S., Garrett, S. S., Brott, M., and R. A. King (2005). P gene mutations associated with oculocutaneous albinism type II (OCA2). Human. Mutat. 25: 323.

O-46

The Biodiversity in Three Cenotes from Cozumel Island

Luis M. Mejía-Ortíz[1] Marilú López-Mejía[1], Germán Yánez[2] & R. G. Hartnoll[3]

[1] Universidad de Quintana Roo -Cozumel, Lab. de Bioespeleología y Carcinología, DDS, e-mail: luismejia@correo.uqroo.mx, e-mail: mlm@ibiologia.unam.mx

[2] Yucatech Expeditions, Cozumel, Quintana Roo, e-mail: german@yucatech.net

[3] Port Erin Marine Laboratory, University of Liverpool, British Isles

Abstract

The subterranean biodiversity in the Cozumel Island was analyzed in this work in order to know his current status. We review three sinkholes in the western coast from Cozumel Island, and we registered the geographical position, the main abiotic parameters (temperature, salinity, pH, and oxygen dissolved), the animals from each sinkhole and we obtain the survey map. The principal taxa collected were crustaceans founding Decapoda, Isopoda & Amphipoda, also we found Pisces, Annelida and Porifera, in this work and we registered for first time the existence of organism from Echinodermata Phylum in anchialine caves and Thermobaceans and Decapods from Genus Barburia (Crustacea), in Cozumel Island. This work showed that the biodiversity in subterranean environment is higher, and the conservation of this systems in necessary, because almost all fauna registered is unique.

Introduction

The biodiversity in underground is few times valuated, however in different countries several authors has been demonstrated that in general the subterranean environments bearing a high biodiversity. In Mexico the underground environments are well represented by caves with different origin, and we can found dry or humid caves, volcanic or dissolution carbonate caves, freshwater, marine or anchialine caves. This type caves are very closer to coast and in Mexico are found mainly in the Yucatan Peninsula, and has been namely from old times by Mayas people as cenotes or sinkholes (Álvarez et al., 2000).

In the Yucatan Peninsula has been previously with scientific aims (Back et al., 1978; Alcocer et al., 1998; Sánchez et al., 2002; Alcocer et al. 1999; Schmitter-Soto et al., 2002; Yager, 1987; Illife, 1993 y 1992; Kallmeyer y Carpenter, 1996; Suárez-Morales et al., 1996; Escobar-Briones et al., 1997). But only few caves has been explored and described in Cozumel Island, there are some isolated studies from this Island. For this reason, the aims from present work is show the species from macro and micro organisms from three sinkhole (cenotes) in the Cozumel Island and show the environmental conditions and the form or kind of each cenote.

Material and methods

Cozumel Island have 482 km² from extension, and is located at 20°48'00" & 20°16'12" of north latitude and between 87°01'48" & 86°43'48" from western longitude. This Island is on the north-eastern area from Yucatan Peninsula in the Mexican Caribbean Sea, and their main sources from water are in the Cenotes and Subterranean water table. The sinkholes (cenote) that were studied in this work are: El cenote Tres Potrillos, El Aerolito, and Sistema Cocodrilo (Fig. 1). The organisms were sampled handled in several surveys to each cenotes. Also were collected using tramps during 24 hours with chicken as bait. The animals were identified to species level and some organisms only to genus or class. During these surveys we measured the physical and chemical parameters (temperature, salinity and pH of each cenote.
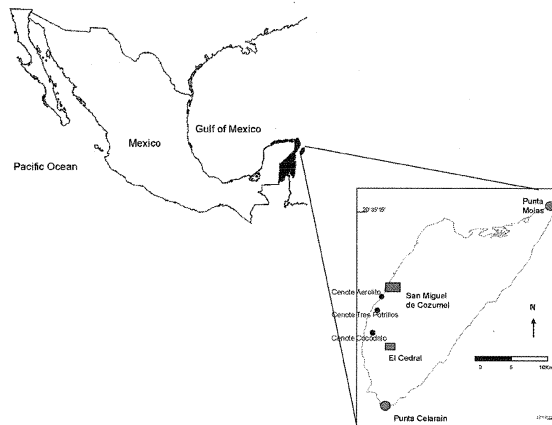
Results

a) Cenote Tres Potrillos

This cenote have a maximum depth of 40 m in vertical, and have a small passage at 12 m with a longitude of 40 meters approximately. This conduct has formations such as stalagmites and stalactites. In this cenote we recorded the follow organisms. The temperature was from 23 to 20 °C and salinity values from 5 to 27 ppt.

i) Procaris sp.

ii) Barburia sp.

iii) Mayawekelia sp.

b) Cenote Aerolito o Sistema Purificación

This system has 6100 m from longitude. Have a connection with Caribbean Sea at 240 m from main entrance. Their conducts were formed mainly by rocks dissolution. Show formations from stalagmite and stalactite, and also have speleothems. The sediments are clay and mud. The water temperature were en average from 25°C, and showed a halocline at 7 m of depth, this change were from 6 ppt to 28 ppt. The species collected in this sinkhole were:

i) Procaris sp.

ii) Yagerocaris cozumel

iii) Bahalana sp.

iv) Echinoidea

v) Asteroidea

vi) Ophiurodea

c) Cocodrilo System

This sinkhole is located on the east side of Island. Have two main entrances with three meters of deep. Posterior have a main passage that have stalagmites and stalactites formations. The water temperature has been between 20 and 22° C. The salinity values were from 7 to 32 ppt. In this cenote the sulphur content was very significative although we not evaluated. In this cenote we recorded the follow taxas:

i) *Tullumella* sp.

ii) *Poecilia* sp.

Discussion

Is evident that the species richness and endemism from each sinkhole to crustaceans group is high, and there are species o members of each genus in almost the cenotes surveyed now by us. However, there are aspects in where is necessary to make emphasis, first, the organisms in underground environments are represented by crustaceans mainly, although there are another phyla as Pisces, Echinodermata (that is represented by animals from class different), Porifera and Annelida only from Aerolito Cenote the major diversity registered in this environments were from salt area, at 28 ppt, and few fishes on freshwater zone. The temperature is lower in comparison with external temperature. However, as we can see in the results although in this work only we reported three natural and underwater caves from Cozumel Island, and some species has been described and reported from this systems, still there are lot work, since from Cozumel is poorly know, in general only from some anchialine systems the scientific know the water characteristics (Back et al., 1978; Hall 1936; Alcocer et al., 1998; Sánchez et al., 2002; Alcocer et al. 1999; Schmitter-Soto et al., 2002) whilst that the so much authors has focus efforts on described the sites and the fauna that in this environments living, making some notes on biology and ecology from these specialised organisms (Yager, 1987; Illife, 1993 & 1992; Kallmeyer y Carpenter, 1996; Suárez-Morales et al., 1996; Escobar-Briones et al., 1997; Suárez-Morales & Reid, 1998). Also, there are few studies on hypothesis that answer the evolutionary questions from these animals in relation with geological history from this area (Holsinger, 1986; 1989; Wilkens, 1982 & 1986).

Acknowledgements

Literature cited.

Alcocer, J., A. Lugo, L. E. Marín & E. Escobar. 1998. Hydrochemistry of waters from five cenotes and evaluation of their suitability for drinking-water supplies, Northeastern Yucatán, Mexico. Hydrogeology Journal, 6(2): 293-301.

Alcocer, J., A. Lugo, M. R. Sánchez, E. Escobar & M. Sánchez, 1999. Bacterioplankton from cenotes and anchialine caves of Quintana Roo, Yucatan Peninsula, Mexico. Revista de Biología Tropical, 47: 73-80.

Álvarez, F., E. Escobar-Briones y J. Alcocer. 2000. Sistemas anquialinos en México. Ciencia y Desarrollo, XXVI (155): 36-45.

Back, W., B. Hanshaw & T. E. Pyle. 1978. Preliminary results: geochemical and hydrologic study of Caleta Xel-Ha, Quintana Roo, Mexico. Field Seminar on water and carbonate rocks of the Yucatan Peninsula, Mexico. New Orleans, Geology Society.

Escobar-Briones, E., M. E. Camacho & J. Alcocer. 1997. Calliasmata nohochi, new species (Decapoda: Caridea: Hippolytidae) from anchialine cave systems in continental Quintana Roo, Mexico. Journal of Crustacean Biology, 17(4): 733-744.

Hall, F. G. 1936. Physical and chemical survey of cenotes of Yucatan. Carnegie Institute of Washington Publications, 457: 5-16.

Holsinger, J. R. 1986. Zoogeographic patterns of North American subterranean amphipod crustaceans. Pp. 85-106 En: R. H. Gore, & K. L. Heck (Editors). Crustacean Issues 4: Crustacean Biogeography, Rotterdam: A. A. Balkena.

Holsinger, J. R., 1989. Preliminary zoogeographic analysis of five groups of crustaceas from anchialine caves in the West Indian Region. Proceedings 10th International Congress of Speleology, 1: 25-26.

Holsinger, J.R. 1992. Two new species of the subterranean amphipod genus Bahadzia (Hadziidae) from the Yucatan Peninsula region of southern Mexico, with an analysis of phylogeny and biogeography. Stygologia, 7:85-105.

Illife, T. M. 1992. An annotated list of the troglobitic anchialine and freshwater fauna de Quintana Roo. En: D. Navarro y E. Suárez-Morales (Eds.), Diversidad biológica en la Reserva de la Biosfera de SianKa'an, Quintana Roo, México. Vol. III, Chetumal CIQRO/Sedesol, pp 197-217.

Illife, T. M. 1993. Fauna troglobia acuática de la Península de Yucatán 673-686. En: Salazar-Vallejo S. I. y N. E. González (Eds.) Biodiversidad marina y costera de México. CONABIO y CICRO México. 867 pp.

Kallmeyer, D. E., & J. H. Carpenter. 1996. Stygiomysis cokei, new species, a troglobitic mysid from Quintana Roo, Mexico (Mysidacea: Stygiomysidae). Journal Crustacean Biology, 16(2): 418-127.

Schmitter-Soto, J. J., E. Escobar, J. Alcocer, E. Suárez-Morales, M. Elias-Gutierrez, L. E. Marin & B. Steinich. 2002. Hydrobiology of cenotes of the Yucatán Peninsula. Hydrobiologia, 467: 215-228.

Suárez-Morales, E., J. W. Reid, T. M. Iliffe, y F. Fiers. 1996. Catálogo de los Copépodos (Crustacea) Continentales de la Península de Yucatán, México. Ecosur-CONABIO, Chetumal 296 pp.

Suárez-Morales, E., & J. W. Reid. 1998. An update list of the free-living freshwater copepods (Crustacea) of Mexico. The Southwestern Naturalist 43(2): 256-265.

Wilkens, H. 1982. Regressive evolution and phylogenetic age: The history of colonization of freshwater of Yucatan by fish and crustacea. Association of Mexican Cave Studies Bulletin, 8: 237-243.

Wilkens, H. 1986. The tempo of regressive evolution: studies of the eye reduction in stygobiont fishes and decapod crustaceans of the Gulf Coast and west Atlantic region. Stygologia, 2(1-2): 130-143.

Yager, J. 1987. Speleonectes tulumensis n. sp. (Crustacea Reimpedía) from two anchialine cenotes of the Yucatan Peninsula, Mexico. Stygologia, 3: 160-166.

O-47
Biospéléologie, sommeil paradoxal (REM)et Monde souterrain
Dr.CHAMA A.

Unité de médecine du travail
Secteur sanitaire d'Es-Sénia (Oran,Algérie)

Avec la découverte de l'EEG par Berger en 1924, il était possible d'explorer le sommeil et d'arriver à des résultats scientifiques sur la physiologie du cerveau particulièrement le fonctionnement de l'organisme humain de façon objective. Les premiers travaux scientifiques

Sur le sommeil commencèrent par des chercheurs américains Kleitman et son élève Aserinsky en 1936 aux USA qui rapportent la présence les mouvements oculaires lors du sommeil qu'ils appelèrent le Rapid Eye Mouvment (REM) et qui suivirent les travaux de William Dément en 1953. La nouvelle s'entendit en France et les travaux expérimentaux sur le chat par le professeur Michel Jouvet,neurophysiologiste ont permit de confirmer les résultats des chercheurs américains sur le REM et aboutit à une découverte scientifique du sommeil paradoxal grâce à l'enregistrement par EEG suivi de l'EOG (élélctrooculogramme), l'éléctromyogramme (EMG) et la fréquence cardiaque (ECG),fonction respiratoire,

Ces études sur le sommeil et son exploration par les méthodes d'enregistrement électrique ont été couronnés de succès et ont vu enfin en 1968 à une standardisation des états de vigilance et une classification internationale des stades de sommeil par A.Rechstachaffen et A.Kales.

Malgré son importance et le rôle que devra jouer dans la pathologie et le programme d'éducation ,le sommeil a suscité de l'intérêt surtout dans les recherches en neurophysiologie et d'autre disciplines qui ont trait à explorer l'homme dans d'autres dimensions.

Les études sur la physiologie et la chimie du sommeil par Michel Jouvet et aussi les travaux de Parmeggiani sur la régulation des fonctions physiologiques du sommeil chez l'homme.

La recherche sur le rôle des neurotransmetteurs , substances actives dans le sommeil dans certains de ses stades ont étudiées avec des hypothèse sur le rôle des stades de sommeil et la théorie mono-aminergique.

Le sommeil et plus particulièrement le sommeil paradoxal ont été étudiés sous l'angle de la phylogénèse chez l'homme et les espèces humaines (mammifères, reptiles...).

Cela n'a pas manqué d'autres disciplines philosophiques et religieuses à étudier le sommeil et l'activité onirique (Upanishades, écritures saintes) et trouvèrent un terrain parfois d'entente avec les théories scientifiques , parfois l'écart comblé d'hypothèses et de réflexions .

Dernièrement la génétique trouva une place de choix dans l'étude du sommeil dans sa profondeur et surtout le sommeil paradoxal grâce aux recherches expérimentales chez les jumeaux homozygotes et chez les animaux (rats).

Le progrès scientifique a souligné la place de la chronobiologie ou études des rythmes biologiques tel que les études du Professeur Alain Reinberg . l'étude du sommeil a été présenté comme l'illustration de choix pour vérifier le bien fondé des rythmes biologiques

Qui ont mis en cause le principe d'« homéostasie » et la notion de « constantes biologiques » considérées erronées en médecine par les chronobiologistes.

On ne peut évoquer la place de cette jeune discipline en perpétuel croissance tant dans sa démarche et de sa fiabilité en médecine pour expliquer le fonctionnement de l'organisme humain sans souligner le rôle qu'a joué une autre discipline : la spéléologie ou science des cavernes et plus particulièrement les expériences hors du temps du célèbre spéléologue français Michel Siffre qui démontra qu'en dehors du repère temporel c'est-à-dire en isolement l'organisme humain adopte un rythme biologique circadien non pas de 24 heures mais d'environ 25 heures avec

un décalage horaire d'une heure environ .Le séjour de Michel Siffre dans le monde souterrain a eu un écho médiatique considérable sur la notion du perte de la notion du temps et aussi le rythme original de l'homme.

La science vient de découvrir que le rythme biologique de l'homme est inné.

La recherche de l'horloge biologique à été sérieusement étudiée pour découvrir le siège de ce « quartz » et pour un meilleur fonctionnement de l'homme. Plusieurs approches ont élucidé Tantôt neurophysiologiste, phylogénétique ou introspective ..

Ces expériences menées dans le monde souterrain ont non seulement révélé leur utilité dans la connaissances des rythmes biologiques mais aussi leurs aspects psychologiques. Dans son journal ,Michel Siffre raconte les rêves lors de son séjour souterrain et témoignent de son tempérament.

Les études sur les expériences hors du temps ont mérité leur place dans les études spatiales menées par la NASA pour évaluer les performances psychomotrices et les erreurs de comportement surtout chez les pilotes,cosmonautes et navigateurs dans les vols trans-méridiens où le décalage horaire existe comme dans le monde souterrain. Il s'agit d'améliorer les rythmes du travail à bord des sous-marins nucléaires et de maintenir la vigilance du personnel navigant en cas de décalage horaire.

Cet aspect de rythmes biologiques a permit non seulement d'évaluer l'impact sur la santé de l'homme mais de souligner l'aspect préventif : Hygiène du sommeil pour préserver la santé de l'homme à travers la relation étroite de l'homme par rapport à son environnement comme il était classique de discuter sur la stratégie de la prévention mais un autre facteur qui ne manque pas d'intérêt qui est le facteur temps.

A travers cette optique élargie et lucide que nous essayerons de présenter notre étude pour cerner les interactions entre l'homme,environnement et temps qui traduit tout l'intérêt des expériences hors du temps et de la biospéléolgie.

En médecine du travail , où le rôle à préserver la santé de l'homme dans son aspect physique, mental,social et ergonomique n'a pas manqué de souligner l'identification des risques professionnels physiques,chimiques,biologiques mais aussi le facteur temps a été considéré comme une nuisance à ne pas négliger. Les études sur le travail de nuit, posté ou alternés ont montré l'impact de l'horaire de travail sur la santé des travailleurs (accidents du travail, erreurs du comportement,désordres du sommeil et troubles psychologiques et végétatifs..).

Conscient de ce risque en milieu du travail,certains pays développés ont établit une législation du travail .Les aptitudes psychomotrices et sensorielles sont menacées lors du travail de nuit (à citer l'exemple des accidents du Titanic en 1912, Bhopal en Inde en 1984, Tchernobyl en URSS en 1986 et enfin Bâle en 1986..).

Le rôle des rythmes biologiques en médecine du travail et la « pathologie de la nuit » nous a motivé à présenter combien est grande la carence en matière du rôle du sommeil chez les préventeurs et dans le programme de prévention. A consulter les carnets de l'enfant ou les dossiers des visites médicaux périodiques des travailleurs pour constater l'absence d'information sur le sommeil et tout particulièrement celui qui exerce la nuit ou travail posté.

A vrai dire l'hygiène du sommeil est rudimentaire malgré la grande avancé de la physiologie du sommeil.

Lors de notre participation au 19ème Congrès national de spéléologie à Bologna (Itale) en 2003 nous avons discuter la place des rythmes biologiques en médecine et la durée du sommeil en dehors du repère tempo-

rel dans le monde souterrain qui est de 24,72 heures avec un coefficient de 3%) que nous baptisé le coefficient de correction ou de resychronisation par rapport au monde ambiant .A travers notre étude intitulée « Histoire de « Ashab al-kahf »

(Les Gens de la caverne) , horloge biologique et vie hors du temps,à travers les données de la chronobiologie, nous avons souligné la dimension de l'homme dans sa composante temporo-spatiale.

Parallèlement aux données scientifiques puisées de la chronobiologie et de la spéléologie et plus particulièrement les expériences hors du temps de Michel Siffre, nous n'avons pas hésité à élargir l'intérêt que peut porter les Ecritures Saintes ou philosophiques tel que les Ecritures indoues ou Upanishades sur les états de vigilance ,éveil, sommeil et rêve (Lanteri)où grâce à la découverte du sommeil paradoxal, l'activité onirique et le sommeil qui ont prit une dimension dans le débat scientifique.

Les Ecritures Saintes ,la Sourate « Al-Kahf » et plus particulièrement « l'Histoire de « Ashab al-Kahf » du Saint-Coran nous a permit d'arriver à des résultats comparables du décalage horaire à celui de Miche Siffre avec une nette précision (voir notre étude en référence) mais à discuter la nature du sommeil des Gens de la Caverne resté énigmatique jusqu'à ce jour et que c'est grâce aux données sur le sommeil et la chronobiologie et la spéléologie que nous essayerons de répondre dans une approche globale et synthétique basée sur la comparaison entre les écritures saintes et les données scientifiques.

Notre étude bibliographique sur le sommeil et son impact sur la santé de l'homme et les différentes variations qui en émanent , souligne le rôle du sommeil paradoxal (REM) comme un second état qui immerge lors du sommeil et qui doit mériter toute l'attention tant sur le plan physiologique de la vie intra-utérine (sommeil agité) ,du nourrisson,de l'enfant jusqu'à l'adolescent et l'homme adulte et ses variations et même en médecine du travail où peu d'études se sont intéressées malgré son rôle comme réparateur des fonctions psychiques, mémorisation ..

Dans les expériences hors du temps, il a été souligné les modifications des paramètres biologiques tel que cortisol , température,mélatonine,sommeil et vraisemblablement le sommeil paradoxal…

Il est rapporté aussi que l'enfant in utéro et même les quatre premiers mois après la naissance,le nouveau-né vit en décalage horaire avec un rythme biologique circadien de 25 heures environ dans un environnement indépendant (surtout le métronome lumière) et le nouveau né commence à s'adapter progressivement au monde ambiant avec une nouvelle organisation du sommeil sur un mode temporel de 24 heures et qui traduit selon certains auteurs la maturation et le développement cérébral.

A côté de l'intérêt que nous avons porté sur le sommeil paradoxal dans la science et les écritures saintes, nous nous sommes posé la question si existe un décalage horaire dans le monde maritime comme l'a fort souligné Michel Siffre dans les conditions suivantes :

1.Le monde souterrain

2.Le monde spatial

3.Les vols trans-méridiens

En médecine du travail, les études menées sur les caissons et plongée sous-marine et plus particulièrement les études du Commandant Jean Yves Cousteau n'ont pas été d'un grand secours pour discuter la présence ou non d'un éventuel décalage horaire en dehors du repère temporel.

Notre recherche a abouti à un choix d'un milieu sensiblement comparable au monde souterrain : le milieu utérin (liquide amniotique)où existe l'absence de lumière, bruit , température constante,enfant en apesanteur et une « dormance »de l'enfant qui traduit une véritable indépendance du milieu. La recherche d'un décalage horaire était l'objectif ainsi que le rythme biologique de 25 heures ?

Nous nous sommes intéressés à la durée de la grossesse physiologique qui est de 266 jours

(en prenant en considération le premier jour de l'ovulation qui est uniquement 14 jours/mois

C'est-à-dire en excluant la phase folliculinique qui est de 14 jours).La durée extrême de l'accouchement est de 296 jours ce qui donnera un rapport de 1,03 .

D'où 1,03 X 24 heures= 24,72 heures

Ce qui revient à dire que la grossesse physiologique dure neuf mois et dix jours et que ces dix jours représentent probablement le décalage horaire sur neuf mois ou qui traduirait un décalage horaire de 0,72 heures /jour .

Par conséquent, pourra t-on conclure que l'enfant « vit hors du temps » dans le ventre de sa mère comme dans les « expériences hors du temps » dans le monde souterrain. Existe-t-il un éveil interne chez l'enfant ? Pourquoi cette « dormance » in utéro ? Est-ce qu'il existe une activité onirique ? Autant de questions qui se posent ?

Nous espérons que notre communication qui a porté sur le sommeil paradoxal et sa portée dans la biologie, pathologie mentale et les différentes approches scientifiques,religieuses et philosophiques et d'autres disciplines tel que la biospéléologie et la chronobiologie et la médecine du travail permettra de résoudre non seulement le sujet du sommeil mais du fonctionnement de l'organisme en entier à travers une approche holistique et saisir enfin le mystère du rêve,de la longévité et la quatrième dimension du temps ?

Mots - clés:

Sommeil paradoxal, monde souterrain, expériences hors du temps,décalage horaire,chronobiologie,Michel Siffre, Michel Jouvet ,horloge biologique,Histoire des gens de la caverne (Saint-Coran),éveil interne,Upanishades ,médecine du travail,vie intra-utérine.

Versets coraniques:

Sommeil paradoxal : résolution musculaire, clignement des paupières.

« Tu aurais cru qu'ils veillaient et cependant ils dormaient, nous les retournions tantôt à droite et tantôt à gauche » (verset 17/sourate « al-kahf).

Décalage horaire : 0,72 heures/jour

« Or,ils demeurèrent dans leur caverne trois cents ans, ils en ajoutèrent neuf » (verset 25/Sourate-kahf).

Références:

1. Ouvrages de médecine du travail et travail de nuit

2. Ouvrages sur le sommeil

3. Ouvrages sur les rythmes biologiques

4. Ouvrages sur la Spéléologie et Expériences hors du temps de Michel Siffre

5. Etudes sur le sommeil paradoxal, génétique et vieillissement.

6. Le Saint-Coran et commentaires (Tafsir)

7.Interprétation des rêves par Ibn al-Qayyim

Tableau 1.Codification des 5 stades du sommeil chez l'homme adulte

Figure 2 :sommeil paradoxal en fonction de l' âge

Tableau 3.Le sommeil paradoxal selon le modèle de Parmeggiani

Figure 4 . L'horloge biologique selon Jouvet et Sommeil paradoxal

Tableau 5 : le décalage du sommeil chez le Nouveau né

O-48

Progressive lowering of the water table in the Grand Canyon, Arizona, Usa as recorded by cave and mine deposits

CAROL A. HILL and VICTOR J. POLYAK

Earth and Planetary Sciences, University of New Mexico, 200 Yale Blvd. Albuquerque, NM 87131, carolannhill@aol.com

Abstract

Speleothem and ore deposits in Grand Canyon (GC) caves and mines record the progressive lowering of the water table over time. The sequence of significant deposits and events in the GC is: (1) Ore mineralization (Cu-U) episode. Sulfide ore mineralization, as exposed in the breccia pipes/mines of the GC, formed in the reduced zone, possibly during the Laramide when H2S migrated up deep basement faults and monoclinal structures. Uranium precipitated in the redox zone and calcite spar formed paragenetically with ore mineralization. Time: Paleocene to Eocene? (2) Hematite/goethite episode. The oldest cave deposits are manganese and iron oxides (hematite/goethite) containing minor halite and trace-metals (e.g., As, Ba, Pb). These deposits fill small solution cavities in the Redwall Limestone exposed by cave passages. These metal-rich deposits formed when ascending warm saline waters mixed with descending oxidized cold waters in the deep phreatic zone. Time: Oligocene? (3) Calcite spar episode. Calcite spar crystals are found lining the walls of a number of GC caves. Since they line cave passages, they must be younger than these passages. Large calcite spar crystals are known to form from low-temperature hydrothermal solutions under quiet phreatic conditions. Time: Miocene? (4) Mammillary-replacement gypsum episode. Mammillaries, consisting of microcrystalline fibrous calcite, are a speleothem type that forms in the shallow-phreatic zone just below the water table. Replacement gypsum rinds form at or just above the water table where degassing H2S reacts with wet limestone. These two cave deposits can be used to determine past water table positions in the Redwall Limestone as well as incision rates for the GC. Time: Middle Miocene-Pliocene in the western GC to Pliocene-Pleistocene in the eastern GC to the present in Marble Canyon. (5) Subaerial speleothem episode. Speleothems such as stalactites and stalagmites record when GC caves became air-filled. Many of these speleothems are very old, surpassing the limit of U-series dating. Time: Pliocene-Recent. U-Pb and U-series dating of mine calcite, calcite-spar cave linings, water-table mammillary calcite, and subaerial speleothem calcite should provide an absolute time scale for the history of water table lowering in, and incision of, the Grand Canyon.

Introduction

The purpose of this study is to understand the evolution of the Grand Canyon with regard to the progressive lowering of the water table over time, and with regard to the age of incision of the canyon itself. In order to accomplish this goal a number of caves and mines within the Grand Canyon area were visited (Fig. 1). Caves (artesian type only) visited during the course of this study were: Cave of the Domes, Babylon, Crystal Forest, Tse'an Bida, Tse'an Kaetan, Bat, Moria, Mother, Diamond, Grand Canyon Caverns, Cathedral, Indian, Cave Spring, Dusty, Falls, IMAX, Chuar Butte, Muav, and Rampart. Mines visited were: Orphan, Grandview, Grand Gulch, Savanic, Ridenour, Riverview, Pigeon, Snyder, Hack Canyon, Ryan, Petosky, Mackin, Anita (Emerald), Copper Queen, Northstar, and Eaststar. Two main types of caves exist in the Grand Canyon area: (1) unconfined (vadose) caves, and (2) confined (artesian, phreatic) caves (Huntoon, 2000a,b). Unconfined caves in the Grand Canyon are simple linear drains in the vadose zone where water recharges at the surface of the Kaibab Plateau and moves under high gradients down along faults (or master joints parallel to faults) to the Redwall-Muav aquifer, and where discharge is mainly from the base of the Muav Limestone to the Colorado River. This modern vadose circulation system has given rise to the great North Rim caves such as Roaring Springs and Thunder River.

However, no vadose caves were visited during this study because they do not contain deposits within them that record the geologic history of the Grand Canyon. They are caves that discharge to the modern Grand Canyon and thus postdate the incision of the canyon. Confined caves in the Grand Canyon come in two varieties: modern and relict. Both of these constitute what is known as the "Redwall artesian aquifer." Modern confined caves are hydrologically active caves that give rise to springs along the Marble Canyon section of the Grand Canyon. They are maze caves that are saturated and inaccessible. Relict confined caves formed like modern confined caves (i.e., under artesian conditions in the phreatic zone), but they have been dissected and dewatered by canyon erosion from west to east over time. Relict Redwall artesian caves are extremely important to understanding the geologic history of the Grand Canyon because they contain remnant deposits that record events that occurred both before and during the incision of the canyon. These cave deposits are (from oldest to youngest): (1) hematite/goethite, (2) calcite spar, (3) mammillaries-replacement gypsum, and (4) subaerial speleothems (Hill et al., 2001). A specific cave may have only one of these deposits, two or three of these deposits (Fig. 2), or all four of these deposits, but in all cases the relative sequence of these deposits is consistently the same.

Copper-uranium ore mineralization episode

Some of the highest-grade uranium ore in North America resides in the breccia pipes of the Grand Canyon (Mathisen, 1987). These pipes were mined in the late 1800s-early 1900s for copper and in the 1950s-1960s for uranium. The breccia pipes have their bases in the Redwall Limestone and they stope up into the Paleozoic section and even into the Mesozoic section where these rocks have not been removed by erosion. The ore deposits of the Grand Canyon not only contain copper and uranium, but also a number of different sulfide minerals and pyrobitumen. Wenrich and Sutphin (1989) suggested a paragenetic sequence for these different ore minerals. The rare-metal sulfides (Ni, Co, As) + pyrite-marcasite formed early in the zone of reduction, and then somewhat later the sulfides of copper, lead and zinc also formed in the zone of reduction. Even later the ore-mineral uraninite probably formed in the redox (reduction-oxidation) zone, typical of "roll-front" type uranium deposits, and still later minerals were deposited in the zone of oxidation. Thus, this paragenetic sequence of minerals records the progressive lowering of the water table over time through the breccia pipes. The general model proposed by this study for the breccia-pipe ore deposits of the Grand Canyon involves two-fluids, where a shallow meteoric oxidizing fluid carrying copper and uranium (as carbonate complexes) from a recharge area to the south mixed with a deep-sourced saline and reducing fluid containing dissolved H2S, CO2, and metals (Fig. 3). In this model, the proposed source of uranium and copper is stratabound uranium-copper deposits once present in above-lying Mesozoic rock (still located in the area east of the Grand Canyon), and the proposed source of reductant is hydrocarbons in the Precambrian Supergroup basement. Time of mineralization is debatable. Ludwig and Simmons (1992) performed U-Pb dates on uraninite from a number of mines and found that these ages congregate in the Triassic - although a number have greater or lesser age values. On the other hand, Beitler et al. (2003) placed the timing of migration of H2S up along monoclines in Southern Utah in the Laramide (Paleocene-Eocene), where this reductant bleached the Navajo Sandstone along monoclinal and anticlinal structures. Therefore it is also possible that Laramide monoclines in the Grand Canyon area were avenues for reductant (H2S) ascending from Precambrian basement faults into breccia pipes.

192

Hematite/goethite episode

The first event recorded in Grand Canyon caves is the hematite/goethite episode. These deposits occur in cavities within the Redwall Limestone, exposed by later cave passage dissolution. Sometimes these deposits are composed of the higher-temperature iron-rich mineral hematite, and sometimes by lower-temperature goethite. Usually this material is high in manganese, and also in the trace elements of As, Ba, Co, Cu, Mo, Ni, Pb, and Zn. Some deposits contain halite. The mechanism for the precipitation of hematite/goethite is shown in Figure 4. Thermal waters rising from depth are often saturated with CO2. Water mixed with gas (H2S, CO2) has a slightly lower density than normal water, so it rises along joints and cools. This cooling caused the dissolution of the Redwall Limestone by the "cooling corrosion" mechanism of Bögli (1980). In addition, the mixture of low TDS, low CO2, shallow meteoric waters with high TDS, high CO2, deep-seated waters creates a solution that dissolves limestone in the mixing zone. This process is called "mixing corrosion" (Ford and Williams, 1989). Dissolution of carbonate (limestone) consumes H + and thus raises the pH allowing for the precipitation of hematite/goethite within the cavities created by the mixing-corrosion mechanism. In turn, the precipitation of hematite/goethite under oxidizing conditions generates acidity according to the following reaction:

$$2Fe_2 + 0.5_{O2} + 2H_2O = Fe2_{O3} + 4H^+ (1)$$
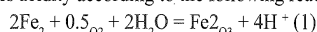
The acidity produced in this reaction further dissolves cavities in the limestone. Therefore, the creation of space for the hematite/goethite and the chemistry of its precipitation goes on simultaneously. Time of this episode is uncertain, but it may date from the Oligocene or Early Miocene.

Calcite spar episode

After the precipitation of hematite/goethite the water table continued to descend until the Redwall Limestone was within the maximum solubility regime of calcite (Fig. 5). As convective water rises and cools, the solubility of calcite gradually increases so that cave passages dissolve in the deep "solutional zone." This usually occurs somewhere between ~250-550 m below the water table (Dublyansky, 1995, 2000). It was in this regime that the artesian-phreatic cave passages formed. As the water table descended further, Grand Canyon caves formed in the "solutional zone" were shifted into the "depositional zone" where the solubility of calcite dropped sharply and solutions changed from aggressive to precipitative (Fig. 5). Since the loss of CO2 is very slow in the phreatic regime, spar crystals had a chance to grow slowly and large, lining previously formed cave passages (Fig. 6). Spar crystals up to 56 cm long have been found lining Grand Canyon caves. These crystals exhibit carbon-oxygen isotope values, fluid inclusion temperatures, and fluorescence (orange to non-fluorescent) that indicate a low-temperature hydrothermal regime, probably somewhere between ~90°C to 30°C.

Mammillary-replacement gypsum episode

Mammillary linings. As the water table dropped to the level of the Redwall Limestone, the deposition of calcite changed from large spar crystal linings to microcrystalline fibrous "mammillary" linings (Fig. 7). Mammillaries are a type of speleothem that forms within a 100 m or so of the water table, most usually within ~50 m to 0 m (Hill and Forti, 1997). In the shallow phreatic zone near the water table the loss of CO2 is much faster than in the deep phreatic zone (Fig. 5); therefore, a rapid precipitation of fine-grained fibrous calcite occurs in this regime. The size of crystals in mammillaries typically varies from several millimeters to a few centimeters. Mammillary coatings are very common in Grand Canyon caves, and some coatings line entire caves or cave passages (e.g., Mother Cave).

Mammillary speleothems are important to the study of the Grand Canyon because they denote the approximate position of the paleo-water table and can thus be used to date canyon incision from one end of the canyon to the other. Three separate pieces of evidence support a near water-table origin for mammillaries: (1) the fine-grained nature of mammillaries, (2) the common association of mammillaries with calcite rafts and folia - two speleothem types believed to form at the water table (Hill and Forti, 1997), and (3) the occurrence of mammillaries forming today near the water table along with folia (e.g., in Devils Hole, Nevada; Kolesar and Riggs, 2004). Far below the water table mammillaries cannot form, and above the water table the growth of mammillaries ceases (Fig. 8).

Preliminary dating of mammillaries in Grand Canyon caves indicates that their age is beyond the U-series method (>0.5 Ma). In most instances, the uranium concentration is high enough, and the lead concentration is low enough, for the U-Pb method to be suitable for dating these water-table/canyon incision speleothem indicators. Preliminary results for a mammillary sample from Grand Canyon Caverns on the western end of the Grand Canyon indicate that the water table was at the Redwall level there sometime during the Middle Miocene (~19 Ma) (Polyak et al., 2004). This timing is consistent with the incision record from the dating of basalt flows on the western side of the Grand Canyon by Young (2004). Preliminary dating results from a Bida Cave mammillary sample on the eastern end of the Grand Canyon indicate that the water table was at the level of the Redwall in this part of the canyon sometime during the Pliocene (~2-3 Ma).

Replacement Gypsum. While mammillary speleothems form near or just below the water table, replacement gypsum rinds form just above the water table where H2S reacts with wet limestone to form gypsum according to the following equations:

$$H_2S + 2O_2 \leftrightarrow H^+ + HSO_4^- \leftrightarrow 2H^+ + SO4^{2-} (2)$$
sulfuric acid

$$2H^+ + SO4^{2-} + CaCO_3 \leftrightarrow Ca^{2+} + SO4^{2-} + H_2O + CO_2 (3)$$
sulfuric acid   limestone   gypsum
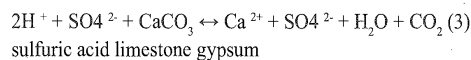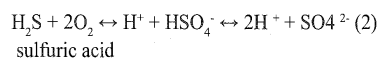
In the case of Grand Canyon caves, this episode was minor in contrast to the sulfuric acid origin of caves in the Guadalupe Mountains of New Mexico (e.g., Carlsbad Cavern and Lechuguilla Cave; Hill, 1990). This episode probably formed in response to Basin and Range-age tectonic extension, where H2S from the Precambrian basement ascended to the level of the Redwall Limestone along master joints parallel to faults. Proof that the gypsum rinds in Grand Canyon caves is of replacement, rather than speleothemic, origin is their enrichment in the light isotope of sulfur (ä 34 S = -17.9‰ to +5.8‰, avg. -3.7‰ for 9 values), whereas Permian gypsum in the overburden averages about +14-15‰).

In some caves replacement gypsum can be seen directly overlying mammillary speleothems (e.g., Cave of the Domes, Mother Cave). In these cases this sequence of deposits records the lowering of the water table through the cave itself. The mammillary coating formed just below the water table, while later in time as the water table dropped through the extent of the cave, the gypsum rind formed just above the water table in the subaerial zone from the replacement of limestone (eq. 3).

Subaerial speleothem episode

After Grand Canyon caves became air-filled, they became decorated with subaerial speleothems such as stalactites, stalagmites, and flowstone. U-series dating has shown that many of the speleothems collected in Grand Canyon caves are very old - that is, beyond the U-series dating method. Today the caves of the Grand Canyon are dry and very few speleothems are still actively growing. Periods of substantial growth of speleothems likely represent climatic episodes of increased precipitation. For example, a stalactite collected from Bat Cave was deposited sometime

193

between 402 and 448 ka, and likely coincides with Oxygen Isotope Stage 12, a global glacial period that could have included increased precipitation for the Grand Canyon area (Shackleton and Opdyke, 1973).

Conclusion

The overall model for the progressive lowering of the water table in the Grand Canyon is shown in Figure 9. Essentially, when the water table was high in Mesozoic strata (position (1) in Fig. 9), the Redwall Limestone was in the reduced zone, and this allowed for the precipitation of sulfide minerals in the breccia pipes of the Grand Canyon. The uranium mineralization followed as the Redwall Limestone entered the redox zone. Even later in time in the deep phreatic zone, mixing corrosion caused the dissolution of cavities in the Redwall Limestone and the precipitation of hematite/goethite within these cavities (position (2) in Fig. 9). In the shallower phreatic zone the limestone was first in the "solutional zone" where cave passages dissolved, followed by a shift into the "depositional zone" where calcite spar lined these cave passages (position (3) in Fig. 9). When the water table reached the level of the Redwall Limestone (position (4) in Fig. 9) the mammillaries and replacement gypsum formed, and when it descended below the level of the caves (position (5) in Fig. 9) subaerial speleothems grew within these caves.

Future U-Pb and U-series dating of mine calcite, calcite-spar linings, mammillary calcite, and subaerial speleothem calcite should provide an absolute time scale for the history of water table lowering in, and incision of, the Grand Canyon.

References

Beitler, B., Chan, M. A., and Parry, W. T., 2003, Bleaching of Jurassic Navajo sandstone on Colorado Plateau Laramide highs: evidence of exhumed hydrocarbon supergiants? Geology, v. 31, no. 12, p. 1041-1044.

Bögli, A., 1980, Karst hydrology and physical speleology: Berlin, Springer, 284 p.

Dublyansky, Y. V., 1995, Speleogenetic history of the Hungarian hydrothermal karst: Environ. Geology, v. 25, p. 24-25.

Dublyansky, Y. V., 2000, Hydrothermal speleogenesis - its settings and peculiar features; in Klimchouk, A. B. et al. (eds), Speleogenesis: Evolution of karst aquifers: Huntsville, AL, National Speleological Society, p. 292-297.

Ford, D. C. and Williams, P. W., 1989, Karst geomorphology and hydrology: London, Unwin Hyman, 601 p.

Hill, C. A., 1990, Sulfuric acid speleogenesis of Carlsbad Cavern and its relationship to hydrocarbons, Delaware Basin, New Mexico and Texas: American Association of Petroleum Geologists Bulletin, v. 74, p. 1685-1694.

Hill, C. A. and Forti, P, 1997, Cave minerals of the world: Huntsville, AL, National Speleological Society, 2 nd ed., 463 p.

Hill, C. A., Polyak, V. J., McIntosh, W. C., and Provencio, P. P., 2001, Preliminary evidence from Grand Canyon caves and mines for the evolution of the Grand Canyon and the Colorado River system: in Young, R. A.,

and Spamer, E. E. (eds.), The Colorado River: origin and evolution: Grand Canyon, AZ, Grand Canyon Ass. Monograph 12, Ch. 22, p. 141-145.

Huntoon, P. W., 1990, Phanerozoic structural geology of the Grand Canyon; in Beus, S. S., and Morales, M. (eds.), Grand Canyon geology: New York, Oxford University Press, p. 261-332.

Huntoon, P. W., 2000a, Karstification associated with groundwater circulation through the Redwall artesian aquifer, Grand Canyon, Arizona, USA; in Klimchouk, A. B. et al. (eds), Speleogenesis: Evolution of karst aquifers: Huntsville, AL: National Speleological Society, p. 287-291.

Huntoon, P. W., 2000b, Variability in karstic permeability between unconfined and confined aquifers, Grand Canyon region, Arizona: Environmental and Engineering Geoscience, v. 6, no. 2, p. 155-170.

Kolesar, P. T. and Riggs, A. C., 2004, Influence of depositional environment on Devils Hole calcite morphology and petrology, in Sasowsky, I. D. and Mylroie, J. (eds.), Studies of cave sediments - physical and chemical records of paleoclimate, p. 227-241.

Ludwig. K. R., and Simmons, K. R., 1992, U-Pb dating of uranium deposits in collapse breccia pipes in the Grand Canyon region: Economic Geology, v. 87, p. 1747-1765.

Mathisen, I. W., 1987, Arizona Strip breccia pipe program: exploration, development and production: American Association of Petroleum Geologists Bulletin, v. 71, no. 5, p. 590.

Shackleton, N. J., and Opdyke, N. D., 1973, Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 10 5 year and 10 6 year scale: Quaternary Research, v. 3, p. 39-55.

Polyak, V. J., Hill, C. A., and Asmerom, Y., 2004, History of headward erosion of the Grand Canyon from a study of speleothems (abs.): Geological Society of America Abstracts with Programs, v. 36, no. 5, p. 549.

Wenrich, K. J., and Sutphin, H. B., 1989, Lithotectonic setting necessary for formation of a uranium-rich solution-collapse breccia-pipe province, Grand Canyon region, Arizona: USGS Open File Report 89-0173, 33 p.

Young, R. A., Miocene drainage history of western Grand Canyon, Arizona (abs.): Geological Society of America Abstracts with Programs, v. 35, p. 549.
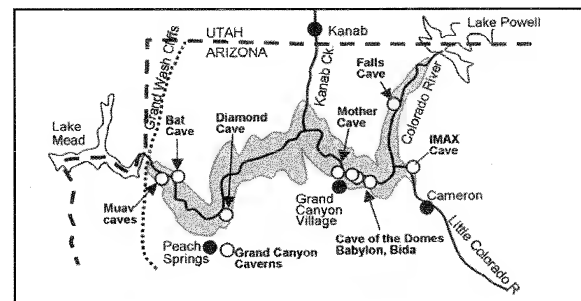
Figure 1. Map of the Grand Canyon and location of the major caves visited during this study.
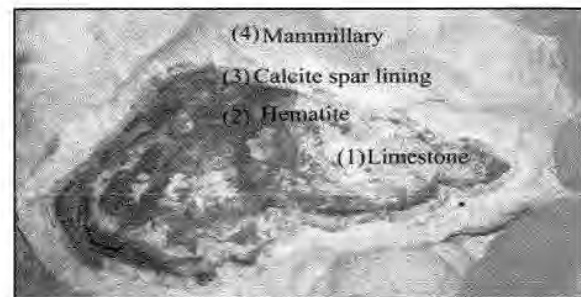
Figure 2. Three of the four types of cave deposits are displayed on wall of Bida Cave. Photo by Bob Buecher.
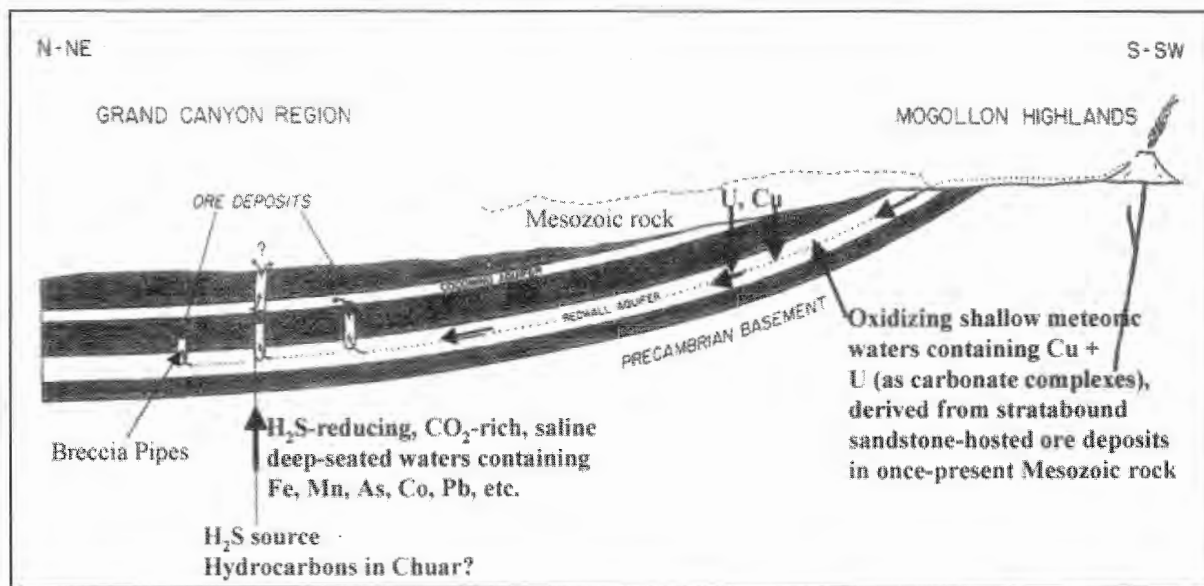
Figure 3. A two-fluid mixing model for the origin of the Cu-U ore deposits in Grand Canyon breccia pipes. It is proposed that the copper and uranium derived from stratabound-hosted ore deposits present in overlying Mesozoic rock before it was eroded away, and that the source of reductant was hydrocarbons in the Precambrian basement. The breccia pipes acted as structural traps for the mixing of these two fluids. Modified from Huntoon (1996).
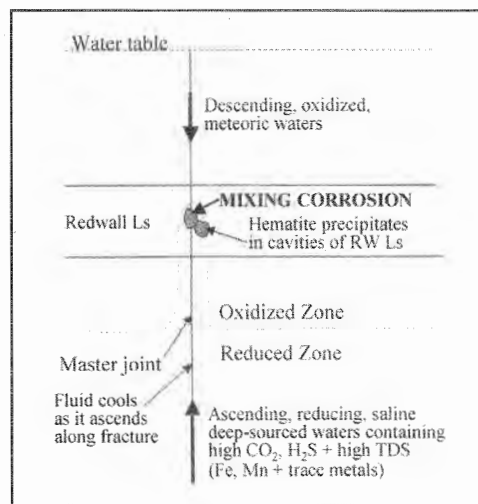
Figure 4. Geochemistry of the hematite episode. The mixture of low TDS, low CO2 meteoric waters with high TDS, high CO2 deep-sourced waters creates a solution that dissolves limestone in the mixing zone of these two types of waters. This dissolution process is called "mixing corrosion."
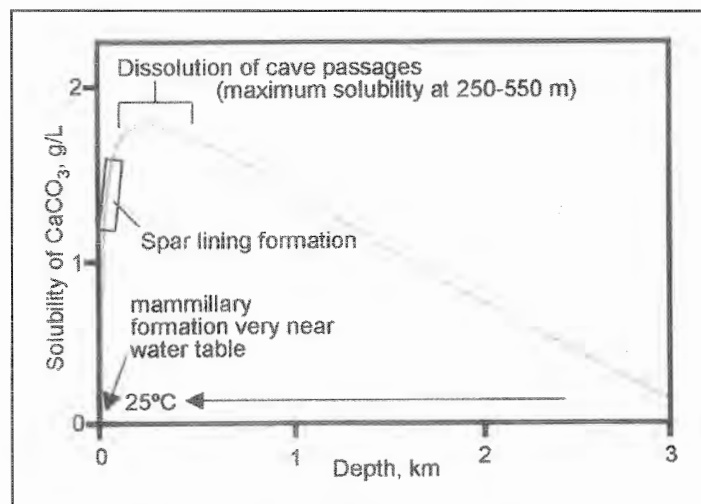
Figure 5. As convective water rises and cools, the solubility of calcite increases so that caves dissolve in the "solutional zone" at ~250-550 m depth. As the water table descends, caves are shifted into the "depositional zone" so that calcite spar lines these cave passages. Mammillary formation occurs very near the water table due to rapid CO2 loss there. After Dubylansky (1995, 2000).
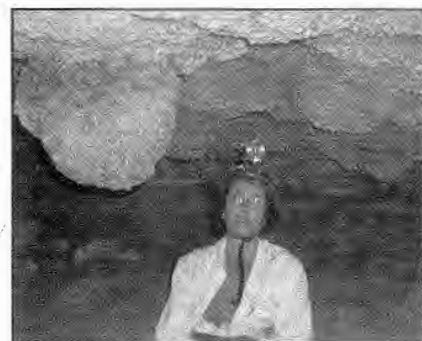
Figure 6. Calcite spar linings covering the ceiling, walls, and floor of Diamond Cave. Photo by Bob Buecher.
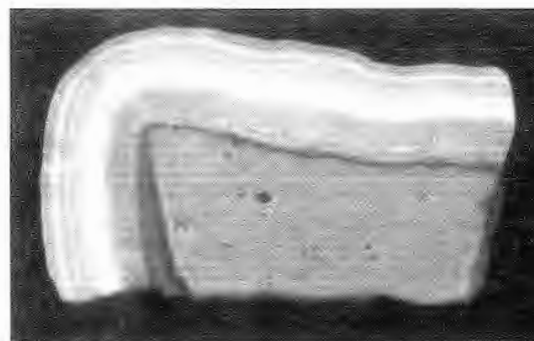
Figure 7. Cross-section of mammillary coating over bedrock, collected from Mother Cave. The mammillaries are composed of microcrystalline fibrous calcite, well suited for dating.
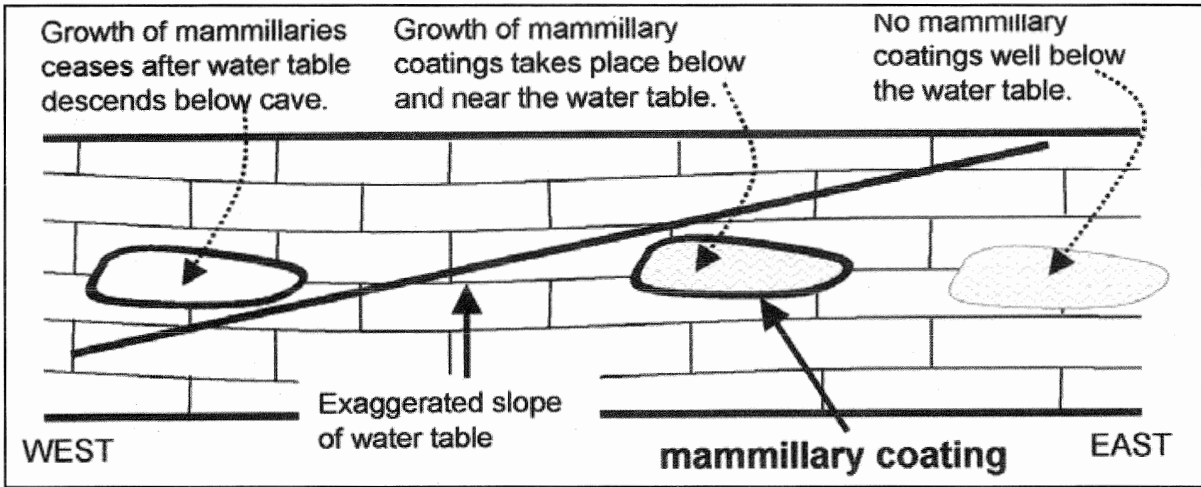
Figure 8. Mammillary coatings form near the water table where there is a rapid degassing of CO2. After the water table descends through the cave, the coatings no longer grow but are well-preserved in the cave environment.
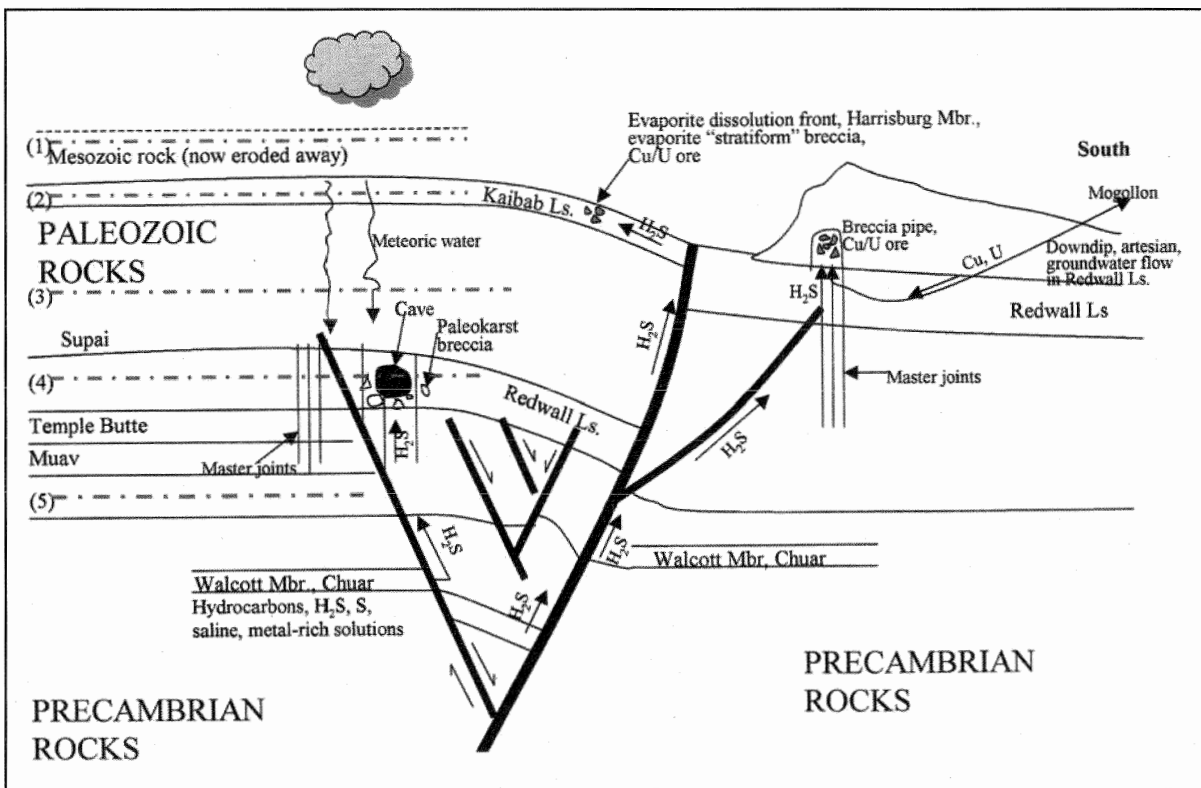
Figure 9. Idealized diagram of the progressive lowering of the water table over time in the Grand Canyon with respect to the different kinds of mine and cave deposits. (See text for explanation).

O-49

Karst on Cayman Brac

R. Tarhule-Lips, D.C. Ford

McMaster University, Hamilton, Canada

Abstract

Cayman Brac is a good example of a small oceanic carbonate island that has experienced cycles of submergence and emergence during the Tertiary and Quaternary. It is well karstified at the surface and underground. During three Tertiary cycles, carbonate rocks were deposited, uplifted and karstified, buried as paleokarst with caymanite fillings. The island was then uplifted with a minor tilt, and Quaternary limestone deposited on its coastal platform. It is girdled by cliffs with a marine notch at +6 m, the Sangamon (125 ka) high sea stand. Phytokarst is well developed on the coastal platform and the interior plateau. Caves occur all over the island. Most prominent are (i) Notch caves, developed at or 1-2 m above the Sangamon notch, and (ii) Upper caves, at varying elevations higher in the cliff faces. Notch caves and some upper caves accord to the flank margin model of speleogenesis for small islands, but speleothem dating indicates that many at the Notch are, in fact, >400 ka in age, having developed at a previous high sea stand. There has been speleothem deposition and dissolution in all caves. Major dissolution and bedrock facetting is attributed to cycles of condensation corrosion, which are modelled from field meteorological and hydrochemical data. "Bellholes", (a rare, very distinctive negative form in caves) are attributed to microbial activity utilising condensation waters in entrance twilight zones.

O-50

Looking back with Cupolas

A. Osborne

University of Sydney, Sydney, Australia

Abstract

Since the last conference at Brasilia in 2001, I have been focussing on the morphology and natural history of cupolas. I have not set out to solve the problem of the origin/s of cupolas, rather my aim has been to find out what cupolas are like, which speleogens are associated with them, in what settings (geological, geomorphic and speleomorphic) they occur and when in the history of speleogenesis do they originate. I now recognise five general types of cupolas (elliptical cupolas, cathedrals, hemispherical cupolas, conical cupolas, and spherical niches) and a range of speleogens and passage types that are frequently associated with cupolas. It is clear that our visual perception of cupolas is quite misleading. Detailed measurements and oriented images are essential to avoid this problem Last year I wrote, "cupolas appear to be common features of uncommon caves". Now I am not so sure. Cupolas are common features of thermal, artesian and other per-ascensum type caves and of flank-margin caves. The examples I have studied in detail have generally been in caves that are suspected of having non-meteoric origins. However, I continue to see and receive reports of cupolas in many "normal", stream type caves, for example in Postojna Cave in Slovenia and the caves of the Demanovska Valley of Slovakia. These cupolas are not, however whole chambers, but partial features preserved in the cave ceiling. While much research is required to test the idea, it seems possible that at least some of the cupolas in the ceilings of stream caves may be relics from earlier periods of non-meteoric speleogenesis that have been intersected by more recent stream cave development. If this is the case then cupolas may be skylights to the past and not just dark domes in the cave ceiling.

197

O-51

Filling deposits of an ancient alluvial cave system in the alpine karst of Mt. Canin

(Julian Alps, NE Italy)

PAOLO PARONUZZI [1] - DAVIDE LENAZ [2,3] - RINO SEMERARO [3]

[1] Dipartimento di Georisorse e Territorio,Università degli Studi di Udine, Via Cotonificio 114, 33100 Udine, Italy

[2] Dipartimento di Scienze della Terra, Università di Trieste, via E. Weiss 8, 34127 Trieste, Italy

[3] Geokarst Engineering S.r.l. - AREA Science Park, Padriciano 99, 34012 Trieste, Italy, rino.semeraro@area.trieste.it

Abstract

The Canin carbonate mountains (Julian Alps, NE Italy) show clear evidences of karstic systems developed at different depths with total thickness of about 1200-1300 meters. One of the oldest karstic levels is constituted by mainly horizontal galleries present from an altitude of about 1980 - 2010 m.

This study illustrates first results from a combined sedimentology and mineralogy work on filling sand-loam deposits present inside the Grotta a Nord del Monte Ursic (5430/FR 2996 at 2005 m a.s.l.) where nordstrandite [Al(OH)$_3$] have been previously found. It's a gallery cave with small transversal sections (about 10-15 m^2); the main axis is horizontal and it is almost completely filled by thin sand-loam alluvial sediments. Filling deposits are mostly constituted by thin and loam sands yellowish-brown to reddish brown in colour. The deposits are present as thick laminated sequences where thin sandy and sand-loam levels (2-20 mm thick) are interbedded with millimetric calcite laminae including a small clay fraction. The thickness of these sandy-calcitic laminae is about 3-4 m.

Thin sands and loam sands forming the laminae are mainly constituted by calcite grains (35-85 %) while the siliciclastic fraction, even if with random percentages, ranges between 20-60%. Even if the cavity develops within dolomite rocks, the clastic dolomite fraction is lower than the calcite one (5-20%) and in the lowest levels misses. Within sandy sediments, the main siliciclastic mineral is represented by quartz (5-30%). Nordstrandite, kaolinite, chlorite, muscovite/illite and interstratified clays

(smectite) are present. Nordtrandite is present in all the samples as sub-rounded transported grains and ranges between 2 and 10 %. Presence of nordstrandite could be referred to intense pedogenetic processes developed on calcareous substrata rather than to speleogenetic processes.

Staurolite, Cr-spinel, pyrite, amphibole, tourmaline and rare garnet in order of abundance are present in the heavy mineral assemblage of sandy fraction. The presence of these minerals suggests that they derived from clastic external supplies involving the erosion of pre-existing sedimentary covers.

It is to notice that the Cr-spinel-pyrite-tourmaline-garnet association suggests the dismembering and weathering of the Upper Cretaceous Flysch of Bovec where these minerals are present and their deposit in the cavity could be probably due to a fluvial transport. Presence of amphibole and staurolite within the heavy mineral assemblage points out to a metamorphic source. As they are not present in the flysch of the area it is supposed that they could be related to a different supply. It is still unclear if this supply refers to completely dismembered Oligo-Miocene molasses, Pliocene deposits or an aeolic supply.

1. Introduction

Canin Massif with its mountains reaching an elevation of about 2500 meters, is located in the western Julian Alps, between Italy and Slovenia. It is characterised by huge karst phenomena and develops along a 17 km main ridge ENE - WNW directed towards the Canin Mt and then following an ESE to WNW direction. A 5 km secondary ridge from Canin Mt follows SSE direction. The massif suffered glaciation during Pleistocene and a small glacier still exists in its Italian side, below the main peak of Canin Mt.

One of the larger European alpine karst develops in this carbonate massif, especially in the Calcare del Dachstein Formation. A network of different cavity levels, at least 17 have been recognised and among them there are 5 considered as mega-levels, sometimes connected by pits, produces cave systems reaching depth of more than 1500 meters. Subterranean karst is represented by syngenetic conduits, erosion shafts, meanders and canyons. In some levels there are also large galleries and huge chambers (Semeraro, 2000; Cucchi et al., 2002). Endokarstic filling deposits are scarce, but it is not difficult to find swallowed morains in depth. It is more difficult to find alluvial deposits or speleothems.

Recently, Cancian & Kraus (1999) noticed the presence of nordstrandite $Al(OH)_3$ in a filling deposit inside the Grotta a Nord del Monte Ursic, in the Canin massif. The mineralogical analysis carried out on two silty loam samples demonstrated the presence of phyllosilicates, quartz, feldspar, calcite and dolomite. By considering the peculiarity of the finding and its possible implications on the evolution of Canin karst, two field trips have been organised (2001 and 2002) to study the filling deposits both from sedimentological and mineralogical viewpoint.

2. Cave morphology and speleogenesis

The Grotta a Nord del Monte Ursic 5430 / FR 2996, found in 1983, is located on the northern slope of the Canin massif (Italian side). There are two entrances, closed each other, at 13° 27' 03,0" longitude and 46° 22' 18,4" latitude, located at about 1999 and 2002 meters a.s.l.. Its depth is 62 meters and the cave develops for a length of about 89 meters. The cave is located in a gully excavated within the rock slope of Ursic Mt. (2543 m). The cave develops in the "Dolomia Principale" Formation (Norian), here represented by whitish dolostones, fine-grained, massive, with concoidal fracture. Layering is oriented 80°/20° concordant with the faulted N-dipping uniclinal constituting the southern part of the massif. The cave probably originated as a consequence of an ancient standing of the phreatic level. In fact, the cave is related with a paleo-level of cavities present between 2030÷1980 meters a.s.l., where conduits with calcite and

sandy-silty deposits are present (Semeraro, 2000).

Geomorphological study allows us to subdivide the cave into three parts. The first one (points 1-2-3 in the map) is represented by an initial gallery, about 30 meters long, ending in a chamber slightly larger (3); the morphology is substantially homogeneous: a rock roof zone about 3-4 meters large, 1-3 meters above the bottom constituted by filling deposits. The second (4-5-7-8) is a narrow conduit, about 28 meters long, starting from the NW side of the hall and continuing toward a vertical pit, partially filled by collapses. The third (5-6) is constituted by a 48 meters long pit with collapsed rock blocks on the bottom. The map of the cave shows a curvilinear shape - almost ring- or meander-like -, so that the terminal conduit is closed to the initial gallery, at about the same level.

Main gallery (1-2-3) represents the oldest part of the cave. The whole roof zone shows a phreatic morphology, but the presence of crusts of thin filling deposits cemented on the roof and the walls and the fact that they are not related to the joint system suggests a paragenesis (Lauritzen & Lundberg, 2000). The N-wall shows scallop-like shapes, about 20 cm long, and a notch, while southern wall is wedge-related. The gallery shows an almost constantly overlapping ovoid section and is about 4-6 meters high.

Ovoids are unitary macro-shapes, similar to entrenchment (erosione regressive) typology described by Dematteis (1965). Ovoid sections are caused by their close overlapping along a low-dipping inclined axis. There was an evident filling phase occluding almost entirely the main gallery. The filling phase was caused by thin (up to sandy fraction) material flooding, due to a slow movement of water, alternated with rhythmic growing of calcite beds and laminae. This phase could have set off the paragenesis.

Lately the main fracture (110°/60° oriented, and other k3 system fractures) enlarged, determining the formation of the phreatic conduit at the expenses of the filling deposits. This conduit is clearly over imposed on the main gallery morphology. According to this, a major energy of water circulation, testified by the presence of sand deposits on the bottom, set off. It is possible that, during this phase, a lowering of water table, combined with massif erosion, caused the pit formation on k3 system fracture. The pit, by driving waters to major depth, deactivated cavity, fossilising it.

More recently, the slope pulling-back determined the present entrance. Thermocrioclastic phenomena began, provoking collapses that are present within 10 meters from the entrance. Within this area, cross-section shows a strong structural control caused by rock breakdown and fracture exposures.

3. Sandy-silty filling deposits

Inside the initial gallery, at about 20 meters from the entrance, sandy and loam deposits, yellowish-brown to reddish-brown in colour (7.5YR 5/6, Munsell Soil Color Chart), are present. Loose sediments are widely present along the gallery between the points 2 and 3 (see map) for about 15 meters. They fill almost completely the cavity, forming both the pavement cavity and some thin concretions covering the dolomite side walls. The sandy-loam deposits are present till the larger sector of the chamber (3) constituting its bottom and seems to continue towards major depth following the actually closed NNE gallery development. Successive erosion determined the outcropping of deposits, provoking their partial removal and their presence as relict plates and encrusting on the walls. According to the cross-sections of the gallery the maximum thickness of these deposits could have been about 4 - 6 meters.

In correspondence with the relict plates present at the N-NE end of the chamber (3) it is possible to notice a well developed thin layering, where thin sandy and loam sediments are interbedded with silty sandstones and calcite laminae. Sandy-loam layers are mainly 0.5 - 2 cm thick, while
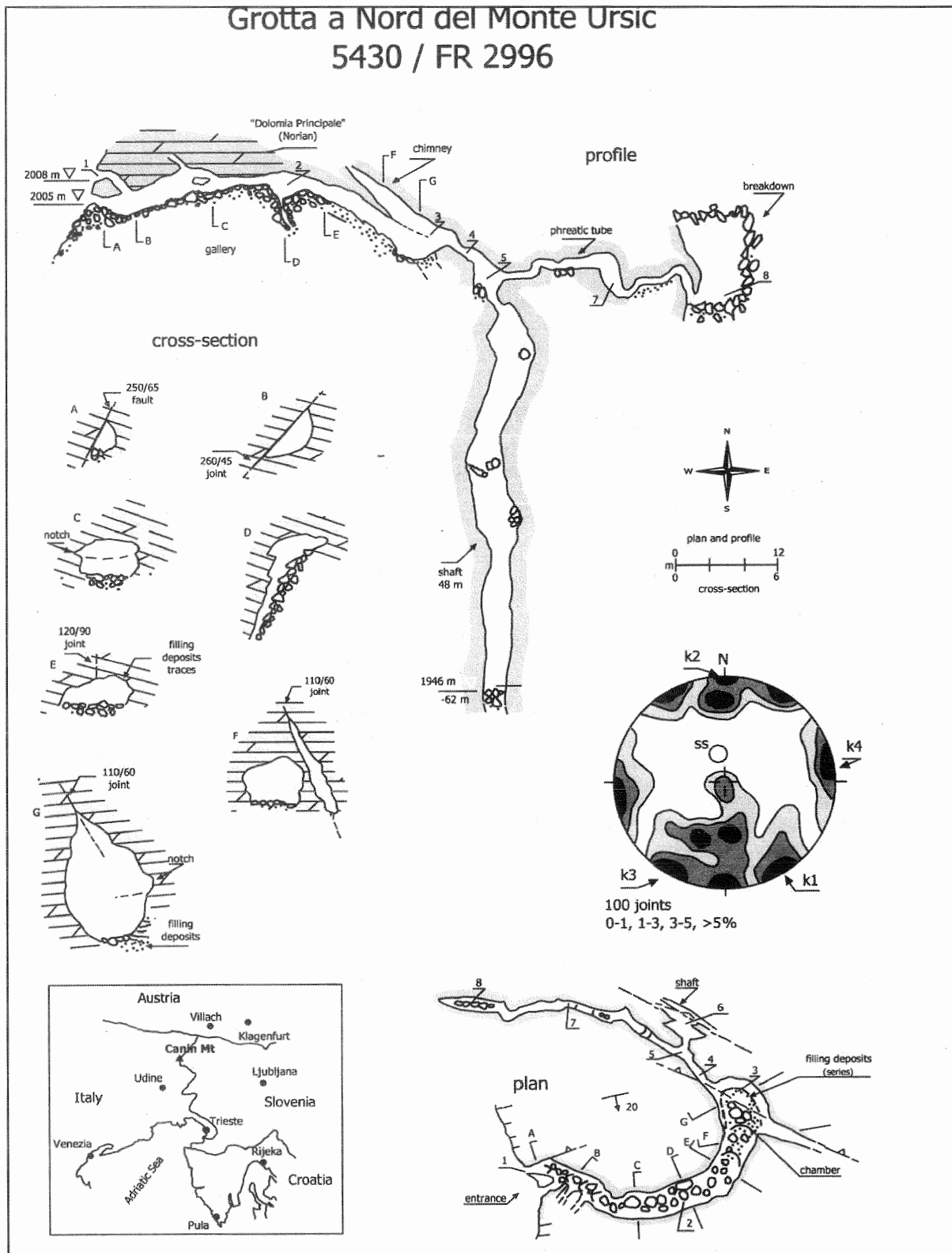
Grotta a Nord del Monte Ursic
5430 / FR 2996

"Dolomia Principale"
(Norian)

profile

chimney

F

G

breakdown

2008 m ▽   1   2

2005 m ▽

3

4

phreatic tube

5

8

A   B   C

gallery   E

D

7

cross-section

250/65
fault

A

B

260/45
joint

C

notch

D

120/90
joint

filling
deposits
traces

E

110/60
joint

F

shaft
48 m

110/60
joint

G

notch

filling
deposits

1946 m
-62 m

N

W   E

S

plan and profile

0   12

m

0   6

cross-section

k2   N

ss

k4

k3   k1

100 joints
0-1, 1-3, 3-5, >5%

Austria

Villach

Klagenfurt

Canin Mt

Udine

Ljubljana

Italy

Slovenia

Trieste

Venezia

Rijeka

Adriatic Sea

Croatia

Pula

8

shaft

6

7

filling deposits
(series)

5   4

3

plan

20

G

chamber

A

B   D   E F

1

C

entrance

2

calcite laminae are 1-4 cm forming layers with more or less irregular surfaces. The thick layering is gently concave and inclined (5-15°) towards the centre of the gallery. Laminae generally shows regular, smooth and sometimes undulated surfaces. Contact within the deposits and the lamine is sharp. Sometimes, within the thicker layer it is possible to recognise a gradation due to some 1-3 mm thick strata formed by a calcite - fine sandstone - silty sand sequence. Within the thicker sandstone layer (3-4 cm), irregular calcite nucleuses caused by intergranular precipitation are present.

The internal structure of the deposit seems to be related to sedimentary processes instead of secondary intergranular cementation processes. These processes, even if present, are influenced by the original layering of the deposit and increase their importance closed to the cavity wall/deposit contact. In this position calcite figures such as dolls, spherical and ellipsoidal concretions caused by intergranular secondary cementation (Sarigu, 2002) can be found. Due to this fact it is more difficult to find the layered structure of the deposit when observing the wall crusts. In fact, water flows along the walls aids the formation of secondary cementation provoking the modification and cancellation of the original layering.

Sedimentological and mineralogical analyses of filling deposits have been performed on three sampling sequences: the first one is a wall crust in the terminal chamber (3) (240 cm, U1-U16 samples), the second is a relict of strong layered deposits (B section; about 25 cm, U109-U100 samples), the third is represented by surface pavement deposits (C section: U203-U200 samples) in order to compare the different characteristics of filling deposits.

Deposits always present thick laminae (ritmites) where thin sand and loam layers (5-40 mm) are interbedded with sandstones and calcite laminae sometimes with a small clay component. Alternate clastic and calcite cyclic sedimentation can be attributed to a low-energy fluvial environment. Episodes of water flow transporting silts and sandy loam into the cave system are present and are alternate with inactivity period causing speleothems formation. This mixed clastic-chemical deposition seems to be quite peculiar and is not comparable with most known Quaternary cave sedimentary sequences. The monotonous character of the sequence and its internal structure suggest a constancy in the sedimentary environment responsible of the deposition. The progressive filling of gallery system continued without break till the complete closure of the cavity. By considering the characteristic of the deposits and their thickness it is possible to suggest that deposit formation occurred in a time range spanning from 20000 to 50000 years.

Originally sandy loam deposits probably filled the gallery, this fact being confirmed by the presence of other totally filled cavities found nearby the Grotta a Nord del Monte Ursic. A similar situation is documented by the cavity relict, completely filled, located about 280 m to the WSW of the here studied cave. Here, it is possible to see the cross-section of a small cavity (about: 1.20 x 2.00 m) developed within dolomites, with layer thickness of about 1-3 m and 40°/20° oriented. This deposit is quite similar to those found inside the Grotta a N del Monte Ursic, being the sandy loam fraction removed by atmospherics. Even in this cave ritmites are well recognisable, with planar-ellipsoidal low-dipping (60°/20-25°) laminae and thin layers.

4. Mineralogy

X-ray diffraction patterns were obtained on powdered sandy samples and on oriented samples for silt and clay fractions using a STOE-D500 X-ray diffractometer at room temperature. Cuka radiation was used through a flat graphite crystal monochromator. Sands were obtained by sieving samples and cleaning them in ultrasonic bath. After drying at about 50°C, grains were observed under a binocular microscope.

In the coarser fraction few samples from section B were analysed. Cal-

cite, quartz and dolomite (in one sample only) were recognised in different amounts.

As regards the silt fraction all the samples were analysed. In section A, calcite, dolomite, kaolinite, muscovite, chlorite and quartz have been recognised. Carbonate minerals represent about 90% of the samples. In section B, the same minerals are present, but carbonate minerals are less evident than in section A. Dolomite is missing in the lower levels. In this section nordstrandite, $Al(OH)_3$, occurs. In Fig. 2 the percentages of main phases in silt fraction of samples from section B are represented. In section C, calcite, interstratified clay minerals, kaolinite, muscovite, chlorite, quartz and nordstrandite are present. Nordtrandite is present in all the samples as sub-rounded transported grains and ranges between 2 and 10 %.

As regards the clay fraction all the samples were analysed. It seems that clay fraction is below 10% of pelitic fraction. In section A, the same minerals of the silt fraction are present with higher amounts of clay minerals. Sometimes brushite, $CaHPO_4 2H_2O$, is present and it is probably related to bat guano. In section B, calcite, dolomite, kaolinite, muscovite, chlorite and quartz have been recognised. In section C, calcite, interstratified clay minerals, kaolinite, muscovite, chlorite and sporadic nordstrandite occur.
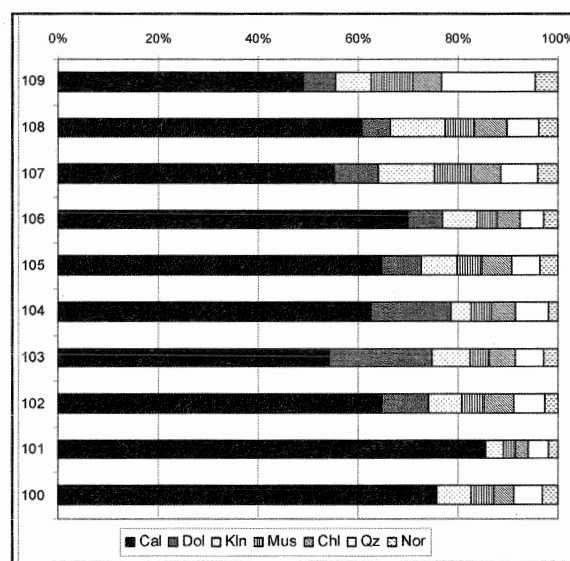
Fig. 2: Percentages of main mineralogical phases in B section

Fe-oxide and -hydroxides represent the main constituents of the heavy mineral magnetic assemblage. Among these, at least five other mineral phases have been recognised: blue-green amphibole, staurolite, Cr-spinel, garnet and tourmaline (green to brown; probably shorl-dravite series). In section A, the most abundant mineral is staurolite, followed by Cr-spinel and amphibole, garnet and tourmaline are sometimes present as traces. In section B, staurolite and amphibole are the main phases with only rare Cr-spinel and tourmaline. Few grains of oxidised pyrite occur in different levels.

Tables 1 and 2 refer to the number of heavy mineral present in the heavy mneral assemblage and their percentages. It is to notice that only two high levels show a number of heavy minerals higher than 100 and there are two samples with about 30 crystals. All the other levels are very poor.

Table 1: Number of grains in the heavy mineral (HM) assemblage and total number of heavy minerals in each sample.

Sample	amphibole	staurolite	tourmaline	garnet	pyrite	Cr-spinel	Total HM
109		6					6
108	21	79	10	1	2	4	117
107	20	94	8		3	2	127
106	4	30					34
105	4	8					12
104	3	8					11
103	3	15			1		19
102	3						3
101	3	13					16
100	13	15	2		2		32

Table 2: Percentage of heavy minerals (HM) in each sample.

Sample	amphibole	staurolite	tourmaline	garnet	pyrite	Cr-spinel	Total HM
109		100					100
108	17.9	67.5	8.5	0.9	1.7	3.5	100
107	15.7	74.0	6.3		2.4	1.6	100
106	11.8	88.2					100
105	33.3	66.7					100
104	27.3	72.7					100
103	15.8	78.9			5.3		100
102	100						100
101	18.7	81.3					100
100	40.6	46.9	6.3		6.3		100

5. Conclusions

The sedimentological and mineralogical study of filling deposits of the Grotta a Nord del Monte Ursic constitutes an important knowledge in order to reconstruct the evolution of Canin Mt karst system, and especially as far as regards the genesis of the oldest gallery system. The integrated geomorphological - sedimentological - mineralogical analyses show the existence of a very ancient karstic phase when a fluvial network was active and responsible of the formation of a huge system of gallery cavities. This network, mainly sub-horizontal, is recognisable at an altitude of about 2030÷1980 as a system of relict passages - completely filled - that have been exhumed by Late Pleistocene and Holocene erosion. Due to the extreme fragmentation of passages it is quite impossible to define the main direction of the drainage of this ancient system, nevertheless it is evident that in this area all the drainages are directed towards NE.

Many aspects suggest that these passages began to develop in ancient times, maybe since the Pliocene time: first of all, fossil cavities are not related with present topographic and hydrographic elements and outcrop on rock slopes. The sedimentological and mineralogical features denote a sedimentary environment quite different with respect to the well known Pleistocene and Holocene stratigraphic cave sequences. The peculiarity of these deposits is also confirmed by the presence of nordstrandite grains in clastic sediments. This fact has not been reported in this alpine sector or nearby. It is possible that nordstrandite derived from the erosion of mature soils (bauxites) formed on calcareous-dolomitic bedrock. Successively, nordstrandite grains, removed by an alluvial system have been settled down within the well developed fluvial karst system of Canin Mt. All these facts suggest that the ancient galleries and their filling deposits are related with a karst system developed during Pliocene, when morphological and climatic context were very different from the present.

As far as concern mineralogy, the presence of quartz and muscovite between the main phases points out to a metamorphic source. This seems also suggested by the presence of amphibole and staurolite in the sand. They are not present in the flysch of the area (Kuščer et al., 1974; Lenaz et al. 2000), so that a different origin has to be considered. It is still unclear if this supply refers to completely dismembered Oligo-Miocene molasses, Pliocene deposits or an aeolic supply. On the contrary the Cr-spinel-pyrite-tourmaline-garnet association suggests the dismembering and weathering of the Upper Cretaceous Flysch of Bovec where these minerals are present (Kuščer et al., 1974; Lenaz et al. 2000) and their deposit in the cavity could be probably due to a fluvial transport.

References

Cancian, G., Kraus, M., 1999: Prima caratterizzazione della nord-strandite Al(OH)₃ nel massiccio carsico del Monte Canin (Alpi Giulie). Atti VIII Conv. Reg. Spel. Friuli-Venezia Giulia, Cave di Selz (Ronchi dei Legionari, Gorizia) 1999, 61-66.

Cucchi, F., Casagrande, G., Manca, P., 2002: Il contributo della speleologia alle conoscenze geologiche ed idrogeologiche del massiccio del M. Canin (Alpi Giulie). Mem. Soc. Geol. It. 57, 471-480.

Dematteis, G., 1965: L'erosione regressiva nella formazione dei pozzi e delle gallerie carsiche. Atti 9° Congr. Naz. Spel., Trieste 1963, Rass. Spel. It. Mem. 7 (2), 153-163.

Kuščer, D., Grad, K., Nosan, A., Ogorelec, B., 1974: Geološke

raziskave soške doline med Bovcem in Kobarid (Geology of the Soča Valley between Bovec and Kobarid). Geologija 17, 425-476.

Lauritzen, S.E., Lundberg, J., 2000: Solutional and Erosional Morphologiy. In: Klimchouk, B., Ford, D.C., Palmer, A.N., Dreybrodt, W. (Eds.), Speleogenesis. Evolution of Karst Aquifers, Nat. Spel. Soc., Jan. 2000 Ed.Huntsville, Alabama, U.S.A., 527 pp.

Lenaz, D., Kamenetsky, V.S., Crawford, A.J., Princivalle, F., 2000: Melt inclusions in detrital spinel from the SE Alps (Italy-Slovenia): a new approach to provenance studies of sedimentary basins. Contributions to Mineralogy and Petrology 139, 748-758

Sarigu, S., 2002: Figure da precipitazione intergranulare nella Grotta di Su Mannau (Sardegna sud-occidentale). Atti Conv. "Il carsismo e la ricerca speleologica in Sardegna" Cagliari 23-25 novembre 2001, "Anthèo" 6, 89-106.

Semeraro, R., 2000. A hypothesis of paleogeography in the Western Julian Alps and its role in the karstic development of Mt Canin. Ipogea 3, 117-166.

O-52

A simple growth model for allogenic pedestals in glaciated karst.

Stein-Erik Lauritzen

Department of Earth Science, University of Bergen

Allegaten 41, N-5007 bergen Norway, Stein.lauritzen@geo.uib.no

Abstract

Limestone pedestals (Karrentische) are believed to develop by differential corrosion beneath and around a protecting boulder. Here, we develop mathematical models for the size of limestone pedestals as a function of time and the properties of the perched boulder. These properties are the shortest horizontal axis of the boulder, its shape factor and the rate of condensation corrosion beneath it. Because the shielding effect will decrease with increasing pedestal height, pedestals will, over time, attain a finite, steady-state height. The time needed to aquire the steady-state height is considerable, and probably longer than the Holocene (10,000 years) for most sites. The present-day height of pedestals in a given site is dependent on up to 3 different parameters that are likely to vary within a pedestal population. Hence, the model also explains the variability observed in pedestal heights within a site. A method for estimating the total denudation by means of measurable pedestal properties was developed and tested with favorable outcome on pedestal populations at the Svartisen karst, north Norway and in north-west Spitzbergen.

Limestone Pedestals.

Limestone pedestals (Karrentische, Bögli 1960) develop underneath boulders. The perched block can either be an allogenic, non-karstic rock type (for instance, a glacial erratic in alpine karst) or it can be an in situ piece of the local limestone (autogenic). The formation of a pedestal is due to differential corrosion between the area beneath the boulder and the surrounding area, Figure 1a. The corrosion rate beneath the boulder is lower than elsewhere because the boulder acts like an umbrella and protects the limestone surface below from the action of corrosive precipitation. Pedestals are mostly found in glaciokarst settings, where the growth process was zeroed by glacial erosion when the erratics were laid down.

In the karst geomorphological literature, much attention has been given to the height of pedestals, and to their significance as measures of total denudation in bare and alpine karst settings (Ford & Williams 1989, Bögli 1961, Peterson 1982, White 1988). The average or maximum height of pedestals have been taken as equivalent to the total denudation; this is rarely the case. Here, we develop a simple mathematical model for pedestal growth, which aims at determining the total denudation of the area outside the pedestal (Lauritzen 1997). This growth model also explains the variability observed in pedestal heights.

Qualitative properties of pedestals

The following observations are based on alpine sites in Norway and Spitsbergen. Within the same area, pedestal heights reveal a rough positive correlation with the size of the perched boulder, although there is a considerable spread and linear models do not work (e.g. Finnesand 2002, 2003). There appears to be a lower threshold for pedestal growth, because pedestals are absent beneath small boulders.

The top surface of the pedestal, beneath the boulder, is always rugged and pitted, indicating that corrosion is going on even under the largest boulders. (The largest boulder observed by the author was more than 4 m across). This corrosion mechanism may be ascribed to condensation
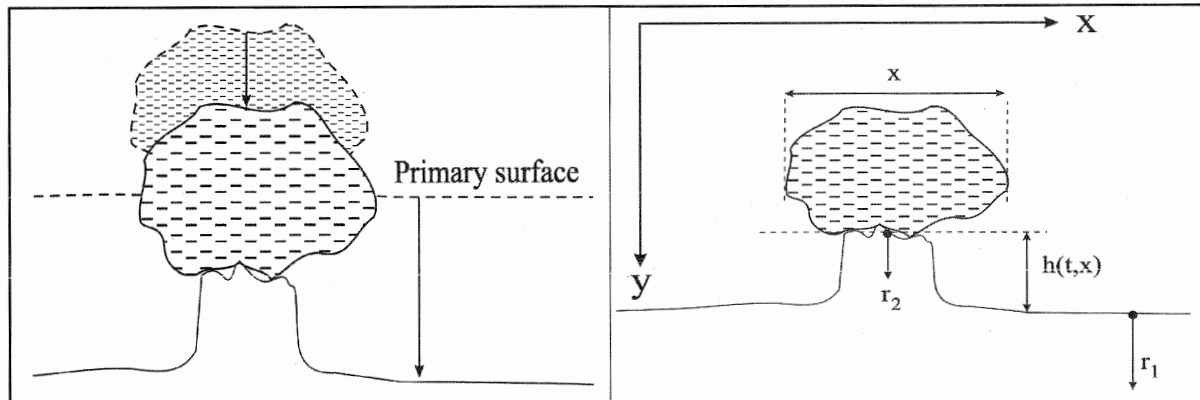
Figure 1. Left: The height of an allogenic pedestal is a function of differential corrosion benath and around the perched block. The height of any such pedestal is only a minimum measure of the total denudation at the site. Right: Coordinate system and variables used in the growth model.

(ε, see below). A block resting on the ground will not only shelter against direct rainfall, but is also a locus of long-lasting, low levels of moisture. Therefore, even the highest pedestals are only a minimum measure of the total denudation around them.

Supporting evidence for various condensation and evaporation-related processes beneath the boulders is the existence of botryoidal precipitates on minor protrusions and edges, due to seasonal evaporation. This is also a common phenomenon on many other karst surfaces, like the sharp edges of rillenkarren.

It must also be kept in mind that there is some difference between the authogenic karrentische (described by Bögli 1961) and allogenic pedestals carrying a non-carbonate, glacial erratic. Only allogenic pedestals have uniquely defined initial conditions, i.e. resetting of the process at t=0. The commencement of growth is not well defined for authogenic blocks resting on its actual bedding plane parting, thus the height of the pedestal is not necessarily a precise measure of the post-glacial denudation of the site. In this case, the pedestal is the exhumed, or 'Hodoo type' (Lauritzen 2005).

The observed evaporational precipitates and the attenuated corrosion deduced for authogenic blocks add complexity to the problem. A growth model which include all these effects will inevitably become extremely complicated and have little but theoretical interest. A simplistic, approximate model which in some way summarize these effects is preferable. A growth model should, as a minimum, accommodate the following criteria:

1. There is a minimum, or threshold size, x_{min}, for a boulder to produce a pedestal. The function describing pedestal height with respect to boulder size must not pass through the origin.
2. The function must include the condensation corrosion that occurs beneath all boulders, regardless of their size.
3. In order to be practically applicable, the model should be as simple as possible.

The model

The observed pedestal height is a result of two independent corrosion rates acting on the karst surface, the rate outside the boulder (r_1), and the rate underneath the boulder (r_2). r_1, is acting everywhere on the surrounding rock surface, and is identical to the surface denudation rate of the location, Figure 1. It is independent of the properties of the boulder, or even the existence of it. Beneath the erratic boulder, the surface is shielded, depending on various properties of both the boulder itself and of its surroundings.
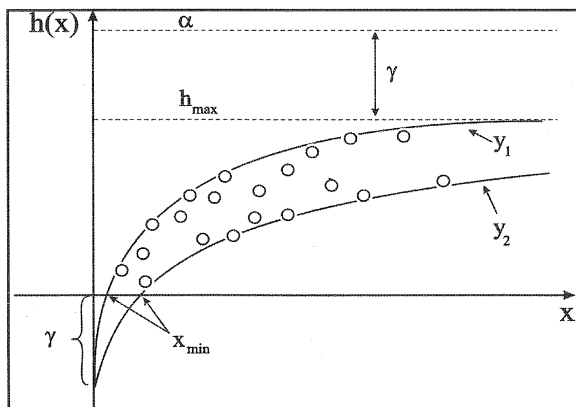
Figure 2. Pedestal growth model, eqn(3). Pedestal height as a function of boulder 'size' is represented by a family of functions, sharing the same α and γ, but with different β. (y_1) and lower (y_2) boundary is shown.

As a first approximation we assume shielding is caused entirely by a shape effect (β), i.e. shielding increases with the 'size' of the block. This effect is controlled by the boulder's ability to keep the underlying rock surface dry from snow and rain. Hence, the shortest horizontal axis of the boulder should be a better measure of shielding than for instance, the shadow-equivalent area. We have :

$$\frac{d r_2}{d t} = -b r_1 \quad with \quad \begin{cases} r_2 = r_1 + e & x = 0 \\ r_2 = e & x \to \infty \end{cases} \tag{1}$$

with solution: $r_2 = r_1 e^{-bx} + e$ (2). The differential rate, $r_1 - r_2$ is integrated with respect to time, and simplified to:

$$h(x) = \begin{cases} 0 & ; x \le x_{min} \\ a\,(1 - e^{-bx}) & ; x > x_{min} \end{cases} \tag{3}$$

where h(x) is the height of a given pedestal beneath a boulder with size x, α is the total denudation far away from the pedestal, β the shielding efficiency, or 'umbrella factor', and finally, γ the amount of condensation corrosion acting on all surfaces, also beneath the boulder. The smallest boulder that can support a pedestal then becomes:

$$x_{min} = -\frac{1}{b} \ln\left[\frac{a - g}{a}\right] \tag{4}$$

The scatter of pedestal heights as a function of boulder size (e.g. shortest horizontal axis) can then be explained with a family of functions (eqn 3), all sharing the same α (i.e. total denudation), but having different β and γ, Figure 2.

Estimating the total denudation (α).

Given a large number of pedestals one may fit curved functions to the data set to accommodate a common α, but with various β and γ values. This may be done by trial and error on a spreadsheet or by designing proper computer algorithms. The model (eqn. 3) may be linearized to:

$$\ln\left[(a - g) - h(x)\right] = -bx + \ln a \tag{5}$$

Realizing that (α - γ) = h_{max}, i.e. the maximum, asymptotic pedestal height, ln(α) may be determined by the y-intercept of straight lines (for
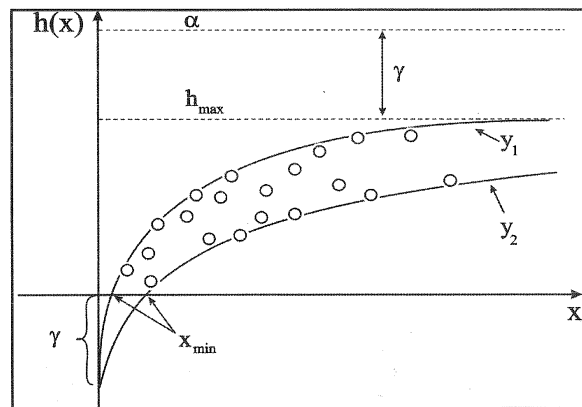
Figure 3. Pedestal data linearized according to eqn (5). The slope of each line is equal to the umbrella factor (), so that this can be determined for each individual.

various β) fitted to a plot of ln[h_{max}-h(x)] versus ln(x), Figure 3. h_{max}, and thereby the common y-intercept (ln(α)) for upper and lower boundary functions (Figure 2) may be determined by iteration. This was done for 4 different pedestal populations, 3 at Svartisen (at The Arctic Circle in North Norway, 67°N) and one at Blomstrand, Svalbard (78°N).

The results are shown in Table 1. Total denudation (α) is 25 - 80 % higher than the highest observed pedestal, but still in accord with independent assessment of the total post-glacial denudation for the sites. Such assessments are the maximum extent of protruding quartz veins, (extrapolated) micro-erosion meter readings, and hydrochemical denudation estimates, e.g. Lauritzen (1983, 1991). For example, for the Pikhaugene karst at Svartisen, we find that α = 200 mm, 1.7 times the highest observed pedestal h(x) = 120 mm. However, the highest observed protruding quartz vein at 220 mm in the area is in good accordance with this higher value. We may assume solutional denudation of a quartz vein as neglible in this environment and timeframe. Assuming that post-glacial denudation time is some 10 ka, this corresponds to 0.020 mm/year, in good accordance with the micro-erosion meter rate (during 14 years) of 0.018 mm/year. Hydrochemical denudation (the autogenic component) is 0.033 mm/year (Lauritzen 1991) which incorporate both exo- and endokarst solution.

What controls the umbrella effect?

In a linearized scatterplot, we may identify families of pedestals sharing the same value of β. So far (august 2004), more than 200 pedestals have not only been measured, but also subjected to accurate photogrammetric shape analysis, GPS positioning, and evaluated in micro- and macroscale landscape context. Multivariate analysis of these data is in progress and will hopefully reveal the factors that most effectively determine the 'umbrella effect'. This work will be presented later. However, just by evaluating photographs of pedestals that display extreme β values, it is very suggestible (or obvious) that boulders with flat or concave underside and distinct drip-edges tend to have high β values, whist boulders with convex undersides and no drip-edges have the lowest β values of them all, Figure 4.

Large pedestals.

As the pedestal grow taller, the sides of the pedestal and the underside of the boulder becomes more exposed, and we should expect the shielding effect to decrease with the aquired height of the pedestal. Given sufficient time, the ultimate fate of a pedestal is extinction, as the top surface of the pedestal may get sufficiently rounded to let the block fall off, and even a new cycle may commence. We may also conceive a steady-state condition, where $r_1 = r_2$. A time-dependent model for pedestal growth is:

$$h(t,x) = \frac{r_1(1 - e^{-bx}) - e}{d}(1 - e^{-dt})$$

(6)

where x, β and ε are as before, and the additional parameter δ describes the inhibition of growth rate as a function of aquired height. A cartoon of a pedestal's life cycle is depicted in Figure.5. Except for very small boulders, it is unlikely that any of the pedestals in the four study areas have attained their maximum height, suggesting that a timespan much longer than the postglacial (> 10 kyr) is needed to see this effect
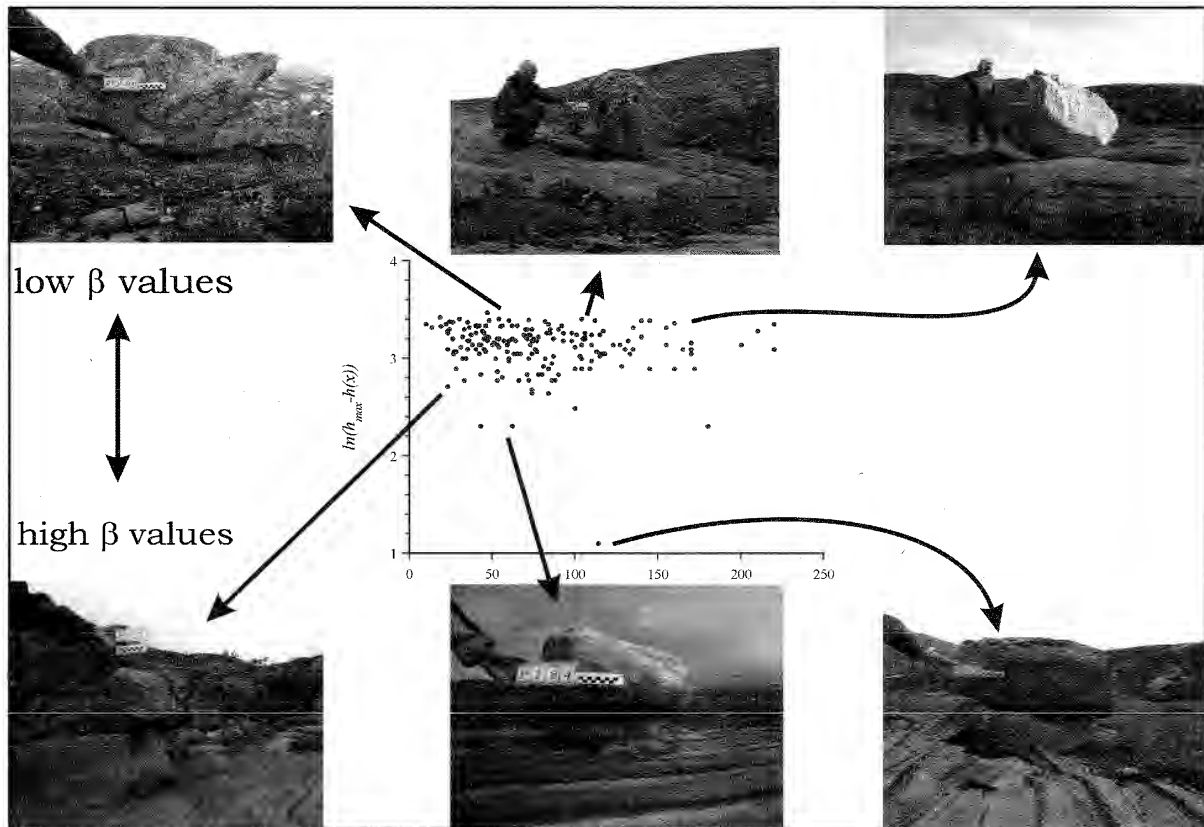
Figure 4. Identifying boulders with various β value in a linearized plot. High β blocks display pronounced drip edges or flat undersides, low β blocks have generally sloping or convex undersides, according to the concept of an 'umbrella effect'. Data set of 185 pedestals at Glomfjell, Svartisen, north Norway
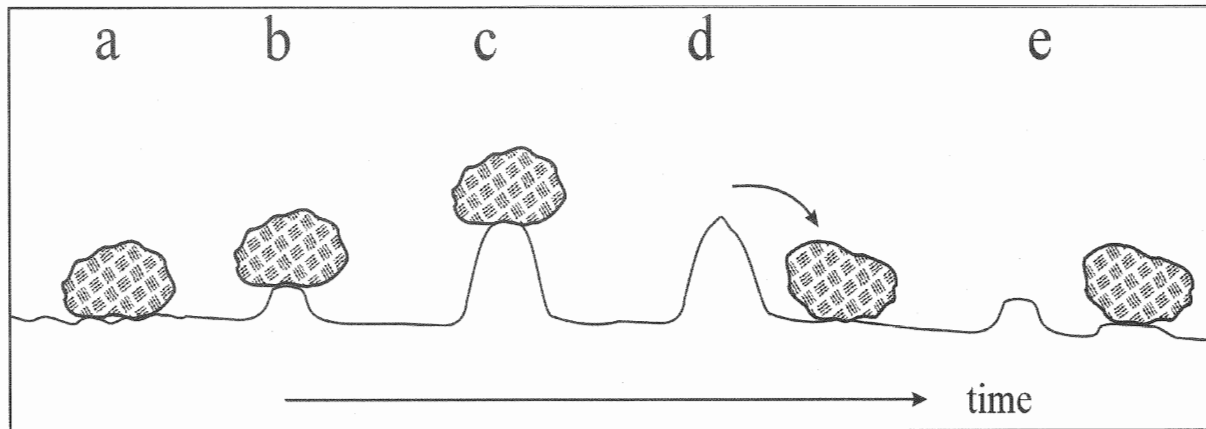
Figure 5. The life cycle of a pedestal. a) commencement of growth, the block is left on a glacially smmothed surface (t=0). b) Shielding (β) is optimal and the pedestal grows fast. c) The pedestal becomes so high that the sides are attacked, and it may reach a steady-state constant height. d) most likely, the pedestal will become rounded and the block will fall off before stage c) is reached. e) a new cycle begins while the old pedestal becomes degraded.

Table 1

Pedestal parameters for various sites (All lengths in mm.)

Location	α	Hmax	Factor[1]	γ1	γ2	β1	β2
Central Glomfjell	330	260	1.26	70	160	0.0033	0.0009
Fiskvatn	260	160	1.62	90	140	0.0035	0.002
Pikhaug	200	120	1.66	60	60	0.003	0.00075
Blomstrand	65	36	1.80	25	45	0.07	0.05

[1] "Factor" is α / h_{max}.

Conclusions.

A mathematically simple growth model for allogenic pedestals has been developed. The model has three adjustable parameters, the total denudation of the site, outside the pedestal (α), its umbrella factor (β), and the condensation corrosion acting on all surfaces (γ). This allows us to determine the total, post-glacial denudation of the site from measurable properties of a pedestal population. Estimated total denudation is then some 25- 80% higher than the maximum observed pedestal height.

References.

Bögli, A. (1960) Kalklösung und Karrenbildung. Zeitschrift für Geomorphologie, Suppl. 2, pp. 4-21;

Bögli, A. (1978) Karsthydrographie und physische Speläologie Springer-Verlag, Heidelberg, 292. pp.

Finnesand, S. (Lauritzen, S.E.) (2002): Analyse av karstformer i Glomfjellområdet ved Svartisen. Cand Scient. Thesis, Department of Earth Science, Bergen University, 147 pp.

Finnesand, S. (2003) Analyse av overflateformer i Glomfjellområdet ved Svartisen. Norsk Grotteblad. (41), pp. 3-32.

Ford, D.C. & Williams, P.W. (1989) Karst geomorphology and Hydrology Unwin Hyman, London, 601 pp.

Lauritzen, S.E. (1991): Autogenic and allogenic denudation in carbonate karst by the multiple basin method: an example from Svartisen, North Norway. Earth Surface Processes and Landforms, 15, pp 157-167.

Lauritzen, S.E. (1997) A simple growth model for limestone pedestals: determination of surface karst denudation. Supplementi di Geografia Fisica e Dinamica Quaternaria, III, pp. 242-243

Lauritzen, S.E. (2005) A simple growth model for limestone pedestals. Abstract at the 18th. Kongsberg Seminar, Norway (may 3-5, 2005).

Peterson, J.A. (1982) Limestone pedestals and denudation estimates from Mt. Jaya, Irian Jaya. Australian Geographer, 15, pp. 170-173

White, W.B. (1988) Geomorphology and Hydrology of Karst Terrains Oxford; University Press, New York, 464 pp.

O-53

The karstic forms and the Greek mythology

I.D. Mariolakos

National and Kapodistrian University of Athens, Faculty of Geology and Geoenvironment, Division of Applied Tectonic, Applied Geology

It is well known that man since he appeared on earth found use for the different karstic formations. He used the karstic springs for water supply, while caves were used either as permanent or periodic settlement or for the storage of goods.

In Greece, where carbonate rocks cover more than 30% of its total surface and the majority of them are karstified, there is a direct relation between humans and the karstic forms dating back to the Paleolithic age until nowadays.

In the Greek Mythology, many actions of the most ancient deities, such as the Titan Rhea, Poseidon, Demeter and Zeus, are directly connected to different caves. Even younger heroes, among them Theseus but mainly Hercules are related to karstic springs, sinkholes and poljes.

The most well known are the following:

- The Titan Rhea, mother of Poseidon and Zeus, is related to the homonymous cave, located on Mount Mainalo in Arcadia.
- Zeus was brought up in a cave on Pseiloritis mountain, in Crete island.
- Poseidon is connected to the coastal and submarine springs in the bottom of the Argolic Gulf, near the actual village of Kiveri. This is a karstic spring system composed of more than one spring, known

since Antiquity as "Dini spring". Dini spring discharges the water that accumulates in the Argo Pedio polje and flows into the Nestani sinkhole, located in the Tripolis plateau. This underground hydraulic connection was known since the ancient times.

- Hermes was born in a cave on Kyllene mountain. Kyllene was part of Arcadia at ancient times.
- Demeter, sister of Zeus and Poseidon, lived in a cave in the same area (Arcadia) for a great period of time.

These facts, and many others, describe the relationship between the great Gods during the older prehistoric times.

Apart from these, many heroes of younger prehistoric and mainly Mycenaean times are related to caves, such as Ulysses, Theseus and Hercules. Especially Hercules can be considered as the "hydrogeologist - hydraulic engineer" of the Mycenaean times, specialized in karstic hydrogeology, since three of his more important mythical labours are related to karst: the myth of the Lernean Hydra, the myth of the Stymphalian birds and the destruction of the drainage and anti-flooding works of the Minyans in the plain of Kopais. Especially in the myth of the Lernean Hydra, all the mythical details coincide with the hydrogeologic conditions of karstic system of Lerni springs.

O-54

Grotte e Leggende Dell' Antica Grecia

FRANCO GHERLIZZA

(Club Alpinistico Triestino - Gruppo Grotte)

Riassunto

Non ci sono dubbi che il patrimonio mitologico dell'antica Grecia sia il più famoso e il più conosciuto al mondo, questo, senza togliere nulla a quello di altri paesi che, comunque, vantano un corposo pantheon di dei, eroi, esseri e animali fantastici.

Su tutti spiccano (grazie a una sterminata produzione letteraria, teatrale e cinematografica), i temi cari ad Omero: la guerra di Troia (Iliade) e le conseguenti peripezie di Ulisse (Odissea). La grande popolarità acquistata dalla famosissima saga omerica ha dato, ai personaggi che la animano, una notorietà che, per altri testi antichi, è stata sicuramente di minore impatto presso il grande pubblico.

Ecco che, limitatamente al "soggetto" grotta, ci si limita al ricordo della grotta di Polifemo e della maga Circe, per l'Odissea e alla descrizione del Tartaro da parte di Zeus, nell'Iliade.

Per tutte le civiltà della terra, invece, le grotte erano un elemento indispensabile e sempre presente nei loro miti. Nella maggioranza dei casi erano collegate agli inferi (o, comunque, all'oltretomba), ma non mancano rappresentazioni che le descrivono come luoghi di culto, dimore di dei, rifugi di briganti, tane di mostri o prigioni dove detenere, nascosti al mondo, uomini e animali.

Nel presente lavoro vengono presentati quei personaggi, della mitologia classica, le cui storie si svolgono - con motivazioni e scopi diversi - all'interno di grotte, caverne o ipogei artificiali dell'antica Grecia.

Al folklore ipogeo ellenico sono stati associati, oltre ad alcuni dei più famosi dei dell'Olimpo (Ade, Zeus, Hermes, Dionisio), anche diversi eroi (Eracle, Teseo, Orfeo, Ulisse). A questi, seguono delle divinità minori (Erinni, Naiadi, Arpie, Nereidi, Centauri, Ciclopi), affiancati da un inquietante e fantasmagorico campionario di esseri mostruosi, sia umani che

animali (Scilla, Cariddi, Cerbero, Echidna, ecc.).

È la "valorizzazione" di un ambiente unico e parallelo a quello epigeo, nel quale si svolgono le vicende terrene di uomini e dei. Valore dato dall'innegabile realtà che la grotta (qualora venga citata con cognizione di causa) è un punto fisico, ben determinato e riscontrabile sul terreno con precisione.

Con l'identificazione della grotta (ingresso o interno, non fa differenza), il mito si fissa, senza possibilità di errori, nel luogo esatto che gli antichi avevano scelto per renderlo "vivo".

Condizione che non può essere riferita ai monti, alle colline o alle pianure (e tanto meno alle regioni) che, pur essendo ben riconoscibili e identificabili su terreni e mappe, presentano aree talmente estese che non permettono di localizzare, con sicurezza, un determinato punto nel quale ricondurre, in un secondo tempo, l'azione descritta.

In attesa di poter riscontrare sul terreno questi luoghi, e consapevole dall'essere ben lungi dall'aver fornito un panorama completo sul binomio leggenda-grotta, mi accontento di pubblicare i dati raccolti sinora.

Spero che, questa monografia, possa essere un punto di partenza per coloro che, interessati al tema e alle prospettive di ampliamento della ricerca, vogliano colmare le eventuali lacune e arricchire, con nuovi personaggi e nuove storie, il ricco e poliedrico patrimonio delle leggende ipogee dell'antica Grecia.

Premessa

Nell'apprendere i miti dell'antica Grecia, non bisogna attendere molto per trovare delle leggende che includano un passaggio o una scena che si svolga all'interno di una cavità. Nelle diverse versioni che hanno per sog-

getto la creazione del mondo (e della terra) vengono citate grotte, caverne o, comunque, luoghi posti sotterra.

Dal mito omerico, apprendiamo che tutti gli dei e tutte le creature viventi sono generate dal fiume Oceano (che scorre attorno al mondo) e che Teti fù la madre di tutti esseri. Una sua figlia, la dea della Notte, venne amata dal Vento (per altri dal Caos) e depose un uovo d'argento nel grembo dell'Oscurità. Da quell'uovo nacque Eros, il dio dell'amore fisico il quale, una volta cresciuto, creò la Terra, il Cielo, il Sole e la Luna. La dea della Notte e Eros vissero per molto tempo in una caverna. Davanti all'ingresso, sedeva l'inesorabile magna mater Rea, che percuotendo con le mani un tamburo di bronzo costringeva gli uomini a prestare attenzione agli oracoli della dea della Notte.

La versione del mito pelasgico della creazione ci informa che, all'inizio del tempo, Eurinome, dea di tutte le cose, creò dal Vento del Nord il grande serpente Ofione. Dal loro rapporto, Eurinome concepì l'Uovo Universale attorno al quale, per volere della dea, Ofione si arrotolò per sette volte, covandolo amorevolmente. Dall'Uovo uscirono il sole, la luna, le stelle, la terra e, naturalmente, tutte le creature viventi, animali e vegetali.

Eurinome e Ofione si stabilirono sul Monte Olimpo e vissero in armonia sino al giorno in cui Ofione iniziò a vantarsi di essere l'unico creatore dell'Universo. La dea, infuriata, lo colpì alla bocca con un calcio, gli spezzò tutti i denti e lo imprigionò nelle buie caverne sotterranee della Terra.

Comunque siano andate le cose, gli antichi greci hanno ritenuto giusto ambientare, alcuni passi relativi alla creazione del mondo, in grotta, e questo, a prescindere se come dimora o come prigione.

Il Mondo Sotterraneo Dell'oltretomba

Nel pantheon dell'antica Grecia, c'erano diversi dei che regnavano sotterra o che erano associati agli Inferi. I più famosi erano: Ade, Crono, Plutone, Persefone, Demetra, Dionisio, Ecate ed Hermes. Gli dei inferi venivano celebrati, alla fine di febbraio, dopo la commemorazione dei defunti.

Le ombre dei morti venivano definite anche con gli appellativi di Larve, Lari, Lemuri, Geni o Mani. In alcuni testi, molto vecchi, viene riferito che questi spiriti conducevano una triste esistenza confinate nei loro sepolcri oppure in caverne sotterranee. Da questi ipogei, potevano ritornare nel mondo dei vivi soltanto sotto l'aspetto di serpenti, topi o pipistrelli; era loro negato di poter reincarnasi nuovamente in esseri umani.

Dando credito ai testi classici, per raggiungere l'oltretomba, bisognava passare attraverso l'ingresso di una grotta e quello maggiormente citato, nell'antichità, è l'ipogeo di Efyra, in Epiro. Si apriva nei pressi di una palude (compresa tra il fiume Acheronte e il Cocito), conosciuta con l'inquietante nome di Nekromanteion (oracolo dei morti) dove, a poca distanza, si trova un promontorio denominato "Cimmerion".

È, molto probabilmente, lo stesso luogo che diversi autori indicano con il nome di Aornon; (termine greco che significa privo di uccelli), termine che, in seguito, venne trasformato nel latino Avernum.

Omero, nell'Odissea, (Canto X e XI), colloca in questo luogo l'ingresso dell'Ade: è il paese dei Cimmeri, dove Ulisse si reca, per evocare i morti e interrogare l'indovino Tiresia, seguendo le indicazioni della maga Circe: "O Circe, ma chi mi guiderà per questa via? Nessuno mai giunse all'Ade con una nave nera". (...) tu alza l'albero, spiega le vele bianche, e rimani seduto: ti porterà il soffio di Borea. (...) quivi è la bassa spiaggia, qui sono di Persefone i boschi, negri pioppi giganti, piangenti sterili salici. Qui sui profondi gorghi d'Oceano ferma la nave, e tu stesso sprofonda nell'umida casa d'Averno. Nell'Acheronte qui Piriflegetonte si versa, Cocito qui, ch'è un ramo divelto dall'acqua di Stige: sotto una rupe insieme s'incontrano i fiumi mugghianti (...).

Come per Ulisse, anche ad altri famosi eroi greci (Teseo, Orfeo ed Eracle), venne concesso di scendere nell'oltretomba da vivi e ritornare alla luce, e alla vita, senza conseguenze.

Di Teseo (accompagnato da Piritoo), sappiamo che: "discese nel Tartaro, dall'ingresso secondario che si trova nella caverna di Tenaro, in Laconia" per rapire Proserpina. Ne uscì, grazie all'intervento di Eracle, dall'orrido di Trezene (Τροιζηνα) dove, all'esterno, costruì un tempio e lo dedicò ad Artemide Salvatrice. In seguito, sullo stesso luogo, vennero eretti alcuni altari in onore degli dei Inferi.

Orfeo, che discese nell'Ade con la speranza di riportare sulla terra Euridice, si servì di un passaggio sotterraneo che si apre ad Aornon. Probabilmente, come già detto, si tratta dello stesso ingresso usato da Ulisse.

Per catturare liberare Teseo, Eracle penetrò nel sottosuolo dalla caverna di Tenaro (Ταιναρο), in Laconia, e ne uscì, dall'orrido che si trova presso Trezene.

Per catturare Cerbero, invece, il semidio entrò dalla penisola Acherusia (presso Eraclea, sul Mar Nero) e ne uscì seguendo un sentiero sotterraneo che conduceva alla grotta di Acona, presso Mariandine, sempre sul Mar Nero. Un'altra versione, narra che ritornò sulla superficie terrestre attraversando nuovamente la caverna di Tenaro.

Un'ultima variante, riporta che Eracle uscì, da un ipogeo, nel sacro recinto di Zeus Lafistio (lo stesso nel quale Giasone appese il vello d'oro), sul monte omonimo, nei pressi del paese di Orcomeno (Ορχομενοζ), in Acaia.

La caverna di Tenaro, situata in cima ad un promontorio del Peloponneso, veniva ritenuta l'ingresso secondario del Tartaro. Ancora oggi è possibile vedere (e visitare) il cosiddetto "cancello di Ades", una piccola grotta con l'ingresso seminascosto da un muretto a secco e, nelle vicinanze, i resti del tempio, a forma di grotta, dedicato a Poseidone.

Gli Inferi

Hermes non era soltanto il messaggero degli dei e il protettore di mercanti e ladri. Tra le sue mansioni c'era anche quello di guida per le anime dei defunti; infatti, uno dei suoi epiteti è quello di Psicopompo (guida delle anime nell'oltretomba).

Omero, narrando la discesa di Ulisse negli Inferi (Odissea: XXIV, 3-14), descrive come Hermes svolgeva questo compito: "Tenea la bella in man verga dell'oro, onde i mortali dolcemente assonna, sempre che il vuole, e li dissonna ancora. Con questa conducea l'alme chiamate, che stridendo il seguiano. E come appunto vipistrelli nottivaghi nel cupo fondo talor d'una solenne grotta, se avvien che alcun dal sasso, ove congiunti l'uno appo l'altro s'atteneano, caschi, tutti stridendo allor volano in folla; così movean gli spirti, e per la fosca via precedeali il lansueto Ermète".

Le anime attraversano le acque di Oceano, la Rupe Bianca, le Porte del Sole e il Paese dei Sogni e, giunte nella grande caverna dell'Ade, attraverso alcuni passaggi, arrivano all'Orco dove vengono relegati gli uomini malvagi. Molto più in basso trovano il Tartaro, uno spaventoso luogo di pena riservato esclusivamente ai titani e agli dei.

Quando le ombre scendevano al Tartaro, dovevano essere munite di una moneta, che i parenti avevano posto sotto la loro lingua. Con questo denaro, potevano pagare Caronte, l'infernale nocchiero che traghettava, con la sua barca, le anime dei defunti al di là dello Stige (fiume odiato). Le ombre prive di denaro dovevano rimanere, in eterno, sulla sua riva.

Lo Stige delimita il Tartaro a occidente e ha come tributari l'Acheronte (fiume doloroso), il Flegetonte (fiume ardente), il Cocito (fiume gemente), l'Averno (fiume senza uccelli) e il Lete (fiume dell'oblio), nel quale i defunti si abbeverano per dimenticare la loro triste sorte.

Qui impera Ecate (figlia di Zeus e di Era), una divinità infernale che tiene per cento anni le ombre di coloro che sono morti e sono rimasti senza sepoltura. Regna anche sulle ombre e sui demoni malvagi, evoca gli spiriti e spaventa gli uomini vagando nella notte annunciata dai latrati dei cani, sensibili alla sua malvagia presenza.

Chi supera lo Stige, invece, giunge nella Prateria degli Asfodeli (fiori degli inferi), dove i fantasmi degli eroi vagano senza pace e i morti meno illustri svolazzano, dappertutto, come pipistrelli.

L'Erebo

Superata la Prateria degli Asfodeli le anime dei morti arrivano nell'Erebo, il luogo dove si trova il palazzo di Ade e Persefone. Qui si trovano anche le Erinni (Tisifone, Aletto e Megera), che erano più vecchie di Zeus e di tutti gli altri dei dell'Olimpo.

Le Erinni, compagne di Ecate, sono la personificazione dei rimorsi che tormentano la coscienza. Sono vecchissime e hanno serpenti al posto dei capelli, la testa di cane, il corpo nero, le ali di pipistrello e gli occhi sempre iniettati di sangue. Impugnano pungoli con le punte di bronzo con i quali tormentano le loro vittime.

Erebo (che significa oscuro), prende il nome dal figlio del Caos e delle Tenebre e, col suo nome, viene designata la parte più profonda e tenebrosa degli Inferi. I fiumi dell'Erebo erano il Lete e il Flegetonte.

Sul lato sinistro del palazzo di Ade, un cipresso bianco ombreggia la fonte del Lete: qui le anime comuni si raccolgono per bere. Le ombre iniziate, invece, si dissetano alla fonte della Memoria, indicata da un pioppo bianco.

A poca distanza, in un punto dove si incrociano tre strade, i defunti vengono giudicati da Radamanto, Eaco e Minosse.

Radamanto giudica le anime degli asiatici e degli africani, Eaco quelle degli europei, mentre i casi più difficili vengono lasciati alla saggezza di Minosse.

Dopo il verdetto le anime si avviano lungo una delle tre strade; la prima riporta alla Prateria degli Asfodeli, dov'erano destinati coloro che, in vita, non furono né virtuosi né malvagi; la seconda porta al campo di punizione del Tartaro, dove vengono mandati i malvagi; la terza ai Campi Elisi dove giungono soltanto i virtuosi.

Un cane con tre teste, chiamato Cerbero, sta a guardia dell'Erebo, pronto a divorare i viventi che tentano di introdursi laggiù, o le ombre che tentano di fuggire.

Il Tartaro

Esiodo, il poeta che cantò l'origine del Cosmo e degli Dei, tenta di descrivere, con un paragone, la vastità del Tartaro: "Un'incudine di rame, cadendo dal cielo, avrebbe impiegato nove giorni e nove notti per giungere sulla terra. Altrettanto impiegherebbe dalla superficie della terra per raggiungere il profondo Tartaro".

Così, invece Zeus, in un passo dell'Iliade (Canto VIII): "Se vedrò uno di voi che, all'insaputa degli altri dei, cerca di aiutare Danai o Teucri, costui, colpito dal fulmine, se ne tornerà in Olimpo in malo modo; oppure lo scaglierò giù nel Tartaro tenebroso, in fondo all'abisso che sotto la terra sprofonda, là dove sono le porte di ferro, la soglia di bronzo, tanto lontano dall'Ade quanto il cielo lo è dalla terra (...).

In questa particolare regione dell'Ade, che prende il nome dal figlio dell'Etere e di Gea, le supreme divinità dell'Olimpo confinano i loro nemici (come nel caso di Zeus con i Titani o di Crono con i Ciclopi e gli Ecatonchiri), e vengono imprigionati i mortali che si sono macchiati dei più orrendi delitti (Issione, Sisifo, Tantalo).

In seguito, con l'appellativo di "Tartaro" venne indicato, genericamente, tutto l'Inferno greco.

I Campi Elisi

I Campi Elisi, su cui regna Crono, si trovano presso il palazzo di Ade e il loro ingresso è accanto alla fonte della Memoria. Le ombre qui confinate possono rinascere e tornare sulla terra. Poco più oltre si trovano le Isole Beate, riservate a coloro che sono nati tre volte e che, ogni volta, hanno vissuto virtuosamente.

I tre giudici dell'Ade

Eaco, figlio di Zeus e della ninfa Egina, fu re di Egina e padre di Peleo. Quando morì, divenne uno dei tre giudici del Tartaro, ma veniva consultato anche per fare da arbitro nelle contese tra gli dei. Secondo alcuni Eaco aveva in mano le chiavi del Tartaro, imponeva un pedaggio e controllava che le anime, guidate da Hermes, non vi giungessero contro la volontà di Atropo (una delle tre parche che, con le sue forbici, recideva la vita dei mortali).

Radamanto era stato re di Creta, figlio di Zeus e di Europa, fratello di Minosse. Regnò saggiamente e, ogni nove anni, si recava in una grotta sacra a Zeus per ricevere, dal dio, nuove leggi da insegnare agli uomini. Fra queste: la legge del taglione e quella del giuramento imposto agli accusati in mancanza di testimoni.

Minosse, figlio di Zeus e di Europa, fu, anche lui, re di Creta. Diede ai cretesi le prime leggi, dettate da Zeus stesso, e divenne, dopo la morte, giudice supremo dei morti.

Luoghi di Culto
Delfi

Nel panorama religioso dell'antica Grecia ci sono diversi Oracoli, o "luoghi di profezia", situati all'interno di grotte naturali o di ipogei artificiali. L'Oracolo più famoso dell'antico mondo ellenico è, senza dubbio, quello di Delfi (Δελφοι), dove la presenza di Apollo si manifestava attraverso i responsi dati da una sacerdotessa, la Pizia (o Pitonessa), che veniva scelta tra le vergini delfiche.

All'inizio, i responsi venivano dati una sola volta all'anno (il 7 del mese di Bisio, ossia, febbraio-marzo); poi, per poter soddisfare il gran numero di pellegrini, l'oracolo divenne accessibile per tutto l'anno ad eccezione dell'inverno, quando si diceva che Apollo abbandonava il suo santuario.

La Pizia, seduta sopra un tripode situato nell'adyton (cella sotterranea) del tempio, se ne stava avvolta nel fumo di foglie di lauro e di farina d'orzo; al suo fianco sgorgava l'acqua della fonte Castalia e si trovava l'ònfalos, pietra conica che simboleggiava il centro del mondo.

La sacerdotessa, con una foglia di alloro in bocca e un ramoscello in mano, seduta sul sacro tripode, cadeva in estasi, quindi compiva movimenti ed emetteva suoni che i sacerdoti interpretavano e traducevano in forma comprensibile e mettendoli per iscritto in prosa o versi (esametri), indicando in tal modo a quale dio dovessero farsi sacrifici affinché un'impresa fosse coronata dal successo, cosa si sarebbe dovuto fare per superare determinati ostacoli, eventuali riti con cui espiare colpe, etc.

La Sibilla

Sibilla è un titolo generico che i greci ed i romani davano a certe donne invasate di spirito profetico, ispirate dalle divinità (in genere Dioniso o Apollo) e che si esprimevano con parole evasive, di ardua interpretazione o tendenti a confondere l'interlocutore; da qui l'uso del termine "sibillino".

Gli oracoli delle sibille erano quasi sempre raccolti in forma scritta. Le Sibille erano in tutto dieci e venivano consultate in caso di gravi sciagure cittadine o quando si doveva decidere se intraprendere, o meno, una guerra. Le più famose erano: la Sibilla Marpesiana, o Troiana, che viveva in una grotta sul fianco del Monte Ida (Ιδαιο Οροσ), forse identificabile con lo Spìleo Kamaron (Σπηλαιο Καμαρων); la Sibilla d'Eritrea (detta anche Erofile) e la Sibilla Cumana che predisse il destino ad Enea e viveva, in un antro dalle cento porte, all'interno del tempio di Apollo, a Cuma, in Italia.

Trofonio

Figlio di Apollo e Epicasta, nella mitologia greca era considerato una

208

dio infero il cui oracolo, associato all'oltretomba, si trovava nel bosco sacro di Lebadea (Λαιβαδεια), tra Atene e Delfi.

Lo storico Pausania, nella Periegesi della Grecia (libro IX) riporta l'elaborato rituale associato all'oracolo: "Il supplice deve purificarsi con parecchi giorni d'anticipo e alloggiare in un edificio dedicato alla Buona Fortuna e al Buon Genio. Quando è in condizioni di consultare l'oracolo, il supplice viene condotto al fiume da due fanciulli tredicenni e colà è lavato e unto. Poi beve a una fonte chiamata Acqua del Lete, che lo aiuterà a scordare il suo passato, e a un'altra fonte vicina, dell'Acqua della Memoria, che lo aiuterà a rammentare ciò che ha visto e udito. Calzati zoccoli da contadino, indossata una tunica di lino e una rete, come se fosse una vittima sacrificale, egli si avvicina alla voragine dell'oracolo che somiglia a un enorme forno da pane, profonda sette metri, dove discende con l'aiuto di una scala. Giunto sul fondo, trova una stretta apertura in cui insinuerà le gambe, reggendo in entrambe la mani un pane d'orzo impastato con miele. Dopo un improvviso strattone alle caviglie, gli parrà di essere travolto come dal gorgo di un fiume in piena e nell'oscurità sarà colpito alla nuca e gli parrà di morire, mentre una voce invisibile gli rivela il futuro e molte altre cose segrete. Non appena la voce si tace, il supplice perde i sensi e viene trasportato alla bocca della voragine con i piedi in avanti, privo delle focacce d'orzo.

Dopo di che lo si insedia sul Trono della Memoria, dove gli si chiede di ripetere ciò che ha udito. Infine, con la mente ancora annebbiata, ritorna alla case del Buon Genio, dove ricupera i sensi e la capacità di sorridere".

Orfeo

Dopo averlo ucciso e smembrato, le Menadi tentarono di purificarsi le mani dal suo sangue immergendole nel fiume Elicona (Ελικων). Il dio del fiume, per evitare di essere considerato complice del delitto, si tuffò sottoterra e risalì in superficie quattro miglia più avanti, cambiando anche il nome: fiume Bafira. La testa di Orfeo, venne deposta nella grotta di Antissa (Αντισσα) a Lesbo, in una caverna sacra a Dionisio. Cominciò immediatamente a profetizzare, giorno e notte, finché Apollo, vedendo che i suoi oracoli di Delfi, Grinio e Claro non venivano più frequentati dai fedeli, si precipitò nella caverna e ordinò alla testa: "Cessa di interferire nel mio culto: ti ho sopportato anche abbastanza". Da quel giorno la testa di Orfeo tacque.

Le Erinni

Divinità ctonie, pre-olimpiche, della vendetta anche se, in questo specifico caso, sarebbe meglio definirle con l'altro nome con il quale sono conosciute, ossia "Eumènidi" (dèe benigne): un vero e proprio eufemismo visto che il terrore, da loro suscitato negli antichi greci, era tale da indurli a non pronunciarne nemmeno il nome.

Atena, propose loro di stabilirsi in una grotta nei pressi di Atene, dove sarebbero state onorate da una folta schiera di devoti. Le Erinni accettarono l'offerta di Atena e, accompagnate dal popolo in processione, si recarono in una profonda grotta situata sul lato sud orientale dell'Areopago (forse identificabile con il santuario di Colòno, un sobborgo di Atene). Terminati i riti sacrificali, discesero nella grotta che, da allora divenne sia un oracolo che un rifugio sicuro per i supplici. Da quel giorno, le Erinni, vennero indicate con il nome di "Venerande" e la cavità prese, di conseguenza, il nome di "Grotta delle Venerande".

Lino

Lino era il più grande musicista, nato tra gli uomini, che venne ucciso da Apollo, invidioso della sua abilità. Sul monte Elicona (Ελικων Ορος), in una grotta che si apriva all'interno del bosco sacro alle Muse, c'era un suo ritratto, inciso sulla parete. Ogni anno, all'interno della cavità, venivano celebrati in suo onore dei riti sacrificali che, addirittura, precedevano quelli delle stesse Muse.

Naiadi

A Itaca (Ιθακη), è possibile visitare una caverna, conosciuta con il nome di Marmarospilia (Αντρον Νυμφον) che, secondo la tradizione, è consacrata alle Naiadi. La grotta viene ricordata anche in un passo nell'Odissea, come luogo nel quale Ulisse nascose il tesoro donatogli dai Feaci.

Zerinzia

È, tradizionalmente, uno dei tanti epiteti di Afrodite. L'antro Zerinzio, era un'antro, nell'isola di Samotracia (Σαμοθρακη), nel quale si offrivano sacrifici in onore di Ecate e di Afrodite.

Dimore, Tane e Prigioni Sotterranee
Borea

Figlio di Astreo e di Eos, nonché fratello dei Venti del Sud e dell'Ovest, Borea aveva il corpo che terminava in serpente e abitava sul Monte Emo (in Tracia), in una caverna, dai sette meandri, dove Ares teneva i suoi cavalli. Secondo altre fonti, Borea era confinato in una caverna delle isole Eolie, dove Eolo, il re dei venti, lo teneva prigioniero.

Eolo

Riconosciuto, universalmente, come "dio dei venti", Eolo era un mortale che prese possesso delle sette isole Eolie (mar Tirreno), dove divenne famoso come consigliere degli dei e custode dei venti.

La sua reggia si trovava sull'isola di Lipari dove, in profonde caverne, teneva prigionieri i venti su incarico personale di Era o, per altri autori, di Zeus. Il suo compito consisteva nel rimetterli in libertà secondo il suo giudizio o per espresso desiderio di qualche divinità dell'Olimpo. Eolo era così abile e prudente nel gestire i venti che, quando suonò l'ora della sua morte, Zeus non gli permise di scendere nel Tartaro, ma lo pose su di un trono, nella Grotta dei Venti, dove tuttora si trova.

Ecate

Figlia dei Titani Asteria e Perse era, nella tradizione più antica, una divinità della Tessaglia. In seguito, venne confusa con uno dei tanti aspetti di Artemide (associato alla Luna) e, precisamente, a quello relativo alla faccia nascosta dell'astro, che non usciva mai dalla sua dimora sotterranea.

Efesto

Figlio di Era e di Zeus, era il mostruoso e deforme dio del fuoco e dell'arte di lavorare i metalli.

La dea, quando vide di aver partorito una creatura così ripugnante, lo buttò giù dall'Olimpo ed Efesto precipitò in mare dove fu allevato da Teti e Eurinome, con le quali rimase per nove anni. La sua prima officina venne allestita in una grotta sottomarina e, solo in seguito, Efesto trasferì la propria fucina nelle viscere dell'Etna.

Hypnos

Figlio della Notte e dell'Erebo, era il padre dei sogni e il fratello gemello di Thanatos, la Morte. Se si vuole dar credito ad Omero, Hypnos viveva nell'isola di Lemno (Λημνος), mentre per i romani (Ovidio), viveva in una grotta del paese dei Cimmeri, probabilmente Efyra.

Pan

La tradizione lo colloca in una grotta dell'Arcadia, nei dintorni della quale pascola i suoi greggi e si diletta nell'allevamento delle api. Pigro e bonario, nulla gli dava più piacere della siesta pomeridiana e, pur avendo un buon carattere, si vendicava su chi, anche inconsciamente, veniva ad

209

interrompere il suo riposo. In questo caso, lanciava, dal fondo della grotta, un urlo tale da far rizzare i capelli in testa agli incauti disturbatori.

Nereo

Figlio di Gea e di Ponto, era rappresentato come un vecchio buono e saggio che dimorava, assieme alle figlie (le Nereidi), in una grotta tutta d'oro sul fondo del mare Egeo. Le Nereidi, erano le cinquanta figlie di Nereo e dell'oceanina Doride, bellissime ninfe del mare che proteggevano i naviganti. A loro, i fedeli offrivano latte, miele, dolci e frutta che depositavano all'ingresso di grotte situate in prossimità del mare.

Anteo

La Madre Terra, concepì Anteo in un antro libico. Era un gigante che costringeva gli stranieri a lottare con lui poi, quand'erano esausti, li uccideva e prendeva il loro teschio come trofeo per adornare la caverna in cui viveva. Anteo era fortissimo e, ogni volta che toccava il suolo, riceveva dalla Madre Terra nuova forza e vigore; in questo modo non si stancava mai. Per ucciderlo, Eracle dovette strangolarlo tenendolo alto e lontano dal suolo.

Arpie

Erano le alate figlie di Taumante e della Ninfa Elettra che avevano il compito di catturare i criminali perché venissero, in seguito, puniti dalle Erinni. Alcune fonti le collocano nella Caverna di Ditte (Δικταιο Αντρο), sull'isola di Creta.

Centauri

Tra le tante leggende sui Centauri ce ne sono un paio che li mettono in relazione con le grotte, come nel caso del centauro Chirone che allevò e istruì, nella sua caverna del Monte Pelio (Πηλιο Ορος), il mitico Achille.

Un'altra storia che coinvolge i Centauri (e le grotte) è quella del matrimonio di Piritoo con Ippodamia. Poiché gli invitati alle nozze erano più di quanti il palazzo potesse contenerne, i Centauri, cugini di Piritoo, vennero fatti accomodare, assieme a Nestore, Ceneo e altri principi tessalici in una vasta caverna.

I Centauri bevvero molto vino, senza diluirlo con l'acqua, e si ubriacarono in modo tale che, quando la sposa apparve nella caverna per salutare gli ospiti, uno di loro, Eurizione, cercò di rapirla, subito imitato dagli altri Centauri che si gettarono sulle altre donne. Piritoo e Teseo accorsero in aiuto di Ippodamia, amputarono il naso e le orecchie di Eurizione e, con l'aiuto di altri eroi, riuscirono a gettare i Centauri fuori dalla caverna.

Anche il Centauro Reto, era presente alle nozze di Piritoo, ma la grotta che lo vede protagonista non è la stessa nella quale si svolge l'azione precedente. Il racconto è, comunque, simile: "invaghitosi di Atalanta, tentò, con un altro centauro, Ileo, di rapirla. Atalanta però, dal fondo della sua grotta, li uccise entrambi con le sue frecce".

Eracle

Oltre a quanto già narrato in precedenza (la discesa agli Inferi e la cattura di Cerbero), Eracle viene messo più volte a contatto con il mondo delle grotte. Nel compiere le leggendarie dodici fatiche sono cinque i casi nei quali il semidio deve entrare nel sottosuolo per continuare o per portare a termine l'impresa.

Nella prima fatica, Eracle si reca sul monte Treto (a due miglia dalla città di Nemea - Νεμεα) dove, in una grotta con il doppio ingresso, vive il leone Nemeo. Dopo aver bloccato uno degli ingressi della caverna con un masso il semidio entra nella grotta e uccide l'animale.

Nella seconda fatica, affronta l'Idra di Lerna, un drago che viveva in un antro presso le fonti di Amimone.

Segue (terza fatica), la cattura del cinghiale Erimanzio, una terribile bestia, che stabilitasi nella zona dei monti Erimanto e Lampia

(Ερυμανθος Ορος, Λαμπειο Ορος), devastava i campi nei dintorni di Psofide (Ψουφιζ).

In questo caso, non è il soggetto (Erimanzio) e vivere in una grotta, bensì il Centauro Folo che invita Eracle ad un banchetto. L'eroe gli rammenta che, ben quattro generazioni prima, Dionisio aveva accantonato una giara di vino nella grotta, affinché venisse aperta in quella particolare occasione. Il forte aroma del vino fa perdere la ragione agli altri Centauri che, dopo essersi armati, si precipitano verso la grotta di Folo. Eracle riesce a respingerli ma, nella foga della battaglia, una freccia vagante (intinta nel veleno dell'Idra) colpisce il suo vecchio amico e maestro, Chirone. Il Centauro, assalito da un intenso dolore, si rifugia sul fondo della grotta, dove muore.

Anche nella decima fatica (le mandrie di Gerione) c'è un brano che, indirettamente, interessa un sito ipogeo: "Più avanti, nel deserto scitico, gli vennero rubati i cavalli dal suo cocchio. Eracle vagò in lungo e in largo alla ricerca delle cavalle finché raggiunse la boscosa regione di Ilea dove uno strano essere, metà donna e metà serpente, gli lanciò un richiamo dalla sua grotta. Era disposta a restituire gli animali solo se Eracle fosse diventato il suo amante. Eracle acconsentì e, per un periodo rimase nella grotta con lo strano essere".

La dodicesima fatica riguarda la cattura di Cerbero.

Cariddi

Restando in tema delle dodici fatiche, è doveroso ricordare anche la storia di Cariddi; la figlia di Gea e di Poseidone che, per aver rubato e divorato ad Eracle le mandrie di Gerione venne trasformata da Zeus in un mostro marino. Nascosta in una grotta, nello stretto di Messina (di fronte a Scilla), divorava i naviganti inghiottendo e vomitando tre volte al giorno le onde del mare.

Scilla

Nell'Odissea, Omero racconta come il dio marino Glauco, innamorato di Scilla, rifiutasse l'amore della maga Circe. Costei, per vendicarsi della rivale, versò erbe malefiche all'acqua della fonte nella quale Scilla andava a bagnarsi. Quando la ninfa toccò l'acqua si trasformò in un orribile mostro: la tradizione la descrive con busto di donna, sei teste di cane e dodici zampe. Sconvolta dal suo ripugante aspetto, Scilla si gettò in mare e si nascose in una cavità, vicino alla grotta di Cariddi, nella zona compresa tra Reggio Calabria e Messina. Al passaggio di una nave, Scilla sporgeva le sue sei teste, azzannava e divorava i terrorizzati marinai.

Sybaris

Alcioneo, era un bellissimo giovane di Delfi che venne scelto, per ordine di un oracolo, come vittima da offrire in sacrificio a Sybaris (o Lamia), un mostro terrificante che viveva sul Monte Parnaso (Παρνασσοζ) in una grotta del Monte Cirfi, nei pressi di Crisa, nella Focide.

Mentre lo conducevano sul monte, venne visto dal nobile Euribato che, preso dalla sua bellezza, volle prendere il suo posto. Effettuato lo scambio Euribato trascinò fuori dalla grotta il mostro e lo scagliò sulle rocce aguzze. Immediatamente il cadavere scomparve e, al suo posto, scaturì una fonte che, da quel giorno, viene chiamata Sybaris.

Ciclopi

"All'inizio di tutte le cose, la Madre Terra emerse dal Caos e generò nel sonno suo figlio Urano. I primi figli della dea, con aspetto umano, furono i giganti dalle cento braccia (gli Ecatonchiri), seguiti da tre feroci Ciclopi monocoli: Bronte, Sterope e Arge".

Questi tre Ciclopi vennero subito associati ai vulcani, tanto che il mito costrinse le loro ombre a vagare in eterno nelle caverne dell'Etna, da quando Apollo li uccise per vendicare la morte di Asclepio. In questo modo si interpretava (e giustificava), il fuoco, il fumo e le fiamme che

uscivano dal cratere del vulcano. Il termine Ciclope significa "dall'occhio rotondo" ed è verosimile che, durante la civiltà ellenica primitiva, questi non fossero altro che i membri di un'associazione di fabbri ferrai. È probabile che venissero descritti come monocoli soltanto perché usavano una benda per proteggere un occhio dalle scintille.

Polifemo

Figlio di Poseidone e della ninfa Toosa. Il suo nome significa celeberrimo ed è, senza ombra di dubbio, il Ciclope più famoso, grazie all'Odissea: "Ulisse naufragò con i suoi compagni nell'isola dei Ciclopi, videro una grotta, nelle vicinanze dell'Etna, ricca di ogni tipo di cibo e rimasero nella grotta, curiosi di conoscere chi ci viveva (...)".

In questo caso i Ciclopi non sono dei fabbri, ma sono descritti come giganti monocoli e antropofagi che vivevano, assieme ai loro greggi di pecore e capre, in caverne che si aprivano nei fianchi delle montagne sicule, a poca distanza dal mare.

Encelado

Terribile gigante, figlio di Urano e Gea, che combatté coi suoi fratelli contro Zeus.

Una versione del mito narra che Encelado venne seppellito, da Zeus, sotto l'Etna. Quando si muoveva, faceva tremare tutta la Sicilia e quando sbuffava, faceva uscire getti di fuoco dalla cima del vulcano.

Secondo Virgilio (Libro III), dopo lo scontro con gli dei, Encelado si nascose in Sicilia, ma venne ritrovato da Zeus che gli scagliò un fulmine. Poi, coprì il suo corpo seppellendolo sotto il monte Etna. Quando Encelado si scuoteva, provocava un terremoto e quando sibilava e tirava fuori la sua lingua di fuoco, l'Etna eruttava.

Una terza versione narra che Encelado venne ucciso da Atena. La terribile dea lo colpì scagliandogli addosso l'intera Sicilia ed egli, da allora, è costretto a vivere in una angusta caverna posta sotto l'Etna. Come nei precedenti casi, la lava che usciva dal vulcano non era altro che l'alito infuocato del gigante e i terremoti, che scuotevano tutta l'isola, erano provocati dai suoi tentativi di cambiare posizione.

Echidna

Echidna, che in greco, significa "vipera", era per metà una bellissima donna, per metà un serpente dalla pelle maculata. Viveva in una grotta profonda tra gli Arimi (in una caverna della Cilicia datale, come dimora, dagli dei), e si nutriva di uomini crudi. Generò, con suo marito Tifone, numerosi mostri del panorama leggendario ellenico. I più famosi sono: Cerbero, l'Idra di Lerna, il leone di Nemea, la Chimera e il drago della Colchide, custode del vello d'oro.

Tifone

Era il mostruoso figlio di Gea e di Tartaro che riuscì a sconfiggere Zeus e lo imprigionò nella stessa grotta nel quale era stato concepito (Grotta Coricia), lasciando di guardia la sorella Delfine. Hermes e Pan si introdussero nella grotta e, sconfitta Delfine, liberarono Zeus. Dopo una terribile lotta, Tifone, come nel mito di Encelado, scappò in Sicilia, dove Zeus pose fine alla sua fuga schiacciandolo sotto il monte Etna che, da quel giorno, erutta fuoco e fiamme. Tifone, non a caso, significa "fumo stupefacente".

Luoghi di Nascita e Alcove

Alcune grotte (per lo più caverne) dell'antica Grecia, hanno il privilegio di essere state testimoni della nascita di importanti dei olimpici. Tra questi, spiccano: Zeus, Hermes e Dionisio. Anche per questo motivo, le grotte venivano considerate importanti luoghi di culto e di iniziazione religiosa.

Zeus

A Crono era stato profetizzato che uno dei suoi figli l'avrebbe detronizzato ed egli, per evitare che ciò potesse succedere, divorava subito i suoi figli. La moglie Rea, quando partorì Zeus, gli dette in pasto una pietra avvolta nelle fasce dicendogli che si trattava dell'ultimo figlio partorito.

Il neonato venne affidato alla Madre Terra che lo portò a Litto (Creta) e lo nascose all'interno della grotta Diktea (Δικταιο Ανδρο), sulla collina Egea. All'esterno della grotta, montavano la guardia i Cureti che, battendo con le spade contro gli scudi riuscivano a coprire i vagiti del neonato.

Ad un certo punto, però, Crono cominciò a sospettare la verità e si mise alla ricerca di Zeus che, avvisato del pericolo, si rifugiò in un'altra caverna; forse la grotta di Psihro (Ψγχρο).

Raggiunta l'età matura, affrontò il padre e la profezia, naturalmente, si avverò.

A riguardo della grotta Diktea, una leggenda narra che un certo Celeo, ladro di Creta, cercò con alcuni compagni, di rubare il miele dalla sacra caverna di Zeus. Scoperti dal dio vennero trasformati in uccelli soltanto perché, all'interno della grotta sacra, era proibito uccidere qualsiasi forma vivente. La stessa sorte toccò anche ad Egolio, un altro ladro cretese che tentò di entrare nella grotta per rubare un alveare. L'armatura di rame, con la quale credeva di proteggersi, cadde e, assieme ai suoi compagni, venne trasformato in uccello.

Hermes

Il messaggero degli dei, protettore dei commercianti, dei ladri e dei bari, nacque in una grotta sul Monte Cillene (Ορος Κυλληνη), in Arcadia.

Ancora in fasce, Hermes rubò una magnifica mandria di vacche ad Apollo il quale promise una ricca taglia a chi trovava il ladro. Un gruppo di Satiri, attirati dalla ricompensa, si mise subito alla ricerca del colpevole. Girando l'Arcadia, vennero attirati da una musica bellissima, mai udita prima che usciva da una grotta. La ninfa Cillene, senza uscire dalla caverna, disse loro che la melodia proveniva da un ingegnoso strumento musicale, costruito con un guscio di tartaruga e con le interiora di vacca. A quel punto, i Satiri notarono due pelli di vacca poste a disseccare davanti alla grotta e pensarono di avvisare Apollo. Il messaggero degli dei si precipitò sul luogo e, entrato nella grotta, trovò Hermes che, per ricompensarlo del furto e della perdita, gli regalò la sua lira.

Dionisio

Nella grotta Coricia, sul Monte Parnaso (Παρνασσος Ορος), le Baccanti organizzavano le loro feste orgiastiche per commemorarne la nascita. Durante queste feste, le caverne venivano addobbate con fiori e con i "letti per le ninfe"; sorta di altari che servivano ad ospitare le anime che s'incarnavano.

Dionisio, oltre a condividere con Zeus ed Hermes la nascita in caverna, ebbe più volte salva la vita proprio grazie alle grotte. Narra il mito che i Titani, obbedendo ad Era, rapirono Dionisio e lo uccisero, ma la nonna, Rea, accorsa in suo aiuto, gli ridonò la vita. Per sottrarlo alla collera della moglie, Zeus ordinò ad Hermes di trasformarlo in un capretto e di consegnarlo alle ninfe Macride, che vivevano in una grotta sul monte Nisa, in Eliconia. Dionisio venne nascosto nelle profondità della grotta e nutrito di miele, restando con loro fino alla maturità.

Un'altra leggenda racconta che Dionisio venne assalito da Licurgo, re degli Edoni, che voleva ucciderlo. Si salvò tuffandosi in mare e trovando rifugio nella grotta di Teti.

Zagreo

Zeus la generò, con Persefone, prima che venisse condotta nell'Oltretomba da Ade. Affidò poi ai Cureti cretesi, il compito di custodire la sua culla nella Grotta Idea (Ιδαιο Αντρο). Come già avvenuto per

211

lui, nella grotta Dikte, questi guardiani danzavano davanti all'ingresso, battendo le loro armi l'una contro l'altra, anche se, in questo caso, il motivo non viene specificato.

Tifone

La Madre Terra lo generò, col Tartaro, nella grotta di Coricia, in Cilicia (Monte Casio?). Nella stessa grotta Tifone continuò a vivere con la sorella e compagna Delfine

A Delfi, in un'altra grotta Coricia, il compagno di Delfine, viene chiamato Pitone (serpente) e personificava la forza distruttrice del vento del Nord (i venti, all'epoca, venivano raffigurati con lunghe code di serpenti).

Peleo e Teti

Sono il padre e la madre di Achille. Zeus decise che Peleo doveva sposare la Nereide Teti ma sapendo che Teti avrebbe rifiutato di sposare un mortale, mandò un messaggero alla grotta di Chirone per ordinare a Peleo di prenderla con la forza. Seguendo le istruzioni di Chirone, Peleo si nascose nelle vicinanze di una grotta, situata sulla spiaggia di un'isoletta della Tessaglia, dove Teti andava a riposare. Non appena Teti si fu addormentata, l'uomo le saltò addosso e solo dopo una lunga e faticosa lotta riuscì a possedere la Ninfa. In seguito, le loro nozze vennero celebrate all'esterno della grotta di Chirone, sul Monte Pelio (Πήλιο Ορος).

Finita la guerra di Troia, Teti, vedendolo straziato per la morte del figlio Achille, chiese al marito di recarsi nella grotta, dove si erano uniti per la prima volta, e di attenderla. Peleo si recò alla grotta dove, poco dopo, la Ninfa lo raggiunse e lo portò con sé negli abissi marini.

Toosa

Era una ninfa, figlia di Forco e di Cete, amata da Poseidone che la sorprese in una grotta marina. Dalla loro unione nacque Polifemo.

Endimione

Sul bellissimo figlio di Zeus e della Ninfa Calica il mito ha riservato tre versioni.

La prima racconta che Endimione chiese a Zeus di farlo dormire, eternamente, in una grotta del monte Latmos (nell'isola di Pathos) perché era terrorizzato dall'idea di invecchiare.

L'altra, invece, che venne condannato da Zeus a dormire per trent'anni (per alcuni, eternamente), per aver offeso Era.

In una terza versione, il giovane fu l'amante di Selene (la luna), che da lui ebbe cinquanta figlie. La dea chiese a Zeus di farlo dormire eternamente per evitarle nuove gravidanze. Quando la fase di luna nuova portava Selene ad essere invisibile, era perché la dea scendeva nella grotta a contemplare il suo Endimione.

Europa

Colpito dalla sua bellezza, Zeus le si presentò sotto l'aspetto di un giovane toro bianco, talmente mansueto, che Europa non ebbe paura di cavalcarlo. Immediatamente, l'animale si immerse nel mare e la portò a Creta, dove si unirono nella grotta Diktea.

Ione

È uno dei figli di Apollo che amò segretamente Creusa, figlia di Eretteo e moglie di Suto, in una grotta che si apriva sotto i Propilei di Atene.

Onfale

Era una regina della Lidia che acquistò i servigi di Eracle per un anno.

I due stavano visitando i vigneti di Tmolo, quando vennero visti da Pan che immediatamente si innamorò della regina. Mentre Pan tentava di raggiungerli, Eracle e Onfale entrarono in una grotta sacra a Dionisio e, per gioco, si scambiarono le vesti. Giunta la sera si coricarono in giacigli separati perché, il giorno seguente, dovevano offrire sacrifici a Dionisio che, in queste particolari occasioni, pretendeva dai suoi devoti la castità coniugale.

Giunta la mezzanotte, Pan si intrufolò nella buia grotta e, a tastoni, trovato quel che gli parve il letto della bella regina, si infilò sotto le coperte.

Ma nel letto c'era Eracle che, svegliatosi di soprassalto, colpì, con un calcio, l'intruso fecendolo volare attraverso tutta la grotta. Il rumore provocato dalla sua caduta svegliò Onfale che, accese le torce, si trovò davanti la comica scena di Pan steso a terra, tutto ammaccato e dolorante.

Conclusioni

È un mondo incredibilmente vasto e complesso quello del folklore, in genere.

Come si è potuto vedere, spesso gli stessi personaggi si muovono in luoghi e in situazioni che sono paralleli ad altri soggetti creando, tra chi non è avvezzo a districarsi nelle maglie del mito ellenico, non poca confusione. Anche per i testi riportati in questa monografia (che ho cercato di rendere di piacevole lettura), è stato così.

Selezionando i brani che parlano di grotte è logico che vengono omesse tutte quelle storie, ben più complesse, nel quale si inquadrano, con maggior dettaglio, tempi, luoghi e personaggi delle singole leggende.

Come già detto, l'intento di questo elaborato è quello di dare - qualora non ci sia già qualcosa di preesistente - uno stimolo per la ricerca, lo studio, la raccolta e la divulgazione (relativo al mondo ipogeo), di quello che, personalmente, ritengo essere "la sorgente del mito": il patrimonio folkloristico dell'antica Grecia.

Chiedo scusa, agli uomini e agli dei, per la mia presunzione.

O-55

SEA CAVES AT LAMPEDUSA (ITALY)

Graziano Ferrari

(No affiliation)

Via Vignati 18, I-20161, Milano, Italy - gwferrari@gwferrari.it

Summary

Lampedusa is the southernmost island in Europe (N 35° 30' latitude). From the geological point of view, it is a pack of nearly horizontal limestone beds, of Tortonian-Messinian age (about 10-7 My b.p.). No caves were registered, and few references were found in literature.

Actually, the island is rich in littoral caves, and several submerged caves are reported by the local diving centres.

Preliminary results of a survey campaign are presented: 86 littoral caves and 15 submerged caves are positioned. Developments are small, but rich sea habitats are present, mainly in Poriphera.

Introduction

In the central Mediterranean Sea, between Sicily and Africa, the Pelagie Islands belong to Italy but they are placed on the North rim of the African plateau. The word "Pelagie" comes from the ancient Greek, meaning "high sea islands". Lampedusa is the main island (extension 20.2 km², coastal development 33.3 km, maximum elevation 133 m). It has a roughly triangular shape, 10 km long in the East-West direction, with a maximum width of about 4 km in the eastern half. A single town (about 5000 people) is also named Lampedusa. Tourism is the main revenue, followed by fishery. The island is an important scuba diving place. The Rabbits' Beach, in the middle of the southern coast, is a breeding ground for sea turtles (Caretta caretta); in 1995 a land protected area was established in the place. In 2002, most of the sea around Lampedusa was established as a sea protected area.

From the geological point of view, Lampedusa is a flat table of Tortonian-Messinian limestones and grainstones (Grasso & Pedley, 1988). Beds are nearly horizontal. The north coast is a cliff, 50 to 130 m high, while the south-eastern side slopes gently into the sea. On the northern and eastern sides, the sea bed quickly reaches a depth of about 60 meters while on the southern side the sea is shallower. Several bays mark the southern side of the island. Just south of the town lies Maluk Cape, the southern point of land in Europe (N 35° 29' 24").

Apparently, no caving researches were performed at Lampedusa in the past. No caves were registered in the Sicily Cave register (Messana & Panzica La Manna, 1994). Just two references were found in caving literature (Frassoni, 1967; Criscuolo & Miragoli, 1988). Both papers are reports about short trips in the area. They point out the presence of some interesting caves.

In 2001, during a scuba diving holiday at Lampedusa, the author positioned about 50 littoral caves. Furthermore, the local diving centres reported several references to underwater caves. At that time, the author was involved in the development of the Census of Italian sea caves (Cicogna et al., 2003). A small research campaign was designed. Each year, the author spends one October week scuba diving and positioning sea caves. In the meantime, some land caves and several WW II bunkers were reported and positioned. Presently, 151 caves are identified; 16 of them were surveyed. It is a very relaxed caving activity, with little effort and small results. Unfortunately, caves on the northern side and on the westernmost half of the southern side are reacheable only by boat, so most of them are just positioned and they are not described in this paper.

The next chapters report about known caves at Lampedusa. Just certainly identified caves are reported. Many other large and small entrances are known and positioned, but they are not yet explored and/or surveyed.

Caves are divided into two categories: submerged and littoral (semi-submerged). Caves with completely underwater entrances are considered "submerged"; they are identified by a letter "S" and a progressive number. Caves with partly water-filled entrances are littoral; they are identified by a letter "L".

Submerged caves

Several small underwater caves are reported. Most are tunnels, at shallow or medium depth. Some caves are reported at greater depths. Most caves show a phreatic origin. Some of them are short tunnels and S1 is just a longer one. On the other side, S14 is more complex: an emerged domed room is connected to a larger semi-submerged one, which in turn is connected to the sea by a large tunnel (24 x 16 x 7 m).

Most caves (S1, S6, S7, S10, S11, S14) show a WNW-ESE main direction, parallel to the main island direction, or an orthogonal one (S3, S13).
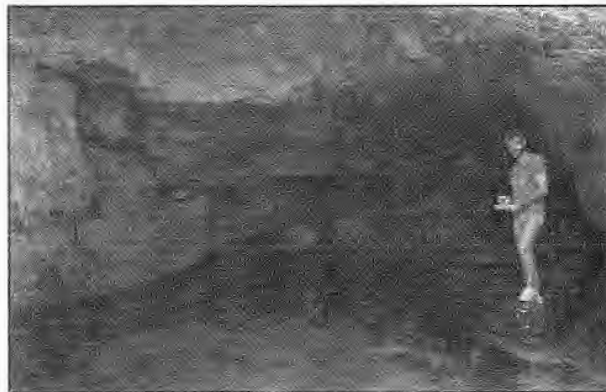
"Take it easy" sea caving: M. Giordani surveys at L84 (left, 2002); G. Ferrari surveys at L5 (right, 2002)

Code	Name	Depth	Devel.	Survey	Notes
S1	Taccio Vecchio cave	-20 - -12	57	Yes	Tunnel, three entrances. Nice and easy dive.
S3	Our Lady's cave	-15 - -5	11	Yes	Tunnel, two entrances. Nice and easy dive.
S4	1st Scoglio di Fora cave	-17 - -10	16	Yes	Tunnel, two entrances. Nice and easy dive.
S6	Punta Russeddu cave	-5 - -0.5	17	No	Tunnel, two entrances.
S7	Punta Pesce Spada cave	-15 - -11.5	16	No	Tunnel, two entrances. Southernmost cave in Europe.
S10	1st cave SE of Eastern Grottaccia	-11 - -7	11	Yes	Tunnel, two entrances. Rich in sponges and serpuloideans.
S11	2nd Scoglio di Fora cave	-12 - 0	20	Yes	Large tunnel. Nice and easy dive.
S12	3rd Scoglio di Fora cave	-9	6	Yes	Small chamber.
S13	Punta Cappellone cave	-18 - -10	16	Yes	Two entrances.
S14	2nd Taccio Vecchio cave (Salvo's cave)	-12 - +8	61	Yes	Tunnel + large semi-submerged chamber + emerged chamber. Nice light effects.
S16	2nd cave SE of Eastern Grottaccia	-15 - -11	~10	No	Three entrances. Rich in sponges.
S21	2nd Punta Guitgia submerged cave	-4 - -2	~10	No	Two entrances. Chamber.

Littoral caves
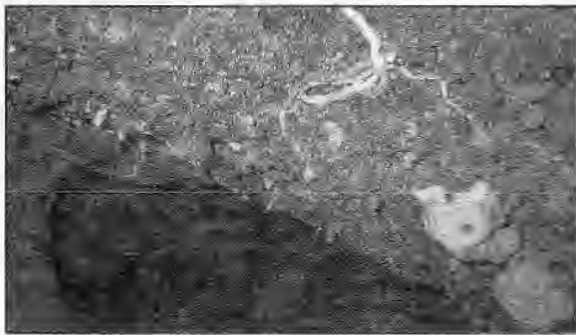
Dark cave biocoenosis in S10

86 littoral caves are positioned. They are distributed all along the island coast. In summer, tourist boats offer scenic tours of the island; they visit several littoral caves. The north cliffs show a large number of domed or triangular entrances (L26-L63). On the eastern side, just under the end of the airport runway, there is a number of large littoral caves (L71-L77). Two of them are named from the monk seal (Monachus monachus). Another area, named "Le Grottacce", is on the south-eastern side (L82-L85).

Cala Pulcino cave (L17) deserves a special note: it is a 32 m long tunnel half filled with water. It is placed on the side of a bay in the southern side of the island. Its entrance is protected from the waves, since it faces the inner part of the bay.

Most littoral caves are simple, horizontal straight tunnels with one or two entrances. L42 has a submerged side branch with a fresh water spring. Up to now, this is the only case of fresh water spring in Lampedusa caves.

As submerged caves, several littoral caves show a WNW-ESE main direction (L5, L14, L42, L67, L68, L85) or an orthogonal one (L84).
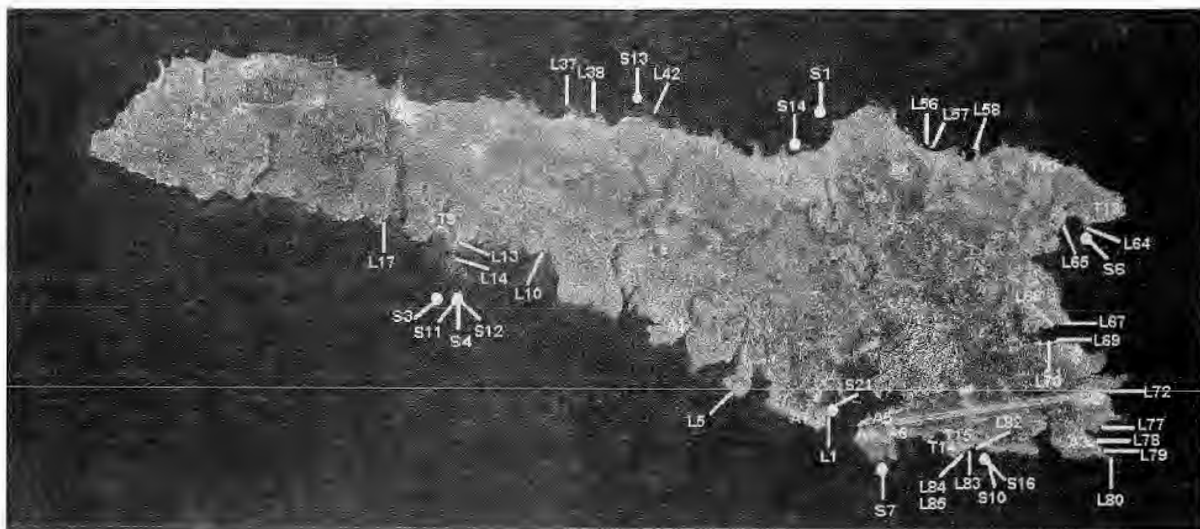
Lampedusa: cave positions

Code	Name	Elevation	Devel.	Survey	Notes
L1	Punta Guitgia cave	0	?	No	Small horizontal cave. Some garbage.
L5	4th Punta Pagghiareddu cave	-3 - +2	14	Yes	Small horizontal cave. Very nice pool in the entrance.
L10	1st Tabaccara cave	-1	10	Yes	Large cavern. Not a cave.
L13	Rabbits' Beach cave	0	?	No	Tight semi-submerged passage. Too small.
L14	1st Rabbits' Island cave	-1 - +2	20	Yes	Tunnel.
L17	Cala Pulcino cave	-5 - +4	32	Yes	Tunnel.
L37	Solaro caves	0	?	No	Wide entrance half filled with water. Probably connected with L38.
L38	'A Rutta delli Palunni Selvaggi (Wild Pigeons' cave)	0	30	No	Large cavern half filled with water. Probably connected with L37.
L42	4th Punta Cappellone cave	-7 - 0	?	No	Large half filled cavern. A 16 m long side branch brings fresh water.
L56	4th Cala Alaimo cave	0	?	No	Large half filled triangular entrance.
L57	5th Cala Alaimo Cave	0	?	No	Large half filled domed entrance.
L58 L59	'A Rutta dell'Innammorati (Lovers' cave)	0	?	No	Large half filled cavern. Two entrances.
L64	Punta Russeddu arch	0	?	No	Large tunnel. Two entrances.
L65	2nd Mare Morto cave	0	?	No	Half filled cavern with a large underwater room.
L67	1st Cala Pisana cave	-6 - +5	18	Yes	Horizontal half filled chamber.
L68	2nd Cala Pisana cave	-6 - +2	24	Yes	Horizontal nearly filled tunnel.
L69	3rd Cala Pisana cave	0	17	Yes	Small cavern. One sea and one land entrance.
L70	4th Cala Pisana cave	0	?	No	Small half filled tunnel with a second submerged entrance.
L73	Sea Monk's cave (1st)	0	>100?	No	Large half filled cavern. A small beach at the end.
L77	Sea Monk's cave (2nd)	0	?	No	Very large half filled tunnel.
L78	Punta Sottile tunnel	0	?	No	Small half filled tunnel. Two entrances.
L79	1st Vacca Aranciu cave	0	?	No	Very large cavern. Not a cave.
L80	2nd Vacca Aranciu cave	0 - +4	?	No	Two entrances, pipe cave. Horizontal half filled entrance from the sea; vertical pit in the plateau.
L82	Eastern Grottaccia	0	?	No	Very large round half filled collapsed dolina. Not a cave.
L83	Sima	0 - +10	?	No	Vertical shaft in the plateau reaches sea level.
L84	Cave East of Western Grottaccia	-6 - +1	17	Yes	Large nearly filled tunnel with short submerged continuation.
L85	Western Grottaccia	-6 - +10	?	No	Large open roofed channel with a terminal cavern.

215
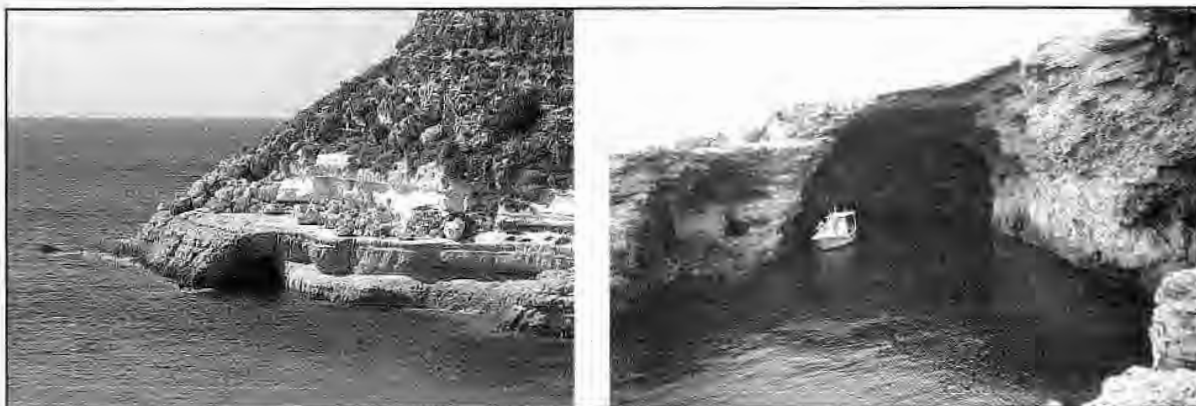
Littoral caves: Cala Pulcino cave (L17, left), Western Grottaccia (L85, right).

Land caves and artificial caves

No special research was performed on land caves. However, 24 references were registered. Some of them are small caverns. Postu Maraventanu cave (T10, in local dialect Postu Maraventanu means "place of bad wind") is a set of small orthogonal phreatic tunnels in the northern cliffs.

On the other side, Capo Grecale cave (T13) is a very high tunnel that opens at sea level just under the Capo Grecale lighthouse. Apparently it is not a littoral cave, since the sea water does not reach the cave entrance. However, the internal reaches are not yet explored.

Code	Name	Elevation	Devel.	Survey	Notes
T9	Rabbits' Beach pit	+65	?	No	Vertical shaft on the cliff just over the Rabbits' Beach. Closed by an iron grating.
T10	Postu Maraventanu cave	+15	?	No	Small orthogonal passages on three levels.
T13	Capo Grecale cave	0	?	No	Very large cave just under the Capo Grecale lighthouse. Can be reached only by boat.
T14	1st cave West of Western Grottaccia	2	?	No	Small passage on a side wall of Western Grottaccia.
T15	2nd cave West of Western Grottaccia	2	?	No	Small room just outside Western Grottaccia.

Lampedusa is also rich in artificial caves. In the past, local people mined several small rooms in the soft grainstone. Furthermore, during the second World War, Lampedusa was a strategic place for the control of African supply lines. The Italian Army built a large number of bunkers, mainly on the southern side of the island, as a protection for the harbour. Several bunkers were nearly destroyed by bombing. A special case is a bunker on the eastern side of the harbour entrance: it is placed on the cliff side, just above the entrance of L86, a littoral cave.

Biologic notes

Usually littoral caves suffer from a heavy hydrodynamism. Their wall population is poor, mainly algae. On the other side, in several occasions rich schools of fish were observed, in particular juvenile specimens. In this sense, littoral and submerged caves act as shelters and help in the replenishment of the fish population.

Underwater caves, on the other hand, usually show rich habitats, with several species of algae, sponges, hydroids, scleractinians, polychaetes. In some cases, lobsters were observed; fish schools are common in minor caves. A rumour reports that an undetermined hydroid is present in the mixed salt-fresh water submerged side branch of L42.

A notable exception to the rich population of submerged caves is S1, Taccio Vecchio cave. It is one of the largest known submerged caves, a

57 meters long tunnel with three entrances. Its tunnel portion is quite dark and poorly populated. Probably this is due to the heavy frequentation by divers. The cave is one of the most important and frequented diving places in Lampedusa.

Conclusions and future developments

Clearly, the present work is a low level one, with the simple aim of having a nice time in a nice place at positioning and surveying Lampedusa sea caves. Up to now, just part of the coast was examined in detail. An obvious future development is to carry on cave positioning and survey, in order to gather complete, detailed knowledge of sea caves at Lampedusa. Furthermore, other islands in the Pelagie archipelago have much to show: Lampione is a small uninhabited rock 10 km NW from Lampedusa, with a 300 m side length and a 36 m maximum elevation. It is made by Lutetian-Priabonian grainstone. A very quick survey revealed two submerged (S8, S9) and two semi-submerged small caverns (L23, L24). The sea bottom drops quickly to 50 meters. Lampione needs a more detailed underwater survey.

Linosa is a volcanic island 57 km NE of Lampedusa, with a 5,43 Km² extension. From the caving and sea caving point of view, it is yet unexplored. Some diving or tourist reports about lava tubes are present.

Since the biologic and economic relevance of both submerged and

littoral caves at Lampedusa, a detailed study would be very useful in assessing the biologic and tourist resources and the sustainability of their exploitation.

Bibliographic references

Cicogna F., C. N. Bianchi, G. Ferrari & P. Forti (eds.), 2003. Le grotte marine: cinquant'anni di ricerca in Italia. Ministero dell'Ambiente e della Tutela del Territorio, Roma. 1-505.

Criscuolo M. C. & M. Miragoli, 1988. Lampedusa e Malta, un po' di carsismo... Il Grottesco, Bollettino del Gruppo Grotte Milano, 48: 95-105.

Frassoni F., 1967. Esplorazioni del Gruppo Grotte S. Pellegrino Terme nelle isole mediterranee. Rassegna Speleologica Italiana, 19 (3): 105-113.

Grasso M. & H. M. Pedley, 1988. Carta Geologica dell'Isola di Lampedusa. Ministero della Pubblica Istruzione e Regione Sicilia.

Messana E. & M. Panzica La Manna, 1994. Consistenza attuale del Catasto delle grotte della Sicilia. In: Atti del II Congresso regionale di Speleologia, Catania, 8-11 dicembre 1994, Bollettino dell'Accademia Gioenia di Scienze Naturali, 27 (348): 373-376.

217

Surveys 1 (Author: G. Ferrari, 2005)

Surveys 2 (Author: G. Ferrari, 2005)

O-56

The deepest and the longest caves in Greece

Kostas ADAMOPOUIOS

(SELAS Club, Athens, Greece)

Preface

A large number of caves has been recorded and explored in Greece with a great variety of interest spanning geological, hydrogeological, palaeontologjcal, archaeological and folkloric. The caves in Greece are estimated to number around 10.500 (including underground karst forms of all kinds). These are recorded in lists which are usually categorized with various criteria in several speleological indexes. In the past, the unforgettable Anna Petrochilou had drawn up and published indexes with the country's deep long caves in the Bulletin of the Hellenic Speleological Society (HSS). Enough databases can be found on the internet related to deep and / or long caves at national and worldwide level. One of the oldest and probably most valid cave databases is that of the French speleologist **Eric Madelaine** which can be found at the following URL: **(http://www-sop.inria.fr/agos-sophia/sis/DB/database.html)**. This database has been used as a reference for the present work. It should be underlined that the specific database in question does not include caves for which there is no publication. It includes caves or potholes with depth more than 300m and / or length more than or equal to 3 kilometres. For the aims of present study caves **with depth more than -400m** and / or length **more than 6 kilometers** have been isolated and studied. The database has been updated with findings of recent explorations (period 2001-2005) in Greece.

Big potholes and caves are exceptionally infrequent and simultaneously their exploration is particularly laborious. Greece has an extent of 131.940 square km, that is to say if we suppose that the number of 10.500 caves is right, it corresponds to **one (1) cave or pothole for each 12.5 Km ^{2}**. Currently in Greece there are only 11 caves with depth more than -400m that is to say hardly **one (1) per 12.000 Km^2** and hardly **one (1) cave with length more than 6000m per 44.000 Km^2**. That is to say that within 12.000 Km^2 there are barely 1000 caves / potholes and only one of these is considered big (= > 400m depth or > 6000m length). In a lot of cases these caves have important geological or hydro geological importance with result their protection is immediately connected with the protection of underground water.

In the statistical analysis that follows, they are mentioned given based on the most topical list that is available today for the bigger caves (length and depth) in Greece. Simultaneously, an effort is made to correlate this with corresponding data from the rest of the world, the growth of explorations over time, the correlation of the number of caves with demographic elements (such us population), geographic distribution and other statistical analyses round these caves.

The main indicators that are used are the following:

- Number of deep / long caves (more than -400m depth)
- Number of deep / long caves per 50.000 Km^2
- Number of deep / long caves per million of residents

Most explorations (of big potholes or caves) in our country have been made by mainly French speleologists while secondary explorations have been carried out by Greeks and British Speleologists. The majority have been found to be on Crete (45%) (see Table 1b).

The deepest and longest Greek caves

According to the World cave database, 619 caves deeper than 400m have been explored worldwide (up to 2001 – **Annex Table P3**). In Greece there have been explored until 2005 eleven (11) potholes with a depth greater than -400 metres (**Table 1a**).

Table 1a: Greek caves with depth greater than 400m (at year 2005) in descending classification (depth)

Nr.	Cave Name	Depth	Length	Year
1	Gourgouthakas	-1,208	1,000	1997
2	Tafkura	-860	6,570	1996
3	Tripa tou Orniou	-610	30	2003
4	Stoichiomeni	-581	886	2000
5	Peleta	-493	500	2000
6	Tafkos sta Petradolakia	-473	1,010	1991
7	Spilia Sternou	-460		1992
8	Epos 1	-452		1969
9	Epos 2	-419		1979
10	Provatina	-405	40	1968
11	Diplotafki	-400	1,033	1994

In Greece, only 3 caves with a length greater than 6.000 meters have been explored until 2005 (**Table 2 a**).

Table 2a: Greek caves with length greater than 6.000m, in the year 2005 in descending classification (length)

Nr.	Cave Name	Depth	Length	Year
1	Diros		15,400	1974
2	Maaras		10,340	1985
3	Tafkura	-860	6,570	1996

Today the only cave in Greece which satisfies both the two criteria above of (length and depth) is the pothole **"Tafkura"** (- 860m) in the Anogeia of Mylopotamos, in the Rethymnon Prefecture of Crete (**Table 3**). Respectively, at world level, there have been hardly 155 caves explored that satisfy both conditions.

Table 3: Caves with length greater than 6000m and depth greater than 400 meters.

Nr.	Cave Name	Depth	Length	Year
1	Tafkura	-860	6,570	1996

Table 1b: Greek caves with depth, more than -400m (at year 2005) per geographic region.

Nr.	Cave Name	Geographic region
1	Gourgouthakas	Crete
2	Tafkura	Crete
3	Tripa tou Orniou	Epirus
4	Stoichiomeni	Sterea Ellada
5	Peleta	Peloponnesus
6	Tafkos sta Petradolakia	Crete
7	Spilia Sternou	Crete
8	Epos 1	Epirus
9	Epos 2	Epirus
10	Provatina	Epirus
11	Diplotafki	Crete

Table 2b: Greek caves with length bigger than 6.000m, at year 2003 per geographic region.

Nr.	Cave Name	Geographic region
1	Diros	Peloponesus
2	Maaras	Macedonia
3	Tafkura	Crete

In world level it appears that the number of deep caves are roughly equal to the number of long ones (619 and 671 respectively). However, the possibilities to discover a cave which is both deep and long are much less (155 worldwide) that is to say hardly **13.7%** of the total Number of big caves.

History of explorations in the deepest caves of Greece.

The deepest caves

You may find below a concise exploration background according to the relative bibliography, chronologically categorized from the oldest to the newer explorations for the deeper caves of the country.

"Provatina" (-408 m)

Provatina was explored by a British army expedition in 1968. The pothole was located for first time by English cavers in 1965 (Cambridge University Caving Club). Jim Eyre (1966) was the first who tried to descend and explore the cave but he stopped at -156m (he used rope ladder). The next year, British soldiers used a mechanically-driven winch and a basket with iron cable in order to descend to the bottom of the cave. Their effort was performed in two phases, first up to the depth of -177m the summer of 1967 and finally down to the bottom of the cave (-408) in 1968. An American expedition in 1973 descended the cave using speleological techniques (ropes) while the first European cavers who repeated their achievement were the French P. Sombardier and F. Poggia 1976. Since then a lot of expeditions have gone down to the bottom of this cave both foreign and Greek. The first Greek who descended Provatina was Kostas Zoupis, founding member of SPELEO club (Athens) and today Chairman of Hellenic Speleological Federation (HSF). The last known exploration effort was undertaken in 1998 by SELAS club (Athens). Nikos Mitsakis, the leader of this

expedition reported that the team explored three small new chambers after climbing from the bottom of the cave.

"Epos 1 and 2" (451m and - 419 m)

First exploration attempts took place between 1966-67-68 but without result. Only in 1969 the first of the two twin caves was explored (**"Epos 1"**) by P. Livesey while shortly later (in 1973) American cavers repeated their achievement. **"Epos 2"** cave was also explored by British cavers 4 years later, in September of 1979. Since that time many expeditions have been in the cave in order to push the exploration but without any significant progress (zero new passages reported). From the day of its discovery, Epos remained the deepest cave in Greece up to 1991.

"Tafkos sta Petradolakia" (-475m)

The cave was explored in 1989 up to the depth of -380m (lake). In 1991 after a cave dive (Ph.Brunet), the cave reached its current depth of -473m and thus remained the deepest in the country (until 1995). The exploration was conducted by the French cavers (GRESPA VI – responsible J.Y. Perrier). The first Greek cavers to make the descent were members of HSS (up to -380m). The most recent explorations of new departments [1] were realized by SELAS club (Athens) in 2002 during "Anogia – Ntelina 2002" with myself leading the expedition.

"Spilia Sternou" or "Sternon" (-460 m)

The cave is located in Leuka Ori Mountains (2456m) on Crete at an altitude of 2080m. It was explored for the first time by French cavers (GSO – ASEAUPS) in the years 1990, 1991 and 1992. The French team published their report in "Spelunca" (their survey describes the cave up to -400 m depth). The last exploration attempt took place in the summer of 2005 by SELAS club (Athens), during the "Sternes 2005" expedition led by the author. During this expedition the Greeks cavers went down as far as the -460m mark and stopped in a narrow passage with very good perspectives. The Greek cavers realized that the cave had been explored up to this point (but unfortunately there had been no publication of the results).

"Djplotafki" (-400m)

This cave was initially explored in 1984 by British cavers (SUSS) up to a depth of (-174m). In 1993 the French expedition (GRESPA VI - SCSP Ales, led by J.Y.Perrier and Th. Monges) went down to a depth of -330m, while in 1994 the exploration was terminated at a depth of -400m (due to a siphon) – There was a limited participation by Greek cavers in both the 1993 and 1994 expeditions. A completely unexplored part, 250m long, was found in 2002 during "Anogia – Ntelina 2002" expedition (led by the author).

---

[1] Long sections at a depth of -130m as well as an alternative route that leads once again to the final sump (-450m) but bypassing the lake at-380m (It is no longer necessary to carry boats into the cave), Mission Report for Anogeia Delina 2002, (under publication)

"Tafkura" (-860 m, length 6570m)

Tafkura was explored for the first time in 1978 by R. Maire (FR), up to a depth of -100m. In 1995 the exploration reached a depth of -485m (and length of 1000m) under the French association "La Tonche" with the participation of Greek cavers (Leader Th. Monges, member of CREI (committee of FFS). In 1996 a common expedition between three clubs (La Tonche – ASBE – Caving Team of the Technical University of Heraklion Crete) continued the explorations up to depth -810m and to a length of 4500m. In 1997 the first purely Greek mission "Tafkura 1997" (SP. OM. TEI and H.S.S. Dep. Crete) led by the author. At that time 500m of length were added to the cave. Finally in 2002 during SELAS expedition "Anogia – Delina 2002" the cave ended up with a new length (6570m) and a new depth after a successful -50m dive (by N.Mitsakis) in the siphon at -810m.

"Gourgoûthakas" (-1208m)

As result of a consistent effort for many years, the French team GS Catamaran succeded in 1998 to explore the Gourgouthakas cave up to its current depth (-1208m). Since that day the cave is by far the deeper know cave in Greece and one of the deepest in the world. The latest exploration in the cave took place under SELAS and SPOK clubs in 2001 (expedition leader A. Christodoulou).

"Stoichiomeni" (-581m)

The cave is situated in Viotia and was first explored (up to the depth of -70m), in the late 50's by the unforgettable I. Petrocheilos the founder of the HSS. The cave was re-explored by SPELEO club (Athens) in the early 80's up to the depth of -280m (expedition leader K.Zoupis). Later, in 1998 SELAS club organized an expedition which pushed the cave deeper (up to 463m, led by N.Mitsakis). Finally in the year 2000 a SELAS expedition led by the author (in cooperation with French cavers) reached today's known deepest bottom of Stoichiomeni at the depth of -580m. Unfortunately the cave is a subject of a major environmental catastrophe and at the present time it is not accessible. Greek cavers are undertaking actions for the protection of the cave and the restoration of its entrance.

"Peleta" (-493m)

This sinkhole was initially explored and surveyed by the unforgettable Anna. Petrocheilou (HSS) up to the depth of -70m. In year 2000 the SPELEO club Athens continued the exploration (expedition leader S.Nikolaidis) up to depth -493m. During that expedition (Peleta 2000) SPELEO's cave diver V.Trizonis dived in the bottom sump at -488m without achieving a major breakthrough (stopped at narrow underwater passage).

"Tripa tou Orniou" (-610m)

On of the most recent discoveries in Greece, which took place in the Autumn of 2003 by a joint French – Greek (Youth Committee/FFS and M. Diamantopoulos/SELAS) expedition in Astraka (Epirus). This expedition explored a completely new cave in the Vathylakkos area and descended to the depth of -580m. In the year 2004 the exploration continued until the current known bottom of the cave at a depth of **-610m.**

Biggest in length

The longest caves in Greece (except Tafkura) are also the major show caves in the country.

"Diros Caves'" (15.400m)

Diros (Glyphada Dirou or Vlyhada Dirou) cave was discovered in 1923 by residents of the region. The first systematic exploration of the cave was done by the unforgettable I. Petrocheilos and his spouse in 1949. After the death of I. Petrocheilos (in 1960), Anna Petrocheilou and the HSS continued the explorations. Up to 1960, 1.6km of corridors had been explored. Since 1961 the cave is open to the public (show cave) after a proposal of A. Petrocheilou and HSS. The HSS explored some 1500m more in the period between 1960 and 1966. In the year 1971 a team of American cave divers contributed with 300m new underwater passages. In 1975 a new artificial entry was created. Up to 1989 after explorations of SPELEO club (Athens) and HSS the length of cave is almost doubled (approx. 5.3km). In 1992 the length of the cave was 6.2km due to exploration efforts of HSS, SPELEO and Hellenic Ministry of Culture. In the year 2000 Speleo Club of Nafplion and the ministry of Culture pushed the cave to 10.606m length. Most recent explorations took place in the year 2003 and 2004 by the Ministry of Culture (V.Giannopoulos) and Swiss – Italian Cave divers (J.J. Bolanz, P.Deriaz, L.Cassati). The current length is approx. 15.400m

"Maaras" (10.340m)

The underground river **"Maaras"** is the source of the river Aggitis in Drama district. It is the cave with the longest ground plan development in Greece. The cave has huge passages and it is developed without many branches. The first systematic exploration started in the year 1978 by a French team in which Greek cavers G.Avagiannos and N.Ioannidis participated. The leader of this expedition was Mr. P. Reile. The French caver continued the explorations in 1980,.1981,.1982 and 1983 with the attendance of N. Ioannidis. In 1995 he came back with Xeidakis and continued further. Accordingly to the reports of the French team the cave (up to 2000) had a length of 10.040m. In 2002 an expedition led by T.Theodosiadis (SPELEO club Athens) undertook some diving in the caves which resulted in the exploration of 300m more.

Number of deep caves (more than the 400m depth)

Among all continents, by far the most deep caves (400m or more) are located in Europe (including also new independent states that resulted from the dissolution of Soviet Union). **(Diag.1)**

221

Diagram 1: Number of caves with depth bigger than 400m per continent.

ASIA 1%
NORTH AMERICA 1%
NEAR EAST 2%
AFRICA 1%
OCEANIA 2%
LATIN AMERICA AND CARIBBEAN 7%
EUROPE AND NEW INDEPEDENT STATES 86%

▦AFRICA	▦ASIA
☐NORTH AMERICA	☐NEAR EAST
▪OCEANIA	▨LATIN AMERICA AND CARIBBEAN
▦EUROPE AND NEW INDEPEDENT STATES	
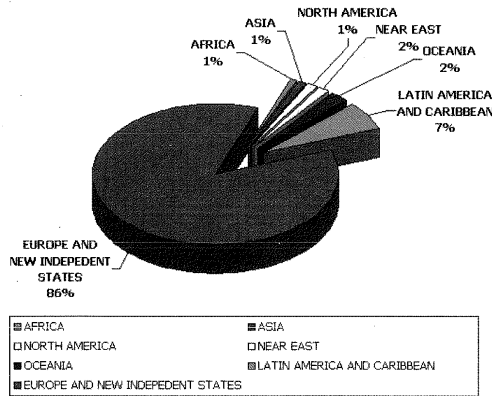
This it is explained because Speleology (and especially vertical techniques) is more developed in Europe than other regions. More specifically, 533 deep caves (the 86% of deep caves on the planet) exist in Europe, 43 exist in Latin America (6.7%) while 14 exist in Oceania (2.2%).

Speleology in Greece, is developing rapidly in the last 20 years. The number of speleological clubs is increasing continuously (**Diagr.4**) which combined with the efforts of foreign expeditions and the development of techniques and equipment had contributed to rapid increases in the number of deep caves explored in Greece. (**Diagr.2 and 3 and 3a**).

Diagram 2: Number of known deep caves in Greece per exploration year (classified every five-years).

				11
			8	
		6		
	3			
1				
'65	'75	'90	'95	'00
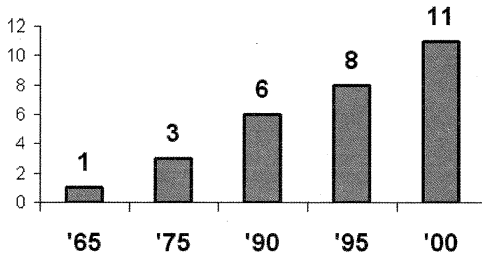
It should be noted that not only did the number of deep caves increase but so did the absolute depth of caves in Greece, which almost tripled compared to previous decades. (**Diagr.3a**)

Diagram 3: Trend of number of deep caves explored in Greece per year of exploration.

12
10 11
10
8
7 8
6
5 6
4
3 4
2 3
1 2
1969 1976 1979 1991 1992 1994 1996 1997 2000 2003
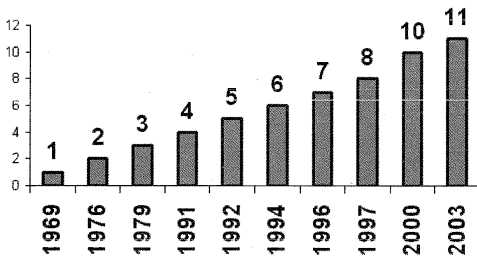
It can be noticed that there is a very rapid growth over the last ten years. Up to 1995 the number of deep caves was six (6) and in a period of eight (8) years this almost doubled and became 11 (in 2003 - **Diagr.2**). Today, Greece is ranked 11th in the worldwide classification and 9th in the European classification of countries by number of deep caves (**Diagr.5** and **Diagr.6**)

Number of deep caves per 50.000 square kilometers

It is true that deep caves are exceptionally infrequent. In the European continent today we find on average 0.98 deep caves per 50.000 km^2 (**Diagr.7**).

In Greece this ratio appears to be much higher (4.3 caves per 50.000 km^2, explaining to a certain extent how the country is classified **11th** in world and **9th** in Europe. Slovenia, now the base of UIS, is ranked first (with 49.3 caves per 50.000 km^2) followed by Austria (38.2 caves per 50.000 km^2) and Switzerland (with 29.1 caves per 50.000 km^2) (**Diagr.8**). The worldwide (Top 15) classification is almost the same as the European one. (**Diagr.9**)

Diagram 3a: Depth of the deepest cave in Greece by the decades.

1400
1208
1200
1000
800
600 452 453 473
400
200
0
1965-1975 1975-1990 1990-1995 1995-2003
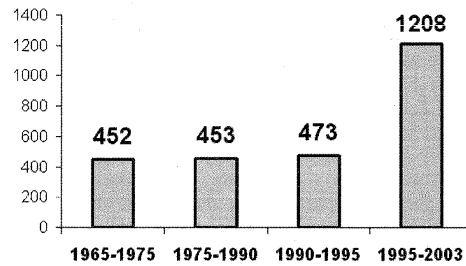
Diagram 4: Number of speleological clubs in Greece per decade.

20
19
15
12
10
6
5
2 3 3
0
50 60 70 80 90 00
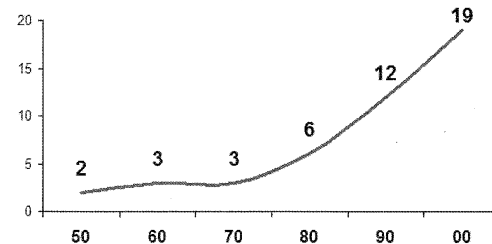
Diagram 5: Number of deep caves per country - World classification - Top 15 countries
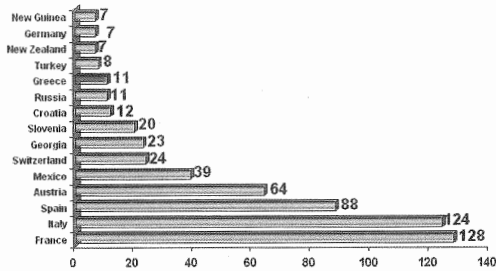
Diagram 6: Number of deep caves European countries– classification – Top 15 countries
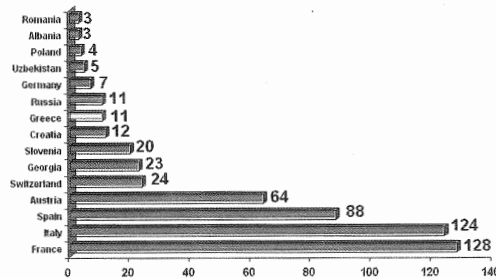
Diagram 7: Number of deep caves per 50.000 Km² (per continent).
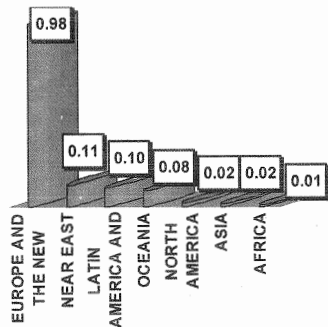
Diagram 8: Number of long caves per 50.000 Km² – World classification - Top 15 countries.
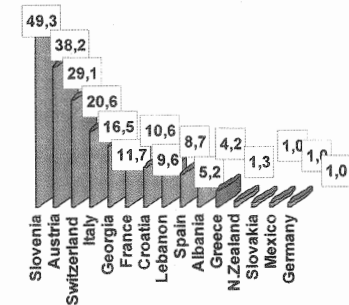
Diagram 9: Number of deep caves per 50.000 Km² - Classification of Top 15 countries in Europe.
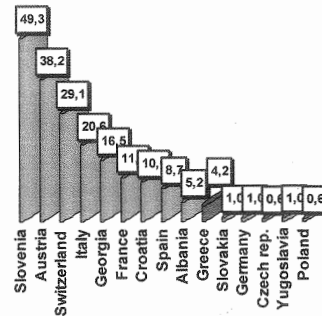
Number of deep caves per million of habitants

In examining number of deep caves per million habitants in differetnt countries (or continents) a slight variance between Europe (with 0.7 caves / million inhabitants.), Oceania (0.5 caves / million inhabitants), Latin America (with 0.1 caves / million inhabitants) and the rest of the world becomes visible (**Diagr. 10**).

Diagram 10: Number of deep caves per million habitants by Continent
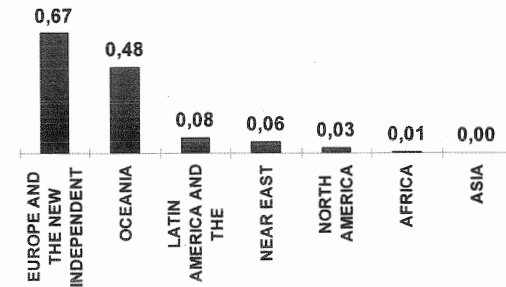
Diagram 11: Number of deep caves per million habitants by country - World classification of Top 15 countries.
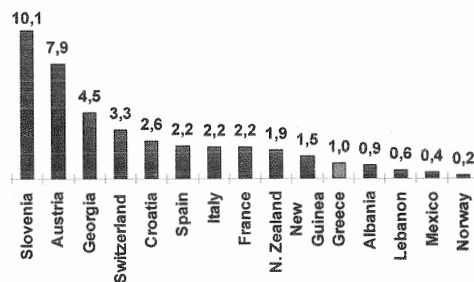
At country level (world classification) Slovenia appears to have 10.1 deep caves per million habitants, Austria follows with 7.9 and Georgia with 4.5. Greece, takes the 11th place with 1 deep cave per million inhabitants. (**Diagr.11**). The picture is same for the

223

top three countries in Europe. Greece is ranked 9th in this classification (**Diagr.12**).

Diagram 12: Number of deep caves per million habitants per country – European classification of Top 15 countries.

10,1 7,9 4,5 3,3 2,6 2,2 2,2 2,2 1,0 0,9 0,2 0,1 0,2 0,2 0,1

Slovenia Austria Georgia Switzerland Croatia Spain Italy France Greece Albania Norway Romania Uzbekistan Slovakia Poland
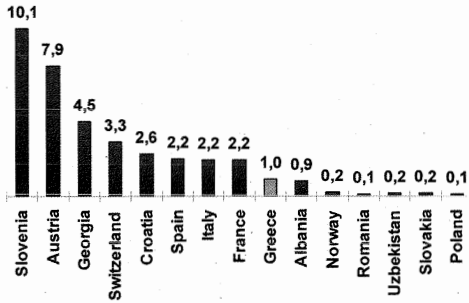
Number of long caves (more than 6000m length)

The number of long caves in Greece is very small compared to other countries in Europe and worldwide. In the diagrams that follow (Nrs 14 to 21) Greece is absent. Comparing continents, Europe is in the lead with 354 long caves against 185 of North America. The 3rd position is occupied by Latin America with 51 caves of this category. (**Diagr.13**). At the country level, the USA is ranked 1st worldwide with 178 long caves (including the longest cave ever found in the world) followed by France (108 caves) and Italy (40 caves) (**Diagr.14**). France and Italy are also at the top of the European classification followed by Spain (35 caves) (**Diagr.15**)

Diagram 13: Number of long caves per 50.000 Km^2 (by continent).

NEAR EAST 6
AFRICA 17
ASIA 28
OCEANIA 30
LATIN AMERICA AND THE CARIBBEAN 51
NORTH AMERICA 185
EUROPE AND THE NEW INDEPENDENT STATES 354
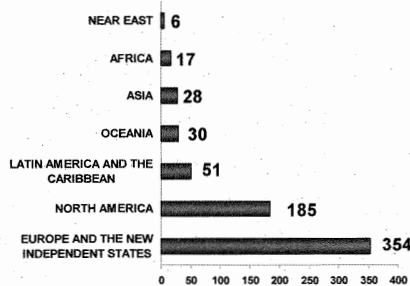
Diagram 14: Number of long caves by country – World Situation of 15 leading countries.

Cuba 9
Slovenia 11
Brazil 12
New 12
Australia 12
Russia 16
Switzerland 18
Romania 18
Mexico 21
UK 22
Austria 27
Spain 35
Italy 40
France 108
USA 178
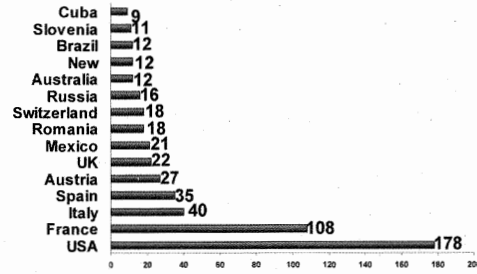
Diagram 15: Number of long caves by country – European classification of 15 leading countries.

Poland 6
Georgia 4
Slovakia 5
Germany 5
Ukraine 7
Croatia 5
Slovenia 11
Russia 16
Switzerland 18
Romania 18
UK 22
Austria 27
Spain 35
Italy 40
France 108
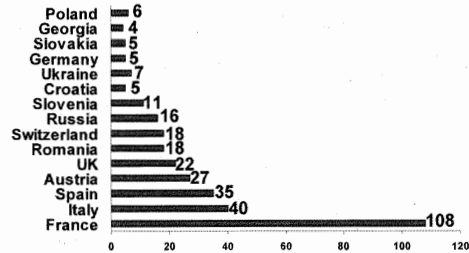
Number of long caves per 50.000 Km2

The European Continent once again appears to have the higher frequency of in the number of long caves per 50.000 Km^2 (0.65 caves per 50.000 Km^2) - see **Diagr.16**) while North America has 0.42 and Oceania 0.18. The first country in the worldwide classification is Slovenia (with 27.1 caves), .followed by Switzerland (21.8 caves) and Austria (with 16.1 caves) (**Diagr.17**)

Diagram 16: Number of long caves per 50.000 Km^2 (by continent).

0.65 0.42 0.18 0.12 0.07 0.06 0.03

EUROPE AND THE NEW NORTH AMERICA OCEANIA LATIN AMERICA AND NEAR EAST ASIA AFRICA
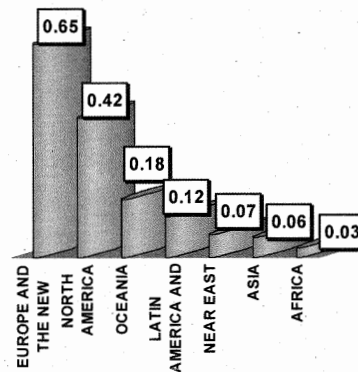
Precisely the same picture is also observed at European level (**Diagr.18**) it is clear that the way Europe is broken into states is a decisive factor especially affecting this indicator.

Diagram 17: Number of long caves per 50.000 Km^2 – World classification by country.
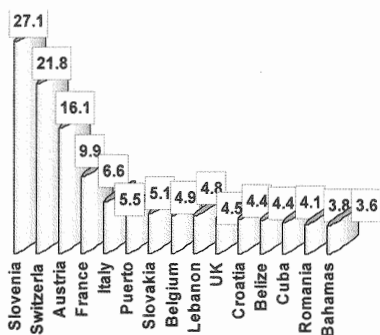
Diagram 18: Number of long caves per 50.000 Km² – European classification by country.

Number of long caves per million of habitants

Nr of Long caves per million of habitants in countries or in continents gives different perspectives. Oceania is present for the first time in a leading place (1.02 per million habitants) (**Diagr.19**) At country level (worldwide classification) countries with very small populations appear to be at the top (Belize, Slovenia and New Caledonia) (**Diagr.20**). At the European level Slovenia is once again first followed by Austria and Switzerland (**Diagr.21**).

Diagram 19: Number of long caves million habitants (by continent).

Diagram 20: Number of long caves per million inhabitants – Worldwide classification by country.

Diagram 21: Number of long caves per million habitants – European classification per country.

Conclusions

Unfortunately there is no world database of all caves regardless of length and depth. Such a database would allow us to make statistical analysis and to answer questions like "which is the country with more caves than any other in the globe?" etc. However with the data that are availiable it is confirmed inductively that Greece is a country with great potential and a very high number of deep caves compared to the rest of Europe or rest of the wolrd. Future developments in the explorations will increase these figures more. The potential of the country both in number of caves and in depth is great. It could be stressed that the unforgettable E.Platakis had recorded in Anogia region (Crete) only three (3) caves while in practice today more than 250 have been explored.

From the statistical analysis it is obvious that in Europe there are not so many long caves as commpared to the American continent. The opposite is the case with the number of deep caves, which exist in much higher numbers in Europe than in America.

At country level, Slovenia the base of UIS, possesses the first place above all the others, almost in every indicator, whereas Greece is usually ranked well (between 8 and 12) in most indicators concerning the deep caves.

225

Bibliography

- "Contribution in the study modern and old environments of most important Greek caves", Doctoral Thesis, V. I. GIANNOPOYLOS, ATHENS 2000
- "The largest caves of Greece", 3rd Pan-Hellenic Speleological Meeting, K.ADAMOPOULOS (S.EL.A.S), Glyphada, 2000.
- "Helenic-French expedition in the Astraka September 2003, M.DIAMANTOPOULOS (S.EL.A.S), (under printing)
- "Peleta 2000" Report of expedition, P. NIKOLAIDIS (SP.EL.E.O), Athens 2000
- "Stoichia 2000", Report of expedition, K. ADAMOPOULOS – T. MONGES (S.EL.A.S – G.S.H.L), Athens, 2000
- "Anogia-Ntelina 2002", Report of expedition K. ADAMOPOULOS (S.EL.A.S), Athens 2002
- "Le Karst du Massif du falakro, Resurgence de Maaras", P. RILE (F.F.S), France 2000
- "Expedition Speleo en Grece", P.DUMORTIER – A.WALTHAM, Bulletin d'Information et de Liaison – Semestriel – No 10 – Societe Speleologique du Plantarel, France Avril 1982
- "Sternes 2005" Report of expedition K. ADAMOPOULOS (S.EL.A.S), Athens under printing (2005)

Sources from the internet (Internet)

- World Cave Database, **E.MADELAINE**, http://www-sop.inria.fr/agos-sophia/sis/DB/database.html,
- Demographic data: U.S. Census Bureau, Population Division, International Programs Center, Washington, DC 20233-8860, Sep 2003
- Extent per country: Information taken from Internet (see Annex)

ABSTRACT

This article is a statistical analysis on the number of deep and long caves using several indicators like number of deep caves, number of deep caves per 50000 sq Km, number of deep caves per million inhabitants, number of long caves, number of long caves per million inhabitants and number of long caves per 50000 sq Km. Caves deeper or equal to the depth of -400m are considered as deep while caves longer or equal to 6000m are considered as long. Greece is the focus but the analysis was made against the rest of the world using Eric Mandelane's, World Cave Database (**http://www-sop.inria.fr/agos-sophia/sis/DB/database.html**) as a source. Population data is sourced from U.S. Census Bureau, Population Division. Land surface information per country has been collected through internet resources. As a general conclusion caves found in Europe and Asia are deeper than the caves in all other continents. Caves in America are longer than those in the rest of the World. The top country according to most of the indicators is Slovenia. Greece is ranked between 8 [th] and 11 [th] place worldwide or within Europe on the indicators concerning deep caves.

226
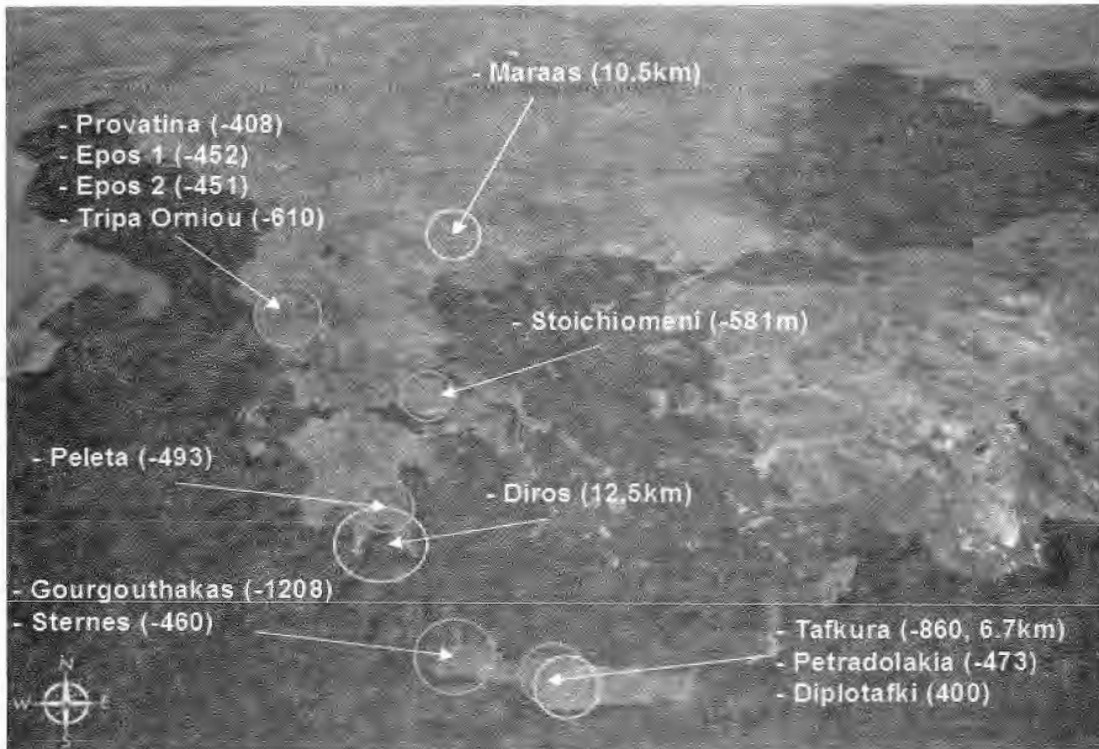
Pict.1: Satelite image of Greece with the approximate deep and long cave locations.

Table P 1: Number deep and long caves per country – Elements 2001 World Cave Database.

Geographical Area	Country	Nr of Deep Caves	Nr of Long Caves	Total Nr of Caves
AFRICA	Algeria	3	1	4
	Ethiopia		1	1
	Kenya	1	1	1
	Madagascar		6	6
	Morocco	1	2	3
	South Africa		4	4
	Tanzania		1	1
	Zaire		1	1
AFRICA Total		5	17	21
ASIA	China	2	4	5
	India		1	1
	Iran	1		1
	Japan	2	1	3
	Laos		2	2
	Malaysia	2	4	6
	Philippines		6	6
	S. Korea		3	3
	Thailand		4	4
	Vietnam		3	3
ASIA Total		7	28	34
EUROPE AND THE NEW INDEPENDENT STATES	Albania	3		3
	Austria	64	27	68
	Belgium		3	3
	Bosnia		1	1
	Bulgaria		3	3
	Croatia	12	5	17
	Czech rep	1	3	3
	France	128	108	196
	Georgia	23	4	26
	Germany	7	5	12
	Greece	11	3	13
	Hungary		3	3
	Ireland		2	2
	Italy	124	40	144
	Moldova		1	1
	Norway	1	1	2
	Poland	4	6	6
	Portugal		2	2
	Romania	3	18	19
	Russia	11	16	25
	Slovakia	1	5	6
	Slovenia	20	11	27
	Spain	88	35	104
	Switzerland	24	18	30
	Turkmenistan		3	3
	UK		22	22
	Ukraine	2	7	9
	Uzbekistan	5	2	5
	Yugoslavia	1		1
EUROPE AND THE NEW INDEPENDENT STATES Total		533	354	756
LATIN AMERICA AND THE CARIBBEAN	Bahamas		1	1
	Belize		2	2
	Brazil	1	12	13
	Cuba		9	9
	Guatemala		1	1
	Honduras	1		1
	Mexico	39	21	51
	Peru	1		1
	Puerto Rico		1	1
	Rep Dominicaine		1	1
	Venezuela		3	3
LATIN AMERICA AND THE CARIBBEAN Total		42	51	84
NEAR EAST	Lebanon	2	1	3
	Syria		1	1
	Turkey	8	4	11
NEAR EAST Total		10	6	15
NORTH AMERICA	Canada	3	7	9
	USA	5	178	179
NORTH AMERICA Total		8	185	188
OCEANIA	Australia		12	12
	New Caledonia		1	1
	New Guinea	7	5	10
	New Zealand	7	12	14
OCEANIA Total		14	30	37
Grand Total		619	671	1135

227

Table P 2: Extent per country in square kilometers (km²).

Country	Land-Km2	Country	Land-Km2	Country	Land-Km2	Country	Land-Km2
Afghanistan	647,500 km2	Dominica	754 km2	Kuwait	17,820 km2	Romania	237,500 km2
						Russia	17,075,200 km2
Albania	28,748 km2	Dominican Republic	48,730 km2	Kyrgyzstan	198,500 km2		
Algeria	2,381,740 km2	East Timor	15,007 km2	Laos	236,800 km2	Rwanda	26,338 km2
American Samoa	199 km2	Ecuador	283,560 km2	Latvia	64,589 km2	Saint Helena	410 km2
Andorra	468 km2	Egypt	1,001,450 km2	Lebanon	10,400 km2	Saint Kitts and Nevis	261 km2
Angola	1,246,700 km2	El Salvador	21,040 km2	Lesotho	30,355 km2	Saint Lucia	616 km2
Anguilla	102 km2	Equatorial Guinea	28,051 km2	Liberia	111,370 km2	St. Pierre & Miquelon	242 km2
Antarctica	14 mil km2	Eritrea	121,320 km2	Libya	1,759,540 km2	St.Vincent Grenadines	389 km2
Antigua and Barbuda	443 km2	Estonia	45,226 km2	Liechtenstein	160 km2	Samoa	2,944 km2
Arctic Ocean	14.056 mil km2	Ethiopia	1,127,127 km2	Lithuania	65,200 km2	San Marino	61.2 km2
Argentina	2,766,890 km2	Europa Island	28 km2	Luxembourg	2,586 km2	Sao Tome Principe	1,001 km2
Armenia	29,800 km2	Falkland Islands	12,173 km2	Macau	25.4 km2	Saudi Arabia	1,960,582 km2
Aruba	193 km2	Faroe Islands	1,399 km2	Madagascar	587,040 km2	Senegal	196,190 km2
Ashmore and Cartier Islands	5 km2	Fiji	18,270 km2	Malawi	118,480 km2	Serbia/Montenegro	102,350 km2
Atlantic Ocean	76.762 mil km2	Finland	337,030 km2	Malaysia	329,750 km2	Seychelles	455 km2
Australia	7,686,850 km2	France	547,030 km2	Maldives	300 km2	Sierra Leone	71,740 km2
Austria	83,858 km2	French Guiana	91,000 km2	Mali	1.24 mil km2	Singapore	692.7 km2
Azerbaijan	86,600 km2	French Polynesia	4,167 km2	Malta	316 km2	Slovakia	48,845 km2
Bahamas, The	13,940 km2	French Antarctic s	7,829 km2	Man, Isle of	572 km2	Slovenia	20,273 km2
Bahrain	665 km2	FYROM	25,333 km2	Marshall Islands	181.3 km2	Solomon Islands	28,450 km2
Baker Island	1.4 km2	Gabon	267,667 km2	Martinique	1,100 km2	Somalia	637,657 km2
Bangladesh	144,000 km2	Gambia, The	11,300 km2	Mauritania	1,030,700 km2	South Africa	1,219,912 km2
Barbados	431 km2	Gaza Strip	360 km2	Mauritius	2,040 km2	S.Georgia-S.Sandwich	3,903 km2
Bassas da India	0.2 km2	Georgia	69,700 km2	Mayotte	374 km2	Southern Ocean	20.327 mil km2
Belarus	207,600 km2	Germany	357,021 km2	Mexico	1,972,550 km2	Spain	504,782 km2
Belgium	30,510 km2	Ghana	239,460 km2	Micronesia	702 km2	Spratly Islands	less than 5 km2
Belize	22,966 km2	Gibraltar	6.5 km2	Midway Islands	6.2 km2	Sri Lanka	65,610 km2
Benin	112,620 km2	Glorioso Islands	5 km2	Moldova	33,843 km2	Sudan	2,505,810 km2
Bermuda	53.3 km2	Greece	131,940 km2	Monaco	1.95 km2	Suriname	163,270 km2
Bhutan	47,000 km2	Greenland	2,166,086 km2	Mongolia	1.565 mil km2	Svalbard	62,049 km2
Bolivia	1,098,580 km2	Grenada	344 km2	Montserrat	102 km2	Swaziland	17,363 km2
Bosnia and Herzegovina	51,129 km2	Guadeloupe	1,780 km2	Morocco	446,550 km2	Sweden	449,964 km2
Botswana	600,370 km2	Guam	549 km2	Mozambique	801,590 km2	Switzerland	41,290 km2
Bouvet Island	58.5 km2	Guatemala	108,890 km2	Namibia	825,418 km2	Syria	185,180 km2
Brazil	8,511,965 km2	Guernsey	78 km2	Nauru	21 km2	Taiwan	35,980 km2
British Indian Ocean Ter	60 km2	Guinea	245,857 km2	Navassa Island	5.2 km2	Tajikistan	143,100 km2
British Virgin Islands	153 km2	Guinea-Bissau	36,120 km2	Nepal	140,800 km2	Tanzania	945,087 km2
Brunei	5,770 km2	Guyana	214,970 km2	Netherlands	41,526 km2	Thailand	514,000 km2
Bulgaria	110,910 km2	Haiti	27,750 km2	NL Antilles	960 km2	Tokelau	10 km2
Burkina Faso	274,200 km2	Heard & McDonald Isl.	412 km2	New Caledonia	19,060 km2	Tonga	748 km2
Burma	678,500 km2	Holy See (Vatican City)	0.44 km2	New Zealand	268,680 km2	Trinidad and Tobago	5,128 km2
Burundi	27,830 km2	Honduras	112,090 km2	Nicaragua	129,494 km2	Tromelin Island	1 km2
Cambodia	181,040 km2	Hong Kong	1,092 km2	Niger	1.267 mil km2	Tunisia	163,610 km2
Cameroon	475,440 km2	Howland Island	1.6 km2	Nigeria	923,768 km2	Turkey	780,580 km2
Canada	9,976,140 km2	Hungary	93,030 km2	Niue	260 km2	Turkmenistan	488,100 km2
Cape Verde	4,033 km2	Iceland	103,000 km2	Norfolk Island	34.6 km2	Turks & Caicos Isl.	430 km2
Cayman Islands	262 km2	India	3,287,590 km2	N.Mariana Isl.	477 km2	Tuvalu	26 km2
Central African Republic	622,984 km2	Indian Ocean	68.556 mil km2	Norway	324,220 km2	Uganda	236,040 km2
Chad	1.284 mil km2	Indonesia	1,919,440 km2	Oman	212,460 km2	Ukraine	603,700 km2
Chile	756,950 km2	Iran	1.648 mil km2	Pacific Ocean	155.557 mil km2	United Arab Emirates	82,880 km2
China	9,596,960 km2	Iraq	437,072 km2	Pakistan	803,940 km2	United Kingdom	244,820 km2
Christmas Island	135 km2	Ireland	70,280 km2	Palau	458 km2	United States	9,629,091 km2
Clipperton Island	6 km2	Israel	20,770 km2	Palmyra Atoll	11.9 km2	Uruguay	176,220 km2
Cocos (Keeling) Islands	14 km2	Italy	301,230 km2	Panama	78,200 km2	Uzbekistan	447,400 km2
Colombia	1,138,910 km2	Jamaica	10,991 km2	Papua N. Guinea	462,840 km2	Vanuatu	12,200 km2
Comoros	2,170 km2	Jan Mayen	373 km2	Paracel Islands	NA km2	Venezuela	912,050 km2
Congo	2,345,410 km2	Japan	377,835 km2	Paraguay	406,750 km2	Vietnam	329,560 km2
Congo, Republic of the	342,000 km2	Jarvis Island	4.5 km2	Peru	1,285,220 km2	Virgin Islands	352 km2
Cook Islands	240 km2	Jersey	116 km2	Philippines	300,000 km2	Wake Island	6.5 km2
Coral Sea Islands	less than 3 km2	Johnston Atoll	2.8 km2	Pitcairn Islands	47 km2	Wallis and Futuna	274 km2
Costa Rica	51,100 km2	Jordan	92,300 km2	Poland	312,685 km2	West Bank	5,860 km2
Cote d'Ivoire	322,460 km2	Juan de Nova	4.4 km2	Portugal	92,391 km2	Western Sahara	266,000 km2
Croatia	56,542 km2	Kazakhstan	2,717,300 km2	Puerto Rico	9,104 km2	Yemen	527,970 km2
Cuba	110,860 km2	Kenya	582,650 km2	Qatar	11,437 km2	Zambia	752,614 km2
Cyprus	9,250 km2	Kingman Reef	1 km2	Reunion	2,517 km2	Zimbabwe	390,580 km2
Czech Republic	78,866 km2	Kiribati	811 km2				
Denmark	43,094 km2	Korea, North	120,540 km2				
Djibouti	23,000 km2	Korea, South	98,480 km2				

228

Table P 3: Elements of population per continent and per country (in thousands habitants) –1998.

Region	Country	Total
AFRICA	Algeria	30,481
	Egypt	66,050
	Libya	5,691
	Morocco	29,114
	Tunisia	9,380
	Angola	10,865
	Benin	6,101
	Botswana	1,448
	Burkina Faso	11,266
	Burundi	5,537
	Cameroon	15,029
	Cape Verde	400
	Central African	3,376
	Chad	7,360
	Comoros	546
	Congo (Brazzaville)	2,658
	Congo (Kinshasa)	49,001
	Cote d'Ivoire	15,446
	Djibouti	441
	Equatorial Guinea	454
	Eritrea	3,842
	Ethiopia	58,390
	Gabon	1,208
	Gambia, The	1,292
	Ghana	18,497
	Guinea	7,477
	Guinea-Bissau	1,206
	Kenya	28,337
	Lesotho	2,090
	Liberia	2,772
	Madagascar	14,463
	Malawi	9,840
	Mali	10,109
	Mauritania	2,511
	Mauritius	1,168
	Mayotte	109
	Mozambique	18,641
	Namibia	1,622
	Niger	9,672
	Nigeria	110,532
	Reunion	705
	Rwanda	7,956
	Saint Helena	7
	Sao Tome and	150
	Senegal	9,723
	Seychelles	79
	Sierra Leone	5,080
	Somalia	6,842
	South Africa	42,835
	Sudan	33,551
	Swaziland	966
	Tanzania	30,609
	Togo	4,906
	Uganda	22,167
	Zambia	9,461
	Zimbabwe	11,044
AFRICA Total		760,503
NEAR EAST	Bahrain	616
	Cyprus	761
	Gaza Strip	1,054
	Iraq	23,034
	Israel	5,644
	Jordan	4,435
	Kuwait	1,913
	Lebanon	3,506
	Oman	2,364
	Qatar	697
	Saudi Arabia	20,786
	Syria	16,673
	Turkey	64,567
	United Arab Emirates	2,303
	West Bank	1,557
	Yemen	16,388
Total		166,298

Region	Country	Total
OCEANIA	American Samoa	62
	Australia	18,613
	Fiji	803
	French Polynesia	238
	Guam	148
	Marshall Islands	63
	New Caledonia	194
	New Zealand	3,625
	Northern Mariana	67
	Papua New Guinea	4,600
	Samoa	225
	Solomon Islands	441
	Tuvalu	10
	Vanuatu	185
OCEANIA Total		29,274
EUROPE AND THE NEW INDEPENDENT STATES	Albania	3,331
	Bosnia and	3,366
	Bulgaria	8,240
	Croatia	4,672
	Czech Republic	10,286
	Hungary	10,208
	FYROM	2,009
	Montenegro	680
	Poland	38,607
	Romania	22,396
	Serbia	10,526
	Slovakia	5,393
	Slovenia	1,972
	Armenia	3,422
	Azerbaijan	7,856
	Belarus	10,409
	Estonia	1,421
	Georgia	5,109
	Kazakhstan	16,847
	Kyrgyzstan	4,522
	Latvia	2,385
	Lithuania	3,600
	Moldova	4,458
	Russia	146,861
	Tajikistan	6,020
	Turkmenistan	4,298
	Ukraine	50,125
	Uzbekistan	23,784
	Andorra	65
	Austria	8,134
	Belgium	10,175
	Denmark	5,334
	Faroe Islands	42
	Finland	5,149
	France	58,805
	Germany	82,079
	Gibraltar	29
	Greece	10,662
	Guernsey	65
	Iceland	271
	Ireland	3,619
	Italy	56,783
	Jersey	89
	Liechtenstein	32
	Luxembourg	425
	Malta	380
	Man, Isle of	75
	Monaco	32
	Netherlands	15,731
	Norway	4,420
	Portugal	9,928
	San Marino	25
	Spain	39,134
	Sweden	8,887
	Switzerland	7,260
	United Kingdom	57,721
Total		798,154

Region	Country	Total
LATIN AMERICA AND THE CARIBBEAN	Anguilla	11
	Antigua and Barbuda	64
	Argentina	36,265
	Aruba	68
	Bahamas, The	280
	Barbados	259
	Belize	230
	Bolivia	7,826
	Brazil	169,807
	Chile	14,677
	Colombia	38,581
	Costa Rica	3,605
	Cuba	11,045
	Dominica	66
	Dominican Republic	7,999
	Ecuador	12,337
	El Salvador	5,752
	French Guiana	163
	Grenada	96
	Guadeloupe	416
	Guatemala	12,008
	Guyana	708
	Haiti	6,781
	Honduras	5,862
	Jamaica	2,635
	Martinique	407
	Mexico	98,553
	Netherlands Antilles	213
	Nicaragua	4,583
	Panama	2,736
	Paraguay	5,291
	Peru	26,111
	Puerto Rico	3,857
	Saint Kitts and Nevis	42
	Saint Lucia	152
	Saint Vincent and the	120
	Suriname	428
	Trinidad and Tobago	1,117
	Uruguay	3,285
	Venezuela	22,803
	Virgin Islands	118
Total		507,357
ASIA	Afghanistan	24,792
	Bangladesh	127,609
	Bhutan	1,908
	Brunei	315
	Burma	47,305
	Cambodia	11,340
	China	1,236,915
	Hong Kong S.A.R.	6,707
	India	983,377
	Indonesia	212,942
	Iran	68,960
	Japan	125,932
	Laos	5,261
	Macau	507
	Malaysia	20,933
	Maldives	290
	Mongolia	2,579
	Nepal	23,698
	North Korea	22,178
	Pakistan	135,135
	Philippines	77,726
	Singapore	3,490
	South Korea	46,417
	Sri Lanka	18,934
	Taiwan	21,908
	Thailand	60,037
	Vietnam	76,236
ASIA Total		3,363,431
NORTH AMERICA	Canada	30,675
	Greenland	59
	United States	270,312
Total		301,046

229

O-57

The cave of Kapsia at Mantinia and its anthropological findings

C. Merdenisianos M.D. PhD.

University of Athens, Museum of Anthropology, Athens, Greece

The cave of Kapsia is located at the foot of Mainalo Mountain, at an altitude of 637 meters, on the western part of the karst plain of ancient Mantinia. It is 14 km from the town of Tripoli and only 1.5 km north of the village of Kapsia.

It is a pothole belonging to the complex system of potholes of the Mantinia plateau. This underground system of natural drains absorbs a big part of the waters of the plain which in winter is transformed into a lake by the strong rainfalls.

From the historical data we have to date, we know that the first person who visited the cave was the French archaeologist G. Fougeres in 1887 because of the excavation works then carried out in the area of ancient Mantinia. The first one, though, who is believed to have systematically explored the cave, is the engineer N. Siderides that led a Greek- French expedition in 1892. He published the results of his research in Spelunca, the French scientific magazine in 1911. From the other expeditions that followed, three are considered to be the most important ones to-date. The new Greek-French expedition of 1974 led by I. Ioannou (ESE [Greek Speleology Society] bulletin XIII, issues 6,7,8 1976), the expedition of 1979 with K. Merdenisianos and A. Bartsioka (Publication by A. Bartsioka, K. Merdenisianos, K. Zafeiratos in ESE bulletin XVIII issues 1-2 1981-82) and the research, specially about the study of paleoanthropological material carried out by Professor Th. Pitsios in 1980.

From a geo-morphological point of view, the cave is horizontal and consists of a series of complex corridors of 600 m. length and total area of 6,500 m², leading to two rooms, the second of which is the biggest. It should be noted that the ground at the entrance of the cave and almost up to the last big room is extremely muddy. This happens because during the period of strong rainfalls, a part of the waters of the Mantinia plateau is drained mainly through its first corridors, sweeping along sludge and other sediment. It seems that in the past, the cave used to be flooded by rainwater and its first sections were underwater. This is shown by the traces of water level left by the floods on the walls of the cave.

Most of the parts of the cave exhibit important stone decoration. However, the special aesthetic interest of Kapsia is mainly focused on the last big room which due to the absence of sludge displays a crystalline formation of incomparable beauty made of columns, stalactite and stalagmite complexes as well as draping formations in rare shades of yellow and red. For these reasons, this hall was named "Room of Miracles" by the first explorers.

The cave of Kapsia has great scientific interest apart from the tourist one. More specifically, numerous pieces of human bones from males, females and children were found inside the cave. Along with the bones, many pieces of ancient pottery and clay oil lamps dating from the 4th and 5th centuries AD were also found. The first explorers mention that they found 45-50 human skulls most of which were gathered in a room almost in the middle of the cave which was named "Room of skulls and bones". The origin of all this anthropological material remains a puzzle for science which has not found a satisfactory solution yet.

According to the opinion of A. Bartsioka, K. Merdenisianos and K. Zafeiratos, (1981-82), the existence of osteological material is supposed to originate from the sudden drowning of people who occasionally used the cave (maybe for worshipping reasons) and who were trapped after a big flood. Later research by Th. Pitsios, (1987-88), showed that the presence of paleoanthropological findings may not be due to some extra-ordinary event, as the one mentioned above, but to the long-term use of the cave as a burial spot and a place of worshipping the dead.

Dimensions

Total passages Length : about 620 metres.

Total area : about 6.700 square metres.

Greatest height of ceiling : 7 metres.

Climatological Data

2/9/1979: (entrance of cave) temperature 19°C

(hall of Skulls and Bones) temperature 13°C. Relative humidity 95%

8/1/1994: (hall of Wonders) temperature 13°C. Relative humidity 100%

Hall of "Wonders". Observe the old level of the water from inundation of the cave.

The hall of "Skulls and Bones"
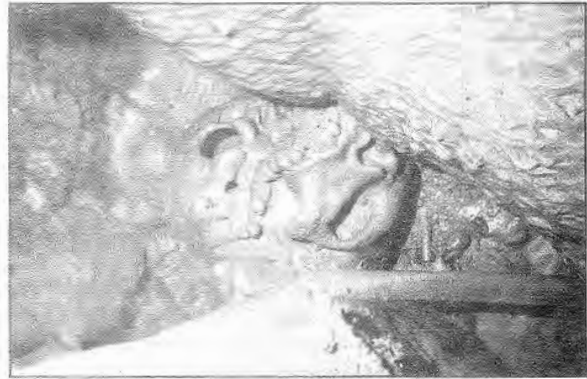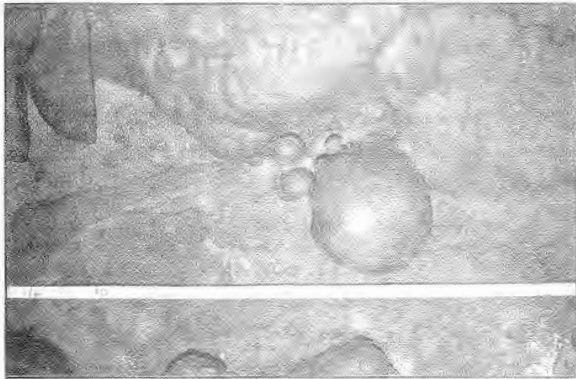
Human skulls and bones covered with stalagmite material
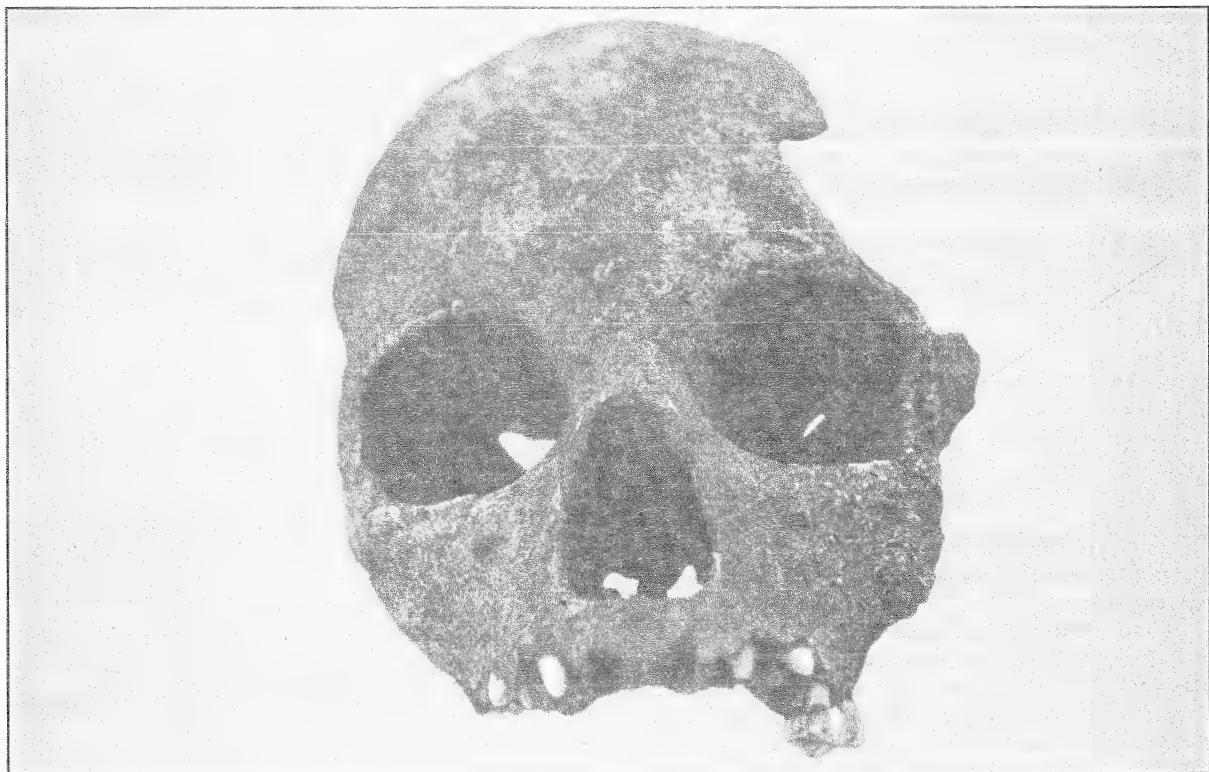
Skull from a child of age about 9 years
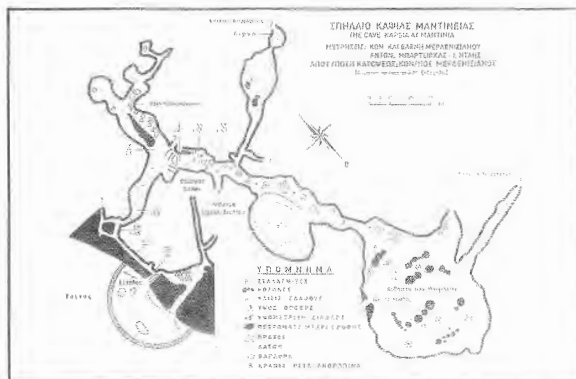
Bibliography

ANGEL J. L. 1971: "The People of Lerna: Analysis of a Prehistoric Aegean Population".

(Princeton and Washington. American Shool of Classical Studies at Athens and Smithsonian Institution Press).

BAHN P. 2003: " Written in Bones". «Γραμμένο στα οστά». (Ελληνική μετάφραση: Β. Παυλίδης. Επιστημονική επιμέλεια: Δ. Αυγερινός. Αθήνα).

BARTSIOKAS A. 2000: "The Eye Injury of King Phillip II and the skeletal evidence from the Royal Tomb II at Vergina". (Science, 288).

BASS W.M. 1987: "Human Osteology" (A Laboratory and Field Manual, 3rd ed. Missouri Archaeological Society, Columbia, Missouri).

BROTHWELL D. R. 1981: "Digging up Bones". (3rd Edition, Ithaca, New York: Cornel University Press).

BUIKSTRA J., UBELAKER D. H. 1994: "Standards for data collections from human Skeletal remains". (Arkansas Archeological Survey Research Series. No 40. Arkansas).

ΔΕΡΜΙΤΖΑΚΗΣ Μ. 1994: «Γλωσσάριο Γεωλογικών Εννοιών». Αθιήνα.

ΔΕΡΜΙΤΖΑΚΗΣ Μ. 1995: «Ο πρώτος άνθρωπος στα σπήλαια και οι καλλιτεχνικές του ανησυχίες». (Ιστορία, τόμος 322, Απρίλιος 1995. Αθήνα).

ΔΕΡΜΙΤΖΑΚΗΣ Μ. 1998: «Αναζητώντας τους προγόνους μας». Αθήνα.

DEROBERT L. 1974: «Medecine Legale ».

ELLIS BRYAN 1976: "Surveying Caves". (Somerset, Great Britain).

FORD T., CULLINGFORD C. 1976: "The science of speleology". (New York).

HARRIS E. F., WOODS M.A., ROBINSON Q.C. 1993: "Dental health patterns in an urban Midsouth population: sex and age changes". (Quintes - sence International. 24, p. 45-52).

HILL C., FORTI P. 2004: "Cave minerals of the world". (Alabama, U.S.A.).

HILLSON S. 1996: "Dental Anthropology". (Cambridge University Press. London).

JASINSKI M. 1966: "Speleologie". (Geneve).

ΖΑΦΕΙΡΑΤΟΣ Κ. 1980: «Θέματα εργαστηριακών ασκήσεων Φυσικής Ανθρωπολογίας».

(Εκδόσεις Πανεπιστημίου Αθηνών).

ΗΛΙΑΚΗΣ Κ. Ε. 1976: « Ιατροδικαστική». (Εκδόσεις Παρισιάνος - Αθήνα).

ΙΩΑΝΝΟΥ Ι. 1976 : « Πραγματοποιηθείσαι εξερευνήσεις εις περιοχάς Κοσμά Λεωνιδίου και Τριπόλεως Αρκαδί -Καταβόθρες χωρίου Κάψιας Τριπόλεως ΑΣΜ 38 » (Δελτίο Ε.Σ.Ε. τόμ. XIII, τεύχ. 6,7,8, σελ. 219-221).

ΜΑΝΩΛΗΣ Σ. 1999: «Βιολογική Ανθρωπολογία». Αθήνα.

ΜΕΡΔΕΝΙΣΙΑΝΟΣ Κ. 1971: «Στοιχεία Σπηλαιολογίας». (Εκδόσεις Ε.Π.Ε.ΑΝ., Αθήνα).

ΜΕΡΔΕΝΙΣΙΑΝΟΣ Κ. 2000: «Το αρχαιολογικό σπήλαιο Ειδωλείων Παλιάμπελων Βόνιτσας». Δελτ. Ε.Σ.Ε. τόμ. ΧΧΙΙ, 1995-2000).

ΜΕΡΔΕΝΙΣΙΑΝΟΣ Κ. 2000:«Το παλαιοανθρωπολογικής σημασίας σπήλαιο Κουκούρι Δρυάλου Λακωνίας». (Δελτίο Ε.Σ.Ε. , τόμ. ΧΧΙΙ 1995-2000).

ΜΕΡΔΕΝΙΣΙΑΝΟΣ Κ. 2003: « Το σπήλαιο Βύθακας Δυρού Μάνης και το αρχαιολογικό του ενδιαφέρον». (3ο Συμπ. Αρχαιολογίας Γεωλογίας και Παλαιοντολογίας Σπηλαίων. Αθήνα 17-19 Οκτ. 2003).

ΜΕΡΔΕΝΙΣΙΑΝΟΣ Κ. 2004: «Παλαιοπαθολογική μελέτη του σκελετικού πληθυσμού από το Βυζαντινό νεκροταφείο των Αβδήρων στη Θράκη». (Διδακτορική διατριβή. Έκδοση Πανεπιστημίου Αθηνών).

ΜΕΡΔΕΝΙΣΙΑΝΟΣ Κ., ΠΙΤΣΙΟΣ Θ. 1994:«Πιθανή περίπτωση τρυ-

πανισμού κρανίου από Το βυζαντινό νεκροταφείο των Αβδήρων». (5ο Διεθνές Συνέδριο Ανάπτυξης, Εξέλιξης και Περιβάλλοντος Σπηλαίων. Δελτ. Ε.Σ.Ε. τόμος ΧΧΙ, 1993-94, σελ. 181-185. Αθήνα).

MERDENISIANOS K., ZAFIRI B., PITSIOS TH. 2002: "Two cases of surgical trephina- tion in ancient Greece". (13o Inter. Congr. Of E.A.A. Zagrep).

MOORE G., SULLIVAN N. 1978: "Speleology. The study of caves". (Alabama, U.S.A.).

ΜΠΑΡΤΣΙΩΚΑΣ Α., ΜΕΡΔΕΝΙΣΙΑΝΟΣ Κ., ΖΑΦΕΙΡΑΤΟΣ Κ. 1981: «Τα ανθρωπολογικά ευρήματα του σπηλαίου Κάψια Τριπόλεως και η ιστορία τους». (1ο Πανελλ. Σπηλαιολ. Συμπ. Αθήνα 1981. Δελτίο Ε.Σ.Ε.τ. XVIII τευχ. 1-2, 1981-82).

ΜΠΡΟΥΣΑΛΗΣ Π. 1953: « Σημειώσεις ενός Αθηναίου ». (Καθημερινή, 20.5. 1953, έτος 34ον Αριθμ. 12493).

ΜΠΡΟΥΣΑΛΗΣ Π. 1957: « Καταβόθρα Κάψιας». (Το Βουνό. Τευχ. 196. Μαϊος-Ιούνιος 1957).

ΠΕΤΡΟΠΟΥΛΟΣ Μ.Σ. 1966: «Το σπήλαιο Καταβόθρας». (Ελεύθερος Κόσμος 2-9-1966)

ΠΕΤΡΟΧΕΙΛΟΣ Ι. 1958: « Τα σπήλαια της Πελοποννήσου. Η καταβόθρα Κάψιας». (Πελοποννησιακή Πρωτοχρονιά. Β΄Τόμος, Αθήνα).

ΠΕΤΡΟΧΕΙΛΟΥ Α. 1984: « Τα σπήλαια της Ελλάδας». (Εκδοτική Αθηνών Α.Ε.).

ΠΙΤΣΙΟΣ Θ. 1984: « Η ανθρωπολογική μελέτη των σκελετικών ευρημάτων αρχαιολογικών ανασκαφών». (Ανθρωπολογικά. Τ. 6, σελ. 41-51).

ΠΙΤΣΙΟΣ Θ. 2000: «Ο Ταινάριος Άνθρωπος - Ανθρωπολογικές διαδρομές στη Μέσα Μάνη». (Αθήνα).

PITSIOS TH. 2000: "The fossil hominid from Apidima and the evolution of Neanderthals In Europe". (4th Kongr, D. Gesell. f. Anthropologie, 25-28.9.2000 Berlin).

ΠΙΤΣΙΟΣ Θ. 2003: «Εξελικτική Ανθρωπολογία». (Ιατρικές κδόσεις Πασχαλίδης- Αθήνα).

PITSIOS Th., IOANNOU I., MERDENISIANOS K. 1994: "Palaeoanthropological Findings of the Cave Kapsia, Mantinia". (5th International Congress on Cave Development, Evolution and Environment. Athens. Deltion ESE Vol. XXI).

SIDERIDES N. A. 1911:« Les Katavothres de Grece. Katavothre de Kapsia ». (Spelunca v. VIII. No 63. et 54. p. 59-66).

STEINBOCK R.TED. 1976: "Paleopathological Diagnosis and Interpretaton". (Charles Thomas, Publisher. Springfield, Illinois, U.S.A.).

ΣΥΜΕΩΝΙΔΗΣ Ν., ΔΟΥΚΑΣ Κ. 1993: «Η Εξέλιξη του Ανθρώπου». Αθήνα.

ΤΖΙΡΙΤΗΣ Ε. 1964: «Επιστολαί». (Αρκαδικά Νέα, 17. 5. 1964. Έτος 23ον , Αρ. Φύλλου 926).

TROMBE F. 1973: "La Speleologie". (Paris).

ZAFEIRATOS K. 1988: "Anthropology and Paleopathology Research in Greece". (Newsletter in Paleopathology. Detroit U.S.A., 62: 9-10).

232

O-58

A new speleothemic carbonate deposit in grave Grubbo cave (Southern- Italy): Microbiological and stratigraphycal aspects

P. Cacchio, G. Ferrini, A. Lepidi

University of L'Aquila, Coppito, Italy

Abstract

Calcium carbonate precipitation in caves is commonly considered to be an abiogenic process even if the presence of microbes in underground deposits is reported. However, various studies have demonstrated the effects of heterotrophic bacteria and, particularly, actinomycetes in formation of specific speleothems such as moon milk and pool fingers. Bacteria and fungi can precipitate calcium carbonate extracellularly through a variety of processes, correlated with 1) metabolic activities, involving: i) autotrophic pathways (non-methylotrophic methanogenesis, anoxygenic photosynthesis and oxygenic photosynthesis); ii) the nitrogen cycle (ammonification of amino-acids, dissimilatory reduction of nitrate, degradation of urea or uric acid); iii) the sulfur cycle (dissimilatory reduction of sulphate), and 2) cell wall structure of microorganisms through mechanisms that have yet to be clearly elucidated. We investigated a cave biomineral structure of new morphology recognized in Grave Grubbo: a karst system developed for more than 2 km, in a gypsum-arenaceous formation in Southern Italy. The cave, hollowed in an alternation of thin bedded gypsum-arenites and carbonaceous pelitic levels, is entirely scoured by a subterranean stream with a quite uniform discharge; at present the new formation has been recognized only in one site in correspondence of this main water flow and strictly related to it. The deposit, which mantled the pelitic bedrock, shows a decimetric layered structure with, at least, two different stages of formation; petrographic and mineralogical analysis point out a tubular structure, constituted by concentric carbonatic laminae, oriented according the water flow. In order to seek evidence of bacterial involvement in its formation, we isolated an abundant cultivable heterotrophic microflora associated with the upper layer of the concretion which precipitated $CaCO_3$ in vitro within the colonies. We found that the percentage of calcifying strains near the colony or far away in the medium was related to the growth temperature. The microbial isolates can grow in NaCl up to 10% and about 38% of the isolates at a concentration of 15% NaCl. Almost all the isolates were rod-shaped bacteria, one strain displayed pseudomyceliar growth.

O-59

Stable isotopes (delta13C, delta15N) as indicators of trophic structure in central Texas (USA) cave ecosystems

S.J. Taylor, K. Hackley, J.K. Krejca, S.E. Greenberg, M.L. Denight

Illinois Natural History Survey, Illinois USA • Isotope Geochemistry Laboratory, Illinois State Geological Survey, Illinois USA
Zara Environmental LLC, Buda, Texas • U.S. Army Engineer Research and Development Center, Illinois, USA

Abstract

Caves in central Texas (USA) harbor numerous rare and endemic invertebrate species, some of which are listed as federally endangered species. The various cave invertebrates, including species of spiders, millipedes, and beetles appear to be threatened by the invasive Red Imported Fire Ant (Hymenoptera: Formicidae, Solenopsis invicta), which forages within the caves. We briefly review the biology of typical cave communities of central Texas, with emphasis on the role of surface foraging Ceuthophilus (Orthoptera: Rhaphidophoridae) species, then present results of a study of carbon and nitrogen isotope ratios (delta13C, delta15N) s of the cave communities. We studies three caves at Fort Hood, a military installation in Bell and Coryell counties, Texas. More than 70 samples, representing 18 cave-inhabiting invertebrate species, were collected from two caves in November 2003, and two caves in May 2004, along with more than 100 samples of a plants growing around the cave entrances. Dried samples were analyzed for nitrogen and carbon isotopes using a mass spectrometer with an attached elemental analyzer. We found some isotopic differences between caves and between sampling seasons. In addition, the differences in delta15N between two co-occurring Ceuthophilus species provides evidence that they function at differing trophic levels. Our data suggest many of the cave taxa feed at more than one trophic level, and thus source partitioning of isotope fractionation appears to reflect complex trophic relationships. Many of the taxa feed within a single food chain, and thus all are dependent on a single energy source. Protection of rare or federally species, then, depends on maintaining the entire cave ecosystem to protect top predators (e.g., Cicurina spiders). Knowledge gained regarding trophic relations can facilitate development of management plans for central Texas caves, and is applicable to the management of the federally endangered cavernicoles.

233

O-60

Salt Ingestion Caves

Lundquist, Charles A., *University of Alabama in Huntsville, 214 Jones Valley Drive, Huntsville, AL 35802, USA, lundquc@email.uah.edu*

Varnedoe, William W. Gr., *Huntsville Grotto of the National Speleological Society, 5000 Ketova Way, Huntsville, AL 35803, USA, billvar@comcast.net*

ABSTRACT

Large vertebrate herbivores, when they find a salt-bearing layer of rock, say in a cliff face, can produce sizable voids where, over generations, they have removed and consumed salty rock. The cavities formed by this natural animal process constitute a unique class of caves that can be called *salt ingestion caves*. Several examples of such caves are described in various publications. An example in Mississippi U.S.A., Rock House Cave, was visited by the authors in 2000. It seems to have been formed by deer or bison. Perhaps the most spectacular example is Kitum Cave in Kenya. This cave has been excavated to a length over 100 meters by elephants. An ancient example is La Cuerva del Milodon in Chile, which is reported to have been excavated by the now extinct milodon, a giant ground sloth. Still other examples can be cited. This class of caves deserves a careful definition. First, the cavity in rock should meet the size and other conventions of the locally accepted definition of a cave. Of course this requirement differs in detail from country to country. The intent is to respect the local conventions. The characteristic that human entry is possible is judged to be a crucial property of any recognized cave definition. Second, the cavity should be significantly the result of vertebrate animal consumption of salt-bearing rock. The defining process is that rock removed to form the cave is carried away in the digestive track of an animal. While sodium salts are expected to be the norm, other salts for which there is animal hunger are acceptable. Also some other speleogenesis process, such as solution, should not be excluded as long as it is secondary in formation of a cave in question.

BACKGROUND CIRCUMSTANCES

From the dawn of civilization, humans have observed that some animals congregate at "salt licks" and that these are auspicious sites to hunt these animals. Starting from such ancient fundamentals, Derek Denton, in his monumental tome, Hunger for Salt, An Anthropological. Physiological and Medical Analysis, reviews all aspects of animal and human need for salt [Denton 1982]. In his Introduction he stresses "the role of sodium as the principal cation of the circulating blood and tissue fluids of animals. Sodium predominates over the other constituents of tissue fluids such as potassium, calcium, magnesium, phosphate, bicarbonate, sulfate and chloride". Denton observes that in large areas of the continents, there is very little sodium, as a result of meteorological processes. Sodium content in plants is accordingly very low. This creates an evident evolutionary advantage that accrues to animals that are able to detect salt in geological circumstances and ingest it. The animals in greatest need are the herbivores because of the low sodium content of plants. Carnivores obtain the bulk of their required salt from the flesh of the animals they eat. Large vertebrate herbivores, when they find a salt-bearing layer of rock in a cliff face, can over generations produce sizable voids where they have removed and consumed salty rock. These cavities can have the characteristics of a cave.

This class of caves, which is the subject of this paper, requires a definition. First, the cavity in rock should meet the size and other specifications in the locally accepted definition of a cave. This requirement can differ in detail from country to country and from state to state. The intent is to accept the local conventions. The characteristic that human entry is possible is a crucial property of any recognized cave definition. Second, the cavity should be significantly the product of vertebrate animal consumption of salt-bearing rock. The defining process is that rock removed to form the cave is carried away in the digestive track of an animal. While sodium salts are expected to be most common, other salts for which there is animal hunger are acceptable. Also some other cave formation process, such as solution, should not be excluded as long as it is secondary in formation of a cave in question. The authors recognize that these two requirements are somewhat arbitrary, but the scope of discussion needs to be constrained.

Many speleological, scientific and popular documents contain descriptions of caves that seem indeed to satisfy the definition above for inclusion in this study. For example, Denton, in his chapter "The natural history of sodium deficiency and salt appetite in wild animals", gives a rather comprehensive global review that includes references to a number of animal produced caves. This paper is based largely on such published documents having many forms and purposes. It is often unclear whether a cited cavity or cave meets the stated conditions to be included in this paper. Some judgment must be exercised in placing a candidate either on an accepted list or in a tabulation of potential cases for which data is insufficient to make an informed determination.

A location illustrating this situation is Cambodia [Wharton 1957]. A typical Cambodian salt lick is described as a *stinking quagmire of mud with thousands of animal tracks, to one side of which is the freshly exposed stratum with large holes several feet in diameter eaten out of it*. An examination in the field might show that some specific examples of these holes deserve to be called caves. Similarly, a review, Natural Game Licks in the Rocky Mountain National Parks of Canada, mentions a few sites that have cavities that may qualify as caves [Cowan and Brink 1949]. The Glacier Lake lick in Banff Park has the description *"White cliffs overlooking Howse River at its union with Glacier Lake Creek are deeply excavated by goats"*. A lick in Jasper Park is *"Athabaska Falls – A large white-earth cliff on the east bank of the Athabaska River, twenty-three miles south of Jasper, serves a population of twenty or more goats from nearby Mount Kerkealin. Holes eaten into the cliff face are large enough to accommodate adult goats."*

234

Although not a prime subject here, it is worth noting that the animal consumption can be an interesting secondary process in caves of other principal origins. Animals may modify wall characteristics locally or perhaps even create a room off a larger cave. A potential example of this sort is Deer Cave in Mulu Mountain, Sarawak. The cave is so named because deer come into the cave to lick salt-bearing rocks [Tsen 1993]. Since this cave contains one of the largest cave passages known to man, it is certainly not the result of the deer visits. Still, the deer may have left their mark in localized areas.

ALTAI MOUNTAIN CAVES, ASIA

The concept of speleogenesis by salt ingestion by animals is not recent   For example, in 1826, Carl Friedrich von Ledebour published a commentary on his travels through the Altai mountains of central Asia [Ledebour 1826]. His report is quoted and discussed in an 1873 paper by G. Bunge [Bunge 1873].   Ledebour describes an occurrence of shale on the lower elevations of a mountain that bordered one side of the very flat, swampy, and somewhat wide valley of the Kan River. This site was near the confluence of the Kan and Tscharnsch Rivers. He reports that the stone, (shale) that forms the mountain appeared to contain a significant amount of salt, and questioned whether it might be epsom salt. He observed that "*all livestock of the Kalmucks find this rock, which gives the mountain an ash-gray appearance, very desirable and consume it in not small amounts, so that one not infrequently finds grottoes built in this way*". He continues that these animals, and even wild ones, frequently visit this mountain to eat the salty, easily broken shale. It seems reasonable to conclude that these grottoes must have some appreciable size to have warranted mention as grottoes by von Ledebour.

ROCK HOUSE CAVE, U.S.A.

Rock House Cave in Mississippi, is close to Alabama, the home of the authors. It was therefore easy to visit, which we did in 2000. The animal origin of small caves in Rankin County was recognized by Hilgard in 1860 in his "Report on the Geology and Agriculture of the State of Mississippi" [Hilgard 1860]. In 1971, Baughman discussed Rock House Cave as an example of such a cave [Boughman 1971]. The cave was brought to the attention of the NSS membership by an article in the NSS News [Carey and Middleton 1973].

The cave is situated in a small bluff. Its entrance is 10 feet wide, inside it widens to about 20 feet and goes into the bluff 15 feet. The roof is just high enough for a person to stand.   The cave has been enrolled as MS 21 in Caves of Mississippi, [Knight, Irby and Carey 1974].

The formation from which animals have ingested the salt-bearing rock is soft, fine-grained sandstone of the Cataboula Formation. An analysis by Francis L. Schmehl found that the rock contains from 0.52 to 2.12 percent NaCl [Baughman 1971]. There appears to be no evidence of water solution contributing to the cave size. The walls of the cave have a uniform sandy texture that one can accept as being formed by licking. In the vicinity of Rock House Cave are other bluff salt lick sites not yet developed into caves. Hilgard says "in some instances the cattle have eaten caves into the hillsides".   However, we judge that originally deer or perhaps also bison are more probably responsible for the cave than cattle.

KITUM CAVE AND SIMILAR CAVES, KENYA

Kitum Cave is the best known of the group of similar caves found on Mount Elgon on the border of Kenya and Uganda. Mount Elgon is a now dormant volcano that rises to 4,321 meters and is built up largely from soft agglomerates solidified from massive pyroclastic flows. Interspersed between the beds of agglomerates are thinner layers of lava flows, which make up about 1% of the mountain. As precipitation runs off the mountain, the lava flows are more impervious to water and resistant to erosion. Hence, where the edge of a lava flow or of a denser agglomerate layer is exposed on the mountain side, cliffs form in the softer agglomerates below the exposed impervious, caprock edge. At least many-tens of caves are formed in these cliff faces, with the lava or other impervious caprock layers providing solid roofs for the caves. Often there is a waterfall off the ledge above the cave entrance. Most of this water goes on down the mountain slope, but some water drains into the cave, forming shallow stagnant pools. Typically, there is no active stream flowing out of the caves. The presence of some ground water seepage through the agglomerate layers is demonstrated by its generation of the unusual mineralogy that is found in the cave [Forti 2005]. Kitum is a typical cave of this sort on the Kenya side of Mount Elgon. It is one of four similar caves open to the public in Kenya's Mount Elgon National Park.

The agglomerates have a small fraction of sodium sulfate, Glauber's salt, incorporated in them. This is an attractive source of sodium for the wild herbivores of the region, particularly elephants. Elephants, buffaloes, antelopes and even monkeys are observed to be regular visitors to the caves in the agglomerates, where they ingest quantities of the soft rock. In Kitum Cave, the rock face now worked by the elephants is some 160 meters into the mountain from the entrance. The elephants loosen the rock with their tusks, pick up the loose pieces with their trunks, put the pieces in their mouths and crush them with their teeth. This process has been recorded by infrared video and was widely viewed on cable television [Mutual of Omaha 2004]. Other animals lick the rock face or eat small fragments left by natural rock falls or by the elephants. These circumstances on Mount Elgon are described by a rather extensive literature, going back to an early observation by Hobley [Hobley 1897]. Other significant background references are [Perkins 1965; Sutcliffe 1973].

Given the circumstances for the Mount Elgon caves, there is some uncertainty found in the literature as to the predominant process that has formed the caves. Some authors favor an undefined solution and erosion process related to ground water sapping or to the waterfalls at the entrances, perhaps during heavy rain or flooding. A thoughtful examination of this question has been provided by Ian Redmont. He spent much of five months camping in a safe spot in Kitum Cave observing and photographing principally the elephants [Redmont 1984]. Importantly, he collected elephant droppings outside the cave to confirm that significant quantities of insoluble rock are removed by the elephants. He then offers the following analysis: *"The volume of Kitum cave is on the order of 1.3 million gallons. If, for the sake of conservative argument, we suppose that elephant excavations average just one quart per week, it would have taken them only 100,000 years for them to dig Kitum. ... the theory of elephant speleogenesis is entirely plausible."*

In 2003, Donald McFarlane and Joyce Lundberg made an eight-day field study at Mt. Elgon National Park, with the *"principal objective to undertake a detailed, quantitative investigation of the relative contributions of solution, collapse, human mining and elephant geophagy to the formation of the larger Mt. Elgon Caves"* [Mc Farlane and Lundberg, 2004]. They suggest multi-step mechanisms and a sequence for cave development. First, a cliff forms where water falling off a caprock layer erodes away softer underlying material. Second, clay sized material from a layer at the floor of the cave is removed by groundwater sapping. Additional mass is removed by animal excavation. Third, collapse of overlying beds makes piles of broken material which are removed by action of water and animal geophagy. Fourth, the cave enlarges by the continuation of these processes. These authors do not estimate the relative quantities of mass removed by action of water and by animals, but they surely recognize that animal consumption is a significant process.

Other valuable insights into the Mt. Elgon caves come from A.J Perkins and Renshaw Mitford-Barberton, who both have lived on Mt. Elgon for many years [Perkins 1965]. They *"have examined over thirty caves on the East and South Eastern slopes of Mount Elgon at altitudes varying from 6,000 feet to 12,000 feet and have found that with very rare exceptions, they all conform to one type"*. They conclude that all must have been formed by a similar agency. They observe that the entrances to the caves are invariably wider than they are high and that water often falls over the lip of the lava caprock above the cave entrance. I some cases, particularly during heave rainfall, some of this water flows back into the cave, temporarily flooding it. In normal circumstances, however, the caves only have small pools of water in them and the water is entirely static. Typically, there are no streambeds in the caves. A common feature in most of the larger caves is the quantity of dung deposited by beasts which have come to the caves from time immemorial to lick or otherwise consume the agglomerate walls. Traces of elephants using the caves are most common, and their tusk marks are clearly recognizable where they have gouged the rock.

In summary, there is ample evidence that animal consumption of material from the cave walls and from breakdown surfaces removes significant quantities of rock. The lack of permanent streams out of the caves precludes removal of mass by that mechanism. That some material is dissolved or washed out during flooding episodes is clear, but the quantity is difficult to estimate. One could perhaps argue that if mass removal during flooding episodes was dominant, then the many tusk marks on exposed surfaces should be removed, and only a few most recent marks should remain. A compelling case is elusive for dominance of either water processes or alternatively of animal processes in forming the Mt. Elgon caves. However, the authors tend to agree subjectively with Redmont's belief that animal consumption of salt bearing rock is the primary process.

MILODON CAVE, PATIGONIA, CHILE

Milodon Cave is presently a Chilean National Monument: La Cueva del Milodon, near Puerto Natales, Patagonia, Chile. La Cueva del Milodon, was explored in February, 1895 by Herman Eberhard, who had established a ranch near Puerto Consuelo on Last Hope Sound in Patagonia [Chatwin 1977]. The entrance was visible from his establishment. A year later, Dr. Otto Nordenskold, a Swedish explorer, visited the cave and found some large bones. These were eventually identified as bones of an extinct giant ground sloth, the milodon, unique to South America. In about 1899, a Swedish archaeologist, Erland Nordenskjold, undertook a dig in the cave. He is reported to have found three stratified levels with milodon remains only in the lowest level. A second contemporary digger, Dr. Hauthal of La Plata, uncovered a layer of well preserved sloth dung, mixed with leaves and grass. More recently, Bruce Chatwin visited the cave and assembled the account of its history sketched above [Chatwin 1977]. The region has complex geology, with numerous volcanic deposits. From his visit, Chatwin relates that the cave mouth is four hundred feet wide in a cliff of gray conglomerate. The side walls glittered with salt encrustation and "animal tongues had licked the back wall smooth". He notes that "the floor was covered with turds, sloth turds, outsized black leathery turds, full of ill-digested grass". The cave was very dry, as it would have to be for the observed material to have survived.

A sign at the Monument attributes the formation of the cave to melting glaciers. A diagram on this sign shows the cave to be a sort of sea cave at the surface of a melting glacier. This argument seems very weak and does not fit the surrounding terrain. But the evidence that Milodon Cave has a salt ingestion origin is only suggestive, not conclusive. The conglomerate rock forming its walls apparently has a salt content of some kind, rather like Kitum Cave. Chatwin believed that the back wall showed evidence of animal licking. The first users of the cave seem to have been the milodons. Hence creation or at least enlargement of the cave by milodons ingesting rocks is quite plausible, if not certain.

CONCLUSIONS

The authors suspect that salt ingestion caves are more prevalent than might be thought. The principal examples we identified seem to be relatively well known, and the literature on them goes back into the 1800s. We doubt that Rock House Cave in Mississippi is the only U.S. example since salt bearing-rock occurs widely. Of course, we have probably missed some examples in the U.S. literature. Some may be discussed in documents not usually read by the caving community. Other salt ingestion caves probably exist whose origin has not been recognized or recorded. We hope that this rather limited study will promote more awareness of this possible cave origin.

The authors further suggest that speleogenesis by salt ingestion offers many fascinating opportunities for scientific investigations. Clearly, for example, the studies on the Mount Elgon, although valuable, have been very limited in scope. A simple automatic camera system at Rock House Cave might record with certainty what animals currently frequent that site. An examination of the preserved droppings in Milodon Cave could reveal whether they contain undigested rock residue as evidence of rock ingestion by the milodons. The possible topics are numerous.

Finally, we re-emphasize that rock ingestion by animals is an old observation. While we have not tried to search the literature of antiquity, we did note one ancient citation: [Aristotle ca 350 BC]. Aristotle wrote about elephants *"And if it eats earth it becomes weakly, unless it eats continually; if it does so continually, it is not harmed. It also swallows stones sometimes"*. This passage must be a reference to elephants eating salt-bearing earth and rocks.

ACKNOWLEDGEMENTS
The authors wish to acknowledge essential help by the librarian at the NSS Library in Huntsville, and by the Interlibrary Loan services of the Salmon Library at the University of Alabama in Huntsville.

REFERENCES

[Aristotle ca 350 BC] Aristotle, History of Animals book VIII 605 23 (See for example the translation by D. M. Balme, Harvard University Press Vol XI p 191, Cambridge, 1991.

[Boughman 1971] Wilbur T. Boughman, Rankin County Geology and Mineral Resources, Bulletin 115, p 54-55, Mississippi Geological, Economical and Topographical Survey, 1973.

[Bunge 1873] G. Bunge, "uber die Bedeutung des Kochsalzes das Verhalten der Kalisalze im menschlichen Organismus" Zeitscrift feur Biologie, Vol 9 p 104-143, Munich, 1873.

[Carey and Middleton 1973] Steven D. Carey and Arthur L. Middleton, "The Rock House -An Unusual Mississippi Shelter Cave", NSS News. Vol. 31 p 198, Nov. 1973.

[Chatwin 1977] Bruce Chatwin, In Patagonia, copyright 1977, pub, by Penguin Books, 1988.

[Cowan and Brink 1949] I. McT. Cowan and V. C. Brink, "Natural Game Licks in the Rocky Mountain National Parks of Canada", p 379 – 385, Journal of Mammalogy, Vol. 30 No. 4, Nov 1949.

[Denton 1982] Derek Denton, The Hunger for Salt. An Anthropological, Physiological and Medical Analysis, Springer-Verlag, Berlin Heidelberg New York, 1982.

[Forti 2005] Paolo Forti, "Genetic Processes of Cave Minerals in Volcanic Environments: An Overview", p 3 – 13 Journal of Cave and Karst Studies, Vol. 67 Number 1, pub by NSS, April 2005.

[Hilgard 1860] E. W. Hilgard, Report on the Geology and Agriculture of the State of Mississippi, Mississippi State Printer, Jackson, MS, 1860.

[Hobley 1897] C. W, Hobley, "Notes on a journey round Mount Massawa or Elgon", Geogr. J., vol 9 p 178-185, 1897.

[Knight, Irby and Carey 1974] E. Leslie Knight, Bobby N Irby and Steve Carey, Caves of Mississippi p 31, pub University of Southern Mississippi, Hattiesburg, 1974.

[Ledebour 1826] Carl Friedrich von Ledebour, Reise durch das Altai-Gabirge und die soongorische kirgisen-steppe; auf Kosten der Kaiserlichen Universitat Dorpat untemommen im jahre 1826. Th 2 p 44, Berlin.

[McFarlane and Lundberg 2004] Donald A, McFarlane and Joyce Lundberg, Zoogeomorphic Analysis of the Mount Elgon Caves, Kenya, Final Report, May 15, 2004.

[Mutual of Omaha 2004] "Mutual of Omaha's Wild Kingdom, Cave Elephants" Video shown on Animal Planet Channel in 2004.

[Perkins 1965] A. J. Perkins, "Some Notes on the Caves of Elgon" p 21-24. Cave Exploration Group of East Africa Newsletter No 3, Nairobi, Dec 1965.

IRedmond 1984] Ian Redmond, "Underground Elephants", Animal Kingdom p 30-37, Dec 1984 -Jan 1985.

[Sutcliffe 1973] Anthony J. Sutcliffe, "Caves of the East African Rift Valley", p 41-65, Trans. Cave Research Group of Great Britain, Vol 15 No 1, Feb 1973 (This paper has a large list of references).

[Tsen 1993] Darell Nyuk Choi Tsen, The Show Caves of Mulu. Sarawak, Caxton Printing Sdn. Bhd., Kuala Lumpur, second edition, 1993.

[Wharton 1957] G. W. Wharton, An ecological study of the Kounrey, Monograph No 5, Institute of Science and Technology, Manila, 1957.

237

O-61

20 Years Paleoluminescence Techniques for Reconstruction of Past Environmental Changes.- UIS Contribution

Yavor Y. Shopov

Faculty of Physics, University of Sofia, James Baucher 5, Sofia 1164, Bulgaria • E-mail: YYShopov@Phys.Uni-Sofia.BG

Abstract

This paper discusses advance of the research on Speleothem Paleo-luminescence Records of Environmental Changes after it have been first introduced by the author 20 years ago. It is demonstrated that most of the progress in this field was made in result of the operation of the International Program "Luminescence of Cave Minerals" of the commission on Physical Chemistry and Hydrogeology of Karst of UIS of UNESCO.

Potential, resolution and limitations of high resolution luminescence speleothem proxy records of Paleotemperature, Solar Insolation, Solar Luminosity, Glaciations, Sea Level advances, Past Precipitation, Plants Populations, Paleosoils, Past Karst Denudation, Chemical Pollution, Geomagnetic field and Cosmic Rays Flux variations, Cosmogenic Isotopes production and Supernova Eruptions in the Past, Advances of Hydrothermal Waters, and Tectonic Uplift are discussed.

It is demonstrated that speleothems allow extremely high resolution (higher than in any other paleoclimatic terrestrial archives) and long duration of records. Some speleothems can be used as natural climatic stations for obtaining of quantitative proxy records of Quaternary climates with annual resolution.

Introduction

Luminescence is the most sensitive to depositional conditions property of cave minerals (Tarashtan, 1978). Therefore it can be used for reconstruction of these conditions. So in 1988 commission of Physical Chemistry and Hydrogeology of UIS of UNESCO decided to start an international programme on study of "Luminescence of Cave Minerals". Most of the further progress in the field was made in result of the operation of this programme. Infact it developed a new fielf of science called "paleoluminescence" like paleomagnetism.

Many speleothems exhibit luminescence when exposed to ultraviolet (UV) light sources or other high-energy beams. In dependence of the excitation source there are specific kinds of luminescence: "photoluminescence" (excited by UV and other light sources), "X-ray luminescence" (by x-rays), "Cathodoluminescence" (by electron beam), "Thermoluminescence" (by heat), "Candoluminescence" (by flames) and "triboluminescence" (by crushing). Different types of excitation may excite different luminescent centers- electron defects of the crystal lattice; admixture ions substituting ions in the crystal lattice or incorporated in cavities of that lattice; inclusions of other minerals; or fluid inclusions, molecules, ions or radicals adsorbed inside of the lattice (Shopov, 2004). Some or all of them may exist in a single speleothem Shopov (1997).

If the emission proceeds only during the excitation than it is called "fluorescence", if it proceeds after the termination of the excitation than it is called "phosphorescence". Some luminescent centers produce only fluorescence, but other both fluorescence and phosphorescence.

The type of luminescent centers determines the colour of luminescence. Colour may vary with changes of the excitation sources.

Brightness of luminescence is function of the concentration of luminescence centers. It is almost linearly proportional to concentration of luminescent centers.

Origin of luminescence of Cave Minerals

Most known luminescent centers in calcite are inorganic ions of Mn, Tb, Er, Dy, U, Eu, Sm and Ce (TARASHTAN, 1978, SHOPOV, 1986, SHOPOV et al., 1988). Luminescence of minerals formed at normal cave temperatures (below 40° C) is due mainly to molecular ions and adsorbed organic molecules. Luminescence of uranil- ion is also very common in such speleothems. Usually several centers activate luminescence of the sample and the measured spectrum is a sum of the spectra of two or more of them. Before using a speleothem for any paleoenvironmental work it is necessary to determine that all luminescence of the sample is due to organics (Shopov, 2004).

238

Table 1. Origin of luminescence of Cave Minerals

Luminescence activator	Excitation source	Color of luminescence	After glow	Origin	Reference
Calcite:					
24 types of luminescence (see (SHOPOV, 2004), same volume)					
Aragonite:					
11 types of luminescence (see (SHOPOV, 2004), same volume)					
Vaterite:					
36.Organics?	N_2-Laser,	blue-green	long	infiltration	Shopov(1989b)
37.Organics?	N_2-Laser,	green	long	infiltration	Shopov(p.c)
Huntite:					
38.Organics?	N_2-Laser	blue	long	infiltration	Shopov(1988)
39.Organics?	N_2-Laser	yellow-green	long	infiltration	Shopov(1988)
Hydromagnesite:					
40.Organics?	N_2-Laser	green	long	infiltration	Shopov(1989b)
41.Organics?	N_2-Laser	yellow-green	long	infiltration	Shopov(1989b)
Dolomite:					
42. Organics	N_2-Laser	yellow-green	long	infiltration	Shopov(1989b)
Gypsum:					
43. Organics	N_2-Laser	yellow-green	long	infiltration	Shopov(1989b)
44. Organics	Ar -Laser	yellow	long	infiltration	Shopov(1989b)
45.?	Hg (LWUV)	deep-yellow	long	infilt.	White,Brennan(1989)
46.?	Hg (LWUV)	orange		infilt.	White,Brennan(1989)
47. Mn^{2+}	Ar -Laser	red	0.1s	hydrothermal	Shopov & al.1989
48. Fe^{3+}	fl. Ar -Laser	dark red+ IR		hydrothermal	Shopov & al.1989
Halite					
49. Organics	fl, Ar -L.	blue	long	infiltration	Shopov(p.c)
50. Organics	fl, Ar -L	blue-green	long	infiltration	Shopov(p.c)
Darapscite					
51.Organics	fl, Ar -L	blue-green	long	infiltration	Shopov(p.c)
Purpurite:					
52.?	Ar -Laser	green-yellow		guano in lava	Shopov(1989b)
$CaCO_3$ -II:					
53. Pb^{2+}	Xe-lamp(SWUV)	UV		hydrothermal	(Shopov, 1989b)
54.Organics	Xe (SWUV)	violet	long	low-temper.h-t	Shopov(1989b)
55.Mn^{2+}	Ar -L,He-Ne-L	dark red	0.1s	hydroth	Shopov &al. (1988b)
56.Fe^{3+}	Xe-lamp (SUV)	dark red-IR		hydroth	Shopov &al. (1988b)
Opal					
57.Organics	Ar-Laser	yellow-green	0.1s	?	Shopov &Slacik(p.c.)
58.Organics	Ar-Laser	yellow	0.1s	?	Shopov &Slacik(p.c.)
Quartz:					
59.AlO^{4+}	Xe-lamp (LWUV)	blue		hydrothermal	Shopov(1989)
60.O^*_{Fe}	Xe-lamp	(LWUV)	yellow	hydroth.	Shopov & al.(1989)
61.Fe^{3+}	Xe-lamp	(SWUV)	dark red	hydroth.	Shopov & al.(1989)
Hydrozincite:					
62.Organics	N2-Laser	yellow-green		ore-weathering	Shopov(1989b)
63.Organics	N2 Laser	yellow		ore-weathering	Shopov(1989b)

Luminescence of Cave minerals at other excitations

activator	Excitation source	Color of luminescence	Origin	Reference
		Cathodoluminescence		
		calcite		
64.Mn^{2+}	electron beam	pink	?	White, 1974
65.CO_3^{3-}	electron beam	blue	infiltration,	Shopov (p.c.)
		halite		
66.Cl^-	defect, el. beam	violet	infiltration,	Shopov (p.c.)
		darapskite		
67. ?	el. beam	violet	infiltration,	Shopov (p.c.)
		Candoluminescence of Gypsum		
68.Mn^{2+}	hydrogen flame	green	Hess et al 1971,	White, Brennan 1989
69.?	hydrogen flame	lemon yellow	infilt.,	White,Brennan,1989
		Calcite Thermoluminescence		
70.?	UV+ warming	glow at 105 K	infilt.,	White,Brennan,1989
71.?	Xe+ heating	glow at 350,500 K	?	Dublyansky(in p.)
		X-Ray luminescence of calcite		
72.CO_3^{3-}	X-rays	blue	infilt.,	Shopov,Spasov,1983

Comments to table 2:

36- 41 Organic origin of luminescence of these minerals is under question, because molecules of absorbed water may cause similar luminescence (Tarashtan, 1978) in aggregates like studied samples (moonmilk).

Measurements and Photography of Luminescence

The most common method of excitation is irradiation by UV light sources producing photoluminescence and when luminescence is usually spoken about it is with this kind of excitation in mind. Phosphorescence of speleothems in caves can be seen by irradiating of speleothems with a photographic flash with closed eyes, with following rapid opening of the eyes after flashing. Such "Visual Luminescent Analysis" (VLA) has been widely used in caves. For this purpose (TARCUS, 1981) used also other simple devices such as portable UV lamps with short wave UV (SWUV) and long wave UV (LWUV). Slacik (1977) used a simple apparatus, which registered total emitted light by a galvanometer with a photocell for the quantitative evaluation of the luminescence intensity. But data obtained by the VLA method are subjective and the determination of luminescence activators is not possible. In fact attempts to determine activators of the luminescence with VLA and chemical analysis leads to incorrect results.

Investigations of the spectra of luminescence reveals new possibilities for luminescent research in mineralogy: - for example determination of luminescent centers, the character of isomorphic substitution, structural characteristics of the admixtures and defect centers, and typomorphic peculiarities of minerals (Tarashtan, 1978).

Luminescence spectra of cave minerals have been measured by means of exciting them with nitrogen Lasers (Ugumori, Ikeya, 1980; Shopov, Spasov, 1983; Shopov, 1988, 1989a,b), Xe- or Hg-lamp (Shopov et al., 1988; White, Brennan, 1989), Argon Lasers (Shopov, 1989b, White, Brennan, 1989) or by He- Ne Lasers. A disadvantage of this method is that it is destructive and gives total spectra of luminescence of the entire sample and is inapplicable for research of fine mixed aggregates such as moonmilk.The conventional method for photography of fluorescence (PF) is not adaptable for cave photography, because it needs long exposition times (30-60 min) and a permanent electric source. This method always distorts the colour of luminescence, because it is impossible to choose a pair of filters, which can absorb whole emission of the UV-lamp, without absorbing a part of the luminescence of the sample. If an UV- absorption filter is not used to absorb lamp emission, UV photos will be obtained instead of photos of fluorescence.

The simplest method for luminescent research (table 2) is Impulse Photography of Phosphorescence (IPP) (Shopov and Grinberg, 1985b, Shopov, 1989a, 1991). Equipment used for this consists of a photo camera with a shutter delayer, which opens the shutter, several milliseconds after flash emission ends. It uses ordinary photoflash to excite speleothem luminescence. Adding of an impulse UV-source (flash with an UV-passing filter) (IPFP, table 2) can give both photos of fluorescence and phosphorescence together or separately. Photo slides obtained by this method can be measured by Colour Slide Spectrophotomerty (CSS), (table 2) to measure spectra of diffuse reflectance, phosphorescence or fluorescence (Shopov, Georgiev, 1987, 1989) of the speleothem. It is designed for research of wideline spectra, such as luminescence of most speleothems formed at normal cave conditions (at temperature below 40° C), Shopov et al. (1989a). It allows easy non-destructive determination of objective information for mineral composition and speleothem luminescence, easy collection of information for cave minerals and conditions of their formation in caves.

Conventional luminescent research methods have number of disadvantages, so several special speleothem research methods has been developed recently (table 2). They allow considerable enlargement of kinds and quality of the obtainable information.

Table 2. Special Speleothem Luminescence Research Methods

Method	Authors	Obtainable information
I. Impulse Photography of Luminescence (IPL): 1.Photography of phosphorescence (IPP) 2.Photography of fluorescence & phosphorescence (IPFP).	Shopov, Tsankov (1986) Shopov, Grynberg (1985)	Diagnostics of minerals; registration of colour & zonality of fluorescence, phosphorescence and its spectra; UV photography; extraction of single mineral samples; chemical changes of the mineral-forming solution; Climate and Solar Activity variations during the Quaternary.
II. Laser Luminescent Microzonal Analysis (LLMZA)	Shopov (1987)	Microzonality of luminescence; changes of the mineral-forming conditions; High Resolution Records of Climate & Solar Activity variations (with resolution up to 0.4 days). Reconstruction of annual rainfall and annual temperature in the past. Estimation of past Cosmic Rays (CR) and Galactic CR. Speleothem growth hiatuses.
III.Color Slide Spectrophotometry (CSS)	Shopov, Georgiev (1989)	Wide-band spectra of phosphorescence, fluorescence and diffuse reflectance of minerals; spectra of quick processes.
IV.Autocalibration Dating (ACD)	Shopov, Dermendjiev Buyukliev (1991)	High Precision Speleothem Dating of Speleothems of any age, Climatic and Solar Activity cycles, variations of the Speleothem Growth Rate.
V.Time Resolved Photography of Phosphorescence (TRPP)	Shopov et al. (1996-d)	Determination of the lifetime of the luminescent center. Uplift of the region. Past mixing of surface and epithermal or hydrothermal waters during mineral growth. Estimation of the temperature of the deposition, plus all information obtainable by IPP

Paleoenvironmental applications of Speleothem Luminescence

Before using of a speleothem for any luminescence paleoenvironmental records is necessary to determine that all luminescence of the sample is due to organics. Otherwise a subsequent research may produce major confusions. To prove that all speleothem luminescence is due to organics is a very complicated task (Shopov, 1997).

Paleoluminescence, Paleotemperature and Paleo- Solar Activity.

Calcite speleothems frequently display luminescence, which is produced by calcium salts of humic, and fulvic acids derived from soils above the cave (Shopov, 1989a,b; White, Brennan, 1989). These acids are released (i) by the roots of living plants, and (ii) by the decomposition of dead matter. Root release is modulated by visible (650- 710 nm) solar insolation (SI) via photosynthesis, while rates of decomposition depend exponentially upon soil temperatures that are determined primarily by solar infrared radiation (Shopov et al., 1994) in case that the cave is covered only by grass or upon air temperatures in case that the cave is covered by forest or bush. In the first case, microzonality of luminescence of speleothems can be used as an indirect Solar Activity (SA) index (Shopov et al., 1990c), but in the second as a paleotemperature proxy. So in dependence on the cave site we may speak about "solar sensitive" or "temperature sensitive" luminescent speleothem records like in treering records, but in our case raw record may depend only on temperature either on solar irradiation:

- In the case of Cold Water cave, Iowa, US we obtained high correlation coefficient of 0.9 between the luminescence record and Solar Luminosity Sunspot index measured since 1700 AD (Shopov et al., 1996-a) and reconstructed sunspot numbers since 1000 AD with precision of 10 sunspot numbers (which is within the experimental error of their measurements);

- In the case of Rats Nest cave, Alberta, Canada we measured correlation of 0.67 between luminescence intensity and air temperatures record for the last 100 years and reconstructed annual air temperatures for last 1500 years at the cave site with precision of 0.35°C (Shopov et al., 1996-a). Intensity of luminescence was not dependent on actual precipitation and sunspot numbers (zero correlation).

Time series of a Solar Activity (SA) index "Microzonality of Lumines-

cence of Speleothems" are obtained by Laser Luminescence Microzonal analysis (LLMZA) of cave flowstones described by Shopov (1987). This technique uses relatively simple device, but the quality of results is as good as high is the experience of the researcher, because every sample require different approach. Many restrictions for samples for LLMZA apply (Shopov, 1987). LLMZA allow measurement of luminescence time series with duration of hundreds of thousands years, but time step for short time series can be as small as 6 hours (Shopov et al., 1994) allowing resolution of 3 days (Shopov, et al., 1988). IPP and LLMZA devices (Shopov & Grinberg, 1985, Shopov& Tsankov, 1986, Shopov, 1987) are the only ones allowing reliable measurements of the intensity of luminescence of speleothems. The wide range of devices used for measurement of speleothem annual growth by annual bands of luminescence do not produce reliable intensity of luminescence of speleothems, so can not be used for any other luminescent paleoenvironmental reconstructions.

Luminescence proxy records of the Solar Activity has been used for solving of many astrophysical problems (Dermendjiev et al. 1989, 1990, 1992)

Paleoluminescence Reconstructions of the Solar Insolation

Basically all solar sensitive raw paleoluminescence records (if measured properly using IPP or LLMZA devices) are solar insolation records (Stoykova et al., 1998, Shopov, et al., 2000). Other proxies can be derived from such records using different types of digital analysis.

Paleoluminescence Reconstructions of the Solar Luminosity

NASA used a record of luminescence of a flowstone from Duhlata cave, Bulgaria to obtain a standard record of variations of the Solar Irradiance ("Solar constant") in [W/m²] for the last 10000 years (D. Hoyt, personal communication) by calibration of the luminescence record of (Shopov et al., 1990b) with satellite measurements.

Paleoluminescence solar insolation proxy records contain not only orbital variations, but also solar luminosity self variations, producing many cycles with duration from several centuries to 11500 years with amplitude

ranging respectively from 0.7 to 7 % of the Solar Constant (Shopov et.al 2004, same volume). Solar luminosity variations can be obtained from paleoluminescent records by extracting of the orbital variation from them using band- pass filtration with frequencies of the orbital variations.

These millennial solar luminosity cycles can produce climatic variations with intensity comparable to that of the orbital variations. Known decadal and even century solar cycles have negligible intensity (100 times less intensive) relatively to these cycles. Solar luminosity (SL) and orbital variations both cause variations of solar insolation affecting the climate by the same mechanism.

Luminescence time series has been used to solve number of problems of solar physics (Dermendjiev et al., 1989, 1990, 1992).

Luminescence and Cosmic Rays Flux (CRF)

Cosmic rays produce cosmogenic isotopes (^{14}C, ^{10}Be, etc.) in the upper atmosphere by nuclear reactions. As it is known, the ^{14}C variations record represents the Cosmic Ray Flux (CRF) and modulation of the CRF by the solar wind (representing solar activity). We have obtained a striking correlation (with a correlation coefficient of 0.8) between the calibration residue delta ^{14}C record and a luminescent speleothem record (Shopov et al., 1994). It is as high as the best correlation ever obtained between a direct Solar index (inverted annual Wolf number) and the CRF (Beer, 1991, $r= 0.8$). Obviously luminescence records can be used as a CRF proxy. To reconstruct the past CRF the luminescent record should be inverted. This way was obtained a reconstruction of the solar modulation of the CRF during the last 50000 years with resolution of 28 yrs.

Luminescence and supernova explosions

Galactic CRF have some short- term variations due to supernova explosions. These variations of the GCRF can be determined only by comparison of a record of production of cosmogenic isotopes (CI) with an independent on CRF solar activity record. The luminescence microzonality is the only independent SA index with such length of record. It was used to reconstruct GCRF variations for the last 6500 years with 20-yr. resolution by subtracting of an inverted luminescent SA record from the residual ^{14}C record (Shopov et al., 1996-b). Obtained record represents self-variations of the GCRF (due to supernova eruptions) beyond Solar system (where solar modulation does not exist).

Luminescence Reconstructions of the Variations of Geomagnetic Field

Variations of intensity of the Geomagnetic field dipole also correlates with speleothem luminescence (Shopov et al. 1996-e), because the geomagnetic field is modulated by the magnetic field of the solar wind (which is one appearance of the solar activity). This is due to formation of induced electromagnetic field in the Earth's magnetosphere in result of rotation of the Earth (which has own magnetic field) in the variable magnetic field of the Solar wind. This process is similar to rotation of a dynamo machine (electric generator).

Luminescence and Paleosoils

Luminescence organics first detected in speleothems by Gilson and Macarthney (1954) are humic and fulvic acids accordingly White, Brennan, 1989, but more precisely they can be divided to 4 types accordingly Shopov (1997):

1. Calcium salts of fulvic acids, soluble in water;
2. Calcium salts of humic acids not soluble in water and acids, but

mobile in karst in form of colloid solutions;

3. Calcium salts of huminomelanic acids not soluble in waters and acids, but soluble in alcohols. They are mobile in karst in form of colloid solutions.
4. Organic esters not soluble in water but soluble in ether.

Each of these classes is usually presented in a single speleothem with hundreds of chemical compounds with similar chemical behavior, but different molecular weights. Superposition of luminescence bands of all this compounds gives the broadline spectra of luminescence of organics in a speleothem. Distribution of concentration of these compounds (and their luminescence spectra) depends on type of soils and plants society over the cave. So study of luminescence spectra of this organics can give information about paleosoils and plants in the past (White, Brennan, 1989). Changes in the visible colour of luminescence of speleothems suggest major changes of plants society and are observed very rarely only in speleothems growing hundreds of thousands years through glacial and interglacial periods (Shopov, 1997).

Luminescence and Annual Growth Rates of Speleothems

Speleothem growth rate may vary up to 14 times within a single sample, resulting in non- linear time scale of the records (Shopov, et al.1992, 1994). These variations represent rainfall variations if there are no growth interruptions (hiatuses) between the dating points in the speleothem. Speleothem luminescence visualizes annual microbanding, not visible in normal light (Shopov, 1987, Shopov et al., 1988a). This peculiar banding have been called "Shopov bands" by S.E. Lauritzen et al. (1996). If this banding is visible in normal light or the luminescent curve have sharp profiles or jumps like in Baker et al. (1993), it suggests that speleothem growth stopped for a certain period during the year and such time series can not be used for obtaining of rainfall proxy records. Maxima of intensity of luminescence reflect air temperature in August, but minima in February in a speleothem from Rats Nest cave, Alberta, Canada (Shopov et al., 1996-a, c). By measuring the distance between subsequent maxima we may derive a proxy record of annual precipitation for the cave site. Shopov et al. (1996-a, c) measured correlation of 0.57 between speleothem annual growth rates (determined by measuring of the distance between maxima of the annual structure of luminescence of a speleothem from Rats Nest cave, Alberta) and the historic record of measured annual precipitation in Banff, Alberta (from August to August) for the last 100 years. This way was reconstructed annual precipitation for last 280 years at the cave site with precision of 80 mm/year (Shopov et al., 1996-a, c). Now studies of 15 labs over the world are concentrated only on this specific topic of paleoenvironmental applications of speleothem luminescence (Baker et al., 1993, Lauritzen et al., 1996, etc.)

We obtained a reconstruction of growth rates and precipitation (for the last 6400 years with averaged time step of 41 years) for Iowa (near Cold Water cave), US (Shopov, et al., 1996-c) by "tuning" of the time scale of a luminescent record to the calibration ^{14}C record (Stuiver and Kra, 1986). It suggests higher speleothem growth rate and higher precipitation between 6400- 2500 years B.P. at the cave site. This speleothem is dated with 7 TIMS U/Th dates.

Using of Paleoluminescence for Determination of the Origin of Glacial Periods and Improvement of their Dating

We measured a luminescent solar insolation proxy record in a speleothem (JC11) from Jewel Cave, South Dakota. This record exhibits a very rapid increasing in solar insolation at 139 kyrs +/- 5.5 kyrs (2 sigma error) responsible for the termination II. This increasing is preceding the one suggested by the Orbital theory with about 10 kyrs and is due to the most powerful cycle of the solar luminosity with duration of 11.5 kyrs

superposed on the orbital variations curve. Solar luminosity variations appear to be as powerful as orbital variations of the solar insolation and can produce climatic variations with intensity comparable to that of the orbital variations (Shopov et al. 2004-b, the same volume). So paleoluminescence speleothem records may serve as a reliable tool for studying the mechanisms of formation and precise timing of glaciations.

Paleoluminescence and Sea Level Variations

Using speleothem luminescence solar insolation proxy records it has been demonstrated, that solar luminosity variations are responsible for almost 1/2 of the variations in high- resolution solar insolation experimental records. Solar luminosity variations are responsible for the short time variations of the sea level (Shopov et al. 2000).

Luminescence Reconstructions of Past Karst Denudation

Reconstructions of past carbonate denudation rates has been made using the quantitative theory (Shopov et. al, 1991) of solubility of karst rocks (in dependence of the temperature and other thermodynamic parameters) and quantitative paleoluminescence reconstructions of the annual precipitation rates (for the last 280 years) and of the annual temperature for the last 1200 years (Shopov et al. 2001).

Pollution and migration of toxic compounds indicated by speleothem luminescence

In many samples all or a significant part of the luminescence is produced by ions of uranium and Pb. Sometimes they even have annual banding due to variations of acidity of the karst waters (Shopov, 2004, in the same volume), causing variations of the solubility of some pollutants or toxic compounds (Shopov, 1997). Uranium compounds have such migration behavior.

Luminescence of Hydrothermal Minerals

Luminescence of the high- temperature hydrothermal minerals is due mainly to cations because molecular ions and molecules destruct at high temperatures. Luminescence of some cations can be used as an indicator of hydrothermal origin of the cave mineral (Shopov, 1989 a, b). Calcites formed by low-temperature hydrothermal solutions have short-life fluorescence due to cations and long phosphorescence of molecular ions (Gorobetz, 1981). Minimal temperature of appearance of this orange-red luminescence of calcite was estimated by Dublyansky (in press) to be about 40^0C by fluid inclusion analysis in hydrothermal cave calcites, but our direct measurements of luminescence of calcites in hot springs show that even at 46^0C such luminescence did not appear. It probably appears at over 60^0C. Such luminescence data are comparable with the stable isotope data used conventionally for this purpose (Bakalowicz et. al., 1987, Ford et al., 1993).

Luminescence and Tectonics

The tectonic uplift of an area (i.e., uplift of bedrock) can be deduced by luminescence in combination with absolute dating methods. For example some speleothems from Carlsbad Cavern, New Mexico exhibit luminescence originated by epithermal mineralizing solutions in the older part of the speleothem. Mixing of these waters with surface waters containing organics appear in younger parts of the speleothem, thus indicating the uplift during the duration of speleothem deposition (Shopov et al., 1996-d). This allows to date the uplift of the Gaudalupe Mountains. The boundary layer

(so the uplift) can be dated by U/Pb dating methods (Ford, 2002).

Luminescence and Dating of Speleothems

Finally, speleothem's luminescence may be used to determine the age of the speleothem itself. Shopov et al., 1991a, Dermendjiev et al. (1996) developed the new Autocalibration dating technique, which is shown to be the most precise speleothem dating method for samples younger than 2000 years (Shopov et.al, 1994).

Although Ugumori and Ikeya (1980) first suggested Optically Stimulated Luminescence (OSL) dating technique on speleothem calcite further attempts were not successful due to interference of luminescence of organics. Therefore OSL- dating cannot be used for speleothems.

Conclusions

In conclusion speleothem luminescence of organics can be used for obtaining of broad range of paleoenvironmental information. Most of the progress in this field was made in result of the operation of the International Programs "Luminescence of Cave Minerals" and "Speleothem Records of Environmental Changes in the Solar System" of the commission on Physical Chemistry and Hydrogeology of Karst of UIS of UNESCO.

Some speleothems can be used as natural climatic stations, for obtaining of proxy records of Quaternary climate with annual resolution.

Acknowledgements

References

BAKALOVICZ M., FORD D.C., MILLER T.E., A.N.PALMER M..V. PALMER.1987 Thermal genesis of dissolution cave from Black Hills, South Dakota.- GSA Bulletin, 99: 729-738.

BAKER,A.,SMART, P.L., EDWARDS, R.L., RICHARDS, D.A, 1993, Annual Growth banding in a cave stalagmite: Nature, 304: 518-520.

BEER, J.1991 Time variations of ^{10}Be and solar activity.: 343-359 In: C .SONETT, M.GIAMPAPA, M. MATWTHEWS (Eds.)- The Sun in Time.

DERMENDJIEV VL, SHOPOV Y.Y., BUYUKLIEV G.1989 Solar activity in the past and the problem of Solar Dynamo. Solar Physics J., 128: 217-25

DERMENDJIEV V.N., BUYUKLIEV G.T.,SHOPOV Y.Y. 1990 The prolonged minima of Solar activity and the Problem of Solar Dynamo.- Abstracts of IAU International Colloquium"The Sun and Cold Stars:- Activity, Magnetism and Dynamos" , July 17-21 1990, Helsinki: 63.

DERMENDJIEV V., SHOPOV Y.Y.(1992) in: Solar- Terrestrial Variability and Global Changes, W.Schoder J.-P. Legrand (eds.), Bremen-Roennebeck, p.145.

DERMENDJIEV V., SHOPOV Y.Y., BUYUKLIEV G.N.1996 High-Precision Method of Cave Deposits Dating and an Implication for Archeometric Study.- Physical and Chemical Technics J. 45 (IV.7): 307-312.

DUBLYANSKY Y.V.,(in press) Luminescence of calcite from Buda Hill caves

FORD D.C. 2002 Explorations in U/Pb dating of calcite speleothems. Extended abstracts of the International Workshop "Cave Climate and Paleoclimate- The Best Record of the Global Change", 24- 27 Sept. 2002, Stara Zagora, Bulgaria: 23-24.

FORD D.C., BAKALOVICZ M., MILLER T.E., A.N.PALMER M..V. PALMER (1987) Uranium series dating of the draining of an aquifer: an example of Wind cave Black Hills, South Dakota.- GSA Bulletin, v.105, pp. 241- 250.

GILSON, R.J., AND MACARTHNEY, E. 1954 Luminescence of speleothems from Devon, U.K.: The presence of organic activators: Ashford Speleological Society Journal, 6:8.(abstr.)

GOROBETS B.S. 1981 Atlas of Spectra of Luminescence of Minerals.VIMS, Moskow. (in Russian)

LAURITZEN S.E., KIHLE J. 1996 Annualy resolved stable isotope data from speleothem calcite by laser ablation/ mass spectrometry. Extended abstracts of Int. Conference on "Climatic Change- the Karst Record", 1- 4 August 1996, Bergen, Norway. Karst Waters Institute Special Publication 2: 84-86

MITSAKI V. 1973 Geochemical study of some spesimens of stalactites from Tourkovonia cave, Athens. Deltio, v.12, 3: 90-95

SHOPOV Y.Y. 1986 Applications of photoluminescence in Speleology.- Bulgarian Caves, 4: 38-45.

SHOPOV Y.Y. 1987, Laser Luminescent MicroZonal Analysis- A New Method for Investigation of the Alterations of the Climate and Solar Activity during Quaternary- in "Problems of Karst Study of Mountainous Countries" (Proceedings of the International Symposium of Speleology 5-1 2 Oct. 1987), MEISNIEREBA, Tbilisi: 228-232

SHOPOV Y.Y. 1988 Methodics of Laser Luminescent Spectral Analysis of Powders and Minerals. 185-190 In: "Spectral Methods of solving of the problems of the Solid State Physics", Scientific Commission on "Atomic and Molecular Spectroscopy" of AS USSR, Acad. Sci. Press, Moskow. (in Russ.)

SHOPOV Y.Y. 1989a Bases and Structure of the International Programme "Luminescence of Cave Minerals" of the Commission of Physical Chemistry and Hydrogeology of Karst of UIS.-Exped. Annual of Sofia University, 3/4:111- 127.

SHOPOV Y.Y. 1989-b Spectra of Luminescence of Cave Minerals. Expedition Annual of Sofia University, 3/4:80-85.

SHOPOV Y.Y. 1991 A new method for photography of luminescence and it's applications in speleology. The NSS Bulletin, 53(2):123

SHOPOV Y.Y. 1997 Luminescence of Cave Minerals: 244-248 In: C.HILL, P. FORTI (Eds.)- Cave Minerals of the world, second edition, NSS, Huntsville, Alabama, USA

SHOPOV Y.Y.1999 Speleothem Records of Environmental Changes in the Past.: 117- 134. In: B.ANDREO, F. CARRASCO, J.J DURAN (Eds.)- Contribucion del Estudio Cientifico De Las Cavidades Karsticas Al Conocimiento Geologico, PCN, Instituto de Investigacion, Malaga, Spain.

SHOPOV Y. 2004 Activators of Luminescence in Speleothems as Source of Major Mistakes in Interpretation of Luminescent Paleoclimatic Records.- in the same volume.

SHOPOV Y.Y., A. DAMYANOVA, Y. DAMYANOV, L.TSANKOV, C.J.YONGE, J. BLAND, D.C. FORD 1996-b Speleothem Records of Processes Beyond the Solar System (Supernova Eruptions)- Extended abstracts of Int. Conference on "Climatic Change- the Karst Record", 1- 4 August 1996, Bergen, Norway. Karst Waters Institute Special Publication 2., 152.

SHOPOV Y.Y., A. DAMYANOVA, Y. DAMYANOV, L.TSANKOV 1996-e. Speleothems Luminescence Proxy Records of Geomagnetic Field Intensity.- Extended abstracts of Int. Conference on "Climatic Change- the Karst Record", 1- 4 August 1996, Bergen, Norway. Karst Waters Institute Special Publication 2., 153.

SHOPOV Y.Y., DERMENDJIEV V.N., BUYUKLIEV G.I.,GEORGIEV L.N, STOYCHEV T.S. 1988 Investigations on the Variations of the Solar Activity during the Holocene by means of LLMZA of Cave Flowstone.-Communications of the Int. Symp. on Phys.,Chem & Hydrogeological Research. of Karst, May 10-15, 1988, 97-100

SHOPOV Y.Y., DERMENDJIEV V.N., BUYUKLIEV G., 1990b, Solar Activity in the Last 35000 years, from data of Luminescence of Cave Flowstones from Bulgaria.-Annales Geophysicae,special issue, 300

SHOPOV Y.Y., DERMENDJIEV VL.1990c Microzonality of Luminescence of Cave Flowstones as a New Indirect Index of Solar Activity.- Comptes rendus de l'Academie bulgare des Sci., 43(7): 9-12.

SHOPOV Y.Y, DERMENDJIEV V, BUYUKLIEV G. 1991 A New Method for Dating of Natural Materials with Periodical Macrostructure by Autocalibration and it's Application for Study of the Solar Activity in the Past.- Quaderni del Dipartimento di Geo., Universita di Padova, 13: 23- 30

SHOPOV Y.Y., FORD D.C., MORRISON J., SCHWARCZ H.P., GEORGIEV L.N., SANABRIA M.E., DERMENDJIEV V., BUYUKLIEV G. 1992 High resolution records of Quaternary Solar Activity, Climate and Variations- Abstracts of the 1992 Geological Soc. of America Annual Meeting, Cincinnati, 26-29 Oct. 1992, 268.

SHOPOV Y.Y., FORD D.C., SCHWARCZ H.P. 1994a Luminescent Microbanding in speleothems: High resolution chronology and paleoclimate. Geology, 22: 407 -410

SHOPOV Y.Y., GEORGIEV L.N. 1987 The Color Slide Spectrophotometry - A New Method for Direct Non-destructive Registration of Spectra of Luminescence and Diffuse Reflectance of Minerals.- Abstracts of IV Int. Sch. Topical Probl. of Karst and Speleo.:12(Bulgarian).

SHOPOV Y.Y., GEORGIEV L.N. 1989 CS- Spectrophotometry- A New Method for Direct Registration of Spectra of Variable Processes.- Abstracts of XXVI Colloquium Spectroscopicum Internationale, 3-7 July 1989, Sofia, Bulgaria, III: 194.(abstract)

SHOPOV, Y., GEORGIEV L.N. 1991 Quantitative theory of the solubility of carbonate rocks in dependence ofthe physico- chemical and climatic conditions.- Exped. Ann. Univ. of Sofia, 5-A: 9-16.

SHOPOV Y.Y., GRYNBERG M.A. 1985-b. A New Method for Direct Photography of Luminescence.-Exped.Ann.Sofia Univ.1: 139-45

SHOPOV Y.Y., IVANOV G.I., KOSTOV R.I. 1988b Phase Analysis of the Polymorphic modifications of $CaCO_3$ by spectra of its photo- luminescence:191-201 In: "Spectral Methods of solving of the problems of the Solid State Physics", Scientific Commission on "Atomic and Molecular Spectroscopy" of AS USSR, Acad. Sci. Press, Moskow. (in Russ.)

SHOPOV Y.Y., SPASOV V.A. 1983 Speleological Applications of Physical Methods for analysis of solids.- Abstracts of the First National Congress of the Physicists in Bulgaria (Sofia, 28 IX- 1 X 1983): 193.

SHOPOV Y.Y., D.STOYKOVA, L.TSANKOV, M.SANABRIA, J. LUNBERG, L.GEORGIEV, P. FORTI, D. GEORGIEVA (2000) Verification of the Causes of Glaciations and Sea Level Changes Using the Records of Calcite Speleothems- International Journal of Speleology, 29 B(1/4): 71-75.

SHOPOV Y.Y., D. STOYKOVA, L.TSANKOV, M.SANABRIA, D. GEORGIEVA, D. FORD, L.GEORGIEV (2004-b) Influence of Solar Luminosity Over Past Climate and Geomagnetic Cycles As Derived From Speleothems- in the same volume

SHOPOV Y.Y., TSANKOV L.T. 1986, A Photographic Apparatus for Luminescent Analysis (B. Patent 40439 from 30 Aug. 1985), Bulletin of IIR, Dec.1986, 12:7. (B)

SHOPOV Y.Y., L.TSANKOV, L.N.GEORGIEV, A.DAMYANOVA, Y. DAMYANOV, D.C.FORD, C.J.YONGE, W. MACDONALD, H.P.R.KROUSE 1996-a Speleothems as Natural Climatic Stations with Annual to Daily Resolution- Extended abstracts of Int. Conference on "Climatic Change- the Karst Record", 1- 4 August 1996, Bergen, Norway. Karst Waters Institute Special Publication 2.: 150-151.

SHOPOV Y.Y., L.TSANKOV, L.N.GEORGIEV, A.DAMYANOVA,

244

Y. DAMYANOV, E. MARINOVA, D.C. FORD, C.J.YONGE, W. MAC-DONALD, H.P.R. KROUSE 1996-c. Speleothem Luminescence proxy Records of Annual Rainfall in the Past. Evidences for "The Deluge" in Speleothems."- Extended abstracts of Int. Conference on "Climatic Change- the Karst Record", 1- 4 August 1996, Bergen, Norway. Karst Waters Institute Special Publication 2: 155-156.

SHOPOV Y.Y., L.TSANKOV, M. BUCK, D.C.FORD 1996-d Time Resolved Photography of Phosphorescence- A New Technique for Study of Thermal History and Uplift of Thermal Caves.- Extended abstracts of Int. Conference on "Climatic Change- the Karst Record", 1- 4 August 1996, Bergen, Norway. Karst Waters Institute Special Publication 2: 154.

SHOPOV Y., LUDMIL.T.TSANKOV,LEONID.N.GEORGIEV, ELENA MARINOVA, DEREK.C. FORD, CHAS.J.YONGE (2001) Quantitative Annual Speleothem Records of Temperature and Precipitation in the past - A new tool for Reconstruction of past karst denudation rates.- in Proceedings of the XIIIth UIS Congress. Brazil, 187-189

SLACIK, J. 1977 Luminescence analysis in speleology. Proc. 7th Int. Cong. Speleol. Sheffield: 31-36.

STUIVER M., R.KRA (Eds.) 1986. Calibration of 14-C Dating. Radiocarbon, Calibration issue, 28

STOYKOVA D. A., Y.Y. SHOPOV, D.FORD, L.N.GEORGIEV,

L.TSANKOV. (1998) Powerful Milleniall- Scale Solar Luminosity Cycles and their Influence Over Past Climates and Geomagnetic Field- Abstracts of AGU Chapman Conference on Mechanisms of Millennial- Scale Global Climate Change, June 14- 18, 1998, Snowbird, Utah: 26.

TARASHTAN A.N., 1978, Luminescence of minerals. Naukova Dumka, Kiev (in Russian)

TARCUS-CSSR 1981 Bibliography of working groop of the CSS ZO 1-O5 GEOSPELEOS for 1973-1980. Prague ,CSS, 31 pp.

UGUMORI, T., IKEYA M., 1980, Luminescence of $CaCO_3$ under N_2- Laser excitation and application to archaeological dating: Japanese J.Appl.Physics, v.19(3): 459-65.

WHITE, W.B. 1974. Determination of Speleothem growth mechanism by luminescence spectrography. Geo², 3(3): 37.

WHITE W.B, BRENNAN E.S. 1989 Luminescence of speleothems due to fulvic acid and other activators. Proceedings of 10th International Congress of Speleology, 13-20 August 1989, Budapest, 1: 212- 214.

O-62

Comparative study of oligotrophic bacterial species cultivated from Jack Bradley Cave, Kentucky.

Adin Pemberton, Jennifer Millette and Hazel A. Barton*.
Department of Biological Sciences, Northern Kentucky University,
Highland Heights, KY 41099, USA
*Corresponding author: bartonh@nku.edu and www.cavescience.com

245

Abstract

Due to geologic isolation and the absence of sunlight energy, the majority of caves represent a starved environment in which microscopic life subsists by scavenging available nutrients. In order to compare the relative diversity of cultivable bacterial species between organic-rich and organic-limited cave conditions, samples were collected from Jack Bradley Cave, Kentucky. Bacteria were taken from a dry passage with no apparent surface input (oligotrophic) and from a lower stream passage with a surface stream inflow (copiotrophic). In order to increase the types and numbers of bacteria that could be cultivated, various media ranging from Luria Bertani to distilled water plates were used. Multiple bacteria species were successfully cultivated, with a greater diversity of colonies being observed on the nutrient deficient plates, indicating that the microorganisms in this environment are adapted to low nutrient conditions. Unique colonies were purified through colony isolation, generating a culture collection of 501 cultivars. In order to identify unique species, genomic DNA was isolated and PCR was used to amplify the 16S rDNA sequence. The species were grouped into 110 unique cultivars using restriction fragment length polymorphism of the 16S rDNA sequence. These species were established using DNA sequencing, BLAST and phylogenetic alignment. The results demonstrate that many of the cultivars identified from these cave environments represent previously undescribed species, belonging to Pseudomonads, Caulobacter, and Actinomycetes. However, these species do not represent major populations in the communities identified in cave environments using non-cultivation techniques. We were able to isolate "non-traditional" organisms from this environment on nutrient limited plates, often only in association with other species. Our results suggest that traditional cultivation techniques from starved environments favor species that demonstrate metabolic flexibility, while oligotrophic organisms may be identified as metabolically adaptable "consortia."

Introduction

We began our studies with a simple question shared by many other microbiologists: what are the chemical limits of life? To answer this question, we wanted to determine the lower limits of nutrient availability able to support microbial community subsistence in extremely starved terrestrial ecosystems. Caves, with limited exception, form through the erosional processes of water. By the time caves are enlarged sufficiently to allow human access, the water has (generally) departed, leaving the cave exposed to an oxygenated atmosphere (15). Without sunlight energy, the entry of nutrients into the system becomes a function of the geology and depth of the cave; significant organic input is limited to the entrance zone and areas fed by surface water, whether percolating through the bedrock or entering the system through faults (15). Due to this geologic isolation, the majority of caves therefore represent an essentially oxidized and starved environment in which microscopic life subsists by scavenging available nutrients.

Unlike other starved environments where one might wish to study oligotrophic survival, caves (with training) are easily accessible and contain a stable environment where diurnal and seasonal variations do not cause substantial physical variations in the system (15). Literature on oligotrophic cave communities is sparse, with studies being carried out in caves of the United States, Spain and Italy (6, 8, 13, 14, 19). However, many of these investigations relied on standard cultivation techniques, while it has been estimated that <1% of microorganisms present in any environment are culturable (2). Due to the sensitivity to the oxidative and osmotic stressors found in cultivation media and a slow growth rate, it is likely that the percentage of unculturable species is significantly higher in the case of oligotrophic organisms living in these starved cave systems (10, 16-18, 20).

Through previous non-cultivation, molecular phylogenetic-based studies in oligotrophic cave environments, we have observed a surprising diversity in the number of species identified (3). This is in contrast to the accepted ecological literature, wherein environments with a limiting energy source should also have limited species diversity through competitive exclusion (5). Contrary to this, Gottschal argues that competitive exclusion only applies to communities where one nutrient is limiting and that in the context of oligotrophic microbial communities, the diverse metabolic activity of different species results in continual nutrient flux and limitation, in which numerous factors effect competition and subsequent diversity (11). In order to answer the question of species diversity and metabolic activity within the oligotrophs living in cave systems, it is important to directly assess the metabolic properties of microorganisms living in these environments. Such data provide measurable metabolic activities, rather than those presumed through phylogenetic comparison (1). Unfortunately there are significant difficulties with the cultivation of oligotrophs, with the assumption that the rate-limiting step in bacterial growth is simply nutrient availability, and not the inherent growth rate of the cell itself (16). We therefore carried out a comparative cultivation study to identify the type of bacterial species that could be cultivated on media with differing levels of carbon and energy, supplements and antioxidants. The ability of individual bacterial species to be cultivated from cave environments with differing amounts of energy entering the system was also compared, to determine whether the oligotrophic nature of the cave does indeed play a role in the level species diversity.

Materials and Methods

Our study was carried out in Jack Bradley Cave, Kentucky, an approximately 1,600 m cave system formed within the Mississippian age St. Genevieve limestone of southern Kentucky. Two passages were identified for sampling within the cave, both of which were approximately 30 m below the surface. One area, considered oligotrophic, was in an upper-level paleo-cave with limited surface input, other than rare flooding events or water percolating into the system. The other location, considered copiotrophic, receives nutrient input from a surface stream entering the cave system. Other than the amount of surface nutrient input, the physical conditions of these two locations were constant (approximately 14°C, >90% humidity).

To test the culturability of organisms from this environment, we developed a series of low-nutrient plates (Table 1). In the cave, the plates were inoculated by swabbing a ~ 5 cm³ area of the wall. The swab is then rinsed in 1 ml of sterile water, used as the stock to swab all the plates; this results in each plate being inoculated from the same source, ensuring the observable growth patterns reflect the growth characteristics on the media, rather than a bias introduced by the area of the wall examined. All the plates are then incubated under aphotic conditions with approximately 50% humidity at 20°C.

Table 1. Cultivation Media Used Within Jack Bradley Cave.

Agar Media[a]	Acronym
Distilled Water	DW
Soil extract	S
Soil extract plus glycerol	SG
Soil extract plus pyruvate	SP
Soil extract plus calcium carbonate powder	SC
Soil extract plus calcium carbonate and Dulbecco's mineral supplement	SCM
Soil extract plus calcium carbonate and Dulbecco's vitamin supplement	SCV
Soil extract plus calcium carbonate, Dulbecco's vitamin and mineral supplement	SCMV
Soil extract plus calcium carbonate, Dulbecco's vitamin and mineral supplement, and pyruvate	SCMVP
Luria Bertani	LB

[a] *Media is listed in ascending nutrient status, with distilled water being the most starved and LB the richest.*

Once a number of colonies were grown on the plates, colonies showing unique morphology were streaked onto fresh media and purified using single colony technique (Figure 1). These cultivars were identified using small subunit (16S) ribosomal RNA (SSU-rDNA) linear sequencing. Briefly, individual colonies were picked into 50 μl PCR buffer with 0.1% NP-40 detergent and subjected to boiling lysis at 95°C for 5 minutes. The supernatant was then used as a template in a PCR reaction using the bacterial specific 8F primer and universal 1525R primer (primer sequences at www.cavescience.com). The 16S sequence was amplified in reaction mixtures containing (final concentrations) 1 M Betaine, 1 X PCR buffer, 2.5 mM MgCl$_2$, 200 μM of each dNTP, 300 nM of each forward and reverse primer, and 0.025 U of AmpliTaq Gold (Perkin Elmer) per μl. Reaction mixtures were incubated on a Mastercycle Gradient thermal cycler (Eppendorf Scientific) at 94°C for 12 min for initial denaturation and activation of the AmpliTaq Gold. PCR was then carried out for 30 cycles at 94°C for 1 min, 64°C for 45 s, and 72°C for 1 min 30 s, with a final extension period of 8 min at 72°C.

In order to identify unique species, all PCR products were screen by restriction fragment length polymorphism (RFLP). Briefly, 20 μl of crude rDNA product was then digested with 1.5 U of the 4-base-specific restriction endonucleases HindPI1 and MspI in 1X NEB buffer 2 (New England Biolabs), in a final volume of 25 μl for 2 hours at 37°C. Digested fragments were separated by electrophoresis on a 2% SeaKem LE agarose gel (FMC BioProducts) and visualized by ethidium bromide staining and UV illumination. Unique RFLP patterns were grouped visually and unique species were selected for sequencing using linear sequencing. This protocol involved an initial 8F/1525R PCR reaction of the unknown species. The PCR product was then purified using a Qiagen PCR cleanup kit, to remove unincorporated primers and template DNA. This DNA fragment was then used as a template for sequencing on a Long ReadIR 4200 DNA sequencer (Li-Cor, Inc.), using the Thermo Sequenase Cycle Sequencing Kit (USB Corp.) and a labeled 515F primer and unlabelled 1100R primer, in accordance with the manufacturer's linear sequencing instructions. Sequences that were problematic through G+C rich areas were sequenced using the Epicenter high GC sequencing kit, again following the manufacturers recommended protocol (Epicenter). Primers for sequencing allowed sufficient coverage to sequence the ~600 base insert of the bacterial rDNAs in both directions. Sequences were speciated by comparison to cultivated representatives by use of the BLAST (Basic Local Alignment Search Tool) network service (http://www.ncbi.nlm.nih.gov/BLAST).
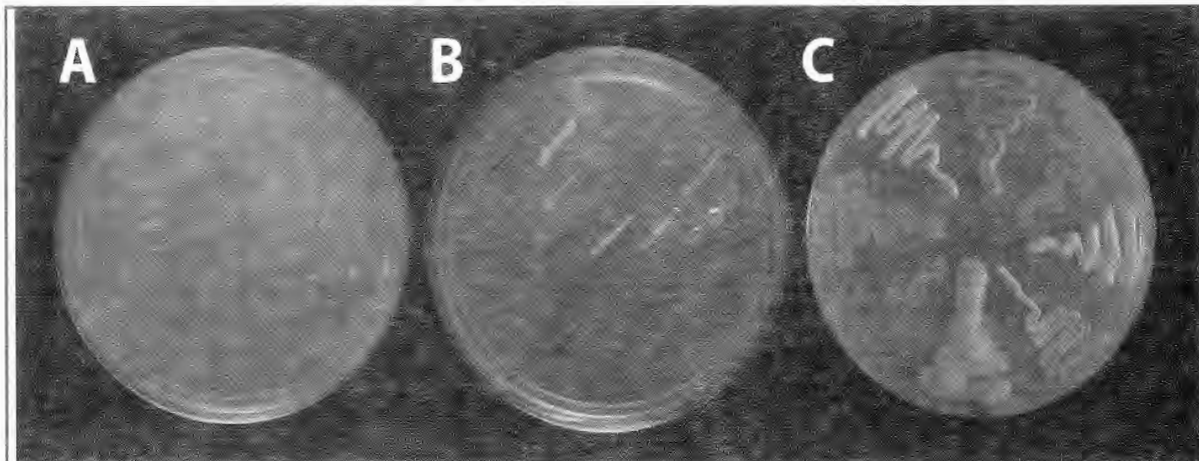
Figure 1. Colony isolation. **A)** Organisms are isolated on oligotrophic media. **B)** Unique colony morphologies are streaked onto a separate plate. **C)** Multiple rounds of single colony isolation leads to 'pure' cultivar cultures. Libraries are stored on ntrient plates at 4°C, in agar stabs at room temperature and as glycerol stocks at -80°C.

Results

On average, following inoculation, colonies were observed on the nutrient media within one day to two weeks. The time for the colonies to appear on the plates roughly corresponded with the nutrient state of the media, with colonies appearing much more quickly on nutrient rich plates, such as LB media, when compared with oligotrophic media such as DW. Once a number of unique colony morphologies were observed on the plates, these were streaked onto identical media for single colony isolation. Due to the length of time required for some colonies to grow, the length of time for single colony isolation occurred anywhere from one week to six months. Beyond that time, it was considered that species could not be isolated in pure culture and represented syntrophic relationships between species, as represented by cultivars such as JBSV2A4. Following colony isolation, a total of 501 different cultivars were identified, which were subsequently grouped into 111 unique RFLP types. These data, supported by the sequencing results, allowed us to successfully identify 111 operational taxanomic units within the Jack Bradley cultivar library.

We began analyzing the culturability of different bacterial divisions on the various media used. Figure 2 demonstrates the impact that increasing levels of carbon and energy have on the diversity of species cultivated. The most starved, DW plates, contain representatives from the Clostridia/Firmacites/Bacillus Group as well as the Alpha- and Gammaproteobacteria, despite the lack of specific energy sources in this media. The agar plates that contained 5% soil extract demonstrated the highest levels of diversity when the media was not supplemented with 0.1% glycerol or the antioxidant 40 mM pyruvate, which can also serve as a carbon and energy source. It is interesting to note that the media which more closely resembles the chemistry found within the cave (S) demonstrates the highest diversity of cultivated species, rather than that containing the most available energy (SG).

In order to address how the role of trace metals and other nutrients affected the culturability of bacteria from Jack Bradley, we tested how the addition of supplements affected the diversity of species observed (Figure 3). As the initial results suggested that, as the nutrient media more accurately reflects the nutritional environment within the cave leads to greater cultivar diversity, we attempted to use supplements that allow the media to better reflect the chemistry of the cave. To this end, we added 0.2% calcium carbonate (C) powder to a number of nutrient plates. We also assumed that there are a number trace minerals within the limestone rock itself, and that microbial species within this environment obtain trace vitamins from other species or from soil detritus percolating into the cave. To test the role of these essential elements on species isolation, we added Dulbecco's defined vitamin (V) and mineral (M) supplement to our media. Last of all, we tested the role of a antioxidant against oxidative stress, which is thought to play a detrimental role in cultivation of oligotrophs (16). As an antioxidant, we added 40 mM pyruvate, although t should be noted that pyruvate also act as a weak carbon and energy source to many of the cultivars isolated (9). These supplements were added to the soil plates, which was the carbon and energy source that had demonstrated the greatest impact on species diversity during our previous cultivation experiment.

The results of the various additives on cultivar growth and diversity (Figure 3) demonstrated that there was no particular supplement that dramatically increased the relative species diversity among the soil media tested. Rather, the results suggest that each additive changes the structure of the bacterial species that can be isolated from the plate. Of the media tested, again it was the media that best reflected the basic chemical structure of the cave (SC) that produced the largest amount of diversity across the bacterial divisions. It is interesting to note that the addition of pyruvate does increase the diversity in the SCPMV plates, although it is not possible to determine the role of oxidative stress protection from the role this nutrient may play as a carbon source.

Finally, while we generated data that demonstrated the effectiveness of various media in isolating bacterial species from these cave environments, it did not demonstrate the numbers and types of organisms that could be comparatively isolated from each location. To this end, using 16S SSU-rDNA sequencing and BLAST alignment, we identified the numbers and types of bacteria that were identified at each location; of the 111 unique phylotypes that were identified, 81 were successfully sequenced to provide species data. We grouped any like-species together based on the sequence date to generate operational taxanomic units (OTUs) similarly to a non-cultivation based phylogenetic study. The results (Figure 4) were striking. Within the organic-rich, copiotrophic environment, we identified 24 OTUs that represented nine disparate genera within the bacteria; however, in our oligotrophic environment we identified 57 OTUs that represent 17 different genera.
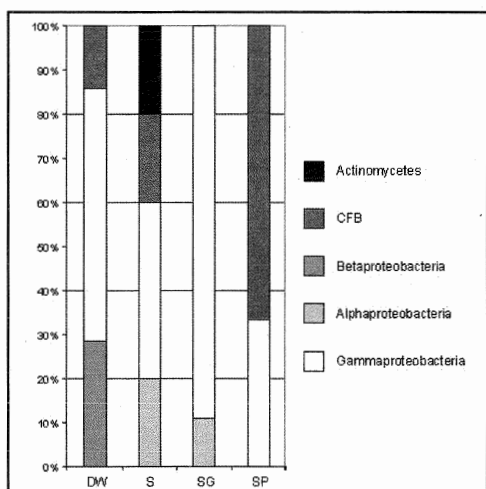
Figure 2. Distribution of bacterial divisions across various media. The number of species representative of each division are indicated as a percentage of the total number of cultivars isolated on that media.
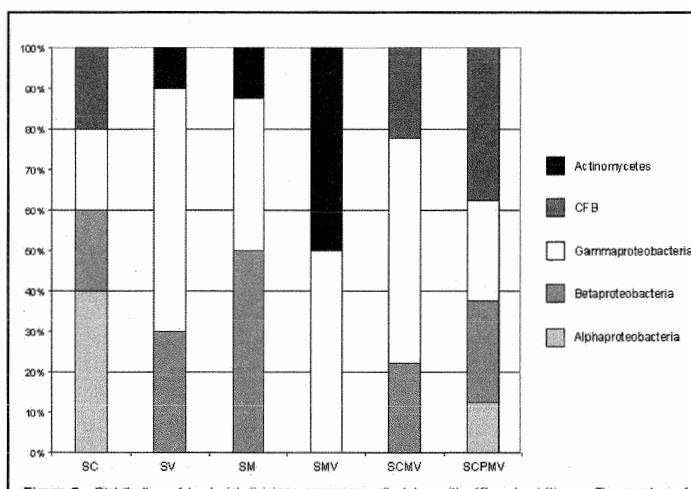
Figure 3. Distribution of bacterial divisions grown on soil plates with different additives. The number of species representative of each division are indicated as a percentage of the total number of cultivars isolated on that media.

Discussion

It was the aim of this work to determine whether the nutritional state of a cave environment plays any role in the type and culturability of bacterial species found within it. Our initial cultivation studies demonstrate that the type of media and additives used has a significant impact on the number of diversity of species isolated. Further, there appears to be an increase in the number of colony forming units as the carbon and energy sources in the plates become weaker. This would seem to be counter-intuitive, but is in accordance with other oligotrophic cultivation studies (18, 20). Nonetheless, the media that appear to most accurately reflect the actual conditions found within the particular cave environment being examined appears to allow the greatest diversity in the cultivated species identified.

It is interesting to note that soil extract appears to be necessary for the cultivation of Actinomycetes, which may be a critical component to the successful cultivation of these important soil organisms. Additionally, in plates where calcium carbonate has been added, no representative species from the Actinomycetes are identified. This may reflect an inability of these organisms to grow or produce colonies in the presence of this additive, although this would be unlikely as we have demonstrated that members of this genus are typically identified in carbonate-rich cave environments (3, 4, 7, 12, 14). This may also suggest why Actinomycetes have often been identified as the predominant species through cultivation from cave environments, as the growth media used classically lacks calcium carbonate (12, 14). Alternatively, the presence of high levels of calcium carbonate may also represent a previously unconsidered component to the cultivation of species from cave environments, such as the buffering capacity of carbonates during bacterial colony growth; the versatile Actinomycetes may be better adapted to acidification of the growth medium. While our results demonstrate important considerations for the cultivation of species from cave environments, they do not suggest an 'ideal' media for cultivation. It therefore remains important to use a number of different media conditions in order to acquire a diverse population of cultivated species.

Between the different environments, there was very little similarity in the types of species cultivated, with representatives from the Bacillus, Flavobacter, Lysobacter, Pseudomonas and Sniorhizobium shared between the two environments. This limited number of shared cultivars, and the type of species identified, may reflect the metabolic flexibility of many representative species within these genera. For example members

of the Bacilli are able to make spores, allowing transition to high nutrient conditions, while species of Pseudomonas are adapted to survive the transition from extremely starved to nutrient replete conditions (9). Indeed, the metabolic flexibility of the Pseudomonads is reflected in the fact that members of this group (within the Gammaproteobacteria) were isolated in every type of medium used within this study. Such metabolic flexibility likely suggests why these species represent such a large number of the cultivated representatives from the oligotrophic environment, whereas they are rarely identified in non-cultivation studies from oligotrophic cave environments (3, 4, 7).

There were a significant number of species that were not shared between environments. Within the oligotrophic environment we identified members of the Rhodococcus, Rhodobacter and Nocardiodes, all of which demonstrate an ability to fix nitrogen gas. Such activity may be critically important within the context of a starved cave system, where nutrients such as nitrogen and phosphorous are limiting. In order to survive in such nutrient-limited conditions, it would be necessary for a microbial community to contain species that were able to fix many of these essential nutrients. Of the most predominant species identified within the oligotrophic environment, a large number of Janthinobacteria were identified, which are successful oligotrophs, able to scavenge an existence within extremely starved environments (9). The lack of these species within the copiotrophic environment may reflect an inability of this species to compete when there are more readily available energy sources for growth. Interestingly, within the copiotrophic environment are representatives from the Burkholderia that, while taxonomically related to the Janthinobacteria, are much better adapted to nutrient rich environments (9).

It was the aim of this study to take a comparative snap-shot of microbial activity within cave environments using cultivation. The results of our study support our hypothesis of increased microbial diversity within extremely starved environments, as well as significant metabolic differences between the species found there. Our results do suggest that within these starved environments it is essential that the growth media used represent, within all reasonable means, the actual chemical environment of the cave. In the future we aim to increase the number of culturable species within these environments by identifying and maintain syntrophic relationships that allow growth of previously non-culturable bacterial species within this environment.
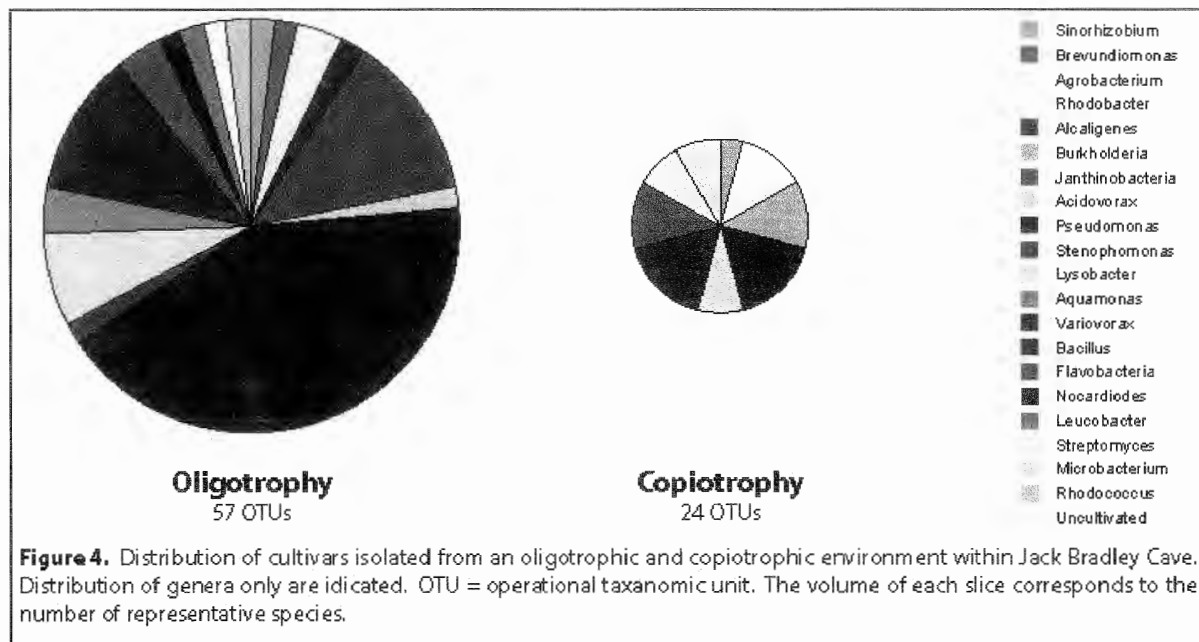
Figure 4. Distribution of cultivars isolated from an oligotrophic and copiotrophic environment within Jack Bradley Cave. Distribution of genera only are idicated. OTU = operational taxanomic unit. The volume of each slice corresponds to the number of representative species.

References

1. Achenbach, L. A., and J. D. Coates. 2000. Disparity between bacterial phylogeny and physiology. ASM News 66:714-715.

2. Amann, R. I., W. Ludwig, and K. H. Schleifer. 1995. Phylogenetic identification and in situ detection of individual microbial cells without cultivation. Microbiological Reviews 59:143-169.

3. Barton, H. A., M. R. Taylor, and N. R. Pace. 2004. Molecular Phylogenetic Analysis of a Bacterial Community in an Oligotrophic Cave Environment. J. Geomicrobiology 21:11-20.

4. Barton, H. A., N. M. Taylor, M. Kreate, and J. Bertog. 2005. The Impact of Organic Load on Geomicrobial Transformations in Subsurface Environments. Applied and Environmental Microbiology. In preparation.

5. Begon, M., J. L. Harper, and C. R. Townsend. 1998. Ecology: individuals, populations and communities. 3rd ed. Blackwell Scientific Publications., Cambridge, Mass.

6. Caumartin, V. 1963. Review of the microbiology of underground environments. Natl. Speleol. Soc. Bull. 25:1-14.

7. Chelius, M. K., and J. C. Moore. 2004. Molecular Phylogenetic Analysis of Archaea and Bacteria in Wind Cave, South Dakota. J. Geomicrobiology 21:123-134.

8. Cunningham, K. I., D. E. Northup, R. M. Pollastro, W. G. Wright, and E. J. LaRock. 1995. Bacteria, fungi and biokarst in Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico. Environmental Geology 25:2-8.

9. Dworkin, M. 2002, posting date. The Prokaryotes: An evolving electronic resource for the microbiological community. Springer-Verlag, New York. [Online. http://link.springer-ny.com/link/service/books/10125]

10. Fry, J. C. 1990. Oligotrophs, p. 93-116. In C. Edwards (ed.), Microbiology of extreme environments. Open University Press, Milton Keynes.

11. Gottschal, J. C. 1993. Growth kinetics and competition -- some contempory comments. Ant. Leeuwenhoek 63:299-313.

12. Groth, I., and C. Saiz-Jimenez. 1999. Actinomycetes in Hypogean Environments. J. Geomicrobiology 16:1-8.

13. Groth, I., P. Schumann, L. Laiz, S. Moral-Sanchez, J. C. Canaveras, and C. Saiz-Jimenez. 2001. Geomicrobiological study of the Grotta dei Cervi, Porto Badisco, Italy. J. Geomicrobiology 18:241-258.

14. Groth, I., R. Vettermann, B. Schuetze, P. Schumann, and C. Saiz-Jimenez. 1999. Actinomycetes in Karstic caves of Northern Spain (Altamira and Tito Bustillo). J. Microbiol. Methods. 36:115-122.

15. Klimchouk, A. B., D. C. Ford, A. N. Palmer, and W. Dreybrodt. 2000. Speleogenesis: Evolution of Karstic Aquifers. National Speleological Society, Huntsville, AL.

16. Koch, A. L. 1997. Microbial physiology and ecology of slow growth. Microbiology and Molecular Biology Reviews 61:305-318.

17. Koch, A. L. 2001. Oligotrophs versus copiotrophs. BioEssays 23:657-661.

18. Kuznetsov, S. I., G. A. Dubinina, and N. A. Lapteva. 1979. Biology of Oligotrophic Bacteria. Annual Review Microbiology 33:377-87.

19. Peck, S. B. 1986. Bacterial deposition of iron and manganese oxides in North American caves. Natl. Speleol. Soc. Bull. 48:26-30.

20. Poindexter, J. S. 1981. Oligotrophy: Fast and Famine Existence. Advances Microbial Ecology 5:63-90.

249

O-63

Karst as a weathering skin phenomenon: Is there a simple, scale-independent model for karstification?

Stein-Erik Lauritzen

Department of Earth Science, Bergen University
Allegaten 41, N-5007 Bergen, stein.lauritzen@geo.uib.no

Abstract

Weathering reactions proceed from exposed surfaces into the rock mass and would be controlled by the rate of weathering, the rate of surface denudation and of inhibition factors. Combining these, it is possible to arrive at a relatively simple equation which describe the diffusion of a weathering, or karstification front into the rock mass. This effect has been tested on phenomena on a large variety of scales, from weathering varnish, phytokarst, epikarst, dolines and deep karst. These tests seem to confirm the Milanovich equation, describing exponential attenuation of karst voids with depth. This principle appear scale-independent over six orders of magnitude and is a solution of a simple, concentration-driven boundary-value problem.

Introduction

Karstification involves dissolution of the bedrock by means of water and acids that are transported into the rock mass. The products - mainly in homogeneous solution - are transported out of the karst, leaving a partly dissolved rock massif, which we call karst. Meteoric karst is a surface- related phenomenon; karstification penetrate from the (sometimes independently eroding) surface into the rock mass, Figure 1. Water flow through the karst is driven by gravity. It is obvious that these processes are complex, where reagents and solutes are distributed by turbulent dissipation and conveyed by highly unsteady flow, etc. so that molecular diffusion at first seems to be too much of a simplification to describe these processes in detail. However, classical diffusion is just a continuum description of a phenomenon that spreads similarly to a discrete random walk mechanism, and it is really only valid for a large number of individuals. These 'individuals' may be either molecules, packets of water, cavers or reindeer, and it is a matter of definition where we would distinguish between 'diffusion' and 'convection', etc. In this paper we will advocate that over longer timespans and space, some of the collective structures in karst may be explained to a large extent by diffusion-type mechanisms. This is supported by an accumulating amount of observations that the concentration of karst voids displays an exponential distribution with depth. These mechanisms also seem scale-independent over several orders of magnitude. The residuals between ground-truth data and the exponential model correspond to deviant zones that can be ascribed to rock structure or perhaps to 'levels'. It is interesting to note that such 'levels' are the targets of speleogenetic analysis.
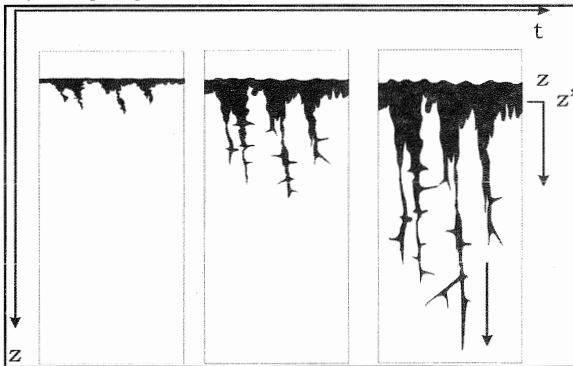
Figure 1. Meteoric karstification penetrates from the surface into the rock mass. The land surface may be eroding independently, or as a result of total disintegration from the solution process.

Diffusion-type mechanisms.

Diffusion has been applied to models for small-scale chemical weathering, like the formation of weathering rinds (e.g. Hoke & Turcotte 2002). This can be applied to various phenomena like core-stone formation and obsidian hydration (Friedman & Long 1978). Such models lead to an exponential decay of weathering damage with depth from the attacked surface. It is tempting to test if such models are applicable to karst void concentration.

Simple diffusion of karst voids into a semi-infinite half-space may be described by the heat equation:

$$\frac{\partial q}{\partial t} = k \frac{\partial^2 q}{\partial z^2} \qquad \begin{cases} q(z,0) = 0 \\ q(0,t) = 1 \\ q(\infty,t) = 0 \end{cases} \tag{1}$$

where θ is the concentration of karst voids, or the amount of karst. κ is the diffusion constant (with dimension L^2/t), t time and z vertical distance. At the land surface, karstification is total ($\theta = 1$), at depth it approaches zero ($\theta(\infty) = 0$). Karstification also commences at a definite point in time ($\theta(z,0)=0$). The solution of this boundary value problem is valid for concentration-driven dissipation of various properties, like heat, particles, ions, etc. and is dealt with in many textbooks (Carlsaw & Jaeger 1959, Crank 1975, Turcotte & Schubert 1982):

$$q(z,t) = q_0 Erfc\left(\frac{z}{2\sqrt{kt}}\right) \tag{2}$$

where Erfc is the complementary error function:

$$Erfc(x) = 1 - \frac{2}{\sqrt{p}} \int_0^x e^{-x^2} dl \tag{3}$$

$\sqrt{kt}$ is the characteristic diffusion distance, and consequently, $\gamma = z/2\sqrt{\kappa t}$ is a dimensionless ratio, or similarity variable. Series expansion of (3) and setting $\theta(z) = \theta_0/2$ in (2) yields $z_{1/2} \approx \sqrt{(\pi \kappa t)}/2 = 0.8862\sqrt{(\kappa t)}$, i.e the time-dependent half- depth of karstification. If the process is controlled by diffusion alone, this depth will grow with the square root of time. Most of the change takes place near the surface along a boundary layer, which we may compare to either the epikarst or to the total explorable karst zone. Analogous to heat diffusion (Turcotte & Schubert 1982), the variable decays exponentially with depth so that an arbitrary definition of 'thickness' for the boundary layer must be made. The standard practise is to define the thickness of the boundary layer where $\theta(z) = 0.1 \square \theta_0$. Thus, from tables we find that $\gamma_{0.1} = Erfc^{-1}(0.1) = 1.16$ and hence, $z_{0.1} = 2\gamma_{0.1}\sqrt{(\kappa t)} = 2.32\sqrt{(\kappa t)}$. Most previous analyses of karst voids, like dolines (White 1988), boreholes (Milanovich 1981), caves and seismic velocities (Lauritzen 2001) used a simple exponential law:

$$q(z) = q_0 e^{-k} \tag{4}$$

with half-depth $z_{1/2} = \ln2/k$. If we assume that half-depth found by eqn (4) is the same physical distance as the one found by eqn (2), then the approximate link between the characteristic diffusion distance and the decay constant is:

$$k \approx \frac{\sqrt{p}}{2h}\,2\sqrt{kt} \approx 1.279\sqrt{kt} \tag{5}$$

Eqn(2) describes chemical weathering penetration through a stationary surface (z=0), corresponding to the situation where karstification suddenly commences on a pristine rock surface, for instance after sudden uplift - a rather odd situation to be found in nature! From the scope of microscopic weathering, Hoke & Turcotte (2002) developed the diffusion concept further. After some initiation time (t_i), weathering will have progressed far enough to make the surface to fall apart, continuously changing the point of chemcal attack at z = 0, resulting in a steady-state equilibrium between surface weathering and the progress of the weathering front. In the beginning, the weathering rind will develop with the square root of time, until t = t_i. After this, surface lowering and the progress of the weathering front is independent of time, i e. the denudation rate is constant under constant hydrochemical conditions. We may regard surface disintegration as a direct analog to surface denudation in karst and the mass flux analogous to endokarst development or hydrochemical denudation. The coordinate system may be transformed by introducing a weathering velocity (v_D= surface denudation rate),

$$z = n_D(t - t_i) + z' \tag{6}$$

where t_i is the threshold or incubation time before surface denudation becomes apparent and z' the (moving) position of the land surface. Putting Eqn (6) into eqn (1), yields an expression for the steady state situation:

$$n_D \frac{dq}{d'} = -k \frac{d^2 q}{d'^2} \quad \begin{Bmatrix} q = q_0 & z' = 0 \\ q \to 0 & z \to \infty \end{Bmatrix} \tag{7}$$

with solution (Hoke & Turcotte op. cit.):

$$q = q_0\, e^{-\left(\frac{n_D z'}{k}\right)} \quad and \quad n_D = \frac{1}{2}\sqrt{\frac{p}{t_i}} \tag{8}$$

Eqn (8) then describes the depth-distribution of karst voids at steady state equilibrium in front of a moving top surface, where z' is the depth from the present-day land surface, v_D is the surface denudation rate, and κ the karst diffusion constant of eqn (1).

It is interesting to note that Eqn (8) is identical to eqn (4) with $k = v_D/\kappa$. In other words, the exponential decay model for karst concentration with depth chosen by Milanovic, White, and others is also a solution to an assumed dynamic diffusion process from a moving surface with boundary and initial value requirements of (7). The half-depth then becomes:

$$z_{1/2} = h\,2\frac{k}{n_D} \tag{10}$$

i.e the characteristic depth of karstification (here half-depth) increases with the diffusion constant, and decreases with surface denudation. Equations (8) and (10) then describe an interesting relationship between surface denudation and endokarst development: if surface erosion rate is high, the characteristic depth of karstification decreases and may become zero. This is a characteristic feature of glaciated karst: independent glacial erosion may completely remove the epikarst and rejuvenate the whole process. From this, we may predict that the re-establishment of epikarst may progress with the square root of time until equilibrium is attained and surface denudation and epikarst progresses in pace at a constant rate.

Results and discussion

Data were collected from the original work of Milanovic (1981), from cross-sectional microphotographs of micro-phytokarst surfaces, from doline morphometry in Svartisen, Norway (Lauritzen 1996), from published doline morphometry (Troester et al 1984, White 1988), and from cave surveys and seismic tomography (Lauritzen 2001).

Estimates of the karst void concentration (θ) were collected from each data set and transformed to a dimesionless index (θ/θ_0), where θ_0 is the maximum density at the surface, i.e. eqn (8). Since the depth range of the studied objects span over six orders of magnitude (10μm to 300 m), depth was converted to dimensionless length $z/z_{1/2}$, where $z_{1/2}$ is the half-length determined from regression. In this way, depth becomes dimensionless in 'units' of half-depth. Results are listed in Table 1. All data are plotted in Figure 1. White (1988, p.35) suggests the use of $z_e = 1/k$ (eqn (4)) as the characteristic depth of dolines, which would scale to units of 1/e rather than half-depths. Although White's approach is more mathematically appealing, the concept of half- depth is easier to grasp for most people and is used here.

Weathering skin

Epoxy-cast and polished cross-sections of micro-phytokarstic weathering skins of various limestone surfaces were imaged under SEM and counted for void concentration as a function of depth. The observed concentration of colonization voids display an exponential decrease with depth from the surface with half-depths of 35- 40 μm. Deviant concentrations were found along cracks and crystal interfaces. The establishment of micro-phytokarst in competition to intense corrosion in flowing water (Figure 2) depicts the effect of κ/v_D (eqn (10)). In flowing water, the denudation rate is greater than the diffusion rate of biological colonization ($\kappa < v_D$) so that no phytokarst skin develops, leaving the clean surface of corroded rock.

Epikarst and grikes

A data set of all (n = 100) grikes in the Greft Stripe karst of north Norway are well described with an exponential distribution with half-depth of 0.95 m (Lauritzen 1996). Similar half-depth (0.8 m) was found for the epikarst zone in arctic Norway, as analysed from a cross-hole seismic survey at a damsite (By et al. 1988). Please note that both epikarst sites are in formerly glaciated areas, where epikarst development might not have attained equilibrium with surface denudation, i.e. $t < t_i$ of eqn (6).

Dolines

All doline data available were taken from the seminal work of Troester et al. (1984). Half-depths varies from epikarst dimension (Florida karst: 0.6 m) to deep tropical cockpits (8 m in Arecibo, Puerto Rico). Among the karst features investigated so far, grikes and dolines display the best fit to exponential distributions, Figure 3.

Endokarst

Few reliable cave data exists, but Lauritzen (2001) argued that well-explored and surveyed cave systems in vertical stripe karsts may provide a relatively true picture of the density of human-sized cave passages. The Salthølene system display a half-depth of 65 m; this is very close to the half-depth (60 m) of the original distribution function of Milanovic (1981), based on 146 borehole logs in the Dinaric karst. The endokarst component of the seismic survey of By et al. (1988), as analysed by Lauritzen (2001)

251

display a half-depth of only 25 m. This lower value may perhaps reflect a disequilibrium situation due to glacial erosion.

Figure 2. Competition between micro-phytokarst colonization and corrosion rate from running water, illustrating the importance of eqn (10). To the left, at the stream level, surface corrosion rate is greater than the microbial colonization rate, and a white, smooth marble surface results. The stream corrosion rate (v_D) is about 0.3 mm/yr. To the right, where a micro-phytokarst skin has developed, the denudation rate ($_D = 0.025$ mm/yr) is only due to atmospheric precipitation.
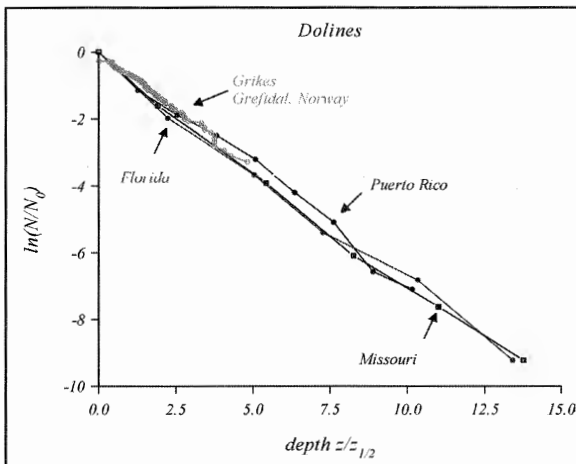
Figure 3. Frequency distribution of dolines and epikarts grikes from north Norway as a function of dimensionless depth. Data from Troester et al (1984) and Lauritzen (1996).
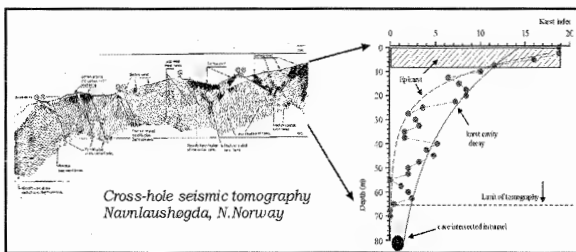
Figure 4 Left: Seismic tomography at a damsite in north Norway (By et al. 1988). Right: Depth-frequency of low- velocity zones ('karst'), two exponential decay functions are used, one for the epikarst zone and one for the deeper karstification (Lauritzen 2001).

Deviations from the smooth distribution

The residuals, or deviation from these smooth distributions contain the most interesting information. Deviations occur where the density of karst voids are greater or less than predicted from the model. Since karst density is projected vertically from the surface (along the z- axis), these deviations would correspond to 'levels'. Most likely, these features represent geological structure and perhaps hydrological levels. These features are truly the most interesting phenomena in karst as they would represent the hydrological anomalies that distinguish karst aquifers from all other aquifers. In fact, these deviant features may also be the most significant and interesting in the context of speleogenetic analysis. More speculative, we may perhaps interpret deviations as a result of a variable forcing function, e.g. long-term climatic change that would propagate a 'wave' of enhanced or retarded karstification through the rock mass. These ideas remain to be investigated.
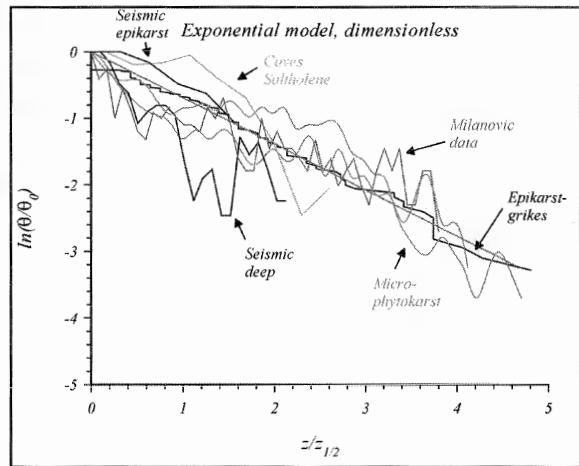
Figure 5. All data, except dolines, plotted together. The data sets cover six orders of magnitude and demonstrate that the exponential approximation is valid over this range.

Conclusions.

Karst features over a scale range of six orders of magnitude can be adequately described by exponentially decaying depth distributions. Exponential depth distribution is a solution of the diffusion equation operating from an independently eroding or denuding surface. In this context, 'diffusion' means a process that is driven by concentration gradients. We may therefore suggest that karst features on the collective scale may be described as a result of this kind of process, although the residuals may perhaps represent the features of greatest interest.

Table 1

Half-depth of some exponentially-distributed karst features

Feature	Object	$Z_{1/2}$ (m)	Regression fit (r^2)
Weathering skin	Micro-Phytokarst 1[1]	3.5×10^{-5}	0.83
	Micro-Phytokarst 2[1]	4.0×10^{-5}	0.76
Epikarst	Grikes, Greftdal[2]	0.95	0.99
	Cross-Hole seismic[3]	0.79	0.92
Dolines	Florida[4]	0.58	0.99
	Missouri [4]	2.2	0.99
	Puerto Rico [4]	7.9	0.99
Endokarst	Saltholene caves [3]	65	0.79
	Cross-hole seismic [3]	25	0.98
	Bore-holes Dinaric karst[5]	59	0.81

252

[1] Lauritzen (2005) unpublished; [2] Lauritzen (1996); [3] Lauritzen (2001); [4] Troester et al. (2004); [5] Milanovic (1981);

References

By, T.L. ; Lund. C. & Korhonen,R. 1988: Karst cavity detection by means ofseismic tomography to help assess possible dam site in karst terrain. Pp. 25-31 in: Romana (Ed) Rock mechanics and Power Plants. Balkema, Rotterdam.

Carlslaw, H.S. & Jaeger, J.C. 1959: Conduction of Heat in Solids. 2nd ed. Clarendon Press. Oxford. 510 pp.

Crank, J. 1975: The Mathematics of Diffusion. Clarendon Press. Oxford. 414 pp.

Friedman, I. & Long, W. 1978: Hydration of obsidian. Science 191, pp. 347- 352.

Hoke, G.D. & Turcotte, D. L. 2002: Weathering and damage. Journal of geophysical research, 107:2210.

Lauritzen, S.E. 1996: Karst landforms and caves of Nordland, North Norway. Guide for Excursion2, Climate Change: the Karst Record, august 5th - 16th 1996. Department of Earth Science, Bergen University. 160 pp.

Lauritzen, S.E. 2001: Marble stripe karst of the Scandinavian Caledonides: and end-member in the contact karst spectrum. Acta Carsologica 30 (2) 47-79.

Milanovic, P. 1981: Karst Hydrogeology. Water-resources Publications. Colorado. 434 pp.

Troester, J.W., White, E.L. & White W.B. 1984: A comparison of sinkhole depth frequency distributions in temperate and tropic karst regions. Proceedings of the First Multidiciplinary Conference on sinkholes, Orlando Florida. (ED. Beck, BF) Balkema, Totterdam)

Turcotte, D.L. & Schubert, G. 1982: Geodynamics. Application of Continuum Physics to geological Problems. John Wiley & Sons. New York. 450 pp.

White, W.B. 1988: Geomorphology and Hydrology of Karst Terrains. Oxford University Press. New York. 464 pp.

O-64

Quaternary speleogenesis and landscape evolution in Scandinavia and Svalbard

Stein-Erik Lauritzen

Department of Earth Science, Bergen University, Allegaten 41, N-5007 Bergen stein.lauritzen@geo.uib.no

Abstract

Karstification of the Caledonian metacarbonates in Scandinavia and Svalbard developed in pace with a landscape that was heavily eroded during the Quaternary glaciations. On the Norwegian mainland, nappe tectonics led to the formation of stripe karst, and regional metamorphosis effectively destroyed most primary stratigraphic and fabric structures which normally guide cave inception processes. Instead, we are left with coarsely crystalline marbles that are almost as impermeable as granites. Karstification and speleogenesis is therefore dictated by late tectonic fracturing in the brittle regime and by chemical contrasts at lithological contacts. Karstification occurred both during ice cover (subglacial speleogenesis) and in ice-free periods. During stadials, water supply was dictated by the thermal conditions within the ice-sheets. Due to the chemistry and immense water supply in the ice-contact environment, enlargement of pre-existing caves (speleogenesis sensu lato) was very efficient, whilst the formation of a proto-cave from a fracture (speleogenesis sensu stricto) is slower than in a non-glacial situation. The present-day conditions on Svalbard may serve as a model for how caves developed on the Norwegian mainland during the Quaternary. Most relict caves in the present landscape may be explained by both interglacial and subglacial evolution phases, but a small number of very large passasges may have survived since the Tertiary.

253

O-65

Maze caves in stripe karst: Examples from Nonshauggrotta, northern Norway

Rannveig Øvrevik & Stein-Erik Lauritzen

Department of Earth Science, University of Bergen, Allégt. 41, N-5007 Bergen, Norway

Abstract

Stripe karst is stratigraphically thin outcrops of karstifiable rocks that intersect the land surface at an angle. Cave systems in stripe karst develop along the interface between the karst rock and non-karstic rock. Caves in stripe karst show the same morphological diversity as caves elsewhere. The morphological nature is a function of how various passage elements are linked together, and how they (once) transported water. Development of maze caves is interesting in the sense that mazes represent zones of extreme porosity. Their development in stripe karst makes them two dimensional and easier to model. We would like to know more about their development: what influences the selection of guiding fractures, their hydrological function and if it is possible to predict passage geometry and trend from fractures and foliation on the surface. As an example results from a thorough investigation and survey of Nonshauggrotta in northern Norway is presented. Nonshauggrotta is a phreatic network maze. Cave passages are developed along two orthogonal joint sets: one sub-vertical and the other oblique. The cave is relict with no present drainage basin. Scallop morphometry demonstrate an integrated network flow.

Introduction

Marble is the main karstic rock in Norway and it appear as stratigraphically thin outcrops that intersect the land surface at an angle, thereby producing long and narrow 'stripes' called stripe karst. Impermeable and insoluble rocks (mostly schists) act as aquicludes that surround and isolate the individual karst stripes. Cave systems in stripe karst tend to develop at or close to the interface between karst rock and non-karstic rock, and consequently they appear elongated and mostly two-dimensional (Lauritzen 2001). Marble has negligible primary porosity which makes speleogenesis exclusively dependent on secondary porosity i.e. fracturing.

Dependent on the dip angle of the strata, aquifers can be divided into different groups (Lauritzen 2001). In vertical strata unconfined aquifers develop. In dipping strata perched aquifers form in contact with the underlying aquiclude interface, while confined aquifers may form in contact with the overlying aquiclude. In this paper, only examples of the latter type are described.

Palmer (1975) classifies maze caves in three categories: 1) Network mazes which are characterized by fissure-like passages with lenticular cross-sections and angular intersections. 2) Anastomotic mazes typically formed by curvilinear tubes of circular or elliptical cross-sections that intersect in a braided or random pattern. 3) Spongework mazes that consist of non-tubular solution cavities arranged in a random, three-dimensional pattern. The latter type does not appear in stripe karst and are consequently not further discussed in this paper.

Maze caves develop through uniform enlargement of all available fissures under conditions of high ratios between discharge and flow distance (Palmer 1991; Kaufmann and Braun 1999). Two main mechanisms for development are described: diffuse recharge through an overlying or underlying permeable, insoluble unit; or flood water. In stripe karst with aquicludes surrounding the marble, diffuse recharge seems unlikely. Flooding from rivers appears to be the main forming mechanism in most places, but this seems not to be the case in Norway.

With respect to the presence of glacier ice, Ford (1977) points out three ice-contact hydrological conditions that generally appear in karst groundwater systems: 1) Polar based ice where karst water circulation ceases. 2) Very thick ice cover with temperate base which significantly slows down the karst water circulation or makes the water immobile. 3) Temperate ice base where karst terrain has the same relief as the glacier, which superimpose glacier hydrology upon the karst hydrology and thereby increase the hydraulic gradients in the karst. The second condition seems to prevail under the large glaciations while the third condition prevailed during glacier advances and recessions (Ford 1977). During Pleistocene glaciations karst systems in Norway probably switched between these states. This made the system to grow under high flow rates, then to fill up with silt and clay deposits before high hydraulic gradients again flushed out the system. In temperate glaciers the hydraulic gradient is determined by the glacier surface, which make the underlying topography insignificant (Lauritzen 1982). Diurnal and seasonal water table variations in glaciers may pump chemically aggressive water into all available voids, thereby creating maze forming environment. Changing environments make the caves pass through several stages of development which might give a very complex morphogenetic history.

Development of maze caves is interesting in the sense that mazes represent zones of extreme porosity. Their development in stripe karst makes them two dimensional and easier to model and we would like to know more about their development, structural settings, and hydraulic function.

Material and methods

The cave was surveyed to BCRA grade 5C. Morphology, scallop directions and sediments were recorded. Scallop analysis was done by the standard procedure of Curl (1974). Orientation of guiding fractures, foliation and marble-schist interface was measured, and these structural data were analysed statistically. Rock samples from the marble unit were analysed by "loss-of-ignition" experiments and acid insoluble residue experiments.

Results

Description of field area

Nonshauggrotta cave (66°57'N 13°58'Ø) is located in Nordland County, on the coast of Norway, just north of the Arctic Circle and the Svartisen
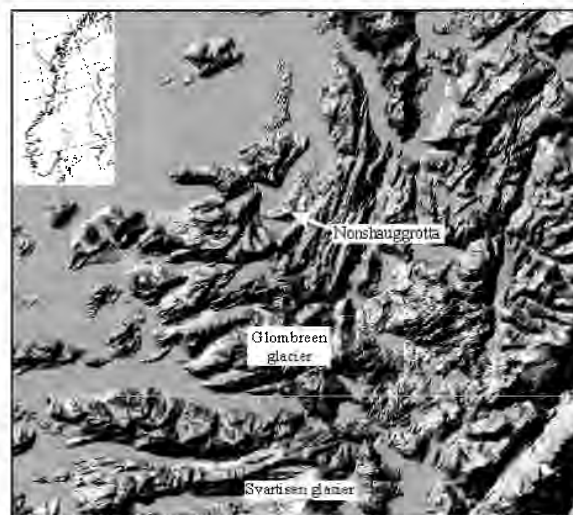
Figure 1. Location of Nonshauggrotta in Nordland County, at the coast just north of the Arctic Circle and Svartisen glacier.

glacier, fig. 1. Nonshauggrotta is situated 260 m a.s.l., in the top of a minor mountain ridge. The cave is formed under confined settings in the sloping interface between marble and overlying mica schist. The interface is dipping about 26° towards the South.

Nonshauggrotta has a total surveyed length of 1 500 m, and is 29 m deep. Morphologic parameters of the cave are summarized in table 1. Some of the parameters are ratio of the absolute cave parameter to the cave field parameter. The term cave field describes an area defined by a

boundary drawn close to the cave (Klimchouk 2000). The specific volume (average cross-sectional area) of the cave is 1.4 m², which is quite small. The coefficient of karstification can be calculated both in term of area and volume. The former parameter has a value of 10.6 % while the latter is only 1.5 %. This is reasonable since the two-dimensional network consists of a quite high density of passages with small cross-sectional area. Parameters from Ukrainian gypsum maze caves are much higher probably because of higher solution rates and higher age.

Table 1. Morphological parameters of Nonshauggrotta and some other maze caves. Grønligrotta is also located in northern Norway, just south of the Arctic Circle and Svartisen glacier.

Cave	Length m	Area m²	Volume m³	Specific volume m³/m	Density of passages km/ km²	Coefficient of karstification, %	
						in area	in volume
Nonshauggrotta	1530	1490	2160	1.4	110	10.6	1.5
Grønligrotta	4100	7500	9750	2.4	103	18.7	1.2
Gypsum maze caves, Western Ukraine *				3.8	198	37	5

* Data from Klimchouk (2000), mean values.

The cave passages form a fairly regular network, fig. 2. Cross-sections are overall phreatic tubes and rifts, only a few minor vadose canyons are developed. The cave is relict with no present drainage area. Passages are developed along two orthogonal joint sets; one sub-vertical directed north-south, the other oblique (~50°) with an east-west trending direction, dipping towards north. This is reflected in passage cross-sections which are mostly high and narrow because they are developed along a single or

a few sub-parallel guiding fractures. Fracture traces as measured on the surface seem more dispersed than the guiding fractures inside the cave, even though the most pronounced set (sub-vertical with orientation north-south) is the same. The two sets of guiding fractures are oriented along strike and dip of the rock interface, fig. 3. This is a typical network maze cave (Palmer 1975).
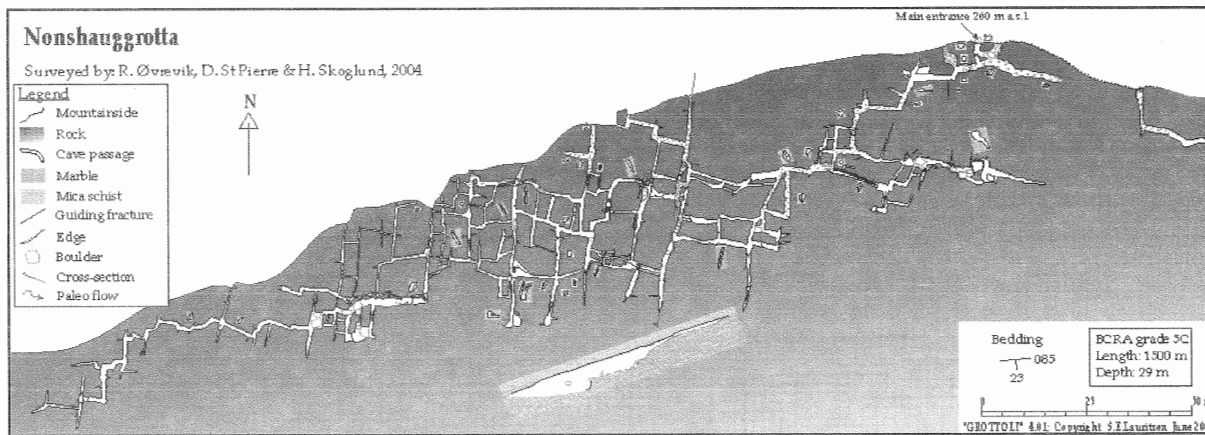
Figure 2. Map of Nonshauggrotta. The cave forms a fairly regular network. Cross-section drawings show that the cave is situated just below the marble-schist interface. The deepest part of the cave are the innermost passages to the South, these are choked by sand.
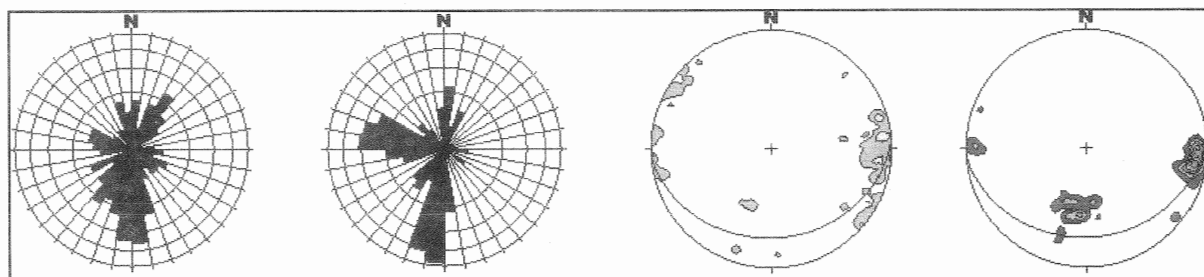
Figure 3. a) Rose diagram of fractures measured at the surface (n = 140). There is one dominant direction towards the south (186/78) the rest is more uniform and less pronounced. b) Rose diagram of guiding fractures measured in the cave passages (n = 121). There are two dominant directions in these data: S (190/79, n = 55) and W (282/49, n = 47). The two main sets of guiding fractures are orthogonal. Each circle counts for 5 % with the outer circle as 20 %. The scale is logarithmic to make true area. c) Contour diagram of poles from fractures measured at the surface and the mean marble-schist interface as a great circle (086/26). d) Contour diagram showing guiding fracture poles and the mean marble-schist interface as a great circle. The two sets of guiding fractures seem to be almost perpendicular to the marble-schist interface.

255
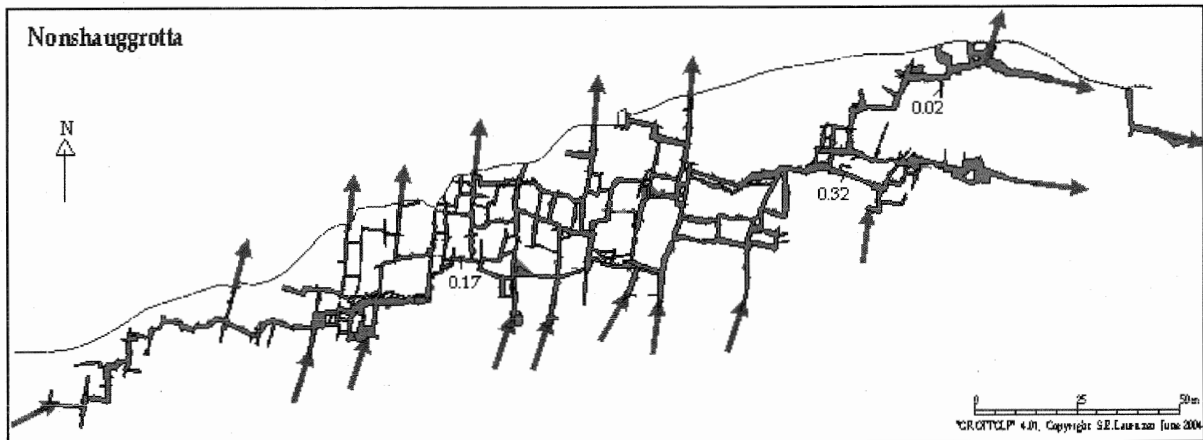
Figure 4. Paleo water flow through Nonshauggrotta as estimated from scallops-analysis. Numbers are paleo water discharge in m³/s.

The ceiling in most passages is mica schist. The marble-schist interface is dipping away from the mountain side, which makes the innermost passages the deepest part of the cave. These are choked by silt and sand, which are the most widespread sediments in the cave. In addition, there are some marble boulders, and, in the outer parts, pebbles and cobbles mostly of mica schist.

Scallop morphometry demonstrate integrated network flow. Flow direction is consistent: towards east in the east-west trending passages and towards north in north-south trending passages, fig. 4. This indicates a hydraulic gradient towards the northeast which makes the paleo flow uphill (towards the mountain side). This indicates that the cave was an effluent network in the last active stage. Unfortunately, scallops are not very good for scallop analysis and only three analyses were made. Sauter mean of scallop length, L_{32}, was 20 cm at two sites and 32 cm at the third site. Paleo flow velocities range from 7 to 18 cm/s, while estimated discharge was between 0.02 and 0.32 m³/s, fig. 4.

The "loss-of-ignition" experiments expel carbon dioxide from the carbonate. This causes a weight loss of 44 % in pure calcite, and 48% in pure dolomite. "Loss-of-ignition" and acid insoluble residue experiments demonstrate that there are quite small variations in the composition of the marble, fig. 5. "Loss-of-ignition" in the marble varies between 34 and 43 %, while acid insoluble residues range from 0 to 21 %. "Loss-of-ignition" is inversely proportional to acid insoluble residue (r = -0.99). The marble does not seem to be purer or more homogeneous in those parts where the cave is situated. Therefore, it seems likely that there are other factors than marble composition that are guiding the speleogenesis to the upper part of the marble.

Substantial precipitates of gypsum and rusty weathering of the mica schist reveal that pyrite may be present in the mica schist. Drip-pits indicate that drip water from the schist is quite acidic; this may also be caused by minor extent pyrite being present in the schist. This makes it conceivable, that pyrite oxidation may have played an important role in the early stages of speleogenesis.

During the last glacial maximum, glacier movement was towards west-northwest. Younger glacier movements where topographically guided. Fjord- and valley-glaciers were dispersed from local glacier culminations
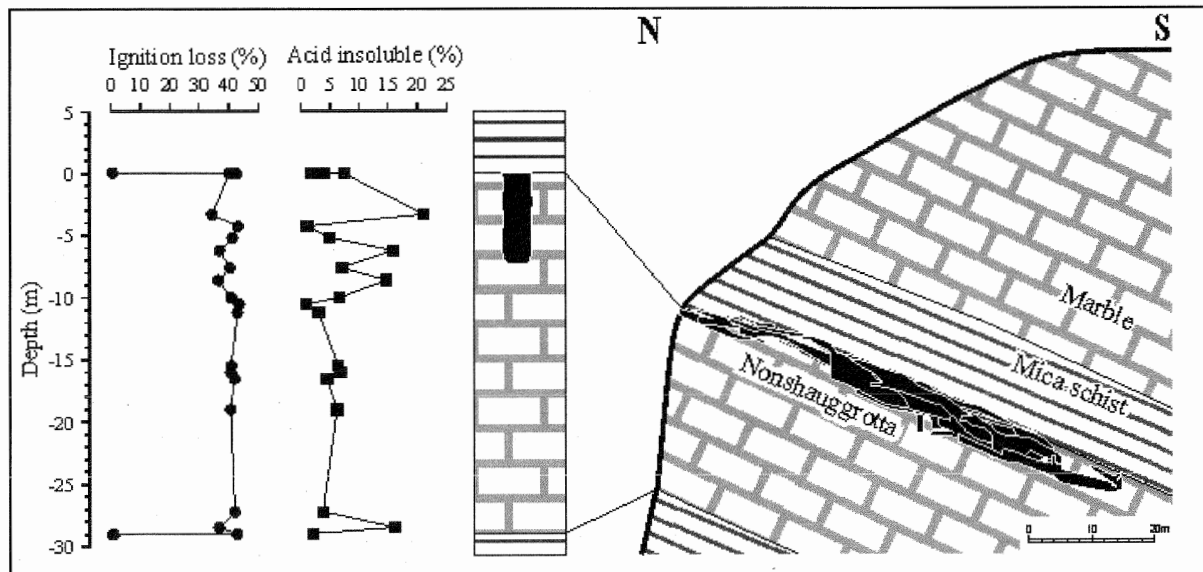
Figure 5. Left: Results from "loss-of- ignition" and acid insoluble residue experiments are shown as a function of depth below upper marble schist interface. Right: Vertical location of Nonshauggrotta. The variation in composition of the marble is small and seems to be largest in the upper part. The upper part of the marble was difficult to sample and surface weathering may be part of the reason for variation between different samples.
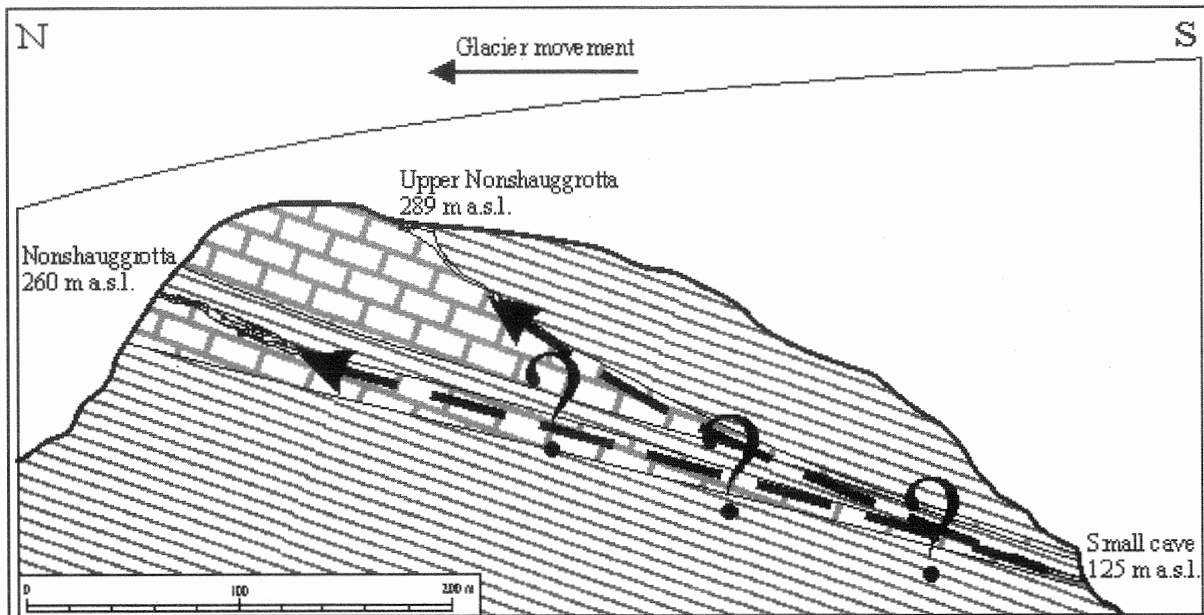
Figure 6. Glacier movement and karst water flow in relation to the cross-section of Nonshaugen ridge as imagined during the last deglaciation. In addition to Nonhauggrotta, two minor caves were surveyed: Upper Nonshauggrotta, length 230 m (BCRA grade 5C); and a small cave on the southern side of the hill, length about 27 m (BCRA grade 1A). Upper Nonshauggrotta seems to have been a phreatic riser. The small cave is almost filled up with sandy sediments and breakdown and only one passage was discovered. Same scale vertically and horizontally.

at Glombreen and Svartisen glaciers, fig. 1 (Rasmussen 1981). The englacial hydraulic gradient tends to be parallel to glacier surface gradient and thus glacier movement. Because the glacier culminations were located south of Nonshaugen and high mountains (800 -1000 m a.s.l.) are located in west and northwest, it seems likely that the local glacier movement at this stage was towards northeast in the area around Nonshauggrotta. This is consistent with observations of glacial striation on the top of the ridge. This may have produced a water flow, up through the marble in Nonshaugen ridge, fig. 6. In conclusion, paleo water flow through the maze cave seems to be connected to moderate glacier distribution (with topographically guided movement) which is equivalent to Ford's (1977) third condition. The network morphology may, thus, in part be a result of ice contact.

Discussion

Another maze cave in stripe karst that has been subject to thorough investigation during the last years is Grønligrotta in Rana, just south of the Arctic Circle and the Svartisen glacier (Skutlaberg 2003). Grønligrotta is 4 100 m long and 110 m deep, and situated in the valley side about 200 m above the valley bottom. It is an anastomotic maze cave with curvilinear passages and many closed loops. Grønligrotta is, as well as Nonshauggrotta, developed in gently dipping marble under confined settings just below the upper marble-schist interface. The paleo water flow was also upwards towards the mountain side, parallel with the surface gradient of a valley glacier (Skutlaberg 2003). The pattern of guiding fractures is complex in Grønligrotta. There seems to be several sub-domains with distinct guiding fractures. Skutlaberg (2003) suggest that this may be due to development under different stages.

In conclusion, we wish to emphasize some similarities between low dipping maze caves in stripe karst. First of all, they seem to have developed as part of confined aquifers. Secondly, they seem to be, at least in part, a result of ice contact. The maze morphology seem to be connected to moderate glacier distribution with topographically guided glacier movement, which correspond to the third hydrological condition

described by Ford (1977). This means that the caves probably were active during glacier advances and recessions. It also seems that these mazes had an effluent function. Thirdly, jointing is an important issue, but this has been difficult to put into system and needs further examination.

References

Curl, R.L., 1974. Deducing Flow Velocity in Cave Conduits from Scallops. The NSS Bulletin, 36(2): 1-5.

Ford, D.C., 1977. Karst and glaciation in Canada, 7th Int. Speleol. Congr., Sheffield, pp. 188-189.

Kaufmann, G. and Braun, J., 1999. Karst aquifer evolution in fractured rocks. Water Resources Research, 35(11): 3223-3238.

Klimchouk, A., 2000. Speleogenesis of the great gypsum mazes in the western Ukraine. In: A. Klimchouk, D.C. Ford and A.N. Palmer (Eds.): Speleogenesis: Evolution of Karst Aquifers. National Speleological Society, Huntsville, Alabama, pp. 261-273.

Lauritzen, S.E., 1982. The paleocurrents and morphology of Pikhåggrottene, Svartisen, North Norway. Norsk Geografisk Tidsskrift, 36: 183-209.

Lauritzen, S.E., 2001. Marble stripe karst of the Scandinavian Caledonides: An end-member in the contact karst spectrum. Acta carsologica, 30(2): 47-79.

Palmer, A.N., 1975. The origin of maze caves. The NSS Bulletin, 37(3): 56-76.

Palmer, A.N., 1991. Origin and morphology of limestone caves. Geological Society of American Bulletin, 103: 1-21.

Rasmussen, A., 1981. The deglaciation of the coastal area NW of Svartisen, Northern Norway. Norges Geologiske Undersokelse, 369: 1-31.

Skutlaberg, S., 2003. Paleohydrogeologi, bruddgeometri og litostratigrafi i Grønli-Setergrottesystemet, Mo i Rana, University of Bergen, Bergen, 188 pp.

257

O-66
Watershed Delineation in Karst Areas of the Tongass National Forest, Southeastern Alaska

J. Kovarik, J. Baichtal, C. Ranger
Western Kentucky University, Bowling Green, KY, USA

Abstract

The geology and climate of Southeast Alaska are particularly favorable for karst development. Extensive areas of very pure carbonate, approximately 2950 square kilometers (km²) (555,770 acres, 869 mi²), are found within the boundaries of the Tongass National Forest. Karst systems have developed to one extent or another within all carbonate outcrops. Karst development includes loosing streams, sinkholes, caves, epikarst grikes, and resurgence streams. Many of the resurgence streams maintain productive salmon populations. Identifying the source areas of the resurgence streams is crucial to protecting water quality. Historically, watershed assessments have only considered the topographic boundaries to define various watersheds. This method is difficult in karst areas where surface waters are rare. Four different projects on the Thorne Bay Ranger District have utilized tracer dye studies to illustrate the complexity of these systems and help redefine watershed boundaries. Through dye trace tests we are able to identify subsurface flow pathways, minimum groundwater flow velocities, identify downstream effects, and better assess cumulative effects on a watershed scale. Success of groundwater tracing efforts hinges on locating the springs that feed coastal streams. This requires careful inventory of shorelines and margins of the carbonate outcrops. Activated charcoal packets are anchored within these streams and springs to absorb dye. Tracer dye injection points are generally discrete karst features where surface waters enter the systems. The packets are recovered at intervals to allow time for the dye to move through the systems. Tracking the location of dye injection and recovery identifies specific subsurface water flow pathways and gives us minimum flow velocities.

O-67
A Quantitative Analysis of Relationships Between Land-Use and Base-Level Conduit Sedimentation in South-Central Kentucky, USA

B. Tobin, S. Kenworthy
Western Kentucky University, Bowling Green, KY, USA

Abstract

In karst basins, significant amounts of surface-derived sediment can enter into cave systems. The transport and deposition of these sediments in underground streams is a function of flow velocity, sediment supply and passage morphology. Changes in the surface environment, can affect the water and sediment supplies to subsurface drainage systems and thus may be reflected in the sedimentary structure, texture and rates of deposition of sediment banks. Cave sediment deposits in south central Kentucky were studied to evaluate a possible relationship between variations in sediment characteristics and changes in land-use. Samples were collected using coring tubes to preserve the structure within the sediment. The structure was documented visually, recording distinct changes in the layering. The textural variations were determined through sieving samples at 5 cm intervals. Passage morphology was documented through detailed mapping of the passage in the vicinity of the sediment banks. Rates of deposition were determined through isotopic analysis of the sediments and these dates were then compared to major changes in land-use in the drainage basin. These findings were then used to correlate major changes in land-use with changes in sediments characteristics. This shows the sediment transport parameters may vary relative to changes in surface disturbances.

O-68
New type of englacial channels

B.R. Mavlyudov
Institute of geography RAS, Institute of geography RAS

Abstract

In September, 2003 in tongue of Aldegonda Glacier, Spitsbergen, the new type of englacial channels was found. It represented a flat slot in ice of width till 10-15 m and height up to 0,5-0,6 m. The floor of a channel was coated with a rounded pebbles (alluvial deposits). In the sides the channel was further prolonged but was squeezed by ice plastic deformation and represented a layer of pebbles fixed in ice. The erosion basis lowering at the glacier tongue lead to channel cutting into ice and to receive usual form of the tunnel which one passed into slot with growing distance from glacier tongue. But even in a tunnel channel the tracks of a primary slot-hole channel were visible. In the autumn of 2003 the channel was surveyed approximately on distance about 250 m from entrance. In autumn of 2004 cave channel in ice was surveyed more then 500 m from its entrance but after first 350 m channel remove away from ice and became subglacial. Segment of bedrocks that was finding in channel can be evidence of subglacial channel conditions. In this part of a cave the ceiling of gallery was also completely flat. The experimental researches of changes of channels evolution in artificial ice monolith in cold laboratory in 2002 have shown a similar path of development of flat channels growing on the flat horizontal joint. It is supposed that such channels could be formed at exuberant hydrostatic pressure in a temperate glacier core that one could arise in ice in the beginning of ablation season because of all lower peripherals part of glacier was frizzed to glacier bottom and dammed water inside ice. The similar channels were found as well on other glaciers: western Grønfjord, Fritjof, Tavle, Åavatsmark. Probably these channels are enough widely widespread. It is possible to suspect that the majority of existing channels that drain water from under polythermal glaciers were origin by such way. However majority of channels were subsequently significant modified and it is not so simply to find out here a primary channel. The scheme of evolution of internal drainage system in polythermal glaciers is considered.

O-69

Modification of cave entrances in Norway by marine action

Trevor Faulkner

Limestone Research Group, University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK • tfaulkne@globalnet.co.uk

Abstract

Several karst caves in north central Norway lie below the (Weichselian) deglaciation marine limit, which is the highest level reached by the sea during the Younger Dryas and Holocene melting and the associated isostatic uplift. Except for mainly vadose caves of Holocene age, such caves commonly exhibit wide, relatively low, sub-horizontal, tapering, rocky entrances that are larger than internal passages. Such morphology appears diagnostic of erosion by waves and sea ice at a time of falling sea level and confirms the prior existence of the cave passage. However, several Norwegian non-carbonate sea caves and a few karst caves have entrances that are taller and much larger, but lie well above the deglaciation marine limit. It is suggested that these cave entrances were primarily enlarged when the sea approached a glaciation marine limit, perhaps at the start of the Weichselian and / or an earlier glaciation. The different morphology can be explained by enlargement at a time of rising sea level, when the coastline experienced isostatic depression before being covered by ice. In the case of karst caves, these large entrances may indicate that continuing smaller internal passages were in existence before the end of the Eemian interglacial.

Introduction

Large sea caves along the coast of Norway are well known (e.g. St.Pierre and St.Pierre, 1980; St.Pierre, 1988). Most of these caves are in non-carbonate rocks and many appear to be of pre-Holocene age, because they are commonly situated well above the highest post-glacial local shoreline (Sjöberg, 1988) and / or because they contain deposits dated to various stages in the Weichselian glaciation, as in some sea caves in southern Norway (Larsen et al., 1987; Larsen and Mangerud, 1989; Valen et al., 1995; Valen et al., 1996). As part of a wider study of speleogenesis in glaciated Caledonide metacarbonate rocks (Faulkner, 2005), the author compared karst caves near the coast of north central Norway with variations in local sea level and the extent of ice cover during the onset and decay of the Weichselian and earlier glaciations. This paper deduces some relationships between sea level and the formation and modification of caves in both metacarbonate and non-carbonate rocks.

Sea level curves and marine limits

The Late Weichselian deglaciation of Norway was illustrated in an ice margin recession map by Andersen and Karlsen (1986). With the removal of the ice burden, Fennoscandia rebounded isostatically at a very fast rate initially, with the elevation increasing inland. The tilting shorelines were raised progressively, with the oldest and highest raised shorelines showing the greatest tilt, as Møller (1989) showed in a 3D model of Holocene relative sea level changes for northern Norway and as presented in land uplift maps for Norway by Sørensen et al. (1987). Their isolines smooth out scanty observations and uncertain datings, generating local isobases that are remarkably linear and parallel. The uplift always outpaced rising sea level at all parts of the indented north central Norway coast.

The elevation that the sea reached along the coastal fjords and valleys is called the deglaciation marine limit in this paper. It depended on the recession of the ice margin and on the isobase of the location and it varied from c. 125m at 12000¹⁴Ca BP at coastal islands at the 100m Younger Dryas (YD) isobase to 133m at 9080 at the 200m YD isobase in Vefsndal, the farthest east that the sea penetrated in the Holocene. The YD isobase sea level curves in Figure 1 are based on similar ones for Trondheim by Svendsen and Mangerud (1987, Fig. 12) and show (e.g.) that all points on and underneath the surface at the 150m YD isobase below a present 150m

altitude were inundated by the sea at the start of the Holocene at 10000¹⁴Ca BP, providing that the ice had melted by then at that location.

At the onset of each glaciation, valley glaciers and mountain icesheets progressively extended towards the sea. The icesheet grew to a considerable thickness, and at the end of the Eemian interglacial "depression extended ahead of the ice margin" (Lundqvist, 1986, p288). Hence, the sea encroached significantly inland before its surface froze permanently and there must be another limit, not previously explicitly recognised in the literature, that equals the elevation that the sea reached up each valley before freezing (or before falling eustatically relative to the land) during a transgressive glaciation phase, which is called the glaciation marine limit in this paper

Information from the last glaciation phase and from the glaciation and deglaciation of previous stadials and glacials is much more difficult to obtain, because stratigraphical and dating evidence is commonly altered or destroyed by the glaciation process. Hence, the geometry of the glaciation marine limit is presently unknown. However, from the evidence of Mid Weichselian marine-influenced deposits at high elevations, e.g. sediments dated from 35-24ka at 260m near Hattfjelldal in north central Norway (Olsen et al., 2001), it is clear that this interstadial marine limit was 120m above the equivalent local (210m YD isobase) deglaciation marine limit (although the sea did not quite reach this point during deglaciation). This isobase may mark the eastward limit of any Weichselian marine impact in this area because there are no eastern caves and few carbonate outcrops below 260m in altitude. It is also probable from the survival of Mid Weichselian fine grained sediments and Early Weichselian speleothems dated to 80±9ka in the elevated sea cave Skjonghelleren in southern Norway (Larsen and Mangerud, 1989) that that cave was not inundated again by the sea after these depositions, and that it formed at a high sea level even earlier in the Weichselian or before. This suggests that the maximum Weichselian marine limit occurred relatively soon after the start of the Weichselian glaciation. With no evidence to the contrary, it is concluded that this also applied in north central Norway, so that the extra 120m above the deglacial marine limit reported near Hattfjelldal is a conservative value to use for the local glaciation marine limit. Mangerud (1991) and Fredin (2002) also reported that several coastal caves in southern Norway, which are well above the deglaciation marine limit, were submerged after the Eemian, because of rapid isostatic depression caused by the YD-sized Herning glaciation in the Early Weichselian.

The order in which some relevant karst caves in north central Norway were submerged by the sea during the Weichselian deglaciation is presented in Table 1, with estimates of their emergence timescales. This uses data from the sea level curves in Figure 1 and the timings of the west to east recession of the ice margin.

Formation of sea caves and littoral caves in limestoneA few karst caves lie along the coastal strandflat, commonly at altitudes below c. 25m. Many of these short 'coastal' caves show little karstic dissolution, but appear to be littoral caves formed by previous wave action with no continuing passage. They include three of the four relict Brønnøysund Football Pitch Caves, Vistnesoddgrotta and possibly Tarmaunbotngrottene. Their low elevations mean that they were under >100m of sea water at the start of the Holocene; hence, they were not much affected by wedging by YD sea ice. Instead, they were exposed near sea level for ≥1000a during a late phase of the Holocene isostatic rebound. The above-mentioned caves face NE or NW, suggesting that their formation was facilitated by the presence of late Holocene winter sea ice. Two 'coastal' caves appear to be karst caves modified by marine action: Brønnøysund Football Pitch Cave B shows clear signs of the surface erosion of a phreatic tubular passage and Langfjordgrotta is a resurgence cave partly explored by diving that has a relatively large entrance. These

caves were presumably already developed phreatically as part of subglacial waterways during the Weichselian deglaciation (Faulkner, 2005). The previous presence of the sea at both coastal and marine-influenced karst caves is sporadically demonstrated by the occurrence of holes bored by marine molluscs in the walls and ceilings of entrance areas. More rarely, marine deposits are also found in the caves (e.g. Hoel, 1906).

Enlargement of cave entrances that are below the deglaciation marine limit

Karst caves that lie below the deglaciation marine limit and above the strandflat were also inundated by the sea at the end of the Younger Dryas, before being raised isostatically to their present altitudes of 30-167m. Many exhibit wide, relatively low, sub-horizontal, tapering, rocky entrances that seem disproportionately large when compared with the dimensions of internal passages. This group of caves includes: Green Gorge Cave, Marble Arch, Klausmarkgrotta, Klausmark Resurgence Cave (all at Klausmark), Hubruhola, Aunholet, Skånvikgrotta, Tourist Cave, Svartdalgrotta (lower entrance), Evening Cave (H5), Hate Cave (H8), Laveste Langskjellighattengrotta, Jenshola, Risehula 1 and 2, several caves at the Arch Cave complex, Mølnvatngrotta (Forest Entrance), Aunhattenhule 1-3, Nedre Landegrotta, Kalkdalgrotta, Gårdsfjellgrotta, Møllebekkgrotta 1 and 2, plus Remnant Cave and, possibly, Fjellbrygga. Beyond the entrance areas, most of these caves contain obviously dissolutional karstic passages. Many function, or have functioned, as resurgences.

Only caves that contain relict phreatic passages appear to have entrances enlarged by marine action, although some similar caves that are below the deglaciation marine limit do not have significantly enlarged entrances, including Neptune's Cave, Barnacle Cave and Draugenshullet. The reason may be that the entrances are shafts or they were in protected locations or they did not form until after elevation above the sea. Attached barnacles in these three caves (Faulkner, 2005) prove that at least their internal passages existed prior to emergence. The direct evidence of entrance enlargement from individual caves agrees with the greater mean cross-sections of caves with relict phreatic passages if they lie below the deglaciation marine limit (Faulkner, 2005) and shows that such caves were already in existence before marine inundation at the start of the Holocene, as do non-laminated deposits of coarse dry sand reported only in the relict phreatic passages of Søvikgrotta, Nordlysgrotta, Marimyntgrotta, Neptune's Cave and Aunhattenhullet 2 (which suggest marine ingress into cave entrances that mainly face east, when they coincided with beach levels).

Marine cave entrances at altitudes above 80m experienced a very rapid elevation through sea level in the Preboreal, so that they typically rose 10m in only c. 100a (Figure 1). Lower entrances rose above sea level later, and rose more slowly during emergence. In contrast to the lower littoral caves discussed above, the only definite littoral cave recorded in limestone above the strandflat is the single chamber Bordvikgrotta, at an altitude of 40m. Several features at the Arch Cave complex, at the relatively low altitude of 60m, may also be littoral caves. It thus appears that, at altitudes higher than 40-60m, the uplift was so fast that there was insufficient time for the sea and ice to form new, presently inland, littoral caves in limestone before they were elevated above wave height.

The extent of the enlargement of pre-existing entrances has a weak relationship with altitude and the duration of submersion. Thus, five entrances to caves with phreatic passages not obviously enlarged were submerged for a maximum of c. 150 years (although others are exceptions) and enlarged entrances were commonly submerged for many hundreds or thousands of years. Thus, it seems that pre-existing cave entrances were more likely to be enlarged by wave action supplemented by wedging by winter sea ice if they passed slowly through the tidal range after long submersion, with an overall preferred orientation of northwest. The enlargement was probably contemporary with the production of elevated marine terraces (e.g. Andersen et al., 1982, p44). Large sea caves also formed in non-carbonate rocks above

the strandflat (e.g. Sjöberg, 1988). Marmorhølet on the island of Dønna, in predominantly non-carbonate rocks (despite its internal calcite deposits), is probably a short sea cave created early during deglaciation.

No cave that is clearly mainly vadose appears to have an enlarged entrance (Table 1). Thus, it is likely that such caves that lie below the deglaciation marine limit (and, by extension, those above it) did not exist in their present form at the time of their elevation above sea level. This observation is partly supported by the absence of reports of sand deposits in such caves. It is concluded that the 'mainly vadose' caves primarily developed within the Holocene.

Enlargement of cave entrances that are above the deglaciation marine limit

Table 1 lists five caves that are anomalous in a deglaciation context. From their locations, YD isobases and the time of passing of the ice margin, it appears that the entrances to Bollhauggrotta, Øyåskjeleren (Photo 1), Øyfjellgrotta, Lilleelvgrotta and Geitklauvgrotta were already too high to be reached by the sea when they were deglaciated. The first four caves have entrances that appear enlarged by marine action, to the same criteria. The entrance to Geitklauvgrotta (which is upstream to Lilleelvgrotta) is not at all enlarged internally, being a phreatic passage some 1m high by 2m wide. However, there appears to be an unroofed section of cave between this entrance and the end of the upstream Øvre Geitklauvgrotta. The thin roof may have been removed by glacial movement or by the action of the sea and sea ice, or by a combination. If marine action has modified these caves, and it is difficult to envisage any other agency to account for the enlarged entrances to Øyåskjeleren and Øyfjellgrotta, then it seems very likely that this occurred when the marine limit was higher than the last deglaciation marine limit. This leads to the possibility that these entrances were enlarged during the onset of one or more glaciation phases or during a Mid Weichselian interstadial, and were well-enough protected during subsequent glaciation for the enlarged parts to have survived. The five cave entrance floors are at altitudes from 100-150m at YD isobases from 140-170m and are well below the possible maximum Weichselian marine limit discussed earlier. In contrast to many enlarged entrances below the deglaciation marine limit, all five above that limit are on eastern slopes (although the Bollhauggrotta and Øyåskjeleren entrances face west), but this may not be significant with a small sample. There are no other apparently marine-enlarged cave entrance floors above an altitude of 167m, so that the absence of similarly-styled entrances above the maximum Weichselian marine limit provides supporting evidence for entrance enlargement of phreatic passages below marine limits by sea ice and wave action.

Cave entrances modified during the onset of glaciation were enlarged at a time of rising sea level, in contrast to those enlarged during the falling sea level of a deglaciation phase. When a sea level that is falling encounters a cave entrance, that part of the entrance that remains submerged is protected. Hence, the vertical scale of enlargement is related to the tidal range and wave height: ~5-10m (Figure 2a). In fact, the entrances enlarged during deglaciation listed in Table 1 are rarely >5m high (although they may extend to a width of 10-20m). However, when a rising sea level encounters a cave entrance, a vulnerable roof may remain under attack from the time that the wave height reaches it, until the time when the sea either freezes at its maximum level, or starts to fall relative to the land at a glaciation marine limit (Figure 2b). Photo 1 Upper cliff entrance to Øyåskjeleren

Although the roof collapse rate may be overtaken by the rising sea level and the local isostatic depression there is clearly potential for cave entrances to be enlarged vertically by marine action much more during a glaciation phase than during a deglaciation phase.

The only karst cave in north central Norway that has an entrance taller than that of the exceptionally tall inland Grønndalsgrotta (16m) is Øyfjellgrotta, whose lower (main) entrance is up to 30m high and c. 15m wide (Heap, 1968) and is well above the deglaciation marine limit. This evidence

260

as possibilities. Above the marine limits, only three caves appear to have large sand deposits, which were presumably deposited by glacio-fluvial processes.

The deglaciation marine limit at Øyfjellgrotta was c. 125m, reached at its 150m YD isobase soon after the sea encroached south of Mosjøen at 9300 [14]Ca BP (Andersen et al., 1981). This is some 45m below the 170m level of its main entrance roof, confirming that the enlargement above its floor at 140m must have occurred prior to the final deglaciation. This extra minimum 45m of maximum marine limit is well within the extra 120m discussed earlier so that it seems likely that the interstadial or Early Weichselian sea rise overtook the upward stoping of the Øyfjellgrotta entrance, so that the whole cave became submerged.

The upward stoping mechanism also explains the existence of the very large sea caves in non-carbonate rocks along the north central Norway coast that are positioned above local deglaciation marine limits (Sjöberg, 1988, Table 2). For example, Torghatt-hullet and Monshola (at YD isobases of 115 and 120m) are shown as having entrance floors at 138 and 147m, and roof altitudes as high as 160m. At c. 11500 and 10700[14]Ca BP, when the YD ice margin passed them, the sea level was at an elevation of c. 135m for both these caves (Figure 1). Because this level is below the entrance level of each cave, and 25m below roof levels, it seems very unlikely that wave action could have formed them during the final Weichselian deglaciation. On the other hand, if they were formed or enlarged during the onset of the Weichselian glaciation, or during the various interstadials, their maximum

Photo 1 Upper cliff entrance to Øyåskjeleren. At an altitude of 100m, this entrance was probably enlarged by the wave and ice action of a rising sea level.

supports the upward stoping of cave entrances by marine and winter ice activity as a mechanism for entrance enlargement during a glaciation phase. The marine invasion of Øyfjellgrotta is also supported by a statement by Smart (1984, p173): "exotic boulders of (up to 6m) size have been carried in and effectively blocked the system", and by his mention of sand-sized sediments. Sand deposits in Sirijordgrotta (Valen et al., 1997; entrances not enlarged and not listed in Table 1) and Øyfjellgrotta, both on eastern slopes below the glaciation marine limit, may have been brought in by the sea at the onset of glaciation, although fluvial or glacio-fluvial deposition remain

Figure 1 Sea level curves (after Svendsen and Mangerud, 1987)
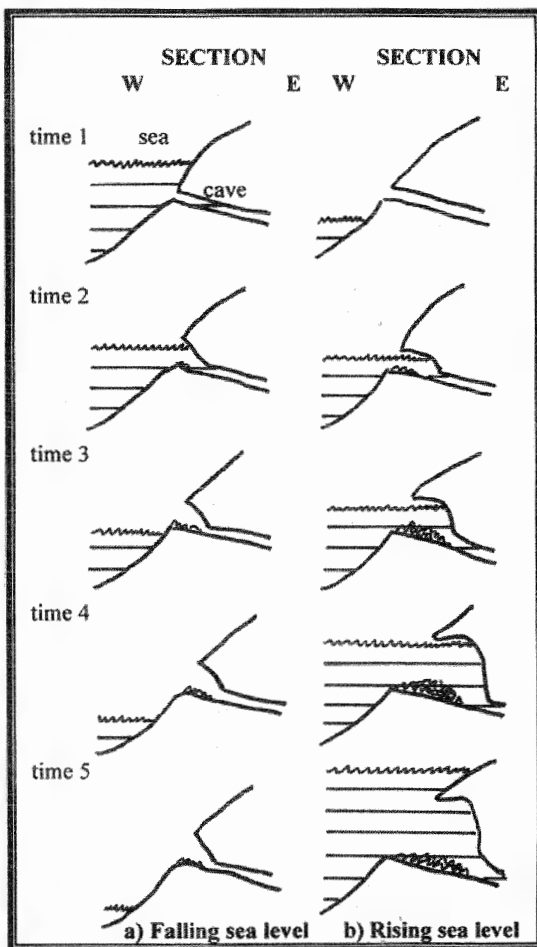
Figure 2 Entrance enlargement by the sea

roof heights of 160m could define the minimum glaciation or interstadial marine limit applicable to their isobase. Subsequently, these, and other sea caves above the deglaciation marine limit, may have changed little in size, being protected by their west-facing aspect beneath a west-moving icesheet. Torghatt-hullet could also have been partly enlarged by deglacial meltwater flows at the end of the Weichselian, because it is a through-cave.

By comparing the height of the local deglaciation marine limit with the cave roof altitudes given by Sjöberg (1988, Table 2), his list of 33 caves can be divided into three classes: those formed only during deglaciation, those formed during glaciation and / or interstadials, and those similarly formed but subsequently enlarged during deglaciation. For the second two classes, the difference between the roof height and the deglaciation marine limit ranges up to 70m, suggesting that an earlier marine limit was ≥70m higher than the deglaciation marine limit for these coastal caves, which is within the extra 120m discussed earlier. It seems likely that this explanation for the formation of sea caves in north central Norway also applies in northern Norway (e.g. Møller, 1985) and in southern Norway (Introduction).

Table 1 Marine inundation of metacarbonate caves during the Weichselian deglaciation

Time of inun. ^{14}Ca BP	Local YD iso-base m	Cave(s)	Alt. m	Time of final emer-gence ^{14}CaBP	Appr. time sub-merged ^{14}Ca	Entrance faces	Notes 1. MV: mainly vadose cave 2. Enlarged entrances are suggestive of wave action 3. Sea / littoral caves are commonly non-dissolutional
12000	90	Marmorhølet	113	11500	500	N	Sea cave, formed in non-carbonate
10700	100	Søvikgrotta	64	9000	1700	SW	Slightly enlarged relict entrance. Sand.
10700	110	Football pitch caves	25	4800	5900	NE	1 of 4 is a dissolutional hybrid
10700	110	Vistnesoddgrotta	10	2000	8700	NE	Short littoral cave
10700	130	Klausmark caves	120-160	10000	0-700	S,E,E,S	4 enlarged entrances, one at 160m
10300	120	Hubruhola	119	10000	300	N	Enlarged entrance
10300	120	Langkilagrotta	40	6800	3500		
10300	135	Aunholet	60	8300	2000	N	Enlarged entrance
10300	140	Holåsen caves HO1-5	110-135	10000	300	(shafts)	Not enlarged: all MV
10300	140	Bordvikgrotta	40	6500	3800	NW	Single chamber littoral cave
10300	140	Nordlysgrotta	155	10200	100	NE	Sand banks below entrance pitch
10300	140	Marimyntgrotta	155	10200	100	SW	Relict entrance. Sand
10300	140	Skånvikgrotta	77	9000	1300	S	Enlarged entrance
10210	145	Tourist Cave	150	10010	200	N	Enlarged sink entrance
10210	145	Svartdalgrotta	180-127	9700	510	NE	Enlarged lower entrance only
10210	145	Neptune's Cave	126	9260	950	E+shafts	Not enlarged. Barnacles. Sand
10210	145	Barnacle Cave	142	9900	310	N	Not enlarged. Barnacles
10210	145	Draugenshullet	137	9600	610	N	Not enlarged. Barnacles
10210	145	Hestfjell H1-4, H6	90-115	9500	710	NW	Not enlarged: all MV
10210	145	Hestfjell caves H5,H8	110, 135	9700	510	NW	Enlarged sink entrances.
10100	155	Tarmaunbotngr. 1-3	5-20	1000	9100	NW	Tectonic and littoral caves
10100	155	L. Langskjellighattengr	167	10000	100	W	Entrances possibly enlarged
10100	155	Langfjordgrotta	10	1500	8600	NW	Coastal karst sumped resurgence cave
10100	160	Jenshola	145	9800	300	NW	Entrance possibly enlarged. Not MV?
10050	140	Trondjordhula	5	1000	9050	S	Coastal resurgence cave. MV
10050	140	Risehula 1 and 2	50, 53	7800	2250	S	Enlarged relict entrances.
10050	155	Arch Caves R6-R16	60-70	7500	2550	vary	Enlarged ents., except 3 MV caves
10050	155	Mølnvatngrotta	140	9800	250	SW	Enlarged relict Forest Entrance
10050	155	5 caves at Saus	21-63	4000	6050		3 are MV. Not enlarged
10050	160	Aunhattenhule 1-4	105-135	9500	550	NW	Enlarged relict ents. to A1-A3. Sand
9900	140	Sildgarngrotta	120	9800	100		
9900	140	Splintågrotta	135	9900	0	E	Not enlarged resurgence entrance
9900	140	Kumragrotta	62	8500	1400		Truncation of entrances
9900	170	Svartdalsholet	160	9850	50	NW+SE	Sea just reached this cave. Not enlarged?
9900	170	Ø. & N. Landegrotta	80, 95	8600	1300	S	Enlarged entrance to lower cave
9800	140	Bollhauggrotta	150	10100	-300	W	Enlarged sink entrance
9800	140	Hestdalgrotta	100	9500	300		
9800	140	Through Cave	100	9500	300		
9800	170	Kalkdalgrotta	50	7000	2800	NE	Slightly enlarged relict entrance
9600	140	Gjeitvikgrotta	70	8900	700	W	Not enlarged

9600	140	Berntvikgrotta	40	7200	2400		
9550	140	Høgligrotta	100	9400	150	S	Not enlarged
9500	150	Gårdsfjellgrotta	56	7800	1700	E	Enlarged relict entrance
9300	150	Øyåskjeleren et al.	100	9500	-200	NW	Enlarged main relict entrance
9300	150	Øyfjellgrotta	180-140	9900	-600	SE	Enlarged lower relict ent. Sand
9300	170	N. Laksfors Rising	55	7200	2100	E	Not enlarged sump entrance (=MV)
9300	170	Møllebekkgrotta 1-3	90-79	8600	700	NW,W	Enlarged entrances at M1 and M2
9300	170	Geitklauvgrotta	148	9800	-500	S	Unroofed cave outside
9300	170	Lilleelvgrotta	150	9800	-500	N	Enlarged entrance
9300	170	Remnant Cave	93	9000	300	E	Cave wall removed
9300	170	Fjellbrygga	110	9300	0	NW	Sea just reached huge 20m long arch

Shading indicates that the cave is above the deglaciation marine limit

Conclusions

This paper shows that at relatively low attitudes below the deglacial marine limit, when there was late and slow emergence above a falling sea level during deglaciation:

- 'new' littoral caves could form in limestone and in other rocks, giving a late Holocene genesis
- existing karst phreatic entrances could enlarge, with heights ≤5m, suggesting origins prior to the Holocene
- the absence of enlarged entrances to 'mainly vadose' caves suggests that few existed prior to the Holocene.

At higher altitudes between the deglacial and glacial marine limit, when there was late and slow submergence below a rising sea level during glaciation:

- very large sea caves could form in non-carbonate rocks (and probably in limestone, but none are known)
- existing karst phreatic entrances could enlarge greatly, with heights ≤30m, suggesting origins prior to the end of the Eemian interglacial.

These conclusions probably also apply to northern Norway. The map by Sørensen et al. (1987) shows that the YD isostatic uplifts at various karst areas vary from 110-180m. Thus, caves below these altitudes potentially have entrances enlarged by marine action during deglaciation. The two huge tapering (commonly dry) entrances of Okshola and Kristihola at c. 160m altitude have almost certainly been enlarged by marine activity. Their entrances were probably above the reach of storm levels when the sea invaded after the start of the Holocene, because the local YD isobase is at c. 145m. However, both are good candidates for enlargement upwards by a rising sea level at the end of the Eemian, as is the c. 10m high Resakjelen entrance to Setergrotta in Røvassdal, at an altitude of 100m and a YD isobase of 150m, which probably enlarged further during deglaciation.

This paper has used published data about marine limits and YD isobases to review influences on speleogenesis and entrance modification. It may also be possible to invert this process and estimate maximum and deglaciation marine limits and relevant isobases more accurately, by a more complete study of both sea cave entrance environments and modified karst cave entrances.

References

Andersen, BG and Karlsen, M. 1986. Glacial chronology - recession of the ice margin. 1:5000000. Nasjonalatlas for Norge. Kartblad 2.3.4. Statens kartverk.

Andersen, BG, Bøen, F, Nydal, R, Rasmussen, A and Vallevik, PN. 1981. Radiocarbon dates of marginal moraines in Nordland, N. Norway. Geografiska Annaler 63A (3-4) 155-160.

Andersen, BG, Bøen, F, Rasmussen, A, Rokoengen, K and Vallevik, PN. 1982. The Tjøtta glacial event in southern Nordland, North Norway. Norsk Geologisk Tidsskrift 62 (1) 39-49.

Fredin, O. 2002. Glacial inception and quaternary mountain glaciations in Fennoscandia. Quaternary International 95/96 99-112.

Faulkner, T. 2005. Cave inception and development in Caledonide meta-carbonate rocks. Unpublished PhD thesis. University of Huddersfield.

Heap, D. 1968. Norway Report for 1967. Kendal Caving Club Journal 3 11-16.

Hoel, A. 1906. Den marine graense ved Velfjorden. Christiana Videnskaps-Selskabs Forhandlinger (4) 1-15.

Larsen, E and Mangerud, J. 1989. Marine caves: on-off signals for glaciations. Quaternary International 3 / 4 13-19.

Larsen, E, Gulliksen, S, Lauritzen, S-E, Lie, R, Løvlie, R and Mangerud, J. 1987. Cave stratigraphy in western

Norway; multiple Weichselian glaciations and interstadial vertebrate fauna. Boreas 16, 267-292.

Lundqvist, J. 1986. Late Weichselian glaciation and deglaciation in Scandinavia. Quaternary Science Reviews 5 269-292.

Mangerud, J. 1991. The Last Ice Age in Scandinavia. Striae. 34 15-30.

Møller, JJ. 1985. Coastal caves and their relation to early postglacial shore levels in Lofoten and Vesterålen, north

Norway. Norges Geologiske Undersøkelse Bulletin 400 51-65.

Møller, JJ. 1989. Geometric simulation and mapping of Holocene Relative Sea-Level Changes in northern Norway. Journal of Coastal Research 5 (3) 403-417.

Olsen, L, Sveian, H and Bergstrøm, B. 2001. Rapid adjustments of the western part of the Scandinavian IceSheet during the Mid and Late Weichselian - a new model. Norsk Geologisk Tidsskrift 81 93-118.

Sjöberg, R. 1988. Coastal Caves Indicating Preglacial Morphology in Norway. Cave Science 15 (3) 99-103.

Smart, CC. 1984. Overflow sedimentation in an alpine cave system. Norsk Geografisk Tidsskrift 38 (3/4) 171-175.

St.Pierre, D. 1988. A History of Cave Exploration and Study in Norway. Cave Science 15 (3) 139-144.

St.Pierre, S and St.Pierre, D. 1980. Caves of Velfjord, south Nordland, Norway, with particular reference to Sirijordgrotten. Trans. British Cave Research Association 7 (2) 70-82.

Svendsen, JI and Mangerud, J. 1987. Late Weichselian and Holocene sea-level history for a cross-section of western Norway. Journal of Quaternary Science 2 113-132.

Sørensen, R, Bakkelid, S and Torp, B. Land Uplift. 1987. 1:5000000. Nasjonalatlas for Norge. Statens kartverk.

Valen, V, Larsen, E and Mangerud, J. 1995. High-resolution paleomagnetic correlation of middle Weichselian ice-dammed lake sediments in two coastal caves, western Norway. Boreas 24 141-153.

Valen, V, Mangerud, J, Larsen, E and Hufthammer, AK. 1996. Sedimentology and stratigraphy in the cave Hamnsundhelleren, western Norway. Journal of Quaternary Science 11 (3) 185-201.

Valen, V, Lauritzen, S-E and Løvlie, R. 1997. Sedimentation in a high-latitude karst cave: Sirijordgrotta, Nordland, Norway. Norsk Geologisk Tidsskrift 77 233-250.

263

O-70

Is it possible to correlate sediments in a glacial cave?

H. Hestangen, S.E. Lauritzen
University of Bergen, Norway

Abstract

Is it possible to correlate sediments in a glacial cave? The sedimentology of the Grønli-Setergrotta cave system, Mo i Rana, Nordland, Norway Hilde Hestangen and Stein Erik Lauritzen Department of earth science, University of Bergen, Allegaten 41, N-5007 Norway. The Grønli-Setergrotta cave system is located 15 km out of Mo i Rana, Nordland, Norway. It consists of two larger caves and several smaller with a total length exceeding 8 km. The Grønli-project was started in 2000, and includes three different theses on the cave systems speleogenesis, sedimentology and hydrogeology (Hestangen 2005, Skutlaberg 2003, Øvrevik 2002). This paper report the Quaternary stratigraphy and sedimentology in the Grønli-Setergrotta cave system. Sediments transported in the karst system are analogues to surface-derived contaminants, and might seriously alter water flow and appearance of springs in the system (Ford 2001). Cave sediments may be preserved for a longer period of time than its counterparts on the outside in glaciated areas. Cave sediments can therefore possibly reveal paleo-climates and paleo-environments in the region. Information about sediments in caves is hence of crucial importance to understand speleogenesis and the surrounding areas affected by speleogenesis. Stratigraphic loggings of sediment sequences in caves are normally used on apparent sediment fillings as a parallel to logging outside in sand-pits (Valen 1991; Nese 1996). In the Grønli-Setergrotta cave system most of the cave floors are evenly covered by sediments. Logging-sections have consequently been accomplished by digging pits, and by traditional stratigraphic logging methods. 25 log-sites have contributed to the understanding of sedimentological history. Sand is dominating the passages of Grønligrotta, while angular boulders are prevail in Setergrotta. U\Th-dating of concretions and flowstone found in Grønligrotta resulted in clustering of dates in the periods 2-3, 10-12 and 27-28 ka. No datable material was found in Setergrotta. Although sequences can be broadly ascribed to hydraulic facies (Stagnant lacustrine, fluvial slow and catastrophic flow, outwash and breakdown), only some neighboring sections could be correlated with confidence. References: Ford, T. D. (2001). "Sediments in caves". BCRA Cave Studies Series(9): 32 p. Hestangen, H. (2005)The sedimentology of the Grønli-Setergrotta cave system, Mo i Rana, Nordland, Norway. MSc thesis, University of Bergen: 195 p. Nese, H. (1996). Sedimentologisk utvikling av grottene i Kjøpsvik- med hovedvekt på Storsteinholsystemet. MSc thesis, University of Bergen: 174 p. Skutlaberg, S.(2003). Paleohydrogeologi, bruddgeometri og litostratigrafi i Grønli- Setergrottasystemet, Mo i Rana. MSc thesis, University of Bergen: 188 p. Valen, V. (1991). Sirjordgrottas sedimentologiske historie. University of Bergen: 261 p. Øvrevik, R. (2002). Hydrogeologi og karstkorosjon i Grønli-Seterakviferen, Mo i Rana. MSc thesis, University of Bergen: 169 p.

O-71

Chemical denudation rates in a polar karst catchment: Londonelva, Svalbard

W.E. Krawczyk, L.E. Pettersson
University of Silesia, Sosnowiec, Poland; Norwegian Water Resources and Energy Directorate, Oslo, Norway

Abstract

Increased interest in chemical denudation rates in the polar regions in recent years is connected with modelling of the potential of weathering processes below large ice-sheets to perturb the atmospheric carbon dioxide concentrations. When large ice sheets were retreating at the end of the Last Glacial Maximum (LGM) large areas of land became ice-free and chemical weathering processes commenced on them. The same thing is occurring in small ice-free catchments in Svalbard today. The Londonelva catchment (0.7 km2) is located on Blomstrandsøya, an island in Kongsfjord, NW Spitsbergen (79°N 12°E). The basement consists of highly metamorphosed rocks, chiefly marble. Small patches of Devonian sandstone and conglomerate are also found. Paleokarst caves have been observed in the SW cliffs of Blomstrandsøya and there are more than 60 sea caves along its 10 km shoreline. The Londonelva catchment is operated by Norwegian Water Resources and Energy Directorate (NVE) station. It has supplied comprehensive discharge data since 1992. The recorded volumes of water draining yearly to the fjord from Londonelva catchment were in the range, 158 026 - 433 728 m3. Outflow from ice-free catchments on Svalbard typically begins in early June and terminates in September/October. In August 2000 daily water samples were taken by a CISCO sampler located at the NVE gauging station. Their specific conductivity was in the range, 209 - 268 mS/cm. Chemical analyses by ion chromatography and atomic absorption spectrometry provided data for partitioning the solute load into crustal, marine and atmospheric components that are being transported from the basin.

O-72

The reasons for high biodiversity in karst landscapes in the Northern Taiga

Goryachkin S.[1], Glazov M.[1], Puchnina, L.[2], Rykov A.A.[2], Rykova S.Yu.[2], Semikolennykh A.[1] (contact author), Shavrina E.[2], Spiridonova I.[1], Tuyukina T.[1], Zakharchenko J.[2]

[1] *Institute of Geography, Moscow, Russia*

[2] *Pinezhsky Natural Reservation, Russia*

Pervomaiskaya str., 94-133. Moscow, 105203. RUSSIA. E-mail:aasemik@list.ru

Abstract:

The character of landscapes can be greatly influenced by underlying soluble rocks and related karst processes. This phenomenon has been studied within an area situated 200 km east and north-east of Arkhangelsk, where karstified material influences taiga & forest-tundra landscapes. The taiga zone in the Russian European North is a territory with predominant swamped glacial plains. Such landscapes are formed in cold & humid climates combined with poor drainage. However, there is another type of landscape that has developed over gypsum & limestone rocks covered by a thin layer of moraine or outcropping to the surface. Here, instead of typical spruce woods, there are low-productive larch woods, natural meadows, and open woodlands with plant species atypical of northern habitats. Bogs occur rarely, but so-called "disappearing" lakes, caves, and other karst forms are common. This is a type of a landscape, where geo-diversity and biodiversity are strongly interconnected, where biotic and abiotic components develop together. The dynamic processes involved in such landscapes were monitored on 2 sites using a three-dimensional approach. Thus, the characteristics of environment (i.e. temperature, moisture, concentration of nutrients in soil solution, etc.) and life indices (i.e. microbiological activity, bird occurrence and frequency, plant community characteristics, etc.) were measured together with their principal quantitative & qualitative differences in conditions of karst & moraine landscapes. Karst areas in northern taiga can shelter some relict arctic-alpine species within sink-holes and support specific oligotrophic plants growing on rock outcrops; karst areas in tundra provide for the development of forest vegetation. In other words, karst processes & topographical features are able to support more sophisticated landscape structures and ecological systems due to the diversity of habitats. The impact model may be represented as follows: "rocks dissolution → dissected relief → intense drainage, contrasting temperatures & nutrition sources → impact on organisms". The existence of local karst areas also contributes to the wider system biodiversity within a whole region.

Introduction

Observations of the dynamic processes in soils and landscapes allow for the formulation of a complex spatial-temporal structural and functional conception of the biosphere and its components. As such studies require a special stationary-based methodology very few works in this field have been conducted within different natural zones (e.g. [Regulatory role..., 2002]). Our research was conducted in the northern taiga (northeastern part of Belomorsko-kuloiskoe Plateau, Arkhangelsk region, Russia) (Fig.1). The post-glacial landscape typical of this territory is complicated by the presence of karst areas; hence we focused our attention on the differences between karst and moraine landscapes. A significant part of our research was carried out within the Natural State Reserve "Pinezhsky", where the highest diversity of landscapes can be observed.

Study Objects

The study was conducted in the northeast of European Russia, in the interfluve between the Mezen and North Dvina rivers. The study area is characterized by a temperate humid climate with the mean annual temperature 0.2°C, mean temperature of January -13.8°C, and mean tempera-

Fig. 1   Study site
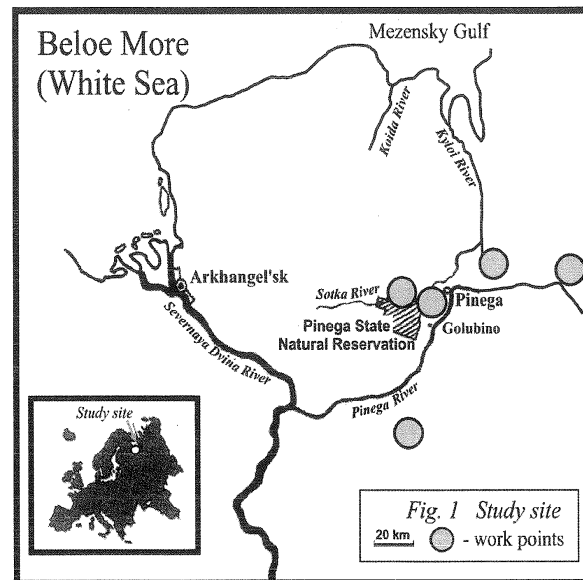
ture of June +15.4°C. The sum of temperatures >10° is 1100°; the annual precipitation is 652 mm with its maximum in summer.

Bedrocks are formed of Paleozoic sulfate, calcareous, and terrigenous sediments. They are overlain by Quaternary moraine clays and loams. Karst processes developed in positions, where the thickness of moraine cover is less than 10 m. Soluble rocks are represented by Early Permian lagoon sediments (gypsum and anhydrite) about 40-70 m thick. The density (frequency) of karst forms is from 100 to 1500 units per 1 sq. km. Karst forms are sinkholes, "organ pipes", karst ditches (ravines, gorges, gullies), and residual hills.

Typical woods in the northern taiga are formed mostly of conifers (Picea abies, Picea obovata, Larex sibirica, Pinus sylvestris). Pine-birch-spruce forests with a ground cover of shrubs and green mosses predominate within post-glacial (non-karst) areas. Their typical soils are Gleyi-Histic Albeluvisols (gleyzation caused by ground water), Stagni-Abruptic Albeluvisols (in loamy moraine with abrupt lithological contact) and Histosols (Note: Here and below soil types are named according WRB Soil Classification [WRB, 1988]).

Karst landscapes are more complicated. There are some atypical plant species, such as relic arctic-alpine ones: Arctous alpina, Dryas octopetala, Pinguicula alpine; boreal Siberian: Atragene sibirica, Diplazium sibirica; nemoral: Stellaria nemoralus, Paeonia anomata; endemic: Gypsophyla uralensis subsp. pinegensis, Thymus talievii and others. The structure of soil cover is related to the geomorphological structure. Gentle slopes and watersheds between single sinkholes are covered by moraine deposits from 10 cm to several meters in thickness, where Haplic Podzols and Stagni-Abruptic Albeluvisols are formed. The bottoms of large sinkholes are filled by coarse organic deposits that are several meters in thickness (Outer accumulated Histosols). The specific soil type - Gypsiric Leptosol (formed in hard gypsum and having the metamorphic horizon) is formed on gypsum outcrops on residual hills and slopes.
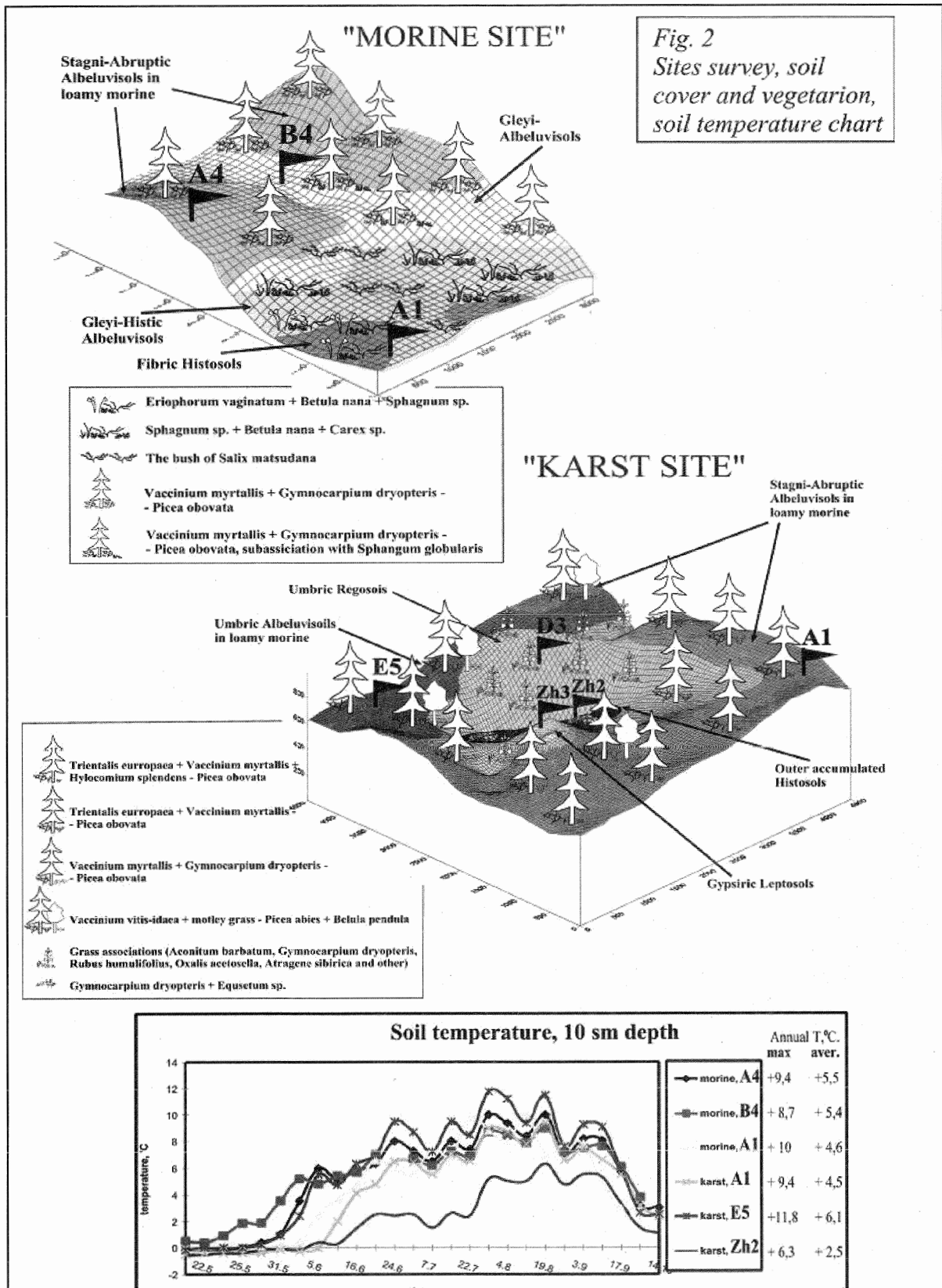
Fig. 2
Sites survey, soil cover and vegetarion, soil temperature chart

"MORINE SITE"

Stagni-Abruptic Albeluvisols in loamy morine

Gleyi-Albeluvisols

Gleyi-Histic Albeluvisols

Fibric Histosols

Eriophorum vaginatum + Betula nana + Sphagnum sp.

Sphagnum sp. + Betula nana + Carex sp.

The bush of Salix matsudana

Vaccinium myrtallis + Gymnocarpium dryopteris - Picea obovata

Vaccinium myrtallis + Gymnocarpium dryopteris - Picea obovata, subassiciation with Sphangum globularis

"KARST SITE"

Stagni-Abruptic Albeluvisols in loamy morine

Umbric Regosois

Umbric Albeluvisoils in loamy morine

Outer accumulated Histosols

Gypsiric Leptosols

Trientalis eurropaea + Vaccinium myrtallis + Hylocomium splendens - Picea obovata

Trientalis eurropaea + Vaccinium myrtallis - Picea obovata

Vaccinium myrtallis + Gymnocarpium dryopteris - Picea obovata

Vaccinium vitis-idaea + motley grass - Picea abies + Betula pendula

Grass associations (Aconitum barbatum, Gymnocarpium dryopteris, Rubus humulifolius, Oxalis acetosella, Atragene sibirica and other)

Gymnocarpium dryopteris + Equsetum sp.

Soil temperature, 10 sm depth	Annual T,°C. max	aver.
morine, A4	+9,4	+5,5
morine, B4	+8,7	+5,4
morine, A1	+10	+4,6
karst, A1	+9,4	+4,5
karst, E5	+11,8	+6,1
karst, Zh2	+6,3	+2,5

Monitoring of the Key Sites

Monitoring of ecosystem dynamics was performed on two key sites in karst and moraine areas that represented the diversity of topographical features, vegetation, and soils. The key sites are located on the right bank of the Pinega River within the fenced-off area of the State Natural Reserve "Pinezhsky". The "moraine site" has an area of about 1200 sq. m. (30x40 m), and the "karst site" - 1800 sq.m (40x45 m) (Look the Fig. 2). The following initial works were carried out: topographic survey (measuring relative heights), plant and soil descriptions, soil and groundwater sampling, and taking samples of leaves and shoots for chemical analysis. The plant and soil descriptions and soil and groundwater sampling were done at 5 meter intervals over the study site areas. The monitoring included measuring air and soil temperatures and soil moisture, phenological observations, setting traps for cursorial insects, experiments for measuring the rate of decomposition of cotton strips, taking soil samples for inoculation of microbiological media in the laboratory, and some other tests. Monitoring points were located at the main elements of the key sites.

Three points were monitored on the "moraine site": point A4 - gentle hill, local watershed; point B4 - small depression; point A1 - bog. Five points were monitored on the "karst site": point A1 - gentle hill, local watershed; point D3 - steep slope to sinkhole; point E5 - gentle slope, low hill; point Zh2 - bottom of sinkhole; point Zh3 - top of residual hill. Chemical analyses included bulk chemical composition analysis, agrochemical analysis (NPK), and X-ray analysis of microelements (Cr, Ni, Cu, Zn, As, Br, Pb, Rb, Sr) in soil and plant samples.

The comparison of the temperature condition during a year shows that karst site has more contrast changes in temperatures in the different soils distributed within the site. The same regularity was found for moisture condition in soils. The diversity of hydro-thermic conditions reflects on development of plants that is illustrated by some phonological data (look at table below).

Species	Phase	"morine", A4	"morine", A1	"karst", E5	"karst", Zh2
Vaccinium myrtallus	Spreading of leaves	29 May	29 May	28 May	-
	Mass florescence	13 June	20 June	12 June	-
	Drupe bletting	5 August	1 August	1 August	-
Picea obovata	Growth of sprouts	13 June	-	13 June	-
Betula pendula	Spreading of leaves	27 May	-	29 May	-
Oxalis acetosella	Beginning of vegetation	-	-	29 May	6 June
	Beginning of florescence	-	-	5 June	13 June
	Mass florescence	-	-	13 June	20 June
Orobus vernus	Beginning of vegetation	-	-	25 May	6 June
	Budding	-	-	28 May	13 June
Geranium sylvaticum	Mass florescence	2 July	-	4 July	25 July
Aconutum barbatum	Mass florescence	-	-	16 July	25 July

As a result of observations on the dynamics of microorganisms, we have revealed the following:

1. The total number of microorganisms increases from spring to autumn; although the relative proportions of phenological groups change. The proteolytic group decreases in number during the autumn season, and at the same time we observe an explosion-like growth of the number of cellulolytic organisms. The number of bacteria in litters during the growing season is a bit higher on the moraine site, however in autumn the moraine site has mostly lower values than the karst site. The number of fungi in litter layers on the moraine site is higher, in autumn as well.

2. The distribution of microorganisms within the soil profile is somewhat different. In Albeluvisols of the moraine site, there is a rapid, but smooth decrease in the number of microorganisms with transition from the litter to mineral horizons. In the well-drained Podzol of the karst site, that transition is rather abrupt. Slope soils tend to exhibit a smooth decrease in microorganism numbers in their transitional horizons, which accounts for a high biological activity within a whole soil profile.

4. The cellulase activity in poorly developed soils, i.e., Leptosols formed in hard gypsum on slopes, doesn't show significant seasonal fluctuations, remaining constant during a whole growing season. The cellulase activity in Podzols increases nearer autumn. Podzols have a curious tendency for significantly changing the proportion of utilized substrates in the litter and mineral horizons towards the end of the growing season. A prominent relative growth of the cellulase activity in the mineral horizons can be connected either with the "retarded" development of microorganisms in these horizons in comparison with that in litters (possibly because the former warm up more slowly in the spring), or with the conditional deficiency of moisture in litters during the dry period in the middle of summer. The influence of temperature can be clearly illustrated by the example of soil occurring in the bottom of the sinkhole (point Zh2) which is the "coldest" one among all monitored soils and gets warm only by the middle of summer.

5. In the north taiga soils, coloured forms of Myxobacteria are predominant in the bacterial community of litters, and the genus Arthrobacter and Spirillum with bacilli-like cells prevail in the mineral horizons.

6. A general tendency in all studied soils is an increase in the total number accompanied by a decrease in the biodiversity of bacteria from summer to autumn.

7. The assessment of the biological diversity using the Shannon's index has revealed the following:

   1) the biological diversity in summer is generally higher than that in spring;

   2) Leptosols formed in hard gypsum have the highest diversity of micromycetes;

267

3) Histosol formed on oligotrophic bog shows the lowest increase in biodiversity during summer.

We compared data on soil regimes over two years, 1996 and 1997, which had very different climatic conditions. The summer of 1996 was characterized by abundant precipitation and relatively low temperatures. In contrast the summer of 1997 was dry and hot. The some results are presented in the table below.

In litters of Albeluvisols on the moraine site, optimization of the water-temperature regime accompanied by an increase in the cellulase activity was observed in 1997. But, in the mineral horizons of those soils, the biological activity little varied between 1996 and 1997. The biological characteristics of Stagni-Abruptic Albeluvisols formed in automorphic position on the karst site remained almost unchanged; though the limiting factor in 1996 was probably heat deficiency, followed by moisture deficiency in 1997. However Podzol on the gentle slope on the karst site demonstrated an important increase in the activity indices, especially, in the mineral horizons. Since its moisture was similar in 1996 and 1997, the difference should be explained, apparently, by an increased warming of its whole profile in 1997.

Oligotrophic karstified open woodlands

ithin the study area, there are specific landscapes that we term "oligotrophic karstified open woodlands"(Fig). They are characterized by a total projective cover (percent of ground surface overgrown by grass-shrub vegetation) of only 20%. The ground cover is formed mostly by various lichens of genus Cladina, and less abundantly by the moss species Pleurozium schreberi. These open woodlands are characterized by a dissected topography with karst forms and the predominance of specific soils formed in hard gypsum (Leptosols and Regosols) and lichen communities. The soil and vegetation patterns are very heterogeneous because of the karst topography. Highly oligotrophic lichen communities on gypsum soils on residual hills occur next to moss communities on Histosols within sinkholes. Such a contrast results from a wide difference (15°C) between the soil temperatures on the hill top and at the sinkhole bottom. However the warmest ecotope is characterized by the most oligotrophic vegetation and the lowest microbial activity.

On the basis of our results of measuring the diameter and height of trees and the data [Molchanov, 1971] on mass proportions of dry and live wood of main tree species in the northern taiga, we estimated the mass of above-ground parts of trees in this community. The mass of live above-ground wood equals to 14.8 ton of dry phytomass per hectare, which is 8-10 times as low as that in typical taiga communities (green moss spruce forest on Albeluvisol and pine forest on Podzol).

Plants that are capable of occupying bare hard gypsum are characterised by a peculiar chemical composition: Festuca ovina - oligotrophic

plant with a wide ecological amplitude, and Gypsophila uralensis Less. Subsp penegensis - gypsophilic plant. As distinct from most other plants of karstified open woodlands, Festuca ovina doesn't concentrate Ca, Sr and S: their concentrations in the above-ground part of this plant in karst and moraine landscapes are similar. At the same time, Gypsophila uralensis Less. Subsp is distinguished among all other plants of karstified open woodlands as a supreme accumulator of calcium (6.38 % of dry weight), sulphur (0.74%), and copper (13 mg/kg) with the total ash content of 15.24 %.

Processes of erosion and accumulation of moraine material in depressions account for a specific spotted pattern of the vegetation cover. Trees and shrubs grow only in depressions, whereas residual hills and steep slopes are occupied by lichens and grasses. Our observations on the colonization of bare rock surfaces and sod formation allow us to suggest that the relationship between the vegetation and the degree of topography dissection is even greater. Trees obtain mineral nutrients from silicate moraine deposits accumulated within karst depressions. The fall-off (leaves, needles, etc.) from the trees is distributed over a wide area including the tops of residual hills. Since the litter accumulates in a sufficient amount, it allows for growth of vascular plants on hard gypsum, where their growth would normally seem impossible. Due to this mechanism, the projective cover (percent of surface overgrown by vegetation) can grow in a certain period of time up to 50% and more, thus forming patches of sodded karst. The cycle of biogenic elements is shown in the figure 4.

Fig. 4
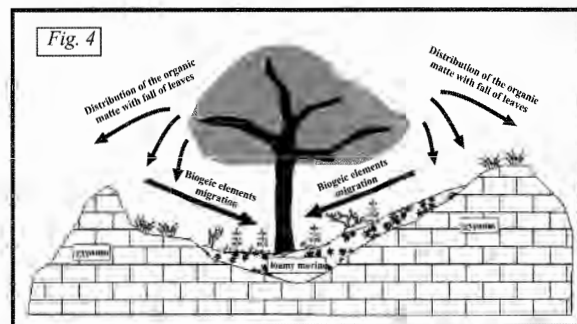
Comparing the values of microbiological activity in similar gypsum soils formed within an open patch and under the tree canopy also revealed some functional differences that have no manifestation in the structure of these soil profiles. It was found that the samples of mineral soil horizons contain the same general quantity of bacteria ($2,04 \times 10^6$ and $2,75 \times 10^6$ colony forming units per a gram of a dry soil). However, there were certain differences in the composition of bacterial associations. We found more actinomycetes and coryne-like organisms in the mineral soil horizons within the bare patch (as compared to the wood patch): 31% versus 5.6% for actinomycetes, and 27% vs. 10% for coryne-like organisms. The proportion of gram-negative organisms in soil under the trees was found to be higher than that in soils of the bare area: 80.4% vs. 20%.

We also studied the rates of cellulose destruction (by application of paper filters) in these soils. The cellulose destruction in the soil litter under trees (that consists mainly of green mosses) is faster than in the soil litter of the bare patch (that consists of green mosses and lichens): 40% vs. 29% per month. However, such rates in mineral horizons are approximately the same: about 4-5% per month.

Nature observations and studies of the natural chronicle

General observations on the flora and fauna distribution over moraine and karst landscapes in the Natural State Reserve "Pinezhsky" revealed that karst influences biological diversity as follows:

Karst landscapes increase the biodiversity of vascular plants. 80% of

plant species occurring on the reserve are found within such landscapes, whereas glacial landscapes can support only 20% of species. This is associated with the appearance and continuous growth of rare and relict species and also with an increase in the proportion of secondary forests as part of the total vegetation cover of karst landscapes.

For the bryoflora of karst areas, the total number of species reaches 127 (as compared to 107 in glacial landscapes). The share of sphagnum species is slightly less.

For the lichenoflora, the number of species that grow on bare rocks is doubled. The total number of lichen species is 43. The share of epiphytic lichens also extends up to 72 species (as compared to 64 in glacial landscapes), which is connected with the appearance of open woodlands and better supply of sunlight.

Fishes increase their biomass in karst lakes with their high concentration of salts. Most likely, this is due to the increase in the biomass of crustaceans Amphipoda in calcium-rich karst lakes; the presence of calcium facilitates the growth of their chitin cover. In karst landscapes one can find species typically occurring in foothills: Thymallus thymallus, Phoxinus phoxinus, Cottus gobio

Amphibians and reptiles increase their numbers in karst areas due to the appearance of meadow communities and secondary forests.

Birds are influenced by karst in two ways. Firstly, the number of species living in water-bog habitats is decreased. Secondly, the total frequency of bird occurrence is higher in karst areas, together with the appearance of specific alpine species (Motacilla cinerea, Mergus merganser, Cinclus cinclus).

Small mammals. Mice-like rodents increase in numbers within meadow phytocenoses. Some species totally disappear in karst areas (Castor fiber, Ondatra Zibetica, Sciurus vulgaris), while others significantly increase in number due to a richer supply of their specific food sources or shelters (Eutamias sibiricus, Lutra lutra, Musteia erminea, Vespertilio nilssonii). Certain species are not specifically influenced by karst (Lutreola vision, Lepus timigus, Mustela martes).

Large mammals. Moose increase in numbers in karst areas due to a better nutrition base (meadows and smaller trees). Bear (Ursus arctos) prefer karst areas, because of the ease of finding shelter (although dens are rarely be found in caves, bears often make their dens among fallen trees and branches in large karst depressions). The frequency of foxes (Vulpes vulpes) decreases in karst landscapes. The influence of karst on large predators (Canis lupus, Lynx lynx, Gulo gulo) has not been revealed.

Conclusion

Thus, the wide spectrum of temperature and moisture conditions in karst areas accounts for the close co-existence of species of soils, plants and animals that are typical for both colder and warmer regions. The appearance of new, atypical regimes of soil functioning affects soil microorganisms, plants and, consequently, cursorial animals that choose their food base and place for resting and nesting. Intense development of karst processes result in the formation of landscapes atypical of the north taiga - oligotrophic karstified open woodlands, where however, biodiversity does not increase due to the nutrient deficiency of soils.

Literature Reference

1. The regulatory role of soil in functioning of taiga ecosystems. Edited by G.Dobrovolsky. Moscow, 2002. "Nauka" Press. (in Russian)
2. World Reference Base for Soil Resources (WRB), 1998. Rome. FAO/UNESCO.
3. Molchanov A.A. The productivity of the organic matter in forests of different zones. Moscow, "Nauka" Press/ 1971.

Related Publications

1. The structure and dynamic of natural components of Pinezhsky reservation. Collective of authors. (2000) Arkhangelsk, 2000. 268 pages. (in Russian)
2. Goryachkin S.V., E.I.Gurkalo, V.N.Malkov, L.V.Puchnina, A.A.Semikolennykh, I.A.Spiridonova, T.Y.Tuyukina, E.V.Shavrina. (2000). Phenomenon, structure and genesis of landscapes of northern taiga karst open woodlands and features of their soil cover". Transactions of XI Congress of Russian Geographic Society. Arkhangelsk, 2000. vol.6, p. 23-24. (in Russian)
3. Goryachkin S.V., L.V.Puchnina, A.M.Rykov, S.Y.Rykova, A.V.Sivkov, E.V.Shavrina (2000). Biogeographical characteristics of natural complex of Pinega reserve (Arkhangelsk region). // Natural and historical-cultural heritage of North-West of Russia". Petrozavodsk. 2000pp. 79-126. (in Russian).
4. Gorlenko M.V., Semikolennykh A.A. The characteristics of functional state of soil microbocoenisises in moraine and karst landscapes of Arkhangelsk region. Bull. of Moscow State Univ., series 17 (Soil science), № 2. 1998. Pages 50-52
4. Lessovaya S.N., Dmitricheva L.E., Goryachkin S.V., Vodyanitsky Y.N., Gagarina E.I., Semikolennykh A.A., Shelemina A.N., Tuyukina T.Y. Soil-ecology conditions of unique taiga landscapes. 2001. (in English). http://soilinst.msu.ru/pub_01/text_paper.htm
5. Semikolennykh A., Ivanova A., Dobrovolskaya T. Microbial communities of the northern taiga // "Pochvovedenie", 2004. Number 1, pages 23-35 (in Russian). The mirror in the Eurasian soil science journal (in English)

O-73

Vertebrate Species Use of Caves in the Chihuahuan Desert

Thomas R. Strong
National Cave and Karst Research Institute, Carlsbad, NM, New Mexico Institute of Mines and Technology, Socorro, NM
James R. Goodbar
Bureau of Land Management Carlsbad Field Office

Abstract

Caves are known to provide habitat for many vertebrate species that spend all or significant portions of their life cycles inside the totally dark areas of the caves. It is less well known that caves, particularly cave entrance areas, provide important resources for a wide variety of species. While many individual observations of vertebrate species in caves have been reported, there have been few attempts to compile this information in any systematic way. Bureau of Land Management files, National Park Service files, general literature, internet sources, and personal observations were used to compile records of species using caves in the Chihuahuan Desert of southeastern New Mexico. At least 80 vertebrate species are now confirmed to use these caves, with reports from at least 160 caves.

The literature search found another 26 species that are reported to use caves in the Chihuahuan Desert.

Mammals are the dominant group of vertebrates reported in these caves, with at least 50 species representing six orders and 18 families. Mammals are found in at least 136 caves. The mammals most commonly reported are generally large and easily recognized, with porcupines and ringtails occurring in the greatest numbers of caves. Birds are less well represented and are reported in 60 caves. Only 16 bird species in eight orders and 13 families have been documented. Cave swallows are the most commonly reported bird, with nesting colonies in several caves. Reptiles are frequently encountered in cave entrances of this region, with records of 11 species in at least 37 caves. The most common species include three species of rattlesnake. Because this is an arid region, amphibians and fish are poorly represented in caves. Only two species of amphibians are present in a total of nine caves, and only one fish species has been reported. There are no cave-adapted amphibians or fish in this region.

Vertebrate species are using caves of this region for a variety of reasons. In this arid desert, caves are likely to provide temporary relief from extreme temperature or humidity conditions and possible hiding places to escape predators. In addition, they are known to provide den sites, nest substrates, roost sites, maternity sites, water sources, predation or foraging sites, and hibernation sites.

In conclusion, the caves of the Chihuahuan Desert provide habitat resources for a large number of vertebrate species. Although none of these species are threatened or endangered, their continued existence in this desert may depend on the availability of cave resources. The importance of caves as wildlife habitat should be considered in any resource management plan.

Introduction

Caves are widely known to provide habitat for a variety of vertebrate species that spend all or significant portions of their life cycles inside the totally dark areas of the caves. It is less well known that caves, and particularly cave entrance areas, can provide an important resource for a wide variety of species. Especially in arid regions, caves may provide temporary relief from extreme temperature or low humidity conditions. In addition, they may provide hiding places to escape predators, den sites, nest substrates, or hunting locations for predators.

While many individual observations of vertebrate species in caves have been reported, there have been few attempts to compile this information in any systematic way. Kingsley et al. (2001) compiled a list of species known to use caves or abandoned mines in the Sonoran Desert. This list was based primarily on personal observations or knowledge of the four authors and on records listed in Hoffmeister (1986), and it did not include a thorough literature review. However, this preliminary list included 67 vertebrate species (4 amphibians, 14 reptiles, 11 birds, and 38 mammals). The primary conclusion of this paper was that caves and mines are significant wildlife habitat resources and worthy of protection through the Sonoran Desert Conservation Plan proposed by Pima County.

The Chihuahuan Desert covers a large area of southern New Mexico, western Texas, and the extreme southeastern corner of Arizona. This desert includes an even larger area of Mexico, extending far south in the central plateau. Average annual rainfall in the Carlsbad, New Mexico, vicinity is about 35.9 cm (14.1 in.), with most precipitation coming during a summer rainy season. Summer daytime high temperatures are around 35°C (95°F), and winter lows are around -2°C (28°F).

Many caves are located in extensive deposits of limestone and gypsum in the Chihuahuan Desert. These caves provide more moderate conditions of temperature and humidity that may be a critical resource for many species. As in other desert regions of North America, there have been no systematic studies of vertebrate species using the cave habitats, although

Bailey (1928) mentioned the use of caves by many species in his account of the vertebrate biology of the Carlsbad Caverns region.

Study Area and Methods

The study area considered in this project was limited to that portion of the Chihuahuan Desert located within the state of New Mexico in the vicinity of the city of Carlsbad. This area includes Carlsbad Caverns National Park and areas of limestone and gypsum administered by the Carlsbad Field Office of the Bureau of Land Management.

Data in this analysis were compiled from a variety of sources. The primary sources of information were in the unpublished records in the files of Carlsbad Caverns National Park and the Carlsbad Field Office of the Bureau of Land Management. Several internet sites have extensive information on vertebrate species and their habitat usage and requirements. In particular, Biotic Information System of New Mexico (BISON-M) (BISON 2004), supported by the New Mexico Department of Game and Fish, and NatureServe Explorer (NatureServe 2004), supported by natural heritage programs. Other standard literature sources were also searched for relevant information.

In order for a cave to provide a habitat resource for wildlife, it must have an accessible entrance. Entrances in both limestone and gypsum provide suitable sites for vertebrate species. A variety of evidence can be used to demonstrate the use of a cave by a vertebrate species. Direct observations of vertebrates were made in several caves of this region. Bird nests, feathers, and eggshells provide positive evidence of bird species using caves. Likewise, tracks and scat provide direct evidence of vertebrate species in caves, although identification may be limited to genus. Skeletal material is additional evidence of a species' presence inside a cave, and it can usually be identified to species.

Data from all of these sources were entered into spreadsheets, including species, caves, dates of observation (if known), and original observers (if known). Each report of a species from a cave was entered as a separate record.

Results

The literature and files searches and personal observations provided 736 reports of at least 80 species of vertebrates in the caves of the Chihuahuan Desert in the vicinity of Carlsbad, New Mexico. There are vertebrate records from at least 160 caves in this vicinity, including 81 caves in Carlsbad Caverns National Park, 78 caves on BLM land, and one cave on State of New Mexico land. In addition to these confirmed reports, there are literature accounts of another 26 species using caves in the Chihuahuan Desert, 17 of which are known to be present in the Carlsbad vicinity.

The data were sorted by species to summarize the number of observations of each species and the number of caves in which each species was reported. The species distribution results are illustrated in Figure 1, which shows the numbers of vertebrate species reported in different numbers of caves. The majority of species appear to have a very limited distribution, being reported in only one or two caves. A few species are more widely distributed, with reports from as many as forty caves, but only 12 species have been reported from ten or more caves.

These data were also sorted by caves to obtain the number of species in each class of vertebrates found in each cave. The species diversity within caves is illustrated in Figure 2, which shows the numbers of caves with different numbers of vertebrates. The majority of caves have reports of very few vertebrate species, with 118 caves having reports of three or fewer species. Some caves have relatively high species diversity, with 30 species reported in Carlsbad Cavern and 19 species reported in Lechuguilla Cave. However, only 11 caves have reports of ten or more species.

270

Mammals are the most commonly reported class of vertebrates in these caves. At least 50 species of mammals have been reported from 136 different caves. These species represent 18 families and six orders. The total number of species is ambiguous because of reports of Myotis sp., Pappogeomys sp., Peromyscus sp., Neotoma sp., and Sigmodon sp. While these reports are likely to be the same species that have been reported in other caves, the possibility exists that they could represent additional species. In addition, the number of reports given is a minimum, because of indefinite references to species being found in numerous caves (i.e., Bailey 1928). The commonly reported mammals are generally medium to large in size and are easily identified visually or by tracks or scat. Bats and carnivores are particularly well represented in these caves, with reports of all species of bats known to occur in this vicinity and all but one of the carnivores known to occur here. There are also many reports of rodents and artiodactyls. The mammals reported from the most caves are the ringtail (Bassariscus astutus), porcupine (Erethizon dorsatum), wood rat species (Neotoma spp.), mountain lion (Puma concolor), mule deer (Odocoileus hemionus), and Townsend's big-eared bat (Plecotus townsendii).

Birds are also common in these caves, but they are less frequently reported than mammals. Sixteen bird species, representing 13 families and eight orders, have been reported from 60 different caves. Nine of these species have been reported nesting in caves or other karst features. Perching birds (Passeriformes) and owls (Strigiformes) account for nine of the observed bird species. Bird species most commonly reported from these caves include the cave swallow (Petrochelidon fulva), great horned owl (Bubo virginianus), rock wren (Salpinctus obsoletus), and canyon wren (Catherpes mexicanus).

Reptiles are commonly found in caves, but they are less commonly encountered than either mammals or birds. Eleven reptile species, representing five families and two orders, have been reported from 37 different caves. These species include two turtle species, two lizard species, and seven snake species. The most commonly reported reptiles are the western diamondback rattlesnake (Crotalus atrox), mottled rock rattlesnake (C. lepidus), and black-tailed rattlesnake (C. mollosus). Rattlesnakes account for 34 of the 50 reports of reptiles, and as venomous reptiles, they present a moderate safety hazard in exploring caves of this region.

Because of the arid conditions of this region, amphibians are infrequently encountered in caves. Only two species, representing two families and two orders, have been confirmed from a total of nine caves. The only amphibians reported in these caves are the tiger salamander (Ambystoma tigrinum) and red-spotted toad (Bufo punctatus). Amphibian reports are limited to caves on BLM and state land, generally in caves with intermittent streams that are related to surface drainage systems.

Only one fish species, the plains killifish (Fundulus zebrinus) has been reported from caves of this region. This species has been found in one gypsum cave that floods intermittently during storm events. This species is relatively common in surface streams of the Pecos River drainage network.

Discussion

At least 80 species of vertebrates have been documented from at least 160 caves of the Chihuahuan Desert in the vicinity of Carlsbad, New Mexico. While some of these data are derived from detailed surveys in particular caves, much of the information is the result of chance observations that happened to be recorded in NPS or BLM files. These data are dependent on the ability of the observers. Those vertebrates identified to species were reported by observers that are known to be qualified to make the identifications. However, many reports of vertebrates just identified to genus or group (i.e., rodent or snake) were made by untrained observers, and it is likely that many other vertebrates were seen but not reported by untrained observers. It is certain that further detailed surveys would provide records of additional species and locations.

One interesting result of this study is that the cave with the greatest diversity of vertebrate species is Carlsbad Caverns. This cave has a large, accessible entrance, and it has been studied with some intensity for over 70 years. However, it has also been subjected to intense development. The Bat Cave area was initially developed and operated for guano mining for many years. Constructed trails with handrails and a lighting system now provide access for several hundred thousand visitors each year. Development of the cave has probably opened it to some wildlife use that was not possible previously, with mice and ringtails now occupying the Lunchroom area and other parts of the cave. Development and human visitation have probably not had an adverse impact on the colonies of Brazilian free-tailed bats (Tadarida brasiliensis) and cave swallows that inhabit the cave.

In other caves, there is some evidence that human visitation has interfered with wildlife use of the caves. Cave swallows appear to have abandoned small nesting colonies in at least two caves after those caves were opened to recreational caving (D. Pate, pers. comm.). Mule deer appear to have vacated a large cave entrance shortly before the arrival of a group of cavers (D. Pate, pers. comm.).

Mammals are well represented in the vertebrate records of these caves, and they are using the caves for a variety of reasons. Bats are using the caves as maternity colonies, daytime roosts, migratory roost sites, and hibernacula. Many of the bat species were identified from skeletal material collected from a few caves (Jablonsky and Kraemer 1992; Pate 1997). Because no ages were associated with these identifications, there is some doubt as to whether these species are still using the caves of this region. For the Yuma myotis (Myotis yumanensis), long-legged myotis (M. volans), and small-footed myotis (M. leibii) there are no confirmed records other than skeletal material.

Other species of mammals, particularly carnivores and rodents, are known to use caves as nest or den sites. Wood rat nests have been reported in many caves (Mosch et al. 1991; Novack 2004; Allison 2004), but the species building the nests cannot be identified without visual confirmation. Bailey (1928) reported that mountain lions were using caves as den sites, and lions have been encountered in caves in this region (Parent 1998; Allison and Roemer 1998; J. Goodbar, pers. obs.). Piles of small mammal bones may indicate the presence of carnivore den sites (T. Strong, pers. obs.). Porcupine den sites have been noted in numerous caves (Fleming and Hummel 1977b; Hummel 1977; Belski 1979), and live porcupines have been encountered (Pate 1992; Fleming 1977; T. Strong, pers. obs.).

Several bird species are known to use caves in this vicinity for nest sites, with confirmed nesting for nine species (turkey vulture (Cathartes aura), ferruginous hawk (Buteo regalis), great horned owl, mourning dove (Zenaida macroura), white-throated swift (Aeronautes saxatalis), Say's phoebe (Sayornis saya), cave swallow, rock wren, and canyon wren) (Bailey 1928; Belski 1989; Fleming and Hummel 1977a; Lindsley 1967; Pate et al. 1995; Spangle and Thompson 1959; etc.). The cave swallow is the most common nesting bird in these caves, with nesting confirmed in at least 15 caves.

Caves serve as hibernation sites for a variety of species. As noted above, bats have been observed hibernating in several caves (Bailey 1928; Belski 1988; Baker et al., no date; Kerbo 1978; Ek 1991). The common poorwill (Phalaenoptilus nuttallii) is the only known bird confirmed to hibernate, and it could use caves in this region as hibernation sites. It has been reported hibernating (not in a cave) at Carlsbad Caverns National Park (S. West, pers. comm.), and it has been observed in a crevice in a pit entrance to a cave in the Park (P. Seiser, pers. comm.). It is likely that some reptiles and amphibians use caves as hibernacula, but there are no documented observations in the caves of the Carlsbad vicinity.

Caves in this arid region are likely to provide water sources for a variety of animals. Mule deer and bighorn sheep (Ovis Canadensis) have been

271

reported to get water from pools in caves in Slaughter Canyon (Bailey 1928; Welbourn 1978). It seems almost certain that other species are using these water sources, but if it has been observed, it was not reported.

Some species are apparently using caves as foraging sites. Bailey (1928) reported that white-footed mice (Peromyscus leucopus) were common throughout Carlsbad Cavern and were feeding on crickets and food dropped by tourists. Ringtails are likewise found in deep areas of Carlsbad Cavern (Bailey 1928; D. Pate, pers. comm.), and it seems likely that they are feeding on mice. Bailey (1928) also suggested that mountain lions were using a cave with a large entrance as a hunting site. Snakes are also likely to use caves as foraging sites. A paralyzed mouse seen in the entrance of a cave on Carlsbad Caverns National Park had probably been bitten by a rattlesnake that was seen nearby (Reames and Barber 2003). A live mountain patch-nosed snake (Salvadora grahamiae) at the bottom of a 13-meter pit was probably foraging on mice that have been seen at the bottom of the pit (T. Strong, pers. obs.).

Numerous species of mammals have been identified through the presence of tracks or scat, indicating use of the cave. Birds and reptiles may also leave evidence of this type in caves. These observations could fall into the category of incidental use, and evidence of this sort cannot be interpreted to explain why the animal was in the cave. Similarly, there is no direct proof that animals are using the caves to find relief from extreme conditions of high temperature and low humidity, although the favorable microclimates within caves are likely to be deliberately selected by many species.

Another category of use could be called unintentional use of cave resources. Animal remains found at the bottom of entrance pits probably did not intend to enter a cave, and once in, they were unable to get out. In many cases, these animals would be killed by the fall. However, some species appear to be able to survive relatively long drops. For example, a mountain patch-nosed snake apparently survived an overhanging drop of about 13 meters. Once inside the cave, it was seen on multiple occasions, and it was probably surviving on mice that have also been seen at the bottom of the drop. Lizards seen on multiple occasions at the bottom of a 50-meter drop may also be in this category. Skeletal material found in some caves suggests that these animals (or parts thereof) may have carried into the caves as prey items of carnivores. For example, jackrabbit and cottontail bones were found in Boyd's Cave. The short climb down into the entrance of this cave would make it very difficult for these animals to get out of the cave, but carnivores could easily climb in and out. The location of these bones in small alcoves and the presence of ringtail tracks in these areas suggest that ringtails could have carried these animals into the cave. Deer legs found in a cave with a large entrance were probably brought into the cave by a large predator (Carrington 1999), and mountain lions are known to use this cave (Roemer 2000).

Conclusions

The results of this study clearly demonstrate that caves of the Chihuahuan Desert are being used regularly by a wide variety of vertebrates. In spite of the dependence on random observations that happened to be reported, there are reliable records of at least 80 species in 160 caves of this region, and new records are added almost every time a cave is visited. This level of usage and the documented types of usage by these species demonstrates that the caves provide a habitat feature that is an important resource for many species. In an arid environment with extremes of high temperatures and low relative humidity, these caves could be critical to the survival of many vertebrates. Although none of the species observed in these caves are listed as threatened or endangered, their continued presence in the Chihuahuan Desert may depend on these cave resources.

With so many species depending on the caves of this region, it is imperative that management agencies, primarily the National Park Service

and the Bureau of Land Management, maintain policies that provide protection for these species and their habitat requirements. Most caves on Carlsbad Caverns National Park are administratively closed, although three caves are open for commercial tours (including tours in undeveloped areas) and eight others are open for recreational caving. As noted above, Carlsbad Cavern has a high diversity of species in spite of the heavy annual visitation. The Bureau of Land Management maintains a permit system for several of its caves, and there are some seasonal restrictions on visitation because of bats. However, many BLM caves are open for recreational caving with no restrictions.

Under the National Environmental Policy Act (NEPA), federal agencies are required to analyze potential environmental impacts prior to taking any action. Based on the evidence of vertebrate use in these caves, potential impacts on these wildlife species and their habitat requirements must be considered in any action affecting land use in this region. In addition, when these agencies are giving permits for recreational caving or for scientific research, they should provide the permit applicants with information about wildlife species using the caves and any precautions they should take when visiting the caves.

References

Allison, S. 2004. Cave C-108 trip report, 4/18/04. Unpublished data in Carlsbad Caverns National Park files.

Allison, S. and G. Roemer. 1998. Cave C-25 trip report, 9/7/98. Unpublished data in Carlsbad Caverns National Park files.

Bailey, Vernon. 1928. Animal life of the Carlsbad Cavern. Monographs of the American Society of Mammalogists, No. 3. Williams and Wilkins Co., Baltimore.

Baker, J. K., B. Crisman, and D. Geise. No date. Report on Cave C-18, early 1950's. Unpublished data in Carlsbad Caverns National Park files.

Belski, D. 1979. Trip report on Porcupine Shit Pit. Unpublished data in BLM files - Carlsbad Field Office.

Belski, D. 1988. Trip report on Rocking Chair Cave, GYPKAP report. Unpublished data in BLM files -Carlsbad Field Office.

Belski, D. 1989. Trip report on Chalk and Skylite Caves. Unpublished data in BLM files -Carlsbad Field Office.

Biotic Information System of New Mexico (BISON). 2004. Species Account. Internet site: http://fwie.fw.vt.edu/states/nm.htm. Accessed multiple dates, 2004.

Carrington, P. 1999. Goat Cave trip report. Unpublished data in Carlsbad Caverns National Park files.

Ek, D. 1991. Memo on Goat Cave. Unpublished data in Carlsbad Caverns National Park files.

Fleming, S. 1977. Trip Report on Root Cave. Unpublished data in BLM files - Carlsbad Field Office.

Fleming, S. and B. Hummel. 1977a. Cave description of Boyd's Cave. Unpublished data in BLM files - Carlsbad Field Office.

Fleming, S. and B. Hummel. 1977b. Cave description of Honest Injun Cave. Unpublished data in BLM files - Carlsbad Field Office.

Hoffmeister, D. F. 1986. Mammals of Arizona. University of Arizona Press, Tucson. 602pp.

Hummel, B. 1977. Cave description of Klutz Caverns. Unpublished data in BLM files - Carlsbad Field Office.

Jablonsky, P. and S. Kraemer. 1992. Lechuguilla Cave trip report, 6/5/92. Unpublished data in Carlsbad Caverns National Park files.

Kerbo, R. 1978. Deep Cave trip report, January 27, 1978. Unpublished data in Carlsbad Caverns National Park files.

Kingsley, K. J., T. R. Strong, E. L. Smith, and T.K. Snow. 2001. Caves and Mine Adits as Wildlife Resources in the Sonoran Desert Region. Pp. 138-140 in Proceedings of the 15th National Cave and Karst Management

Symposium, October 16-19, 2001, Tucson, Arizona.

Lindsley, P. 1967. Lake Cave trip report, July 5, 1967. Unpublished data in Carlsbad Caverns National Park files.

Mosch, C., M. Goar, T. George, and K. George. 1991. Cave C-72 trip report, 1/20/91. Unpublished data in Carlsbad Caverns National Park files.

NatureServe. 2004. NatureServe Explorer, an online encyclopedia of life. Internet site: http://www.natureserve.org/explorer/. Accessed multiple dates, 2004.

Novack, A. 2004. Cave C-72 trip report, 4/13/2004. Unpublished data in Carlsbad Caverns National Park files.

Parent, L. 1998. Cornering a Lion! Canyons and Caves No. 11, Winter 1998.

Pate, D. 1992. Trip report on Adobe Cave, May 31, 1992. Unpublished data in BLM files - Carlsbad Field Office.

Pate, D. 1997. Bats Found in Carlsbad Cavern. Canyons and Caves, No. 6, Fall 1997.

Pate, D., H. Burgess, and J. Richards. 1995. Cave C-60 trip report, 6/7/95. Unpublished data in Carlsbad Caverns National Park files.

Reames, S. and R. Barber. 2003. Lechuguilla Cave trip report, 10/13/03. Unpublished data in Carlsbad Caverns National Park files.

Roemer, D. 2000. Mountain lion observations report. Unpublished data in Carlsbad Caverns National Park files.

Spangle, P. and M. Thompson. 1958. Report on Cave C-20, May 18, 1959. Unpublished data in Carlsbad Caverns National Park files.

Welbourn, W. C. 1978. Biology of Ogle Cave with a List of the Cave Fauna of Slaughter Canyon. NSS Bulletin 40(1):27-34.
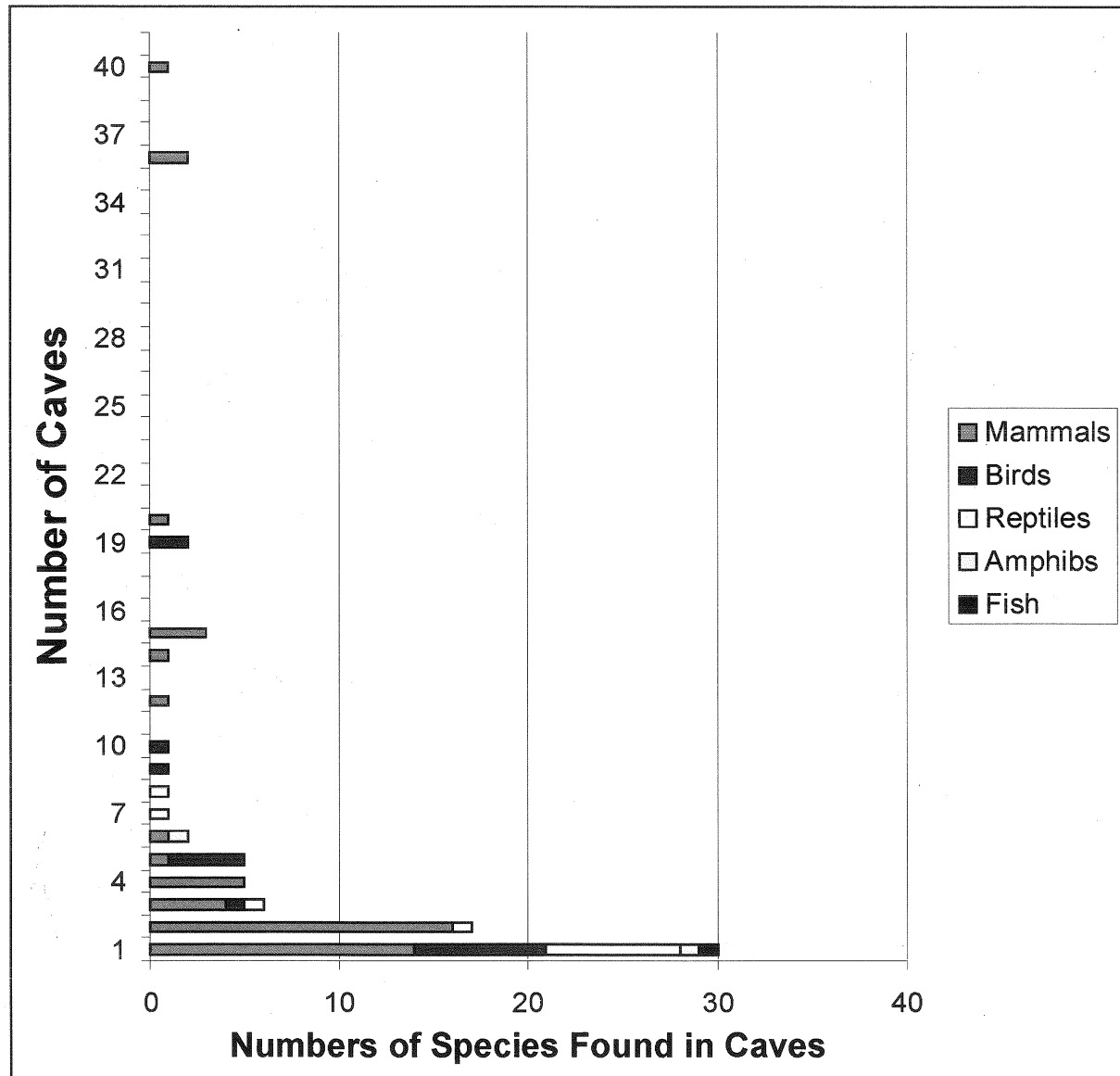
Figure 1. Species Distribution in Caves. The x-axis represents the number of vertebrate species reported in the number of caves on the y-axis. The majority of species are reported in only one or two caves, while a few species have been reported from more than twenty caves.
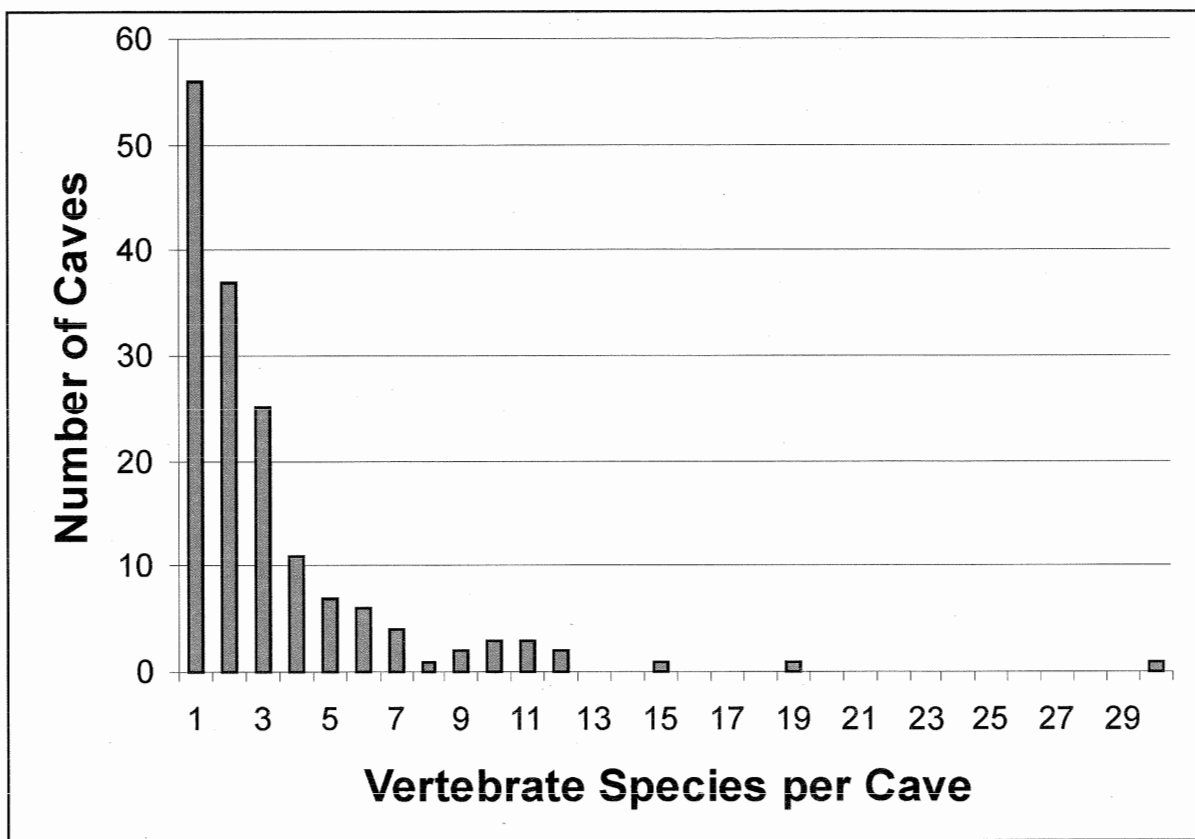
Figure 2. Species Diversity Within Caves. The x-axis represents the diversity of vertebrate species reported in the number of caves on the y-axis. The majority of caves have reports of three or fewer species, while one cave has reports of thirty species.

O-74

An overview on biodiversity of cave dweeling copepods (crustacea) in Romania

S. Iepure

Speleological institute "Emil Racovita", Cluj, Romania

Abstract

Copepods are common components of the cave dwelling fauna, and greatly increase the diversity of cave communities. With more than 900 species/subspecies known from continental groundwater, copepods inhabit all kind of aquifers (karstic, fissured and porous). Here we examine the diversity pattern of cave dwelling crustacean copepods in different karst areas from Romania. The group were analysed primarily from taxonomic perspective with special attention paid to regional diversity and their endemic and rare biota. The karst areas in Romania have been defined as an area of relatively high copepods biodiversity in respect of karst development. Their diversity at higher taxa is similar with those from others Europeans regions, but with less species in each genus. The subclass Copepoda includes members of the two orders Cyclopoida and Harpacticoida; whereas no underground forms of the Calanoida order are known. 5 subfamilies, 17 genera and 49 species were recorded in cave dwelling habitats. Their diversity is mostly a result of ecological and morphological diversification of Bryocamptus genus within harpacticoids and Diacyclops and Acanthocyclops among cyclopoids. Most of the taxa are specialists, but generalists are also present, whith 26 hypogean and 23 epygean species recorded. The high copepods diversity was registered in the most developed karst areas located in north-western and south-western Romania. The cave copepods fauna from the latest karst region seems to be more similar with the Bulgarian one, rather than with that from the north-western part. Species such as Speocyclops lindbergi Damian, Acanthocyclops propinquus Plesa, Diacyclops deminutus Chappuis and probably Acanthocyclops balcanicus Naidenow & Pandourski, among cyclopoids are known from both countries. The strictly subterranean species have very restricted ranges; 16% of them are local or regional endemics, mostly located in karst area from north-western part of Romania. From the total known cave dwelling endemites, 63% are cyclopoids and 54% harpacticoids. The high rate of endemicity was registered in the case of cyclopoids kieferi complex of Acanthacyclops genera. Some taxa that are widely distributed in European groundwater have low species richness and very restricted range in Romania, thus, they were considered rare from our country. Such is the case of stygobitic species from Speocyclops and Graeteriella genera among cyclopoids and Bryocamptus, Echinocamptus and Elaphoidella among harpacticoids. Biodiversity pattern of copepods as well as their endemicity in cave dwelling habitats will provide an essential tool for conservation of a cave or a karst area. Significant efforts remain to be done to conserve not only this small group of crustaceans from Romanian underground, but also all the groundwater fauna.

O-75

How diverse is the Romanian subterranean fauna?

O. Moldovan

Speleological institute "Emil Racovita", Cluj, Romania

Abstract

Romanian karst is patchy, forming small islands between non-calcareous rocks, and covering only 2% of the country surface, but with many caves - more than 10.000. These can explain the high number of cave species in a geographical region where cave adapted forms are rather rare. An overview of Romanian subterranean fauna and comparisons with neighboring regions are presented, together with the state-of-art of protected caves and cave fauna in Romania.

O-76

The impact of organic load on geomicrobial transformations in oligotrophic cave environments.

Nicholas M. Taylor[1], Michael Kreate[2], Janet Bertog[2] and Hazel A. Barton[1*].

[1] Departments of Biological Sciences and [2] Physics & Geology,
Northern Kentucky University, Highland Heights, KY 41099
* Corresponding author: bartonh@nku.edu and www.cavescience.com

Abstract

Due to the oligotrophic nature of caves, to survive in this environment microorganisms utilize a number of different methods to fix carbon, generate energy and obtain nutrients. To asses the effect of organic load on such processes, we carried out a comparative study within Carlsbad Caverns National Park. Carlsbad Cavern is a hypogenic cave system that formed through sulfuric acid speleogenesis. The host rock comprises of the dolomitic Yates formation, with numerous secondary elements including iron, manganese, titanium, silica and other constituents of sedimentary minerals. Samples were collected from different locations based on relative organic load and were analyzed by liquid chromatography mass-spectroscopy, X-ray diffraction and scanning electron microscope with energy dispersive spectroscopy, while DNA was extracted from the bedrock for molecular phylogenetic analysis of the microbial community structure. Our result demonstrate that there is a diverse microbial population associated with the significant mineral transformation takes place in the severely nutrient deprived environment, with a breakdown of the dolomite matrix and the oxidation of Fe(II) to Fe(III) or subsequent reduction to Fe(0). At the site with observable nutrient input there is limited microbial diversity with no observable mineral transformation. Our results suggest that organic input into the cave system dramatically influences the community structure of the microorganisms found there, and the subsequent geomicrobial mineral transformations taking place. This is presumable due to the higher efficiency of obtaining carbon and energy from heterotrophic, versus chemolithotrophic, processes. Our results suggest that the relative levels of geomicrobial activity observed in geologic samples may directly relate to the amount of organic material that has entered the system.

Introduction

Due to extremely low biomass in cave environments and the difficulty in extracting DNA from chemically complex geologic samples, most culture-independent studies of microbial activity have tended to examine areas of measurable energy input (1, 2, 10, 15, 16). Despite this, in a recent study we used molecular phylogenetics to determine what, if any, microbial activity was occurring within an oligotrophic cave without measurable energy input (3). Our results suggested that a diverse microbial flora subsisted in this extremely oligotrophic environment (7, 8). Our results suggested that the microbial community within this environment subsisted by using barely perceptible carbon and energy sources; including organics entering the system through percolation, or the presence of volatile organic molecules within the atmosphere (3). The presence of phylotypes that demonstrated identity to organisms capable of carrying out iron oxidation suggested that microorganisms within the community were able to use energy sources such as reduced iron within the bedrock of the cave itself. We also detected the presence of a high proportion of nitrogen assimilating organisms. This may suggest a source of nitrogen, which along with phosphate, is a limiting nutrient in the majority of organic material percolating into cave systems (13). Such a broad phylogenetic distribution of bacterial species has been identified by other investigators in similarly oligotrophic cave environments (5).

Together, our data have led us to hypothesize that the large diversity of microorganisms found in extremely oligotrophic cave environments reflects syntrophic interactions that support community growth under such starved conditions (Figure 1). Our model suggests that due to the complex nature of organic carbon and energy sources entering the system, not one organism is capable of carrying out all the energetically favorable catabolic reactions necessary to support growth (11, 13). Rather, energetic restrictions only allow certain reactions to proceed through a close interaction with species that remove intermediates, allowing energy conservation in what would otherwise be an endothermic reaction (17). Such syntrophy has been described for anaerobic ethanol fermentation and methane oxidation (where the removal of hydrogen through syntrophic interactions is critical to energy conserving reactions) and the breakdown of complex aromatic compounds (17). Such interactions may also be a central issue in the unculturability of most microorganisms in the environment; syntrophic interactions may make many organisms recalcitrant to cultivation, where appropriate growth conditions may be dependent on specific spatial and metabolic interactions. Our previous data also suggests that such syntrophic interactions allow the bacteria present in the environment to extract nutrients and energy from the rock on which they grow.

In order to address many of the questions regarding nutrient input we carried out a comparative analysis of two microbial cave communities. While the geologic nature of both environments was similar, one community was considered copiotrophic due to organics being brought directly into the system through the entry of surface waters along a geologic fault. The other community was considered oligotrophic, with no measurable organic input. We compared the different organic loads and interactions of the community with the rock matrix in order to determine whether a mineral transformation or geologic signature would indicate microbial-mineral interactions.

Figure 1. Models for potential nutrient flow in microbial communities. **A)** The nutrients pyramid represents the classical view of nutrient flow in macroscopic community systems. Energy from sunlight (e⁻) flows into the community and is fixed by photosynthetic primary producers (c). These primary producers are in turn consumed by species in higher trophic levels (b), until he top consumer is reached (a). **B)** Our proposed model for microbial community nutrient flow. We see that in caves, without significant predation and no higher eukaryotes present in these starved systems, the trophic levels are essentially flat. Looking down on this network, some species are better adapted for energy (e⁻) conservation from the sources available, such as organic molecules in the atmosphere. This energy is fixed into the community with the release of excess metabolites, such as ethanol and formate, to balance reducing power in the cell (a, c and f). Other species can subsequently utilize these metabolites as a carbon and energy source to fix other essential nutrients (n), such as nitrogen, from the environment (b, d and g). In turn, these species release excess nutrients into the community, allowing continued growth by the primary energy fixing species.

Materials and Methods

Sample site and collection. Carlsbad Cavern was formed in Paleozoic reef sediments by hypogenic sulfuric acid speleogenesis, with a postulated biogenic origin. The Carlsbad cave system is dominantly within the reef complex of the Capitan Formation. The Guadalupe Rise is near the contact of the back-reef Yates Formation and the Guadalupe Formation. The relatively impermeable iron-rich, silty Yates Formation traps oxygenated groundwater and releases it into the Capitan Formation (9). The cave is located within a desert area, does not contain any surface streams and is not prone to flooding (12).

Samples for collection were identified based on a number of parameters, including the presence of water, proximity to a joint, altered bedrock or secondary mineralization. During sampling, we recorded temperature and humidity, with no significant differences between locations. Samples were collected from two different areas of Carlsbad Cavern based on the entry of surface organics into the system; WF1 is approximately 30 m from the tourist trail and is located in an area that receives a steady input of seeping surface waters; sF88, is located approximately 1 km from the tourist trail in a rarely visited area of the cave (trip reports indicate only 3 past trips to the area). The area is dry, with no indication of seeping or dripping water and has a significant corrosion residue formed on the surface of the rock. Three 5 g rock samples were collected from each location using a sterilized Dremel drill tool, one each for geology, chemistry and biology. Each sample was preserved in an appropriate manner for the subsequent tests (DNA extraction in 70% alcohol with storage at -20°C, while chemistry and geology samples were collected in gamma-irradiated clean tubes; chemical samples were stored at 4°C). Methods for DNA extraction from the carbonate rock and molecular phylogenetic analyses are described elsewhere (3, 4).

Results

In order to carry out a comparative molecular phylogenetic study of microbial cave communities, we began by identifying two distinct areas in Carlsbad Cavern that had the same geology but quite different levels of available organic material from the surface, WF1 and sF88 (Figure 2). Due to a geologic fault and subsequent conduit for surface water and associated organic material seeping into the cave, WF1 is considered the energy 'rich' (copiotrophic) ecosystem, while sF88 is considered 'starved' (oligotrophic). Each environment was compared for chemical, geologic and biological activity.
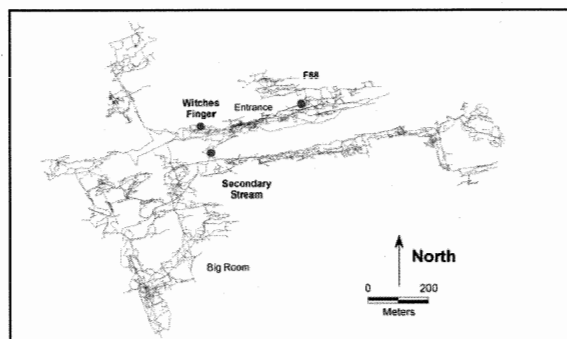
Figure 2. Map of Carlsbad Cavern. Collection sites for Witches Finger (WF1) and sF88 are indicated. The secondary stream location indicates the location of the tourist elevators and underground lunchroom.

To qualitatively compare the amount of organic material present at WF1 and sF88, 100 mg of rock sample was powdered and extracted with water and hexane and then analyzed using liquid chromatography coupled mass spectrometry (LC-MS). A qualitative analysis was carried out to make sure there was no significant difference in the type of organic material present at each location; for example, as a direct result of surface spills from any of the commercial facilities (sewage tanks, fuel tanks, etc.) above the cave. The LC-MS data (not shown) demonstrated that the type of organic material present at each location is similar; however, a significantly higher amount is found at WF1. This is in agreement with our identification of WF1 as an area receiving a larger input of surface organic material. A rudimentary analysis of the LC-MS peaks indicates that the organic material found at each location is rich in phenolic and aromatic compounds, as would be expected for organic material commonly found in soils (18).

Once we had established that there was a significant difference in the organic material present at each location, we used thin-section and X-ray powder diffractometry (XRD) analyses to examine whether there was any structural difference between these locations (Figures 3 and 4). The thin-

sections demonstrated that at WF1 there is no observable change between the native structure of the rock and the surface (Figure 3). In comparison, at sF88 the rock appears to have undergone a dramatic change, with a powdering of the surface. Gross examination of the sF88 site reveals a powdery, red/pink corrosion residue that is > 1 cm thick, bearing little resemblance to the host rock structure.
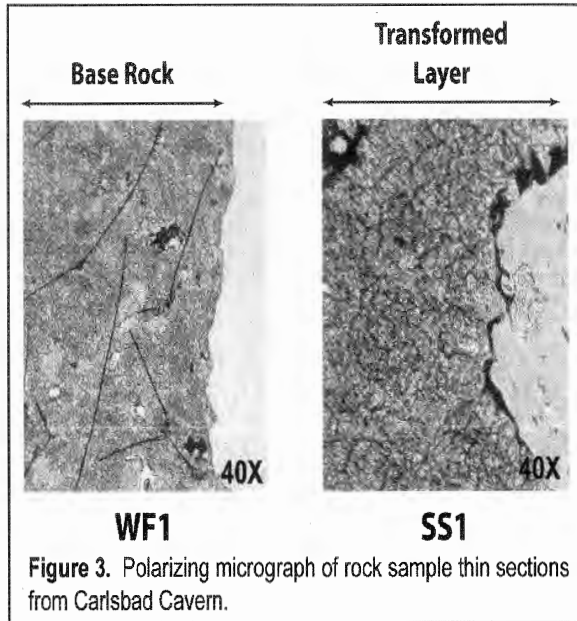
Figure 3. Polarizing micrograph of rock sample thin sections from Carlsbad Cavern.

While the thin section observations suggested that there were significant structural changes occurring at sF88, it is impossible to differentiate biotic versus abiotic processes without further examination. To determine what mineral changes were occurring at sF88, we carried out comparative x-ray powder diffractometry (XRD). At each location the sample collected was broken down into two components; the host (base) rock and the surface layers. The results of the XRD analysis (Figure 4) demonstrated that, in agreement with our thin-section analysis, that there were no changes in the mineral structure at WF1; however, at sF88 there appeared to be significant mineral changes. The peaks indicated that the dolomitic structure of the rock at this location was completely changed, being replaced with material that appeared to contain a large amount of iron oxides.
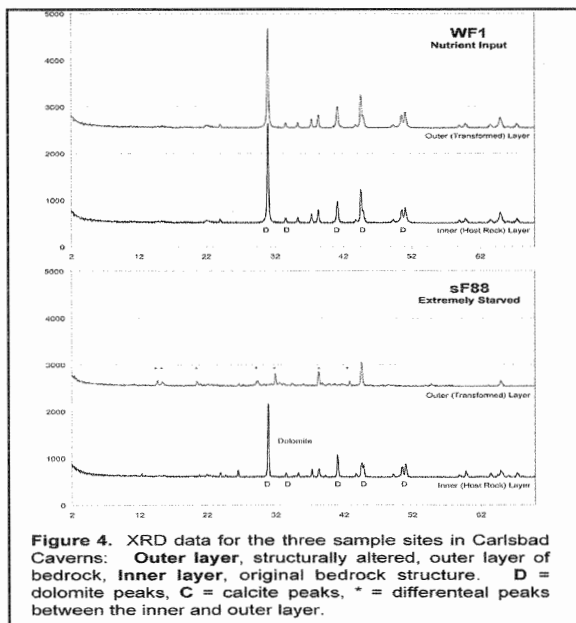
Despite the ability of XRD to identify structural changes within the rock, the new peaks observed at sF88 did not conclusively represent iron oxides. To determine if these new peaks were indeed iron oxides, we extracted the sF88 corrosion residue with hydrochloric acid, allowing the identification of non-dolomitic peaks through energy dispersive spectroscopy (EDS). The results (Figure 5) indicate that the majority of the insoluble particles at sF88 were indeed iron oxides, elemental iron particles or iron-rich clays. The material at WF1 was similarly extracted and subjected to EDS analysis; however, only clay particles were identified in the insoluble particulates. Such clays are a commonly found as particulate matter within the Carlsbad dolomite.

In order to determine whether the amount of organic material we observed at WF1 and sF88 affected the microbial community structure, we carried out a comparative molecular phylogenetic study. Approximately 50 ng of DNA was extracted from each location using our standard DNA extraction protocol (4). To produce 16S SSU-rDNA PCR products for cloning we used the 8F and 805R bacterial specific primer set, which provide the best PCR product for cloning at these low DNA concentrations. While this rDNA product is short (~800 bp in length), it still provides sufficient information for statistically-significant phylogenetic placement (14). Clone libraries were created for both sF88 and WF1, with 144 and 96 clones identified at these sites respectively. The clone sequences were screened by RFLP to identify unique phylotypes, which were screened against the RDP and low-biomass contaminant databases to remove chimeric and contaminating sequences (4). The remaining clone libraries contained 49 unique phylotypes for sF88 and 38 unique phylotypes for WF1. The sequences of these phylotypes were compared with the NCBI database and the closest cultivated relative was identified. The relative taxanomic distribution of bacterial divisions at each environment is shown in Figure 6.

The results of the molecular phylogenetic studies demonstrate that the copiotrophic WF1 community is dominated (84%) by members of the Actinobacteria, a broad class of high G+C, gram-positive bacteria identified in a range of environments, particularly the soil. Interestingly, within the

Figure 4. XRD data for the three sample sites in Carlsbad Caverns: **Outer layer**, structurally altered, outer layer of bedrock, **Inner layer**, original bedrock structure. **D** = dolomite peaks, **C** = calcite peaks, * = differenteal peaks between the inner and outer layer.
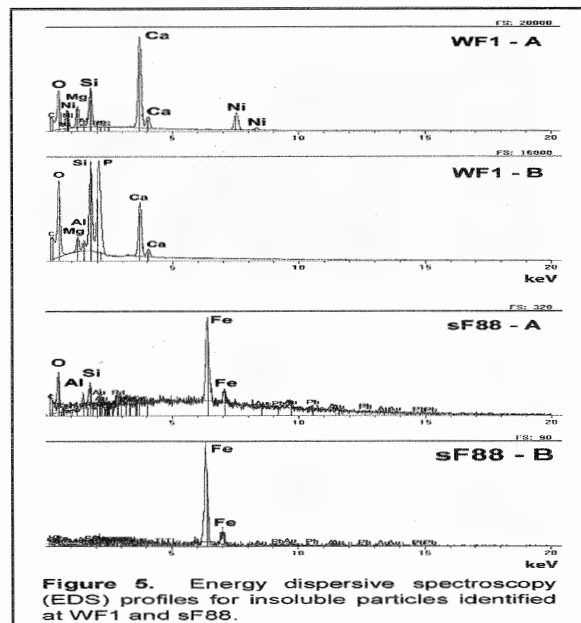
Figure 5. Energy dispersive spectroscopy (EDS) profiles for insoluble particles identified at WF1 and sF88.

oligotrophic sF88 community is much more diverse, including the identification of additional members from the gram-positive Clostridia/Fimucites/Bacilli group. Included within the sF88 clone library is also a much broader representation by members of the Proteobacteria, including the alpha, beta and gamma-subclasses.

Discussion

It was the aim of this study to determine what role the amount of energy entering a cave system has on microbial community structure. To do this, we compared how the organic load entering the system, presumably through the percolation of surface waters, affects the type and mechanism of energy acquisition. Our results support our hypothesis that as the system becomes more starved, there is an increase in the diversity of the microbial species found; a hypothesis which is contrary to the accepted ecological literature regarding nutrient limited conditions. In the context of the cave environment, it is interesting to note that as the amount of available organic material falls, the amount of mineralogical change observed increases, as demonstrated by thin-section microscopy and XRD. Further, our XRD and EDS analyses suggested that in the most starved environment, corrosion residues form that contain iron oxides and elemental iron. While there is a small amount of reduced iron within the dolomite bedrock, this accumulation may suggest that iron oxidation and reduction reactions are being used as a primary energy conserving mechanism.

In order to examine what metabolic activity is supporting community growth between the sF88 and WF1 sites, we examined the unique phylotypes found within each environment. The predominant phylotypes identified at WF1 are members of the Actinomycetes, which demonstrate the ability to break down and utilize complex organic molecules, as would be anticipated in an environment rich in soil detritus (6). The dominance of this copiotrophic community by one bacterial group may suggest that, indeed, in this environment with rich nutrient input, the standard rules of competitive exclusion apply (19). The structure of the microbial community at sF88 is significantly more complicated, with bacterial species that display an array of metabolic activities; these activities include atmospheric nitrogen and organic carbon fixation, methane, hydrogen and iron oxidation, the breakdown of complex organic molecules and the mobilization of inorganic phosphorous (6). The sum of all these metabolic activi-

ties is shown in Figure 7. While simplified, this metabolic web reflects our original hypothesis that syntrophic reactions may be occurring within these extremely starved environments. These metabolic relationships may allow these species to obtain energy and carbon from sources that might otherwise not provide sufficient free energy to support ATP synthesis and growth.

The initial premise of this study was to examine whether syntrophic relationships were responsible for the energy acquisition strategies observed within extremely starved cave environments. Our results, while preliminary, suggest that as the cave environment becomes increasingly starved, bacterial species are forced to rely more heavily on chemolithotrophic strategies for energy acquisition and growth. The sources of energy and nutrients for such metabolic activity appear to be available from the cave atmosphere and host rock, ultimately resulting in geomicrobial transformations through the processes of energy acquisition. Nonetheless, these results remain preliminary, and we are in the process of carrying out cultivation studies to further resolve potential mechanisms of syntrophy and energy acquisition.

Acknowledgements

References

1. Angert, E. R., D. E. Northup, A.-L. Reysenbach, A. S. Peek, B. M. Goebel, and N. R. Pace. 1998. Molecular phylogenetic analysis of a bacterial community in Sulphur River, Parker Cave, Kentucky. Am. Mineralogist. 83.1583-1592.

2. Barton, H. A., and F. Luiszer. 2005. Microbial Metabolic Structure in a Sulfidic Cave Hot Spring: Potential Mechanisms of Biospeleo-

Figure 6. Distribution of identified bacterial divisions within oligotrophic (sF88) and copiotrophic (WF1) environments within Carlsbad Cavern. Slices correspond to the percentage of representative clones within each of the clone libraries.

8. Groth, I., R. Vettermann, B. Schuetze, P. Schumann, and C. Saiz-Jimenez. 1999. Actinomycetes in Karstic caves of Northern Spain (Altamira and Tito Bustillo). J. Microbiol. Methods. 36:115-122.

9. Hill, C. A. 1987. Geology of Carlsbad Cavern and other caves in the Guadalupe mountains, New Mexico and Texas. NM Bureau Mines Miner. Res. Bull. 117:150 p.

10. Holmes, A. J., N. A. Tujula, M. Holley, A. Contos, J. M. James, P. Rogers, and M. R. Gillings. 2001. Phylogenetic structure of unusual aquatic microbial formations in Nullarbor Caves, Australia. Environmental Microbiology 3:256-264.

11. Juttner, F. 1984. Dynamics of the volatile organic substances associated with Cyanobacteria and Algae in a eutrophic shallow lake. App. Environ. Microbiol. 47:814-820.

12. Klimchouk, A. B., D. C. Ford, A. N. Palmer, and W. Dreybrodt. 2000. Speleogenesis: Evolution of Karstic Aquifers. National Speleological Society, Huntsville, AL.

13. Laiz, L., I. Groth, I. Gonzalez, and C. Saiz-Jimenez. 1999. Microbiological study of the dripping water in Altamira Cave (Santillana del Mar, Spain). Journal Microbiological Methods 36:129-138.

14. Nei, M., S. Kumar, and K. Takahashi. 1998. The optimization principle in phylogenetic analysis tends to give incorret topologies when the number of nucleotide or amino acids used is small. Proc. Ntl. Acad. Sci. USA 95:12390-12397.

15. Northup, D. E., and K. H. Lavoie. 2001. Geomicrobiology of Caves: A Review. Geomicrobiology J. 18:199-222.

16. Sarbu, S. M., T. C. Kane, and B. K. Kinkle. 1996. A chemoautotrophically based cave ecosystem. Science 272:1953-1955.

17. Schink, B. 2002. Synergistic interactions in the microbial world. Ant. Leeuwenhoek 81:257-261.

18. Sylvia, D. M., J. J. Fuhrmann, P. G. Hartel, and D. A. Zuberer (ed.). 1999. Principles and Applications of Soil Microbiology. Prentice Hall, Upper Saddle River, NJ.

19. Tilman, D. 1982. Resource competition and community structure. Princeton University Press, Princeton.

279

Figure 7. Metabolic structure of the microbial community identified at sF88. Presumed metabolic activity was obtained by phylogenetic comparison to the next closest cultivated species.

genesis. J. Cave Karst Stud.67:28-38.

3. Barton, H. A., M. R. Taylor, and N. R. Pace. 2004. Molecular Phylogenetic Analysis of a Bacterial Community in an Oligotrophic Cave Environment. Geomicrobiology J. 21:11-20.

4. Barton, H. A., N. Taylor, and A. Pemberton. 2005. DNA extraction from low biomass carbonate rocks: Improving yield while reducing contaminants. Journal of Molecular Methods Submitted.

5. Chelius, M. K., and J. C. Moore. 2004. Molecular Phylogenetic Analysis of Archaea and Bacteria in Wind Cave, South Dakota. Geomicrobiology J. 21:123-134.

6. Dworkin, M. 2002, posting date. The Prokaryotes: An evolving electronic resource for the microbiological community. Springer-Verlag, New York. [Online. http://link.springer-ny.com/link/service/books/10125]

7. Groth, I., and C. Saiz-Jimenez. 1999. Actinomycetes in Hypogean Environments. Geomicrobiology J. 16:1-8.

O-77

Landscape evolution and speleogenesis in Gråtådalen valley, Northern Norway.

Terje Solbakk & Stein-Erik Lauritzen

Department of Earth Science, University of Bergen, Allègt. 41, N-5007 Bergen, Norway

Abstract

Gråtådalen valley, Svartisen, north Norway is a hanging tributary to a larger valley, where the junction is perched on erosion-resistant schists. Marble bands further up-valley contain numerous caves at various levels above the valley floor. This situation is ideal for testing the possible connection between stages in valley downcutting and corresponding morphological signatures in the caves. The caves are subject to accurate re-surveying, allowing a thorough speleogenetic and speleochronological analysis. This is part of an ongoing master thesis at the University of Bergen, Norway and further details will be given in the oral presentation.

Introduction

The southern part of North Norway; Nordland county, is situated within Caledonian allochtonous rocks containing marble outcrops that has been more or less heavily karstified, classified as the Norwegian stripe karst type (Horn, 1935; Lauritzen 2001). Gråtådalen (66°N 14°E) is a tributary valley situated in the Salten area above the Arctic Circle, Figure 1. The valley displays intense karstification in the mid and lower part. There are approximately 70 caves here, described by Corbel (1957, pp175-184), St.Pierre's (1966), Lauritzen (1983) and others. The valley is generally a glacially sculptured through, but is incised by a smaller fluvial, V-shaped trench along its entire length. , The lower-mid part is an over-deepened basin containing glaci-lacustrine sediments. The fluvially incised valley continues towards the present-day valley outlet. The main valley has several shoulders wchic allude to stages in its erosional history. Several of these shoulders correlate roughly with the position of cave passages.
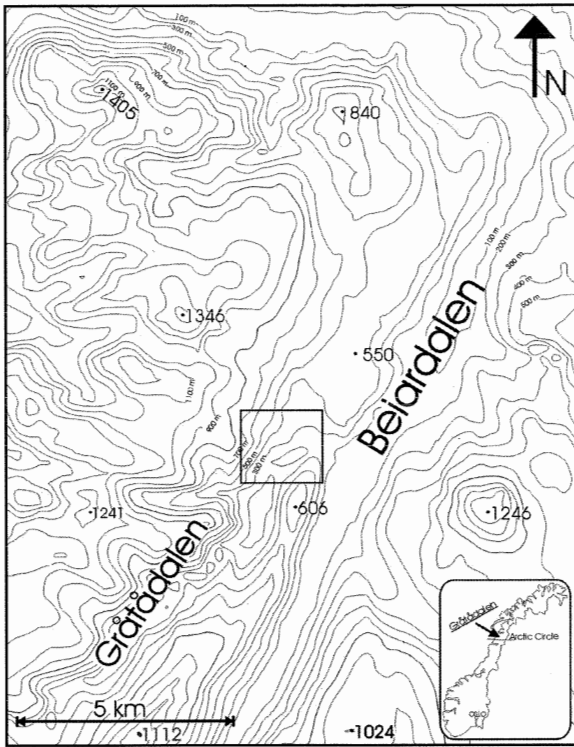
Figure 1.
Topographic setting of the study area, showing Gråtådalen as a tributary to the larger Beiardalen. Heights in meter. The location at The Arctic Circle is shown in the inset; the square at the valley junction depicts the outline of Figure 2.

280

Table 1

Caves of central Gråtådalen, data from previous reports.

No.	cave	length	depth	comments
1	Øvre Rønnalihøla	1800	-110	Caves 1, 2, 3 are linked
2	Smith`s Cavern	1800	-110	
3	Rønnålihøla	1800	-110	
4	Satisfaction Cave	1000	55	
5	Unnamed Cave	270	40	
6	Nedre Svartvassgrotta	160		
7	Øvre Svartvassgrotta	800	-100	
8	Løvstadgrotta	190		
9	Nedre Stormdalshøl	50	55	Depth Cave 9 + 10
10	Øvre Stormdalshøl	1200	55	Caves 10 and 11 are linked
11	Jordbruhøla	1200		
12	Isgrotta	130		

Caves and their topographic setting.

Several valley shoulders in Gråtådalen seem to correlate with the levels of the caves up in the hillsides. The caves are mainly of vadose origin, but with some phreatic elements. Scattered fluvial sediments can be found in several levels within the caves. The change in valley evolution has left behind 10-15 km of the paleic valley further north of the outlet, and can today be seen morphologically as a broad valley shoulder to the main valley of the area. The aim of this study is to test the hypothesis on chang-
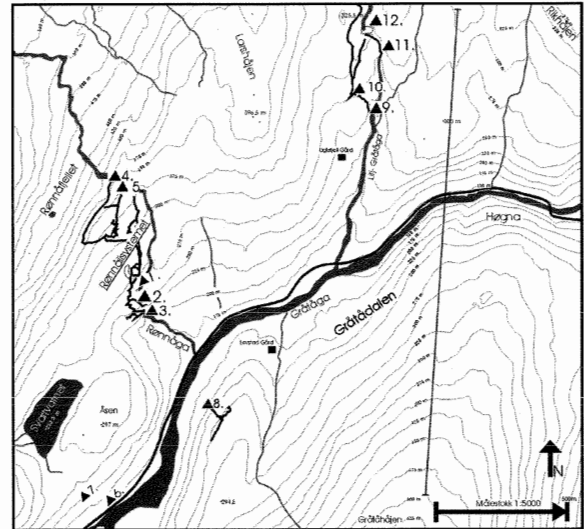
Figure 2.
The caves of central Gråtådalen, in part after StPierre (1966), Holbye & StPierre (1973) and StPierre 2003. Numbers refer to caves listed in Table 1. Most of these caves will be resurveyed in the present project. The vertical line transect represent the valley cross-section used in Figure 3.

ing valley outlet by carrying out accurate cave surveying and to use uranium series dating techniques on calcite concretions and speleothems. It is hopefully possible to gain absolute dates and attach those to reveal part of a successive valley evolution history. Recently an investigation carried out by the Geological Survey of Norway (Olesen et al, 2004) showed a probablye neotectonic feature on the eastern ridge adjacent to the valley. The fracture is associated with gravitational spreading and collapse (sackungen) features. We will investigate whether neotectonic activity might have affected the speleogenetic development in adjacent caves.

Chronology

Speleothems are extremely rare in the caves, although calcareous concretions and local cementation of glacigenic sediments (Höhlenkrapfe or marl balls, Kyrle 1923) are occationally found. We hope to date such deposits at geomorphologically crucial positions in order to post-date erosion or sedimentation episodes. Previously, a flowstone covering a sand deposit in Løvstadgrotta (No. 8, Figure 2 and Table 1) dated to 9.46 ± 0.46 kyr by Uranium-series dating (α- counting).
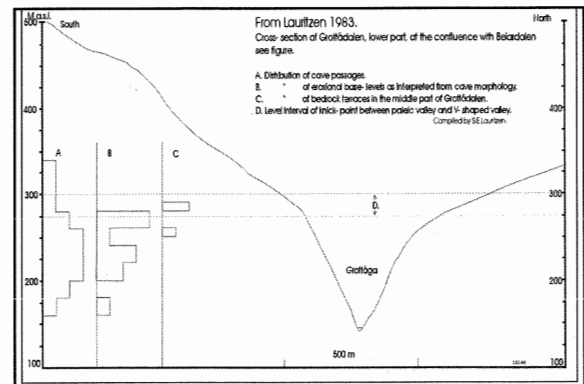
Figure 3.
Compilation of previous data suggests that the cave passages are concentrated at or below the main knick-point of the Gråtådalen valley, after Lauritzen (1983). This knick-point represents the floor of the presumably pre- or early Quaternary, "paleic" valley.

Compilation and further work

A previous compilation of the vertical distribution of all data known up to 1983 suggest that speleogenesis may be linked to the development of the younger, V-shaped incision into the paleic Gråtådalen valley, Figure 3. Both the total vertical distribution of caves, 'probable base-levels' in the cave surveys and the level of bedrock terraces further upvalley are concentrated at or closely beneath the transition between the two valley profiles. The interpretation of cave morphology from the existing cave maps is dubious, as the caves are basically mapped in the horizontal plane and the quality of mapping is not adequate for morphogenetic interpretation. In order to identify clear mesoscale vadose/ phreatic transitions (e.g. Lauritzen & Lundberg 2000) and rule out possible structural influences, detailed 3D surveying and close inspection is necessary.

References

Corbel, J., 1957; Les Karsts du nord-ouest de l`Europe. Mem. Docums. Inst. Etud. Rhodan. 12, 541 pp.

Holbye, U. & St.Pierre, D. 1972: *Caves of the Store Rønåga Gråtådal, Beiarn*. End paper, Swetc caving Club Occational Publication No. 3. p 45.

Kyrle, G. 1923: Grundriss der Theorethischen Speläologie. Speläologische Monographien, Bd 1. 353 pp.

Lauritzen, S.E., 1983; Arctic and Alpine Karst Symposium, August 1-15, 1983, Department of Chemistry, University of Oslo.

Lauritzen, S.E. 2001: Marble stripe karst of the Scandinavian Caledonides: and end-member in the contact karst spectrum. Acta Carsologica 30 (2) 47-79.

Lauritzen, S.E. & Lundberg, J. 2000: Meso- and micromorphology of caves: Solutional and erosional morphology. pp. 408-426 in Klimchouk, A.B.; Ford, D.C.; Palmer, A.N. & Dreybrodt,W. (Eds.) Speleogenesis. Evolution of Karst Aquifers. National Speleological Society, USA, 527 pp.

Olesen, O.; Blikra,L.H.; Braathen,A.; Dehls,J.F.; Olsen,L.; Rise, L.; Roberts, D.; Riis,F.; faleide,J.I. & Anda,E. 2004: Neotectonic deformation in Norway and its implications: a review. Norwegian Journal of Geology, 84, pp 3-34.

St.Pierre, D. and others 1966; The Caves of Graataadalen, Northern Norway. The transactions of the Cave Research Group of Great Britain. 8 (1), pp. 1-64.

StPierre, D. 2003: Norges lengste og dypeste grotter (Norways longest and deepest caves). Norsk grotteblad (40) pp 3-9.

O-78

The Iza Cave studies - previous and present work

T. Tamas

Emil Racovitza Speleological Institute, Cluj Napoca, Romania

Abstract

Iza Cave is a contact cave occurring in the NW Rodnei Mountains, Romania, developed at the contact between crystalline schists and Upper Eocene limestones. The cave passages also expose smaller outcrops of Lower Eocene quartzitic conglomerates, marbles and a tectonic breccia. The total length of the cave is 2300 m, with a maximum depth of 160 m. The first exploration of the cave took place in 1976-1977 and was followed by a survey and morphology report. Several considerations were made on the influences of the host rocks on the passage morphology, with the Eocene limestones participating with only 14% along the whole cave. A large weathering deposit of the schists exposed by the cave river was found on the side of the main passage, 300 m from the entrance and covering a surface of over 5000 m2. A preliminary mineralogic study on the weathering deposit has shown that they consist of illite, muscovite (sericite) and kaolinite, with some remnant quartz. A second study that started in 2000-2001 and which is in (slow) progress, aims to produce a more precise re-mapping of the cave, considering detailed morphologic, structural, petrographic and mineralogic information on the rocks and on the secondary cave deposits. Although the cave has few sectors with speleothems, new mineralogical findings include so far aragonite, goethite, hematite, gypsum, and sulphates from the jarosite group, along with the suite of clay minerals formed by the weathering of metamorphic rocks. This paper reviews the results obtained so far since the first exploration of the Iza cave and presents the state of the ongoing study.

O-79

The morphology of the Izvorul Izei Cave (Rodnei Mountains, Romania)

T. Tamas, A. Persoiu

Emil Racovitza Speleological Institute, Cluj-Napoca, Romania

Abstract

The Iza Spring (Izvorul Izei) is the actual spring of a karst system located in the NW Rodnei Mountains, Romania. The upstream part of the system is the Iza Cave, developed at the contact between crystalline schists and Upper Eocene limestones, and surveyed at a length of 2300 m and a depth of -160 m. Recent work at the Iza Spring has lead to the exploration and survey of a new cave, ca 500 m long, representing the lowermost part of the Iza karst system. Our paper focuses on the morphologic features of the Izvorul Izei Cave and their relation with the structural and tectonic elements. The cave is developed in Upper Eocene limestones with some sandstone intercalations which form a simple monocline structure. The primary development of the main passage of the cave was controlled by structural and tectonic factors, as it may be seen in the passage orientation (along fractures in the limestone body) and the morphology of the ceiling, developed along a bedding plane during the phreatic stage of formation. A good indicator of the influence of bedding planes on the passage morphology is also given by the presence of structural terraces at various heights within the passage walls, with the largest one at the top of the passage. In a second stage, the cave passage was deepened along vadose canyons. Microtectonics, differences in limestone facies and unkarstifiable rock intercalations seem to have an important role in the development of minor scale wall features.

O-80

Chats and facts about the Quarry Cave (Bermuda)

Arrigo A. Cigna

UIS-SSI,Fraz. Tuffo, I-14023 COCCONATO (Asti),Italy

Abstract

The Quarry Cave was uncovered during the excavation of Wilkinson's Quarry, Hamilton Parish, Bermuda, in February 2002. In June 2002 and April 2003 detailed studies on pros and cons of the conservation of the cave were carried out. At the same time rumours based essentially on emotional feelings started to be spread around, particularly within the speleological community. Such statements puzzled sometime persons not adequately aware of the aspects of the situation. Here a rather complete description of the Quarry Cave problem is reported.

Key words: Quarry Cave, safety, environment, protection

Introduction

The Quarry Cave is in the Walsingham Formation (Pleistocene) below the terra rossa palaeosol stratum (Castle Harbour Geosol) which is evident by the red clay geosol that was above the rock surrounding this cave (Vacher et al., 1989; Rowe, 1998). The opening, giving access to the cave, was produced by the collapse of a quarry machine in the very upper part of the cave.

Description of the cave (facts)

The cave has a global lenticular shape, with a dip of about 45 degrees NNE. The length in the direction of this dip is about 30 metres and a width ranging from 15 metres in the upper part to 25 metres in the lower part, next to a pond of tidal water. The depth of the void is 2 to 4 metres. The cave is divided into two parts by a stalagmitic formation (about 1 metre thick) roughly parallel to the dip.

There are many formations inside the cave, mainly stalactites (partly soda-straws), stalagmites, some columns and extensive flowstones. A large part of these formations are broken, as a result of mechanical shocks due to the quarry operations, blasting vibrations, the collapse of the cover at the artificial entrance and subsequent vandalism. On some parts of the walls, along fissures, some helictites (length up to 20-30 cm in general) may be occasionally observed. The Quarry Cave is definitely not comparable with Crystal Cave or Fantasy Cave by either scale or decoration from either the viewpoints of science or the casual visitor. In global terms there is no scientific significance in this cave or in any other aspect.

Before the quarry started, the cover above the cave was around 16 metres above the southern (higher) portion of the cave and 32 metres above the northern (lower). In the present conditions this cover has been reduced to about 2 metres in the upper part, close to the entrance, and less than 7 metres above the lower part, next to the tidal pond. These conditions are shown on the following section.

This cave was subject to a series of prior movements possibly as a result of the erosion of clay deposits under the flowstones and even earthquakes. Such phenomena occurred at different times and they are quite evident in many of the blocks that have fallen to the floor. New formations growing on such blocks give an idea of the time elapsed after the initial breakdown. The influence of the quarry operation (shocks produced by explosions and the movement of heavy machinery) is also very evident. In fact, many blocks have fallen down recently, since the area is now unstable, and there are no new formations growing on them. Any visit to the cave is risky on account of the large and heavy blocks, which can fall and cause serious damage to people. The cave is characterised by a great number of formations, particularly stalagmites and some eccentrics, some of which have broken recently.

Rainwater is percolating freely into the cave, on account of the fractures in the very thin layer of rock above the void. After an abundant rain (about 45 mm) a number of relatively important water flows were detected in the cave as a result of small debris and terra rossa deposited in the rimstone. Some small washed round areas caused by successive drippings were observed and only one day after the heavy rain, the dripping had nearly stopped. This means that the cave is immediately accessible by water passing through the fractures in the rock layer above the cave.

At the same time, in Crystal Cave the dripping was much more abundant, with no evidence of rainwater rapidly passing through the strata above the cave. The condition found in Crystal Cave is to be considered normal, and the condition in Quarry Cave abnormal, since it is indicative of the existence of multiple fractures in the strata above the cave.

The cave is dangerous on account of its instability of the surrounding rock. At present any visit into the cave must be severely regulated and admitted only for evident important reasons, to avoid unnecessary risks. For the same reason the area above the cave should be kept restricted and the presence of people not allowed while the cave exists.
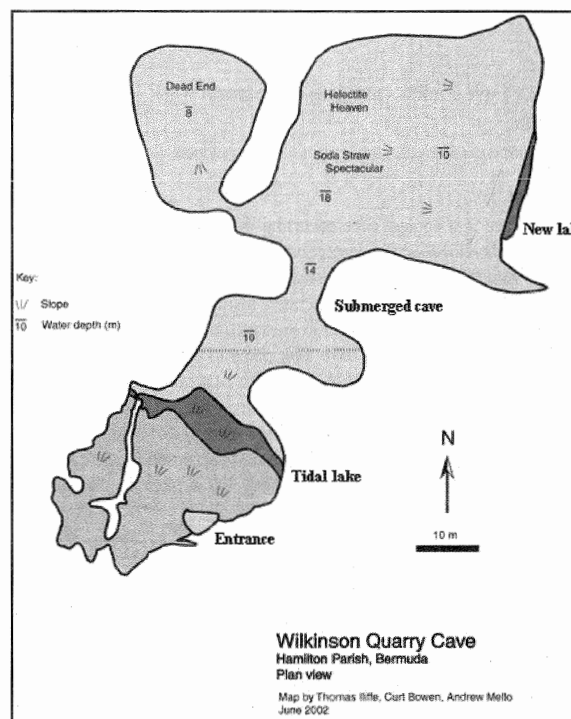
Fig. 1 - Plan of the Wilkinson Quarry Cave (from Iliffe, 2003, modified)

Spread Of News (Chats)

Dr. Tom M. Iliffe, Texas A&M University, started a very strong action in 2002 after the discovery of the cave (Iliffe, 2002) followed by a document in the web (Iliffe, 2003) as well as notes published in journals (Gibbons, 2004: Iliffe, 2004a). The publicity given by dr. Iliffe to his documents was extended to a number of speleologists all over the world, the basic issue being "give your support because a cave is going to be destroyed by a quarry". Obviously the persons not aware of the details reacted positively; others, in particular those people who knew me, were somewhat puzzled and asked me to give some additional explanation.
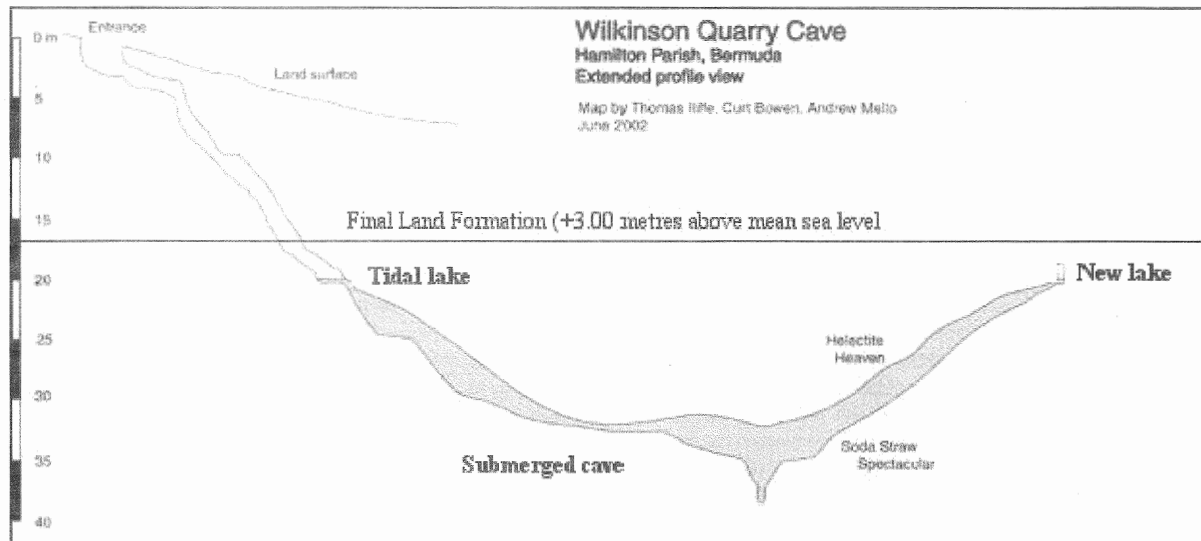
Fig. 2 - Vertical section of the Wilkinson Quarry Cave (from Iliffe, 2003, modified)

Dr. Iliffe's statements may be summarised as follows: the Wilkinson Quarry Cave is going to be destroyed by the near by quarry with a great loss of both the formations developed into the cave and the precious eco-system of some endangered species of anchialine organisms. It must be stressed that the threats to Bermuda caves were duly published

(Gibbons, 2004; Iliffe 2004b) by listing the sources of damage (quar-rying and construction, water pollution, dumping and littering, vandalism) but only the case of the Wilkinson Quarry Cave was accompanied by such a loud noise.

An independent tribunal was established for October 20th, 2004 with the objective of reporting to the Minister of the Environment of Bermuda. On account of the international campaign conducted by Dr. Iliffe to have letters to the Ministry in support of his position, on both the web and newspapers, the tribunal was cancelled.

Discussion

When different points of view exist, the normal procedure within the scientific domain is to meet and discuss the different opinions in order to clarify possible mistakes and find an agreeable solution. Obviously this process is quite effective to reach solutions but is not useful to provide importance to people and notoriety on the stage. Dr. Iliffe preferred the latter pathway.

As it is evident from Fig. 1 and 2, the upper part of the cave (which Dr. Iliffe amazingly calls "dry cave", according a slang used by divers but absolutely far away from the speleological terminology) is about one third of the whole cave. Such an upper part was highly decorated with forma-tions, which have been largely destroyed by the shocks of the quarry when the existence of the cave was unknown as well as by vandals who could enter the cave. The collapse of a quarry machine in the very upper part of the cave produced the fall of many blocks, which make the cave extremely dangerous as reported previously.

This part of the cave cannot be restored and made accessible to persons (in any case not to tourists, on account of its sizes) because the removal of the unstable heavy blocks would results in further heavy damages. In other words this part of the cave is already lost also if it is still existing. The endangered species of the anchialine fauna, which must be preserved at any cost, live in the submerged part of the cave, i.e. in the larger part of the cave itself.

Therefore the submerged part of the cave is not interested by this inter-

vention. The degree of protection of the habitat of the endangered species of anchialine organisms would depend on the detailed procedure adopted to erase the upper part of the cave with the minimum impact on the tidal lake. Consequently any discussion on the consequence of the quarrying activity in the vicinity of the cave should have been concerned essentially with this matter.

In my report (Cigna, 2003) to the management of the Wilkinson Quar-ry, as well as in the reports prepared by my colleagues (Calder, 2003; Davis, 2003) it was clearly stated that the conservation of the upper part of the cave should be avoided in order that a source of potential heavy risk would be eliminated. Since the final land formation of the quarry is established at 3 metres above the mean sea level (Fig. 2), it should have been evident to any person concerned with the problem of the Wilkinson Quarry Cave, that only the upper part of the cave itself, down to 3 metres above the mean sea level, was proposed for destruction.

It must be emphasised that Dr. Iliffe interpreted this suggestion as "we damaged it, therefore we should destroy it" with the obvious possible con-sequences if such a criterion would be applied (Iliffe, 2004a). It is evident that the damages to the cave as a consequence of the quarry activity oc-curred when the existence of the cave was absolutely unknown. Therefore a honest and correct statement should have been "the heavy damages, which occurred when there was no evidence of a cave, transformed the cave itself into a source of potential heavy risk to be eliminated without problems for the anchialine ecosystem".

Conclusion

In the reports prepared by Calder (2003), Davis (2003) and myself (Cigna, 2003) it was quite obvious that any reference to a cave to be sac-rificed concerned the upper part of the Quarry Cave, i.e. the part without anchialine fauna. It was also stated that any temporary disturbance to such a fauna would not had any irreversible damage to it on account of the interconnection of the underground voids.

At present an environmental and socio-economical solution was pre-pared, where safety and environmental protection are the leading con-cepts. A reinforced concrete slab will be cast above the tidal lake and the damaged rock removed. All operations will be carried on with a careful procedure avoiding any disturbance to the lake as rock fall. In this way the original situation, when the cave was isolated, will be re-established.

Recently Boris Sket (2005) in a paragraph entitled "Anchialine fauna

and humans" quoted the anchialine caves of Bermuda which plays an important role in tourism and the economy, but, "nevertheless a number of them have been damaged or destroyed - along with their diverse fauna - by pollution or by quarrying activities". The pollution, quoted correctly, as the first source of damage should be the most important issue to be strongly supported with the Government of Bermuda on account of the consequences, which could very efficiently destroy the anchialine fauna of the island.

The effect of the discharge of sewage directly into the soil was clearly reported by Gibbons (2004) and Iliffe (2004b). In particular nitrate, nitrite, ammonia and phosphate levels were detected in many caves as well as faecal contamination in some of them (Gibbons, 2004). Depletion of dissolved oxygen and anaerobic production of hydrogen sulphide resulted from the use of caves as dumping site (Iliffe, 2004b).

Since the caves of Bermuda can be considered as belonging to the same karst system developed in the karstifiable rock of the island, such widespread source of chemical and biological contamination can produce irreversible damages to the whole ecosystem. Therefore as much energy as possible must be devoted to stop this practice and restore (when still possible) the original status.

The destruction of a cave is always something hurting the feeling of a speleologist. But sometimes it is necessary to choose the minor between two evils: human beings are also part of the ecosystem and therefore also their safety must be assured. Between the safety of people and the conservation of part of a cave not recoverable, I choose the safety!

References

Calder P.N., 2003 - Report concerning a small cave uncovered during the excavation of Wilkinson's Quarry. Wilkinson Quarry unpublished.

Cigna A.A., 2003 - Report concerning the Quarry Cave. Wilkinson Quarry, unpublished.

Davis R., 2003 - Analysis and evaluation of a cave found in Wilkinson's quarry, Hamilton Parish, Bermuda. Wilkinson Quarry, unpublished.

Gibbons D., 2004 - An Environmental Assessment of Bermuda's Cave Health. NSS News, 62(4): 109-110.

Iliffe T., 2002 - Preliminary report on the survey of a newly discovered cave at Wilkinson Quarry, Bermuda. Unpublished report to the Bermuda Ministry of the Environment.

Iliffe T., 2003 - http://www.tamug.edu/cavebiology/Bermuda/Quarry/WQcave.html

Iliffe T., 2004a - Conservation of Bermuda Caves. NSS News, 62(11): 318-319.

Iliffe T., 2004b- Walsingham Caves, Bermuda: Biospeleology. In: Culver D.S. & White W.B., (Eds.) - Encyclopedia of caves. Elsevier/Academic Press: 767-769..

Rowe M.P., 1998 - An Explanation of the Geology of Bermuda. Bermuda Government, Ministry of the Environment, 2nd edition.

Sket B., 2005 - Anchialine Caves. Encyclopedia of Caves and Karst Science, Taylor and Francis-Routledge, New York: 31-37.

Vacher H.L., Rowe M.P. & Garret P., 1989 - The geological map of Bermuda. The Ministry of Woks and Engineering, The Bermuda Government.

O-81A

Polyphased karst systems in sandstones and quartzites of Minas Gerais, Brazil

Luc Willems[1], Joël Rodet[2], André Pouclet[3], Sergio Melo, Maria Jacqueline Rodet[4], Augusto S. Auler[5]

[1] EuReKarst, Laboratory of Sedimentology, Dept. of Geology, B20, University of Liege, 4000 Liege, Belgium, [2] EuReKarst, UMR 6143 CNRS, Continental and Coastal Morphodynamics, Laboratory of Geology, University of Rouen, 76821 Mont Saint Aignan Cedex, France, [3] EuReKarst, ISTO, Earth Sciences Institute, University of Orleans, France, [4] PhD student in Archaeology, University of Paris-X, CNPq grant holder, France, [5] CPMTC - Instituto de Geociências, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil,

Abstract:

The state of Minas Gerais (Brazil) exhibits several major karst areas located in sandstone and quartzite terrains, that display a complex suite of underground and surface karstic forms. In the Espinhaço Ridge, central Minas Gerais, several caves, up to a few hundred metres long, occur in the surroundings of the town of Diamantina. Some of these caves, such as Salitre, represent swallow-holes and show dome pits. Other horizontal caves are characterized by corrosion forms generated into the phreatic zone. In some places, such as in the Rio Preto area, these phreatic forms have been overprinted by ceiling tubes, suggesting a polyphase karst evolution, prior to the draining of the cave. Relicts of passages, with circular cross section up to a metre in diametre, can be found amidst the residual tower-like surface landforms, which constitute a typical scenery in the landscape. Their dissection is due to a generalised karstification in the area, resulting in closed canyons, megakarrens and kamenitzas. In southern Minas Gerais, close to the Mantiqueira Ridge, the caves of the state park of Ibitipoca can extent 2 km in length. These caves are associated with a very large hanging geological syncline. Several of these caves contain active streams, that flow for hundreds of metres before disappearing in sand-choked passages. Keyhole cross sections characterize steeply descending passages in these caves, indicating a change from slow phreatic flow towards a faster vadose flow responsible for the vertical incision of the passage. Such change is probably related to base level lowering and/or to turn in the direction of the water flow. Several generations of wall-pockets, from a few centimetres to over a metre long, occur into the caves. These features are good indicators of the initial phase of speleogenesis, generating the initial conduits by their coalescence. This mechanism is also responsible for cut-off meanders. The main river in the area, which flows along the syncline axis, cuts through a rock barrier, generating a tunnel-like passage. This cave drains, through resurgences in its walls, part of the water that flows in other caves located in the flank of the syncline. The non-carbonate karst features observed in the state of Minas Gerais demonstrate the complex organisation of polyphase karst systems due to the linkage of underground and surface forms not previously connected. As in carbonate areas, these systems may play an important hydrological role.
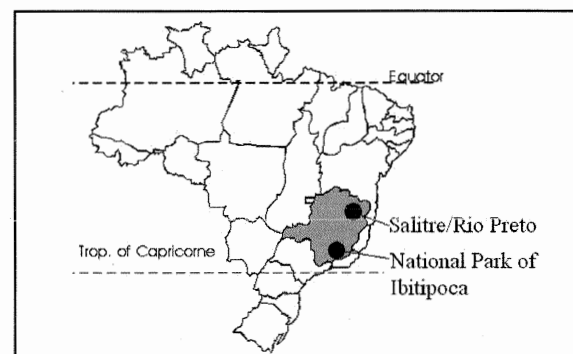
Fig. 1: Localisation of the studied areas

Introduction

Many areas of the Minas Gerais State (Brazil) exhibit a lot of caves developed into sandstones and quartzites. The regions of Serra do Espinhaço and Serra do Ibitipoca allow the study of complex karst systems, which broadly influence the landscapes (Fig. 1).

1. Serra do Espinhaço

The Serra do Espinhaço is a meridian trending mountain range system, that extends to the South of Minas Gerais State up to the Bahia's State, to the North. We have studied two areas, one near the city of Diamantina, with the cave of Salitre, and another one in the high valley of the Rio Preto. The geology of theses areas consist of Mesoproterozoïc quartzitic sandstones of the Sopa-Brumadinho Formation (Genhser and Mehl, 1977 ; Brichta et al., 1980) with metapelites and metabasites intercalations. The Espinhaço's Formations were moderately folded, metamorphosed and thrust westward above the margin of the São Francisco craton.

1.1- Cave of Salitre

The cave of Salitre develops in the axial part of a small meridian trending brachy-anticline (Genhser and Mehl, 1977 ; Brichta et al., 1980), about ten kilometres east of the city of Diamantina. All the surface of these area shows numerous lapiaz and tsingy deeper than several meters. Parallel to the anticline axis, a small canyon, averaging 4 to 10 meters wide for 100 meters long, runs into a cirque, about 50 metres in diameter, with vertical walls hollowed by decimetric to plurimetric alveoli (Figs 2-3).

The cave is opened out in the south-west side of the cirque. Its main entrance is a porch, 65 meters wide for 5 meters height, located few meters above the foot of the cliff. The cave goes on 40 meters inside the rock massif and forms a lowered room with a moderate slope following the stratification. The ground is cluttered up with plurimetric collapsed blocks from the roof. These blocks are coated with abundant niter and subordinate variscite. Niter is collected by the local inhabitants that gave the name "salitre" (= niter) to the cave.

A narrow corridor with a ceiling channel extends at the bottom of this room. It opens on wide passages with lower height (averaging 1 metre). Parallel to the anticline axis, a vertical fracture cross the roof and allows the infiltration of water, that moistens all the ceiling and caused chemical precipitation of fine deposits. In the western and lower part of the cave, the slope of different passages increases, in following the dipping stratification of the rock beds (10° to 20°). Numerous ceiling bells and ceiling channels can be observed. A second entrance of the cave is situated in the western cliff foot, 15 metres below the first entrance. The ceiling of these part of the cave is made by a talus-fan with plurimetric collapsed blocks. A water flow disappears inside small fractures at the bottom of the cave, that is located 27 meters below the entrance. The water comes from a closed valley ending at the canyon that leads to the cirque and to the cave. According to the local inhabitants, the water reappears some hundred metres farther, at the riverside of the rio Jaquitinhonha. Almost all the ceiling and a large part of the cave's walls are coated with a red to dark substance mainly made with Mn, K and Fe. The most important impregnation locates at the axial fracture zone or the ceiling. X-ray diffraction analysis allows to determine cryptomelane and pyrolusite. This
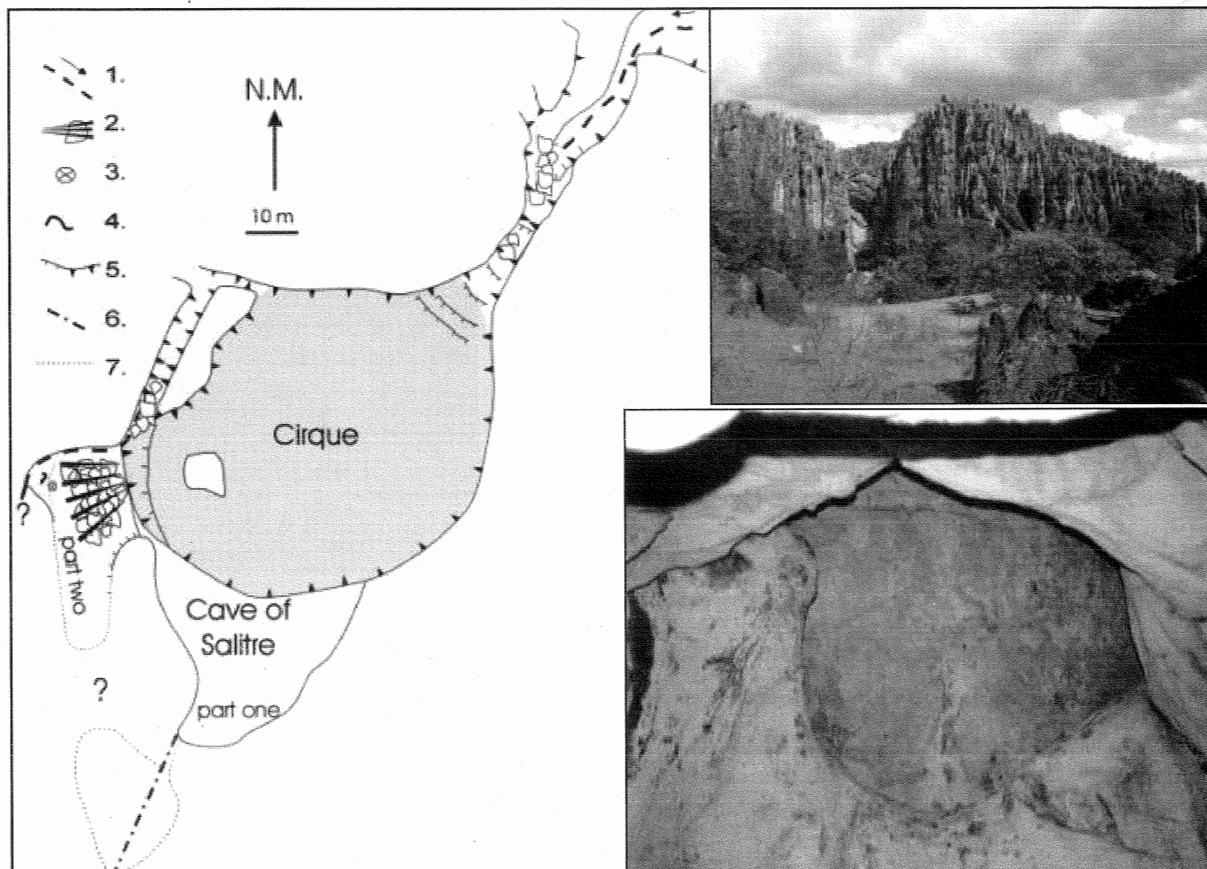
Fig. 2 : Plan of the site of Salitre. 1: flow; 2: fan-talus; 3 ceiling dome; 4: ceiling channel; 5: talus/cliff foot; 6: fracturing; 7: Non surveyed zones. Fig. 3: General view of the Salitre block with the entrance of canyon and lapiaz (B. Laignel, 2004). Fig. 4: Ceiling bell in the cave of Salitre, part two. The dark grey parts are remains of coating (L. Willems, 2003).
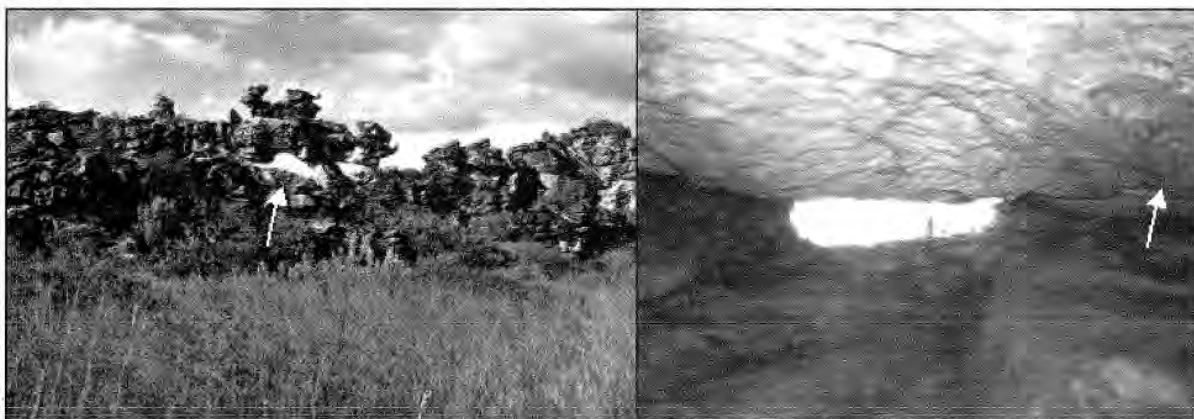
Fig. 5: Example of tower-like relief with lapiaz and relicts of sbuhorizontal passages (white arrow). In the foreground, part of the flat surface, several kilometres long for some hundred metres wide, located in mid-side of the Rio right bank. (L. Willems, 2003). Fig. 6: Ceiling with characteristic corrosion forms cut by a ceiling channel (white arrow). The cave (10 m long) connects two canyons (L. Wllems, 2003).
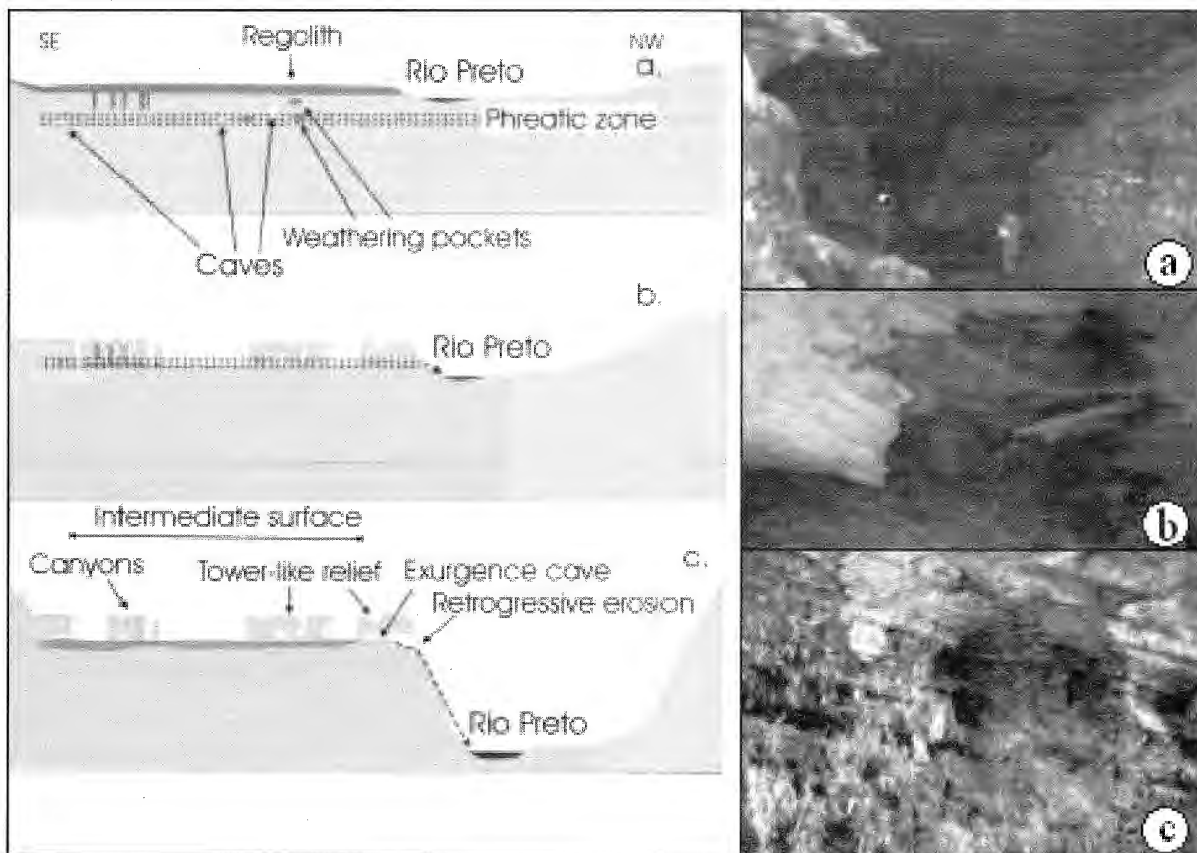
Fig.7 : Genetic hypothesis of the karst system of Rio Preto.
Figs 8:a: Gruta dos Fugitivos (National Park of Ibitipoca, J. Rodet, 2003). b: Gruta dos Moreira (National Park of Ibitipoca). Collapsing of quartzitic strata (L. Willems). c: Caverna_Ponte de Pedra (National Park of Ibitipoca) Alveoli developed on the walls of the cave-tunnel, in the right bank of the Rio do Salto (L. Willems, 2003)

coating preserves the initial forms like ceiling bells (Fig. 4), alveoli or ceiling channel developed in a crumbly lithology. Millimetric to centimetric pop-corn speleothems of pop-corn type are found in numerous places of the steep passages.

According to Genhser and Mehl (1977), the canyon and the cirque where is the cave outlet, could be the rest of a more important cave that collapsed.

1.2 Karsts of Rio Preto

The high valley of Rio Preto is 50 km to the northeast of the city of Diamantina. Upstream of a water fall caused by a geological dam of gently folded quartzitic strata, the valley widens out for some hundreds of metres. At the edges of this flat area (intermediate surface) (Fig. 7c) , the valley flanks exhibit numerous karstic-related works: inselbergs, closed canyons, tens meters long for more then 10 meters deep and tower-like

reliefs (Fig. 5) grooved by lapiaz and megalapiaz. Suhorizontal caves, relicts of passages with circular cross section and canyon-caves are opened in the steep edges of the valley. Orientation of the canyons is controlled by the north-south vertical fracturing associated with the regional strike-slip faults.

The walls of the closed canyons show decimetric to metric alveoli. They are attributed to pedogenetic process and look like basal notches found in numerous carbonated or not-carbonated rocks, as well as alveoli that developed at the contact with endokarstic fillings. Tower-like reliefs are generated by surface weathering, partly due to organic acids produced by mosses and lichens which widely cover the rock surface. Some canyons and tower-like reliefs crosscut many horizontal caves. One of them connects two canyons and has a ceiling with characteristic corrosion forms that were generated into a ground water zone. By places, rests of ceiling channels cut the previous corrosion shapes (Fig. 6). They support the opening of a karst system with increasing of the drainage. Rests of circular passages cross throughout tower-like reliefs. They give evidence of the former direction of drainage. The different reported galleries are essentially developed in following the subhorizontal stratification.

A particular large cave (more than 100 meters of development) in process of dismantling is observed. It cross throughout a tower-like inselberg located between the flat bank of the upper valley and the lower bed of the river. Outlet lateral circular conduits and vertical dissolution columns are evidenced. Further more, the floor of the cave is locally overdug to give canyons that reech the river, several metres deeper

The altitude of the upper flat bank and of the different cavities is quite similar. The cavities seem to be the relict of a karst system at a former phreatic water table level (Fig. 7). Surface erosion has dismantled this system that appeared outside and became a kind of polje. The embayment of the Rio isolates the flat surface. The water drained from this level cross throughout the caves towards the river. Due to the sinking of the river valley, regressive erosion generates canyons inside the caves.

The different forms observed in the high valley of Rio Preto attest the genesis of a complex karst system, that resulted from the connecting of an endokarst with an exokarst.

1. 2.1 Serra de Ibitipoca

The Sierra of Ibitipoca is a natural barrier between the states of Minas Gerais, São Paulo and Rio de Janeiro (Fig. 1). It's a large synclinal ridge upstanding several hundreds meters higher than the surrounding areas. The lithological composition of the Sierra consists of Meso-Proterozoic quartzites. Dozens of caves are reported in this area and some are among the biggest in the world, for this type of rock (e.g. Gruta das Bromélias, 2750 m of development) (Figs. 8a,b).

2.1- Ponte de Pedra e affluentes (Gruta dos Coelhos, Gruta das Casas)

The cave of Ponte de Pedra is a tunnel about 50 metres long, for 10 metres wide and 12 metres high. It is developed in the west flank of the syncline, parallel to the fold axis. It allows the passage of Rio do Salto throughout the rock barrier. The cave has a keyhole cross section formed by a late vertical erosion due to a lowering of a regional or local base level.

Several generations of centimetric to plurimetric alveoli are developed on the walls of the tunnel, in the right bank of the Rio (Fig. 8c). Some of them are larger and show complex shapes resulted from the coalescence of smaller alveoli. They can be overprinted or dismantled by other alveoli. By places, water outpoured from drains parallel to the dip of strata. They would come from several caves developed higher in the flank of the syncline, where subterranean draining is observed (Gruta dos Coelhos, Gruta das Casas). All alveoli are situated over the notch of late vertical erosion of the tunnel. None of them is observed in the wall of the Rio left bank.

Various alveoli are interpreted as rests of primary endokarsts which have organized the first drain system by their coalescence (Fig. 9). They allowed the underground cut-off of Rio do Salto. Then, the digging of the tunnel increased. This caused a more pronounced erosion on the left bank, according to the dipping disposition of the strata. Primary alveoli are completely erased on this wall, while in the right bank, abandoned by the drainage, they are preserved. Current resurgences, along the west wall of the tunnel provoke a modification of forms by piping.

1.2.2-The drainage of Rio Vermelho (Grutas dos Moreiras, dos Três Arcos, dos Fugitivos).

The drainage of the Serra presents an organization in two directions. The first (Rio do Salto) follows the axis and the pitching of the syncline towards the southwest. The second develops in an opposite direction to the structure, to the northeast (Rio Vermelho). In the cavities of this northeast zone, the sinking of Rio Vermelho corresponds to the development of keyhole cross sections of drains parallel with this last direction. They give evidence of a general change of drainages initially towards Rio do Salto for the benefit of the river basin of Rio Vermelho.

1.2.3 - Discussion

Numerous caves examined in the Ibitipoca Park presents walls or ceilings in process of dislocation (Fig. 8b). Quartzite disintegration produces abundant sandy material, that is evacuated downstream by underground rivers. If the current evolution of cavities mainly resulted from mechanical erosion, initially (bio)chemical process had to prevail in the genesis of caves. Indeed, several subterranean drainages disappear in impenetrable cracks within the block. Yet, only the chemical erosion allows to explain that the volumes of residual sands did not seal large part these caves and did not inhibit their development. Indeed, no downstream resurgence allows a mechanical evacuation of these residues.

The chemical erosion is at the origin of cavities and it implies a weathering dissolution both of the quartz grains and of the siliceous cement such as observed by Chalcraft and Pye (1984) in the tepuys of Venezuela. The aeration of systems causes a change to a incomplete dissolution (Wiegand, J et al., 2004) associated with a mechanical erosion. Bio-physico-chemical conditions currently observed in the visited cavities must to differ from the initial environment in which were generated Ibitipoca's various caves.

The study of the various caves shows that:
-   they are generated by general quartzite dissolution according to karstic process that have to be more precisely determined;
-   they result from several genetic phases and of adaptation;
-   they are the witnesses of the former phases of the regional hydro-geomorphological evolution.

Conclusion

The process of forming and development of cavities in sandstones and quartzites of Minas Gerais are due to the dissolution of siliceous cement and/or quartz grains. The important development of caves, swallow hole, underground rivers, lapiaz, sinkholes and poljes set up complete karst systems. Genetic processes are identical to those of carbonate rocks. Thus, it is a question of karsts in sandstones and quartzites.

287
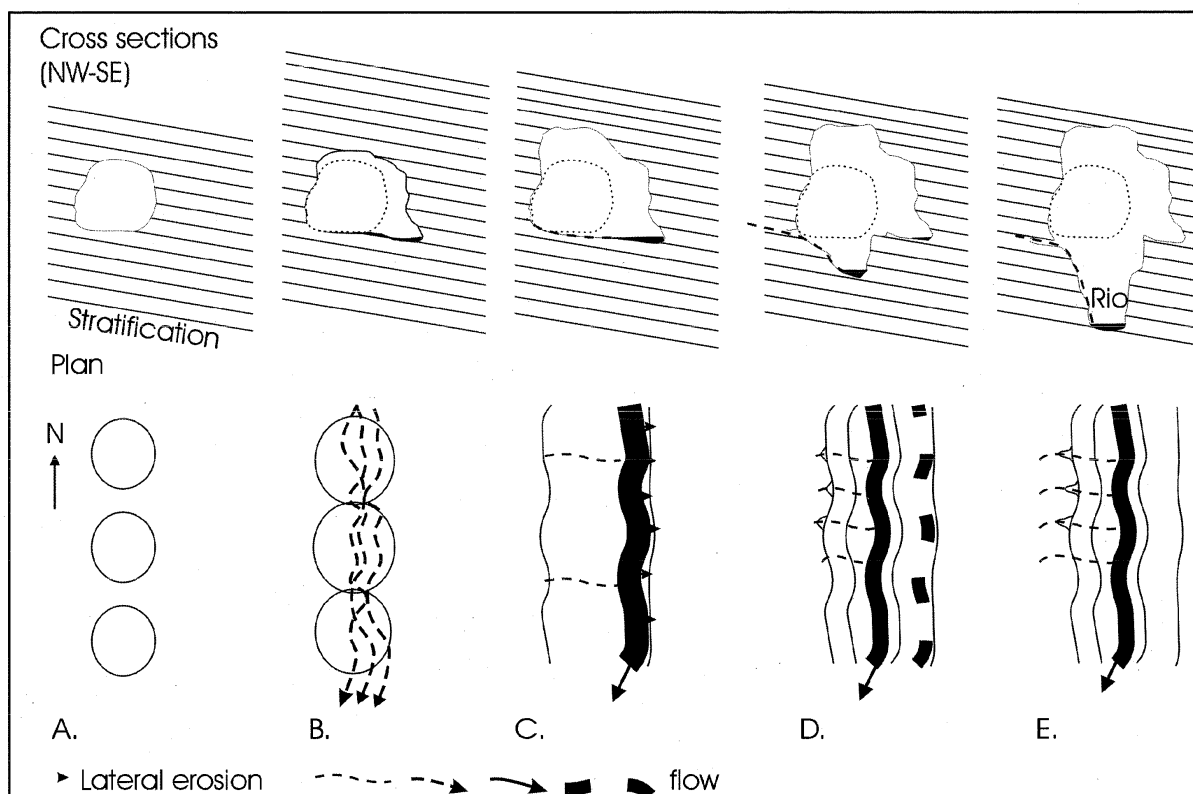
Fig. 9: genetic hypothesis of the Caverna Ponte de Pedra (see text for explanations).

Bibliography

Auler A.S., 2003. Quartzite caves of South America. Encyclopedia of caves and karst science, John Gunn (ed.), Fritzroy Dearborn: 611-613.

Chalcraft, D. & Pye, K., 1984. Humid tropical weathering of Quartzite in southeastern Venezuela. Z. Geomorph. N.F., Berlin-Stuttgart, 28, 3, pp. 321-332.

Brichta, A., Paternoster, K., Schöll, W.U., Turuinsky, F., 1980. Die Gruta do Salitre bei Diamantina, Minas Gerais, Basilien, kein „Ein-stursloch". Z. Geomorph. N.F., 24-2, 236-242, Berlin - Stuttgart.

Corrêa Neto A.V., 2000. Speleogenesis in quartzite in Southeastern Minas Gerais, Brazil. Speleogenesis - evolution of karst aquifers, National Speleological Society: 452-457.

Genser, H, Mehl, J., 1977. Einsturzlöcher in silikatischen Gesteinen Venezuelas und Brasiliens. Z. Geomorph. N.F., 21, 4: 431-434, Berlin, Stuttgart.

Martini J.E.J., 2000. Quartzite caves in Southern Africa. Speleogenesis - evolution of karst aquifers, National Speleological Society: 458-461.

Martini J.E.J., 2003. Silicate karst. Encyclopedia of caves and karst science, John Gunn (ed.), Fritzroy Dearborn: 649-653.

Melo da Silva S., 2004. Carstificação em rochas siliciclásticas. Estudo de caso na Serra do Ibitipoca, Minas Gerais. Universidade Federal de Minas Geraïs, Inst. Geociências, 157 p.

Wiegand, J; Fey, M; Haus, N; Karmann, I. 2004. Geochimische und hydrochimische untersuchung zur genese von sandstei-und quartzitkarst in der Chapada Diamantina und im eiserne viereck (Brasilien). Z. dt. geol. Ges. 155: 61-90.

Willems L., 2000. Phénomènes karstiques en roches silicatées non carbonatées. Cas des grès, des micaschistes, des gneiss et des granites en Afrique sahélienne et équatoriale. Thèse de doctorat, 257 p., 145 figs., 137 photos, Université de Liège, Belgique.

Willems L., Rodet J., Auler A.S., Piló L.B., Pouclet A., 2003a. Karsts en roches non carbonatées - l'exemple des quartzites et des itabirites de Minas Gerais (Brésil). «Le karst de la craie en Normandie», J. Rodet (dir.), Journées de l'AFK 2003, Rouen, 10-12 septembre 2003, poster, colloque et excursions : 31.

Willems L., Auler A., Rodet J, Melo da Silva S., Pouclet A., 2003b. Karsts en roches non carbonatées dans l'état de Minas Gerais - Brésil : résultats préliminaires. Journées 2003 de Spéléologie Scientifique, Centre Belge d'Etudes Karstologiques, groupe de contact du F.N.R.S., et la Commission Scientifique de l'Union Belge de Spéléologie, Han sur Lesse, 15-16 novembre 2003, résumé : 1 p.

Willems L., Rodet J., Auler A.S., Pouclet A., 2004a. Reflexões sobre a gênese do carste. Exemplos em diferentes litologias: Brasil, Niger, Camarões, França e Holanda. Carste-2004, Belo Horizonte, 27-31 juillet 2004, Caderno de Resumos: 85, poster.

Willems L., Rodet J., Pouclet A., Rodet M.J., Hatert F., Compère P., Auler A.S., 2004b. Carste no quartzito: Gruta do Salitre (Diamantina, Minas Gerais, Brasil). Carste-2004, Belo Horizonte, 27-31 juillet 2004, Cadernos de Resumos: 86, poster.

Willems L., Rodet J., Pouclet A., Rodet M.J., Hatert F., Compère P., Auler A.S., 2004c. Carste no quartzito: o Parque Estadual do Rio Preto (São Gonçalo do Rio Preto, Minas Gerais, Brasil). Carste-2004, Belo Horizonte, 27-31 juillet 2004, Caderno de Resumos: 86, poster.

Willems L., Rodet J., Auler A., Piló L.B., Pouclet A., 2004d. Karsts en roches non carbonatées - l'exemple des quartzites et des itabirites de Minas Gerais, Brésil - Karsts in non carbonated rocks - examples in quartzite and itabirite rocks from Minas Gerais, Brazil. Actes des Journées Européennes de l'AFK 2003, Rouen, J. Rodet (ed.), novembre 2004 : 74-75.

O-81B

ΑΡΧΑΙΟ ΛΑΤΟΜΕΙΟ «ΛΑΒΥΡΙΝΘΟΣ» ΓΟΡΤΥΝΟΣ ΗΡΑΚΛΕΙΟΥ ΚΡΗΤΗΣ

ΕΙΣΗΓΗΤΗΣ: ΚΟΝΙΑΡΗ ΕΛΕΝΗ

Το χωριό Καστέλλι βρίσκεται στο νομό Ηρακλείου Κρήτης και σε απόσταση 51χλμ. από το Ηράκλειο. Είναι κτισμένο σε υψόμετρο 200μ. Προς ΒΒΔ του χωριού, είναι η είσοδος του αρχαίου λατομείου «Λαβύρινθος».

Ο Λαβύρινθος είναι αρχαίο λατομείο πέτρας απ' όπου χτίστηκε η γειτονική πόλη Γόρτυς και πιθανώς ογκόλιθοι να μεταφέρθηκαν και να χρησιμοποιήθηκαν για το χτίσιμο της αρχαίας πόλης Φαιστού.

Το λατομείο είναι υπόγειο, δηλαδή σκαμμένο μέσα στην καρδιά του λόφου, χωρίς να υπάρχουν εξωτερικά δείγματα κοψίματος του λόφου. Σχετικά με τον Λαβύρινθο της Γόρτυνας υπάρχουν πολλές αναφορές από ξένους περιηγητές που το επισκέφτηκαν την περίοδο της Ενετοκρατίας.

Οι επισκέπτες έγραφαν ή χάραζαν τα ονόματά τους και τις χρονολογίες στα πλευρικά τοιχώματα των διαδρόμων του λατομείου. Από το 120 μ.Χ. αρχίζουν επισκέψεις στην Κρήτη ξένων περιηγητών, πολλοί από τους οποίους ήταν και αξιόλογοι ερευνητές (γεωγράφοι, γεωλόγοι, αρχαιολόγοι, ιστορικοί κ.λ.π.) που επισκέφτηκαν και τον «Λαβύρινθο» Γόρτυνος.

Αναφέρουμε τους κυριότερους από αυτούς:

1. Christophorus Bondelmondious, καθολικός ιερέας από τη Φλωρεντία, επισκέφτηκε την Κρήτη κατά τα χρόνια 1415-1418.
2. Laurentious Demonacis, επισκέφτηκε την Κρήτη κατά τα χρόνια 1421-1428.
3. Pierre Belon du Mans, Γάλλος φυσιοδίφης που επισκέφτηκε την Κρήτη το 1548.
4. William Lithgow, Άγγλος περιηγητής που επισκέφτηκε την Κρήτη το 1610.
5. Bernard Randolph, Άγγλος περιηγητής που επισκέφτηκε την Κρήτη το 1680.
6. Joseph Pitton de Tournefort, Γάλλος βοτανολόγος που επισκέφτηκε την Κρήτη το 1700 και παρατήρησε γραμμένες στο «Λαβύρινθο» Γόρτυνος τις χρονολογίες 1444, 1495, 1516, 1539, 1560, 1579, 1699 και ο ίδιος έγραψε 1700 σε τρία διαφορετικά μέρη μέσα στο «Λαβύρινθο».
7. Richard Pococke, Άγγλος κληρικός που επισκέφτηκε την Κρήτη το 1739.
8. Claude-Etienne Savary, Γάλλος περιηγητής που επισκέφτηκε την Κρήτη τα χρόνια 1779-1780.
9. Charles-Nicolas Sigisbert Sonnini de Manoncourt, Γάλλος φυσιοδίφης που επισκέφτηκε τη Κρήτη τα χρόνια 1777-1780.
10. Guillaume Antoine Olivier, Γάλλος εντομολόγος που επισκέφτηκε την Κρήτη το 1794.
11. Frans Wilh. Sieber, Αυστριακός γιατρός που επισκέφτηκε την Κρήτη το 1817.
12. Robert Pashley, Άγγλος περιηγητής που επισκέφτηκε την Κρήτη το 1834.
13. Felix-Victor Raulin, Γάλλος γεωλόγος που επισκέφτηκε την Κρήτη το 1845. Κατά την εποχή του η σπηλαιολογία χωρίστηκε από τη Φυσική, Γεωγραφία και αποτέλεσε ξεχωριστό κλάδο επιστήμης. Επίσης σχετικά με τον «Λαβύρινθο» έχουν γράψει κείμενα και άλλοι που ονομάζονται «Προβλεπταί» ή «Προνοηταί» που είχαν καθήκοντα διοικητικά και στρατιωτικά για δύο χρόνια. Μετά τη λήξη της θητείας τους υπέβαλλαν εκθέσεις προς την Ενετική Δημοκρατία σχετικά με την Κρήτη.

1. Francesco Barozzi, γόνος της Ενετικής οικογενείας Barozzi, 1577.
2. Lunardo Querini, 1587.
3. Francesco Basilicata, μηχανικός, 1630.

4. Marco Boschini, σχεδιαστής χαρτών, 1658.

Τον «Λαβύρινθο» επισκέφτηκε μια τριμελής ομάδα σπηλαιολόγων, από τους Κ. Ζούπη, Ν. Λελούδα, Π. Ρωμανά στις 12, 13, 14 Ιουνίου 1981. Η ομάδα οδηγήθηκε μέχρι την είσοδο του λατομείου από τον κάτοικο του χωριού Καστέλλι κ. Μανώλη Βολονάκη, ο οποίος και τους ανέφερε λεπτομέρειες σχετικές με τη διαμόρφωσή του.

ΙΣΤΟΡΙΚΟ: Από τις εργασίες των ξένων και των Ελλήνων περιηγητών-ερευνητών, σχετικά με τον «Λαβύρινθο» Γόρτυνος, φαίνεται ότι μεγάλη εντύπωση προκαλούσε και προκαλεί η ονομασία και η χρήση του. Αναφέρουν ότι από τον «Λαβύρινθο», χτίστηκε η αρχαία πόλη Γόρτυς, καθώς και η αρχαία Φαιστός που βρίσκετε δυτικά του σπηλαίου σε απόσταση 10χλμ.

Το λατομείο κατά τους χρόνους της τουρκοκρατίας χρησιμοποιήθηκε από τους ντόπιους κατοίκους σαν κρυψώνα-καταφύγιο, λόγω της δαιδαλώδους μορφής του.

Επίσης υπάρχει ο μύθος ότι ο «Λαβύρινθος» Γόρτυνος αποτελούσε τη κατοικία του Μινώταυρου. Κατά την περίοδο της γερμανικής κατοχής το 1941, οι γερμανικές δυνάμεις χρησιμοποίησαν τις πρώτες αίθουσες του λατομείου για αποθήκη πυρομαχικών και μάλιστα για να πετύχουν εύκολη πρόσβαση στην είσοδό του, που δεσπόζει πάνω στο λόφο όλης της γύρω περιοχής, διάνοιξαν δρόμο που χρησιμοποιείται μέχρι σήμερα. Για τη διάνοιξη του δρόμου, επιστράτευσαν χωρικούς από τα γύρω χωριά και σήμερα αν και ο δρόμος είναι εγκαταλελλειμένος από καιρό, βρίσκεται σε ικανοποιητική κατάσταση και επιτρέπει την πρόσβαση μέχρι την είσοδο του σπηλαίου, με αυτοκίνητο.

Οι Γερμανοί για να προφυλάξουν την είσοδο, από βομβαρδιστικές επιθέσεις, έχτισαν μπροστά της τσιμεντένιο τούνελ-γαλαρία, μήκους 17μ. το οποίο προστάτευε από κάποια πιθανή έκρηξη τις αποθηκευμένες εκρηκτικές ύλες.

Για την αποθήκευση και την μεταφορά από και προς το λατομείο των εκρηκτικών, χρησιμοποιούσαν μικρά βαγονέτα, πάνω σε σιδερένιες ράγες. Για το φωτισμό των γαλαριών είχαν εγκαταστήσει στον πρώτο θάλαμο γεννήτρια παραγωγής ηλεκτρικού ρεύματος, απ' όπου ξεκινούσαν σύρματα ηλεκτροφωτισμού και λάμπες τοποθετημένες στην οροφή των γαλαριών.

Οι Γερμανοί κατά την αποχώρηση τους από την Κρήτη το 1945, ανατίναξαν τις γαλαρίες με τα πυρομαχικά και μεγάλο μέρος των πρώτων θαλάμων του λατομείου γκρεμίστηκε, πλακώνοντας αρκετές γαλαρίες. Σημειώνουμε εδώ ότι οι Γερμανοί έχτισαν στα πλευρικά τοιχώματα των γαλαριών τοιχεία μέχρι την οροφή και παγίδευσαν μεγάλες βόμβες ανάμεσα στις χτισμένες πέτρες και έτσι υπήρξε μεγάλη σε έκταση η κατακρήμνιση των πρώτων γαλαριών του λατομείου.

Το 1955 το Ελληνικό Δημόσιο, όπως αναφέρουν οι χωρικοί της περιοχής, έκανε σύμβαση με Ιταλική εταιρία που θα έκανε ανασκαφές στις γκρεμισμένες από την έκρηξη γαλαρίες για να βγάλει τις ποσότητες πυρομαχικών που είχαν καταπλακωθεί και να χρησιμοποιήσει τους κάλυκες των οβίδων αφαιρώντας την εκρηκτική ύλη (μπαρούτι). Αυτό γιατί οι κάλυκες αποτελούνται από κράμα χαλκού που είναι απαραίτητο σε διάφορες χρήσεις.

Μεγάλες ποσότητες πυρομαχικών, μεταφέρθηκαν έξω από τις γαλαρίες και καθάρισε από τις επικίνδυνες ύλες μεγάλο μέρος του σπηλαίου. Όμως παρέμειναν μεγάλες ποσότητες βλημάτων.

Οι χωρικοί της περιοχής έμπαιναν στο λατομείο κατά τις περιόδους των γιορτών (Χριστούγεννα-Πάσχα) και χρησιμοποιούσαν το μπαρούτι που είχε μείνει μέσα, για να φτιάχνουν κροτίδες και βεγγαλικά, χρησιμοποιούσαν για φωτισμό αναμμένα κεριά και δάδες και έτσι υπήρχε μεγάλος κίνδυνος έκρηξης. Το 1962, σε μία επίσκεψη που έκαναν στο

O-82

2-D Geoelectrical survey to identify the entry and sectors of the natural cave of Sidirokastro, N. Greece

A. Atzemoglou, E. Eleftheriadis

Institute of Geology and mineral exploration, Thessaloniki, Natural History Museum of Sidirokastro

Abstract:

In the region of Sidirokastro, N. Greece, more precilly at the locality of "Mandri Patouna" in Mavros Vrachos, we applied an intermediate extent of geophysical researches with the method of electric tomography (configuration dipole - dipole). Our aim was the 2-D presentation of the subsoil structure. During the application of the dipole - dipole configuration in electric tomography, we mesure the resistivity in certain depth (that depth depends from the distance between the electrodes) along the different profiles. Thus we receive measurements along each profile and to the depth. Object of this research was the localisation of the entry or sectors from a cave that is developed in the region of Black Rock. The information on the existence of these sectors of the cave emanated from local old man and from the study of regional geological data. Geologically limestones cover the region. The measurements were realised in altitude of about 380 metres and in an intense bas-relief with dense and low vegetation. The measurements were realised in one almost regular grid of 100x100 metres roughly. We drain, in the ground, electric current via 2 electrodes and we measure the potential in 2 different electrodes that are found in distance from the electrodes of current. The results obtained from the measurements treatment during the application of electric tomography are pictures of real value of the measured parameter (resistivity).

Based on the interpretation of measurements that resulted from the application of electric tomography, we have the following conclusions:

In the region "Mandri Patouna" 2 sectors of voids are clearly distinguished. The first sector is developed with a direction from the "Mandri Patouna" to W-SW of this locality, while the second sector is developed with a nearly N-S direction concerning the "Mandri Patouna" locality.

The second region of research (in the basement of Mavros Vrachos) is a big void having very small regions of compact rock. This place appears that it constitutes a sector of the cave that it is presented in the basement of Mavros Vrachos. In the same region, almost above the researched cave, we realised another profile of electric tomography. We localised a void

---

O-83

Some New Speleological Research of Caverns in route of the Highways in Croatian Karst

Prof.dr.sc. Mladen Garašić, dipl.ing.geol.[1,2] mgarasic@public.srce.hr

[1]*University of Zagreb, Faculty of Civil Engineering, HR-10000 Zagreb, KaČićeva 26, Croatia*

[2]*Croatian Sopeleological Federation, HR-10000 Zagreb, Nova Ves 66, Croatia*

While building highways in karst regions of Croatia during the last fifteen years, over 767 caverns (speleological objects without natural entrance) were discovered and thoroughly explored. Research were carried out sistematically on sections of roads, highways, cuttings, tunnels, bridge foundations, viaducts, etc. while building Zagreb-Rijeka highway, Zagreb-Split Highway, Ypsilon of Istria semi-highway, Rijeka-Rupa highway, Zagreb-Zadar semi-highway, Rijeka by-pass, etc. Until June, 30th 2005, over 9000 caves and pits were discovered in Croatia.

Research goals were geotechnical solutions of cavern improvement, treated accordingly to engineering geological and hydrogeological parameters obtained by thorough speleological research, measuring, surveying and filming. Using geostasistical methods combined with computer programs, interesting data concerning groupations of certain speleological objects were obtained (lithostratigraphical indicators and speleogenesis type, hydrogeological parameters in relation to tectonic and lithostratigraphical factors, their relation towards topographic position, morphometric parameters in relation towards overbeds above caverns, etc.). Aditionally, average lengths and depths of speleological objects in certain areas (different from earlier data got by treatment of known speleological objects with entrances on the surface of the terrain) were also noted. Explanation for this is that laws of «inner» speleogenesis rule in the caverns, and the influence of sudden changes on terrain surface affects them slower. Speleological objects with surface entrances have faster and more intense development of speleogenesis. Caverns can be in «initial» or «fossil» phase of speleogenesis, but those processes are slower. Caverns (in their morphometric parameters) are in big percentage larger than objects in those areas with surface entrances. Explanation for this is that many of the objects with surface access are already in «fossil» or «older main» karstification phase in the moment of their self-destruction. Caverns with more than 100 meters of rock overbeds (except in Jelar beds and limestones of Liass) are no different than speleological objects

with natural entrances situated on the road level in that area. Some of the caverns were later connected with speleological objects known earlier. Detailed measurements of natural radioactivity were also carried out. Radioactivity in caverns was almoust negligible, while in nearly all other objects it had much bigger intensity. Highest dose of radioactivity is brought into speleological objects by every visitor when entering from the terrain surface. Some of those caverns ask for special attention because of their dimensions (length, depth, width, highth) or seconday sediments (speleothems).

There were 688 (89,71%) vertical (of 767 fully researched caverns), and 79 (10,29%) horizontal speleological objects (features). No combined or complexed objects were noted. Partial explanation for slight change in general picture of vertical : horizontal : complexed relation (V:H:C=78: 21:1) is that built sections mostly go through outer and middle area in Dinaric karst.

Average depth was 34,50 meters (more than average for 9000 other speleological objects known so far in Croatia- except Min/max peaks). Average length was 52 meters (no peaks). Deepest pits was 196 meters, longest cave 1137 meters. (Garašić, 2004.) Large cavern was the one in «Sveti Rok» tunnel (left tube), on stationage of tunnel km 200+525, where 1137 meters of surveyed cave channels, with vertical altitude difference of 147 m, was speleologically researched and surveyed. Throughout long-lasting research of about fifty caverns in «Sveti Rok» tunnel, several kilometers of profiles and plans (appearing in certain pattern) were surveyed with precission. Speleogenesis of caverns is directly linked with litostratigraphical, hydrogeological and tectonic predispositions on every location in tunnel. Speleological objects are mostly vertical (shafts, pits), kneelike morphological type, with hydrogeological function of spring (permanets or semipermanent). Only one true exeption is the cavern o stationage km200+525, with explored big cave chamber of 148m x 53m x 62 meters. Some objects are even deeper (they are connected to the surface

- bats were found). Caverns in «Mala Kapela» tunnel (left tube, Lika side) presented a problem for building improvement several times, because of their posotion and morphlogy.

In Rijeka-Karlovac (Zagreb) highway area, there are all three speleogenesis phases. General relation between «main» and «fossil» phase of karstification is different in particular parts of highway, and totally, it equals 3:1 (exactly 3,11:1). In inner karst area (area from Karlovac to Bosiljevo) situation is completely different. Here the relation between «main» and «fossil» phase of speleogenesis equals 1:7 (exactly 1:6,89), which indicates that most caverns are filled with cave in material, calcite or in most cases with high plastic clays, color red to brown-red. In center karst karstic area (Bosiljevo to Fužine), highway goes through area where speleogenesis in relation «main» : «fossil» phase equals 2:1 (exactly 2,36:1) to 3:1 (3,05:1). (Garašić&all, 2003a, 2003b). In outer karst areas (Fužine to Rijeka area), relation equals 4:1 (4,20:1). All known and researched objects on this route and all the ones nearby were taken into consideration while calculating relations of particular speleogenesis phases. (Garašić, 2002.)

Studiing genesis of speleological objects in Croatian karst on great number of examples, it was concluded that they are situated immediately next to fault planes - paraclase. Cavers and speleologists used different technics to explore some of the speleological objects with natural entrances on the surface, and that was the end of research. Research of numerous caverns (speleological objects without natural entrance on the surface) discovered while building highways, bridges, tunnels, viaducts, etc. have

made possible paraclase zone research. It was found that speleological objects always come in several groups per fault, depending on type of rocks, intensity of karstification, neotectonic activity, etc.

Corelation of measuring absolute movements (neotectinic activity) showed that most of speleological objects on the same fault (or fault zone) by a vertical arrangement in case of neotectonic raising and lesser deviation of neotectonic force direction in relation to predisposed fault are relevant to speleogenesis. Faults on which horizontal continuation of caverns are created, are usually in the area of neotectonic dipping off or change of neotectonic forces direction in relation to prdisposed fault.

There were examples of calculating probability of vertical or horizontal cavern continuation in advance, and documenting the real situation in field later. Method could assume the way in which many speleological objects in Croatian karst spread out. Comparing neotectonic (today) direction and intensity of movements, speleological objects within rocks of same type could be compared with relatively large punctuality. Along with comparison of their karstification intensity, the data would corelatively be very indicative. In some caverns karstification intensity are being measured and compared. Influence of seizmic waves on them in relation to continually measured neotectonic movements are also being observed.

In Zagreb-Split highway (without «Bosiljevo 2» road cross) section to «Pirovac» road cross, situation is different, as is in Istra, Rijeka by-pass, etc.
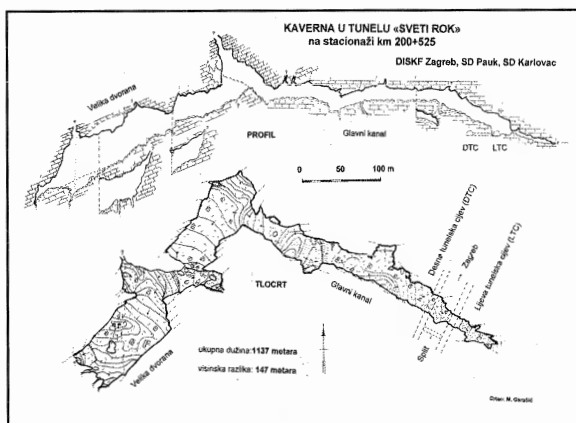
Figures: Photo 1. - Special kinds of Speleothems in Cavern in tunnel "St. Rok" on km 200+525

Literature:

GARAŠIĆ, M. (2002): Speleološke pojave u tunelu "Sveti Rok". Ceste i mostovi, vol. 48, br.1-2, str.11-20, Zagreb.

GARAŠIĆ, M. & VIVODA, B. (2003a): Speleološke pojave (kaverne) u trasi autoceste Zagreb-Rijeka. Ceste i mostovi, vol.49, br.5-6, str.104-111, Zagreb.

GARAŠIĆ, M. , VIVODA, B. & KARLOVAC, Z. (2003b): Geološke značajke tunela "Rožman brdo".Ceste i mostovi, vol.49, br.11-12, str. 58-66. Zagreb.

GARAŠIĆ, M. (2004): Istraživanje kaverni u tunelu "Sveti Rok". Speleozin, vol. 12, br.17, str.21-27, Karlovac.

Fig 3. - Survey of one of the caverns in tunnel of "St. Rok" in Velebit mountain on highway Zagreb - Split in Croatian Dinaric Karst area

Photo 2.- Large and big cave channels in cavern "St.Rok" on highway Zagreb-Split

O-84
The most important and spectacular Greek caves
G. Avagianos
HSS. Athens, Greece

<div style="text-align:center">

ΑΝΑΚΟΙΝΩΣΗ ΣΤΟ ΠΑΓΚΟΣΜΙΟ
ΣΥΝΕΔΡΙΟ ΣΠΗΛΑΙΟΛΟΓΙΑΣ
ΤΑ ΣΠΟΥΔΑΙΟΤΕΡΑ ΚΑΙ ΟΜΟΡΦΟΤΕΡΑ ΕΛΛΗΝΙΚΑ ΣΠΗΛΑΙΑ
Η ανακοίνωση συνοδεύτηκε με προβολή διαφανειών από τα μή τουριστικά τμήματα των
αναφερομένων σπηλαίων

του σπηλαιολόγου Γιώργου Αβαγιανού
μέλους της Ελληνικής Σπηλαιολογικής Εταιρίας
κείμενο για δημοσίευση στον τόμο των πρακτικών

</div>

1) Σπήλαιο Αγγίτη " Μααρά " Προσοτσάνης Δράμας.
Πρόκειται για το μεγαλύτερο σε μήκος και όγκο Ελληνικό καρστικό σύστημα. Από το
σπήλαιο, πηγάζει ο ποταμός Αγγίτης. Το 1978 Ελληνογαλλική αποστολή με αρχηγό τον
σπηλαιολόγο Γιώργο Αβαγιανό, με σπηλαιοκατάδυση εξερεύνησε τα πρώτα 400 μέτρα.
Ο Γιώργος Αβαγιανός τα επόμενα χρόνια, κατηύθυνε τις εργασίες για τη διάνοιξη στοάς
προς το εσωτερικό του σπηλαίου με σκοπό την τουριστική του αξιοποίηση. Ο ίδιος με
σπηλαιοκαταδύσεις, συνεχίζει την εξερεύνηση του υπόγειου ποταμού, ξεπερνώντας τα
10.000 μέτρα από την είσοδο.
Το σπήλαιο είναι ενεργός υπόγειος ποταμός που το διατρέχει σε όλο του το μήκος. Οι
διαστάσεις του είναι γιγάντιες καθώς η κοίτη του ποταμού έχει πλάτος 30 - 60 μέτρα και
ύψος 10 - 40 για περισσότερο από 8.500 μέτρα. Την υπόγεια πορεία του, διακόπτουν
υποβρύχια τμήματα που είναι προσπελάσιμα με σπηλαιοκατάδυση. Η τροφοδοσία του
υπόγειου ποταμού με νερό γίνεται από την πόγλη του Νευροκοπίου, που βρίσκεται
βόρεια του σπηλαίου. Τα νερά του οροπεδίου πέφτουν σε καταβόθρες που καταλήγουν
στην υπόγεια κοίτη. Εκτός από τα νερά των καταβοθρών, μεγάλο μέρος των νερών,
προέρχεται από τον ορεινό όγκο του Φαλακρού όρους. Το σπήλαιο είναι σήμερα
τουριστικά αξιοποιημένο για τα πρώτα 500 μέτρα. Ο επισκέπτης διατρέχει την πορεία
του υπόγειου ποταμού, ανάμεσα από τεράστιους σταλακτίτες που μερικοί έχουν μήκος 5
- 10 μέτρα και διάμετρο 1 - 2 μ.
2) Σπήλαιο " Γλυφάδα " Δυρού Μάνης.
Είναι το δεύτερο σε μήκος και όγκο Ελληνικό σπήλαιο.Τουριστικά αξιοποιημένο για
1.600 μέτρα, είναι κοίτη υπόγειου ποταμού. Το γλυκό νερό περιορίζεται στην επιφάνεια,
ενώ βαθύτερα, το νερό είναι αλμυρό.
Εξερευνήθηκε αρχικά από το ζεύγος Πετρόχειλου. Το 1978, ο Γιώργος Αβαγιανός
εξερεύνησε με σπηλαιοκαταδύσεις νέα τμήματα, χερσαία και λιμναία, διπλασιάζοντας
ουσιαστικά το μήκος και όγκο του σπηλαίου. Τα νέα αυτά τμήματα είναι ασύγκριτης
ομορφιάς ώστε να θεωρούνται από τα ομορφότερα τμήματα σπηλαίων του κόσμου.
Κρυστάλλινες λίμνες εναλάσσονται με χερσαία τμήματα γεμάτα κρυστάλλους,
εκκεντρίτες και κάθε μορφής λιθωματικό διάκοσμο.

Στα τμήματα αυτά, βρέθηκε ένας τέλεια διατηρημένος απολιθωμένος σκελετός πάνθηρα. Μεγάλοι σταλαγμίτες υπάρχουν στους βυθούς των λιμνών, γεγονός που δείχνει ότι κάποτε το σπήλαιο ήταν χερσαίο. Κάθε χρόνο με σπηλαιοκαταδύσεις, εξερευνούμε νέα τμήματα και το συνολικό μήκος του σπηλαίου, αυξάνει συνεχώς.

3) Σπήλαιο " των Λιμνών " Καστριών Καλαβρύτων.

Είναι λιμναίο, με 13 κλιμακωτές λίμνες με ολοκάθαρο νερό και κρυστάλλινα τοιχώματα. Το μήκος του είναι 2 χιλιόμετρα. Τουριστικά αξιοποιημένο στο πρώτο τμήμα του. Το τμήμα εκτός τουριστικής διαδρομής είναι εκπληκτικής ομορφιάς με κατάλευκο λιθωματικό διάκοσμο που συνδιάζεται με το γαλαζοπράσινο χρώμα των λιμνών. Πρόκειται για ένα από τα ομορφότερα σπήλαια του κόσμου. Έρευνες του Γιώργου Αβαγιανού αποκάλυψαν την ύπαρξη ενεργού υπόγειου ποταμού σε κατώτερο επίπεδο από όπου σε περίοδο πλημμύρας, τα νερά φθάνουν στο σπήλαιο.

4) Σπήλαιο Αλιστράτης Σερρών.

Πρόκειται για χερσαίο σπήλαιο, τουριστικά αξιοποιημένο κατά τα δύο τρίτα. Εξερευνήθηκε από την Ελληνική Σπηλαιολογική Εταιρία. Έχει μεγάλο μέγεθος, με εντυπωσιακά ογκώδη λιθωματικό στολισμό. Τεράστιες αίθουσες διαδέχονται η μιά την άλλη, καθώς ο επισκέπτης διασχίζει το σχεδόν οριζόντιο σπήλαιο. Σε πολλά σημεία υπάρχουν εντυπωσιακοί ελικτίτες. Ο διάκοσμος στις εκτός τουριστικής διαδρομής αίθουσες, ιδιαίτερα σε ορισμένες που βρίσκονται ψηλά, κοντά στην οροφή του σπηλαίου, είναι θαυμάσιος.

5) Σπήλαιο Περάματος Ιωαννίνων.

Το πρώτο τουριστικά αξιοποιημένο σπήλαιο της Ελλάδος. Χερσαίο με εντυπωσιακό διάκοσμο και μεγάλη ποικιλία σταλακτιτών. Εξερευνήθηκε από το ζεύγος Πετρόχειλου. Στα μη τουριστικά τμήματα υπάρχουν εντυπωσιακές μικρές λίμνες και πολύχρωμοι κρύσταλλοι ασβεστίτη. Εκπληκτικής ομορφιάς είναι λιθωματικές λεκάνες που συγκρατούν τα νερά των λιμνών και τα λίθινα " νούφαρα " μέσα σ αυτές.

6) Σπήλαιο " Συκιάς " Ολύμπων Χίου.

Εξερευνήθηκε από τον Γιώργο Αβαγιανό το 1985. Βαραθρώδες, με εντυπωσιακό διάκοσμο είναι τουριστικά αξιοποιημένο. Το φως του ήλιου, σχηματίζει δέσμη φωτός που περιδιαβαίνει το σπήλαιο τις μεσημεριανές ώρες και προσφέρει φαντασμαγορικό θέαμα. Στον στολισμό του περιλαμβάνονται πολύχρωμοι κρύσταλλοι και εκκεντρίτες.

O-85
Open air and in caves rock carvings at the gorge of Aggitis at the prefecture of Serres
L. I. Chatzilazaridis*

Rock carvings have been discovered in four spots at the gorge of Aggitis river (which is a tributary to the Strymon river) The gorge is a natural monument of unparalleled beauty. It holds interesting fields for research for geologists - paleontologists, archeologists, speleologists and other scientists.

I. The first spot is located near the village Symboli at Serres, at about 200 metres south of the tributary of the Angitis river, the water which drains from the plain of Fillipi and the blue water river. It is an open air marble surface 4 by 3,5 metres on which more than 25 depictions of riders, deer and animal figures can be seen.

II. The second spot is the floor of a small cave which is the southernmost of a cluster of caves at about 1300 metres to the south of the cave of Alistrati and 100 metres above the riverbed at the east side of the gorge. At about 150 metres to the north of these caves on the same eastern bank of the gorge there is a long natural bridge. The access to the three caves and to the natural bridge is possible from the village of Nea Mpafra and through a shorter way from the village of Krinida in the prefecture of Serres. A part of the floor of the southern cave is like a balcony which overlooks the abyss of the gorge. It consists of an irregular, horizontal surface, ellipsoid in shape. Its largest dimensions are 6m x 3m. On this surface there is a total of 60 depictions of animals and deer carved in a threadlike manner.

III. The third spot is "Alistrati 1". It lies about 1000 metres to the southwest of the cave of Alistrati, which can be reached from the village

* Ph.D at the Aristotle University of Thessaloniki - Geologist , State School Advisor for Physics

of Alistrati.It is situated towards the downflow of Aggitis on the left of the railway line, at the first level of the edge of the gorge at a height of 90 metres. On the opposite side of the gorge one can see the large impressive natural bridge of Aggitis. This spot is a marble horizontal surface under a towering rock shelter. It is round in shape with a diameter of 3 metres. Around it the soil is dug by gold miners or treasure hunters. On this surface there are about 60 carvings which undoubtedly were carved at different periods. They depict deer and other animals hunters and warriors and other non defined lines.

IV. The fourth spot is "Alistrati 2". It lies on the same side and at the same level as "Alistrati 1", around 100 metres before the latter. Individual etchings can be seen but less in number than the ones at "Alistrati 2".

The dimensions of the etchings vary between 5 - 40 cms. Carvings and etchings is a characteristic activity of humans, through time. Essentially they are the first tools of expressing human thought and storage of this thought since antiquity. It is suggested that the dating of a considerable part of this rock art should be from the Neolithic age to the Copper age.

«Ακιδογραφήματα σε υπαίθριες θέσεις και σε σπήλαια του φαραγγιού Αγγίτη Ν. Σερρών.»

Από τον Λάζαρο Ι. Χατζηλαζαρίδη**

Εισαγωγή - Περίληψη

Σε τέσσερις, κυρίως, θέσεις εκατέρωθεν του φαραγγιού του ποταμού Αγγίτη, που είναι παραπόταμος του Στρυμόνα ποταμού στην Β. Ελλάδα έχουν εντοπιστεί ακιδογραφήματα - βραχογραφήματα. Το φαράγγι του Αγγίτη είναι ένα, απαράμιλλης ομορφιάς, μνημείο της φύσης. Παρουσιάζει πολυποίκιλα ενδιαφέροντα, που αποτελούνε παρθένα πεδία έρευνας για τις επιστήμες της γεωλογίας - παλαιοντολογίας, αρχαιολογίας, σπηλαιολογίας κλπ.

Ι. Η πρώτη θέση βρίσκεται κοντά στο χωριό Συμβολή του Ν. Σερρών. Περί τα 200 μ. νότια της συμβολής των νερών του Αγγίτη με τα νερά που αποστραγγίζουν την πεδιάδα των Φιλίππων καθώς και της συμβολής του Αγγίτη με τα γαλάζια νερά. Πρόκειται για μία υπαίθρια μαρμάρινη επιφάνεια με διαστάσεις 4m X 3,5m που στην επιδερμίδα της έχει περισσότερες από 25 παραστάσεις ελαφιών, ζώων, ιππέων κλπ.

ΙΙ. Η δεύτερη θέση είναι το δάπεδο ενός μικρού σπηλαίου, που είναι το νοτιότερο μιας συστάδας τριών σπηλαίων, περί τα 1300μ. νότια του τουριστικά αξιοποιημένου μεγάλου σπηλαίου της Αλιστράτης και 100μ. πάνω από την κοίτη του ποταμού στο ανατολικό χείλος του φαραγγιού. Περί τα 150 μέτρα βορειότερα από τα σπήλαια, βρίσκεται μια μεγάλη και εμφανής φυσική γέφυρα. Η προσέγγιση των τριών σπηλαίων και της φυσικής γέφυρας γίνεται από το χωριό Νέα Μπάφρα και συντομότερα από το χωριό Κρηνίδα του Ν. Σερρών. Ένα τμήμα του δαπέδου της μικρής σπηλιάς με ελλειψοειδές σχήμα και με μεγαλύτερες διαστάσεις 6μ. X 3μ. φιλοξενεί περισσότερες από 60 παραστάσεις κυρίως ζώων και ελαφιών, που είναι κυρίως χαραγμένα νηματογραφικά

ΙΙΙ. Η τρίτη θέση είναι η «Αλιστράτη 1». Βρίσκεται περί τα 1000μ. προς τα νοτιοδυτικά του σπηλαίου της Αλιστράτης, στο οποίο φθάνει κανείς από την πλευρά της ομώνυμης κωμόπολης. Είναι προς τα κατάντη του Αγγίτη, αριστερά από την σιδηροδρομική γραμμή, αμέσως στο πρώτο επίπεδο κάτω από το χείλος του φαραγγιού σε υψόμετρο 90μ. Απέναντι από τη θέση, στην άλλη πλευρά του φαραγγιού, βρίσκεται η μεγάλη εντυπωσιακή φυσική γέφυρα του Αγγίτη. Η θέση είναι μια επιφάνεια μαρμάρινη κάτω από βραχοσκεπή. Η επιφάνεια της θέσης είναι σχεδόν οριζόντια. Έχει κυκλικό σχήμα με διάμετρο περίπου 3μ. Περιφερειακά το έδαφος κατά περιόδους σκάβεται από χρυσοθήρες ή κυνηγούς θησαυρών. Η επιφάνεια φιλοξενεί, στην σκληρή της επιδερμίδα, περισσότερες από 60 παραστάσεις, οι οποίες είναι χωρίς αμφιβολία δημιουργημένες σε διαφορετικές περιόδους που απέχουν μεταξύ τους ίσως και χιλιετίες. Θεματικά απεικονίζονται ελάφια, άλλα ζώα, κυνηγοί, θωρακισμένοι πολεμιστές και άλλες απροσδιόριστες γραμμές.

IV. Η τέταρτη θέση είναι η «Αλιστράτη 2». Βρίσκεται στην ίδια πλευρά και στο ίδιο επίπεδο με την θέση «Αλιστράτη 1»,περί τα100μ. πριν από αυτήν και πλησιέστερα προς το αξιοποιημένο σπήλαιο. Απεικονίζονται μεμονωμένα ακιδογραφήματα ανάλογα της θέσης «Αλιστράτη 1» αλλά πολύ λιγότερα σε αριθμό.

Οι διαστάσεις των ακιδογραφημάτων είναι μεταξύ 5 - 40 cm. Η δημιουργία των βραχογραφημάτων - ακιδογραφημάτων είναι ένα διαχρονικό χαρακτηριστικό του ανθρώπου. Αποτελούνε στην ουσία τα εναπομείναντα πρώτα εργαλεία σκέψης και αποθήκευσης της γνώσης του παλαιού ανθρώπου. Για ένα σημαντικό σύνολο από τις παραπάνω παραστάσεις, προτείνεται η χρονική τοποθέτησή τους στη νεολιθική εποχή μέχρι την εποχή του χαλκού. (ΧΑΤΖΗΛΑΖΑΡΙΔΗΣ, Λ. 2000),

Ι. Θέση χωριού Συμβολής και Φαραγγιού Αγγίτη Ν. Σερρών

Εικ. 1.Εικονίζεται η επιφάνεια με τα βραχογραφήματα της περιοχής Συμβολής. Σε μικρή απόσταση στο βάθος βρίσκεται το φαράγγι του παραπόταμου Αγγίτη του ποταμού Στρυμόνα.

Εικ. 2. Κεντρικό τμήμα της επιφάνειας με τα βραχογραφήματα της Συμβολής. Διακρίνονται γραμμικές παραστάσεις ζώων, ήλιοι κλπ.

** *Διδάκτωρ Φιλοσοφίας Α.Π.Θ. - Γεωλόγος , Σχολικός σύμβουλος Φυσικών Επιστημών Δυτ. Μακεδονίας*
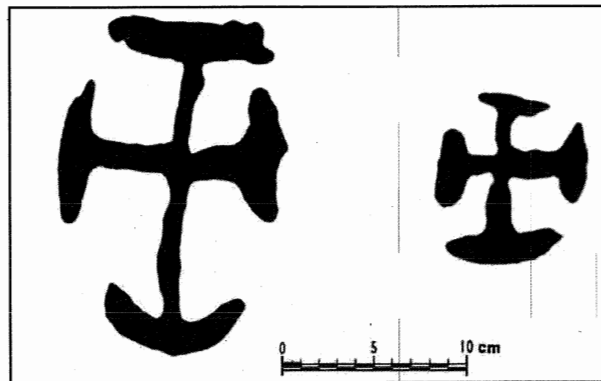
Εικ. 3. Λαξευμένοι σταυροί ή συμβολισμοί ανθρώπων από επιφάνεια που βρίσκεται περί τα 30 μέτρα ανατολικότερα της κεντρικής επιφάνειας με τα βραχογραφήματα της Συμβολής.
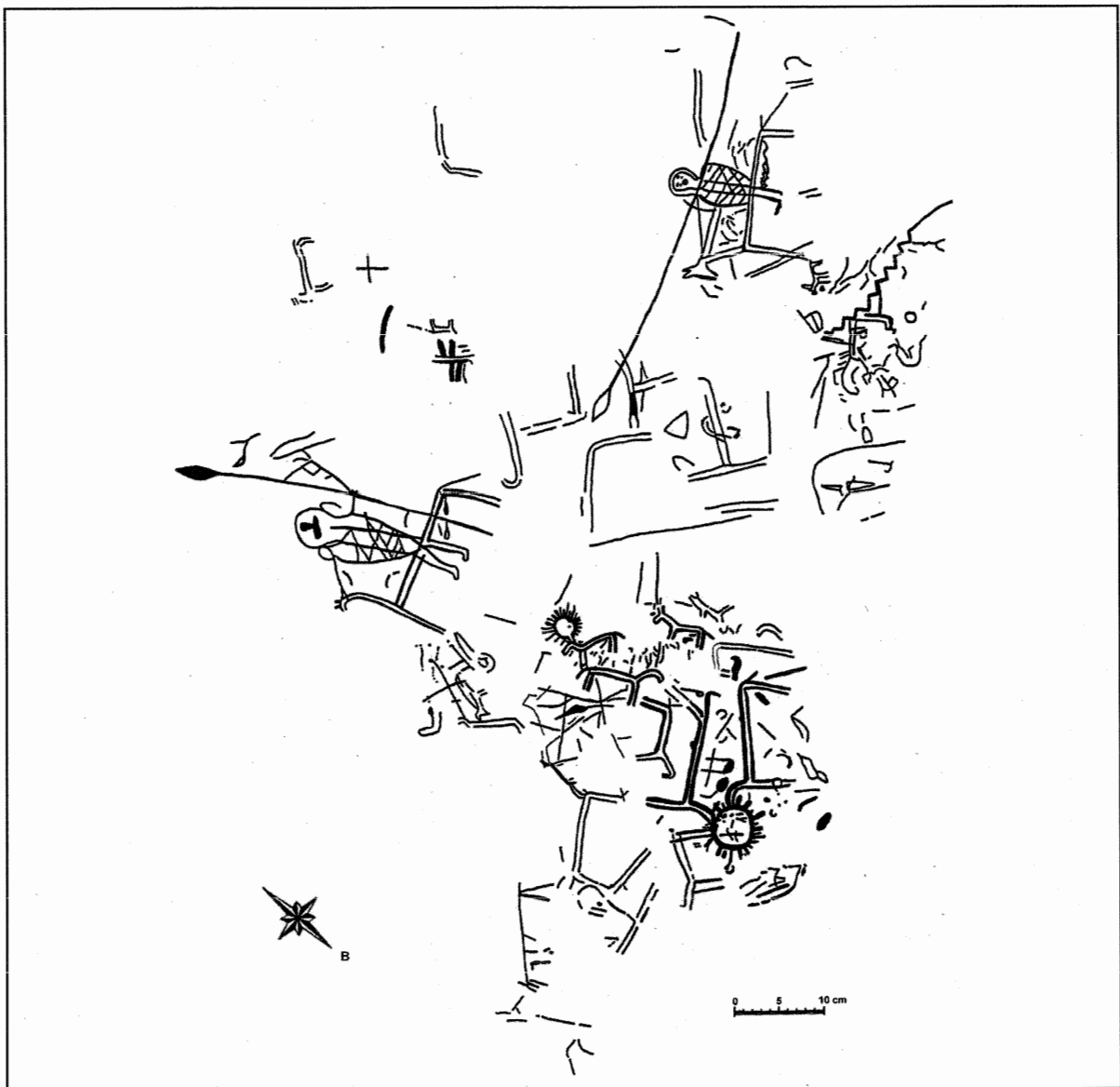
Εικ. 4. Απεικονίσεις των παραστάσεων των βραχογραφημάτων από το κεντρικό τμήμα της επιφάνειας της Συμβολής. Χαρακτηριστικά είναι τα ζώα με τους ήλιους στο κεφάλι και οι θωρακισμένοι πολεμιστές.

ΙΙ. Θέση Κρηνίδας - Νέας Μπάφρας - Αγγίτη Ν. Σερρών

Εικ.5 Άποψη από την δυτική (περιοχή Αλιστράτης) προς την ανατολική πλευρά του φαραγγιού του Αγγίτη ποταμού. Διακρίνονται (κέντρο δεξιά) οι τρεις είσοδοι των σπηλαίων. Αυτό με την τριγωνική σκούρα εμφάνιση είναι το σπήλαιο με τα βραχογραφήματα (ΧΑΤΖΗΛΑΖΑΡΙΔΗΣ, Λ. 2003).
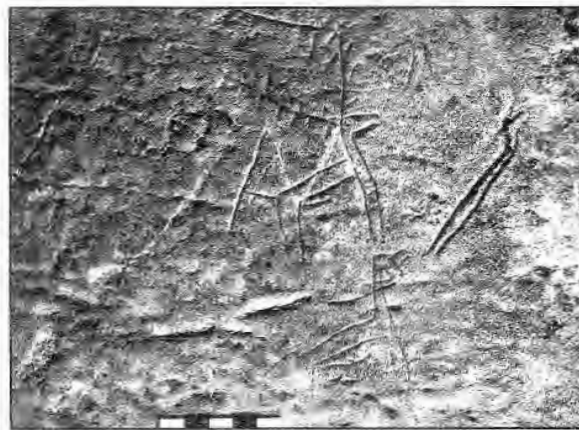
Εικ.6

Εικ. 7

Εικ.6, Εικ.7. Κεντρικό δεξιό τμήμα της κύριας επιφάνειας. Στο κέντρο της κάθε εικόνας εντοπίζονται γραμμικές παραστάσεις ελαφιών και άλλα ζώα.
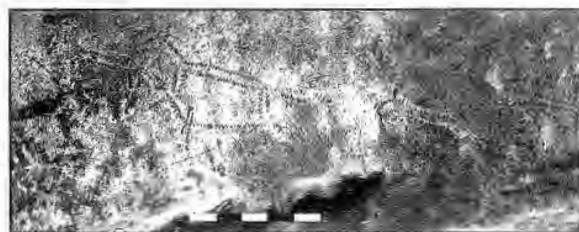
Εικ. 8. Τμήμα από το αριστερό μέρος της επιφάνειας του σπηλαίου Κρηνίδας. Διακρίνεται πριονωτή απόδοση των περιγραμμάτων των ζώων. Είναι η μικρή αγέλη.
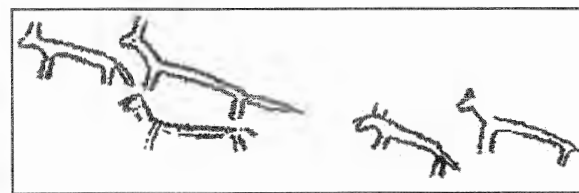
Εικ. 9. Γραμμική απεικόνιση των παραστάσεων της εικόνας 9, της μικρής αγέλης.
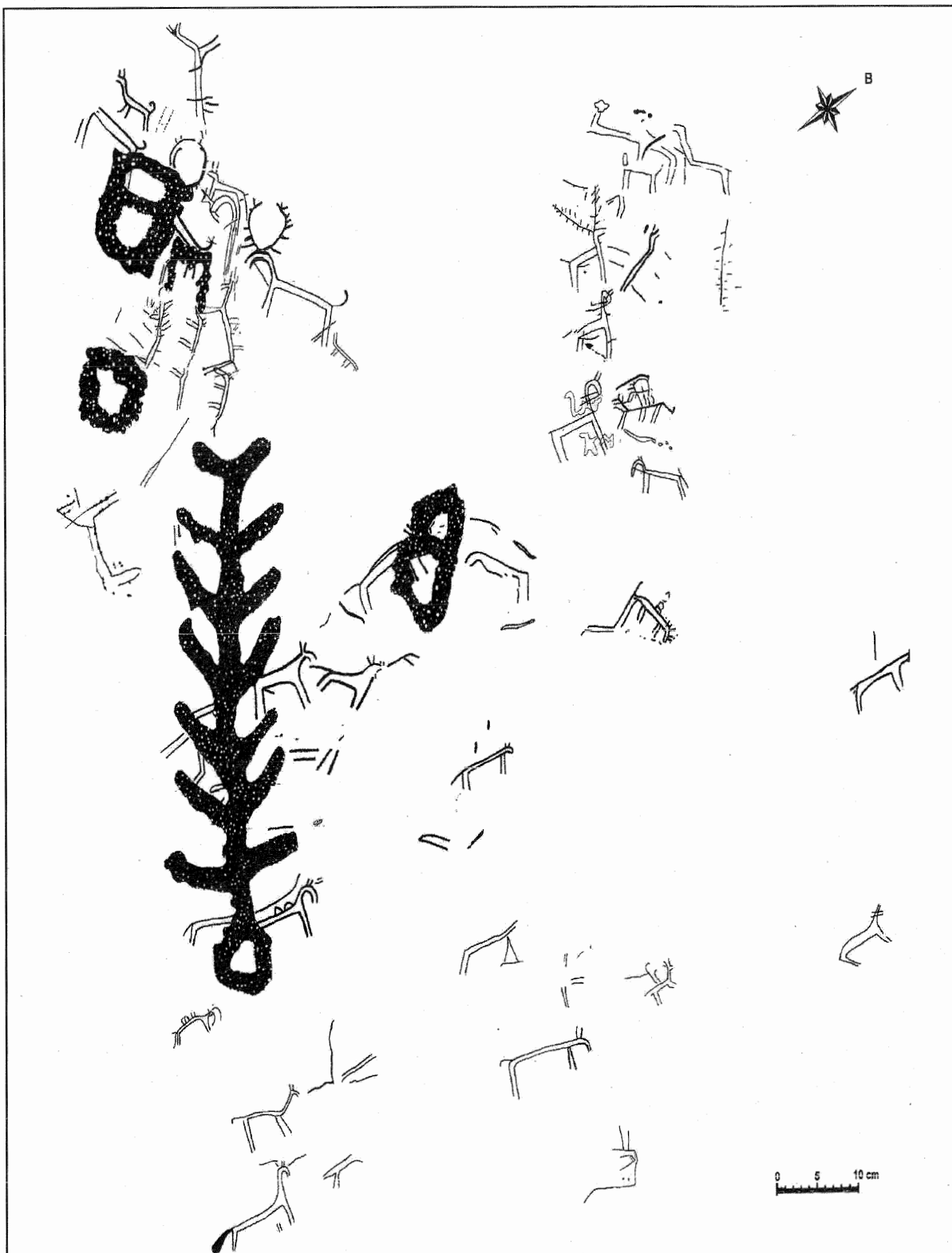
Εικ. 10. Γραμμική απεικόνιση των χαραγμάτων του κεντροδεξιού τμήματος της επιφάνειας του δαπέδου τους σπηλαίου Κρηνίδας - Νέας Μπάφρας Ν. Σερρών. Παριστάνονται ελάφια και άλλα ζώα. Οι έντονες σκούρες απεικονίσεις με την μορφή του γράμματος Θ, ή του ψαροκόκαλου είναι κατά πολύ νεότερες και δημιουργήθηκαν με κρούση της επιφάνειας με πέτρα ή σφυρί .

III. Θέση Αλιστράτη 1 Ν. Σερρών .
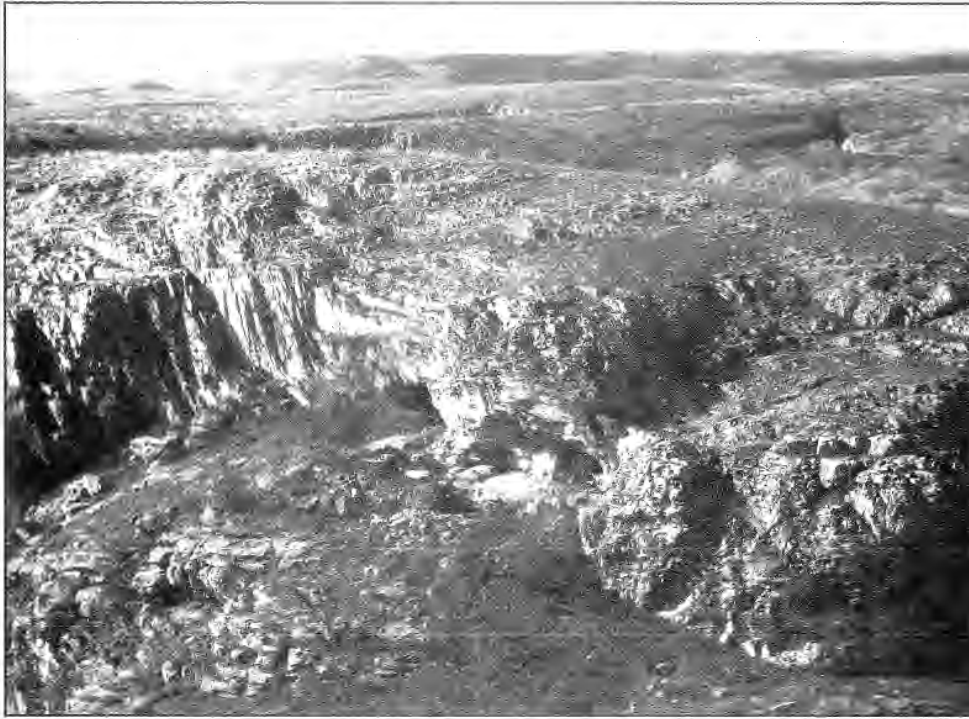
Εικ.11. Είναι η θέση Αλιστράτη 1, όπως φαίνεται από την απέναντι (ανατολική) πλευρά του φαραγγιού Αγγίτη, από την πλευρά της μεγάλης φυσικής γέφυρας. Η προσέγγισή της γίνεται από την πλευρά του σπηλαίου της Αλιστράτης. Στο κέντρο κάτω από βραχοσκεπή είναι η κύρια επιφάνεια των βραχογραφημάτων.

Εικ.12. Οι χαρακτηριστικότερες παραστάσεις ελαφιών από την επιφάνεια Αλιστράτη 1, που ίσως έχουν ακόντια στα πλευρά τους . Κατά θέσεις στην επιφάνεια υπάρχουν εσκεμμένες κρούσεις για καταστροφή των παραστάσεων.
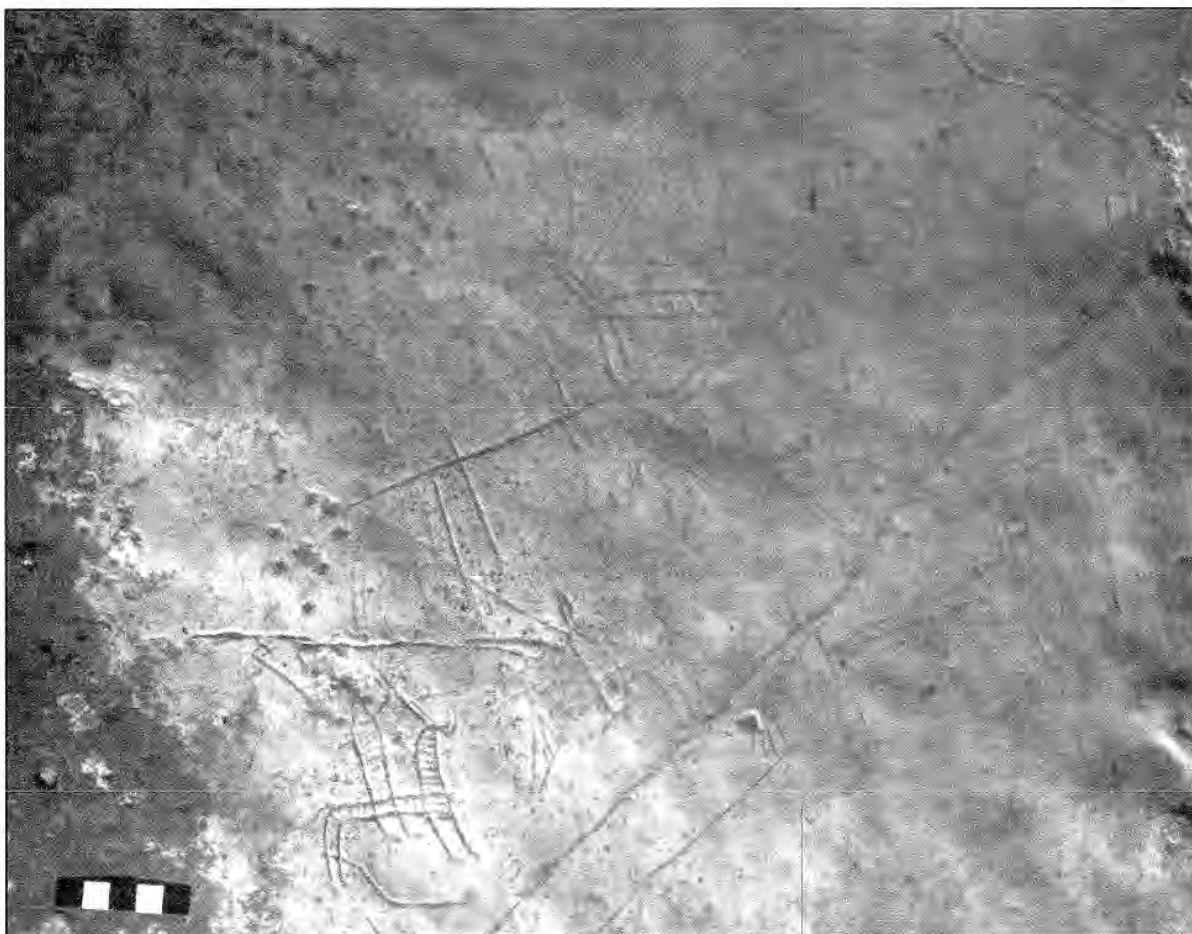
Εικ. 13. Τμήμα της επιφάνειας με τα βραχογραφήματα από την θέση Αλιστράτη 1. Διακρίνονται κάτω δύο αντιμέτωποι ιππείς πολεμιστές (MAIS, K.- SEEMAN, R.- ΣΥΜΕΩΝΙΔΗΣ, N. 1978). Στο κέντρο απεικονίζεται ένα ελάφι, ίσως, τραυματισμένο. Κάποια βραχογραφήματα είναι καλυμμένα μερικά με ασβεστοαργιλικά ιζήματα. Μια μελλοντική ραδιοχρονολόγησή τους θα αποδώσει τεκμήρια για την ηλικία των παραστάσεων.
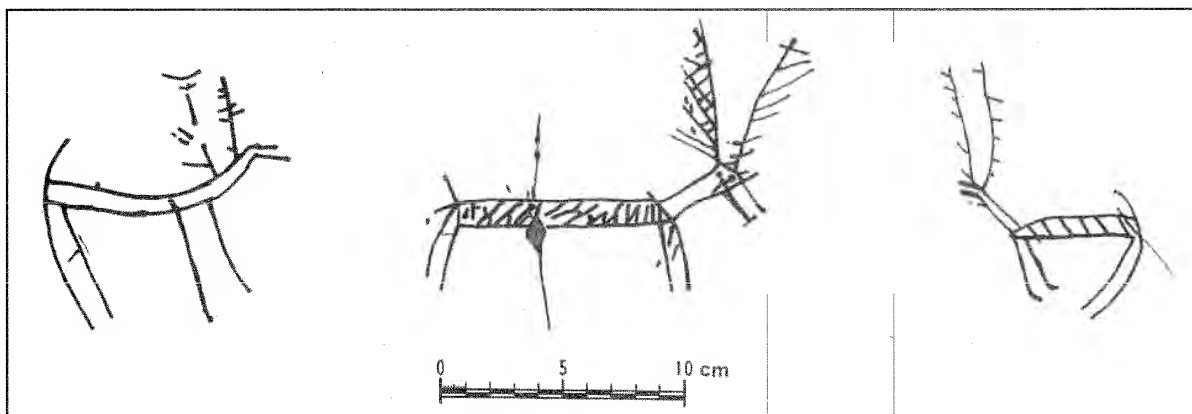
Εικ. 14. Γραμμικές απεικονίσεις των ελαφιών που φαίνονται στις εικόνες 12 και 13.

IV. Θέση Αλιστράτη 2, Ν. Σερρών.
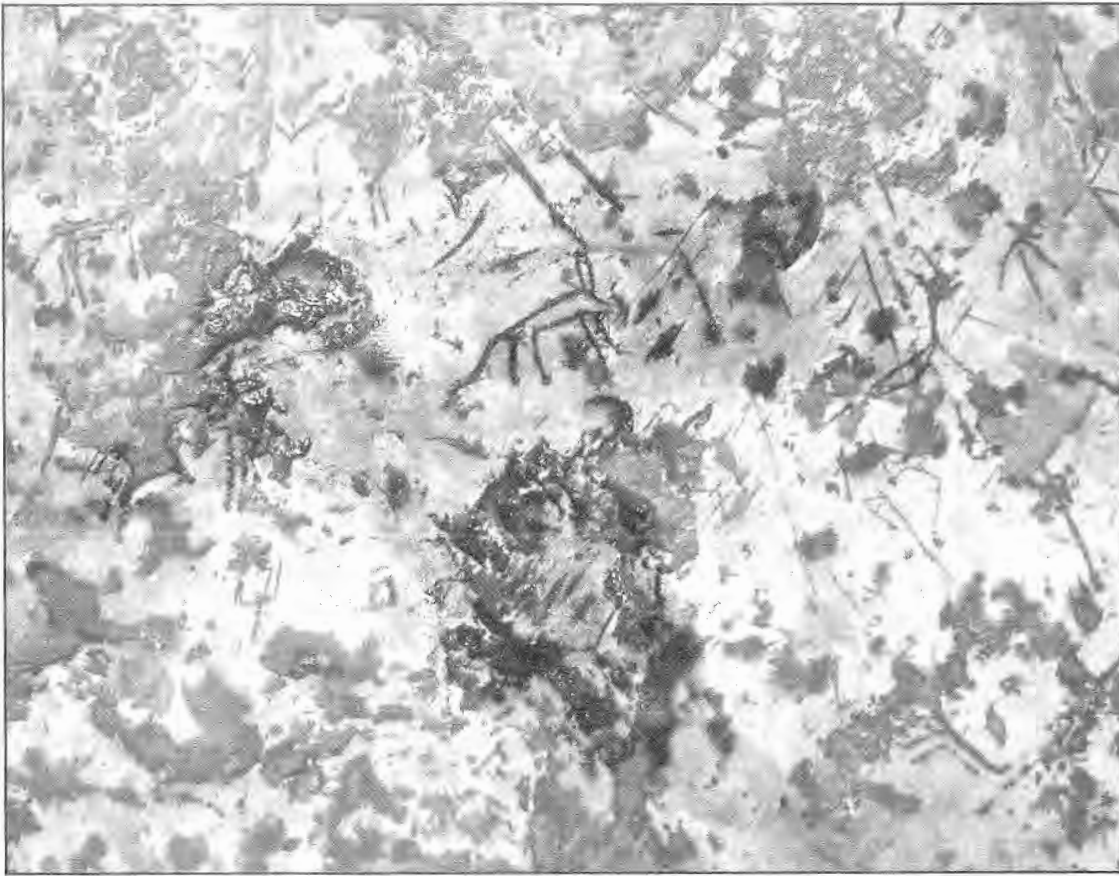
Εικ.15. Επιφάνεια από τη θέση Αλιστράτη 2. Στις θέσεις που είναι βρεγμένη η επιφάνεια οι χαραγές γίνονται ευδιάκριτες, διαφορετικά ο εντοπισμός των παραστάσεων δεν είναι εύκολος. Οι απεικονίσεις δεν χαρακτηρίζονται από την αντίστοιχη πλαστικότητα των παραστάσεων από άλλες θέσεις.

Εικ. 16. Θέση Αλιστράτη 2. Μάλλον απεικονίζεται μία αλεπού.

Εικ. 17. Θέση Αλιστράτη 2. Οι χαραγμένες παραστάσεις ίσως απεικονίζουν λαγούς.

Συμπεράσματα

Κάθε «πρωτόγονη» ανθρώπινη ομάδα επινοεί τους δικούς της τρόπους επαφής και συνύπαρξης με το φυσικό περιβάλλον. Έτσι ένα σύνολο αντικειμένων, ενεργειών, σχέσεων, συμβόλων και αξιών τροφοδοτούν την έμπνευση του πρωτόγονου χαρακτήρα, ο οποίος αναπαριστά στα βραχογραφήματα στοιχεία της ατομικής ή της συλλογικής εμπειρίας. Πρόκειται για μαρκάρισμα τόπων, για μέσο απομνημόνευσης και μεταφοράς τεχνικών γνώσεων, για κώδικα επικοινωνίας, για τελετουργικές πράξεις μαγείας και λατρείας ή ακόμα για την πρώτη έκφραση της καλλιτεχνικότητας και της αισθητικής αναζήτησης. Τα βραχογραφήματα αποτελούν βασική μαρτυρία της ιστορίας του νοήμονος ανθρώπου. Είναι η απαρχή της εικαστικής σημειολογίας, καθώς ο άνθρωπος για κάθε ζώο, πρόσωπο ή αντικείμενο, σχέση ή ιδέα, χρησιμοποίησε τη ζωγραφική ή τη χαρακτική για να τα απεικονίσει. Έτσι αποτελούν τα πρώτα δείγματα εικαστικών τεχνών, ένα επίπεδο νοητικής αφαίρεσης που διαφοροποιεί την ανθρώπινη ομάδα από τα υπόλοιπα έμβια όντα, που εξαντλούν τη δράση τους για την ικανοποίηση μόνο των αναγκών της βιολογικής επιβίωσης.

Επομένως τα προϊστορικά βραχογραφήματα είναι μια ειδική, χωρίς ήχο, φωνή της επιδερμίδας των βράχων της γης, που φωτίζει το άγνωστο παρελθόν των νοημόνων προγόνων μας (ΧΑΤΖΗΛΑΖΑΡΙΔΗΣ, Λ. 2004). Ο «πρωτόγονος» άνθρωπος παράγει τα βραχογραφήματα ως μια σύνθετη εκδήλωση της εσωτερικότητάς του αλλά και ως αποτύπωση κοινωνικών σχέσεων, επιδιώξεων και εμπειριών (ΧΑΤΖΗΛΑΖΑΡΙΔΗΣ, Λ. - ΒΟΝΤΣΑ, Β. 2005). Η μελέτη τους μας παραπέμπει στον ιδιαίτερο τρόπο ζωής μιας «πρωτόγονης» ανθρώπινης ομάδας, η οποία ξεπερνά τα όρια της αναγκαίας βιολογικής επιβίωσης και συγκροτεί έμφρονες δραστηριότητες, όπως η τελετουργική μαγεία, η μνημονική αποτύπωση και κυρίως η καλλιτεχνική έκφραση και η εικαστική δημιουργία.

ΒΙΒΛΙΟΓΡΑΦΙΑ

ANATI, E. (1994), «World Rock Art. The primordial language», Valcamonica, Italy.

AUERNHEIMER, G. (1992), «Ethnizitaet und Modernitaet», στο Institut fuer Migration und Raumforschung, Racismus und Migration in Europa, Hamburg, Argument.ΘΕΟΧΑΡΗΣ, Δ. (1967):"Η Αυγή της Θεσσαλικής Προϊστορίας",(Έκδοση της Φιλάρχαιου Εταιρείας Βόλου, Θεσσαλικά μελετήματα, αριθμ. 1.), σ.44-61, εικ.10, πιν. 7, Βόλος.

ΙΩΑΝΝΟΥ, Ι.(1963): "Σπήλαια και πελεκημένες πέτρες στη Νάξο", περ. Ελλάδα, τ.2, Μάιος 1963, σ.12-15.

LUHMANN, N. (1995), «Gesellschaftsstructur und Semantik. Stuchien zur Nissensoziologie der modernen Gesellschaft», Frankfurt/M, Suhrkamp (τομ. 4)

ΜΠΑΚΑΛΑΚΗΣ, Γ. (1940): «Θρακικά χαράγματα. Εκ του παρά την Αμφίπολιν φράγματος του Στρυμόνος» ΘΡΑΚΙΚΑ 13,σ.5-32. Αναδημοσίευση από ΑΠΘ, ΟΙΝΟΣ ΙΣΜΑΡΙΚΟΣ τιμητικός τόμος για Γ. Μπακαλάκη. Θεσσαλονίκη,1990

MAIS, K.- SEEMAN, R.- ΣΥΜΕΩΝΙΔΗΣ, N. (1978): "Βραχογραφίες σε σπήλαια της περιοχής Αλιστράτης Σερρών". Δελτ. Ελλ. Σπηλ.Εταιρίας XV - 1, σ. 71-77, Αθήνα.

ΜΟΥΤΣΟΠΟΥΛΟΣ, Ν. (1995), «Νεολιθικό ακιδογράφημα στις όχθες της Χειμαδίτιδας λίμνης και το δίδυμο μενχίρ του Πελεκάνου», Αρχαιολογία, τ. 56, Σεπτέμβριος 1995, σελ.: 39-45

ΝΤΟΥΜΑΣ, Χ.(1966) :"Κορφή τ' Αρωνιού, Μικρά ανασκαφική έρευνα εν Νάξω", Αρχαιολογικό Δελτίο, τ.20 (1965), σ.41-64, πιν.26-41, σχ.1-13. Αθήναι.

ΠΑΠΑΝΙΚΟΛΑΟΥ, Σ. (2004), « 555 Γραμμένες πέτρες». σελ.120, Λάρισα, ΕΛΛΑ

ΤΡΙΑΝΤΑΦΥΛΛΟΣ, Δ. (1973): "Μεγαλιθικά μνημεία (Dolmen) και βραχογραφίαι εις την Δυτικήν Θράκην", «Αρχαιολογικά ανάλεκτα εξ Αθηνών» τομ. 6, τεύχ. 2, σ. 241-255, εικ. 1-20, σχ. 1. Αθήνα.

ΧΑΤΖΗΛΑΖΑΡΙΔΗΣ, Λ. (1981) : "Βραχογραφίες Κρυονερίου Καβάλας" (προκαταρκτική ανακοίνωση) στο 1ο Πανελλήνιο Σπηλαιολογικό Συμπόσιο, Δεκ. 1981. Δελτίο Ελλην. Σπηλαιολ. Εταιρείας, τ.18, τ.1-2, σ. 346-366, Αθήνα.

ΧΑΤΖΗΛΑΖΑΡΙΔΗΣ, Ι. Λ. (1988) : "Βραχογραφίες- ακιδογραφήματα Αν. Μακεδονίας", σ.85-88,σχ.14, Περιοδ. «Ανθρωπολογικά Ανάλεκτα» τομ.49, τευχ. 1, Αθήνα.

ΧΑΤΖΗΛΑΖΑΡΙΔΗΣ, Ι.Λ. (2000) : «Προϊστορικά βραχογραφήματα στη Β. Ελλάδα», τ.Ι σ.1-250, τ.ΙΙ 24 σχεδιασμένες επιφάνειες. Διδακτορική διατριβή. Θεσσαλονίκη.

ΧΑΤΖΗΛΑΖΑΡΙΔΗΣ, Λ. (2003), «Βραχογραφήματα σπηλαίου Κρηνίδας - Ν. Μπάφρας φαραγγιού Αγγίτη Ν. Σερρών», σελ. 9, πρακτικά 3ου Συμποσίου. Ε.Σ.Ε. τ. XXIII Αθήνα.

ΧΑΤΖΗΛΑΖΑΡΙΔΗΣ, Λ. (2004), «Προϊστορικά Βραχογραφήματα στη Β. Ελλάδα», σελ. 290, Εκδόσεις : Νέα Θέσις. Αθήνα,

ΧΑΤΖΗΛΑΖΑΡΙΔΗΣ, Λ. - ΒΟΝΤΣΑ, Β. (2005), «Προϊστορικά Βραχογραφήματα, Πρώτες καλλιτεχνικές

εκφράσεις του έμφρονος ανθρώπου. Πρακτικά συνεδρίου ΕΠΙΣΤΗΜΗ & ΤΕΧΝΗ της Ε.Ε.Φ. σ. 6,

4ος τ. (υπό έκδοση). Αθήνα.

ΧΟΥΡΜΟΥΖΙΑΔΗΣ, Γ. (1985): "Η τελευταία λέξη για τα βραχογραφήματα δεν έχει ειπωθεί ακόμη" συνέντευξή στην εφ/δα «Πανεπιστημιακά Νέα», φύλλο 29,

Μάϊος 1985, σ.11 και σ.14, Θεσσαλονίκη.

302

O-86

Karstmorphologie von Akarnanien und der Insel Lefkada
(West-Griechenland)

Max H. Fink

Dr. Max H. FINK, Metzgergasse 5, A-3400 Klosterneuburg, Austria word2000: FINK14ICS
(e-mail: finkweidling@hotmail.com)

Akarnanien, ein überwiegend gebirgiges Land, springt als Halbinsel des westlichen Griechenland in die Nebengewässer des Ionischen Meeres vor. Der Küstenverlauf ist stark gegliedert; durch den Amvrakischen Golf, ein ehemaliges großes, transgrediertes Polje, dringt das Meer tief in das Festland ein und bildet die Nordgrenze Akarnaniens. Westlich vorgelagert ist die große Insel Lefkada (auch: Lefkas). Die akarnanisch-lefkadische Karstlandschaft ist auf der Übersichtskarte zur Darstellung gebracht. Genauere Karten und ausführlichere Beschreibungen enthalten die Publikationen von M.H. FINK und S. VERGINIS aus 1974 und 1976. Das Klima wird durch die peripher gelegene Station Aktion (südlich Preveza) mit einem Jahresmittel von 16,9 Grad C und rund 1000 mm Jahresniederschlag gekennzeichnet.

Das Gebiet gehört der Ionischen Zone Griechenlands an, die im Osten von der Gabrovo-Zone und im Westen von der Paxos-Zone begrenzt wird; die Ionische Zone ist auf die Paxos-Zone aufgeschoben, was auf Lefkada sichtbar wird. Die Hauptgesteine sind größtenteils Kalke und Dolomite triadischen bis kretazischen Alters; Jurakalk ist dabei am weitesten verbreitet. Innerhalb des Triasgebietes treten triadischer Gips und miozäner Flysch auf.

Akarnanien weist drei Hauptstockwerke auf:

1. Hoch-Akarnanien besteht aus mehreren Nord - Süd verlaufenden Kalkketten, die in Ipsili Korifi (1589 m) kulminieren.

2. Mittel-Akarnanien schließt östlich der Linie Monastiraki - Thirion - Aetos - Chrisovitsa - Astakos an und besteht aus einem Plateauland zwischen 600 und 200 m Höhe und umfasst zwei Teilstockwerke: Das Hochland von Katouna und Papadhatos und die Poljentreppe von Drokives, Aetos und Mahera.

   Hoch- und Mittel-Akarnanien ist ein stark verkarstetes Gebirgsland, das infolge seines Wassermangels auch als "Xeromeros" bezeichnet wird.

3. Nieder-Akarnanien umfasst die Ebene von Agrinion bis zum Rand der Flyschzone und das Mündungsgebiet des Flusses Acheloos.

Hoch-Akarnanien: Zwischen kahlen Kalkketten, die auf ihren Höhen intensiv verkarstet sind, bildet der Flysch schmale Tiefenzonen. Im Westen liegt die Gebirgskette Serekas (1171 m), anschließend die kurze Kalkkette Ennea Adelfia (1142 m). Darauf folgt die Höhenzone des Agriabidaki (1395 m) und schließlich als höchste Kette die des Ipsili Korifi (1589 m), die sich nordwärts im Perganti (1428 m) fortsetzt. Zwischen den Höhenzügen liegt südlich von Monastiraki das große Polje Livadi in einer Höhe von 760 m. Die Längserstreckung verläuft NNW-SSE und beträgt 4 km, die größte Breite 2 km. Es wird von einem Bachlauf entwässert, der in einem Ponor am Westrand versinkt. Die geologische Position ist durch Jura- und Triaskalk gegeben, die einen schmalen Flyschstreifen umschließen, der den Poljeboden bedingt. Die Genese ist mit einer Petrovarianz und mit Bruchsystemen verknüpft. Das Polje ist eine polygenetische Karsthohlform (M. H. FINK 1973) mit ehemals oberirdischer Entwässerung.

Mittel-Akarnanien: Im Bereich westlich und südwestlich von Vonitsa befinden sich viele Dolinen und Karstmulden, von denen einige mit Wasser erfüllt sind. Die bis zu 300 m breiten Dolinen Miuro Linovrochi und Mega Linovrochi (= "Sauberer Regen") südwestlich Vonitsa mit ihren Seen sind typisch für die Großdolinen dieses Raumes. Starke Zerklüftung und Anzeichen für junge tektonische Bewegungen deuten auf Einsturzdolinen hin. Zwischen Vonitsa und Aktion ist die im Grundriss

nierenförmige, mit einem See erfüllte Karstwanne Linovrochi Livavaou anzuführen, die am Kontakt zwischen Jurakalk und marinen Pliozän-Sedimenten liegt. In der Umgebung gibt es eindrucksvolle Karren, die ausgedehnte Karrenfelder bilden. Ausgangsflächen für die Karrenbildung sind hier flach geneigte Schichtflächen des Jurakalkes. Alle aus dem alpinen Hochgebirgskarst bekannten Formen wie Firstrillen, kavernöse Karren, Kamenicas und Rinnenkarren sind in nur 50 m Meereshöhe modellhaft vertreten. Eine oft behauptete Karrencatena, basierend auf der Korrelation Höhenlage - Karrenvarianz trifft daher nicht zu! Die Karrentypen sind nicht von der Höhenlage, sondern nur vom Wechselwirkungsgefüge der geoökologischen Faktoren abhängig.

Das Gebiet zwischen Monastiraki, Thirion und dem Amvrakischen Golf zeichnet sich durch eine Fülle von Karsthohlformen verschiedener Größe aus, wobei Poljen, Karstmulden, Karstwannen und Karsttäler dominieren. Alle großen Karsthohlformen sind an funktionslose Talungen gebunden. Z.B. das kleine, episodisch überflutete Polje Lakkos ton pedion (= "Kinderloch") bei Paliambela und die Karstwannen Livrochi und Vocho mit ihren Seen. Die Inundationen sind auf Tagwasserstau und Schwankungen der Karstwasseroberfläche zurückzuführen; das Wasser versickert nicht in Ponoren, sondern diffus. Das 5 km lange und bis über 2 km breite Polje Avilaria zwischen Paliambela und Thirion ist in die nördlichen Vorlagen Hochakarnaniens eingesenkt. Die Hauptachse streicht NW - SE, die tiefste Stelle des Poljebodens liegt 170 m über dem Meer. Es ist an einer Deckenstirn am Kontakt von Trias- und Jurakalk, Flysch und Gips entwickelt. Das Polje besteht aus Teilvertiefungen, von denen die im Westen von einem ständigen See mit wechselndem Wasserstand erfüllt wird.

Zwischen Avilaria und Monastiraki entspringen am Gebirgsrand die Karstquellen von Korpi, die auch das Trinkwasser für die Stadt Vonitsa liefern. Das Wasser wirkt therapeutisch gegen Nierenleiden und kommt auch als Mineralwasser in den Handel.

Östlich des Ipsili Korifi, nahe von Komboti und Achira, liegt das 4 km lange, bis zu 2 km breite Semipolje Paleo kambos. Der ebene Boden ist über Miozän-Flysch zur Ausbildung gelangt; die Umrahmung selbst wird vorwiegend aus Jurakalk gebildet. Ursprünglich haben die Karstgesteine den gesamten Raum der heutigen Hohlform eingenommen; deren Denudation führte zur Exhumierung der überschobenen Flyschgesteine. Das Becken wird zur Gänze durch den Nisas-Fluss oberirdisch entwässert. Bevor der Nisas jedoch Mittelakarnanien Richtung Amvrakischen Golf verlässt, durchströmt er zwischen Voustri und Trifos ein weiteres Becken, das die Bezeichnung Nisa trägt. Dieses nur 2 km lange, bis zu 1 km breite Becken wird von Triaskalk und Gips umrahmt und muss wegen seiner oberirdischen Entwässerung ebenfalls als Semipolje bezeichnet werden.

Das Polje von Trifos ist talgebunden und setzt sich aus zwei Becken zusammen. Der von Terra rossa bedeckte Boden hat einen episodischen Abfluss und versinkt in einem Ponor. Im Westen schließt eine intensiv verkarstete Hochfläche an, die durch eine große Dolinendichte im Triaskalk gekennzeichnet ist. Am Abfall gegen das Nisas-Tal tritt verkarsteter Gips mit Gipskarren und Gipsquellen auf.

Am Nordostrand Mittelakarnaniens, nahe von Katouna, befindet sich das große Polje Vliches. Die spindelförmige, 9,5 km lange, bis zu 1,5 km breite Wanne fügt sich in die NNW - SSE verlaufende Hauptstreichungsrichtung Akarnaniens ein und ist ein tektonisches Teilbecken der bedeutenden Agrinionsenke. Dieses Senkungsfeld wurde im Pliozän mit

limnischen Sedimenten erfüllt. Erst nach der Landfestwerdung setzte die eigentliche Phase der Poljengenese im Quartär ein. Es erfolgte die Umwandlung von einem plombierten tektonischen Senkungsfeld zu einem Polje mit vollständiger unterirdischer Entwässerung. Am mesozoischen Rahmen des Poljes sind Trias-, Jura- und Kreidekalke beteiligt, im SW auch Gips. Der NW-Teil des Poljebodens mit Terra rossa birgt den namengebenden Schilfsee „Vliches" mit wechselndem Wasserstand. Der gesamte Boden mit Ausnahme des Schilfsees wird landwirtschaftlich genutzt. Der sommerliche Wassermangel wird durch zahlreiche künstliche Wassergruben ("sternes") behoben, von denen aus die Bewässerung der Felder mittels „fliegender" Leitungen durchgeführt wird.

Im mittelakarnanischen Hochflächenkarst zwischen Trifos, Katouna und Papadatos kommen neben Bereichen großer Dolinendichte auch kleinere Poljen vor, von denen jene von Trifos, Drokives, Agios Prokópios, Statopigado, Agios Paraskevi und Ftéri anzuführen sind.

Zwischen Hochakarnanien und dem Hochflächenkarst Mittelakarnaniens ist eine Tiefenzone eingeschaltet, die in südlicher Richtung treppenförmig über Chrisovitsa zur Mündungsebene des Flusses Acheloos absinkt. Sie wird von großen Talpoljen und Semipoljen eingenommen, die sich in ihrer Längserstreckung in die allgemeine Abdachung dieses Gebietes nach Süden einfügen und zugleich der generellen Streichungsrichtung der akarnanischen Gebirge folgen. Südlich von Katouna liegt am Rand des mittelakarnanischen Hochflächenkarstes das kleine trockene Polje Drokives, das mit dem östlich anschließenden Polje Agios Prokópios den Übergang vom Hochflächenkarst zur Tiefenzone darstellt.

Bei einer Längserstreckung von 10 km und einer Breitenentwicklung bis zu 3 km ist das Polje von Aetos das größte echte Polje Akarnaniens. Eine Besonderheit ist der mächtige Karstrestberg (Hum) Mirovigli (605 m), der aus Jurakalk besteht und der an seiner Ostseite mittels einer Schwelle mit dem östlichen Poljerahmen verbunden ist. Weitere kleinere Humi befinden sich im NW und Süden des Mirovigli; auch sie werden von Jurakalken aufgebaut. Die Umrahmung besteht im W und S aus Jurakalk, im N und NE aus Triaskalk. Der flache, nach S geneigte Poljeboden, der sich mit scharfem Knick von der Umrahmung absetzt, wird von Terra rossa eingenommen, die gegen S zunehmend mit fluviatilem Material, vorwiegend Schotter, durchmischt ist. Der tiefste Punkt des Poljes liegt bei 190 m Höhe, nahe der inaktiven Karsttalung, die in das Karstbecken von Mahera leitet. Dieser Teil hat den Flurnamen „Katavothre", was auf die unterirdische Entwässerung durch Ponore hinweist. Bei Hochwasser können die Ponore das anfallende Wasser nicht zur Gänze ableiten und es kommt zu episodischen Inundationen.

Das Becken von Mahera, besteht aus den Teilfeldern Neopigadi - Megas Kambos, ist gegen S zu offen und daher als Semipolje zu bezeichnen. Die Großform setzt im N bei Papadatos an und findet nach 12 km ihr südliches Ende zwischen Chrisovitsa und Agrambela, wo sich der bis zu 3 km breite Boden in der offenen Talung "Remma" fortsetzt. Die Anlage des Semipoljes ergibt sich aus dem Kontaktbereich zwischen Trias- und Jurakalk. Das gleichsinnige Gefälle des Poljebodens gegen S, das auch an den begleitenden Terrassen festzustellen ist, weist auf eine fluviatile Präformierung und eine rezente episodische Aktivität der Großform hin.

Der mehr als 14 km² große See Limni Amvrakia befindet sich am Ostrand Mittelakarnaniens in einem Semipolje, das der tektonischen Agrinionsenke angehört. Die Umrahmung bilden größtenteils mesozoische Karbonatgesteine, nur im Süden schließen Pliozän-Sedimente die Hohlform ab. Für die Genese der großen Hohlform sind auch eine große tektonische Störung am Westrand und Gips-Diapirismus bedeutsam.

KARST FORMS in AKARNANIA and on LEFKADA Island (Western Greece)
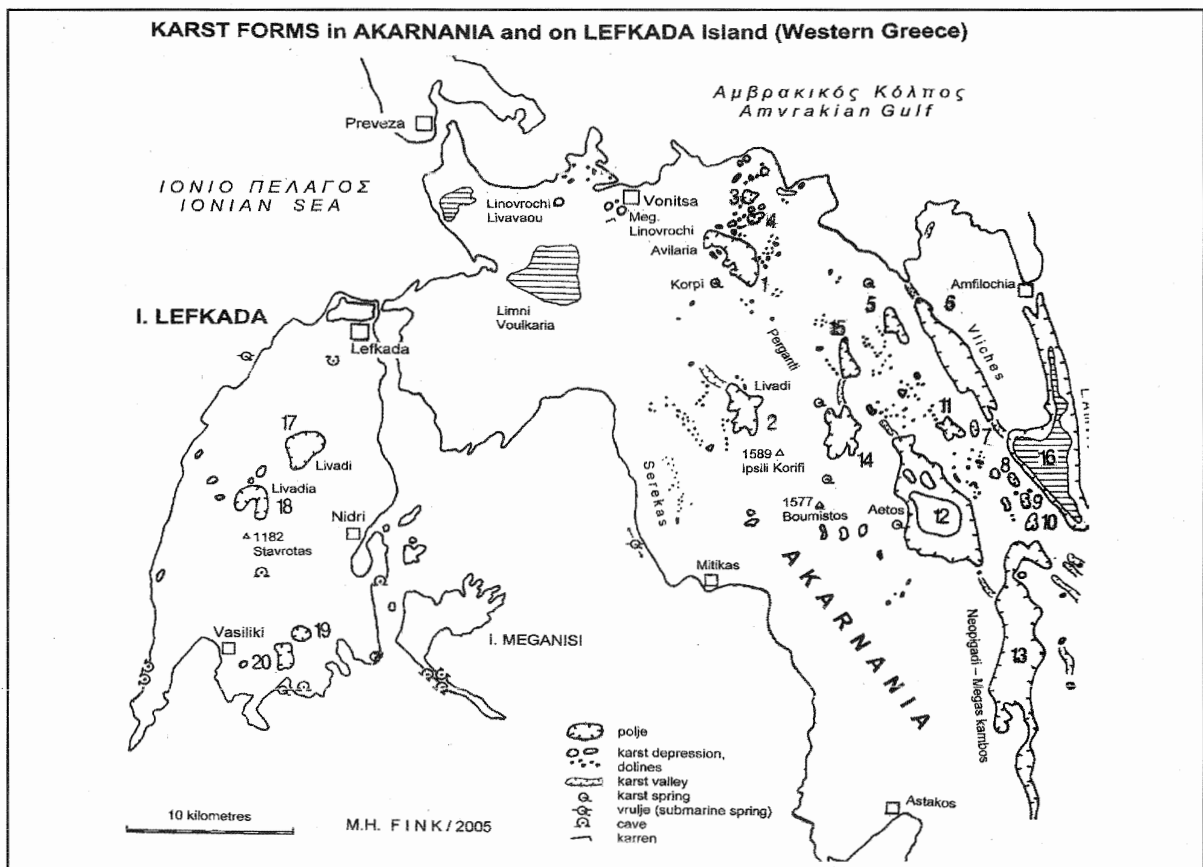
Poljes of Akarnania and Lefkada Island, Western Greece

	Name	Geomorphological position /altitude	Area km²	Geological position	Tectonical position	Hydrology
1	AVILARIA Akarnania	foothills, ±170 m N Monastiraki	8,4	gypsum, limestone, Flysch	nappe	dry/lake
2	LIVADI Akarnania	highland, ±760 m S Monastiraki	4,1	Jurassic limestone, Flysch	rift-valley	dry/creek
3	LAKKOS TON PEDION Akarnania	littoral, ±50 m E Paliambela	0,5	Triassic/Jurassic limestones		dry/episod. inundated karstwater
4	PALEOMILOU Akarnania	littoral, ±40 m SE Paliambela	0,5	Triassic/Jurassic limestones		dry/creek, epis.
5	Polje TRIFOS Akarnania	hilly country, Hum ± 375 m	1,5	var. limestones	nappe, fracture	dry, epis. creek
6	VLICHES Akarnania	valley, ± 50 m NE Katouna	11,8	gypsum, var. limestones	rift-valley	dry, lake, epis. creek
7	Polje of AGIOS PROKOPIOS	hilly country, 190m SE Katouna	0,4	gypsum/Triassic limestone	Gypsum-diapirism	dry
8	STATOPIGADO Akarnania	hilly c.,270 m NW Papadatos	0,2	Triassic/Cretaceous limestones		dry
9	Polje of AGIOS PARASKEVI	hilly c., 240 m, NW Papadatos	0,4	Triassic limestone/ Terra rossa		dry
10	FTERI Akarnania	hilly c., 270 m NW Papadatos	0,3	Triassic/Eocaen-limestones	nappe, fracture	dry, lake
11	DROKIVES Akarnania	hilly c., 185 m valley-controlled Humi, S Katouna	1,4	Triassic/Jurassic/ Cretac. limestones	nappe	dry
12	Polje of AETOS Akarnania	valley-controlled, ± 200 m, Humi E Aetos	15,6	Triassic/Jurassic limestones	nappe, fracture	dry, lake, epis. creek
13	NEOPIGADI - MEGAS KAMBOS Akarnania	semipolje, valley-controlled, ± 60 m E Maheras	19,8	Triassic/Jurassic limestone	fracture	dry, episod. creek
14	PALEO KAMBOS Akarnania	semipolje, valley-controlled 340 m, E Achira	4,6	contact of various limestones, Flysch	nappe, fracture	episod. creek
15	NISA Akarnania	semipolje, valley-controlled 270 m, W Trifos	1,2	gypsum,Triassic/ Jurassic limestone, Flysch	nappe	episod. creek
16	AMVRAKIA Akarnania	semipolje, valley controlled, ± 50 m S Amfilochia	29,1	contact of various limestones, gypsum	rift-valley gypsum-diapirism	lake „Limni Amvrakia", 14,2 km²
17	LIVADI Lefkada Island	highland, ± 330 m E Kariá	2,5	Jurassic limestone, marl, Terra rossa		dry/lake
18	LIVADIA Lefkada Island	highland, ± 900 m S Englouvi,	1,1	limestone, Terra rossa	fractures	dry
19	PISAS Lefkada Island	foothills, ± 100 m, N Marantochori	0,9	Jurassic/Cretac.-limestone, marl	nappe	dry/lakes, epis.
20	VIGLA Lefkada Island	foothills, ± 65 m S Marantochori	1,8	Jurassic/Eocaen-limestone, marl		dry

305

Die vier größeren Poljen der Insel Lefkada sind: Livadi und Livadia im zentralen Hochland sowie Pisas und Vigla im Küstenland im Süden der Insel. Das größte Polje von Lefkada ist Livadi nahe von Kariá mit 2,5 km² Fläche, ebenem Boden mit Terra rossa und einem genutzten See. Das kleinere, trockene Polje Livadia südlich von Englouvi gehört zu den Hochlagen der Insel um den Berg Elati (1125 m), ist deutlich talgebunden und weist ein Gefälle gegen Westen auf. Die küstennahen, benachbarten Poljen Pisas und Vigla bei Marantochori liegen im Kontaktbereich unterschiedlicher Karstgesteine und ihre flachen Böden werden von abdichtenden Mergel-Kolluvionen bedeckt.

In der Tabelle wird ein Überblick auf die Poljen Akarnaniens und der Insel Lefkada gegeben. Nach der Kommission für Terminologie der UIS lautet die Definition eines Poljes: „ausgedehnte, allseits geschlossene Hohlform im Karst mit zumeist ebenem Boden, stellenweise steiler Umrahmung und deutlichem Hangknick. Das Polje hat unterirdischen Abfluss. Es kann trocken liegen, ganzjährig oder zeitweise durchflossen oder inundiert sein". Die Poljen und Semipoljen des Untersuchungsgebietes fügen sich in die generelle geologisch-tektonische Streichungsrichtung der Ionischen Zone NNW - SSE ein. Fast alle akarnanischen und lefkadischen Poljen sind an Gesteinsgrenzen angelegt. Aus den karstgeologischen Karten über Nord- und Mittel-Akarnanien (M. H. FINK & S. VERGINIS, 1974, 1976) und der Insel Lefkada (S. VERGINIS, 1976) ist zu ersehen, dass Poljen sowohl im Kontaktbereich unterschiedlicher Karstgesteine als auch am Kontakt von Karst- gegen Nichtkarstgesteine

angelegt sind. Ihre Böden werden zumeist von wenig durchlässiger Terra rossa bedeckt; bei einigen haben episodische Gerinne undurchlässiges Material (z.B. Mergel-Kolluvionen) auf den Poljeboden eingeschüttet, wodurch eine randliche Ausweitung der Hohlform durch Lateralkorrosion begünstigt wird.

Die geomorphologische Position der Poljen lässt erkennen, dass der überwiegende Teil eine fluviatile Vorform aufweist. Besonders deutlich fügen sich die großen Hohlformen der mittelakarnanischen Poljentreppe in eine ehemals oberirdische Entwässerung nach Süden ein. Dies lässt sich sowohl aus der Neigung der Poljenböden und der sie randlich begleitenden Terrassen, als auch aus den Lagerungsverhältnissen der fluviatilen Sedimente ableiten. Für die Genese der akarnanischen und lefkadischen Poljen und Semipoljen ist die Kombination unterschiedlicher Geoelemente und Geofaktoren wesentlich, wodurch diese Großformen des Karstreliefs als polygenetische Formen anzusprechen sind.

Literatur

AUBOUIN, J. (1959) : Contribution à l'étude géologique de la Grèce septentrionale: les confins de l'Epire et la Thessalie. Annales géol. Pays Hell. (I) 9, 484 p.

BORNOVAS, J. (1964) : Geological study of Levkas Island. Geological and geophysical research Athens. (I.G.S.R.) 10, No 1, 142 p.

BOUSQUET, B. (1976): La Gréce occidentale. Interprétation géomorphologique de l'Epire, de l'Acarnanie et des Iles Ioniennes. - Thése de Géographie, Paris IV, Atelier des reproduction de l'Université de Lille III. 566 p., croquis, biblio., 1 annexe de 8 cartes.

BOUSQUET, B. (1977): Les Xeromeros d'Acarnanie. - Comité national de Géographie, Commission des phénomènes karstiques, Bulletin Nº 1, mars 1977, 4-5, croquis.

FELS, E. (1951-1952): Die ätolisch-akarnanischen Seen in Griechenland. Die Erde, 3: 304-317; Berlin.

FINK, M.H. (1976): Poygenetische Formen im Karst der Ostalpen. Proceedings 6th Internat. Congr. Spel. Olomouc 1973, vol. II, 141-150. (Abstract of paper 1973).

FINK. M.H. (1976a): Zum Stand der phänomenologischen und typologischen Karstforschung. Mitt. Österr. Geogr. Ges. 118, 211-236, bes. 223-229. Wien.

FINK, M.H. (1984): Poljen und poljenähnliche Formen im Karst der Ostalpen. Wiener Geogr. Schriften 59/60 (= Österreichische Beiträge zur Geographie der Ostalpen), 36-44. Wien.

FINK, M. H. & VERGINIS, S. (1974): Beiträge zur Karstmorphologie von Nord-Akarnanien (Westgriechenland). - Die Höhle, 25/4, 116-131, Karte. Wien.

FINK, M. H. & VERGINIS, S. (1976): Karstmorphologische Studien in Mittel-Akarnanien (Westgriechenland). - Die Höhle, 27/1, 17-29. Karte.Wien.

KRAUS, Fr. (1892): Sumpf- und Seebildungen in Griechenland mit besonderer Berücksichtigung der Karsterscheinungen und insbesondere der Katabothren-Seen. - Mitt. Geogr. Ges. Wien, 35, 373-417. Wien.

LEONTARIS, S. (1967): Geomorphologische Forschungen über das Becken der aetoloakarnanischen Seen. Ann. Geol. d. Pays Hell. 19: 541-620; Athen.

PHILIPPSON, A. (1958): Die griechischen Landschaften. Eine Landeskunde. Bd. II: Das westliche Griechenland und die westgriechischen Inseln.: 299-417: Die Landschaft Aetolien (der aetolische Pindos) und Akarnanien. Verlag Klostermann, Frankfurt/Main.

RENZ, C. (1925): Zur Geologie der akarnanischen Küste und Inseln. Verh. Naturforsch. Ges, Basel, 36, 298-311.

RIEDL, H. u.a. (1971): Geographische Beobachtungen in Griechenland. Exkursionsberichte d. Geogr. Inst. d. Universität Salzburg, H. 4, Salzburg. (S. 28: Raum Amfilochia)

RIEDL, H. (1977): Klimatisch bedingte vorzeitliche Leitformen Griechenlands. Mitt. Geogr. Ges. München, Bd. 62: 145-154.

The BP Co Ltd. (1971):The Geological Results of Petroleum Exploration in Western Greece. No. 10. Inst. for Geology and Subsurface Research; Athen.

VERGINIS, S. (1976): Monographie der Insel Levkas unter besonderer Berücksichtigung der hydrologischen Verhältnisse. Phil. Diss. Univ. Wien, 190 Bl., Karten, ill., Diagr., Tab.

VERGINIS, S. & LEONTARIS, S. (1978): Beiträge zur Morphologie und Entwicklung des Semipoljes Amvrakia (Limni Amvrakia), Westgriechenland. - Int. Revue d. ges. Hydrobiologie, 63, 6, 831-839, Karte, Profile.

O-87

Mineralogy of mine caves in Sardinia (Italy)

Jo De Waele (1)* and Paolo Forti (2)

(1) Dipartimento di Scienze della Terra, via Trentino 51, 09127 Cagliari, Italy geoam@unica.it

(2) Istituto Italiano di Speleologia, via Zamboni 67, 40126 Bologna, Italy forti@geomin.unibo.it

* corresponding author e-mail : geoam@unica.it

Abstract

An important mineralogical study has been conducted on the "mine caves" of Southwest Sardinia, Italy in the past two years (National Research Project COFIN 2001-2003). This research involved the Universities of Bologna, Modena and Cagliari and the IGEA (Geo-Environmental Projects) Society of Iglesias. The area is part of the "Geomining Park of Sardinia" recently instituted in a European framework

"Mine caves" are natural cavities formed in contact with or within mineral deposits, sometimes developing far below the present topographical surface, and generally lacking a natural entrance. Their access is possible through artificial excavations such as mine shafts and tunnels. At present more than hundred mine caves are known in the area.

Many specific morphological and mineralogical studies on speleothems from mine caves have been done in the past 20 years, but only recently these researches have been conducted in a much more organised manner. In some of these mine caves mineralogical and speleogenetical research has been performed comprising in situ analysis and observations (climatic and physical-chemical parameters) and sampling of minerals and speleothems.

The morphological and mineralogical analysis allowed not only to enhance the knowledge, up to date relatively scarce, on these special depositional environments represented by mine caves, but also permitted to increase the mineralogenetical knowledge of some rare minerals (especially, but not only, phosphates and sulphates). A short overview of all these minerals is given together with some morphological and genetical observations.

The scientific data obtained in this field of research will surely be of great practical use for the individuation of the most important areas of scientific and/or didactical interest inside the Geomining Park of Sardinia, areas which can be effectively protected and valorised. These researches will also be of immediate practical use for the definition of the territorial planning of the Geomining Park of Sardinia, allowing to identify both caves of great scientific interest that are extremely vulnerable and should therefore be adequately protected and eventually foreseen to become "scientific subterranean laboratories", and caves for which a didactic-tourist valorisation plan would be appropriate in the framework of a cultural development inside the Geomining Park.

In the near future a Monography on the "mine caves" of Mount San Giovanni, the most representative karst area of the entire Iglesiente mining district, will be printed with the aim to be the starting point for the development of similar studies in other karst areas in mine districts outside Sardinia.

Previous studies

Mine activities in Sardinia have started many centuries ago making of the Island one of the most important mine regions of Europe since Prehistory. Also Phoenicians and Romans extracted Ag-rich galena from the underground, mainly in South-Sardinia, and also in Medieval times this mineral remained the most researched mineral resource. But it is especially since industrial age that mineral exploitation grew exponentially in dimension and in space, scattering the territory with mine shafts, drafts and impressive underground workings. It is mainly in this period that mine works started intersecting and reporting natural cavities, the so-called "mine caves", karst caves with no natural entrance and accessible only through artificial ways. Prevalently the mines of Southwestern Sardinia, in the Iglesiente-Sulcis region, have encountered many of those mine caves, because the Pb-Zn mineralization is hosted in well karstified Lower Cambrian limestones and dolostones. In 1888 the Grande

Sorgente (1694 SA/CA) at Monteponi mine has been discovered at +7 m a.s.l. during the perforation of the drainage tunnel that connected this mine with the Sa Masa pond close to the sea at 8 km distance. This mine cave, of great hydrogeological importance, is one of the first to be often mentioned in official mine reports (Fabbri & Forti, 1981; Civita et al., 1980; 1983). Another important mine cave, discovered in the early XXth century, is Rolfo cave (1301 SA/CA), close to Domusnovas, described in a report written by a mine engineer as "very well decorated and multicoloured". At present more than hundred mine caves are known in the Iglesiente-Sulcis area, most of which are located in the following mines: San Giovanni, Monteponi, Campo Pisano, Masua, Acquaresi and Barega at Iglesias, Santa Lucia, Gutturu Pala and Su Zurfuru at Fluminimaggiore, Rolfo, Perda Niedda, Sa Duchessa and Barraxiutta at Domusnovas, Monte Onixeddu at Gonnesa-Carbonia and Caitas at Buggerru (Fig.1).

The mineralogical interest of these mine caves has been treated only since recently, exception given for a few papers regarding cerussite stalactites in Arenas mine (Uras, 1957), barite crystals of the famous Santa Barbara mine cave (Rossetti & Zucchini, 1957; Forti & Perna, 1981) and blue aragonite from Crovassa Azzurra at San Giovanni mine and some other natural karst caves (Cervellati et al., 1971). More systematic studies have been carried out in the period 1979-1982 in the framework of a European Project (Contract CEE CREST 114-79-7-MPP I) aimed to the definition of the hydrogeological parameters of the water circulation in the carbonatic mine areas. During these researches many mine caves have been documented and studied (Forti & Perna, 1982a) and mineralogical samples taken during these campaigns have allowed to publish many articles on cave minerals and speleothems during the following 5 years, reporting many new mineral species for the cave environment such as Bianchite, Monteponite (Forti, 1985; Forti & Perna, 1988), melanterite (Bini et al., 1986), gaspeite (Cadoni et al., 1986) besides other more common cave minerals such as calcite (Forti et al., 1981; Forti & Perna, 1982b; 1982d), aragonite (Forti & Perna, 1982c; 1983) and many others (Hill & Forti, 1997).
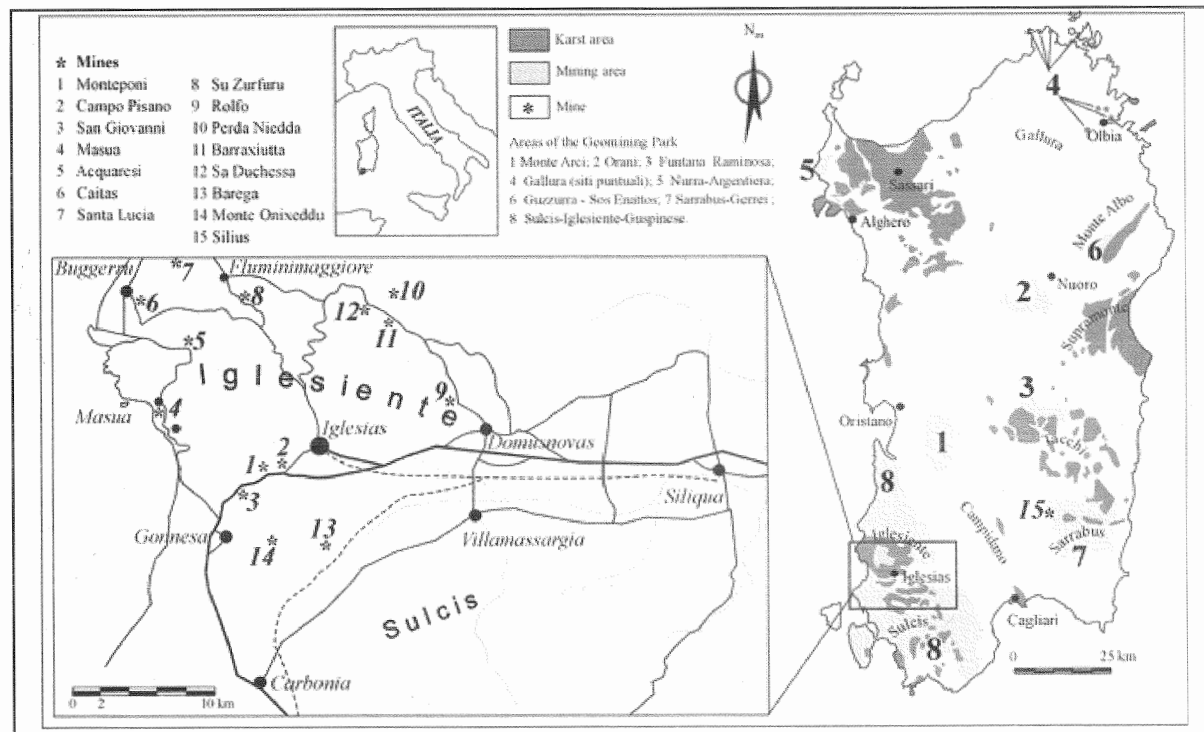
Fig. 1 - The Geomining Park of Sardinia, the karst areas and the main mines of speleological interest

Papers have also been published on fluid inclusions of quartz, barite and calcite from mine caves, allowing to better understand the genesis of ore deposits and gangue minerals (De Vivo et al., 1987; Cortecci et al., 1987; Ludwig et al., 1989), on cave sediments and palaeokarstic fills (Bini et al., 1988), on hyperkarst phenomena (Forti & Perna, 1986; De Waele et al., 2001) and on cave morphologies (Forti & Perna, 1982b; Fabbri & Forti, 1986; Chiesi & Forti, 1987) enabling to make more detailed speleo-genetical observations.

With the beginning of the debate on the institution of the Geomining, Historical and Environmental Park of Sardinia, recognised by National Law in October 2001, sporadic research has permitted to discover some new mine caves of scientific interest (De Waele et al., 1999), including the Quartziti cave (2469 SA/CA) in San Giovanni mine with its hemimorphite flowstones (Forti et al., 1999).

Recently, a new impulse on cave mineral studies has been given by the Italian National Project PRIN 2002-2004 "Morphological and mineralogical study of speleothems for the reconstruction of particular karst environments" (Resp. Paolo Forti) during which many new mine caves have been visited and explored (De Waele et al., 2003; De Waele et al., 2004a; 2004b; De Waele & Frau, 2005), leading to the discovery of a whole set of new minerals, further enriching the already long list of cave minerals of the Sardinian mine caves (Forti, 2005; Forti et al., 2005a; 2005b; 2005c).

Cave minerals of Sardinian mine caves

In this short paper the Authors resume the knowledge on cave minerals in the Sardinian mine caves. A list of cave minerals reported from Sardinian mine caves is reported in Table 1. Cave minerals are secondary minerals derived by physico-chemical reactions from a primary mineral in bedrock or detritus. A cave mineral is formed because of a unique set of conditions within the cave environment (Hill & Forti, 1997). The paper deals only with these secondary cave minerals, excluding thus all those minerals that can be found in caves but that haven't been formed in this peculiar environment. In fact, many minerals that were present in the host rock before the cave was formed or have been transported from outside are not considered as "cave minerals".

No native elements are known in Sardinian mine caves, even though the presence of sulphur should not be excluded. Sulphur, in fact, can be produced in caves by the oxidation of pyrite, that often occurs in the host rock and has also been described from small mine caves in the Silius barite-fluorite mine (Forti, 1983). Abundant sulphides that occur in many mine caves of Sulcis-Iglesiente are galena and Sphalerite, respectively lead and zinc sulphides. Both minerals have been found in karst caves intercepted by the underground workings of many mines (Hill & Forti, 1997) and galena sometimes fills paleokarst conduits entirely, demonstrating post-depositional remobilisation processes (Forti et al., 2005b; 2005c). In small caves discovered in the Silius mines and Santa Lucia mines (Fluminimaggiore) fluorite occurs in crystals of up to 1-2 cm. Fluorite is formed by deposition from hydrothermal fluids that circulate in the karst voids (Forti, 1985). Many oxides and hydroxides occur in Sardinian mine caves, such as the common minerals Hematite, Goethite and Gibbsite, but also very rare mineral species such as Monteponite (Forti & Perna, 1988), Coronadite (?), Heterolite and Hydroeterolite, Chalcophanite, Cesarolite (Forti et al., 2005c) and Brianyoungite (Fig. 2a and c) (Forti et al., 2005a). These minerals usually occur inside the terra rossa sediments, produced by the oxidation of primary sulphide deposits, and are deposited in karst pockets.
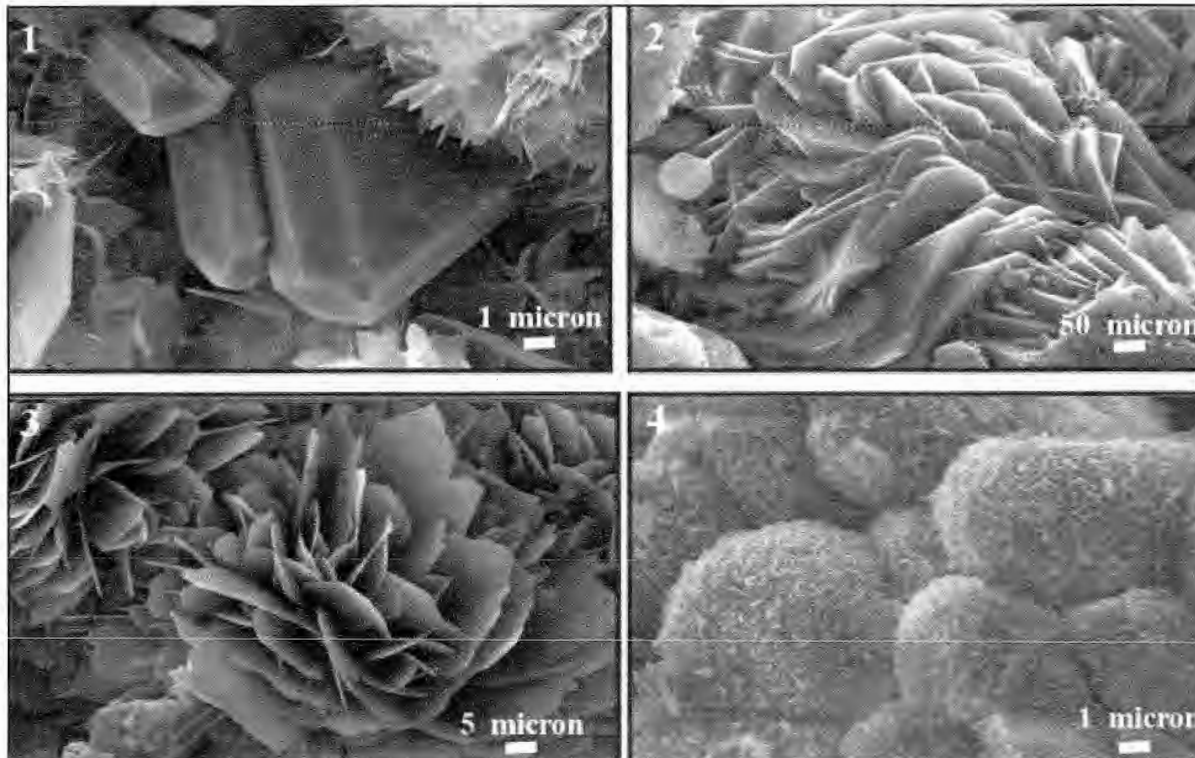
Fig. 2 - a) Gypsum crystals on Brianyoungite of Su Zurfuru; b) Microspheres of Jarosite from Perda Niedda mine; c) Spheroid crystal aggregates of brianyoungite with laminar crystals of an unknown hydrated hydroxisulphate of Zn of Su Zurfuru mine ; d) Hydrozincite of Su Zurfuru.

Tab. I - Minerals of cave mines in Sardinia

Mineral	Chemical Formula	Crystal system	Locations
Sulphides			
Galena	PbS	Isometric	Many localities
Sphalerite	ZnS	Isometric	Masua, Monteponi, C. Pisano, S.Barbara
Pyrite	FeS_2	Isometric	Silius
Halides			
Fluorite	CaF_2	Isometric	Silius, Santa Lucia
Oxides/Hydroxides			
Monteponite	CdO	Isometric	Monteponi
Coronadite (?)	$PbMn_8O_{16}$	Monoclinic	S.Barbara
Hematite	$\alpha\text{-}Fe_2O_3$	Monoclinic	Perda Niedda
Heterolite	$ZnMn_2O_4$	Tetragonal	S.Barbara
Hydroeterolite	$Zn_2Mn_4O_8 \cdot H_2O$	Tetragonal	S.Barbara
Chalcophanite	$ZnMn_3O_7 \cdot 3H_2O$	Trigonal	S.Barbara
Cesarolite	$PbMn_3O_7 \cdot H_2O$	Hexagonal ?	S.Barbara
Goethite	$\alpha\text{-}FeO(OH)$	Orthorhombic	Perda Niedda, S.Barbara
Brianyoungite	$Zn_3(Co,SO_4)(OH)_4$	Orthor./Monocl.	Su Zurfuru
Gibbsite	$\gamma\text{-}Al(OH)_3$	Monoclinic	Perda Niedda
Carbonates			
Aragonite	$CaCO_3$	Orthorhombic	Almost all locations
Calcite	$CaCO_3$	Trigonal	Almost all locations
Cerussite	$PbCO_3$	Orthorhombic	Many localities
Dolomite	$CaMg(CO_3)_2$	Trigonal	Almost all locations
Smithsonite	$ZnCO_3$	Trigonal	Masua
Siderite	$FeCO_3$	Trigonal	Monteponi
Phosgenite	$Pb_2(CO_3)Cl_2$	Tetragonal	Monteponi
Hydrozincite	$Zn_5(CO_3)_2(OH)_6$	Monoclinic	Albert 7, Su Zurfuru
Aurichalcite	$(Zn,Cu)_5(CO_3)_2(OH)_6$	Monoclinic	San Giovanni
Gaspeite	$(Ni, Mg, Fe)CO_3$	Trigonal	San Benedetto
Arsenates			
Ediphane	$Ca_2Pb_3(AsO_4)_3Cl$	Hexagonal	S.Barbara
Sulphates			
Barite	$BaSO_4$	Orthorhombic	S. Lucia, Silius, Barega, Su Zurfuru, S.Barbara
Anglesite	$PbSO_4$	Orthorhombic	San Giovanni, Monteponi
Gypsum	$CaSO_4 \cdot 2H_2O$	Monoclinic	Montevecchio, Su Zurfuru
Melanterite	$FeSO_4 \cdot 7H_2O$	Monoclinic	Montevecchio, Genna Luas
Siderotile	$FeSO_4 \cdot 5H_2O$	Monoclinic	Montevecchio, Genna Luas
Copiapite	$(Fe,Mg,Cu)Fe_4(OH)_2(SO_4)_6 \cdot 20H_2O$	Triclinic	Montevecchio, Genna Luas
Pisanite	$(Fe,Cu)SO_4 \cdot 7H_2O$	Triclinic	Montevecchio, Genna Luas
Epsomite	$MgSO_4 \cdot 7H_2O$	Orthorhombic	San Giovanni
Bianchite	$Zn_2Fe(SO_4)_3 \cdot 18H_2O$	Monoclinic	Campo Pisano
Bechererite	$Zn_7Cu(OH)_{13}SiO(OH)_3SO_4$	Trigonal	Su Zurfuru
Jarosite	$KFe_3(SO_4)_2(OH)_6$	Trigonal	Perda Niedda
Silicates			
Kaolinite	$Al_2Si_2O_5(OH)_4$	Tricline	S.Barbara
Allophane	$Al_2SiO_5 \cdot H_2O$	Amorphous	Perda Niedda
Hemimorphite	$Zn_4Si_2O_7(OH_2 \cdot H_2O)$	Orthorhombic	S. Lucia, Su Zurfuru, San Giovanni
Opal	SiO_2	Amorphous	San Giovanni, Santa Lucia

309

Also carbonates are very abundant, with the very well known cave minerals calcite, dolomite and aragonite, and metal carbonates such as cerussite, smithsonite and siderite, respectively of lead, zinc and iron. Less usual carbonates found in mine caves of south-west Sardinia are hydrozincite (found as tall stalactites and stalagmite floors in San Giovanni mine caves and as blue flowstone in Su Zurfuru mine) (Fig. 2 d) (Forti, 1985), aurichalcite (inside a blue aragonite coating in San Giovanni mine), and the very rare minerals gaspeite (coating small karstic voids in San Benedetto mine) (Cadoni et al., 1986) and phosgenite (well-known and very much appreciated mineral found in karst voids of Monteponi mine). Very rare is also ediphane, a calcium-lead chloride arsenate, found in the terra rossa of Santa Barbara cave (Forti et al., 2005c).

Fig. 3- Barite crystals covered with calcite in the Santa Barbara cave.

By oxidation processes of primary sulphide deposits, besides oxides and hydroxides also many sulphates are formed, e.g. barite, anglesite, gypsum, melanterite, chalcantite, epsomite and other more rare mineral species. Large beautiful barite crystals occurs extensively in the Santa Barbara cave system at San Giovanni mine where it coats floor, walls and ceiling of the cave, demonstrating a phreatic origin (Fig. 3) (Rossetti & Zucchini, 1957; Forti et al., 2005c). Other barite, in big crystals, has been described in mine caves of Barega (Naseddu, 1993). Beautiful anglesite crystals have been found in a small geode inside a drill core of a subacqueous cave cloud concretion in the Santa Barbara 2 cave (Forti et al., 2005c), and anglesite is also known from Monteponi mine caves. Gypsum is not as abundant as could be thought and has been reported only from Su Zurfuru and from Montevecchio mines. The scarce presence of gypsum in Sardinian mine caves is probably due to the fact that it is highly soluble. Melanterite and epsomite are ephemeral minerals that have been occasionally found in mine caves. Melanterite, together with its transient mineral species siderotile, copiapite and pisanite, have been reported from Genna Luas and from Montevecchio (Bini et al., 1986) while cotton like and bitter tasty epsomite flowers occurs seasonally in some caves not far from the entrances of the mine shafts and tunnels. The rare sulphates bianchite, bechererite and jarosite have been found respectively at Campo Pisano, Su Zurfuru and Perda Niedda. Bianchite at Campo Pisano covered the walls and ceilings of mine galleries in an area where evaporation of solutions with high concentration of sulphuric acid was enhanced by air currents. Bechererite and jarosite, instead, are metal sulphates formed by oxidation of sulphides under the presence of bacteria, respectively in a lead-zinc mine with minor quantities of copper and in an iron mine (Fig. 2 b).

Among the silicates formed in Sardinian mine caves kaolinite and allophane have been described from Santa Barbara and Perda Niedda respectively. Both could be of allochthonous origin, but given the acid and oxidising conditions of their environment it is not excluded that they formed inside the cave environment (Forti et al., 2005a, 2005c). The most

extraordinary cave silicate of mine caves is hemimorphite, discovered in Su Zurfuru mine (Forti et al., 2005a), at Santa Lucia mine (Forti, 1985) and in Quarziti cave in San Giovanni mine (Forti et al., 1999). In the first two mines the mineral occurs as small flowstones blue in colour, while at San Giovanni mine hemimorphite forms a tall flowstone and some stalagmitic crusts (Forti et al., 1999). This mineral forms in these lead-zinc mines close to quartzite rocks and is related to the acid dissolution of the latter and subsequent deposition of the zinc-silicate. Hemimorphite often occurs together with opal, found as fine layers inside flowstones.

Conclusion

Sardinia has been one of the most important mining regions of Europe and industrial activities stopped only recently. Many ore deposits, especially in Southwest Sardinia, are hosted in dolostones and limestones of Cambrian age and thus mining activities have enabled to discover many mine caves, natural cavities that have no direct communication with the surface. These mine caves are "natural laboratories" in which many rare and interesting cave minerals can be found and recently some Italian research projects have enabled to discover several interesting mineral associations.

The scientific data obtained during these research projects will be of practical use for the individuation of the most important areas of scientific and/or didactical interest inside the Geomining Park of Sardinia, in order to protect and to valorise them. The short description of forty cave minerals already gives an idea of the importance of these mine caves from a mineralogical point of view, and future researches will surely allow to find other mineral species, enriching thus the already very long list of Sardinian cave minerals.

References

Bini A., Cadoni E., Forti P., Perna G. (1986) - La melanterite della miniera di Montevecchio nella Sardegna sud-occidentale. Notiziario di Mineralogia e Paleontologia 48, pp. 7-13.

Bini A., Cremaschi M., Forti P., Perna G. (1988) - Paleokarstic fills in Iglesiente (Sardinia, Italy): sedimentary processes and age. Annales Societé Géologique Belgique 111, pp. 149-161.

Cadoni E., Forti P., Perna G. (1986) - La gaspeite magnesifera della miniera di S.Benedetto (Ca). Rivista Mineralogica Italiana 2, pp. 62-67.

Cervellati R., Forti P., Zavatti R. (1971) - L'aragonite azzurra sarda. Speleologia Emiliana 3(7), pp. 43-60.

Chiesi M., Forti P. (1987) - Studio morfologico di due nuove cavità carsiche dell'Inglesiente (Sardegna sud occidentale). Ipoantropo 4, pp. 40-45.

Civita M., Cocozza T., Forti P., Perna G., Turi B. (1980) - Hydrogeology and geochemistry of groundwater in the mining district of Iglesias (South-Western Sardinia) and its correlation with the speleogenesis and cave mineralizations. Proceedings of the European Regional Conference on Speleology, Sofia, Bulgaria 2, pp. 467-474.

Civita M., Cocozza T., Forti P., Perna G., Turi B. (1983) - L'idrogeologia del bacino minerario dell'Iglesiente. Memorie dell'Istituto Italiano di Speleologia, Serie 2, 2, 137 p.

Cortecci G., Fontes J-C., Maiorani A., Perna G., Pintus E., Turi B. (1989) - Oxygen, sulfur, and strontium isotope and fluidi inclusion studies of barite deposits from the Iglesiente-Sulcis mining district, Southwestern Sardinia, Italy. Mineral. Deposita 24, pp. 34-42.

De Vivo B., Maiorani A., Perna G., Turi B. (1987) - Fluid inclusion and stable isotope studies of Calcite, Quartz and Barite from karstic caves in the Masua mine, Southwestern Sardinia, Italy. Chemische Erde 46, pp. 259-273.

De Waele J., Forti P., Naseddu A. (1999) - Le "Grotte di Miniera": patrimonio scientifico e risorsa turistica. In Atti del Convegno Internazionale di Studio "Paesaggio Minerario"- Cagliari, 7-10 Ottobre 1999.

De Waele J., Forti P., Perna G. (2001) - Hyperkarstic phenomena in the Iglesiente mining district (SW-Sardinia). In "Water-Rock Interaction 2001", R. Cidu (Ed.), A.A.Balkema Publishers, Lisse: 619-622.

De Waele J., Messina M., Naseddu A., Papinuto S., Sanna F., Sotgia S. (2003) - Le grotte di miniera in Sardegna. Anthèo (Bollettino del Gruppo Speleo-Archeologico "Giovanni Spano" Cagliari) 7: 46-52.

De Waele J., Frau F. (2005) - Le grotte di miniera nelle aree del Parco Geominerario Storico ed Ambientale della Sardegna. Memorie dell'Istituto Italiano di Speleologia (in print)

De Waele J., Frau F., Forti P., Galli E., Rossi A. (2004a) - The scientific and didactic importance of the mine caves of Mount San Giovanni (Southwest Sardinia, Italy). 32nd IGC, Florence, August 20-28 2004, Abstract Vol. 2: 1015.

De Waele J., Forti P., Frau F., Galli E., Naseddu A., Rossi A. (2004b) - Le grotte di miniera del Monte San Giovanni (Iglesiente, Sardegna sud-occidentale): una risorsa scientifica e turistica di inestimabile valore. Atti del II Convegno Nazionale "Geologia e Turismo", Bologna, 3-4 Novembre 2004: 106-108.

Fabbri M., Forti P. (1981) - Esplorazioni nell'Iglesiente. Sottoterra 59, pp. 31-35.

Fabbri M., Forti P. (1986) - Recenti esplorazioni nelle miniere dell'Iglesiente (Sardegna sud occidentale). Sottoterra 74, pp. 20-28.

Forti P. (1983) - I minerali di grotta. Speleo 9, pp. 9-24.

Forti P. (1985) - Alcuni nuovi minerali carsici dell'Iglesiente. Notiziario di Mineralogia e Paleontologia 44, pp. 3-10.

Forti P. (2005) - L'importanza scientifica delle grotte di miniera. Memorie dell'Istituto Italiano di Speleologia (in print)

Forti P., Galli E., Rossi A., Naseddu A. (2005a) - Studio mineralogico di una concrezione della Fontana dello Zinco (Miniera di Su Zurfuru, Fluminimaggiore) e dati preliminari su analoghe concrezioni della Miniera di Perda Niedda (Iglesias). Memorie dell'Istituto Italiano di Speleologia (in print)

Forti P., Messina M., Naseddu A., Papinuto S., Sanna F., Sotgia S. (1999) - Emimorfite in una "grotta di miniera" Gonnesa-Sardegna. Speleologia 41, pp. 61-68.

Forti P., Pagliara A., Galli E., Rossi A., De Waele J., Borsato A., Zanchetta G., Shopov Y. (2005b) - Santa Barbara cave (Sardinia, Italy): some hundred million years of development as recorded in speleothems. Geophysical Research Abstracts, 7, 01160

Forti P., Pagliara A., Galli E., Rossi A., De Waele J., Naseddu A., Papinuto S. (2005c) - Studio morfologico e mineralogico di dettaglio del concrezionamento del sistema carsico di Santa Barbara (Miniera di San Giovanni, Iglesias). Memorie dell'Istituto Italiano di Speleologia (in print)

Forti P., Perna G. (1981) - La turisticizzazione della Grotta di Santa Barbara nella Miniera di San Giovanni e la creazione di un Museo Minerario ad essa connesso (Iglesias-Sardegna sud occidentale). Le Grotte d'Italia 4(10), pp. 181-187.

Forti P., Perna G. (1982a) - L'area speleologica dell'Iglesiente: carsismo e speleogenesi. Memorie dell'Istituto Italiano di Speleologia 2(1), pp. 27-34.

Forti P., Perna G. (1982b) - Orientazione dei cristalli di calcite nelle crevasse della Miniera di Nebida (Sardegna sud occidentale). Periodico di Mineralogia 51(2), pp. 155-160.

Forti P., Perna G. (1982c) - Studio morfologico e genetico delle pisoliti di aragonite rinvenute in due gallerie minerarie presso Iglesias (Sardegna SW). Atti del XIV Congresso Nazionale di Speleologia, Bologna, 2-5 settembre 1982, pp. 407-419.

Forti P., Perna G. (1982d) - Concrezioni e cristallizzazioni nei karst dell'Iglesiente (Sardegna SW). Atti del XIV Congresso Nazionale di Speleologia, Bologna, 2-5 settembre 1982, pp. 421-430.

Forti P., Perna G. (1983) - Studio morfologico e genetico delle pisoliti di aragonite rinvenute in due gallerie minerarie presso Iglesias (Sardegna SW). Sottoterra 64, pp. 18-30.

Forti P., Perna G. (1986) - L'ipercarsismo con particolare riguardo all'Iglesiente (Sardegna Sud Occidentale). Natura Alpina 36 (2-3), pp. 85-100.

Forti P., Perna G. (1988). Genesi della monteponite di Monteponi. Riv. It. Min. 1: 45-51.

Forti P., Perna G., Turi B. (1981) - Genetical observations on some natural cavities of the Masua mines (SW Sardinia). Atti del VIII Congresso Internazionale di Speleologia, Bowling Green 1981, pp. 779-780.

Hill C., Forti P. (1997) - Cave minerals of the World. National Speleological Society, Huntsville, 463 p.

Ludwig K.R., Vollmer R., Turi B., Simmons K.R., Perna G. (1989) - Isotopic constraints on the genesis of base-metal ores in southern and central Sardinia. European Journal of Mineralogy 1, pp. 657-666.

Naseddu A. (1993) - Grotte in miniera. Sardegna Speleologica 3, pp. 8-14.

Rossetti V., Zucchini A. (1957) - Baritina della grotta di Santa Barbara. Rendiconti Seminario Facoltà Scienze Università di Cagliari 26(3-4), pp. 240-255.

Uras I. (1957) - Su una cerussite stalattitica della Miniera di Arenas. Resoconti dell'Associazione Mineraria Sarda 61(5-6), pp. 5-12.

311

O-88

Cave Aragonite in NSW, Australia

Jill Rowling

2 Derribong Place, Thornleigh NSW, Australia 2120., rowling@ali.com.au

Abstract

Aragonite is unstable in fresh water and usually reverts to calcite, but it is actively depositing in some caves in New South Wales (NSW), Australia. Several factors were found to be associated with the deposition of aragonite speleothems in NSW caves. They include the presence of ferroan dolomite, calcite-inhibitors and both air movement and humidity. Several NSW caves were examined for aragonite, concentrating on sites at Jenolan, Wombeyan and Walli. Aragonite at Jenolan Caves is precipitated as anthodites, spathites, helictites, cavity fills, vughs and coatings. The substrate for the aragonite is porous, altered, dolomitised limestone which

is wedged apart by aragonite crystals. At some sites, pyrite occurs in the dolomite. Calcite-inhibitors at Jenolan are mainly minerals containing ions of magnesium, manganese, sulfate and to a lesser extent, phosphates. Aragonite, dolomite and rhodochrosite are being actively deposited in Contact Cave. During winter, cold dry air pooling in the lower part of some caves may concentrate minerals by evaporation. Aragonite formed under these conditions tends to have fine crystals due to more rapid precipitation, whereas aragonite formed in more humid areas tends to have larger crystals. Aragonite at Wombeyan Caves is less common than that at Jenolan. The calcite-inhibitors are similar to those at Jenolan, sourced partly from bedrock veins and partly from breakdown of minerals in sediments sourced from mafic igneous rocks. Air movement may assist in the rapid exchange of CO_2 at speleothem surfaces. At one low-humidity site, the presence of vaterite and aragonite in fluffy coatings infers that vaterite may be inverting to aragonite. Aragonite at Walli caves is associated with gypsum and barite veins, coatings containing calcite-inhibitors and, in some areas, low humidity. Calcite-inhibitors include sulfate (mostly as gypsum), magnesium, manganese and barium. The source of these calcite-inhibitors appears to be weathering of ferroan dolomite and pyrite in chert nodules.
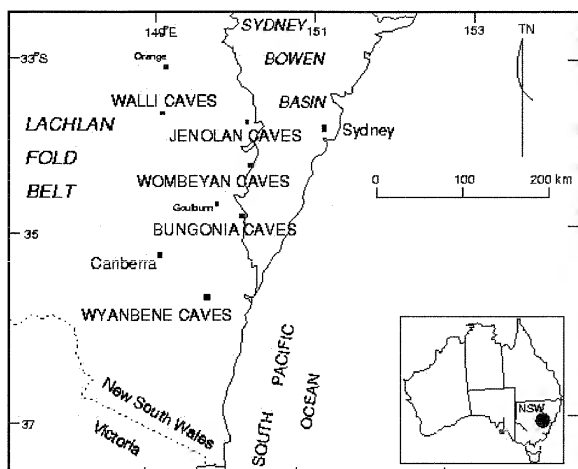
Figure 1: Part of NSW showing tectonic regions and cave areas. Map bases: NSW Dept. Mineral Resources and Geosciences Australia.

Introduction

Aragonite is a polymorph of calcium carbonate, $CaCO_3$, actively depositing in many limestone caves around the world (Hill & Forti 1997). Most speleothems in NSW caves are calcite, and aragonite is minor. Calcite is the more common polymorph encountered, as the cave environment is well within the pressure-temperature stability region for calcite. Calcite inhibitors are substances which disrupt the calcite crystal lattice (crystal poisoners) by physically blocking calcite growth points, allowing aragonite to precipitate instead. Morse (1983) listed the following ions as calcite inhibitors: Mg, heavy metals and rare earths (Cu, Sc, Pb, La, Y, Cd, Au, Zn, Ge, Mn, Ni, Ba, Co), SO_4, and PO_4. Mg is particularly influencial on the precipitation of aragonite (Curl 1962). Studies on aragonite in NSW caves began in 1892, but little scientific work was done until the mid 20th century (Rowling 2005). In show caves, aragonite is valuable as an attractive or unusual tourist showpiece. The main sites examined were at Jenolan, Wombeyan and Walli, all located in the Lachlan Fold Belt tectonic region (Cas 1983) - Figure 1.

Methods

Caves are non-renewable, fragile environments and it is important to preserve the appearance of the sampled site. Speleothems are classi-

fied as per Hill & Forti (1997). Cave temperature, relative humidity and CO_2 concentrations were measured. Samples were examined using optical microscopy and scanning electron microscopy (SEM), with a Philips SEM505. X-Ray Diffraction (XRD) was the primary diagnostic tool for identifying minerals, using a 3kW Siemens Kristalloflex 710D X-Ray generator, model 7kP5000-8AE, with a Siemens D5000 Diffractometer. Generator: 40kV, 40mA, Cu target. Slits: 1 mm at source, 1 mm, 0.2 mm, 0.6 mm (at receiver). Monochromator: graphite crystal (2d = 0.2708 nm) for Cu $K\alpha$ radiation. $K\beta$ filters: nickel, 12 μm thickness. Scans: 2 to 70° 2θ in 28 minutes (2.4° / minute). All XRD and SEM work was done at the Electron Microscope Unit at the University of Sydney.

Jenolan Caves

Jenolan Caves are a world-famous tourist destination, about 110 km west of Sydney (Figure 1), on a dissected plateau with an average elevation of 1100 m ASL. The caves are situated in a north - south trending band of Silurian sediments, volcanics and limestone. The limestone crops out as a narrow band, and is intruded by several dykes. The limestone generally dips to the west, overturned in most areas, with almost-vertical bedding near the show cave complex, more shallow bedding (overturned) to the north and is crossed by several faults. Most caves at Jenolan contain calcite speleothems, and some have aragonite.

Figure 2: Anthodites in Contact Cave

Contact Cave
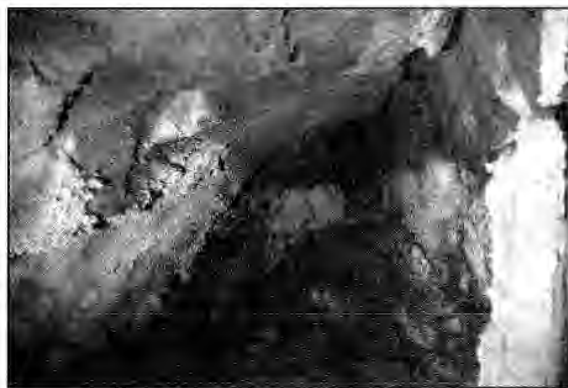
Figure 3: "Popcorn Line", Contact Cave

Contact Cave is a small cave near the eastern edge of the limestone north of the show caves. The original limestone micrite has been preferentially replaced with ferroan dolomite, with larger bioclasts unaltered by dolomitisation. Aragonite in the lower part of the cave occurs either as a ceiling coating (associated with substrate crystal wedging) or as stalactitic

forms such as anthodites along joints (Figure 2). Minerals associated with aragonite include dolomite and rhodochrosite and others containing ions of Fe, Mg, Mn, CO_3, SO_4 and PO_4. Bat guano is a suggested source of the PO_4. Aragonite deposition in Contact Cave is enhanced by the calcite-inhibitors Mg, Mn, and to a lesser extent, PO_4. During winter, cold dry air pooling in the lower part of the cave may concentrate minerals on the stalactites and walls by evaporation, leading to a "popcorn line" in the cave (Figure 3). Possibly strong acid (e.g. H_2SO_4) released from the slow oxidation of pyrite in the thinly-bedded limestone and ferroan dolomite above the cave releases Mn and Mg from the bedrock. These seep into the cave, react with carbonates and outgas CO_2 to precipitate
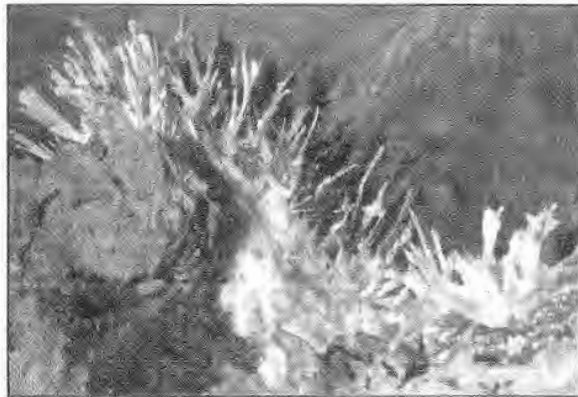
Figure 4: Anthodite on ochre, Wiburds Lake Cave

as speleothems.

Wiburds Lake Cave

Wiburds Lake Cave is near the northern end of the limestone outcrop. Fault zone breccias of sheared chert and mudstone crop out, and a faulted mafic dyke is exposed in parts of the cave. Its 7 km of passages are guided both by faulting and the strike of the bedding. Near the entrance are coatings, helictites and small anthodites, comprising gypsum and aragonite, minor pyrolusite, kaolinite and hydromagnesite, and trace calcite and huntite (XRD). A chamber in the northern area of the cave, far from the entrance, has a dyke in its ceiling, sheared bedrock, and aragonite speleothems. These include a spathite, and anthodites with an ochre substrate (Figure 4).

Aragonite is associated with calcite inhibitors Mn, Mg and SO_4. Small aragonite "stars" are associated with a red gelatinous material in sediment, possibly bat-guano derived, comprising diadochite and epsomite with organics, sediments and other phosphates. SO_4 may be derived either from
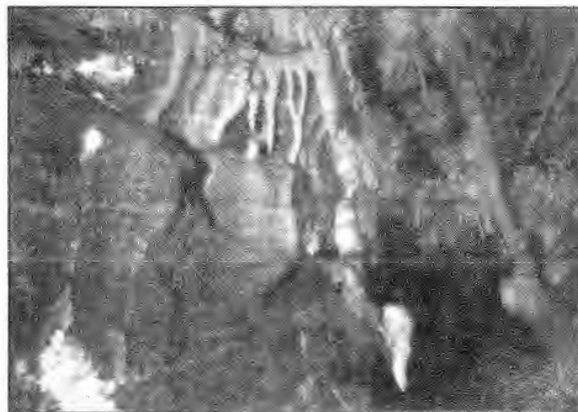
Figure 5: Aragonite Canyon view

the bat guano or from oxidising pyrite in the dyke.

Other Caves at Jenolan

Glass Cave contains aragonite-like speleothems associated with gossans and minerals containing Mg and PO_4. Aragonite has been confirmed from the following show caves: River Cave, Mud Tunnels and Ribbon Cave (Osborne 1999, Osborne, Pogson & Colchester 2002, Rowling 2005). Aragonite-like speleothems have been reported from several others. Forms taken include spheroids ("stars"), helictites, and white and brown "furze bushes" - tight combinations of stalactite, column, stalagmite, beaded helictites and flos ferri, often associated with huntite and hydromagnesite. The substrate to the show cave aragonite speleothems is typically red ochres and dolomitised limestone or dolomitic palaeokarst. In Mammoth and Spider Caves, aragonite-like speleothems have developed on possibly dolomitised substrates and with minerals containing Mg, Mn and possibly SO_4.

Wombeyan Caves

Wombeyan Caves are about 130 km to the south-west of Sydney and about 19 km west of the western edge of the Sydney Basin (Figure 1). The caves have formed in saccharoidal marble, in an irregular area completely surrounded by effusive silicic to intermediate igneous rocks and intruded by gabbro and granite. The marble features dyke-like joints filled with pyroclastic material (Osborne 1993]. The area forms a broad basin surrounded by steep hills, and is part of the Sydney catchment. There are about 500 speleological features, including six well-decorated show caves.

Sigma Cave

Sigma Cave is in the south-east of the marble outcrop, near a gabbro intrusion. It has about 3 km of passages forming an overall branching pattern, developed along joints and also possibly the strike of the original bedding. Aragonite and aragonite-like speleothems occur in several places, but mainly at Aragonite Canyon far from the entrance (Figure 5). Aragonite occurs as a prickly wall coating on marble bedrock and on mud, on walls and fringing edges of holes where breezes are felt. Aragonite forms include skeletal coralloids, anthodites, helictites, stalagmites and spathites. Substrates include fine gravel, mud, marble and moonmilk. Mineral associations with aragonite include calcium silicates, clays, calcite, magnesian calcite, phosphates, epsomite, whewellite, hydromagnesite and huntite (XRD). "Twigs" fallen from a helictite "bush" comprise calcite, minor magnesian calcite, aragonite and hydromagnesite, with traces of huntite and kaolinite (XRD). The original aragonite structures are preserved in the shape (Figure 6). The most likely source of silicates is

Figure 6: "Twig" (SEM photo). Aragonite laths coated with Mg-rich minerals.

gabbro in the gravel, altered by bat guano.

The spiky central canal of a small stalactite includes aragonite (XRD). Elsewhere, aragonite-like speleothems include 3-horned helictites, a saw-shaped helictite and small splinters on a dyke-like filled joint. Cave coral-loids have depressions in their centres filled with needle crystals (possibly aragonite) and white pasty "moonmilk". Small (1 cm to 4 cm diameter) "cave turnips" have broken open naturally, possibly by gas build-up. Inside the speleothem is a radially arranged hollow sphere of needle crystals, resembling aragonite, with a centre of mud with white "moonmilk". The air in the cave is humid (>98% RH) and has mildly elevated CO_2 (0.3 to 0.5%) ascribed to organic decomposition.

Wollondilly Cave

Wollondilly Cave is a show cave with two entrances and mainly calcite speleothems. Aragonite-like anthodites occur in The Cathedral, and an aragonite-like (calcite) coating occurs in a pool. Aragonite has been positively identified in two sites near the middle of the cave. Air movement in both sites is slight but noticeable. Aragonite was found as a minor mineral in small speleothems in Star Chamber, and in The Loft where the relatively humidity is low (76%, 16°C). Cobbles and gravel on the floor comprise weathered fragments of porphyry and clays altered by ancient bat guano. Aragonite is a minor component of coatings, and in a white to creamy yellow and orange fluffy fungus-like material present on the fine gravels (mainly needle-form calcite with vaterite, aragonite and other minerals). Calcite-inhibitors associated with aragonite in Wollondilly Cave include Mn, Mg, PO_4 and SO_4. Other caves at Wombeyan contain aragonite or aragonite-like speleothems, such as coralloids, "cave turnips" and coatings, sometimes associated with dolomitic bedrock.

Walli Caves

Walli Caves are located about 215 km west of Sydney in an area of gently rolling, rounded hills at about 440 m ASL and are part of the Lachlan catchment (Murray-Darling system). The caves are located in the western part of a faulted, 460 m thick foetid Ordovician limestone deposit and are relatively warm (19°C) compared with the average annual temperature of 16°C. About 4 km northeast of Walli Caves is a warm spring (28.5°C). The limestone is dolomitised in places (to dolomite and ankerite), and contains veins of barite, quartz and chalcedony, and dolomitised chert nodules with barite, anhydrite, goethite, pyrite and other metal sulfides. Cave outlines vary from branching to networks, formed around the local joint and fault pattern, with bedding influencing some passage cross sections. Gypsum occurs in the caves, usually as a coating on the limestone and as selenite needles on the surface of exposed chert nodules. Two caves were examined, Deep Hole and Piano Cave, both located in the southern area of the limestone outcrop. Although aragonite is not common at Walli, there are two types: a fine crystalline type associated with low humidity and a more coarse crystalline type in a humid area associated with mineralised veins and faults. Calcite-inhibitors associated with aragonite and low humidity include Mg and SO_4 as epsomite ($MgSO_4$) and gypsum. In humid areas small orange aragonite efflorescences have developed along seams associated with barite, gypsum, hexahydrite ($MgSO_4.6H_2O$), pyrolusite and traces of other barium minerals (XRD). Aragonite occurs where the bedding is very steep, or is cut by near-vertical faults, allowing oxygen-rich groundwater derived from rainfall to penetrate the beds, oxidise pyrite and mobilise ions.

Aragonite in other NSW caves

Large aragonite-like speleothems, identified by morphology alone, occur in a cave near Jaunter, west of Jenolan Caves. Aragonite in Fly-

ing Fortress Cave at Bungonia is associated with minerals containing Mg and Mn in an area with steeply-dipping, weathered dolomitised limestone beds close to a weathered dolerite dyke. Speleothems include small efflorescences, needles, hemispheres, crusts, flos ferri, spathites, curved and beaded helictites. Aragonite and aragonite-like speleothems in Wyanbene Cave are associated with a low-grade, disseminated base-metal ore body and dolomitised limestone. Speleothems include anthodites and coralloids. Aragonite-like helictites, small anthodites and coatings were reported from Colong Cave, southwest of Jenolan Caves. Aragonite-like speleothems at Wellington Caves, about 240 km NW of Sydney, are associated with phosphorite and some dolomitisation.

Conclusions

Calcium carbonate is depositing in NSW caves as aragonite wherever it cannot deposit as calcite due to chemical and physical factors, mainly calcite-inhibitors, with Mg present at most sites, usually the result of pyritic weathering of ferroan dolomite. Aragonite was associated with the following minerals which contain Mg: huntite, hydromagnesite, epsomite, dolomite, magnesian calcite, nesquehonite, lansfordite and hexahydrite.

Mn was also commonly present, possibly originating from the weathering of ferroan dolomite and weathering of ferromagnesian minerals from nearby mafic rocks. Aragonite was associated with the following minerals containing Mn: rhodochrosite, todorokite, pyrolusite, braunite, mangano-calcite, manganoan calcite, rabbittite, birnessite and hausmannite.

SO_4 was present in many sites examined. Three origins were suggested, one biological (bat guano) and two mineralogical (weathering pyrite and hydrothermal minerals). Biogenic sulfates were often associated with phosphates and vaterite. The following SO_4-bearing minerals occurred with aragonite: gypsum, letovicite, epsomite, bassanite, natron and hexahydrite.

PO_4 was present in some sites, and a bat guano origin is suggested. The following phosphatic minerals were associated with aragonite: diadochite, vauxite, koninckite, leucophosphite, arrojadite, variscite, collinsite, hydroxyapatite, ardealite, cacoxenite and heneuite.

Vaterite: $CaCO_3$ was present in the form of vaterite, aragonite and needle-form calcite ("lublinite") at some sites. It was suggested that these minerals were associated with old bat guano deposits, and that the aragonite in this case may be forming by inversion of vaterite to aragonite. Other minerals present contained Mg, Mn, SO_4 and PO_4.

Tectonic region: Possibly something in the geological history of the Lachlan Fold Belt has emplaced more dolomite and pyrite than in other regions.

Steeply-dipping beds, joints or faults: All sites have steeply-dipping beds, joints or faults, which may allow meteoric water to seep into the site and oxidise pyrite.

Mafic rocks: Weathering of mafic rocks may release calcite-inhibitors and may be assisted by oxidising pyrite and the corrosive effect of bat guano. Dykes may also host dolomite by mineral replacement during deep burial, e.g. the dyke in Wiburds Lake Cave. Filled joints may host calcite-inhibitors (e.g. in Sigma and Wyanbene Cave).

Association with ochres and gossans: Aragonite was associated with ochres and gossans in many sites examined, especially where the ochre appeared to be made of highly weathered ferroan dolomite. Calcite-inhibitors present in the ochres and gossans appear to have the most influence on whether aragonite is present or not.

Low Humidity: Aragonite was found in sites with high humidity and low humidity. In both cases, calcite-inhibitors were also present. Low humidity affects evaporation rate, which concentrates minerals containing calcite-inhibitors.

Air Movement: Aragonite was found both in sites with little air movement and sites with perceptible air movement. One effect of air movement is to increase the rate of exchange of CO_2 between the speleothem and the

314

air, allowing a higher rate of deposition than with still air. In areas with low humidity and perceptible air movement, evaporation rate is increased. In areas with high humidity and perceptible air movement, aragonite speleothems form filigree patterns such as frostwork. It is possible that the rate of deposition only affects the shape, and the mineralogy is dependent on the presence or absence of calcite-inhibitors.

Humidity contributes more to the form taken by the speleothem and less to the polymorph. In low humidity, crystal size is smaller and crystal orientation is more random as rate of deposition is faster. Forms taken by aragonite speleothems include irregular masses, very small helictites and simple coatings. In the case of high humidity, crystal size is generally larger and crystal orientation usually follows that of the substrate as rate of deposition is slow, forming anthodites, large helictites and spherulites.

In the caves examined, there was no correlation between aragonite and temperature (from 12.2°C to 18.8°C), CO_2, pressure, clays, or strontium.

Implications for site management in show caves

As the aragonite polymorph is dependent on the presence of often soluble calcite-inhibitors, it is worthwhile preserving these minerals in order to preserve the aragonite speleothems in show caves. Cave cleaning often involves the use of water sprays; this method is not advisable in areas with aragonite, as without the calcite-inhibitors the material may revert to calcite. Other cleaning methods should be investigated. Dr Vaclav Cilek (pers. comm. 2004) also suggested tourists should not stand directly under cave aragonite, as lint and bacteria rising with body heat may damage the speleothem.

Acknowledgments

References

Cas, R. (1983), Palaeogeographic and tectonic development of the Lachlan Fold Belt southeastern Australia - Special Publication No. 10, Geological Society of Australia, Inc., Sydney, NSW Australia.

Curl, R. L. (1962), 'The aragonite-calcite problem', Bulletin of the National Speleological Society 24(1), 57-73.

Frank, R. (1974), 'Sedimentary development of the Walli Caves, New South Wales', Helictite pp. 3-30.

Hill, C. A. & Forti, P., eds (1997), Cave Minerals of the World, 2nd edn, National Speleological Society, Huntsville Alabama, USA.

Morse, J. W. (1983), The kinetics of calcium carbonate dissolution and precipitation, in R. J. Reeder, ed., 'Carbonates: Mineralogy and Chemistry', Mineralogical Society of America, pp. 227-264.

Osborne, R. A. L. (1978), 'Structure, sediments and speleogenesis at Cliefden Caves, New South Wales', Helictite 16(1), 3-32.

Osborne, R. A. L. (1993), 'The history of karstification at Wombeyan Caves, New South Wales, Australia, as revealed by palaeokarst deposits', Cave Science: Transactions of the British Cave Research Association.

Osborne, R. A. L. (1999), 'The origin of Jenolan Caves: Elements of a new synthesis and framework chronology', Proceedings of the Linnean Society of NSW 121, 1-27.

Osborne, R. A. L., Pogson, R. E. & Colchester, D. M. (2002), 'Minerals of Jenolan Caves - Geosphere meets Biosphere (Abstract)', Journal and Proceedings of the Royal Society of New South Wales 134 (3/4)(401 - 402), 111.

Rowling, J. (2004), Cave aragonites of N.S.W., Master of Science Thesis (unpubl.), The School of Geosciences, Division of Geology and Geophysics, The University of Sydney.

Rowling, J. (2005), 'Studies on aragonite and its occurrence in caves, including New South Wales caves', Journal and Proceedings of the Royal Society of New South Wales 137(3,4), 123-149.

Webb, J. A. & Brush, J. B. (1978), 'Quill anthodites in Wyanbene Cave, Upper Shoalhaven District, New South Wales', Helictite 16(1), 33-39.

Wilkinson, C. S. (1892), 'Description of the Belubula Caves, Parish of Malongulli, Co. Bathurst', Records of the Geological Survey of N.S.W. III(1), 1-5, plates I-III.

315

O-89
Various types of gypsum crystals from Tajna jama, Slovenia

Nadja Zupan Hajna

Karst research Institute ZRC SAZU, Titov trg 2, 6230 Postojna, Slovenia, zupan@zrc -sazu.si

Abstract

Gypsum as a cave mineral is very rare in Slovenia, because there are no gypsum or anhidrite strata present. Caves are developed in pure limestone and dolomite and there are not a lot of chances to have solutions enriched by sulphates present in the caves. In Slovenian caves sulphate ions originate from the Eocene flysch sediments, impurities in limestone, from sulphide deposits and volcanic rocks. Usually gypsum is presented as crusts or small "flowers"; there are few caves where larger crystals were formed. In two caves larger gypsum needles were found in the clastic sediments and in Tajna jama also the subhedral crystals to 15 cm long are present. Needles in that particular cave grow in silty-clay, which is allothonous clastic sediment brought to the passage with flowing water, and they are to 10 cm long. Subhedral crystals are poorly developed crystals of gypsum, formed in sandy silt. Large individual crystals can grow because sediment around them is soft and plastic. The genesis of these crystals is due to water, rich with sulphate ions, seeping through the sediments. Deposition occurs when the water in sediment is over-saturated; that usually happens during evaporation. In the same cave also "gypsum ice" which covers some parts of cave passages can be found.

Introduction

Gypsum as a cave mineral is very rare in Slovenia, and may be found just in a few caves. Sulphate ions originate from the Eocene flysch sediments, impurities in limestone, from sulphide deposits and volcanic rocks.

Usually gypsum is presented as crusts or small "flowers"; there are few caves where larger crystals were formed.

In two caves larger gypsum needles were found. Tajna jama is one of them. Crystals were found by JK Crni Galeb Caving Club (Naraglav, 1976), but they didn't recognise them as gypsum. As a location for gypsum crystals the cave was first time described by A. Mihevc in 1992. Cave is located in the isolated karst of central part of Slovenia (Fig.1). It is developed in isolated area of Triassic limestone and dolomite South of Velenje.
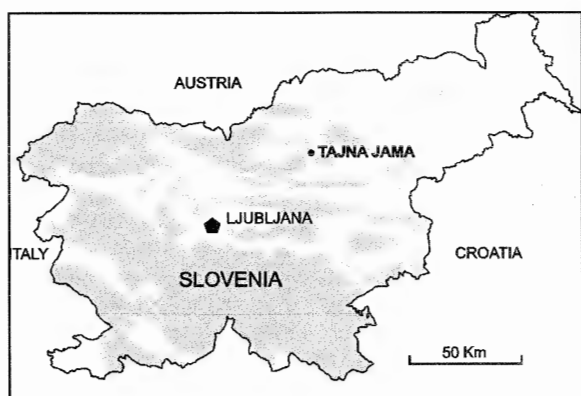
Fig. 1: Location of the Tajna jama cave.

Geology and speleology

Tajna jama is about 1 km long cave and 30 m deep ponor cave in small isolated contact karst area N of Celjska kotlina Basin. The main passage of the cave has a keyhole shaped profile. Cave is formed in the contact between Upper Triassic limestone and Oligocene andesitic tuff, volcanic breccia and limestone breccia containing limestone, dolomite, andesite and quartz keratophyre clasts, with tuff in the matrix (Buser, 1977). Main water passage is up to 6 m high meander which in some parts cut older, now dry passages, filled by clastic sediments (gravel, sand, silt, clay) and speleothems (calcite, aragonite, gypsum). Temperature in the cave is from 10 to 12°C.

In meandering canyon, later erosion left about 2 m high profile of fine laminated sediments. The upper part of the profile is horizontal; the lower parts show slightly inclined layers probably due to plastic deformation of the sediments after the erosion-subsidence of the sediments from the passage. The profile was dated by paleomagnetic method (Pruner et al. 2005). Alternation of normal and reverse magnetised zone was defined by detailed paleomagnetic analysis. The interpretation is unclear. One dates sediments back to about 3.0 to 3.4 Ma, i.e. to Gauss chron. The erosion surface within the lower recerse magnetised zone is related also with change of layer inclination. The boundary, if representing prominent hiatus, can shift the datation of the lower reverse/normal boundary even down to 4.180 Ma (top of Cochiti event). This interpretation can be supported by some paleomagnetic parametres (especially average declination values). The another possibility is younger. The top boundary of normal and reverse polarised zones can represent Brunhes/Matuyama (0.78 Ma), lower normal zone is than Jaramillo event (0.99-1.070 Ma) and bottom reverse-normal boundary is 1.77, i.e. top of Olduvai event. This interpretation ca be supported by erosion within the lower reverse polarised magnetozone.

Mineral composition of sand and clay

Mineral composition was defined by X-ray powder diffraction method (Philips X'Pert APD) in Laboratory of Physical Methods, Institute o Geol-

ogy CAS, in Prague, Czech Republic. Two samples have been taken, one of sand and one of the silty-clay (Fig.2).

In the sample of sand (Fig. 2, a.) quartz and gypsum prevail, there are small amounts of mica, kaolinite, K-feldspar and chlorite in the traces.

In the sample of silty-clay (Fig. 2., b.) quartz prevails, there are small amounts of gypsum, kaolinite, mica, smectite and chlorite in the traces.
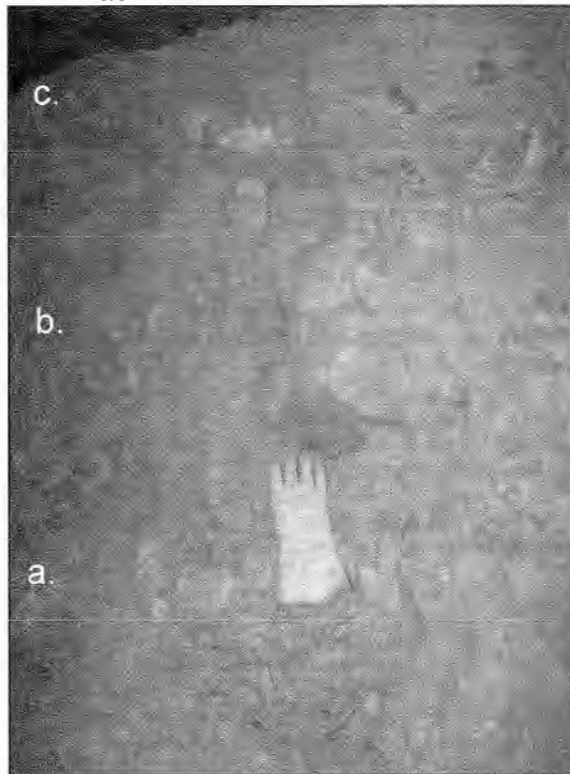
Figure 2: Profile of the clastic yellow sediments in the final part of the cave, where larger gypsum crystals are presented. a. - sand, b. - silty-clay, c. - gravel with sand.

Gypsum crystals

In the cave gypsum is presented in different forms. Most common are gypsum crusts and "flowers" with crystals to 2 cm long. Crystals in Some of gypsum flowers surround the pyroclastic clasts of breccia and jut out of the wall. Some of the crystals form big clusters on the wall. Gypsum grows also from fissures, covers the cave walls like ice crust. We call it "gypsum ice", because of its transparency. It is thin crust of small crystals deposited all over the wall. But important are big gypsum crystal from the cave sediments. There are needles and big subhedral gypsum crystals. Large individual crystals can grow because sediment around them is soft and plastic.

Subhedral crystals from the sandy sediment are to 15 cm long (Fig.3), they look like eroded crystals (Hill & Forti, 1986), but they are not eroded. Individual crystal is not fully developed, because during its growing, crystal had not have enough energy to push aside the confining particles of the sediment. Some of them have them form twin crystals in the shape of swallow-tail. Needles are usually shorter, but they can be to 10 cm long.

Origin of sulphate ion

In both samples there is no evidence of pyrite, marcasite or limonite, which can be the source of the sulphate for gypsum deposition. That

means, that the origin of sulphate ions is from somewhere else, perhaps from the sulphate ore bodies (pyrite, galena), which are developed in the wider area on the contact between limestone and quartz keratophyre (Germovšek, 1953).

The genesis of large crystals is due to water, rich with sulphate ions, seeping through the sediments. Deposition occurs when the water in sediments is over-saturated; that usually happens during evaporation.

For the presence of the gypsum in the cave sediments is important that
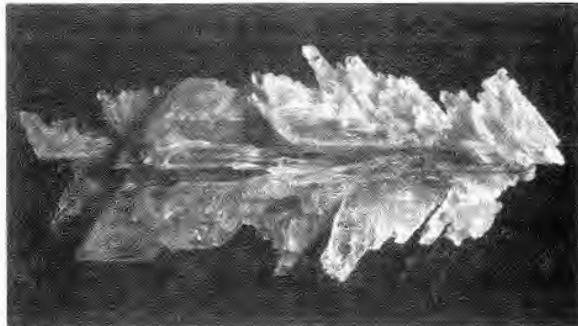
Figure 3: Subhedral crystals are poorly developed crystals of gypsum, formed in sandy silt. This particular crystal is 15 cm long.

a new coming water is over-saturated by sulphate ions in other way all gypsum will be dissolved in it.

References

Buser, S., 1977: Basic geological map, 1: 100000, Sheet Celje.Federal Geological Survey, Beograd.

Germovšek, C., 1953: Kremenov keratofir pri Veliki Pirešici. Geologija 1, 135-168, Ljubljana.

Hill, C.A. & Forti, P., 1986: Cave minerals of the world. p. 121., National speleologica society, Huntsville.

Hill, C.A & Forti, P., 1997: Cave minerals of the worl. Second Edition, 187-193, National speleologica society, Huntsville.

Mihevc, A.,1992: Sadra v Tajni jami in jami Kubik. Acta Carsologica, 21, 175-183, Ljubljana.

Naraglav, D., 1976: Zapisnik terenskih ogledov 1971- 1976. Cave Register IZRK ZRC SAZU and JZS.

Pruner, P., Zupan Hajna, N., Mihevc, A., Bosák, P., Man, O., Schnabl, P. Šlechta, S., 2005: Palaeomagnetic research of cave sediments in Slovenia in 2004. 13th International Karstological School "Classical karst", Karst in various rocks. Guide-booklet for the excursions and abstracts of presentations. Karst Research Institute ZRC SAZU, 35-36, , Postojna.

O-90

The pearls of the Kanaan Cave (Lebanon): petrographic and geochemical studies

J. Doummar, F. Nader

American University of Beirut, Beirut, Lebanon

317

Abstract

The Kanaan cave is located in the vicinity of the Antelias town (5km north of Beirut City, capital of Lebanon). The cave entrance has an altitude of about 100m above sea level. It has a total underground network exceeding 100m. A very richly decorated gallery was found in this cave, featuring momentous speleothems (e.g. soda straw stalactites, eccentrics, gours, pearls etc....). This contribution is the first to discuss the petrography and geochemistry of cave pearls from Lebanon. Twenty seven cave pearls, ranging in size from 1 to 2 cm, were collected from the Kanaan cave. These speleothems were subjected to petrographic (conventional and scanning electron microscopy) and geochemical analyses (major/trace elements and stable isotopes). Temperature measurements inside the cave were performed and water samples were analyzed. The formation of these pearls depends mainly on the quantity of flushing water into the gour pool. If the input of water is small, microbial agents would play an important role in the genesis of the pearls, whereas if the water flux is high enough to keep the forming pearls in suspension in the gour pool, then the rotation and turbulence is the controlling factor. Most of the studied pearls from the Kanaan cave are highly spherical with a well polished external surface, pointing out towards a highly agitated environment of formation. Some pearls enclose a nucleus made up of fine grained sand or dust. Conventional petrographic microscopic investigations show that the pearls laminae are concentric and range in thickness from few millimeters to 1cm. These laminae consist of micrite or equant interlocking calcite cement. The scanning electron microscopic investigations show that the outer crystals display repetitive angular edged-surfaces in a stair like-fashion, where the crystal faces are terminated abruptly. Major and trace element analyses of the pearls show a relatively low content of insoluble residue (<2%; after dissolution in 1M HCl). The various concentric laminae reveal similar major and trace element concentrations (Ca 36.5% wt, Fe 49 % wt, Mn 5-7% wt, Sr 1-3% wt) This implies that the water entering the gour-pool - where the pearls were formed - was either mud free, or that the mud was flushed away by water. In the latter case the environment in which the pearls were formed was a rather highly agitated environment. Complete chemical analysis of the water in the pools from which the cave pearls were precipitated shows that the hosting water is a neutral water (pH= 7.66) with a high Ca/Mg ratio (57.082/1.908 ml/L). The Iron and Zinc concentrations were below detectable limits, whereas strontium and Sodium concentrations values reached 0.058 and 10 mg/L respectively, The oxygen isotopic values (‰ PDB) show a clear depletion towards the outer layers of the 18O of the water where the outer layers were?pearls, implying 1) lighter precipitated, 2) an increase in temperature during the precipitation, 3) probable recrystallization of the outer lamina. Keywords: Scanning electron microscope, oxygen isotope, manganese content Lebanon.

O-91

How geometric factors determine which type of speleothem will grow in a cave environment

CHARLES A. SELF

4 Tyne Street, Bristol, BS2 9UA, England; self@globalnet.co.uk

CAROL A. HILL

17 El Arco Drive, Albuquerque, NM 87123, USA; carolannhill@aol.com

Abstract

A speleothem is a physical mineral body which can be described without regard to its chemical composition or mineral species. A stalactite, for example, can be defined purely by its morphology and internal organization. Most speleothems are mineral aggregates, formed from several (sometimes many) crystals of the same mineral species. The component crystal individuals do not simply grow together, they interact and compete for growth space and/or the supply of new material. This interaction between individuals causes a distinctive pattern of crystal boundaries to develop in the aggregate. This pattern is called texture.

Texture describes the geometric aspects of construction of an aggregate and depends mainly on the characteristic (Curie) symmetry of the medium from which crystallization occurred. The symmetry groups used in textural analysis are spherical, cylindrical and conical. For aggregates with conical symmetry, each crystal has neighbouring crystals diverging from it. The capillary film environment has conical symmetry because of the geometry of evaporation physics. In this environment, branching aggregates such as coralloid speleothems and frostwork are found.

The many different speleothem types are classified not only by their internal construction, but also according to their morphology. Morphology describes the typical physical shape of a speleothem. Stalagmites, flowstone and draperies are the same type of aggregate and may form together in the same gravitational water environment. Because of a different geometry of supply of the feeding solution, there is a difference in morphology between these texturally similar speleothems.

РЕЗЮМЕ

Спелеотем - физический объект, состоящий из минералов, - может быть описан без его химического или минерального состава. Сталактит, например, можно определить морфологией и внутренней организацией. Большинство спелеотемов - минеральные агрегаты, сформированные несколькими (иногда многими) кристаллами одного и того же минерального вида. Составляющие индивидуальные кристаллы не просто растут вместе, они взаимодействуют и сражаются за пространство для своего развития и/или подачу нового материала для роста. Это взаимодействие между индивидуальными кристаллами является причиной характерной конфигурации кристаллических границ, которая развивается в агрегате. Эта конфигурация называется текстура.

Текстура определяет геометрические аспекты конструкции агрегата и зависит в основном от характеристической (Кюри) симметрии среды, в которой происходит кристаллизация. Группы симметрии, использующиеся при анализе текстуры: сферическая, цилиндрическая и коническая. Если у агрегата - коническая симметрия, у каждого кристалла есть соседние кристаллы, расходящиеся от него. Среда, создаваемая капиллярной пленкой, имеет коническую симметрию, обусловленную геометрией физического процесса испарения. В этой среде найдены такие ветвящиеся агрегаты как кораллоиды и кристаллактиты - спелеотемы.

Многочисленные различные типы спелеотемов классифицируются не только внутренней конструкцией, но также в соответствии с своей морфологией. Морфология описывает типичную физическую форму спелеотема. Сталагмиты, натеки и драпировки - один и тот же тип агрегата и могут расти вместе в одной и той же гравитационной водной среде. Различие в морфологии между этими спелеотемами подобной текстуры - результат различной геометрии подачи питающего раствора.

Introduction

A cave mineral is a secondary mineral deposit, growing in a cave, that is described by its chemistry and mineral species. Fluorite, ice and high-magnesium calcite are all cave minerals. More than 250 cave minerals have been recorded (Hill and Forti, 1997) but only three species (calcite, aragonite and gypsum) can be considered common.

A speleothem is a secondary mineral deposit, growing in a cave, that is described as a physical body. Stalagmites, pool spar and cave rafts are examples of speleothems. These speleothem terms refer only to the physical nature of the mineral deposit, so an epsomite cave flower is constructed in the same way as a gypsum cave flower. This means it is possible to disregard mineral species when studying the different speleothem types. For a detailed description of how speleothems grow, the reader is referred to Self and Hill (2003). A more concise version appears in these Proceedings (Self and Hill, "An introduction to genetic mineralogy etc.") and in Self (2004).

So how does a single cave mineral, such as calcite, produce so many different speleothem forms? The physical description of a speleothem has two components: external shape (morphology) and internal construction. Morphology depends on how new material is supplied to the speleothem, whereas internal construction can be related to the environmental conditions of the crystallization space as a whole. The internal construction of a speleothem is therefore more informative.

Speleothems are generally not built from single crystals; gypsum (selenite) needles are the only common exception to this rule. Most speleothems are built from several (sometimes many) crystals of the same mineral species and are thus mineral aggregates. The component crystals (mineral individuals) of an aggregate do not simply grow together, they interact and compete for growth space and/or the supply of new material. Often, this competition leads to a reduction in the number of individuals constituting the aggregate, a situation called selection.

The most important selection process is geometric selection: the mineral individual whose greatest growth vector during competitive growth is best aligned for mass-transfer with the environment is the one that will continue its growth at the expense of neighbouring individuals of other orientations (Self and Maltsev, 1999; Self and Hill, 2003). Aggregates are therefore much more than similar individuals of the same mineral species, growing together simultaneously. Interaction between individuals directly affects and limits the growth of each crystal. This interaction causes a distinctive pattern of crystal boundaries to develop in the aggregate. This pattern is called texture and different aggregate types are distinguished by having different textures.

It is worth repeating here that speleothem type is not the same as aggregate type. A speleothem is described by both morphology and texture. Thus, flowstone and stalagmites are the same type of aggregate (based on texture) but are different types of speleothem.

The curie universal symmetry principle

There is no effect without cause (Curie, 1894). The symmetry aspects of this relationship can be expressed as: the characteristic symmetry (or the dissymmetry) of an object or medium must be found in the causes that generated that object or medium. This is known as the Curie Universal Symmetry Principle (Stepanov, 1998), and is a simplification of the 1894 original observation.

The characteristic symmetry of a phenomenon may be regarded as an ideal symmetry for that object or medium. A similar concept has been used in regular mineralogy to divide all mineral species into seven different crystal systems. It does not matter if a crystal is deformed or broken, it belongs to a particular crystal system because this is a function of the internal structure of the mineral species itself (e.g., calcite belongs to the trigonal system). The characteristic symmetry of a medium does not depend on the physical shape of the space in which it is enclosed, but is innate to the medium itself. The symmetry groups for phenomena identified by Curie include three static groups (spherical, cylindrical and conical) and a further four which involve motion (e.g., a magnetic field has the symmetry of a rotating cylinder). Only the three static groups are needed to describe the texture of mineral aggregates and the mediums from which they form.

Spherical symmetry is indicated when the texture of an aggregate displays complete disorder, since all directions from any point are equivalent. Similarly, a medium has spherical characteristic symmetry when it is isotropic. An example is phreatic deposition from a supersaturated solution. Whatever the shape of the crystallization cavity, crystal embryos (crystallites) nucleate on all available surfaces and are randomly oriented during the first stage of growth.

The distinctive feature of cylindrical symmetry is growth along one axis. This axis may change direction as the aggregate develops, but growth in other directions is severely limited. This means that each crystal has neighbouring crystals sub-parallel to it, whatever its location and orientation. The classic example is a helictite, where several crystals surround and grow parallel to the central feeding channel. (For the growth mechanism of helictites, see Self and Hill 2003).

Conical symmetry has a single axis, which is the preferred direction of aggregate growth, but some growth in other directions is allowed. Each crystal has neighbouring crystals diverging from it, whatever its orientation and location. The capillary film environment has conical symmetry because of the geometry of evaporation physics. Solvent molecules are most easily lost in the direction of the open cave, but some molecules leaving at an oblique angle to the substrate will also be lost, particularly where the substrate is convex. This allows branching aggregates such as corallites and crystallictites to grow in this environment (Figure 1).

Dissymmetry can be thought of as the set of symmetry elements which are missing. (Note: dissymmetry is not the same as assymmetry, which is a general lack of symmetry.) Unidirectional forces, such as gravitation and geometric selection, are dissymmetries which commonly affect mineral growth. If we return to the case of phreatic deposition from a supersaturated solution, which has spherical symmetry, the randomly oriented crystallites all grow at the same rate until they start competing for growth space. Geometric selection then reduces the number of individuals forming the aggregate (Figure 2) to leave a new growth front of druse crystals oriented perpendicular to the substrate (a parallel-columnar aggregate). The dissymmetry of gravitational selection therefore causes a reduction in the symmetry of the aggregate.

At the local level, a druse has cylindrical symmetry. However, druse crystals cover the walls, floor and ceiling of the crystallization space, and so point in every direction. Also the druse grows to the same thickness on all surfaces. These are surviving features of the original spherical symmetry. From this we can see that the texture of a druse has two levels of symmetry: cylindrical when examined at the local level, spherical when the whole aggregate is studied. This example shows how texture responds to environmental factors that operate at different scales, with genetic information conserved on all levels.

Geometry of supply

Texture describes the internal organization of an aggregate, but it does not control its external shape. Variations in morphology are particularly well seen in caves, where the same type of aggregate can produce speleothems of radically different appearance. The reason for this lies in variations in the geometry of the supply scheme (supply of solute and/or loss of solvent). It is important to note that this is not the same as the symmetry of supply to a crystallization space (which controls texture). These are different concepts and operate at different organizational levels in the cave environment. There are four basic supply geometries.

Bulk supply is any supply scheme that is isotropic. The essential point is that the medium itself does not impose any dissymmetry on the texture of the crystalline products. Bulk supply may be completely subaqueous (as in a phreatic or cave-pool setting), laminar or turbulent gravity flow streams (as for flowstones), bulk solutions moving slowly through a porous medium, or the bulk freezing of a melt. This supply scheme does not allow individuality in an aggregate, so the only differences that can be seen are in the size and habit of the component individuals.

Area supply is a two-dimensional feeding scheme whereby solutions spread out slowly over a crystallization surface from capillary thin films. The evaporation of capillary films is very sensitive to local air flows and to irregularities in the substrate, so considerable variation in morphology is seen among the corallites which grow in this environment. Area supply also applies to crystallization along phase boundaries, such as the growth of rafts at the air/water interface of cave pools.

Linear supply is where a solution gathers into linear streams or issues from fracture openings. Mostly, this supply scheme modifies aggregates that form by bulk or by axial supply. It always results in the appearance of dissymmetry, usually with the elimination of the rotation axis. On steep or overhanging cave walls, the bulk supply of gravitational water gathers into linear streams and flowstone converts into draperies. These two speleothem types have essentially the same texture, but their morphologies are different. Shields grow from fracture openings by linear supply, but when solution overflows from the edge of the shield, the supply scheme reverts to bulk supply and flowstone overgrows the underside of the shield. Crystalline shields can also develop from helictites when the axial supply of the capillary channel becomes blocked and solution escapes through a structural line of weakness.

Axial supply is a one-dimensional feeding scheme typified by solutions moving through the middle of a speleothem, or feeding one single growth spot. These are "point-source" solutions where growth is aligned along a single axis. The most obvious point source in caves is water dripping from the roof and landing on the floor, from which grow regular stalactites and stalagmites. Axial supply causes them to grow out into the cave void, but it is the bulk supply of solutions running down their sides which thickens them. Stalactites and stalagmites are thus essentially the same type of aggregate as flowstone, but with a different supply scheme. If the linear supply to a drapery ends at a drip point, a stalactite will grow from this place. Another type of axial supply is solution seeping along the central canal of a helictite, which causes it to grow outwards from the substrate.

319

In the subaerial environment of caves, there may be differences in the supply scheme to different parts of a single speleothem. For example, in a cave with a strong airflow, the bulk supply of solution on one side of a stalactite may evaporate and become a capillary thin film. Corallites may start to grow on this side, while the rest of the stalactite continues to

Figure 1. Aragonite frostwork grows from substrate protrusions where evaporation is concentrated, such as on the sides of this inactive stalactite

Figure 2. Growth of a parallel-columnar aggregate (from Grigor'ev, 1961). The dissymmetry of geometric selection changes spherical to cylindrical symmetry

Stalactites - a case study

A stalactite is the world's most widely recognised speleothem type, but its internal construction is actually quite complicated. In its outer part, it is the same type of aggregate as flowstone, draperies and stalagmites. This explains why these aggregates all grow together in the gravitational water environment. However, a regular stalactite also has a monocrystalline tube running through its centre (Figure 4). When examined closely, the drip point of this tube has a crown of skeleton crystals. A stalactite

develop normally (Figure 3). Large stalagmites may find that drip water does not flow evenly down their sides, but gathers into rivulets giving locally enhanced growth rates. These minor variations in the supply scheme are responsible for the great variations in morphology that we see in some speleothems.

Figure 3. The dissymmetry of a strong seasonal wind causes evaporation on one side of this stalactite and the growth of corallites directly into this wind.

Figure 4. Schematic cross-section through a conical stalactite (from Moore, 1962). The monocrystalline tube grows by axial supply, the overgrowth by bulk supply.

therefore has three textures and is a polytextural multiaggregate (Self and Hill, 2003).

It is important to understand that stalactites are not soda straws overgrown by a later surface crust - the three textures form together and simultaneously. Maltsev (1999) has shown that the central tube appears as a consequence of the growth mechanism, not as a cause; stalactites are not supplied with solutions down the central tube. Stalactites therefore grow entirely as a result of water oversaturated with carbonate running down

the outside and dripping from the tip.

According to Maltsev (1999), the reason for the growth of skeleton crystals is mechanical agitation of the solution at the tip of the stalactite as the drip disconnects. Carbonate solutions are very sensitive to local changes in pressure, caused by such vibrations, and respond by releasing CO_2 and depositing calcite. Typically, mechanical degassing produces skeleton crystals (Shafranovskiy, 1961). If we look at the symmetry of this, the solution itself has spherical symmetry but rapid degassing at the phase boundary causes a local dissymmetry at the surface of the drip. This is in agreement with the observation that skeleton crystals form in a ring and grow only in the plane of the phase boundary.

The second texture, the monocrystalline tube, has its greatest growth vector oriented vertically and is a result of recrystallization. It cannot have formed by the growing together of the skeleton crystals because too much energy is tied up in all the crystal edges and faces. The most likely trigger for this recrystallization is the shock wave that travels vertically up the solution column, inside the central tube, when each drip is released. These first two textures are extremely local in extent and only develop in the special environment of the drip point.

The third texture, which comprises the rest of the stalactite, is the overgrowth around the central tube. This forms from the bulk supply of solution running down the side of the stalactite, which itself has no dissymmetries. Many small crystals grow with random orientation, then competition and selection leads to sub-parallel crystal growth (as in Figure 2). However, because the substrate is sharply curved, this becomes a variation of parallel-columnar texture known as a spherulitic aggregate (Stepanov, 1998). The result is a radiating fan of crystals around the central tube.

References

Curie, P., 1894, Sur la symetrie dans les phenomenes physique, symetrie d'un champ electrique et d'un champ magnitique: Journal de Physics, ser. 3, v. 3, p. 395-415.

Grigor'ev, D. P., 1961, Ontogeny of minerals: Lvov, Izdatel'stvo L'vovskogo Univ. In Russian. English translation 1965, Israel Program for Scientific Translations, 250 p.

Hill, C. A., & Forti, P., 1997, Cave minerals of the world (2nd ed.): National Speleological Society, Huntsville, Alabama, 463 p.

Maltsev, V. A., 1999 (for 1998), Stalactites with "internal" and "external" feeding: Proceedings of the University of Bristol Spelaeological Society, v. 21, n. 2, p.149-158.

Moore, G. W., 1962, The growth of stalactites: National Speleological Society Bulletin, v. 24, n. 2, p. 95-106.

Self, C.A., 2004, The internal organization of speleothems: Acta Carsologica, v. 33, n. 1, p. 245-255.

Self, C.A., & Hill, C.A., 2003, How speleothems grow: An introduction to the ontogeny of cave minerals: Journal of Cave and Karst Studies, v. 65, n. 2, p. 130-151.

Self, C. A., & Maltsev, V. A., 1999, Translators' note: Cave Geology, v. 2, n. 4, p. 193-195.

Shafranovskiy, I. I., 1961, Crystals of minerals: curved-faced, skeletal and granular forms: "Gosgeoltekhizdrt", Moscow, 230 p. In Russian.

Stepanov, V. I., 1998 (for 1997), Notes on mineral growth from the archive of V. I. Stepanov (1924-1988): Proceedings of the University of Bristol Spelaeological Society, v. 21, n. 1, p. 25-42.

321

O-92
Silicate pseudo-speleothem in Gradašnica Cave

Predrag Djurović • Dragan Milovanović • Nebojša Vasić
Mt.Miroč, Eastern Serbia

Introduction

Gradašnica Cave is situated in Eastern Serbia, on the western slopes of Mt.Miroč, which is a part of Carpatho-Balkan mountain belt (Fig. 1). The cave is located on the left side of the valley of Velika Gradašnica River, which feeds directly into the Danube River. The entrance to the cave is situated in a wide natural amphitheatre, 15 m above the riverbed of the Velika Gradašnica. The area is a part of the Djerdap (Iron Gates) National Park. Total length of the cave is 529 m (Djurović, P. Ed., 1998).
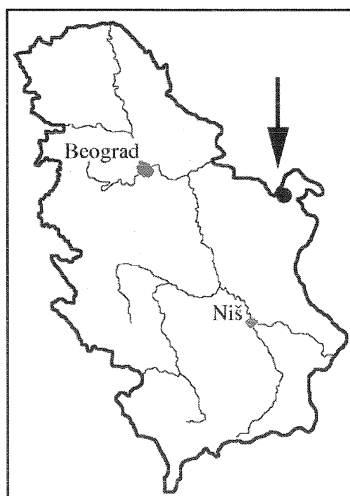
Fig. 1 - Location of the Gradašnica Cave

The cave is formed in Lower Cretaceous limestones, defined as micrites or biomicrites, consisting of microcrystalline and recrystallized calcite, with the occurrences of fossils and stylolites. Thickness of beds varies from several tens of centimetres to more than one metre, when the limestones may be defined as massive.

Geological setting of western slope of Mt. Miroč

According to the accepted tectonic division of the Carpatho-Balkanides of Eastern Serbia, Mt.Miroč is a separate unit. The whole area of the mountain can be structurally defined as a horst-anticlinorium. Western part of Miroč tectonic unit, where the cave is situated, is characterized with folding and faulting tectonics, resulting in anti-forms and sin-forms, isoclinal folds and several major fault structures (Miroč and Urovica faults). Gradašnica Cave is situated close to the point of intersection of these two faults (Fig. 2). Stratigraphically, in this part of Miroč tectonic unit, Jurassic and Lower Cretaceous sediments are distinguished. Further to the west, they are overlaid by the Getic tectonic unit, consisting of Proterozoic plagioclase gneisses. In this area, Jurassic is exposed as a narrow belt along the Miroč fault, as well as in small tectonic-erosional windows. Gradašnica Cave is situated exactly in one of those windows, where Upper Jurassic limestones are exposed (Fig.2). Lithological column of Upper Jurassic (Malmian) sediments is represented by carbonate rocks, starting with bedded dark-gray and gray arenaceous limestones, changing upwards to white massive highly karstified, sometimes dolomitized limestones. The column of Malmian carbonate rocks has gradual transitions both to Dogger and Lower Cretaceous rocks (Marković, V. & Danilova, A., 1973).

Morphological and hydrological characteristics of the cave

Gradašnica Cave is a permanent outflow cave of dendritic pattern, consisting of the main, hydrologically active passage, and several lateral confluent passages that are out of hydrological function (Fig.3).
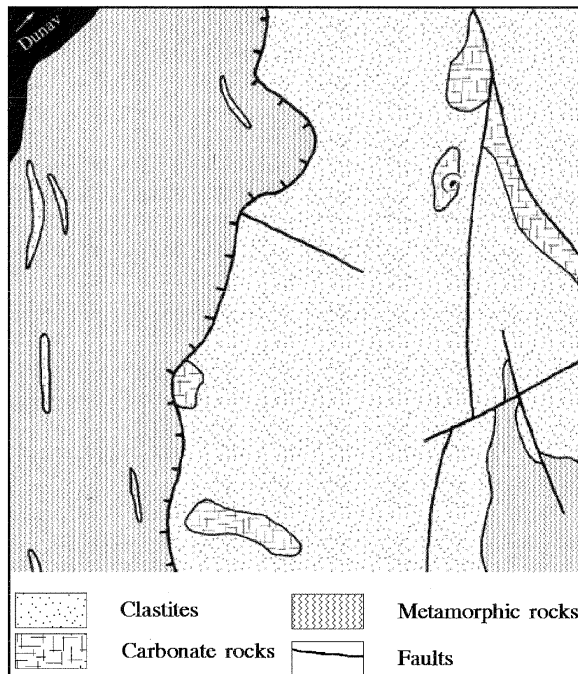
Fig. 2 - Schematic geological outline of a part of Velika Gradašnica drainage area

Clastites   **Metamorphic rocks**

Carbonate rocks   **Faults**

By its shape and size, the entrance part varies from the rest of the cave. It has a form of natural rocky amphitheatre, with the diametre of about 70 m and height exceeding 30 m. In the eastern part of the amphitheatre there is a river terrace cut by the cave stream in accumulated clastic material. Its height ranges from 1,5 to 2 m. Parts of big limestone blocks protrude from clayey-sandy material. These blocks, as well as the whole entrance part are the result of cave ceiling collapse, which led to retreat of cave entrance and formation of the great amphitheatre.

The Main passage starts from the entrance, stretches towards north and then sharply turns towards west. It represents a morphological unit that connects all the passages of the cave, and has various morphological and hydrological characteristics. In the entrance part, it has huge dimensions - width of about 30 m, and height about 15 m. The floor is rather flat, covered with clayey-sandy fluvial sediments. There is a permanent cave stream that emerges downstream from the sharp bend of the Main passage. In the stream-bed, the intensive precipitation of calcium-carbonate contributes to forming of small tufa dams along the whole course. On the walls, there are calcite flowstones and draperies 3 to 5 m wide and up to 10 m high. Widely opened entrance enables the penetration of cold air, which, during winter time, leads to freezing of films of water seeping over flowstone and draperies. Consequently, calcium-carbonate precipitation has stopped. Micro-climate conditions have considerably changed since the period of flowstone and draperies formation, so nowadays they are being destroyed by frost erosion. Therefore, their dimensions are much smaller than before. Sub-zero winter temperatures reach almost to the sharp bend of the Main passage.

In the second part of the cave, after the sharp bend, the Main passage has different morphological, hydrological and sedimentological characteristics. The passage is much narrower (2 to 3 m), while the height decreases until it reaches impassable dimensions. This part of the Main passage is periodically active, only after snowmelt or heavy rains. On the cave floor,
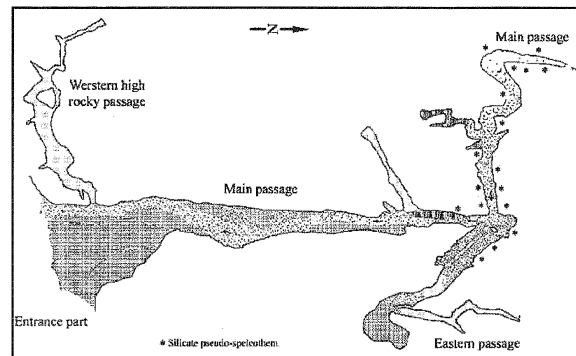
Fig. 3 - Plan of the Gradašnica Cave

there are deep rimstone dams filled with fluvial gravel. Two types of dams, differing in age, may be distinguished. Older rimstone dams are bigger in size and eroded by the stream. Younger dams are smaller, fitted into the older ones, and partially filled with fluvial gravel. Their formation is still active, during short period of hydrological activity of the passage. Such morphological and sedimentological characteristics point to considerable changes of cave stream regime, after stopping of its incision into the limestone bedrock. Intensive and long-lasting process of calcium carbonate precipitation, when the older rimstone dams were formed, switched to the process of increased fluvial accumulation of gravel and sand. Subsequently, the travertine accumulation process started, when younger and smaller rimstone dams were formed. In the next phase, they were filled with fluvial gravel and sand as well. Present accumulation of mechanical river sediments or growth rates of calcium-carbonate in the river bed cannot be measured due to the short period of existence of the stream. By comparison of stream characteristics in the lower part of the Main passage, it can be concluded that present accumulation in the upper part of the Main passage is also related to calcium-carbonate deposition.

Upstream from the sharp bend, the walls and ceiling of the Main passage are rocky, with very small quantities of calcium-carbonate, in forms of thin coatings, small soda-straws and stalactites. Apart from those, wide accumulations of spongy material have been noticed. By shape and structure, this material considerably differs from normal, calcite speleothem. That spongy and crumbly mass protrudes from the carbonate bedrock for up to about 10 cm. It spreads either in a form of several metres long belts, or in separate, isolated patches. The material covers continual surfaces of up to several square metres. Hollows within the mass are of irregular shape, several centimetres in size. In the direction of carbonate bedrock, the hollows contain carbonate fragments.

In the most upstream parts, walls and ceiling are covered with forms that morphologically resemble flowstone, but also erosional forms made by whirlpool erosion of the stream. By their dark brown colour, they substantially differ from the surrounding gray-white features - limestone bedrock and travertine accumulations. These forms are often covered with travertine coating, several milimetres thick, which often masks their real distribution. At the places where travertine coating is missing, one can notice their compact, glassy structure. At the cross-sections of this material, its striped to wavy-laminar fabric is visible.

By optical examinations, it was determined that both materials contain dominantly silicate materials - chalcedony and, to a smaller extent, quartz.

Eastern passage joins the Main passage close to the sharp bend. It is not in the active phase of formation, which is obvious from the relative height of its floor, 3 m higher than the Main passage floor. The floor is, except in the first part, covered with thick sandy-clayey sediments, in which remnants of Ursus Spelaeus have been found. The walls are rocky, without carbonate speleothem. Only in the first part of the passage, on the

322

northern wall, there is spongy silicate material identical to the one in the Main passage. The mass is present as a horizontal belt 1 to 1.5 m wide and several metres long.

Western high rocky passage joins the Main passage in the entrance part of the cave. It is characterized by relatively small width and considerable height. Cave floor and walls are without chemical or mechanical sediments. By morphological and sedimentological characteristics, this part differs completely from other passages of the Gradašnica Cave.

Petrology of silicate material

By its macroscopic and microscopic characteristics, spongy silicate material was primarily a silicate cement that cemented the limestone fragments (Fig.5). Limestone fragments are of mm or cm dimensions. Their shapes are irregular, but the roundness is quite high, so at first sight they resemble real pebbles. These fragments, by their sedimentological characteristics, are micritic and alochemomicritic varieties (presence of association of pelagic microorganisms, with prominent radiolaria skeletons replaced by calcite). Pore space between such grains and fragments is filled with fine-grained chalcedony and quartz pigmented by Fe oxides and hydroxides. Sporadically, in such cement mass there are small rhombohedral crystals, which by appearance resemble siderite (dolomite and ankerite cannot be excluded either). Structural characteristics of the cement point to its multi-phase character. It is manifested as various grain size of chalcedony and quartz, and as various degree of pigmentation by Fe oxides and hydroxides, which give striped to wavy-laminar appearance to the cement. The first phase of cementation is growth of coarser-crystalline chalcedony on the fragment surfaces. These zones are of sub-milimetric dimensions. The next phase is deposition of finely-crystalline Si cement, which was filling the largest part of the pore space. Depending on the character of solution (smaller or greater Fe input), the cement with smaller or greater Fe-mineral content was deposited, which gave it striped to wavy-laminar appearance.

Spongy silicate material, which is present on the walls and ceiling of the cave passage, was formed by dissolution of limestone fragments and grains, as less stable in comparison to silicate cement. Therefore the morphology of hollows responds to the shape of limestone fragments.

Silicate material of striped to wavy-laminar structure is composed of chalcedony and quartz as well. Different extent of dark-red colouring is a consequence of various Fe mineral content. Poliphase deposition is even more prominent than in the case of spongy material. The phases are characterized with various size of chalcedony and quartz grains, from micro- to coarse-crystalline. Phases with coarse-crystalline grains are mostly of quartz. Certain phases are characterized with the presence of Fe minerals in large regular cubic forms, which could point to primarily sulphide ineralization. In these silicate rocks, coarse-grained siderite rhombohedres are present. Regarding this material, it must be stressed that there are two generations of fissures, filled with chalcedony and quartz.

Genesis of silicate pseudo-speleothem

In the wider spring area of the river Velika Gradašnica, which is composed of limestones, there is an active karstification process resulting in development of certain karst surface forms (Fig.4). Karstification process has caused lowering of the permanent spring from 520 m to 420 m a.s.l. (Fig. 4/N°1). From that elevation, to the mouth at 70 m a.s.l, the river Velika Gradašnica has cut a steep river bed with numerous smaller steps. One of the spring confluents, as well as all right tributaries to the Gradašnica Cave (Fig. 4/N°2,3,4), have been transformed from surface to underground river courses. These tributaries are of periodic character; their springs are in clastic rocks, but they sink soon after reaching limestones. Karstification process, except for the tributary that is closest to
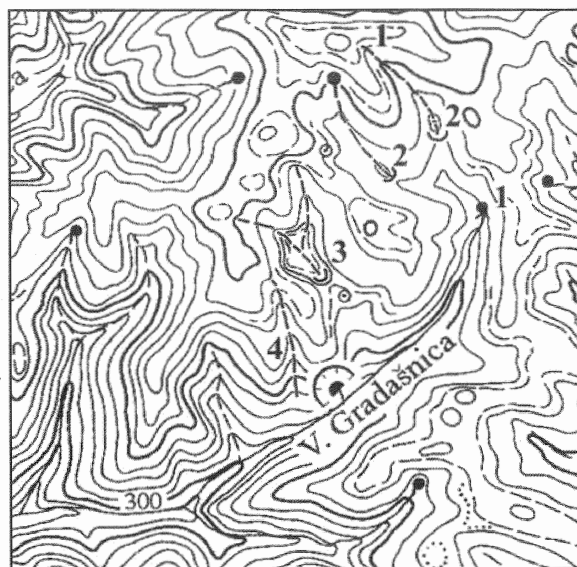
Fig. 4 - Orographic relations in a part of the Velika Gradašnica drainage basin

the Gradašnica Cave, is only at the early stage. This can be concluded from the size of dolines in which the mentioned streams sink, as well as lack of blind valleys. Regarding the confluent closest to the Gradašnica Cave (Fig. 4/N°3), the situation is different. At the place of joining of its two spring confluents, a small irregularly-shaped uvala has been formed. Downstream from the uvala, there is a remaining dry valley, the bottom of which is about 15 m higher than the uvala bottom. In the dry valley, all the way to its mouth to the river Velika Gradašnica, there are neither stream nor springs. It is obvious that here the karst process was more intense and lasted longer. By analyzing the passage directions in the Gradašnica Cave, the uvala gains importance for understanding of speleogenesis. General direction of the cave is northwards (towards the uvala), except the Western high rocky passage, which stretches westwards. Analyzing the immediate surroundings of the Gradašnica Cave, another short dry karst valley has been noticed (Fig. 4/N°4). It passes close to the entrance to the cave, from the west side. The morphological relation between the Western high rocky passage and this dry valley is obvious.

Geological settings of these two valleys, their hydrological characteristics and evolution have directly influenced the speleogenesis of the Gradašnica Cave.

Silicate features that were studied in the Gradašnica Cave are (by appearance, way and time of genesis) substantially different from seemingly similar features (chert layers and nodules in limestones). Silicate material was formed in specific geological conditions, and in subsequent speleogenetic processes it gained its present form. Therefore it is distinguished as speleothem feature. This is a complex form, whose evolution had certain phases. Taking into account that it was not formed in the same way as the usual, calcite speleothem, it was added a prefix - pseudo. Furthermore, as it is not of carbonate composition, it was finally determined as 'silicate pseudo-speleothem'.

The issue of genesis of silicate pseudo-speleothem is primarily a petrological problem, but it is speleological as well. In the Gradašnica Cave, two groups of silicate pseudo-speleothem were distinguished: spongy and striped-wavy-laminar. Regarding the spongy silicate pseudo-speleothem, it is undoubtable that the carbonate bedrock was formed first (Fig.5/A). In the process of tectogenesis, it was fissured (Fig.5/B), and water solutions from greater depths had started to seep through the voids (Fig.5/C). These solutions carried silica and cemented the voids and hollows in the carbonate mass through which they were flowing and seeping. Besides, they
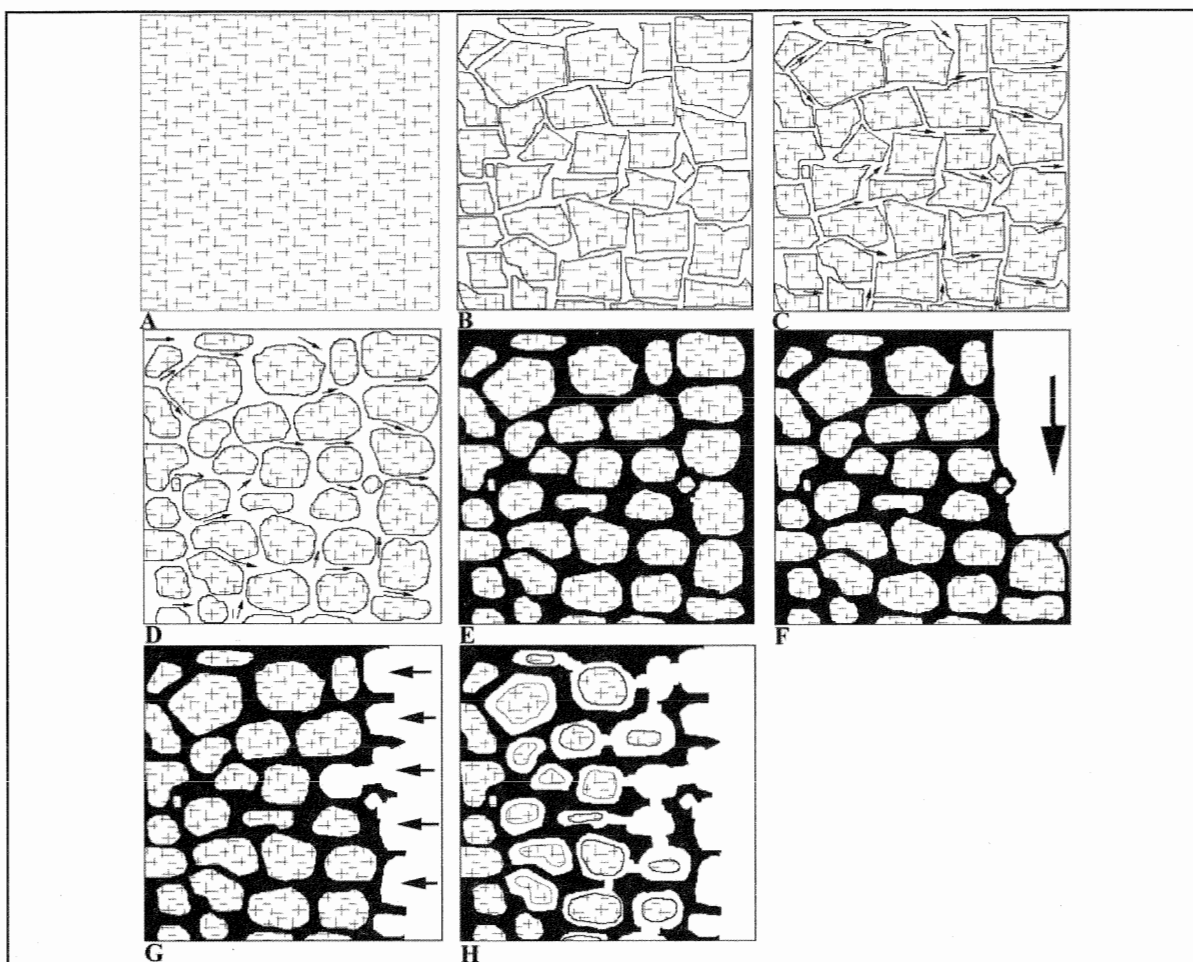
Fig. 5 - Scheme of silicate pseudo-speleothem development

contributed to partial dissolution of carbonate mass, thus making carbonate fragments that were rounded in situ (Fig.5/D). On several limestone fragments, the processes of metasomatic replacement of carbonate by silica were noticed. This phase finished by filling the fissures in carbonates with silicate material (Fig.5/E). Much later, in these limestones the process of speleogenesis has started. Waters that formed the surface drainage system started to sink and flow through limestones along tectonically guided directions, forming the cave passages. During that process, the underground flow has cut also through the limestones whose fissures and voids had been previously filled with silicate material. Fluvial erosion is strong enough to erode both limestones and silicate material within them. Therefore, at the level of the river bed and immediately above it, there is no spongy silicate pseudo-speleothem (Fig.5/F). Only after cessation of fluvial erosion, the process of limestone dissolution starts. Chemical erosion is stronger in limestones than in silicates, so the limestone bedrock is faster eroded (Fig.5/G). Limestone within the silicate material become completely or partially dissolved, and the hollows with or without limestone fragments remain (Fig.5/H).

Presence of rhombohedres of high Fe-carbonates, preserved cubic forms of other Fe minerals, fissure systems filled with chalcedony and quartz in case of striped and wavy-laminar silicate pseudo-speleothem are also the arguments pointing that the primary rock system is related to the fault zone.

During the Paleogene, this part of Eastern Serbia was mainland. In that time, strong tectonic movements took place, caused by Laramian and Pyrenean folding phase. These phases reflected to the folding of Mesozoic rocks, faulting combined with igneous intrusions and certain mineralization. Rock system in which the Gradašnica Cave is developed was formed during the mentioned tectonic phases. Silicate pseudo-speleothem was formed much later, during karstification of limestones and the speleogenetic process, most probably during various phases of the Pleistocene (Filipović, I. et all, 1978).

References

1. Djurović P. (Ed.) (1998): Speleological Atlas of Serbia, SANU, "Jovan Cvijić" Geographical Institute, Special Issues N° 52, Belgrade, 216-217

2. Marković V., Danilova A. (1973): Jura i kreda na Miroču i Velikom Grebenu i novi pogledi na tektonici ovih planina (Severoistočna Srbija), Glasnik prirodnjačkog muzeja, Ser. A., Knj. 28, Beograd, 131-142

3. Filipović I., Marković B., Pavlović Z., Rodin V., Marković O. (1978): Osnovna geološka karta 1:100.000, Tumač za list "Gornji Milanovac", L 34-137, Beograd, 61-62

O-93

High-Resolution Speleothem Records from Soqotra Island (Yemen), Provide Clues to the Indian Ocean Monsoon System

P. De Geest, S. Verheyden, H. Cheng, L. Edwards, E. Keppens
Vrije Universiteit Brussel, Department of Geology, Brussels, Belgium

Soqotra is an arid tropical island in the Indian Ocean, situated between the Horn of Africa and the Arabian Peninsula. There is a bi-annual rainy season, due to the passage of the inter-tropical convergence zone (ITCZ) twice each year, known as the Indian Ocean Monsoon system. Because neither lake sediments nor trees suitable for paleoclimate studies occur here, speleothems are the only high resolution continental proxies with the ability to record paleoclimate changes. Based on 12 TIMS 234U/230Th dating, two active speleothems from Hoq (S-STM1) and Kazekas Caves (S-STM5) have formed over the past 6 ka BP and the past 1 ka BP 18O measurements were carried out on a 1 mm to a 500?13C and ?respectively. micrometer resolution. Regarding to the variations in growth rate we obtain a 18O-values vary?time resolution ranging between 2 and 7 years. In S-STM1 13C-values between -10.5permil andbetween -4.5permil and -1.5permil and -5.5permil; while for S-STM5 these values evolve respectively between -4permil 13C (vs. VPDB). A?18O and between -7permil and -3permil for ?and -2permil for 18O-values occurs throughout the?13C and ?clear co-variation (R2= 0,7) between complete time series, exhibiting long term (millennial) and short term (decadal) variations. Layers of white porous calcite (WPC) (100-500 micrometer) alternate with layers of dark dense calcite (DDC) (10-100 micrometer) in both stalagmites, 13C and?most probably due to seasonal variations. The WPC shows more positive 18O-values, while the DDC has more negative values. Sampling at a 50? micrometers (monthly) resolution exhibits clear seasonal variations in the isotopic composition. To qualify the climatic significance of these records, adapted Environmental Data Acquisition Systems (EDAS) are installed in and near Hoq Cave to acquire information on the actual transfer functions between the environment and the proxies in our speleothems. Meteoric waters, vadose waters, cave drip waters and recent deposited calcite are analysed for their stable isotopic composition in order to understand the local carbonate-water interactions. Before a detailed paleoclimate interpretation can be made, the relative importance of SW versus NE Monsoon rainfall intensity and variability needs a better comprehension. Some references Fleitmann, D., Burns, S.J., Mudelsee, M., Neff, U., Kramers, J., Mangini, A., and Matter, A., 2003, Holocene forcing of the Indian monsoon recorded in a stalagmite from Southern Oman: Science, v. 300, p. 1737-1739. Fleitmann, D., Burns, S.J., Neff, U., Mudelsee, M., Mangini, A., and Matter, A., 2004, Palaeoclimatic interpretation of high-resolution oxygen isotope profiles derived from annually laminated speleothems from Southern Oman: Quaternary Science Reviews, v. 23, p. 935-945. Genty, D., Baker, A., and Vokal, B., 2001, Intra- and inter-annual growth rate of modern stalagmites: Chemical Geology, v. 176, p. 191-212. McDermott, F., 2004, Palaeo-climate reconstruction from stable isotope variations in speleothems: a review: Quaternary Science Reviews, v. 23, p. 901-918. Neff, U., Burns, S.J., Mangini, A., Mudelsee, M., Fleitmann, D., and Matter, A., 2001, Strong coherence between solar variability and the monsoon in Oman between 9 and 6 kyr ago: Nature, v. 411, p. 290-293. Sondag, F., van Ruymbeke, M., Soubies, F., Santos, R., Somerhausen, A., Seidel, A., and Boggiani, P., 2003, Monitoring present day climatic conditions in tropical caves using an Environmental Data Acquisition System (EDAS): Journal of Hydrology, v. 273, p. 103-118. Verheyden, S., 2001, Speleothems as palaeoclimatic archives: Unpublished Ph.D. thesis, Vrije Universiteit Brussel, Belgium, pp. 131.

325

O-94

Karst connection model for the Grand Canyon, Arizona, USA

Carol A. Hill
Earth and Planetary Sciences, University of New Mexico, 200 Yale Blvd., Albuquerque, NM 87123, carolannhill@aol.com
Noel Eberz
Box 380, Naalehu, HI 96772, noelwendy@earthlink.net
Robert H. Buecher
Cave Research Foundation, 7050 E. Katchina Ct., Tucson, AZ 85815, buecher@comcast.net

Abstract

The Colorado River did not become integrated through the Grand Canyon to the Gulf of California until ~5.5-6 million years ago, the most logical explanation being that the present route of the Colorado River was blocked by the Kaibab structural arch before this time. How the ancestral Colorado River crossed the Kaibab arch remains a central question in understanding the evolution of the Grand Canyon. A related question is: Why do the "young" narrow Marble and Little Colorado River Canyons meet at the Confluence, whereas down-gradient from the confluence of the Little Colorado River with the Colorado River the canyon becomes "old" and wide? The three major models of Grand Canyon evolution - McKee et al's (1964), Hunt's (1969), and Lucchitta's (1984) - are based mostly on speculation and have a number of problems. In this paper we propose a new model for the connection of the eastern and western Grand Canyon, one that applies and extends Huntoon's (2000) hydrologic-basin model back to >6 Ma, before integration of the Colorado River through the Grand Canyon. In essence our model proposes that water falling on the Kaibab Limestone surface of the Marble Platform immediately descended vertically via sinkholes, collapse features, joints, fractures, and breccia-pipe structures to the Redwall aquifer, and then this water under artesian pressure moved to spring outlets located at structural low points in the aquifer. In this manner, karst aquifer flow followed routes "under" or "through" structures (e.g., the Kaibab arch barrier) as it pursued its path along the steepest hydraulic gradient. Evidence that this process is still happening today are the collapse structures of Loughlin (1983) in the Blue Springs area, and the sinkholes Ah Hol Sah, Black Abyss (Paiute), and Indian Pit in the northeastern part of Marble Canyon. These three sinkholes provide vertical routes for flow down to the Redwall aquifer, discharging the Kaiparowits hydrologic basin at the Colorado River along the Fence Springs/Eminence graben system. Projecting this process back in time and spatially southward, we propose that at ~6 Ma a similar sinkhole(s) may have existed at the Confluence, and that water descending this sinkhole(s) to the Redwall aquifer discharged *through* the Kaibab arch to a structural low point in a headward-eroding western Grand Canyon. A karst-aquifer hydrologic connection was established first between the eastern and western Grand Canyon, followed by collapse and canyon incision. Support for this karst-connection model may be found in the geomorphic evolution of the Chuar Basin and in the rapid headward erosion of Marble Canyon and

Little Colorado River Canyon from the "kingpin" location of the Confluence. The rapid incision of the eastern Grand Canyon following the connection at ~6 Ma is still reflected today in a ~0.2-0.5 mm/yr incision rate for the eastern Grand Canyon versus a ~0.07 mm/yr incision rate for the western Grand Canyon (Pederson and Karlstrom, 2001). Karst processes are key to understanding the Grand Canyon, from its connection to time of its incision; yet these processes are rarely invoked in the "standard" models of its evolution.

Introduction

Four of the most persistent and perplexing problems in understanding the geomorphic evolution of the Grand Canyon are: (1) How were the eastern and western sections of the Grand Canon connected across the topographic high of the Kaibab arch?, (2) Why do the "young" narrow Marble and Little Colorado Canyons meet at the Confluence, whereas down-gradient from the confluence of the Little Colorado with the Colorado River the canyon becomes "old" and wide?, (3) Why does the Colorado River take a 90° turn from south to west in the area of Desert View?, and (4) What route did the ancestral Colorado River take before the canyon became integrated at ~6 Ma? The purpose of this study is to address all four of these problems by proposing a "karst connection" model.

Each of the three past models of how the Colorado River assumed its present course are problematic. To McKee et al. (1964) the Kaibab uplift/arch presented an insurmountable barrier to the course of an ancestral Colorado River, so these authors had the Colorado River flowing south and then east toward the Rio Grande River in New Mexico, with the river depositing the Bidahochi Formation. There are two main objections to this model: (1) studies along the course of the Little Colorado River have failed to yield any evidence for southeast drainage coming from Arizona; rather, the only drainage pattern is toward the northwest, and (2) the recent work of Dallegge et al. (2001) supports a lacustrine/playa origin for the Bidahochi, not a Colorado River origin.

Hunt (1969) had the Colorado River crossing the Kaibab arch by means of an ancient (Oligocene-age) valley, which then flowed south of the present-day Grand Canyon to the area of Kingman, Arizona. At ~18 Ma the deposition of the Peach Springs Tuff disrupted this hypothetical drainage system, causing a lake to pond in the area of the western Grand Canyon. This lake water then somehow discharged across the Grand Wash Cliffs by means of "subterranean piping". A number of problems also exist with Hunt's model: (1) there is no evidence for an ancient valley or lake that antedated the present Grand Canyon, (2) since the Gulf of California did not open up until ~6 Ma, where did this supposed ancestral Colorado River flow to?, and (3) what is meant by the elusive term "subterranean piping"? According to karst terminology, "piping" refers to the mechanical washout of caves (of gravels, soils, etc.) plus associated collapse (Ford and Williams, 1989). Also, recent karst studies in the western Grand Canyon reveal no evidence for subterranean flow to the west; rather, passages in Bat Cave reveal a paleo-flow to the north (Hill et al., 2001). The karst model discussed in this paper has *no* relationship to Hunt's "subterranean piping."

Lucchitta (1984) had a Miocene ancestral Colorado River crossing the Marble Platform in its present route to about Desert View, and then somehow traversing the Kaibab arch northwestward along a broad open strike valley to an unknown destination. The main objection to Lucchitta's model is: Where is the evidence for this route? There are no Colorado River-type gravels high on the Kaibab Plateau; rather, the arch seems to have been a topographic high since its emergence in the Laramide, with Claron-type gravels being deposited from the north along its flanks but not its crest (Hill et al., 2005).

Eberz (1995) was the first to propose a karst connection model for the eastern and western Grand Canyon. Eberz envisioned the Marble Platform as the recharge area and Chuar Basin the discharge area for springs issuing

along the west side of the Butte fault. The karst connection model proposed in this paper represents a substantial modification of Eberz' original idea. It extends Huntoon's (2000) present-day Redwall karst aquifer/hydrologic basin model back to 6 Ma by proposing that a large sinkhole(s) was then present at the Confluence, and from this sinkhole water went *under* or *through* the Kaibab arch to discharge on the western side of the arch. One of the most important characteristics of karst aquifers is that permeability pathways are produced by the fluid of the flow system rather than by some inherited geologic fabric (Huntoon, 1995). Initially structure (e.g., joints) is important because dissolution is along these weaker zones. However, as karst conduits become larger and better integrated, the hydrologic flow system becomes dominant. Conduits develop along the steepest hydraulic gradients, and flow in karst aquifers can cross faults and folds, move opposite to dip, and go under or through structures as it pursues a path along the steepest hydraulic gradient to discharge.

Present-day Hydrology

Groundwater basins. Three groundwater basins bounded by divides have been identified south and east of the Grand Canyon: the Cataract, Black Mesa, and Kaiparowits (Huntoon, 2000; Fig. 1). The springs that drain these basins are localized within structural lows in outcrops of the Redwall Limestone. The Cataract groundwater basin drains most of the Coconino Plateau and discharges at Havasu Springs. In this case the down-gradient spill point for water is aligned along a structural low known as the "Coconino trough." The Black Mesa basin encompasses an area of ~70,000 km 2 of northeastern Arizona and northwestern New Mexico, and water discharges this basin at the Blue Springs complex (Cooley, 1976). The main supply of water to this system is the Coconino aquifer, but where Coconino water encounters the Blue Springs fault zone, it moves down fractures to the Redwall artesian aquifer. In the case of the Black Mesa basin the Blue Spings fault provides the structural low for spring discharge from the Redwall, exposed by incision of Little Colorado Canyon. The Kaiparowits groundwater basin drains the northeastern part of the Marble Platform and discharges at the East Fence Springs complex. In this case the Fence fault is the avenue carrying water down to the Red wall aquifer and then to discharge.

Sinkholes. Not only does water move down to the Redwall aquifer along structural lows and faults/fractures, it also accesses the Redwall along sinkholes, collapse features, and breccia pipes. Three such sinkholes in the northern part of the Marble Platform are Ah Hol Sah, Indian Pit, and Black Abyss (Paiute). Ah Hol Sah is more than 150 m in diameter and 40 m deep (Fig. 2). Water is today being pirated into this sinkhole along a wash. Indian Pit has a total depth of 70 m, and Black Abyss a total depth of 165 m - the deepest cave in Arizona. All three of these sinkholes are presently collapsing into the Redwall artesian aquifer below, which implies that aquifer water is actively dissolving collapse material and carrying it to discharge - most likely to the Fence Springs complex (solid arrows, Fig. 1).

Collapse features/breccia pipes. Loughlin (1983) mapped more than 100 collapse features/breccia pipes in the vicinity of the Little Colorado River Canyon/Blue Springs fault zone, and Sutphin and Wenrich (1983) and Sutphin (1986) also mapped collapse features and/or breccia pipes in this area (Fig. 3). The problem with such studies is: Which of these are collapse features and which are breccia pipes? Only if a canyon dissects the side of a breccia pipe, or if ore mineralization occurs along it, can a circular feature on the Kaibab surface be accurately diagnosed as a breccia pipe. For our discussion either feature could have functioned as avenues along which water descended to the Redwall artesian aquifer.

Paleohydrology

Laramide. The Laramide (Paleocene-Eocene) was a time of tectonic compression on the Colorado Plateau. Major features relevant to our discussion formed at that time are: the Kaibab arch, Grandview and East Kaibab monoclines, and Butte fault. The Butte fault extends from north of the Nankoweap area to just south of where the Colorado River crosses the fault today (~200 km). Maximum Laramide reverse displacement (up to 800 m, east block down) was along its center section. At first, water flowing off the uplifted Kaibab arch would have flowed eastward down the Paleozoic slope, as documented by remnant shallow valleys along the Palisades of the Desert canyon rim (Babenroth and Strahler, 1945). This drainage off the arch could have flowed to an ancestral Little Colorado River confined approximately to the synclinal axis of the East Kaibab monocline (as it still is today). However, at such time when the uplifted (on the west) soft Precambrian rock was encountered by erosion, the severely upturned Paleozoic rock along the Butte fault would have become an escarpment, blocking eastward drainage. Instead, a drainage system (like Carbon Creek today) would have developed along the base of the Butte Fault escarpment, and from this confined north-south drainage, headward erosion would have proceeded updip (westward) along the eastern side of the Kaibab arch (the drainage pattern present today in the Chuar Basin). Conceivably the route of the Butte Escarpment drainage was southward to where the escarpment could be breached (where the Butte fault dies out southward), and then back northward to the Confluence where it met with an ancestral Little Colorado River meandering northward on a mature Kaibab surface to an ancestral Colorado River somewhere in southern Utah. Another important structure affecting drainage off the Kaibab arch may have been the Grandview monocline. This structure has a displacement of ~200 m accomplished within a short horizontal distance, with maximum dips ranging from 30° to 70°. Thus, a structural low would have been produced at the foot (synclinal axis) of the Grandview fold, one that probably contained a belt of weak Moenkopi and Chinle shales (Babenroth and Strahler, 1945). The Grandview monocline low could have been the locus for water flowing down southward- to southwestward-dipping beds of the Kaibab arch, and it may have been responsible for initially establishing a proto-Grand Canyon route for water flowing westward.

Miocene. The drainage patterns set up in the Laramide may have persisted until modified by Miocene tectonic extension. In the Grand Canyon area extension began ~16 Ma and continued at high rates along the Grand Wash fault until ~13 Ma, by which time most of the structural and topographic demarcation between the Colorado Plateau and Basin and Range Province had been achieved (Faulds et al., 2001). Significant headward erosion into the Colorado Plateau by a westward-flowing stream could thus have begun shortly after ~16 Ma. Basin and Range-age extension produced normal faulting, often with east-side-up displacement parallel to the strike of Laramide monoclines. In the Blue Springs area, extensional tectonics produced the Blue Spring fault and numerous associated north-south trending fractures (Fig. 3). Dissolution and collapse along these fractures provided pathways for water to descend from the Kaibab surface to the Redwall aquifer. However, since the Redwall Limestone was not yet exposed by erosion of the Little Colorado River at this time, this water would have had to discharge elsewhere. The proposed hydrologic flow path in the ancestral Black Mesa basin is: waters flowing westward in this basin, eastward down the East Kaibab monocline, vertically down the Blue Springs fault zone, and vertically down the numerous collapse features/breccia pipes, would have all descended to the Redwall aquifer. Then this aquifer water flowed northward until it reached the southeastward dipping beds of the Cedar Ridge anticline, at which point it was diverted westward to the Confluence (**B** to C, Figs. 1 and 3).

Karst connection at ~6 Ma. It is also proposed that by ~6 Ma headward erosion up the proto-western Grand Canyon had reached the Redwall level along the east-side-up faults in the Hance Rapids area. Headward erosion in the Chuar Basin had also removed much material there, but Chuar Basin drainage still joined with the ancestral Little Colorado River

at the Confluence. However, because Redwall artesian karst water was also congregating in the subsurface at the Confluence, a sinkhole began to form there, in the same manner as Ah Hol Sah is forming today (Fig. 2). The creation of this sinkhole (or series of sinkholes) caused the ancestral Little Colorado River and Chuar Basin surface waters to be pirated down the sinkhole, which significantly recharged the Redwall artesian aquifer. Thus, no longer did the ancestral Little Colorado River flow to the north, but at the Confluence the presence of a collapsing sinkhole disrupted Little Colorado drainage and initiated headward erosion up what is now the Canyon of the Little Colorado. The Cedar Ridge anticline (Fig. 3) could have caused Redwall aquifer water to divert south-southwestward toward the Confluence sinkhole, against dip, thus starting headward erosion up Marble Canyon. Due to the pirating of Little Colorado River water by the Confluence sinkhole, drainage along the Marble Canyon section of the ancestral Little Colorado River *reversed* from north to south. Now comes the important question: Where did all of the water conjoining in the Redwall artesian aquifer at the Confluence discharge? It is proposed that this subterranean water went southward, along the old northward section of the Chuar Basin route, until it reached the highly fractured zone of the Butte fault, and from there this karst water went *under* the Kaibab arch to exit at a Redwall spring in the Hance Rapids area (Fig. 3). In this manner a *karst connection* was established between the eastern and western Grand Canyon, and collapse and incision later followed this original subterranean route. Other artesian springs could have exited the Redwall exposed along the Butte fault (Eberz, 1995).

Evidence supporting a karst connection model

As with the models of McKee et al. (1964), Hunt (1969), and Lucchitta (1984), any model of the evolution of the Grand Canyon must be speculative because of canyon erosion. However, some evidence does remain for the karst connection model proposed herein. First, the barbed tributaries in Marble Canyon (e.g., South and North Canyons) may attest to a drainage reversal. Second, sinkholes presently collapsing to the Redwall artesian aquifer (Fig. 2) show that this proposed hydrologic process is operative in the Grand Canyon area - our model just projects this process backward in time and spatially southward. Also, suggestive evidence is the "line-up" of Sutphin's (1986) zone of collapse features with the Confluence (Fig. 3); i.e., the Confluence sinkhole was the southernmost member of this series. Damon et al. (1974) presented evidence that the Little Colorado River had cut down more than 460 m by 4.2 Ma, an incision perhaps instigated by a rapidly collapsing sinkhole at the Confluence sometime before ~6 Ma. Also, the rapid incision rate of the eastern Grand Canyon compared to the western Grand Canyon (~0.2-0.5 mm/yr versus ~0.07mm/yr; Pederson and Karlstrom, 2001) may be due to the gradient in the eastern Grand Canyon still "catching up" with a western Grand Canyon headward-eroded earlier in time. Finally, the model follows basic karst principles that are at work today in the canyon (Huntoon, 2000). A structural low along the Grandview monocline on the west side of the Kaibab arch could have been the down-gradient spill point for water in the ancestral Black Mesa basin - the spring point for this water simply retreated to Blue Springs (from **H** to B, Fig. 3) once the Little Colorado River had incised to the Redwall Limestone aquifer at that location.

Conclusion

We will now attempt to answer the four problems mentioned in the Introduction. According to a karst connection model, the ancestral Colorado River never flowed through the Grand Canyon before ~6 Ma. Instead, an ancestral Little Colorado River flowed to the north to connect with an ancestral Colorado River somewhere in southern Utah. The "kingpin" location of the Confluence sinkhole caused the headward erosion of the

327

"young" narrow Little Colorado and Marble Canyons, which formed *independently* of the more ancient Chuar Basin less than a mile to the west of Marble Canyon. The eastern and western sections of the Grand Canyon were connected via the Redwall karst aquifer that carried water *under* the Kaibab arch to a headward-eroding western Grand Canyon. Following this original karst route, incision and erosion caused the canyon to bend from south to west in the area of Desert View.

Acknowledgments

We would like to acknowledge verbal and/or written communication with Wayne Ranney and Bob Scarborough on geomorphology-related issues, and with Donald Davis, Pete Huntoon, and Art Palmer on karst-related issues. Thanks to Debbie Buecher, Victor Polyak, Doug Powell, Alan Hill, and Paula Provencio for field support. Permission to visit field areas and collection of samples was by permit from Grand Canyon National Park and the Navajo and Hopi Nations.

References

Babenroth, D. L., and Strahler, A. N., 1945, Geomorphology and structure of the East Kaibab Monocline, Arizona and Utah: *Geological Society of America Bulletin*, v. 56, p. 107-150.

Cooley, M. E., 1976, Spring flow from pre-Pennsylvanian rocks in the southwestern part of the Navajo Indian Reservation, Arizona: *U.S. Geological Society Proessional Paper* 521-F, 15 p.

Dallegge, T. A., Ort, M. H., McIntosh, W. C., and Perkins, M. E., 2001, Age and depositional basin morphology of the Bidahochi Formation and implications for the ancestral Upper Colorado River; *in* Young, R. A., and Spamer, E. E., *Colorado River: origin and evolution*, Ch. 6: Grand Canyon, AZ, Grand Canyon Association, Monograph 12, p. 47-51.

Damon, P. E., Shafiqullah, M., and Leventhal, J. S., 1974, K-Ar chronology for the San Francisco volcanic field and rate of erosion of the Little Colorado River; *in* Karlstrom, T. N., Swanm, G. A., and Eastwood, R. L., eds., Geology of Northern Arizona, pt. 1: *Guidebook Geological Society of America, Rocky Mountain section*, p. 221-235.

Eberz, N., 1995, Redwall Limestone karst and Colorado River evolution during the Late Tertiary, Grand Canyon National Park, Arizona (abs.): *Geological Society of America Abstracts with Programs*, v. 27, no. 6, p. A-211.

Faulds, J. E., Price, L. M., and Wallace, M. A., 2001, Pre-Colorado River paleogeography and extension along the Colorado Plateau-Basin and Range boundary, northwestern Arizona; *in* Young, R. A., and Spamer, E. E., *Colorado River: origin and evolution*, Ch. 14, Grand Canyon, AZ, Grand Canyon Association, Monograph 12, p. 93-99.

Ford, D. C., and Williams, P., 1989, *Karst geomorphology and hydrology*: London, Unwin Hyman, 601 p.

Hill, C. A., Polyak, V. J., Buecher, D. C., Buecher, R. H., and Graf, C. G., 2001, Trip Report: Bat Cave, Grand Canyon National Park, Arizona: Unpublished report to Grand Canyon National Park, June 11, 2001, 48 p.

Hill, C. A., Ranney, W. D., Scarborough, R. B., and Powell, J. D., 2005, Search for the ancestral Colorado River (abs.): *Geological Society of America Abstracts with Programs*, Rocky Mountain section, Grand Junction, CO, in press

Hunt, C. B., 1969, Geologic history of the Colorado River; *in* The Colorado River region and John Wesley Powell: *U.S. Geological Survey Professional Paper* 669-C, p. 59-130.

Huntoon, P. W., 1995, Is it appropriate to apply porous media groundwater circulation models to karstic aquifers?, *in* El-Kadi, A. I., ed., *Groundwater Resources Analysis and Management*: Boca Raton, Lewis Publishers, p. 339-358.

Huntoon, P. W., 2000, Variability in karstic permeability between unconfined and confined aquifers, Grand Canyon region, Arizona: *Environmental and Engineering Geoscience*, v. 6, no. 2, p. 155-170.

Huntoon, P. W., Billingsley, G. H., et al., 1996, Geologic map of the Eastern Grand Canyon National Park, Arizona: Grand Canyon, AZ, Grand Canyon Association, scale 1:62,500.

Loughlin, W. D., 1983, The hydrogeologic controls on water quality, ground water circulation, and collapse breccia pipe formation in the western part of the Black Mesa hydrologic basin, Coconino County, Arizona: Unpublished M.S. Thesis, University of Wyoming, Laramie, 117 p.

Lucchitta, I., 1984, Development of landscapes in northwest Arizona: the country of plateaus and canyons; *in* Smiley, T. L., Nations, J. D., Péwé, T. L., and Schafer, J. P., *Landscapes of Arizona*: Lanham, Univ. Press America, Ch. 13, p. 269-301.

McKee, E. D., Wilson, R. F., Breed, W. J., and Breed, C. S. (eds.), 1964, Evolution of the Colorado River in Arizona: Symposium on Cenozoic geology of the Colorado Plateau: *Museum Northern Arizona Bulletin*, v. 44, 67 p.

Pederson, J. L., and Karlstrom, K. E., 2001, Relating differential incision of Grand Canyon to slip along the Hurricane/Toroweap fault system; *in* Young, R. A., and Spamer, E. E., *Colorado River: origin and evolution*, Ch. 25, Grand Canyon, AZ, Grand Canyon Association, Monograph 12, p.159-163.

Sutphin, H. B., 1986, Occurrence and structural control of collapse features on the southern Marble Plateau, Coconino Country, Arizona: Unpublished M.S. thesis, Northern Arizona University, Flagstaff, 139 p.

Sutphin, H. B. and Wenrich, K. J., 1983, Structural control of breccia pipes on the southern Marble Plateau, Arizona: U.S. Geological Survey Open File Report 83-908, 7 p.
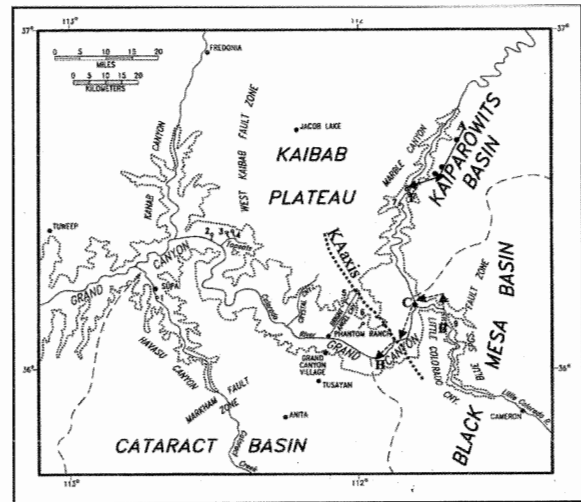
Figure 1. Map showing groundwater divides (dashed lines) between hydrologic basins. Springs: 1 Havasu; 2 Deer; 3 Thunder; 4 Tapeats; 5 Roaring; 6 Cheyava; 7 Vasey's; 8 Fence; 9 Blue. Blue Springs (B) is the discharge point for the Black Mesa basin today. Solid arrows show the probable route water takes today from the three pits (Ah Hol Sah, Indian, Black Abyss) to Fence Springs (AF). Dashed arrows show the proposed karst connection route that ancestral Black Mesa basin water took ~6 Ma: north along the Blue Springs fault, west to the Confluence, and then south and southwest to the Redwall exposed along a fault in the Hance Rapids area (BCH). Note that this route goes under the Kaibab arch (KA axis). Base map from Huntoon (2000).

328

Figure 2. Ah Hol Sah sinkhole, 150 m across and 40 m deep. The sinkhole is actively collapsing into the Redwall karst aquifer, which is probably discharging at Fence Springs. A small wash (foreground) now drains directly into the sinkhole; i.e., drainage to Tanner Wash has been pirated by the Ah Hol Sah sinkhole.
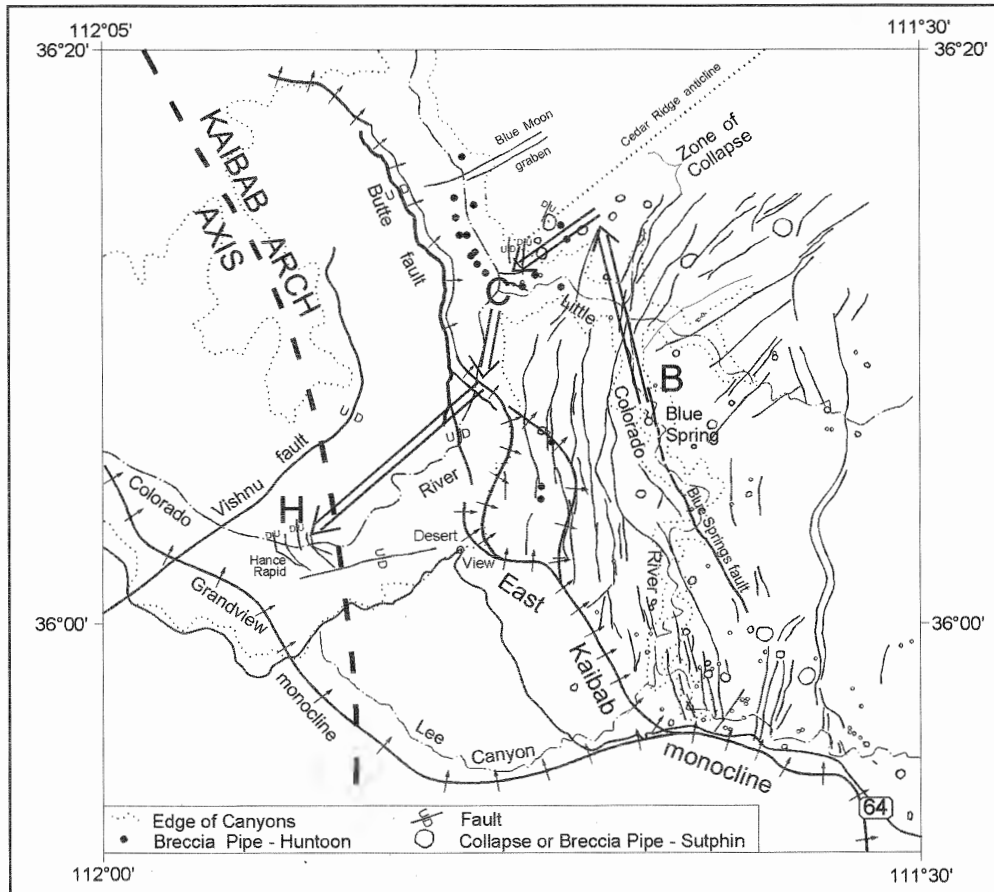
Figure 3. Map showing the proposed karst connection route and structural features controlling that hydrologic route. Water in the ancestral Black Mesa hydrologic basin, combined with water flowing east off the Kaibab arch, moved down collapse features/breccia pipes and down Basin and Range-age extensional fractures of the Blue Springs fault zone to the Redwall artesian aquifer. Then it flowed north along the Blue Springs fault (B) to the southeast flank of the Cedar Ridge anticline, where it was diverted west along the collapse zone of Sutphin (1986) to the Confluence (C). Then water in the Redwall artesian karst aquifer flowed south, beneath the old northward section of the Chuar Basin surface route, until it reached a highly fractured section of the Butte fault. Finally, it flowed southwest, under the Kaibab arch, to discharge the Redwall karst aquifer in the faulted (east side up) Hance Rapids area (H). In this model the ancestral Black Mesa hydrologic basin extended beneath the arch because the synclinal axis of the Grandview monocline offered the lowest structural spill point for basin water ~6 Ma when the connection occurred. Collapse and canyon incision/erosion later followed along this initial karst connection route. Breccia pipes, collapse features, and structure are from Loughlin (1983), Sutphin and Wenrich (1983), Sutphin (1986), and Huntoon et al. (1996).

O-95

Eogenetic karst, glacioeustatic cave-pools and anchihaline environments in Mallorca island. A discussion on coastal speleogenesis

A. Gines, J. Gines

Universitat de les Illes Balears, Palma de Mallorca, Spain

Abstract

Coastal karst is characterized by special geomorphological and hydro-dynamical conditions as well as by peculiar sedimentary, geochemical and biospeleological environments. As a general trend, the more distinctive karstic features produced near the coast-line are strongly influenced by sea level changes, which are able to generate a broad set of interferences between littoral processes and karst development. Because of pleistocenic climatic fluctuations, the consequent glacioeustatic rises and falls of the sea level affected the coastal karst in different ways, namely: vertical and horizontal shifts in the shoreline position, changes in elevation of the local watertable and vertical displacements of the halocline. From the point of view of karstologists, the vast majority of eogenetic karsts have been subjected over long time spans to repeated altimetric changes of very different vertically-zoned geochemical environments: vadose, phreatic meteoric-water, brackish mixing-waters and even marine ones. From the point of view of speleologists, a great number of coastal caves appears today passively drowned, after the holocenic sea level rise, showing large or small glacioeustatic pools where the current watertable intersects formerly air-filled rooms or passages. From the point of view of biospeleologists, the phreatic waters of glacioeustatic pools, whose sea level controlled surfaces fluctuate with tides and which waters frequently are brackish and sometimes even marine, must to be considered anchihaline habitats that are inhabited by troglobites. All these aspects can be studied in detail at the eastern coast of Mallorca island owing to the widespread outcrop of Upper Miocene calcarenites, wherein the development of eogenetic karst features started from the end of the Messinian times. Some of the caves resulting from this kind of speleogenetical processes are outstanding, as are the cases of the celebrated Coves del Drac (explored by E.A. Martel in 1896) and the recently explored Cova de sa Gleda (whose submerged passages are longer than 10 km, after scuba-diving surveying). Furthermore, near all the caves located in this area present glacioeustatic cave-pools that allow to the prospection of a rich anchihaline stygofauna. These glacioeustatic ponds are highly specific coastal-karst features, almost neglected in the speleological literature in spite of the occurrence of some interesting topics related to them, like the presence of phreatic speleothems that are able to record ancient sea levels. Careful observations and detailed mapping, carried out in a significant number of caves developed in the Upper Miocene reefal rocks of Mallorca, permit a better understanding of the coastal speleogenetic processes involved in a typical eogenetic karst over the time span of 107 years. The role played by recurrent glacioeustatic oscillations of the sea level and the subsequent rises and falls of the watertable are emphasized in our model. In this respect, it must to be outlined two remarkable associated mechanisms: the triggering of breakdown processes caused by the loss of buoyant support that follows to each lowering of sea level (during glaciations or smaller cold events) and the later underwater solution of boulders and collapse debris (during interglacials that correspond to high sea levels). Additionally, it can be expected that tidal fluctuations affecting groundwaters enhance solutional enlargement of caves and vug-porosity connected to the sea, rather than conventional karstic flow that probably is not a so important agent in eogenetic karst speleogenesis.

O-96

The Role of Joint Slope on the Shafts Speleogenesis at a Base of Epikarst

I. Baron

Czech Geological Survey, Brno, Czech Republic

Abstract

Speleogenesis of narrow and relatively deep karst shafts (avens) was studied at the Slovak part of the Dolný Vrch Plateau (the Slovak Karst National Park, SE Slovakia). Most of the 211 shafts and to shafts related depressions, located at the plateau, have similar characteristics. The shafts are relatively narrow and deep (up to -260m in Hungarian part of the plateau and -112m in the Slovak part), vertical steps have a section of a rectangular triangle and the entrances are relatively narrow. The entrance width is related to the shaft age: presently dug out shafts have very narrow ones. Most of the shaft entrances and the depressions are located on flat surface outside large dolines (40%), in the doline slopes (30%), doline slopes-foot (20%) and doline edges (10%); no entrance was found just in the doline centre. Dominant tectonic ruptures were measured in some of the shafts. All of the ruptures were subvertical (sloping 70 - 90°). Corrosive and erosive forms have been studied in the young shafts. Small scallop-like forms occur on vertical or pendent walls in deeper part of the shafts. They have probably developed due to corrosive and erosive effect of unsaturated water film. Vein networking evidences selective action of condensation corrosion on the rock walls in upper shaft parts. Large "wall troughs", occurring on vertical walls, are formed with corrosive and erosive action of dripping water on subvertical joint surface. The troughs are tens of cm in diameter, tens of meters long and they compose essential part of the shaft volume. Trough base as well as the shaft bottom, is usually covered with debris-loamy sediment and recent organic detritus. Carbon dioxide occurring in the shaft atmosphere (up to 5%) makes water solution more aggressive. The CO_2 is of the recent organic origin, coming probably from the soil environment. Shaft drainage forms were studied in the Včeláre quarry in E part of the Dolný Vrch plateau. There was found a profile of a shaft base with the wall troughs and drainage channels below, developed on the subvertical rupture. The channels were branched and water flow modelled. Film corrosion widened joints occurred beside the shaft. The shafts have developed in vadose conditions along subvertical tectonic rupture due to several factors. Water film extends the rupture, usually at the base of the epikarstic zone (Klimchouk 1995). Then corrosive and erosive action of dripping water takes place and the wall troughs arise downwards -the shaft develops progressively now. Water film action and condensation corrosion, both are responsible for the shaft development upwards. Increased carbon dioxide concentration makes the solutions more aggressive and enables these processes working on the shaft bottoms. Later, the shaft opens to surface with concurrence of the surface denudation.

O-97

Karst as a settling factor

Viacheslav Andrejchuk

University of Silesia, Bedżińska 60, 41-200 Sosnowiec, Poland

Abstract

Karst is a natural factor, which influence actively on to human settling on karstified territories and on to their economic developing. Karst transforms all components of a landscape and forms a specific environment of human life. A water component of karst landscape is subjected to transformation in the most degree. Just it - presence or absence of water - is a main factor that limits or stimulates the settling processes in karst areas. Presence or absence of water in karst landscapes is determined, first of all, by the depth of ground (karst) water table location that, in one's turn, is depended on the hypsometric character of karst massives (mountains, highlands, flats etc.). Significant importance has also climatic position of karst landscape: depending on zone of nature (coefficient of humidifacation) karst can drain or dry up a landscape and, thus, to improve (in areas with redundant humidification) or to worsen (in areas with deficiency of water) an environmental conditions of human life.

Introduction

Transforming a landscape, karst forms the specific environment of life and activity of the human. Karst areas are long since populated by the human. At the initial stages of their developing the presence of natural shelters - grottoes and caves, was determinative. After transition to productive activity (first of all, to cultivation of plants and animals) the presence of water, an opportunity of soils cultivation and cattle pasture began to get a principal value. Not all karst landscapes met to the marked requirements, therefore their settling occurred differentially. Distinctions in a degree of development of different types of karst landscapes, including, in comparison with non-karstic, are well appreciable even now. On several examples we shall consider peculiarities of karst inhabitancy of the human from the point of view of the natural landscape preconditions described above.

Certainly, determinative importances in development of karst landscape by the human had and have such factors, as presence (an opportunity of access) of water, making possible or impossible his ability to live, and also a degree of humidifying of territory, a secondary from mutual imposing of climatic and karstic factors. Considering the marked factors the karst landscapes may be divided on favourable and unfavourable concerning human life (fig. 1, A, B).

The first factor - the availability to water, depends, mainly, on depth of karst water table. As deeper they are bedded, as less accessible they are for use. Depth of water surface is determined, first of all, by height of a karst massif. On fig. 1-A this regularity is reflected in the generalized kind, and its features are uncovered in the text on the examples designated in figure.

Karst influence on settling processes in mountain and upland regions

High-mountainous karst massives, as a rule, are dehydrated and lifeless. Their surface is rocky, is dotted by karst dolines and depressions, fractures filled with fragments of frosty weathering of rocks. Primitive soils may be formed only in karst depressions where clayey eluvium accumulates. In middle-mountains the karst massives are frequently covered with a forest, however their high karstification and aridity also predetermine the absence of stable settlements. Their use by the human is limited to the summer period - pasture of cattle on mountains (and that in case if on a massif suspended lakes for a pond are available). At the high and

middle mountain karst, as a rule bared or soil-covered, the underground water are situated on depth inaccessible to use and measurable in hundreds and in thousand meters.

As much lifeless (in relation to the human) are mountain-karst massives, as densely their periphery is populated. Foots of massives with powerful karst water effusions and abundance of eluvial material with fertile soils, differ by "concentration of life". Karst massives of Mountain Crimea (Ukraine), Caucasus, as well as many regions of the Mediterranean with a strip of continuous settlements and resort cities at their bottom can serve classical examples in this respect. Thus, being waterless, mountain karst massives frequently irrigate the non-karstic surroundings, predetermining its settling and active economic development.

Low-mountain and upland karst areas and uplands also lack the surface moisture. Despite of, as a rule, bigger than in high mountains thickness of eluvial deposits and vegetation covering, karst waters are situated there on depths of 50-100 and more meters, that also makes their use (by traditional ways) impossible or rather inconvenient. The network of settlements and also a transport network in such regions are rarefied, but their percentage of forestlands is higher. The Ufa Plateau (Pre-Urals, Russia) is an example of such region. It represents the upland (350-400 m a.s.l.), built with the Permian limestone and towering above the neighbouring territories on 50-100 m. Its surface is karstified, but significant thickness of residual eluvial material allows forest vegetation to exist here. Because of a freely filtration of precipitation through cracks and karst channels, the upland is waterless. Underground waters are situated on depths of 70-100 m and river valleys (except for the large transit rivers) are dry. The given circumstance has predetermined weak economic development of the region and preservation of almost continuous forest cover (92 %) within its borders, while in its surroundings the forest coverage is only 47 % (fig. 2-A). It would be visible from the fig. 2-B that the density of settlements as well as roads on the upland is lower, than on the next territories. Both settlements and roads within its borders gravitate to valleys of rivers crossing through the Upland (the factor of water).

At the same time, as well as in the case of mountain landscapes, along borders of the Plateau and on the next territories the increase of quantity of settlements and a closeness of roads network are observed.

As well as in the previous case, the main reasons of this phenomenon are the plentiful karst water effusions (springs with the discharge of 0,1-1,0 m³/s) with water of high quality. The debit of the largest (the Krasny Kluch) peripheral spring (of the vaucluse type) in average annual expression is 12 m³/s, but its maximal debit achieves 58 m³/s. Near the large springs, which are the sources of rivers, large and rich settlements with ponds, water mills etc. arose. It is remarkable, that names of many settlements specify their landscape localisation - near karst springs and lakes - Kluchi (springs), Kluchiki (little springs), Ozera (lakes), Ozerki (little lakes) etc. On the fig. 2-B the names being toponymic reflection of the described phenomenon are given.

The Krakow-Czenstochova Upland (in Poland) built with Jurassic limestone, may serve as the other, not less interesting example of the environment of karst uplands. Inside the Upland bounds the same regularities, as in the previous case (a rarefied river network, considerable forest-covering, smaller density of settlements and roads, a peripheral concentration of settlements etc.) are observed. However, owing to the historical reasons (position inside a populous part of Europe) and the less depth of underground waters occurrence (50-80 m) we find set of examples of rational water use in this region. The basic distinction in character of water use within the borders of the karst upland and out of its bounds is observed.

Fig. 1. Position (depth from a surface) of underground water table (inside the karst massives) (A) and degrees of humidification (B) as a man-related environmental factor.

For the population of Upland water is the wealth, which difficult getting (deep, up to 70 m pits) predetermines its very rational use (down to exception of vegetable gardens watering). Outside of the Upland, or along its periphery with karst springs, water is a basis of transforming activity in a landscape (melioration, irrigation, power production etc.), supposing the other attitude to it (the mental moment).

The described examples show that with decrease of the karst massives heights from mountains to uplands the degree of their adversity for settling and economic development is reduced. Nevertheless, as a whole, the karst environment of regions with deep karst waters occurrence excludes or considerably complicates life of people and is adverse. The regions with "mature" karst present some exception in this respect. Owing to long-time karst denudation large forms (for example, poljes), which bottoms are covered with thick accumulation of waterproof clay

deposits (residual deposits) and their depth reaches the local drainage bases, were formed (for example, Karst Upland in Slovenia, many low-mountain and high karst regions of tropical areas). The age of karst softens dependence of the human on the water factor.

Karst influence on settling processes in plain and lowland regions

The picture varies in case of lowlands or plains. Despite of relative aridity and rarefaction of a surface network, the close (5-50 m) underground waters occurrence (a constant source) and simple ways of their extraction promote settling within their borders. Moreover, the karst

Fig. 2. Forestation degree (A) and transport- settlement infrastructure (B) in the Ufa karst Plateau: A: 1 - non-forested areas, 2 - forested areas, 3 - Ufa Plateau area; B: 1 - villages outside Plateau, 2 - villages within the limits of the Plateau, 3 - settlements, 4 - railways, 5 - roads, 6 - Ufa Plateau area.

drainage, in most cases, is the positive factor for the agricultural activity, creating within the borders of karst landscapes the better edaphic conditions than on surrounding, frequently over-damped or boggy territories. Let's consider the given thesis on the several examples concerning the right part of fig. 1-A, while moving by the Eastern-European region from the north to the south.

Within the Onega River basin on sites of limestone development under plain-lowland conditions (130-230 m a.s.l.) the high karst sites called susha (dry land area among swamped territories) were formed. Landscape of Kargopol' Susha is the most known. The region is situated in taiga zone with over-humidifying and is surrounded with bogs, as well as others sushas. Within borders of Susha, owing to drainage impact of karst, boggy sites are almost absent, fertile demo-carboniferous soils were formed, that promoted agricultural development of the territory. The network of settlements and roads developed here. In 14-20-th centuries the region of sushas was a granary of the Russian North, and its towns became large trade centres (as for example, Kargopol) - with stone houses, churches and with cultural life. The local resident told, that people on Kargopolye are more portly and healthy, "thoroughbred" and in the whole richer, than at the Susha surrounding districts. Within borders of sushas the grassy cover is more plentiful, the swarm of midges is less, the cattle better gain weight and skins of fur animals are of better quality, than in surrounding marshy areas (Топсуев, Левин, 1980).

The other example of agricultural "oasis" in taiga zone is the mentioned earlier Izhora Upland[*] (120-150 m a.s.l.), located to the south from Saint Petersburg. Within the borders of the region built with Ordovician limestone, due to karst drainage and fertile rendzinas the initial southern-taiga (mixed) forests were substantially (up to 30-40 %) cut down and replaced with agricultural landscapes (Чикишев, 1979). Forest covering of the territories next to the upland is 83-95 % (Исаченко, 1991).

Vivid examples of positive karst influence on territory development are Baltic uplands, for example Kostivere Upland in Estonia, located in a zone of the mixed forests. It is built with Silurian limestone and towers a little (on 50-70m) above surrounding territories (fig. 3-A). It differs by smaller relief dissection and rarefied river network (0,1-0,3 km/km² in comparison with an environment - 1,0-1,5 km / km²). Low, in part boggy territories (fig. 3-B) surround the upland (Каск, 1963). As well as in the previous cases, karst drainage and the better conditions have predetermined here lower rate of territory forest-covering (39,8 %), than

---

* In this case, as well as in below following examples, the presence at the name of region of the word "upland" reflects their property to tower a little above low boggy or flat over-humidified territories. Taking into consideration their height above sea level (150-250 m!) they are hypsometrically flat territories

Fig.3. Kostivere karst Upland in Estonia:

A - contour line scheme: 1 - river net, 2 - channels, 3 - lakes, 4 - the border of Upland area, 5 - swamps; B - scheme of river net density: 1 - 0,0 км/км², 2 - 0,10 - 0,30 км/км², 3 - 0,31 - 0,70 км/км², 4 - 0,71-1,0 км/км², 5 - >1,0 км/км², 6 - the border of Upland area; C - degrees of forestation: 1 - forested areas, 2 - non-forested areas, 3 - the border of Upland area; D - scheme of roads and settlements: 1 - towns, 2 - villages, 3 - farms, 4 - railways, 5 - main roads, 6 - local roads, 7 - the border of Upland area.

Fig.4. Irregular distribution of settlements in the lower part of the Sylva River valley (Pre-Urals, Russia): 1 - karst forms, 2 - dry valleys, 3 - small towns, 4 - villages, 5 - non-karstic areas, 6 - gypsum karst area.

in its surroundings (76, 4%) and, accordingly, higher rate of agricultural grounds (fig. 3-C). The higher density of settlements (3,5 per 100 km²) and communication networks (0,62 km/km²) reflects the increased economic activity of the population within the borders of the Upland (fig. 3-D). On territories surrounding the upland these parameters are, accordingly, 2,0 per 100 km² and 0,02-0,05 km/km². This region of Estonia is among the optimum ones from the agricultural point of view (the first of eight categories of a regional scale) and is used for cultivation of a winter wheat and neigh, while on next territories the potato and fodder plants are cultivated. The similar situation takes place within Zemgal'skaja Plain in Latvia, built with strongly carbonated and permeable moraine with fertile rendzina on it. Agricultural grounds occupy 80 % of territory of the Plain. Because of high crop capacity the region is called "Ukraine" of Latvia (Жучкова, Смирнова, 1963).

Plenty of examples of karst improvement of the grounds can be found in east part of the Eastern European region where alongside with carbonate rocks, gypsum have a wide distribution. One of such areas covers the downstream of the Sylva River (to a southeast from Perm City). Under conditions of rather shallow (up to 50 m) dissection of area, close (2-20 m) underground water occurrence and normal (K≈1) or some increased humidifying (the southern part of forest zone), karst provides a good drainage and promotes formation of forest-steppe landscapes with fertile grey forest soils and chernozem-like soils here. The ground resource, in turn, promoted settling of this area. Now the density of settlements here is 8,9 per 100 km², while on the next non-karstic territories only 2,6 (fig. 4).

Above mentioned examples are taken from zones with the excess humidifying. In all examples the karst positively influences the natural environment in aspect of opportunities of its use by the human. In N.P.Torsuev's opinion (1980), the maximum positive effect of karst impact on environment in taiga zone is observed.
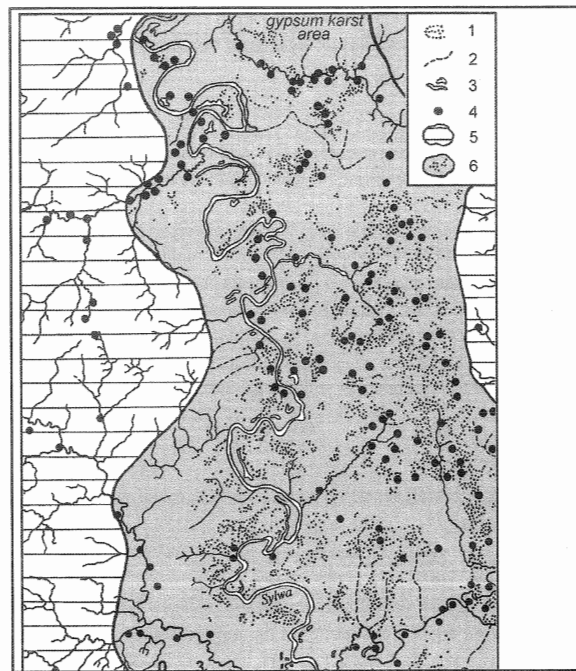
To the south from the forest-steppe zone, in geographical zones with lack of moisture (steppe, semi-desert and desert, dry savannah), the karst drainage of area is transformed from the positive factor into negative one (fig. 1-B). It causes dehydration of a territory, strengthening its aridity. For example, it almost excludes growth of forest vegetation in a steppe zone, even in valleys and depressions, where rain or subsoil waters may collect.

333

References

1. Жучкова В.К., Смирнова Е.Д., 1963. Физическая география СССР.МГУ. Москва. 68с. (Zhuchkova V.K., Smirnova E.D., 1963. Physical geography of the USSR. MGU. Moscow. 68 p.) (In Russian)

2. Исаченко А.Г., 1991. Ландшафтоведение и физико-географическое районирование. Высшая школа. Москва. 366с. (Isachenko A.G., 1991. Landscape science and physical-geographical regionalisation. Vysshaja shkola. Moscow. 366 p.) (In Russian)

3. Каск А.Г., 1963. Исследование минимального стока рек северной Эстонии в связи с карстовым питанием. В: Сб. Работ по гидрологии, №3. Гидрометеоиздат. Ленинград. (Kask A.G., 1963. Research of the minimal flow of rivers of Northern Estonia in connection with karst recharge. In: Sbornik rabot po gidrologii, #3. Gidrometeoizdat. Leningrad.) (In Russian)

4. Торсуев Н.П., Левин С.А., 1980. Географические аспекты изучения равнинного карста. Казанский университет. Казань. 207с. (Torsuev N.P., Levin S.A., 1980. Geographical aspects of karst research of plains. The Kazan University. Kazan. 207 p.) (In Russian)

5. Чикишев А.Г., 1979. Проблемы изучения карста Русской равнины. Москва. 302с. (Chikishev A.G., 1979. Problems of karst studying of Russian plain. Moscow. 302 p) (In Russian)

O-98

Analysis of the Karst Dynamic System of Vertical Zoned Climate Region in Jinfo Mountain State Nature Reserve, Chongqing, China

C. Zhang, Z. Jiang, S. He

Abstract

High resolution measurements of stage, pH, conductivity, temperature, and hydrochemistry parameters of groundwater at two locations within the vertical zoned climate region of the Jinfo Mountain Nature Reserve, Chongqing, China, were made using data loggers recording with 15 minutes resolution. While Bitan spring 700m a.s.l. represents subtropic climate, Shuifang spring 2000m a.s.l. represents plateau temperate climate. The results showed that hydrochemistry parameters of epikarst springs at different altitudes are very sensitive to environmental change and mainly controlled by two factors: air temperature and soil CO2 concentration. Lower altitude means higher air temperature and CO2 concentration, thus more active karst processes. Water temperature, pH of Bitan spring has a remarkable diurnal variation with high value in the day and low value at night. During flood pulse, at least there are two effects impacted on hydrochemistry of groundwater: one is dilution effect, the other is CO2 effect, the pH of Bitan spring drops while the conductivity falls. Inversely, and at the same time, the pH of Shuifang spring rises, while conductivity falls. It may indicate that Bitan spring represents conduit-fissure flow and Shuifang spring fissure media. Key Words: Karst dynamic system; Hydrochemical variation; Vertical zoned climate; Jinfo mountain of Chongqing; China

O-99

Study on the rainfall sensitivity and hydrochemical variations in epikarst system and its comparison with phreatic syste

Y. Liu, D. Yuan

Abstract

Epikarst dynamic system is characterized by instability and heterogeneity, and its regulation capacity is limited. Automatic measurement of rainfall, water table, temperature, pH, conductivity of ground water of two adjacent springs within the peak cluster karst of the Guilin Karst Experimental Site in Guangxi Province, China, were made using data loggers recording with 15 minutes resolution. The epikarst spring responded to small rainfall, 9.5mm/d, 6 hours earlier than the phreatic spring which almost had no change in hydrochemical parameters except its discharge. In addition, at the beginning of discharge response, hydrodynamic effect, CO2 effect and dilution effect were increasing synchronizely, until 4 hours later dilution effect began to dominate. As to medium rainfall, e.g., 35mm/d, the duration of the integration of hydrodynamic and CO2 effect as well as dilution effect, was much shorter as for the epikarst spring, whereas, phreatic system still had no obvious change in hydrochemistry. Under the condition of rainstorm, 92.5mm/d, the spring of the epikarst system responded only 1 hour earlier and dilution effect dominated from the beginning of response, whereas for the phreatic spring there was still 3 hours duration of integration of hydrodynamic, dilution and CO2 effects before replaced by merely dilution effect. In conclusion, shallow karst dynamic system is sensitive to the environment and it acts differently both physically and chemically in different parts. Therefore, the further study of regulation capacity of karst dynamic system and its response to rainfall have great significance for the study of karst development including the forming of cave in south of China with complicated climate which enjoys frequent rainstorm and various types of rainfall.

O-100

A reconnaissance on the use of the speleothems in Korean limestone caves to retrospective study on the regional climate change for the recent and geologic past

Woo, K. S.[1], Jo, K. N.[1], Hong, G. H.[2], and Suk, B. C.[2]

[1]Cave Research Institute of Korea, Kangwon National University, Chuncheon, Kangwondo 200-701, Korea

[2]Korea Ocean Research and Development Institute, Ansan P.O.Box 29, Gyeonggido 425-600, Korea

[3]Department of Geology, Wayne State University, Detroit MI 48202, USA

Abstract

Limestone caves are extensively developed in Kangwondo and Chungcheongbukdo (Korea) and more than 1000 caves are estimated to be present. A variety of numerous speleothems are actively growing in these caves today. A potential to use speleothems as regional paleoclimate proxy was explored by analyzing soda straw, stalactite and stalagmite. These proxy recorders that have grown during the past a few decades were investigated using the presence of excess [210]Pb. Most specimens collected from six limestone caves were found to have an excess ^{210}Pb, indicating that they are less than ~100 yrs old. This excess ^{210}Pb was employed to obtain the growth rate for a tubular "soda straw" that yielded a longitudinal growth rate of 0.17 cm yr^{-1}. Coeval δ^{13}C values of the soda straw, spanning the time period of about 1930~1995 AD, may reflect the carbon isotope ratio of atmospheric CO_2 for the same period. Studies on fine scale variations in the isotopic composition of recent speleothems along with age control using ^{210}Pb excess method from the Korean caves promise a great potential for the reconstruction of climate and environmental changes during the past hundred years or so.

Introduction

Soda straws are one kind of dripstones pointing vertically downwards from the cave ceiling. They are usually straight, thin and fragile, and always have a diameter of approximately 5 mm. They are always hollow, and composed of calcite crystals. When water responsible for the growth of calcite stays at the tip, slow degassing of dissolved CO_2 takes place, thus lowering the carbonate solubility eventually leading to the crystalline calcite deposition (Woo et al., 1999). As the internal hole may be blocked by the growth of calcite within the hole or by the blockage by detritus or as the supply rate of water from the ceiling increases, the calcite crystals begin to grow on the side of soda straw and become a typical stalactite (called icicle-shaped stalactite) that grows downwards. Speleothems have

been widely used as a proxy to retrieve continental paleoenvironmental information (e.g., Zhao et al., 2003) along with varved lake sediments (Ojala and Saarinen, 2002), tree-rings (Eronen et al., 2002), peat land (Charman et al., 2001) and ice cores (Saveringhaus and Brook, 1999). These continental records have provided more detailed regional paleoclimatic information than marine records from stable isotope data of pelagic sediments or shallow marine corals (Suzuki et al., 2001) which have been used as proxies for global paleoceanographic information. The unique advantage of speleothems is that it is ubiquitous and provides proxy information on the local climate and environmental changes. The objective of this paper is to evaluate the potential of obtaining regional paleoclimatic information by establishing the chronology using excess ^{210}Pb data and stable carbon and oxygen isotope values of the speleothems in Korean limestone caves.

Material and Methods

The speleothem samples were collected from Baegryong and Sanjidang Caves (Pyeongchanggun), Daeya and Yongdam Caves (Yeongwolgun) and Biryong Cave (Jeongseongun) in Kangwondo, and Ansanan Cave (Danyanggun) in Chungcheongbukdo. All of the caves listed above maintained relatively constant temperature (14~16 °C) and humidity (>80%) throughout the year. The soda straw was obtained from Daeya Cave, and the icicle type stalactite samples were collected from Sanjidang and Yongdam Caves. The stalagmite samples were obtained from Baegryong and Daeya Caves, and one bacon sheet from Yongdam Cave. To determine excess ^{210}Pb and stable carbon isotope data, carbonate powders were microdrilled at every 5 cm from the tip with 1.8 cm interval for the soda straw. Other stalactites and stalagmites, and a bacon sheet sample were taken from the surface of the tip normally 1 mm down from the surface.

For ^{210}Pb and ^{226}Ra measurements of the stalactites, stalagmites and bacon sheet, a known amount of the powdered sample was placed in the counting vial and sealed. The sealed samples were left for over 1 month for the daughter products of ^{226}Ra to reach secular equilibrium. For ^{210}Pb and ^{226}Ra, 46.5- keV and 351.9 keV (^{214}Pb) gamma-ray lines were utilized to assay the concentrations of ^{226}Ra and ^{210}Pb. Each sample was counted on HPGe detector for a known amount of time. The counting efficiency curves were obtained using Isotope Products Laboratories multinuclide solution and IAEA gamma-ray reference materials (RGU-1, RGTh-1 and RGK-1) and dpm/cpm ratios for each radionuclide were calculated using IAEA 306 marine coastal sediment (Baltic Sea) reference material. Since the density of samples and reference is very similar, the self-absorption correction was not made (Hasan et al., 2002).

The soda straw specimens from Daeya Cave (DY-1, DY-2, DY-3 and DY-4) were collected in 1996 was handled at Texas A&M University, Galveston. It was cut into segments and weighed. A known amount of ^{209}Po spike was added to the powdered carbonate as a yield monitor and the sample was subsequently dissolved in 6 M HCl. The solution was centrifuged and supernatant used for Po plating onto silver planchets (Baskaran and Illife, 1993). In most samples, no residue remained after acid treatment, indicating that the soda straw is composed of pure carbonates. The planchets were assayed for their activity using a solid state surface barrier detector coupled to S 100 Canberra multichannel analyzer. The parent-supported ^{210}Pb concentrations were determined by gamma counting the sample powder on a high purity Ge-well detector. Parent-supported ^{210}Pb (^{226}Ra) concentration was found to be <0.5 dpm/g and hence parent-supported ^{210}Pb was not subtracted from the measured ^{210}Pb concentrations for soda straw. All errors reported here are 1-sigma propagated error arising from calibration of the detector, background correction and counting statistics. Stable isotopic and elemental analyses were carried out in the Korea Basic Science Institute, using the VG Isotech Prism mass spectrometer. Analytical errors for stable isotope analyses are ±0.1 ‰. All the stable isotope data reported here are relative to the PDB standard.

Results and Discussion

In all the samples, there is excess ^{210}Pb clearly indicating these samples show signs of recent growth, in less than 100 yr time scale. Excess ^{210}Pb concentrations were measured in sequential layers to determine. the age and longitudinal growth rate of the soda straw collected in 1996 from the Daeya Cave. Excess ^{210}Pb concentration is plotted against the median longitudinal distance from the bottom tip in each of the four segments of a soda straw.

Since the soda straw specimen from the Daeya Cave provide a time series ^{210}Pb activity, the corresponding carbon and oxygen isotope compositions were also analyzed for carbon and oxygen isotopes. Plotting the $\delta^{13}C$ and $\delta^{18}O$ values as a function of time, the $\delta^{13}C$ values increased from 1920 (?) to 1937 a little bit (-8.08 to -7.80 ‰), and then decreased to a value of about -10.35 ‰ around 1990s. This overall decreasing trend parallels the $\delta^{13}C$ in a global atmospheric CO_2 deduced from a variety of studies such as the measurement of air trapped in polar ice and direct atmospheric measurements (summarized in Baskaran and Krishnamurthy, 1993). The $\delta^{13}C$ values are depleted relative to the global average as much as ca 2 ‰. This depletion could result from different type of vegetation (C3 plants in Korea), which could lower the $\delta^{13}C$ of soil CO_2. However the temporary enrichment of $\delta^{13}C$ values (~0.3 ‰) during 1937 probably resulted from local deforestation during Japanese colonial period. Forestation since 1960s have increased the organic content in overlying soil and the $\delta^{13}C$ decrease in the soda straw caught up the global decreasing trend. It is interesting to compare that the overall $\delta^{13}C$ decrease between 1920 and 1995 in this study is ~0.030 ‰/yr, which almost coincides with the rate published by Baskaran and Krishnamurthy (1993).

$\delta^{18}O$ values also continue to decrease from -6.65 ‰ (1937) to -6.91 ‰ (1995). As mentioned earlier, $\delta^{18}O$ compositions of calcite could depend upon oxygen composition of cave water from which calcite precipitated or the temperature-dependent fractionation factor of oxygen isotope. The Daeya Cave has been developed at the foot of the mountain and is now located at 190 m in elevation. It can be well accepted that the location of the cave has not changed past a few tens of years, thus it is likely that the oxygen isotopic composition of meteoric water has been the same past ca 60 years. The amount of decrease in the oxygen isotopic composition is about 0.26 ‰, which is equivalent to ca 1 °C temperature increase (Friedman and O'Neil, 1977). It is interesting to note that atmospheric temperature has been increased by 1 °C from 1937 to 1995. Despite the small difference of the oxygen isotopic values during this period, it may be possible to ascribe this difference to the temperature increase in atmosphere. It is not well known whether the temperature change in cave atmosphere could be affected by temperature change in the atmosphere. I thought the cave temperature (in well buffered caves, with limited exchange of air with the surrounding) represents the mean annual surface temperature at that site. However, the coincidence of the amount of temperature decrease and depletion of oxygen isotope value may offer a possible explanation.

This study is primarily a feasibility study. If rapidly growing speleothems can be selected, it will enable to obtain high-resolution radiometric ages for our future study. In the present, of the specimens analyzed, BY-2, BY-3, Br-75 and SJD-1 appear to be most promising.

Conclusions

Several speleothems growing in some limestone caves in Korea were analyzed for excess ^{210}Pb and stable isotopes of carbon and oxygen to evaluate the potential of speleothems as a regional paleoclimatic proxy. Most specimens collected from four limestone caves were found to have an excess ^{210}Pb, indicating that signs of recent growth (less than 100 yrs) and thus can be used as proxy recorders to retrieve paleotemperature and environmental changes. One soda straw specimen shows the decrease from 1930s to 1990s in $\delta^{13}C$, and this may imply the percentage of plant cover above the cave and/or the increase in concentration of atmospheric

335

CO$_2$ released by the consumption of fossil fuel. Further research using this technique will aid in understanding the paleoclimatic variation in the past hundred years.

Acknowledgments

References

Baskaran, M., Hong, G.H., Kim, S.H., Chung, C.S. and Wardle, W., 2004, Dating bivalves using ^{210}Pb-^{226}Ra disequilibrium method and temporal variations of ^{90}Sr and elemental abundances of Sr, Mg, and Ba in the bivalve shells from southern and eastern coasts of USA. Geochimica et Cosmochimica Acta (submitted).

Baskaran, M., Iliffe, T.M., 1993, Age determination of recent cave deposit using excess ^{210}Pb-A new technique. Geophysical Research Letter, 20, 603-606.

Baskaran, M., Krishnamurthy, R.V., 1993, Speleothems as proxy for the carbon isotope composition of atmospheric CO2. Geophysical Research Letters, 20, 2905-2908.

Charman, D.J., Caseldine, C., Baker, A., Gearey, B.R. and Hatton, J., 2001, Paleohydrological records from peat profiles and speleothems in Sutherland, northwest Scotland. Quaternary Research, 55, 223-234.

Eronen, M., Zetterberg, P., Briffa, K., Lindholm, M., Merilanine, J. and Timonen, M., 2002, The supra-long Scots pine tree-ring record for northern Finnish Lapland-Part 1: chronology construction and initial references. The Holocene, 12, 673-680.

Friedman, I. and O'Neil, J. R., 1977, Compilation of stable isotope fractionation factors of geochemical interest. In: M. Fleischer, ed., Data of Geochemistry, U. S. Geological Survey Professional Paper 440 p.

Hasan, M., Bodizs, D., Czifrus, S., 2002, A simplified technique to determine the self-absorption for sediment samples. Applied Radiation and Isotopes, 57, 915-918.

Marino, B.D. and McElroy, M.B., 1991, Isotopic composition of atmospheric CO$_2$ inferred from carbon in C4 plant cellulose. Nature, 349, 127-131.

Moor, G.W. and Krishnaswami, S., 1972, Coral growth rates using ^{226}Ra and ^{210}Pb. Earth and Planetary Science Letters, 15, 187-190.

Severinghaus, J.P. and Brook, E.J., 1999, Abrupt climate change at the end of the last glacial period inferred from trapped air in polar ice. Science, 286, 930-934.

Suzuki, A., Gagan, M.K., De Deckker, P., Omura, A., Yukino, I., Kawahata, H., 2001, Last glacial coral record of enhanced insolation seasonality and seawater ^{18}O enrichment in the Ryukyu Islands. northwest Pacific.

Ojala, AEK., Saarinen, T., 2002, Paleosecular variation of Earth's magnetic field during the last 10,000 yrs based on the annually laminated sediment of the Lake Nautajarvi, central Finland. The Holocene, 12, 391-400.

Woo, K.S., 1999, Scientific investigation of Okgye, Dongdae and Namdae Caves in Kangneung City. p. 269.

Zhao, J.X., Wang, Y.J., Collerson, K.D., Gagan, M.K., 2003, Speleothem U-series dating of semi-synchronous climate oscillations during the last deglaciation. Earth and Planetary Science Letters, 216, 155-161.

O-101
Lessons learned from the investigation of an active, sulfidic cave
L. D. Hose
National Cave and Karst Research Institute, 1400 University Drive, Carlsbad, NM 88220 USA

Abstract

The exploration of Cueva de Villa Luz (aka, Cueva de las Sardinas), an active, hypogenic, sulfidic cave in Tabasco, Mexico, presented unique challenges. Unusual atmospheric hazards in the cave include dangerous levels of oxygen (<9.5%), carbon dioxide (>3.2%), hydrogen sulfide (>210 ppm), and the apparent presence of carbon monoxide, an aldehyde, and an unidentified gas (recognized by occasional drops in identified gas levels). The gases are released by hypogenic springs entering the cave. Gas levels vary both spatially and temporally. In general, passages distant from springs (perhaps >20 m), larger passages (cross-sections of >15 m2), and areas near the many skylight entrances consistently remain at safe levels. Some isolated and smaller passages, along with areas adjacent to sulfidic springs, consistently contain hazard gases. In addition, the hazardous gases levels occasionally vary rapidly, filling small chambers with potentially fatal gas concentrations within minutes. These atmospheric conditions have prompted the regular use of personal, electronic gas monitors that travel with the team and constantly report the level of combustible gas (which has not been detected in the cave air), oxygen, hydrogen sulfide, sulfur dioxide, and carbon monoxide. Unfortunately, the conditions cause frequent and costly refurbishing and calibration of the expensive monitors. Investigators also generally wear gas masks that filter out hydrogen sulfide, sulfuric acid, and organic vapors. Each person carries at least one extra set of filters in a water-proof container and changes the filters if they become wet or clogged. Filters are changed at intervals determined by the hydrogen sulfide levels. Passages subject to greater risks prompt the additional use of a carbon dioxide monitor by the team and each individual carries emergency compressed air (SpareAir tanks). Exploration of one remote passage required the use of self-contained breathing apparatus. Additional hazards include acidic ceiling drips, wall surfaces, and floor deposits (including bat guano piles) with pH values of 1 and lower. As long as the investigator exercises some precautions, no special clothing is required in the 28oC environment. Cave streams have a nearly neutral pH (~7.2-7.4) thanks to their contact with limestone and its buffering characteristics. The cave atmosphere has a pH of ~4 and presents no danger to explorers' skin. If the skin (or clothing) comes in contact with almost any of the wall and floor coatings for an extended time, mild-to-serious chemical burns can form. Thus, investigators have learned to wash acidic materials off skin and clothes with the nearly neutral stream water. Drops of water that land on an eye or eyelid cause serious discomfort and, potentially, damage. The eyes should be thoroughly washed with drinking water. Researchers who spend time looking up at these features commonly wear face shields or safety glasses. One short, mud-lined crawlway caused a dermal rash on all flesh exposed to the mud and has necessitated the use of complete chemical protection coverage. The histamine-inducing substance has not been identified.

O-102

Chemistry of cave water in cave from the urban area: A case of Smocza Jama cave, city of Kraków, Poland

J. Motyka, M. Gradziński, K. Różkowski, A. Górny

Faculty of Mining, AGH, University of Science and Technology, Kraków, Poland

Abstract

There has been a growing interest in chemical composition of cave waters in the recent years since the accessible caves give a unique opportunity to study chemical compositions and quality parameters of underground water. Smocza Jama cave (276 m long) is located in the southern part of the Kraków-Wieluń Upland within the city of Kraków. It was developed in the Upper Jurassic microbial-spongy limestone. The limestone builds up a small tectonic horst which is sourrounded by Miocene clay sediment filling the neighbouring grabens. The royal castle Wawel was located on the horst. The historic city centre of Kraków is situated in the close proximity. There occur some pools in the cave. The surface of the pools is located at the altitude about 199 m a.s.l., that is at the similar level as the Vistula (Wisła) river, which flows in the proximity of about 50 m. Water level in the cave mirrors the changes of water level in the Vistula river. Nineteen water samples (mostly from cave pools) were collected between March 1995 and January 1998. All the studied water samples were of weakly alkaline type. Their pH index ranged between 7.27 and 8.67. The TDS of pool waters was lower than that of drip waters. In the former case it ranged from 779.3 mg/L to 1013 mg/L while in the latter one from 1752 mg/L to 2841.7 mg/L. Pool water samples represent multiion type (Ca - Na - HCO3 - SO4 - Cl type) while the pool water is of SO4 - Ca - Na type. Chlorium concentrations in the pool water sample reaches 103.8 mg/L while in drip water samples are lower. The concentrations of NO3 in the studied samples fall into a range between 44.4 and 280.4 mg/L. Also the concentrations of K and Na are high. The studied samples of both the pool and drip water are unusual and differ considerably from the composition typical of cave water. They differ also in its chemical composition from the groundwater of the Kraków-Wieluń Upland. High concentrations of NO3, SO4, Cl, Na, K, and P suggest that the water in Smocza Jama is considerably affected by pollution. The chemical composition of the studied pool water can be the effect of mixing of, at least, two components. The water can: (i) filtrate from the Vistula river, (ii) percolate down from the surface of Wawel Hill, (iii) migrate from the nearby area, where the city centre is located, and (iv) ascend as artesian water from deeper confined aquifer. The former three of the four mentioned water sources may be strongly degraded due to long lasting human occupation of both Wawel Hill and the city centre, as well as pollution of the Vistula river. The high amount of SO4 ions reaching 1439 mg/L in drip water results probably from leaching of litter and rubble poured over the cave in the 19th century.

O-103

A subterranean world

Eva Kamilaki

Speleological Association of Crete

"A subterranean world" is the title of the educational programme which was implemented by the Speleological Association of Crete in the school year 2004.

The program was a pilot and its aims were to introduce and familiarize children with the world of caves through an educational process aiming at active and integrated knowledge.

The central idea of the program was the DISCOVERY and not a sterile communication of facts. Moreover, the aspiration of the organizers was to invert the concepts of fear and mystery which are prevalent about caves and reveal to children the grandeur hidden inside these unique ecosystems.

The educational program "A subterranean world" is addressed to children from the age of 9 up to 12 years old.

The activities included in the program are the following :

1) Understanding the creation and the ecological significance of the caves, through active learning

2) TIME CHART OF THE USES OF THE CAVES

So that children can discover ways for which caves have been used from ancient times to nowadays.

3) WHAT A SPELEOLOGIST DOES AND DOES NOT NEED INSIDE THE CAVES

3) LIFE INSIDE THE CAVES

- so that children can get acquainted with animals which live inside the caves and compare them with other animals living outside caves

4) THE STEPS A SPELEOLOGIST MUST TAKE DURING A MISSION

Educational Brochure - Is used during the visit at the cave

337
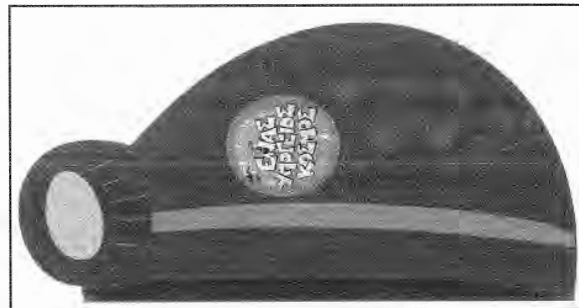
Board Game entitled "A subterranean world".
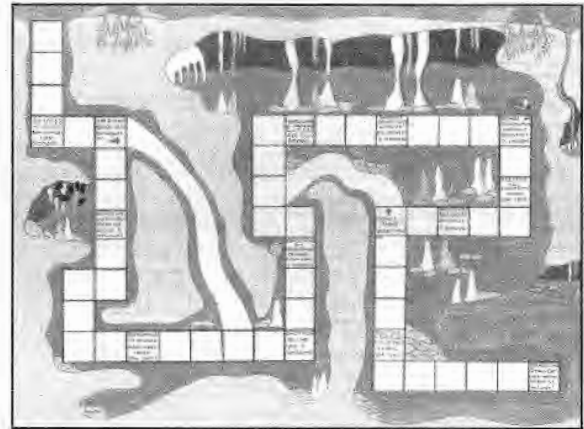
5) EDUCATIONAL BROCHURE

Is used during the visit at the cave

- So that the children come to contact with the cave in an empirical way, organising their own mission, exploring, taking photos, mapping out and measuring the temperature inside the cave.

6) Moving inside a cave safely and with the proper respect for such and environment.

7) BOARD GAME entitled "A subterrenean world".

Among the aims of the programme was the creation of two CAVE CASES (a complete information material and practical instructions) which will give the opportunity for its further implementation by other groups of children through a lending procedure from the teachers.

The educational programme "A subterranean world" was financed by the EC programme "YOUTH" (Action 3: Young Initiatives) of the General Secretariat of the Young Generation.

O-104

Karst field studies, offered by Western Kentucky University's Center for cave and karst studies, and the Mammoth cave National Park International Center for Science and Learning

Leigh Ann Croft*
Nicholas C. Crawford
Center for Cave and Karst Studies
Applied Research and Technology Program of Distinction
Department of Geography and Geology
Western Kentucky University
Bowling Green, Kentucky, USA

Rickard Toomey*
Mark DePoy
Mammoth Cave International Center for Science and Learning
Mammoth Cave National Park
Mammoth Cave, Kentucky, USA

Abstract

The first cave and karst center in the USA, the Center for Cave and Karst Studies (CCKS), was established at Western Kentucky University in 1978 by Nick Crawford. The objectives of the center are to perform basic and applied research on karst environmental problems and to provide educational programs about caves and karst. The CCKS is a part of the Department of Geography and Geology and one of the centers within the Applied Research and Technology Program of Distinction. The CCKS has attracted numerous undergraduate and graduate students over the past 27 years.

In 1979, the CCKS and Mammoth Cave National Park (MCNP) agreed to jointly sponsor the Karst Field Studies Program to offer courses/workshops on caves and karst. The philosophy was to establish a program based upon quality instead of quantity. It was necessary to restrict the enrollment in each course to a maximum of 20 participants for safety reasons and to ensure minimum impact to the cave environment. The combination of outstanding karst scientists as instructors and the use of the world's longest cave as a laboratory has attracted participants for the past twenty-five years from throughout the USA as well as from Great Britain, Slovenia, China, Brazil, Australia and other countries. This cooperative program between the CCKS and MCNP has played an important role in educating students, environmental consultants, government employees and others

about caves and karst. Many of the program's participants have gone on to educate others about karst and the environmental sensitivity of caves, karst groundwater and karst landscapes.

Center for cave and karst studies

The CCKS personnel consists of director and affiliated faculty, chemist/la boratory manager, research hydrologist, education coordinator, office coordinator and 16 graduate and undergraduate assistants.

The objectives of the CCKS are as follows:

1. To be a research center dealing with all aspects of cave and karst studies, with an emphasis on solving environmental problems associated with karst;

2. To provide educational programs concerning cave and karst studies: a) undergraduate and graduate instruction, b) cooperative education program with Mammoth Cave National Park International Center for Science and Learning, c) workshops, seminars, and scientific meetings;

3. To provide public service by assisting individuals, private firms,

and government agencies with karst environmental problems.

Over the past twenty-seven years, the CCKS has attracted outstanding undergraduate and graduate students from various parts of the United States. Graduate and undergraduate research assistants are actively involved in the research efforts of the CCKS. Both graduate and undergraduate students usually graduate with a substantial number of publications and presentations to their credit. Students get "hands-on" experience in dealing with karst environmental problems through CCKS research for government agencies, as well as for private business. Graduates have been very successful in obtaining positions with both government and private consulting firms.

The CCKS is one of the centers in the Applied Research and Technology Program of Distinction (ARTP) at WKU. The ARTP is a multidisciplinary program consisting of 12 scientific and service-oriented centers designed to prepare students for the knowledge-based economy. These centers meet the needs of the community, state, and nation while providing unique opportunities for undergraduate and graduate students to transition from academia to the workplace through participation in supervised, hands-on applied research and technological projects. Each center operates within a cooperative and interdisciplinary framework to apply state-of-the-art science toward solutions to the technological problems of government, industry, and the environment.

The CCKS offices and labs are located within the Department of Geography and Geology in the Environmental Sciences and Technology Building at Western Kentucky University. The Department of Geography and Geology is comprised of 22 full-time faculty members and serves about 275 undergraduate majors, 80 minors, and 30 graduate students in a variety of specializations. The Department offers a B.S in Geography, a B.S. in Geology and a M.S. in Geoscience. In addition to the CCKS, several other educational, research, and public service facilities are housed within the Department that provide exciting opportunities for a combination of theoretical and practical work. The Kentucky Climate Center, also one of the ARTP's centers, is staffed by the State Climatologist and maintains an extensive set of Kentucky climatic data. It has several graduate and undergraduate research assistants involved in meteorological and climatological research. The College Heights Weather Station maintains a fully equipped weather station with remote radar capability. The Hoffman Environmental Research Institute, part of the Center for Water Resource Studies, one of the ARTP centers, is a consortium of scientists and students dedicated to research and higher education at the cutting edge of environmental science. Its primary mission is to be a leader in the development of innovative, basic, and applied research programs aimed at understanding the dynamics of human-landscape-atmosphere interactions. The Department of Geography and Geology offers a GIS certificate through its new Geographic Information Science (GIS) Laboratory. A major goal of the Department's activities is to involve undergraduate and graduate students actively in all aspects of research as an integrated part of their academic programs with the purpose of nurturing their intellectual growth, critical-thinking skills, and technical experience.

Mammoth Cave International Center for Science and Learning

The Mammoth Cave International Center for Science and Learning (MCICSL) is a new collaboration between Western Kentucky University (WKU) and the National Park Service (NPS). Its mission is to improve understanding, management, and interpretation of karst resources in the Mammoth Cave, Kentucky area, nationally, and internationally. Primary goals include 1) developing partnerships to improve karst science, education, and conservation; 2) assembling research catalogs so that karst managers and researchers can readily work together; 3) developing new and enhanced opportunities for undergraduate, graduate, and professional research; 4) increasing international collaboration by providing opportunities for exchange of professional scientists and students; 5) bringing new developments in karst science and management to the public through education outreach; and 6) extending the reach and impact of the CCKS Karst Field Studies Program.

The Center, which was formally inaugurated in August 2004, is jointly funded by WKU and the NPS. It is housed at WKU's Bowling Green, Kentucky campus and at Mammoth Cave National Park. Eventually much of its operation will be based at a renovated classroom, laboratory, dormitory, and research residence complex in the Mammoth Cave National Park. In addition to its cooperative program with WKU, it is also one of the United States National Park System's network of Research Learning Centers. These Research Learning Centers are a program to facilitate research efforts and provide educational opportunities centered on National Parks.

The recently formed MCICSL's programs are still in the development phase. Dr. Rickard Toomey recently took the position of Director of the Center. He is currently working on one of the top priorities which is to actively develop partnerships with various organizations to assist with karst research, management and education.
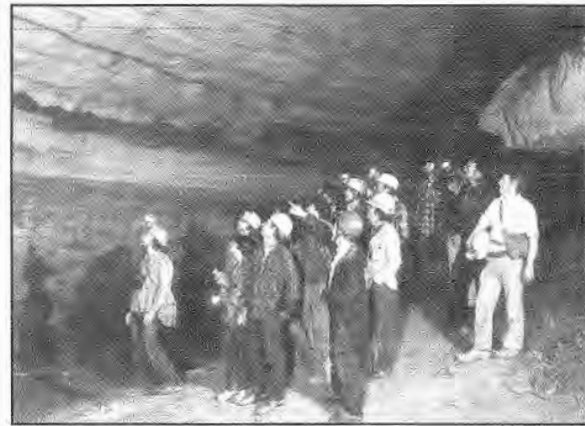
Figure 1: Participants in Dr. Paul Williams' 1981 Karst Geomorphology course.

Karst field studies program
General information

The Karst Field Studies program consists of a series of one-week summer courses focusing on caves, karst and caving. Course professors have been chosen who are internationally-recognized authorities in their fields. While some courses require previous subject knowledge, other courses are designed for those with merely an interest in caves. Several courses have been offered over the years that focus on cave development and genesis such as Karst Geology, Karst Geomorphology (Figure 1) and Speleology. Others courses have dealt with the history of Mammoth Cave, such as, Exploration of Mammoth Cave and Cave Archaeology. Courses dealing with cave life include Cave Biology, Cave Ecology (Figure 2) and Cave Geomicrobiology. Other courses include Cave and Karst Stewardship and Cave Surveying and Cartography, which focus on ways to preserve cave systems through research, resource management, mapping and resource database documentation. Three courses focus on karst hydrology. Two of these courses, Hydrology of the Edwards Aquifer and Management of Karst Aquifers are taught in San Antonio, Texas, USA. Karst Hydrology is taught in Bowling Green, Kentucky, USA and concentrates on environmental problems associated with karst, research techniques in karst hydrology, and methods for remediation of karst environmental problems.

Figure 2: Participants in Dr. Horton Hobbs' 2004 Cave Ecology course.

Format of the courses

Professors typically lecture in the mornings with cave and surface trips and/or field or laboratory exercises scheduled for the afternoons. Special talks, slide shows, and trips into the cave are often scheduled after dinner. Activities may include: 1) all-day trips into Mammoth Cave, 2) surface trips into the Park and surrounding area, 3) various field exercises including geophysical techniques for investigating karst subsurface features,

Figure 3: Participant of the 2004 Karst Hydrology Course injecting Fluorescein dye.

and 4) dye tracer tests to determine groundwater flow, and 5) laboratory analysis.

Professors and Curriculum.

The following are some of the professors who have served as CCKS

adjunct faculty and taught courses/workshops over the 25 year history of the program:

• Paul Williams, Ph.D.	Karst Geomorphology
• Derek Ford, Ph.D.	Karst Geomorphology
• Will White, Ph.D.	Karst Hydrology
• Art Palmer, Ph.D.	Karst Geology
• Tim Atkinson, Ph.D.	Karst Hydrology
• Peter Smart, Ph.D.	Karst Hydrology
• Jim Quinlan, Ph.D.	Karst Hydrology
• Nick Crawford, Ph.D.	Karst Hydrology
• Patty Jo Watson, Ph.D.	Cave Archaeology
• Horton Hobbs, III, Ph.D.	Cave Ecology
• Hazel Barton, Ph.D.	Cave Geomicrobiology
• George Veni, Ph.D.	Karst Hydrology of Edwards Aquifer
• Chris Groves, Ph.D.	Karst Geomorphology
• Tom Barr, Ph.D.	Cave Biology
• Tom Poulson, Ph.D.	Cave Biology
• Stan Sides, M.D.	Exploration of Mammoth Cave
• Patricia Seiser, Ph.D.	Cave and Karst Stewardship
• Roger Brucker	Speleology
• Joe Meiman, Hydrologist, MCNP	Karst Geomorphology
• Daryl Grainger, Ph.D.	Karst Geomorphology
• Ron Kerbo, Nat'l Cave Mgmt Coordinator, NPS	Cave and Karst Stewardship
• Rick Olson, Ecologist, MCNP	Cave Ecology
• Pat Kambesis	Cave Surveying and Cartography

Plans for the future

A major goal for the CCKS and the MCICSL is to attract more international scientists and students to participate in the Karst Field Studies Program at the newly established Mammoth Cave International Center for Science and Learning by offering scholarships and course fee waivers to international participants. The CCKS and the MCICSL would also like to offer courses in other countries in cooperation with other cave and karst centers.

O-105

CAVES OF MARVEL: SPELEOLOGY AS ADULT ENVIRONMENTAL EDUCATION

Nikos Kourampas

Office of Lifelong Learning, University of Edinburgh, 11 Buccleuch Place, Edinburgh, EH8 9LW, UK, e-mail: nkouramp@staffmail.ed.ac.uk

Abstract

Speleology, as any other human endeavour, is not practised in a social and political vacuum. In times of acute environmental -and social- crisis the broader socio-political agenda of human encounters with nature becomes both more apparent and more fiercely contested. Speleology, in either its athletic or scientific versions, is just such an encounter and speleological training and practice inevitably constitute a form of (predominantly adult) environmental education. This paper looks at the wider epistemological and political context of speleological education and its -largely unexplored- potential to foster ecological literacy: environmental knowledge that, beyond contemplation and analysis, can also be translated into social praxis. Speleology, with its interdisciplinary bridging of earth, life, human sciences and the humanities, is particularly well suited to promote understandings of the environment as a system of interdependent parts, consistent with the new paradigm of earth and environmental sciences (the Earth System approach). Issues of use and protection of karstic environments render this interdisciplinarity particularly poignant, as they bring into focus the mesh of human-nature interrelations in a given locale, with their economic, political and cultural resonance. Such resonance is of particular value: if purpose of environmental education is to foster social praxis that addresses the challenges of global environmental and social crisis, then its curriculum needs to converse with root causes of this crisis (subjugation and capitalist exploitation of the environment, associated perceptions of nature as alien from humanity and of environment as of only instrumental value). Viewed within this critical frame, speleological practice, an opportunity for environmental knowledge to be mediated through the bodily engagement of learners with the cave environment, can assist speleological education to become knowledge acquired in/through,

and for, the (cave) environment. Drawing on phenomenological understandings of embodiment, this paper, thus, also looks at the significance of speleology as embodied experience that transgresses the Cartesian dichotomy of human vs. nature -an epistemological precondition of human domination over nature and, hence, of the current environmental and social crisis. It concludes with some suggestions for curricular interventions that open speleological education to a critical environmental perspective: (Earth)-systemic approach, directed interdisciplinary content, emphasis on human ecology, incorporation of historical and epistemological aspects, emphasis on bodily experience of the karst environment.

Introduction

Speleology can be practised in many different ways: as an extreme sport, an academic enterprise, or, as is often the case, a combination of both. Whatever its emphasis, nevertheless, speleology entails meaningful encounters of its practitioners with the karst environment: it is an institutionalised way of acquiring and structuring knowledge about this environment. Speleological education thus cannot but be a form of environmental education. It is widely recognised that educational practices, curricular priorities, epistemological paradigms of the discipline(s) taught, reflect their cultural, social and political context and the ideologies of educational providers, practitioners and students. This contextual imprint on educational practice cannot but become more accentuated in the case of environmental education, practiced in the midst of -and often as a response to- a deepening environmental, and at the same time social and political, crisis of global extent. Within the context of this global crisis human encounters with nature -and the epistemological constructions of nature these reproduce and reinforce- inexorably become subjects of contest. Speleology can be no exception.

Discussions of the environmental dimensions of speleological education have focused on the latter's significance for the protection of karst environments: indeed, this significance is recognised widely (Kačaroğlu, 1999) and public education programmes are in place in regions that utilise karst resources (e.g. Seiser, 2003; Zocaites & Orndorff 2003). Approaching speleological education from a different angle, this paper concerns itself not with the latter's contribution to karst conservation, but with its potential to function as critical environmental education that fosters learners' engagement with the global environment and its crisis. It asks how our changing understandings of the environment can resonate in the speleological curriculum and how the broader political priorities of environmental education can inform it; it examines the potential of speleological practice, as a bodily encounter with nature, to provide experiences that subvert the human/nature dichotomy; it concludes with a series of suggestions for curricular intervention. But, before all these, what kind of education is speleological education?

Speleology as adult free-choice learning: contextual understandings

Speleology is a predominantly adult pursuit. A brief internet survey (April-May 2005) shows that, although speleological education projects for children and teenagers are becoming increasingly common, most speleological education is addressed to adults. Educational provision and formality of setting range from accredited university courses to -the probably more representative- optional alternatives, including visits to caves, lifelong learning courses and training courses offered by local/national speleological societies and clubs. While speleological courses vary in content, they often comprise an earth science, a life science and a practical, exploration-focused component; less commonly an archaeological component is also present. Most speleological education is thus undertaken out of learners' own interest and is unrelated with acquisition of formal qualifications. In other words, and similar with learning in museums,

natural parks and other 'informal' settings, speleological education is usually a type of free-choice learning (Falk & Djerking, 2000; Ballantyne & Packer, 2005; Falk 2005). Free-choice learning is accomplished through a process of meaning-making by the learner, instead of meaning-taking that characterises more formal educational settings. The ways in which free-choice learners make sense of information they encounter are, of course, multiple; multiplicity of meanings is much more important "than whether visitors 'get the message' the provider intended to convey" (Ballantyne & Packer 2005: 283). Falk and Dierking's (2000) contextual model of learning suggests that free-choice learning is the cumulative process and product of a wide array of interactions between three overlapping contexts -the personal, the sociocultural and the physical. Learning is thus seen as an active process of meaning-making, influenced by learners' prior experiences and motivations and constructed over time, as individuals interact with phenomena and knowledge within a social context.

Can free-choice learning facilitate environmental education? Many understandings of environmental education are explicitly programmatic in character (see below). At first sight it might seem that the meaning-making rather than meaning-taking process of free-choice learning does not lend itself to propagation of 'causes'. At the same time, however, it is exactly this freehand character of the meaning-making process, the personal relevance of knowledge to the learner that makes free-choice learning not just suitable but indispensable for critical environmental education. Environmental learning, as understood by Ballantyne and Packer (2005: 287), is "a meaning-making process that incorporates the deepening and expansion of personal knowledge of sustainability issues; changes in awareness, appreciation and concern for wildlife; development of intentions to take or refrain from specific personal actions that have an impact on the environment; and enactment of lifestyle changes designed to support environmental sustainability". Free-choice learning provides opportunities for "learners to engage with and in the environment, to observe the evidence and effects of environmental mismanagement, and to explore and construct their environmental knowledge, skills, attitudes, beliefs and behaviours in personally relevant and meaningful ways" (Ballantyne & Packer, 2005: 290). After all, environmental education, like all education, is a lifelong endeavour, a dialogue of learners with their environment comprising "a lifetime of experiences; some academic and many not" (Falk, 2005: 275).

Which environmental education?

As long as the reality of global environmental and social crisis is accepted, the urgency of environmental education becomes undeniable. But here is where consensus ends: the character and agenda of this education are subjects of contest. The range of opinion is outlined by Lucas' classification of environmental education as education about, in/through and for the environment (1972, from Le Grange, 2004: 389-390). Each of these approaches reflects a distinct epistemological -and experiential- positioning of learner and educational practitioner vis a vis the object of their enquiry. Education about the environment reproduces knowledge about natural systems and processes. This knowledge, often linked with a vocational orientation, reflects neoclassical ideological positions: the environment is understood as 'resources' of only instrumental value. This education, that fosters a perception of the environment as "a passive habitat composed of "objects" such as animals, plants, minerals, and the like that must be merely be rendered more serviceable fro human use" (Bookchin, 1991: 21), is often preparatory to a professional career that perpetuates existing, hierarchical socio-economic structures. Education in/through the environment "emphasises learners' experience in the environment as a means of developing learner competencies and values clarification capacities" (Le Grange, 2004: 389). This approach reflects a liberal-progressive ideological position: knowledge of the environment is appreciated not for its instrumental value but as a value per se. Education for the environ-

ment, or education for sustainability, has an explicitly critical agenda that encourages learners not only to actively explore environmental problems but also engage with social praxis: social action for their alleviation (Le Grange, 2004). Informed from socially critical ideology, education for the environment aims to face up to the root-causes of the environmental crisis (hierarchy, capitalism and their epistemological preconditions; Bookchin, 1991) and encourage critical thinking that will change not only individual learners but also group processes in which these learners participate.

Any environmental education whose perspective extends beyond professional training thus aims to affect understanding of the dynamics of environmental crisis. As human roles in this crisis become increasingly evident, understandings of human interactions with the environment become integral to education for sustainability. This education aims to foster ecological literacy, the appreciation of "how people and societies relate to each other and to natural systems, and how they might do so sustainably" (Orr, 1992: 92), viewed by many as a prerequisite to effective political action for the environment (Cutter-Mackenzie & Smith, 2003). As formulated by David Orr (1992: 90-92), education for sustainability rests on the recognition that, (1) all education is environmental education; (2) environmental issues are complex and cannot be understood through a single discipline or department; (3) education occurs in part as a dialogue with a place and has the characteristics of good conversation; (4) the way education occurs is as important as its content; (5) experience in the natural world is both an essential part in understanding the environment and conductive to good thinking; (6) education relevant to the challenge of building a sustainable society will enhance the learner's competence with natural systems. This educational paradigm was incorporated in United Nations' Agenda 21 (United Nations Conference on Environment and Development, 1992).

Alongside education for sustainability stands the somewhat more radical approach of critical environmental pedagogy, informed from radical human geography and political ecology (Diduck, 1999; Huckle, 2002; Yarnal & Neff, 2004). Not a departure from, or an alternative to education for sustainability, but rather "an attempt to apply certain concepts from environmental education (along with ideas from transformative learning and participatory democracy) in a new context, namely public involvement and environmental management" (Diduck, 1999: 87), critical environmental pedagogy focuses on "empowering students, enhancing their sense of citizenship, encouraging activism, and transforming power relations, both in and out of the classroom" (Yarnal & Neff 2004: 30). Education for sustainability and critical environmental pedagogy are complementary; differences between them are those of emphasis rather than goal. Both approaches place human-environmental interactions -human ecology- at the very core of environmental education. The ultimate goal of radical environmental education is translation of ecological knowledge into social praxis, social and political action: learners are encouraged "to understand more completely and engage more critically the political and economic systems that are at the heart of human-environment issues" (Yarnal & Neff, 2004: 30).

Changing epistemologies of environmental science: the Earth System paradigm and disciplinary integration

The emergence of new educational paradigms is not the only development that reverberates in speleological education and practice: 'internal' developments within environmental sciences also exercise a crucial effect. Environmental sciences are in a period of transformation, as a long phase of disciplinary split and specialisation is succeeded by a phase of conceptual reunification within the context of the emerging Earth System paradigm. The discipline of geography exemplifies these changes: early to mid-20th century disciplinary split led to the emergence of three ap-

proaches with often minimal communication between them: physical geography, human geography and geographical information science. An impending re-integration of the three 'geographies' is indicated by intensification of research on human-environmental interactions since the early 1990's (Yarnal & Neff, 2004) and rekindling of epistemological conversation between human and physical geographers (e.g. Harrison et al., 2004). Geology is almost as illustrative: emergence of several geo-subjects (tectonic geology, geochemistry, sedimentology, etc. -all, nonetheless, accommodated under the umbrella of earth science) during the centrifugal 20th century is currently counteracted by an emphasis on interconnection of variables and synthetic, historical interpretation (Dodick & Orion, 2003). These intradisciplinary transformations are in large part driven by resonances of the global environmental crisis and by the parallel, and to an extent consequent, emergence of a new paradigm in environmental science: the Earth System approach.

The Earth System paradigm views the global environment as an integrated, synergistic system comprising (a) four principal material reservoirs, the geosphere (solid earth, soft sediments and soils), atmosphere, hydrosphere (water and ice), biosphere (the totality of life in the planet), and (b) flows of matter and energy between them (Skinner & Potter, 1995); to these many add the anthroposphere, a distinct sphere of human activity, demarcated to emphasise the crucial influence of human societies on the state of the Earth System, and the exosphere, our planet's cosmic environment, comprising the solar system and interplanetary space (Ruzek, 2004). Located at an "intersection of disciplinary specialties [that] often provides the most fertile and interesting fields for study" (Johnson et al., 1997: 688), the Earth System approach is by definition interdisciplinary, transgressing boundaries between fundamental sciences (chemistry, physics, biology, mathematics), environmental sciences (earth science, biology, ecology, oceanography, etc.) and human and social disciplines (anthropology, human geography, economics, sociology). Educational approaches that follow the Earth System paradigm (e.g. American Geophysical Union, 1996) are closely associated with education for sustainability: in some measure Earth System science emerged as a response to the formulation of Agenda 21, calling for global action for sustainability and attributing great significance to environmental education (Johnson et al., 1997). Emphasising interactions between parts of the Earth System, processes that link biotic and abiotic components, causal connections between human actions and global environmental change, the Earth System approach provides a conceptual framework for understanding a world in perpetual flux. Societal dimensions of change weight heavily on earth-systemic understandings of the global environment. The broader interdisciplinary relevance of Earth System science reshapes not only priorities and practices of academic research but also of education: educational transgressions of traditional disciplinary boundaries, especially those that separate natural from social sciences and the humanities, now become increasingly urgent.

The potential of speleology: free choice, interdisciplinarity, insights into social construction of science

As an environmental endeavour, speleology is de facto environmental education. But of what kind? Has speleology the potential to transform itself into an educational practice that promotes ecological literacy and encourages social praxis for the environment?

The free-choice character of speleology confers important advantages, as it allows learners to construct their environmental knowledge "in personally relevant and meaningful ways" (Ballantyne & Packer, 2005: 290). Close engagement of learners with the -often unfamiliar, even bewildering and 'extreme'- karst environment that speleology entails allows learners to develop emotional responses to the environment and often acquire first hand experience of environmental degradation. In other words, speleological practice has the potential to foster a deep, emotive sense of place,

the "good conversation" with place, replete with "form, structure and purpose", that David Orr values as one of the foundations of education for sustainability (1992: 90-91).

Besides, speleology is epistemologically well-placed to become a venue for critical environmental education. Systemic approaches crucially inform cave research and discussions of caves as environmental systems are incorporated in popular textbooks of cave science (e.g. Gillieson, 1996). The framework of a speleological curriculum allows systemic understandings of karst environments to be advanced at progressively higher levels of complexity: when the emphasis is on abiotic processes of traditional karst geomorphology caves can be approached as process-response geomorphic systems; they progress to ecosystems and humanised places (lived-in and invested with meaning; sensu Tilley, 1994) when cave life and human uses of the karstic environment enter the discussion. Insights from approaches at any level of systemic complexity enrich the understanding of the cave environment at all other levels; to the author's experience post-geomorphic levels of complexity are particularly exciting to learners.

It is especially important that learners are encouraged to face the bigger picture: the place of caves and karstic processes within the larger Earth System. Whether focusing on an ideal, paradigmatic cave that illustrates fundamental processes, or on a real cave, chosen as a case study, speleology can be taught as a systemic discipline. Opportunities for integrating geomorphic, ecological and anthropological insights to the karst environment are ample. Explanations of cave formation and evolution combine information about petrology and tectonic evolution of the host rock with water chemistry, climatology and increasingly topical understandings of global change (e.g. Quaternary climate and sea-level change). Discussions of speleotheme and clastic sediment deposition involve mineralogy, biogeochemistry, hydrogeological models of water flow in karst systems, all examined against the backdrop of global climate change. Fossil assemblages in caves bring to the fore understandings of biological evolution, speciation and extinction, against the backdrop of ecosystem change; archaeological evidence raise fundamental issues of human biological evolution and cultural change and exemplify past patterns of human ecology and their cultural signature. Discussions of cave-dwelling animals and their ecology illustrate the complex dynamics of karst ecosystems, whereas issues of cave management and conservation bring interactions between biotic and abiotic components of the karst system and the multifarious ways human activities affect -and are affected by- their course into especially sharp focus. Since it is now understood, ecosystem management ought to incorporate "both social variables and biophysical factors in decision making" (Seiser, 2003), these discussions cannot leave out issues of ownership of, and conflict over, nature (for an example of armed conflict over the use of karst resources see Urich et al., 2001). In these and many more ways the study of cave environments can exemplify environmental change, its human triggers and societal responses it stimulates.

As any scientific field, speleology has been shaped by its changing social and epistemological context (e.g. Shaw, 1992). The function of speleology as environmental education can be facilitated by incorporation of historical and epistemological dimensions in speleological curriculum. History and philosophy of science encourage learners to understand that their discipline, and, more broadly, the scientific way of looking at the world, is of historic character, that disciplinary developments reflect wider scientific, philosophical, social and political developments; to understand, in other words, that science is socially constructed (Thompson et al., 2000; Sack, 2002). Dorothy Sack's (2002) list of educational benefits from incorporating a historical component in the undergraduate teaching of geomorphology is directly applicable to speleological education as well: the history of the subject explains its association with other disciplines (geography, geology, biology and archaeology); it stimulates learners' interest because "history is a popular subject" (p. 313); it helps learners realize that scientific concepts are products of their time, bound to be

modified and replaced; it promotes a constructivist understanding of the workings of science; it informs them about social and political dimensions of science. Due to its interdisciplinary character, speleological education can stimulate discussion of the broader historical and ideological context of many seminal developments in the history of western knowledge: ordering and classification of life forms, discovery of geological time, biological (including human) evolution, concepts of cultural evolution, origins of human symbolic thought are but a few examples.

Speleology as embodied encounter with nature

This discussion of speleology as environmental education would be incomplete without an account of speleology's physicality. For besides an educational endeavour, speleology is, crucially, a physical activity, a bodily engagement with the karst environment. Far from merely coincidental to its environmental perspective, speleology's physicality can enhance its function as critical environmental education: as a growing number of environmental educators recognise, embodied experiences of nature are those most likely to translate into social praxis (Le Grange, 2004).

To illustrate the nexus between learners' bodily experience and environmental education one has to look at the ideological preconditions of the current environmental crisis. This crisis stems from economic exploitation of nature which accelerated with the making of early modern Europe (16th and 17th centuries) and intensified tremendously during industrialisation of capitalist West and the socialist countries in the 19th and 20th centuries (Bookchin, 1991; Simons, 1993); rapid expansion of global capitalism and technical advances (e.g. in genetic engineering) since the 1990's have added momentum to the process of commodification of nature and radically expanded the range of marketable resources. Cultural prerequisite for such exploitation is an anthropocentric view of nature as devoid of intrinsic value, as nothing but a (potentially inexhaustible) accumulation of resources for human use. To become subjected to domination for profit, nature has thus to be constructed as a category alien from humanity. Construction of an alien, commodifiable nature is made possible by a number of interrelated dichotomous schemata that distinguish between human and natural and privilege the former over the latter (e.g. Plumwood, 1993). This dualistic reasoning, which in the form of civilised vs. savage and male vs. female also opened the way to subjugation of parts of humanity alongside non-human nature, has a legacy traceable in classical Platonic and Aristotelian thought and the origins of Judaeo-Christian tradition. At the heart of the dichotomies that have constituted the prevalent western world-view since early modern times lies the fundamental duality of mind vs. body: reformulated and re-emphasised by Descartes in the 17th century, this duality opened the way to the triumph of domination over nature and disempowered bodies, human and non-human alike (Bookchin, 1991; Marshall, 1992; Plumwood, 1993; Simmons, 1993).

Dualistic reasoning permeates all aspects of our culture, education included. Even in the field of environmental education, education about the environment reflects -and reproduces- understandings of environmental systems as 'resources' fundamentally alien from humanity and appreciated only for their instrumental value (Le Grange, 2004). Influenced by behaviourist approaches to learning, this strand of environmental education utilises an educational praxis that reinforces the mind-body distinction: learning "becomes a mind activity made possible through didactic methods of teaching and textbooks that serve as sources of authority. The assumption [...] is that if the mind is 'fed' with sufficient information about natural systems, the body will follow later with the 'right' actions to protect natural environments-'mind knowledge' will lead to 'right bodily actions'" (Le Grange, 2004: 390). Critical versions of environmental education, by contrast, set out to challenge the mind/body dichotomy, alongside other dichotomies that facilitate hierarchical domination of nature. As long as this challenge remains intellectual, nevertheless, it is futile: mind-privileging educational praxes are often present within

343

critically intentioned environmental education. An urgent task of critical environmental education is thus to seek practices that privilege learners' physical, sensual experience of the environment as much as their intellectual engagement with it. Speleology, in common with other free-choice physical encounters with nature, has a considerable potential to deliver significant bodily experiences; these can contribute to the undermining of mind/body dichotomy as long as speleological educators value them not as just a fortunate by-product of learning process proper, but as an integral and inalienable part of it: if, in other words, they view (all) learning as mediated by the learner's body.

All learning is bodily learning: cognition as embodiment

Perceptions of, and attitudes towards, the environment hinge on human ways of making meaning of the world: human ways of learning. Diverse educational approaches, variants of environmental education included, are underpinned by different theoretical understandings of human ways of learning (Roth, 1997; Mingers, 2001; Le Grange, 2004). When we enquire about the learning process as experienced by the learner engaged in it, we enquire about the phenomenology of human cognition. This enquiry has so far led to three distinct sets of answers, three distinct phenomenological understandings of the ways we make meaning out of our world (Mingers, 2001). One approach, resulting from Husserl's reformulation of Cartesian philosophy, views cognition as pure thought: the transcendental ego becomes cognisant of the world through manipulation of representational mental images. Another approach, advanced by Husserl's student Heidegger in his Being and Time (1962), envisages the self-conscious, enquiring self (Dasein) as knowing the world not through pure reflection but through engaged action, by being-in-the-world: "it is this process of experiencing the world that is the way of being of humans" (Mingers, 2001: 107; emphasis in the original). By being-in-the-world the conscious self (Dasein) is faced with a multitude of encounters: objects and things in this world can be non-selves, other selves and her/his own self, and engages in a multitude of actions, since "[…] in relating to the world, in existing in the world, our basic attitude is always (except in pure contemplation) one of doing, acting, having some aim in mind, having some concern" (Mingers, 2001: 108).

A third approach, that of cognition as embodiment, stems mainly from Maurice Merleau-Ponty's unique synthesis of existentialism and phenomenology, with further elaboration by other thinkers (see Csordas, 1994; Carey, 2000). According to this approach, we become cognisant of the world through neither representational sense-impressions nor Cartesian mind constructs. Our discovery of reality is, instead, viewed as a subject-object dialogue, mediated by our lived bodies. In Merleau-Ponty's words "[t]he body is our general medium for having a world. Sometimes it is restricted to the actions necessary for the conservation of life, and accordingly it posits around us a biological world; at other times, elaborating upon these primary actions and moving from their literal to a figurative meaning, it manifests through them a core of new significance: this is true of motor habits such as dancing. Sometimes, finally, the meaning aimed at cannot be achieved by the body's natural means; it must then build itself an instrument, and it projects thereby around itself a cultural world" (1962: 146). The term embodiment thus describes "the bodily aspects of human subjectivity" (Leland, 1999: 258), source of all experience and existential ground of culture and self (Csordas, 1994). "In so far as, when I reflect on the essence of subjectivity, I find it bound up with that of the body and that of the world, this is because my existence as subjectivity is merely one with my existence as a body and with the existence of the world, and because the subject that I am, when taken concretely, is inseparable from this body and this world'. (Merleau-Ponty, 1962: 408). All cognition is thus mediated through the experience of the (phenomenal) body.

This understanding of human cognition as embodiment resonates in educational theory and practice, as there is a growing recognition that be-

sides and beyond contemplation of the object of enquiry (be it differential equations or formation of stalactites), there is a hitherto unacknowledged cornucopia of sensual responses -bodily sensations of movement or stasis, sounds and smells of the environment where learning bodies are located- that enrich the experience of learning and influence its outcome (Roth, 1997; Carey, 2000; McWhinney, 2001; Satina & Hultgren, 2001). Insights of learning as embodied experience are particularly significant for that educational field that has most to gain from the rehabilitation of the body as source and ground of all knowledge: environmental education (Press & Minta, 2000; Le Grange, 2004). Since undermining the mind/body dichotomy is an important aim of critical environmental education, rehabilitation of embodied experience as an integral part of the process of learning inside and for the environment is a necessary educational praxis. The relevance of speleological practice to this educational priority is obvious: speleology is embodied experience par excellence, an all-senses engagement with the cave environment, a dialogue of the moving body with the subterranean place. As long as speleological education acknowledges the significance of this physicality not as a reward coincidental to some 'serious', mind-centred and objectifying scientific endeavour but as the means through which experiential knowledge of the cave environment is acquired, speleology can contribute significantly to the radical epistemological agenda of environmental education. Even if re-privileging the body in speleology, or, for that matter, any other field-based environmental practice, is certainly insufficient to erase the mind/body dichotomy from learners' world-view, rehabilitation of their bodies as knowing subjects can constitute a crucial turn in the long, cumulative process through witch learners reconstruct their environmental and social values.

Conclusions: speleology as adult education for the environment

In the midst of the current environmental and social crisis speleology, as any form of human engagement with the environment, cannot maintain apperances of neutrality. Speleological education, a type of free-choice learning pursued by predominantly adult learners, reflects the contested character of human knowledge of nature: what we learn about, how knowledge is acquired, what are the (ultimately political) uses of this knowledge, the ways it reflects wider worldviews of, and practices towards, nature. What follows is a -by no means exhaustive- list of curricular interventions that can broaden the environmental perspective of speleological education and tune it with critical strands of environmental education.

(1) (Earth)-systemic approach. Systemic approaches, already present in speleological (as in broader physical-geographical) research and education should be emphasised. Educators should seek ways to connect processes and forms within the cave system with flows of energy and matter across the Earth System, local change in the cave environment with phenomena of regional and global significance (e.g. vegetation, sea level, climate change) and their processes and causes.

(2) Directed interdisciplinary content. Speleological education is excitingly interdisciplinary, including themes that range from petrology and karst hydrogeology to ecology, archaeology and history of art. Housing so many disciplinary approaches under one roof contributes greatly to the subject's allure. To convey an environmentally educative message, however, interdisciplinarity must progress beyond a mere compendium of cave-lore. Themes should be included with a direction in mind, with the aim to make an argument, to exemplify the complexity of organic-inorganic, human-environment relationships. This argument calls for inductive bridges between themes, a quest for scientific, epistemological and historical links between different kinds of speleology.

(3) Emphasis on human ecology -the manifold interactions between human societies and their environment. Interaction of humans with the karst environment is an obvious focus of speleological education

344

with environmental inclinations. One way to approach this interaction is through case studies; selection of cases from among local examples is, perhaps, ideal. Such examples encourage learners to reflect on the diverse ways human societies interact with the karst environment, the disparate values and meanings attached to nature and the contested, explicitly political nature of the environmental debate. As human engagement with karst, nonetheless, is as old as our species, examples of such interaction need not be restricted in the contemporary and the familiar: within the suggested interdisciplinary context, examples from older times and different cultures elucidate the dynamic character of the human-environment relationship, its variation through time and space.

(4) Inclusion of historical and epistemological aspects demonstrates that the scientific approach is just one of the ways of looking at the world; that the practice of science has always reflected the cultural and ideological preoccupations of its practitioners; that science is a product of its (changing) social context. A speleological course can provide a suitable stage for contextual discussion of many seminal developments in natural sciences and the humanities.

(5) Emphasis on bodily experience of the karst environment. Bodily engagement of learners with the environment allows them to relate with this environment sensually and emotionally as well as intellectually. Valuing bodily experience of the environment subverts the mind/body dichotomy that lies at the core of human alienation from, and domination over, a nature invested with otherness. Speleological practice, in the form of field courses or visits to 'wild' caves, provides experiences that potentially reinforce learners' sense of unity with the knowable world.

Acknowledgements

References

American Geophysical Union, 1996. Shaping the Future in Undergraduate Earth Science Education:

Innovation and Change Using the Earth System Approach. Available online at http://www.agu.org/sci_soc/spheres/intro.htm.

Ballantyne R. and Packer, J., 2005. Promoting environmentally sustainable attitudes and behaviour through free-choice learning experiences: what is the state of the game? Environmental Education Research, 11, 281-295.

Bookchin, M. 1991. The Ecology of Freedom: the emergence and dissolution of hierarchy. Black Rose Books, Montréal.

Carey, S., 2000. Cultivating Ethos through the Body. Human Studies, 23, 23-42.

Cutter-Mackenzie, A. and Smith, R., 2003. Ecological literacy: the 'missing paradigm' in environmental education (part one).Environmental Education Research, 9, 497-524.

Csordas, T.J., 1994. Introduction: the body as representation and being-in-the-world. In Csordas, T.J. (ed.) Embodiment and experience: the existential ground of culture and self. Cambridge University Press, Cambridge, 1-24.

Diduck, A., 1999. Critical education in resource and environmental management: Learning and empowerment for a sustainable future. Journal of Environmental Management, 57, 85-97.

Falk, J., 2005. Free-choice environmental learning: framing the discussion. Environmental Education Research, 11, 265-280.

Falk, J. H. and Dierking, L. D., 2000 Learning from museums: visitor experiences and the making of meaning. AltaMira Press, Walnut Creek, CA.

Fien, J., 1993. Education for the environment: critical curriculum theorising and environmental education. Deakin University Press, Geelong, Victoria.

Gillieson, D., 1996. Caves: processes, development and management. Blackwell, Oxford.

Harrison, S., Massey, D., Richards, K., Magilligan, F. J., Thrift, N. and Bender, B., 2004.Thinking across the divide: perspectives on the conversations between physical and human geography. Area, 36, 435-442.

Heidegger, M., 1962. Being and Time, Blackwell, Oxford.

Johnson, D.R., Ruzek, M. and Kalb, M., 1997. What is Earth System Science? Proceedings of the1997 International Geoscience and Remote Sensing Symposium, Singapore, 688-691.

Kačaroğlu, F., 1999. Review of Groundwater Pollution and Protection in Karst Areas. Water, Air, and Soil Pollution,113, 337-356.

Le Grange, L., 2004, Embodiment, social praxis and environmental education: some thoughts. Environmental Education Research, 10, 387-399.

Leland, D. 1999. Embodiment. In Audi, R. (ed.) The Cambridge Dictionary of Philosophy. Cambridge University Press, Cambridge, 258.

McWhinney, W., 2001. Enabling embodiment in education. Cybernetics & Human Knowing, 8, 91-93.

Marshall, P. H., 1992. Nature's Web: an exploration of ecological thinking, Simon & Schuster, London.

Merleau-Ponty, M., 1962. Phenomenology of perception. Routledge, London.

Mingers, J., 2001. Embodying information systems: the contribution of phenomenology. Information and Organization, 11, 103-128.

Orr, D.W., 1992. Ecological Literacy: education and the transition to a postmodern world. State University of New York Press, New York.

Plumwood, V., 1993. Feminism and the Mastery of Nature. Routledge, London.

Press, D. and Minta, S.C., 2000. The Smell of Nature: Olfaction, Knowledge and the Environment. Ethics, Place & Environment, 3, 173-186.

Roth, W.-M., 1997. Being-in-the-World and the Horizons of Learning: Heidegger, Wittgenstein, and Cognition. Interchange, 28, 145-157.

Ruzek, M., 2004. Earth System Science in a Nutshell. Available online at http://serc.carleton.edu/introgeo/earthsystem/nutshell/index.html

Sack, D., 2002. The educational value of the history of geomorphology. Geomorphology, 47, 313-323.

Satina, B. and Hultgren, F., 2001. The Absent Body of Girls Made Visible: Embodiment as the Focus in Education. Studies in Philosophy and Education, 20, 521-534.

Seiser, P.E., 2003. Ecosystem Management and the Idea of Cave Wilderness in Protecting Karst Resources. Abstracts, 16th National Cave and Karst Management Symposium. Available online at http://www.nckms.com/abstarcts.htm

Shaw, T.R., 1992. History of cave science: the exploration and study of limestone caves, to 1900. Sydney Speleological Society, Sydney.

Simmons, I.G., 1993. Environmental history: a concise introduction. Blackwell, Oxford.

Skinner, B.J. and Porter, S.C., 1995. The Blue Planet: An Introduction to Earth System Science. John Willey & Sons, Chichester.

Thompson, D., Praia, J. and Marques, L., 2000. The Importance of History and Epistemology in the Designing of Earth Science Curriculum

345

Materials for General Science Education. Research in Science & Technological Education, 18, 45-62.

Tilley, C., 1994. A phenomenology of landscape: places, paths and monuments. Berg, Oxford.

United Nations Conference on Environment and Development, 1992. Agenda 21: Programme of action for sustainable development. United Nations Department of Public Education, New York.

Urich, P.B., Day, M.J. and Lynagh, F., 2001. Policy and practice in karst landscape protection: Bohol, the Philippines. The Geographical Journal, 167, 305-323.

Yarnal, B. and Neff, R., 2004. Whither Parity? The Need for a Comprehensive Curriculum in Human-Environment Geography. The Professional Geographer, 56, 28-36.

Zokaites, C. and Orndorff, W., 2003. Successful Karst Protection Depends on Education. Abstracts, 16th National Cave and Karst Management Symposium. Available online at http://www.nckms.com/abstracts.htm

O-106

Change in attitudes after first visit to a cave: A Q-methodological study

Linda Gentry El-Dash, *State University of Campinas and SBE-Sociedade Brasileira de Espeleologia, Rua Ruberlei Boaretto da Silva, 8 Cidade Universitária Campinas (SP), Brazil CEP 13084-010*

Oscarlina Aparecida Furquim Scaleante, *Pontifícia Universidade Católica de Campinas and SBE-Sociedade Brasileira de Espeleologia, Av. Oscar Pedroso Horta, 144 Cidade Universitária Campinas (SP), Brazil CEP 13084-510*

Abstract

A previous study (El-Dash and Scaleante, 2001) identified the factors involved in the attitudes of Brazilian adolescents and university students to caves and showed these to be the same, whether or not an individual had had hands-on experience with caves. This does not mean, however, that the point of view or attitude profile of an individual will not change with contact, and the present study has investigated such changes after a first visit to a cave. The authors used Q-Methodology, since this methodology makes the objectivization of subjective reactions possible. A local university offers a two-day basic introduction to speleology, including one day of theory and another in which students actually visit a cave, as part of a program designed to expand the intellectual horizons of the students by exposing them briefly to unfamiliar areas of study. Q-sorts were made by the students reporting for one of these courses and then again after their visit to the cave.

Programs in environmental education are considered to play an important role in the preservation of the natural heritage (FIGUEIREDO, 1988), since they provide information designed to stimulate the awareness of the importance of this heritage. Few programs in Brazil, however, have considered the provision of information to promote the awareness and preservation of our underground heritage. Moreover, caves are especially vulnerable, sue to the extreme delicacy of many of the speleothems and the thousands of years required for their formation.

Nearly thirty years ago, Guy-Christian Collet (1976, 1977, 1978) advocated the structuring of a plan for the teaching of speleology in Brazil, but there have been few concrete attempts to define such strategies or to implement such educational programs and establish the parameters for courses in speleology and practical speleological training. Given the recent interest in ecological tourism in the country, however, demands have grown, and the Department of Tourism of the Pontifícia Universidade Católica (PUC-Campinas), a private university of approximately 22.000 students, has created a special module about caves for this purpose. Encompassing 15 hours of instruction provided on a single weekend, the module emphasizes the preservation of the underground heritage and introduces students to this fascinate new world. On Saturday, the student is introduced to theoretical concepts such the history of speleology, the origin of caves and the formation of speleothems, as well as a notion of biospeleology, archaeology and paleontology; Sunday is devoted to more practical aspects, with a visit to some of the sandstone caves in the vicinity of Itirapira and Ipeúna.

Such programs designed to promote awareness and attitude changes are only effective if they actually induce such changes in their participants, yet attitudes are very personal and private entities to which an investigator has practically no access. In order to investigate whether any actual changes in attitude resulted from the experience, a Q study was undertaken.

Methodological considerations

Q-methodology is especially designed to investigate individual subjectivity. It assumes that each and every individual is unique in relation to his/her beliefs and opinions, and that these can only be analyzed by observations of a person's internal structure of reference (STEPHENSON, 1953; 1978). Such points of view may, however, be shared by others, and the methodology attempts to identify shared points of view (MCKEOWN and THOMAS). Traditional methods for the investigation of opinions are questionnaires and interviews, but these instruments tend to involve pre-established categories that the investigator thinks important, rather than allowing space for the subjects to define their own. Moreover, in Q studies, samples can be quite small.

Q-methodology consists of affirmations extracted from a universe of possible positions or ideas in relation to the topic. These are usually extracted from the speech of the subjects in group discussions, although they can also be based on the literature in the area. The 40-100 items selected should represent all possible positions, usually with equal weight and

number of positive and negative statements for all. The use of this methodology makes it possible for each individual to express his/her own interpretation of the statements.

The present study was based on the factors which underlie the opinions of Brazilian adolescents about caves (EL-DASH and SCALEANTE, 2001), which revealed the existence of five underlying factors: adventure, mystery/mysticism, fear/danger, scientific/factual interest, and the historical role of caves. All subjects in that study reacted to all five of these factors, but their relative importance was not revealed. In the present study, focal groups of student enrolled in a speleology module discussed these aspects and their comments were recorded for the development of the universe of ideas and the selection of Q-statements. To avoid distortion, the same number of affirmations were used for each of the sub groups of the five factors, with an equal number of positive and negative statements. These statements were written on cards and arranged according to specific conditions of arrangement designed to approximate a normal curve, with only a few statements ranked as (subjectively) the most and least important, with subsequent decreases in importance receiving progressively less weight. The result is a measure of a subjective point of view and groups the subjects according similarity of ideas. Based on these results, the research worker can interpret and explain what the points of view of each group have in common.

The study
The statements were submitted to a class of 40 students enrolled in the speleology module prior to the initiation of the theoretical discussion, and again after their exit from the first cave that they visited; the same condition of instruction was used for both instances: how strongly do you agree/disagree with each of the statements? Rank them according to degree of agreement or disagreement. The 44 statements selected were distributed on a 9-column board for agreement ranging from -4 (greatest disagreement) to + 4 (greatest agreement), with the extreme columns containing only 2 items, while the central (0) column had 8.

Results and discussion
The Q-sort prior to instruction failed to reveal any shared points of view. This suggests that although the students had chosen to enroll in the module and were willing to visit a cave, there was no recognizable pattern in their points of view, because they had never had any real contact with caves or information about them and could only imagine what they might be like. After the eight hours of instruction and the visit to a cave, however, the analysis of principal components revealed three factors (points of view). After varimax rotation, loadings greater than 0.39 were considered significant ($p<0.01$). Table 1 shows the prototypical Q-sorts for each factor.

	Factor A	Factor B	Factor C
1 Adventure seems to be something rather irresponsible.	0	- 1	3
2. You can find yourself in the solitude of a cave.	0	- 2	- 4
3. I am afraid of bats and insects. If I meet up with one, I'll have a fit!	- 3	- 4	2
4. It's neat to go into a place and know that no one before has ever been there; it's thrilling!	0	0	- 1
5. Caves have so little contact with the world outside that they establish their own ecosystem.	1	0	- 2
6. I can't imagine living in a dirty hole (in the ground) without air.	1	1	2
7. Am activity which requires a bit of sacrifice is neat.	- 1	1	0
8. In the Stone Age, caves provided protection from large animals and storms.	2	1	0
9. Caves aren't all that silent – there is the sound of water and things that happen in caves.	- 1	2	0
10. The sensation of adventure, despite your fear, is really enjoyable.	3	- 1	- 2
11. It's hard to rind valuable minerals in a cave.	- 1	- 1	1
12. You see an animal passing, a bit, it's really neat.	2	0	- 1
13. The formations are fantastic. It's like a different world.	1	1	- 2
14. It's ridiculous to need raw material and be forced to keep protecting caves.	- 4	- 3	1
15. It's annoying to enter a cave and see all the graffiti; they've done all that could be done. It's frustrating!	4	3	0
16. It's incredible to think there are caves that are more than 100 kilometers long.	- 2	4	0
17. There are lots of tight places to go through.	0	4	- 3

18. You can't imagine how much is down there in the depths of the earth.	2	3	- 1
19. A little exercise is good, but there's no need to exaggerate.	- 1	0	1
20. Caves are really interesting, because they are the opposite of the normal world.	1	3	- 3
21. In really big caves there's a danger of getting lost.	3	3	0
22. Caves? I don't go t caves. I'm afraid!	- 4	- 4	3
23. For me, caves are a different area, just to study. There are minerals, crystals, lots of things.	0	- 2	1
24. Caves are in constant change, but we can't see this because the processes are very slow.	4	0	- 1
25. There are pits, vampires, it's really dangerous!	- 2	- 2	3
26. You lose all notion of time when you spend a long time inside a cave.	0	0	- 3
27. You take a cave and take the minerals out, it's raping the cave.	3	0	- 1
28. It's impressive to go into a little hole and find a huge empty space.	1	2	0
29. In caves you can see rock formations, soil, the path of the water, there inside.	2	1	- 1
30. It's so frightening to imagine the darkness and silence in a cave that my mind shuts down.	- 3	- 3	2
31. I don't care about these caves. I prefer to be where the movement is!	0	- 2	2
32. Stalactites, stalagmites! These form really scary figures.	- 3	- 3	2
33. The deeper a cave, the harder it is to get to.	- 2	2	0
34. Caves are all right, but they aren't worth anything!	- 3	- 2	4
35. I don't like man-made (artificial) things. I prefer the natural state, without simulation.	- 2	- 1	- 1
36. It's great to feel a tingle of fear in the pit of your stomach.	2	- 1	- 3
37. Caves are magical, something you don't see, something rare.	- 1	2	- 4
38. The unknown is frightening. If you know what's around you, it's easier.	1	2	1
39. Imagine the roar of an underground river after a strong rain!	0	1	1
40. Caves are unpleasant [places] because they're cold and full of hard rocks and holes.	- 2	- 1	4
41. Caves must be really comforting; if you build a little fire, it would be even nicer.	- 1	- 1	1
42. The idea of a cave is sinister, it's scary, because the movies present them that way.	- 1	0	3
43. Nothing is dangerous if you prepare yourself for it.	1	- 3	- 2
44. It's really peaceful in a cave, listening to the dripping of the water.	3	1	- 2

Table 1. Prototypical Q-sorts for the three factors

	Factor A	Factor B	Factor C
01f21bio	0	34	-67*
02m23eng	52*	22	- 8
03m20ans	34	30	-63*
04m22jor	35	23	-61*
05f22tur	12	63*	-16
06m22eng	29	26	-46*
07f00jor	17	50*	-44*
08f21bio	15	42*	-67*
09f21nut	46*	64*	-13
10f22adm	36	3	-67*
11m22ans	21	19	-76*
12f23bio	49*	10	-47*
13f21bio	31	20	-65*
14f20med	29	76*	-13
15m27eng	59*	15	-13
16m19law	61*	21	-36
17f24odo	12	39*	-47*
18f22law	8	68*	-44*

19f21tur	25	47*	-39*
20m23ans	63*	28	-49*
21f22ans	56*	27	-49*
22m23eng	38	42*	-15
23f18bio	31	17	-69*

Table 2 describes the loadings of the subjects for each of the factors.

Factor A is composed of seven individuals, Factor B of nine, and Factor C of sixteen. The large number of mixed loaders sharing two different points of view may be a reflection of the wealth of new information and new sensations experienced during the cave module, and it may be more noteworthy that so many actually shared a single identifiable point of view.

Factor A

Factor A is composed of seven individuals; three are defining Q-sorts who have high loadings only on this factor, whereas one of the mixed loaders also loads heavily on Factor B, and three load on both A and C. The statements which are most representative of this point of view, with the highest values(+/_ 4 or +/_3) are listed below. Those items which individually distinguish this point of view from that of the other factors are marked with an asterisk.

	A	B	C
15. It's annoying to enter a cave and see all the graffiti; they've done all that could be done. It's frustrating!	4	3	0
*24. Caves are in constant change, but we can't see this because the processes are very slow.	4	0	1
22. Caves? I don't go to caves. I'm afraid!	-4	-4	3
14. It's ridiculous to need raw material and be forced to keep protecting caves.	-4	-3	1
*10. The sensation of adventure, despite your fear, is really enjoyable.	3	-1	-2
21. In really big caves there's a danger of getting lost.	3	3	0
27. You take a cave and take the minerals out, it's raping the cave.	3	0	-1
44. It's really peaceful in a cave, listening to the dripping of the water.	3	1	-2
3. I am afraid of bats and insects. If I meet up with one, I'll have a fit!	-3	-4	2
30. It's so frightening to imagine the darkness and silence in a cave that my mind shuts down.	-3	-3	2
32. Stalactites, stalagmites! These form really scary figures.	-3	-3	2
34. Caves are all right, but they aren't worth anything!	-3	-2	4

The individuals of this point of view have obviously absorbed the idea of the importance of the preservation of caves during the module, as can be seen in their affirmation of the need for preservation (14) and their rejection of the destruction of caves (27) and the presence of graffiti (15), as well as their respect for the slowness of the processes involved (24). These individuals appreciate the tranquility of the cave experience (4), the darkness and silence (30) and are not frightened by bats and eerie formations (32). They enjoy the thrill of adventure (10, 36), although they respect the potential danger of getting lost (21). What is unique about the ideas of the participants of this factor is the respect for the slowness of the formation of caves and cave processes. For these individuals, the cave module has awoken a desire for preservation. The reliability of the factor is high, although the small number of subjects is reflected in a large standard error.

Factor B

Factor B is composed of nine individuals; 3 are defining Q-sorts. Five also felt the mystical aspects of caves, and only one was especially concerned with their preservation.

	A	B	C
*16. It's incredible to think there are caves that are more than 100 kilometers long.	-2	4	0
*17. There are lots of tight places to go through.	0	4	-3
22. Caves? I don't go t caves. I'm afraid!	-4	-4	3

3. I am afraid of bats and insects. If I meet up with one, I'll have a fit!	-3	**-4**	2
15. It's annoying to enter a cave and see all the graffiti; they've done all that could be done. It's frustrating!	4	**3**	0
18. You can't imagine how much is down there in the depths of the earth.	2	**3**	-1
20. Caves are really interesting, because they are the opposite of the normal world.	1	**3**	-3
21. In really big caves there's a danger of getting lost.	3	**3**	0
14. It's ridiculous to need raw material and be forced to keep protecting caves.	-4	**-3**	1
30. It's so frightening to imagine the darkness and silence in a cave that my mind shuts down.	-3	**-3**	2
32. Stalactites, stalagmites! These form really scary figures.	-3	**-3**	2
43. Nothing is dangerous if you prepare yourself for it.	1	**-3**	-2

This group consists of the observers who admire the incredible size of caves (16) and the tight passages (17), as well as being fascinated by the underground world (18, 20). Like the preservationists, these individuals reject the presence of graffiti (15) and would like to preserve caves (14); they also share an attraction to the darkness and silence and are not frightened by bats and eerie formations, but in contrast, they are more concerned with the dangers of caves (21), even with preparation (43), although they would definitely like to return (22). What is unique about these individuals is their admiration of the physical aspects of the caving experience: extensive horizontal development and narrow passages. These individuals have become interested in caves, but not especially their preservation; however, the arousal of interest may lead them to return to other caves in the future, and they may then develop a more protective view of them. The reliability of this factor is also high, although the standard error is equally large.

Factor C

Factor C is composed of sixteen individuals; 8 of which are defining Q-sorts. Three are mixed loaders also concerned with the protection of caves, whereas five combine the point of view of C with an interest in factual observation. The fact that all individuals linked to this factor have negative loadings means that a change of signs can be considered for all the items to facilitate interpretation. Only those distinguishing items which signal differences once the sign is considered are marked; moreover item 14 has been included, as it distinguishes by its lack of importance in the point of view of the individuals in this factor.

	A	B	C
34. Caves are all right, but they aren't worth anything.	-3	-2	**4**
*40. Caves are unpleasant [places] because they're cold and full of hard rocks and holes.	-2	-1	**4**
2. You can find yourself in the solitude of a cave.	0	-2	**-4**
37. Caves are magical, something you don't see, something rare.	-1	2	**-4**
1 Adventure seems to be something rather irresponsible.	0	-1	**3**
22. Caves? I don't go t caves. I'm afraid!	-4	-4	**3**
25. There are pits, vampires, it's really dangerous!	-2	-2	**3**
42. The idea of a cave is sinister, it's scary, because the movies present them that way.	-1	0	**3**
17. There are lots of tight places to go through.	0	4	**-3**
20. Caves are really interesting, because they are the opposite of the normal world.	1	3	**-3**
26. You lose all notion of time when you spend a long time inside a cave.	0	0	**-3**
36. It's great to feel a tingle of fear in the pit of your stomach.	2	-1	**-3**
*14. It's ridiculous to need raw material and be forced to keep protecting caves.	-4	-3	**1**

This group consists of individuals who appreciate the mystical aspects of caves. After only a single visit to a cave, they appreciate the mystical aspects of a cave (37) and the communication with their innermost thoughts facilitated by the solitude (2) in this fascinating underground world (20). This attraction is accompanied by a denial of any disagreeable nature of a harsh cave environment (40, 42, 25) and the affirmation of the value of caves (34). These individuals share with those of Factor B the enjoyment of the little tingle of fear in the pit of their stomachs (36) and the appreciation of adventure (1, 10). Although they are less concerned with the removal of minerals from caves than are those of the other two factors, they are even more explicit about the value of caves; which may be due to the personal identification with the spiritual nature of their caving experience .

This study of the subjective opinions of university students after their first experience with information about caves and their first visit has revealed that the students have focused on three different aspects of their caving experience, although only one resembles the points of view reflected by habitual Brazilian cavers (EL-DASH and SCALEANTE, 2005). A similar study with a larger sample may reveal even more points of view. However, the emergence of the point of view emphasizing the preservation of caves (and the inclusion of these items for several mixed loaders) is encouraging, as it suggests that the module has been effective.

Bibliographic references

COLLET, Guy-Christian. (1976). A arqueologia e seus amadores. Espeleotema n° 10. Departamento de Arqueologia, SBE-Sociedade Brasileira de Espeleologia. São Paulo, SP.

_____ (1978). Orientação arqueológica/paleontológica para espeleólogos. Espeleotema n° 11. Departamento de Arqueologia, SBE-Sociedade Brasileira de Espeleologia. São Paulo, SP.

_____ (1978). Pré-história e espeleologia. Espeleotema n° 12. Departamento de Arqueologia, SBE-Sociedade Brasileira de Espeleologia. São Paulo, SP.

EL-DASH, L G. and SCALEANTE, O. A. F. (2001). Factor analytic study of adolescent attitudes towards caves. Proceedings of the 13th International Congress of Speleology, Brasilia, p. 289-291.

EL-DASH, L. G. and SCALEANTE, O. A. F. (2005). Atitudes de freqüentadores de cavernas: um estudo usando metodologia "Q". Anais of the 28th. Brazilian National Speleological Congress. Campinas, SP.

FIGUEIREDO, Luiz Afonso Vaz de. (1998). Cavernas Brasileiras e seu Potencial Turístico, um Panorama entre a Escuridão e as Luzes. Em: F. P. Vasconcelos. Turismo e Meio Ambiente. Fortaleza: FUNECE.

MCKEOWN, B, and THOMAS, D. (1988). Q Methodology. Newbury Park: Sage Publications

STEPHENSON, W. (1953). The study of behavior: Q-technique and its methodology. Chicago: Univ. of Chicago Press. _____ (1978). Concourse study of communication. Communication 3: 21-40.

351

O-107

A Century of Linkages and Synergy: Western Kentucky University and the Mammoth Cave System

D. Groves, C. Groves, W. Hawkins
Western Kentucky University, Bowling Green, Kentucky, USA

Abstract

South central Kentucky's Mammoth Cave System is by far the most extensive known cave system on earth, and has been designated not only as an American National Park, but also by UNESCO as a World Heritage Site and International Biosphere Reserve. In addition to the unique natural landscape, there has been a rich human history in and around the cave over several thousand years. Nearby is Western Kentucky University (WKU), which since the early 1900's (and as various precursor institutions including the Potter School for Young Ladies and later the Western Kentucky State Normal School) has had numerous interactions with the cave system and its proprietors. These events and relationships have been remarkably synergistic, for example providing the University with a nearby, world-class learning environment while offering the cave managers, particularly in recent decades, the expertise of faculty and student scholars in interpreting the cave system, landscape, and associated resources. Early interactions include many school field trips to the cave and area, which originally involved multi-day excursions. While some of these were by train between Bowling Green and the cave, at least in some cases the boys would make the 100-kilometer round trip on foot accompanied by horse-drawn wagons loaded with girl students who, while riding ahead of the boys, would sing songs to encourage and provide energy to their walking colleagues. A camping trip along the Green River after one such cave trip was described as having festivities occurring to a level "not seen since the celebrations of the Danes on the morning after the slaying by Beowulf of the sea-monster Grendel." A particularly significant event occurred in early 1925 when the assistance of the WKU football team was requested (along with many others participating) in the attempted, and ultimately unsuccessful, rescue of trapped cave explorer Floyd Collins at Sand Cave. Class field excursions still continue regularly to the cave, and more recently several departments have developed interactions at the cave including professional funded research, graduate thesis and undergraduate research projects, and extensive educational experiences. These include the WKU Center for Cave and Karst Studies Summer Field Studies Program and the Mammoth Cave International Center for Science and Learning, jointly funded by Mammoth Cave National Park and WKU's Center for Cave and Karst Studies. Through the years the WKU library system has built an extensive collection of contemporary and historical print materials concerning Mammoth Cave. An important outreach beyond the cave and University community involves the recent and ongoing collaborative work between The WKU Libraries and Museum and Mammoth Cave National Park, funded through the US National Park Service Cost Share Challenge Program, to inventory, organize, and make available online these materials for broad access through the internet

O-108

CAVES CONNECTED WITH THE Gravitational spreading of the elevated mountain ridges in the Moravian-Silesian Beskids (CZECH REPUBLIC)

Oldrich Krejci[1], Frantisek Hubatka[2] and Jan Svancara[3]

[1]*Czech Geological Survey, Branch Brno, Leitnerova 22, 658 69, Brno, Czech Republic, okrejci@cgu.cz*
[2]*KOLEJCONSULT& servis, spol. s r. o., Krenova 131/35, 602 00, Brno, hubatka@kcas.cz*
[3]*Institute of Physics of the Earth, Faculty of Science, Masaryk University, Tvrdeho 12, 602 00, Brno, Czech Republic, svancara@ipe.muni.cz*

Abstract

According to geomorphologic, seismic and gravimetric analyses carried out in the area between Frenstat pod Radhostem and Vsetin, today, the mountain regions of Knehyne and their wider neighbourhood are not in balance with the platform basement and the processes of erosion. This is caused by the fact that, due to the accumulation of light masses of Lower Miocene rocks of the Carpathian Foredeep in footwall of the Godula nappe and frontal parts of the Magura nappe, mountain peaks arrived to higher altitudes than one would expect from simple overthrusting of the Silesian and Subsilesian units over the underlying foreland. Consequently, the whole mountain massifs experience gravitational spreading and break-up, which is well documented by development of deep and widespread deformations - predomininantly by pseudokarst phenomena. Concept of gravitational break-up of whole mountain complexes by mechanism of gravitational spreading is presented. The mechanism of gravitational spreading may in specific instances generate gravitational nappes but, for the most part, it is effective on continental slopes of the present-day oceans. More recently, however, the gravitational spreading is often considered in explanations of extension of mountain regions during final stages of orogenic cycles when the tectonic uplift exceeds topographic reduction due to denudation and erosion, which is the case of the Western Carpathians flysch.

Introduction

Silesian unit forms a dominant structure within the nappe system of the Outer Western Carpathians. This unit, which is highly differentiated in terms of facies distribution, is exposed mainly in the Moravian-Silesian Beskids. In the N, it is thrusted over the Subsilesian unit and Miocene deposits of the Carpathian Foredeep whereas in SE it dips under nappes of the Magura flysch. Different erosional-denudational properties of the unit are markedly reflected in the morphology of the Moravian-Silesian Beskids and their foothills. Major mountain massifs are composed mainly of Upper Cretaceous sandstone complexes whereas morphological depressions are composed of units with higher representation of mudstones of Upper Cretaceous and Palaeogene age.

Geological setting

The Silesian unit represents one of the most vivid examples of flysch basins in the Outer Western Carpathians. Sedimentation in a relatively long time interval from the Malmian (Oxfordian) to the late Oligocene can be traced in this unit. Deposits of the Silesian unit are well differentiated both vertically and horizontally, offering good examples of possible facies relationships within a flysch basin.

The Silesian unit is a block nappe, which is thrusted on top of the Subsilesian nappe and the autochthonous foreland. The nappes were folded and thrusted far on the platform foreland during the lower to middle Miocene phases of the Alpine orogeny. The original area of deposition of the units is well known and, as indicated by the presence of blocks of Devonian limestones and Carboniferous coal-bearing sediments in conglomerate sections, it was underlain by crystalline rocks of the Brunovistulicum and its sedimentary cover. Horizontal distance of overthrusting is estimated to be more than 50 km.

The Godula partial nappe is represented mainly by lithostratigraphic units of Upper Cretaceous age - the Godula and Istebna Formations. Thickness of the core part of the nappe with the formations slightly interfolded is up to 3 km, which is documented by Stare Hamry-1 borehole (more than 2705 m, Roth 1969). This compact part of the nappe is underlain by Lower Cretaceous sediments - Tesin-Hradiste, Verovice and Lhotka Formations. Overlying units represented by the Sub-Menilite, Menilite and Krosno Formations are preserved only in a marginal fringe of the core nappe. Evidence from seismic profiling indicates that the Silesian nappe is rootless and it quickly wedges out over a small distance from the Magura nappe.

The amount of internal shortening of the Silesian unit calculated by Nemcok and others (1998) is 10.3 km (47%), which gives 11.7 km from the total width of 22 km. However, in case of the Silesian nappe the covering partial nappes with different trajectory of movement became detached due to different rheologies of the body of the Godula nappe and the underlying and overlying units. The Upper Jurassic and Lower Cretaceous members with higher proportion of mudstones and rhythmical, fine-grained flysch successions were disintegrated forming tectonic breccias that, together with the Subsilesian nappe, acted as a lubricant for the Godula nappe core. Today, huge rigid bodies of the Godula nappe core constituting the Knehyne, Lysa hora and several other massifs separated by erosion rest on these unstable sediments. Upper parts of the Palaeocene to Oligocene sediments were detached during the transport and remained buried under the Magura thrust, where they generate gravity minima.

According to our own geomorphologic, seismic and gravimetric analyses carried out in the area between Frenstat pod Radhostem and Vsetin, today, the mountain regions of Knehyne and their wider neighbourhood are not in balance with the platform basement and the processes of erosion. This is caused by the fact that, due to the accumulation of light masses of Lower Miocene rocks of the Carpathian Foredeep in footwall of the Godula nappe and frontal parts of the Magura nappe, mountain peaks arrived to higher altitudes than one would expect from simple overthrusting of the Silesian and Subsilesian units over the underlying foreland. Consequently, the whole mountain massifs experience gravitational spreading and break-up, which is well documented by development of deep and widespread deformations. According to Wagner and others (1990), the accessible depth of the Knehyne abyss is 57.5 m (Fig. 1) and demonstrable depths of several open fissures are more than 100 m. A similar situation can be seen on top of the mount Lysa hora, where the fissures, completely filled with detritus, were exposed during construction of television transceiver (see e.g. unpublished reports by Novosad et al. 1975 - 1984, in CGS-Geofond Praha)

systems intersect in the apical area of the mount Certuv mlyn. Fissures of the N-S fault system on the top of the mount Certuv mlyn, widened by erosion, form a several-metres deep morphological depression with presence of pseudokarst features. A root edge of a bulky sheet slide extended for many hundred metres down to the valley was found at about 100 m distance SW from axis of a ridge outspreading from the top of the mount Certuv mlyn towards SSE.

Also the Knehyne cave was formed on intersection of tectonic lines. Predominant system is represented by vertical, E-W (280-110°) trending fissures, on which also the "Dom objevitelu" (Hall of discoverers) has been formed. Of the same direction is also a pronounced field depression or even gorge located uphill from the cave entrance, where a huge block of bedrock was tilted along a tectonic line providing a precondition for development of an abyss-cave system. Directions of another significant system of joints are 105/80° and 296/85°, i.e. approximately N - S. In concurrence with rockfalls and settling of rock blocks, this joint system combined with the E-W directions played a significant role in shaping of the Knehyne abyss. Directions of additional joint systems found in the cave labyrinth are 48/85o (entrance fissure), 8-188/90o and 95-275/90o, which correspond to directions of the main systems.

To sum up, this abyss developed on intersection of joint systems, which belong to important regional systems of faults. Exogenous processes of settling and sagging of sandstone blocks and flushes of rainwater and waters from snow melting resulted in continuous expansion and deepening of the cave areas. The exogenous processes continue to shape the cave system up to the present day.

Similar situation was found on the highest mountain peak of the Moravian-Silesian Beskids, again composed of the Godula nappe - the mount Lysa hora. A geotechnical and geological investigation within the framework of television transceiver construction was carried out here in the first half of 70s. A dense network of open fissures filled with debris and clays was discovered after removal of stony and clayey talus sediments. The appropriate documentation was prepared by Novosad (1984). He presented a simple geotechnical model assuming that the whole mountain massif was disintegrating along slide planes extending down to the base of the Silesian nappe.

Fig. 1. Entrance to Knehyne cave system through the open fissure.

Nemcok et al. (1998) addressed the issues of erosion of the mountain peak regions estimating the erosion to be 1 to 2 km. Since sediments younger than the Istebna Formation are absent in the peak parts of mount Knehyne and mount Lysa hora, we believe this estimate to be correct, although tectonic erosion during the material displacement within duplex nappe slices might also have been partly involved (it can be assumed that this area has been partially overlapped by the frontal part of the Magura nappe. Despite the estimated loss of material, the denudation processes and degradation are not sufficient and balanced, resulting in gravitational break-up of whole mountain massifs.

Geological conditions in the Knehyne - Certuv mlyn area, description of geodynamic phenomena (pseudokarst, landslide-prone areas)

Middle parts of the Godula Formation with thickly rhythmical flysch and thick-bedded glauconitic sandstones are exposed in landslide-prone areas on the hill slopes of Knehyne and Certuv mlyn Mts. (Figs. 2, 3). Individual layers reach thickness of several metres. Sedimentary bed contacts between individual turbidite rhythms are visible in the Knehyne abyss. Bed strikes and dips in the Knehyne abyss vary from 216/20° and 270/10° near the entrance to 49/10° in the "Dom objevitelu" (Hall of discoverers). Variations in bed strikes and dips are caused by tilting of huge blocks of sandstone layers, whose original dip was relatively very low - 20° or less. Field survey has revealed variations in bed dips on regional scale, due to the tendency of sandstone layers with low dip values to align conformably with the slope as a consequence of mass movements.

A feature which is totally predominant in the central area of the Godula nappe is represented by fault systems. Major faults revealed from geological mapping have N-S, E-W and SW-NE directions. All of the fault

Conclusions

We have compiled gravimetric maps and derived gravimetric maps of the broader vicinity of Roznov pod Radhostem that allowed us to refine the interpretation of reflection seismic profiles 221/77, 221A/80, 221B/79 and 221C/80. Results from the wave image analysis suggest that the lower formations of the Silesian unit together with the autochthonous Karpatian sediments have been overthrusted by the Magura unit. On the contrary, upper complexes of the Silesian unit form a minor, bowl-shaped depression in front of the Magura thrust. The enlarged thickness of lower density masses of outer flysch thrusts and/or autochthonous Karpatian sediments is manifested by residual gravity disturbances minima. The underthrusted lower density masses of Miocene age, off-scraped from the ramp of Palaeozoic sediments, produced a higher topography of the Silesian nappe than one would expect from its simple stratigraphic thickness including tectonic repetition.

The above-mentioned opinions are in accordance with our concept of gravitational break-up of whole mountain complexes by mechanism of gravitational spreading. The mechanism of gravitational spreading may in specific instances generate gravitational nappes (Merle 1998) but, for the most part, it is effective on continental slopes of the present-day oceans. More recently, however, the gravitational spreading is often considered in explanations of extension of mountain regions during final stages of orogenic cycles when the tectonic uplift exceeds topographic reduction due to denudation and erosion, which is the case of the Western Carpathians

353

flysch. A typical present-day example of extensional break-up of main elevation ridge of an orogene is represented by the Apennines. In this mountain range, frequent transtensional, fault-bounded valleys are produced, which are rapidly deepened by erosion (Moores and Fairbridge, eds., 1997). Correctness of our hypothesis is evidenced by measurements of residual shear stress at the base of the Silesian nappe, which indicate directions from SE despite the fact that the thrusting ended already in the Badenian. This residual stress caused destruction of a newly-constructed shaft of the Frenstat pod Radhostem coal mine (Dopita et al., 1997).

References

Dopita, M., et al.: 1997, Geologie ceske casti hornoslezske panve, Ministerstvo zivotniho prostredi Praha, 1-278

Mencik, E., et al.: 1983, Komplexni geologicke zhodnoceni useku Sever, Manuscript. Ceska geologicka sluzba Praha

Merle, O.: 1998, Emplacement Mechanisms of Nappes and Thrust Sheets, Kluwer Academic Publishers, Dordrecht, 1-159

Moores, E. M. and Fairbridge, R. W., eds. : 1997, Encyclopedia of European and Asian Regional Geology, CHAPMAN&HALL, 414-435

Nemcok, M., Houghton, J. J. and Coward, M. P.: 1998, Strain partitioning along the western margin of the Carpathians, Tectonophysics, 292, 1-2, Amsterdam, 119-143

Novosad, S.: 1984, Zaverecna zprava o instrumentaci a kontrolnich merenich stability nekterych objektu souboru staveb televizniho vysilace Lysa hora, Manuscript. CGS-Geofond Praha

Roth, Z., et al.: 1969, Vrt Stare Hamry 1a (okres Frydek-Mistek), Manuscript. CGS-Geofond Praha

Svancara, J.: 1995, Nova definice Bouguerovy anomalie, Manuscript. Geofyzika, a. s. Brno

Wagner, J., et al.: 1990, Jeskyne v Moravskoslezskych Beskyd a okoli., Ceska speleologicka spolecnost Praha, 1-131

O-109

Seismothems caused by neotectonic activity in the Eastern Alps

L. Plan, Ch. Spötl, B. Grasemann, K. Decker, K.H. Offenbecher, G. Wiesmayr

Institute for Geological Sciences, University of Vienna
Institute for Geology and Paleontology, University of Innsbruck

Abstract

During the exploration of the 1.2 km long and 173 m deep Hirschgrubenhöhle, abundant scratched, sheared and broken speleothems were found. This cave follows a system of brittle faults, which are associated with both, cohesive and non-cohesive cataclasites, suggesting progressive deformation of the fault zone during exhumation. Because Quaternary mass movement and ice-movement in the cave, which are known to cause deformations on speleothems, can be excluded, these deformations are presumably seismothems, i.e. speleothems that were broken or deformed by fault slip associated with seismic events. These deformed speleothems are therefore important indicators of neotectonic and palaeoseismic activity (Delaby, 2001). Here, we present evidences for seismic events from Hirschgrubenhöhle, which lies in the centre of the karst-plateau of the Hochschwab Massif (Styria, Austria). This area is located 8 km south of the master fault of the left lateral Salzachtal-Ennstal-Mariazell-Puchberg-Line (SEMP) which was mainly active during the Oligocene and the Early Miocene lateral extrusion of the Eastern Alps towards the Pannonian Basin (e.g. Linzer et al. 2002). The SEMP is situated close to the southern margin of the Northern Calcareous Alps and has a cumulative sinistral offset of several tens of kilometres. Some earthquakes have been recorded along the SEMP and recent GPS measurements suggest ongoing extrusion of the Eastern Alps (Grenerczy et al. 2000). However, because the ongoing extrusion is mainly accommodated by younger strike-slip faults associated with the opening of the Vienna basin (Decker et al, 2005), it has been largely unknown if the SEMP is still an active major fault zone. No direct field evidence for active tectonics or at least neotectonic activity has so far been reported. The seismothems in the Hirschgrubenhöhle consist of a sheared off stalagmites and flowstone, flowstones that were scratched by boulders and broken flowstone. All show a sinistral strike-slip movement which is consistent with the kinematics of the SEMP. Some of the broken fragments of the speleothems are overgrown by younger layers of flowstone. Both fragments and overgrowing flowstones were dated by the mass spectrometric U/Th method in an attempt to constrain the time frame of fault movement. First results suggest that a seismic event with at least 20 cm offset took place between 11 and 86 ka. These observations of neotectonic movement of the SEMP are consistent with GPS measurements, showing an offset of several millimetres per year of the units south of the fault-line. References Delaby, S. 2001. Palaeoseismic investigations in Belgian caves. Geologie en Mijnbouw 80(3-4), 323-332. Decker, K., Peresson, H. and Hinsch, R., 2005. Active tectonics and Quaternary basin formation along the Vienna Basin Transform fault. Quaternary Science Reviews, 24(3-4): 305-320. Grenerczy, G., Kenyeres, A. & Fejes, I. 2000. Present crustal movement and strain distribution in Central Europe inferred from GPS measurements. Journal of Geophysical Research 105(B9), 21835-21846. Linzer, H.-G., Decker, K., Peresson, H., Dell'Mour, R. and Frisch, W., 2002. Balancing lateral orogenic float of the Eastern Alps. Tectonophysics, 354(3-4): 211-237.

354

O-110

Ghost Cave, Eastern Himalayas, Bhutan.

John All, Chris Groves, and Pat Kambesis.

Hoffman Environmental Research Institute, Western Kentucky University, 1906 College Heights Blvd #31066, Bowling Green, KY 42101, USA.
john.all@wku.edu

Abstract

Limestone deposits in the country of Bhutan are relatively sparse and caves are rare because of the rapid uplift of the Himalayas. The major limestone units that do exist, which have been geologically investigated in the context of mining for cement production, occur mainly in the lower elevations of the country's south. However, two caves have been documented in the country to date; one in the Bumthang district and the other near Kahling in eastern Bhutan. In November 2004, a reconnaissance expedition was fielded to the Bumthang district to investigate 'Ghost Cave'. The cave, with an entrance elevation of 3,152 meters, is two hundred meters in length with a mapped vertical extent of thirty-five meters and a steady downward slope. Cave development appears to be a function of turbulent flow as opposed to fracturing which also might be possible in such an active tectonic environment. Secondary mineralization in the form of speleothems reflect heavy precipitation that is typical of Asian monsoon seasons. The cave shows evidence of a long history of speleothem collection and local interviews confirmed that these features have been used as religious offerings. While Buddhist religions generally have a 'soft' environmental impact, for Ghost Cave the impact to speleothems has been severe.

Introduction

The Himalayan Mountains are the largest on Earth and are still actively growing at the geologically rapid rate of over a centimeter per century as the subcontinent of India collides with Asia. The Himalayans stretch in a long arc along India's northern border; nearly reaching Pakistan to the west and Burma to the east. Limestone deposits in the Eastern Himalaya are relatively sparse (Gassner, 1983; Jangpangi, 1971) and when combined with the rapid uplift of the landscape mean that there has been very little cave development. The Eastern Himalayas are part of the upper watershed of the Ganges-Brahmaputra-Meghna River Basin, which has the third largest watershed runoff in the world after the Amazon and the Congo-Zaire Basins (Bandyopadhyay, 2002) and rainfall averages 500-1000 mm per year in the lower alpine elevations. Under these cool moist conditions, limestone dissolution and cave formation is possible if local erosion is more rapid than geologic uplift.

Bhutan and the Eastern Himalayas

Bhutan is the only independent country remaining of the isolated Buddhist Kingdoms. The others have been absorbed by China or India. Bhu-
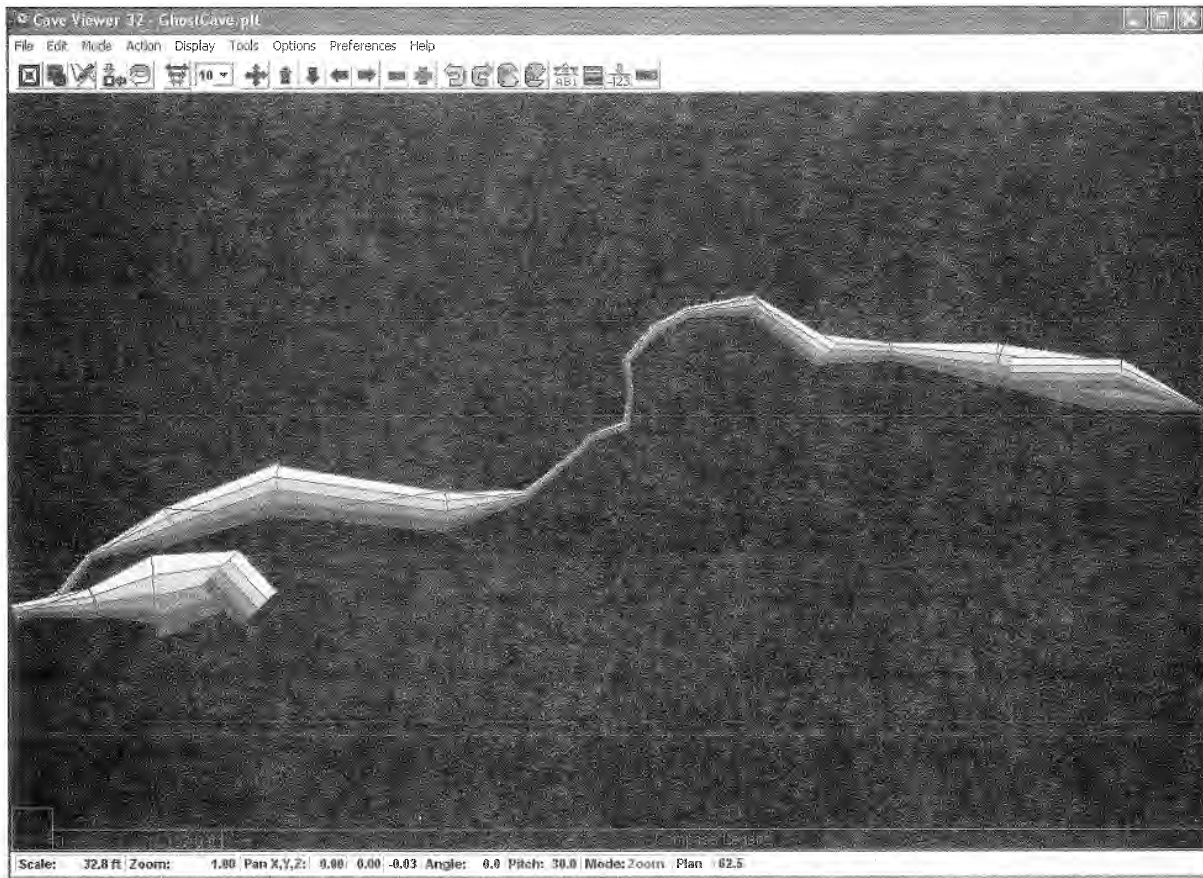

Figure 1: Plan View of Ghost Cave, Ugyen Chholing, Bhutan. The entrance is at the far right.

tan is located on the southern edge of the Eastern Himalayas with Tibet to its immediate north. India surrounds the other sides and is Bhutan's major ally (helping buttress against a potential invasion by China (Staff, 2004)). Bhutan hosts numerous Indian soldiers and India maintains several training facilities and bases in Bhutan. Indian is also Bhutan;'s major trading partner and the major consumer of Bhutan's number one export - electricity. Nepal is very close to Bhutan's eastern border and Bangladesh is near the southern border and also a major trading partner. Bhutan is an extremely rugged country with a major elevational gradient. The country stretches 200 km north to south and the elevation changes from less than 100 m to over 7500 m. Overall, less than eight percent of the country is available for agriculture due to the steep slopes and soil composition (Baillie et al., 2004).

This reclusive Kingdom has been essentially closed to outsiders for most of its history and even now it is very difficult and expensive to gain access for research purposes. However, thanks to some good contacts and luck, the Hoffman Institute had the opportunity to explore the karst regions of Bhutan with financial support from the Western Kentucky University Office of Sponsored Programs and logistical support from the World Foundation for Environment and Development. Most known caves (normally 'shelter' caves) in Bhutan are associated with religious figures and have served as long-term meditational retreats. Caves have long been associated with religious figures in the Buddhist religion because they provide instant, temporary shelter for a person to retire and meditate for a period without having to create a hut or other domicile. Also, they are associated with overcoming the demons that are thought to dwell within such dark spaces. Most of the caves are small shelter-type overhang caves rarely more that 5 meters deep. Reconnaissance by the author of various rumored caves in the study area revealed this to be the dominant cave type.

During the expedition, it was decided to focus on an area that contained a rare limestone cave located in the province of Bumthang (Motegi et al., 2001). Bumthang is located in the north-central part of Bhutan and is relatively flat compared to most of the rest of the country. Population density is relatively higher in this province than elsewhere due to the flatter land and increased agricultural opportunities. The high population density means that existing caves are more likely to have been encountered. In Bumthang there were rumors of additional caves and similar rumors persist throughout the poorly explored east and south of Bhutan.

Ghost Cave

The cave, with an entrance elevation of 3,152 meters, is two hundred meters in length with a mapped vertical extent of thirty-five meters and a steady downward slope. According to local residents of Ugyen Chholing (the small village nearest the cave), Ghost Cave is the local name for the cave. The cave developed by turbulent water flow rather than simple fracturing. The cave mostly follows the dip of the local strata, though for a short segment, does trend on the strike (Motegi et al., 2001). The cave's passages are tube-like and thus probably phreatically formed (Palmer, 1991). It is speculated that the cave is an old meander cutoff of the massive Tang River. Ghost Cave is well decorated with speleothems - derived from the heavy precipitation associated with the Asian Monsoon

The cave entrance is formed at the contact between a calcite formation and a calcarenite formation. The existence of the cave raises the question of whether tectonic stability would have been required over the period of the cave's evolution in an otherwise continuously uplifting tectonic regime. Calcarenite (a sandstone-like rock composed of calcite rather than quartz particles) is susceptible to very rapid physical and chemical erosion and thus it is possible that only a short period of stability would have been required to form the cave. The cave passage's lowest level ends with breakdown on the floor and strongly blowing cool air issuing from the

breakdown blocks, suggest that the cave continues beyond what is currently known.

Caves and Nyingma Buddhism

Guru Rimpoche (the most important of Bhutan's spiritual and historical figures) was first invited into Bhutan to save a local ruler from a cave-dwelling demon (Armington, 2002). Traditionally, such demons are faced by 'enlightened' figures, such as Guru Rimpoche, who are buoyed with Buddhist spiritual power. The demons are usually converted by this spirituality into a protective Buddhist deity for local areas according to interviews. After the successful conversion of this particular demon (called Shelging Karpo), Guru Rimpoche used the cave to meditate for several years before he began traveling and teaching in Bhutan. The cave is now part of a temple complex called Kurjey Lhakhang and it is considered so holy that when the kings of Bhutan die, their bodies are cremated here. Guru Rimpoche and other figures such as Ngawang Namgyal (the founder of the country of Bhutan) and Pema Lingpa have a variety of caves associated with them including Taktshang Goemba (Tiger's Nest), Gom Kora, and Membartsho (Burning Lake; which is surrounded by small shelter caves) among many others.

Speleothems in these types of shelter caves are exceedingly rare but when they have been encountered they are removed and placed on alters, in shrines, or in chortens according to interviews with the local residents. Chortens are sealed religious structures built to surround and protect a holy artifact and desecration of these chortens is one of the most heinous of crimes in the Buddhist religion; equal to or surpassing murder (very striking in this vegetarian, non-killing focused religion) and in Bhutan results in a lifetime jail sentence. Based on local interviews, chortens are created by governments to appease local spirits and ward away floods or traffic accidents. A special set of chortens near the capital (Thimphu) was created after a border skirmish in order to atone for the nation's spiritual burden resulting from killing their enemies. Individuals generally create a chorten as a means of getting good karma and to atone for past misdeeds. Most chortens are created by individuals.

In Ghost Cave, speleothems appear to have slowly been removed over perhaps hundreds of years. Removal began from the entrance and the easiest to reach and then moved inward to the areas where they are more actively forming (the cave gets wetter as you move further into the passage). All of the easily reached speleothems were gone (even including large draperies). The oldest ones near the entrance (now quite dry and inactive) were removed so long ago that they began forming new features over the scars before they dried out. The speleothem scars typically generated 'popcorn' formations as opposed to the stalactites/stalagmites they were replacing.

Hundreds of kilograms, perhaps even tons of speleothems have been removed in this very active cave. With the lack of market economy, economies of scale, lack of history of exploitation or harvest, and lack of a road to transport them, this must have been done over hundreds or even thousands of years. None of the locals (including a man 70+ years old) even realized that more than a handful had been removed. This indicates that it was done by monks (who didn't talk about it) or was done over a very long time period, or most likely, both of the above. The cave is located on an unstable slope exceeding 50 degrees and removal of large features would have been a very difficult process. There is no beaten trail of any kind leading to the cave and even a 50-year old man who had been there on several occasions in the past who was acting as a guide had to retrace his steps several times to find its exact location. A 25-year old man from this small village had never visited the cave and did not know its location. Systematic short-term removal by teams of people would have created a safer, more defined trail even if it had occurred in the past.

Discussion

From the appearance of the cave and local interviews, it is theorized that entrance into the cave (with a torch) was seen as a way to pay penitence for past crimes. Such penitence is extremely common throughout the Buddhist religion as practiced in Bhutan. Thousands of chortens and other religious shrines throughout the country are created in such a way. The terror and difficulty in obtaining speleothems with a flickering torch would make them especially valuable for karmic retribution and penance. In fact the local name of 'Ghost' cave describes the fear with which such features are generally treated.

There were also rumors that the cave at one time extended to a monastery on the road to the Tang village. While this is probably impossible (the cave would have to descend hundreds of meters and then cross the Tang river at its current level, 200 meters below the groundwater level during the cave's formation period and then trend back upward to the monastery) it raises interesting questions about the existence of other caves in the area and how involved monks were in their explorations. A key question is if there is in fact another long cave hidden within the Monastery boundaries. Perhaps entrance into the cave and retrieval of a speleothem was required for entrance into the formal monkhood (generally at the age of 15 years).

The removal of large sections (0.5m x 0.5 m pieces) of draperies and large (20 cm diameter) stalagmites would have been difficult to break loose and to carry at a weight of dozens of kilograms. This indicates that tools were used and that several people were involved in many cases. For speleothems in the rear of the cave, these would have been dragged through the low narrow passage (0.5m height x 0.5m width) in the middle of the cave length. Locally, there is absolutely no tradition of stone working or artist working of cave features and a complete lack of evidence of the whereabouts of the missing speleothems. Due to their weight and the long unpaved nature of the road. (the section to Ugyen Chholing itself was only bulldozed in 2000 and the bridge and road from Tang village are less than 35 years old, there were no paved roads anywhere in the country prior to 1961 (Staff, 2004)), these features were almost certainly not exported. The only explanation for these disappearing speleothems is that they have been hidden in the local monastery or placement inside chortens.

Ghost Cave in Bhutan is a rare example of a limestone cave in the rapidly uplifting geological environment of the Himalayas. While the cave has actively formed many speleothems, nearly all have been removed over a long time period. Overcoming the fear of entering "Ghost" Cave and removing a small piece of the cave to put in a chorten has probably been a traditional religious practice that has led to the complete removal of small and medium speleothems from the cave. Future work is needed to see if this practice is followed in other parts of Bhutan and in other Buddhist regions.

Bibliographic References:

Armington, S. 2002. Bhutan. Oakland, Ca:Lonely Planet Publications. 320 pp.

Baillie, I. C., K. Tshering, T. Dorji, H. B. Tamang, T. Dorji, C. Norbu, A. A. Hutcheon, and R. Baumler. 2004. Regolith and Soils in Bhutan, Eastern Himalayas. European Journal of Soil Science, 55:9-27.

Bandyopadhyay, J. 2002. A Critical Look at the Report of the World Commission on Dams in the Context of the Debate on Large Dams on the Himalayan Rivers. Water Resources Development, 18(1):127-145.

Gansser, A., 1983, Geology of the Bhutan Himalaya. Basel: Birkhauser-Verlag, 178 p.

Jangpangi, B. S. 1971. Stratigraphy and Tectonics of Parts of Eastern Bhutan. Himalayan Geology. Delhi:Wadia Institute of Himalayan Geology, Vol. 4.

Motegi, M., T. Koike, and P. Norbu. 2001. The First Finding of the Limestone Cave in the East Himalayas, Ugyen Chholing, Bumthang. Bhutan Geology, 5:5-7.

Palmer, A. N. 1991. Origin and Morphology of Limestone Caves. Geological Society of America Bulletin. 103:1-21.

Seeland, K. National Park Policy and Wildlife Problems in Nepal and Bhutan. Population and Environment, 22:43-62.

Staff. 2004. The Pursuit of Happiness: Bhutan. Economist, 373:55-57. December 18.

357

O-111

Cave systems in the Eastern Totes Gebirge (Austria) and their implication on alpine speleogenesis

R. Seebacher, M. Behm, L. Plan

Caveingclub of Upper Styria, Austria

Caveingclub for Vienna and Lower Austria, Vienna, Austria

The Totes Gebirge, which covers an area of 700 km², is one of the largest karst plateaus in the Northern Calcareous Alps. The stepped plateau reaches from an altitude of about 1500 m a.s.l. up to the summit at 2515 m. On all sides the massif is truncated by deep valleys situated between 400 to 800 m a.s.l. An impressive karst landscape has developed on the plateau and until now about 1400 caves are surveyed. Nevertheless, many areas are still more or less unexplored. Here we focus on the eastern part of the karst massif, which comprises mainly of Upper Triassic Dachstein Limestone. However, it must be mentioned that also in the western part of the Totes Gebirge large cave systems can be found (e.g. Raucherkarhöhle: 83 km and Schwarzmooskogel-Höhlensystem: 56 km). Our contribution is confined to Eastern Totes Gebirge (Südostmassiv, Austrian mountain range No.:1625). Systematic cave exploration started in the 1950'ies, since when overall nearly 100 km cave passages have been surveyed by different groups including french expeditions. However, the majority has been and is explored systematically by the caving clubs of Upper Styria

(VHO) and Vienna. A short description of the major cave systems of the Eastern Totes Gebirge is given, including the Burgunderschacht (length: 18.7 km, depth: -845 m), the DÖF-Sonnenleiter-Höhlensystem (17.6 km, -1054 m), the Grubstein-Westwandhöhle (10.5 km, -396 m) and the Grauer Riese (2.3 km, -418 m). All of these and many other caves in the area have common morphological features: they comprise of "old" horizontal passages which probably date back to the Miocene. These large horizontal passages can be found at the same altitudinal levels in almost all systems. The galleries are intersected by active vertical passages, which developed probably in Quaternary times. Furthermore, sediments and speleothems show very similar characteristics. Some relict cave levels near the summits of the plateau could even date back to Oligocene times. The presented type of multiphase cave development, which is found in many cave systems of the Eastern Alps, can be observed textbook-like in the Eastern Totes Gebirge.

O-112
Geological investigation of the speleothems in limestone caves, Korea

Kim, R., and Woo, K. S., and Choi, D. W.

Cave Research Institute of Korea, Kangwon National University, Chuncheon, Kangwondo, 200-701, Korea

Abstract

There are more than 1,000 limestone caves in South Korea. The caves are mostly distributed in the lower Paleozoic carbonate rocks (Joseon Supergroup) of the central part of the peninsula. Textural and geochemical investigation of the speleothems has been carried out to understand the original mineralogy, formation processes and carbonate diagenesis, using coordinated textural, isotopic and elemental data. Among the speleothems studied, curtain, fried-egg stalagmite, cave shield, and rimstone are solely composed of calcite, and anthodite is composed of aragonite. However, cave coral, stalactite, stalagmite, flowstone are composed of aragonite and/or calcite. Based on the textural observations of more than 500 speleothem samples, five types of aragonitic and ten types of calcitic texture could be categorized.

The aragonitic speleothems show higher Sr and lower Mg contents than calcitic ones. All the speleothems from different caves show their distinctive Sr and Mg compositions, indicating that the fluids responsible for the formation of the speleothems had the different Sr and Mg contents according to locality. The $\delta^{18}O$ values range from -9.4 to -4.0 per mil (PDB) and those of cave water and adjacent stream water range from -10,7 to 9.3 per mil (SMOW), suggesting that most of the speleothems formed in oxygen isotopic equilibrium, except for some enriched aragonitic speleothems. These enriched aragonitic speleothems may indicate that they were formed by evaporation rather than degassing of carbon dioxide. The $\delta^{13}C$ values are quite variable from -10.0 to -5.0 per mil (PDB). These values are between the carbon isotopic compositions of the measured organic carbon in overlying soils and those of the carbonate rocks surrounding the limestone caves. Based on the mass balance calculation about 10 to 25% of the carbon in speleothems studies were from the organic carbon in overlying soils.

Some of the originally aragonitic spleothems such as cave coral, stalactite, and flowstone in a few caves have been calcitized. The neomorphic calcite crystals contain relics of the original aragonite crystals and growth laminae. The presence of these relics in normorphic calcite as well as the similar elemental contents to the original aragonite suggests that the calcitization processes took place in a semi-closed system via thin-film alternation front.

Introduction

Since 1970's, cavers have explored the caves in Korea. Six caving clubs at the universities have played the major role in cave exploration in Korea. The first scientific report on caves was published on the limestone caves of the Daeiri area (Samcheok) in 1987 by Prof. Chong-Kwan Won. After that, many scientific and exploration reports have been published. Cave Research Institute of Korea was established in 2001. The institute has carried out the following aspects of research.
- Scientific investigation of limestone cave
- Environmental and management problems of showcaves
- Cave exploration
- Evaluation of natural caves as monuments
- Geological (sedimentologic and paleoclimatic) research
- Biospleology

Contents of reports and publication lists

There have been three kinds of reports published by Korean cavers and scientists: exploration report, report from scientific investigation, and report on the evaluation of management of showcaves.

Scientific investigation of limestone caves includes:
- Geologic mapping of the cave area
- Cave mapping
- Cave environment (air temp. & humidity, CO2 contents)
- Cave water (water temp. & pH, stable isotopes, trace (and toxic) elements
- Cave sediments
- Micro-topography in cave
- Origin and distribution of speleothems
- Organisms in cave

Published scientific reports by CRIK are as below.
- 1987, Daei-ri area including 7 caves
- 1989, Baekryong Cave
- 1995, Yongyeon Cave
- 999, Okgye, Dongdae, and Namdae Caves
- 2000, Gwaneum Cave, Chodang Cave
- 2001, Gossi Cave
- 2002, Yongdam Cave
- 2004, Cheonho Cave
- 2005, Daigeuml Cave

The report on the evaluation of management of showcaves includes:
- Cave environmental change (temp., humidity, CO2 content, water temp., pH, elemental compositions, etc..)
- Lampenflora problems
- Ecological change of cave animals
- Electrical problems
- Safety of constructed facilities
- Potential rock-fall problems

Published reports on the evaluation of showcaves are as below:
- 1999, Hwanseon Cave
- 2000, 8 show-caves (national monuments)
- 2001, Gossi Cave
- 2003, Seongryu Cave
- 2004, Manjang Cave (lava tube)
- 2005, Yongyeon Cave

The report from cave explorations includes:
- 1997, 38 caves in Mitanmeon, Pyeongchang County
- 2001, 45 caves in Gangneung City
- 2001, 64 caves in Yeongwol County
- 2004, 89 caves in Chungcheongbuk Province

Topics of the published geologic papers are as below:
- Origin of speleothems in Gwaneum and Hwanseon Caves
- Texture of the speleothems in limestone caves
- Origin of speleothems in Dangcheomul Cave
- Paleoclimatic implications from the speleothems in Dangcheomul Cave
- Speleogenesis of Okgye Cave
- Calcitization process of aragonite speleothems

- Origin of cave corals in lava tubes in Jeju Island
- Origin of gypsum flower in Okgye Cave
- Paleoclimatic studies from soda straws
- Paleoclimatic studies from stalagmites

Geological publications in journals and books

Nine papers have been or will be published about the geological aspects of limestone caves and carbonate speleothems. Woo and Won (1989) firstly published the speleothem paper from the Hwanseon and Kwaneum limestone caves in Samcheok. They reported the kinds of speleothems and related to the genesis of speleothems with the supply rate of cave water. Woo et al. (2000) reported the origin of carbonate speleothems in Dangcheomul Cave, which is a lava tube. They suggested that the speleothems were formed by water that was transported through plant roots. Woo (2002) presented the paper in the International Symposium held by the Samcheok City about Cave EXPO and its meaning. Choi et al. (2003) published the comprehensive paper on the genesis of the Okgye Cave (limestone cave) and speleothems. Woo (2003) published the paper about the volcanic landforms and lava tubes and their possibility of the World Heritage nomination. Choi and Woo (2004) reported the calcitization of the aragonite speleothems in Korean limestone caves. Woo et al. (2004) analyzed the stable isotope compositions of the carbonate speleothems in the Dangcheomul Cave (lava tube cave) and tried to relate the data with paleoclimatic variations. Woo et al. (2005) submitted the paper about 80 year-old soda straw and suggested that carbon isotopic data may indicate the global increase in carbon dioxide past several decades. Woo and Choi (2005) suggested that the calcitization of aragonite speleothems takes place in a semi-closed diagenetic system. In addition to the publications above, about 33 abstracts were published in international and Korean geological conferences, and among them, 15 abstracts were published at the international geological conferences.

Conclusions

Geological investigation of the natural caves in Korea started in the late 1980's. Four cave exploration reports were published including the discovery of 233 limestone caves.

Six reports were published on the evaluation of the cave management. Nine scientific reports were published since 1987. Nine papers were published on the genesis of limestone caves and speleothems, and 33 abstracts

were published in international and Korean geological conferences.

References

Woo, K. S., and Won, C. K., 1989, Original mineralogy and carbonate diagenesis of speleothems in Kwanum and Hwansun Cavern, Kangweon-do, Korea: Preliminary results: Jour. Geol. Soc. Korea, 25, 90-97.

Woo, K. S., Choi, D. W., Kim, R. and Kim, J. K., 2000, The origin of the speleothems in Dangcheomul Cave, Jeju Island, Korea, Journal of the Geological Society of Korea, 36, 411-434. (in Korean)

Woo, K. S., 2002, Cave EXPO and its scientific meaning in Korea, The Sustainable Management of Cave: "Academic and Policy Implications", Samcheok, 128-146.

Choi, D. W. and Woo, K. S., Kim, L., and Lee, K. C., 2003, Origin of the Okgye Cave and speleothems, Kangneung City, Journal of the Geological Society of Korea, 39, 41-64. (in Korean)

Woo, K. S., 2003, Natural heritages in Jeju Island and significance of the World Heritage nomination, International symposium on natural heritages in Jeju Island, Cultural Properties Administration, p. 23-53. (in Korean)

Choi, D. W. and Woo, K. S., 2004, Calcitization of aragonite speleothems in some limestone caves, Korea, Journal of the Geological Society of Korea, 40, 227-239. (in Korean)

Woo, K. S., Kim, L., Kim, J. K., Choi, D. W., and Jo, K. N., 2004, Textural and stable isotopic results of the columns in Dangcheomul Cave, Jeju Island, Korea, Journal of the Geological Society of Korea, 40, 133-144. (in Korean)

Woo, K. S., Hong, G. H., Choi, D. W., Baskaran, M., and Lee, H. M., submitted, A reconnaissance on the use of the speleothems in Korean limestone caves to retrospective study on the regional climate change for the recent and geologic past, Geoscience Journal.

Woo, K. S. and Choi, D. Won, in press, Calcitization of aragonite speleothems in limestone caves in Korea: Diagenetic process in a semi-closed system, Geological Society of America Special Publication.

359

O-113

Climate information record in the stalagmites in the Chongqing regions, China

T. Li, D. Yuan, L. Wang, X. He, J. Wang

School of Resource and Environment Sciences, Southwest Normal University, Chongqing, Beibei, China
Karst Dynamic Laboratory, Ministry of Land and Resources, Guangxi, China

Abstract

The East-Asian Monsoon affects the Chongqing region Deeply , but there are rarely Paleoclimatic research done there. In this paper, the authors report the pilot study of two stalagmites in this region which dated by TIMS-U series age method and analyzed for the $\delta^{13}C$ and $\delta^{18}O$. One stalagmite, LT14, deposited in 31.90±0.20ka.BP——15.21±0.08kaBP, record three H events. The date of the H1, H2, H3 are 15.793ka.BP, 24.863kaBP and 30.244ka.BP separately. In the LT14 stalagmite , $\delta^{13}C$ and $\delta^{18}O$ curve have the positive correlation. By analyzing the $\delta^{13}C$, $\delta^{18}O$ and deposit characteristics,separate four primary climate phases.1 in 31.99-30.842ka BP, the smaller values of $\delta^{18}O$ and greater values of $\delta^{13}C$ suggest a warmer and drier climate.2 in 30.842-18.29ka BP the greater values of $\delta^{13}C$ and $\delta^{18}O$ suggest a cooler and dryer climate, but the ampli-tude is limited. 3 in 18.29-16.96ka BP the climate change abruptly. In the beginning of this period the climate is warm and humid, but in the evening of this period the climate turn to dry and cool.4 in the 16.96-15.02ka BP the climate go on turning to dry and cool. The other stalagmite ,SM1, which deposit in 26.50 ±0.09 ka.BP——24.17 ±0.08 ka.BP in another cave about hundred kilometer far away from the LT14,record the H2 event. The most remarkable difference of the $\delta^{13}C$ and $\delta^{18}O$ values between the two stalagmites is that in the LT14,the $\delta^{13}C$ and $\delta^{18}O$ values have the positive correlation ,but in the SM1 stalagmite the correlation is negative. In the past research there are quite a few articles report this difference in the correlation of $\delta^{13}C$ and $\delta^{18}O$,especially in South China and North China , in the regions which affected by the Asian-monsoon. This need more research to be done to interpret this phenomenon

O-114

Submerged Speleothem and Groundwater Chemistry of Inazumi Cave, Oita Prefecture, Japan

K. Yoshimura, K. Kurisaki, K. Urata, H. Schwarcz, D. Ford

Kyushu University, Kyushu University, Fukuoka, Japan

Abstract

A submerged calcite speleothem (stalactite) sample from Inazumi Cave, Oita Prefecture, Japan, was dated by isotope-dilution thermal ionisation mass spectrometry. The speleothem became submerged by accumulation of the Aso welded-tuff, Aso-4, and a resulting rise in the local water table that occurred 85,000 - 89,000 years ago. The age of the analysed portion of the sample was 170,000 years B.P., suggesting that it was deposited before the earlier Aso-2 and -3 eruptions and has been drowned in the groundwater at least three times. Many speleothems are submerged for a period longer than over 85,000 years, and therefore the groundwater had been nearly at dissolution equilibrium with respect to calcite due to slow water circulation. However, undersaturation with calcite dissolution has sometimes happened to the groundwater after the cave was opened for public in 1976 by artificial lowering of the water level by about 4 m.

O-115

Polycyclic origin of fossil karst at Hranice Paleozoic, Czech Republic

Jiří Robert Otava

Czech geological survey, Czech Republic, 658 59 Brno, Leitnerova 22, otava@cgu.cz

Abstract

Hranice karst is a small region of carbonate surface outcrops at the contact of European Variscides and Alpides. The paleokarst history of the karst area has been extremely complicated since Devonian up to present. The oldest karstification is of Upper Devonian age and was proved by conodont stratigraphy. The second one developed at the top of the pre-Cenomanian karst period and its products are kaolinic sands and clays in depressions. The Paleogene and Lower Miocene paleokarst period left buried depressions and valleys filled with Karpatian and Lower Badenian marine sediments. The contemporary karst is in its southern part strongly influenced by hydrothermal processes.

Introduction and the geological beckground

The present surface outcrops of Upper Devonian and Lower Carboniferous limestones in the Hranice Paleozoic are scattered and do not exceed several square kilometers. Nevertheless the limestones are part of a large carbonate platform, its margin and slope. The carbonates are widespread both southeastwards under the Carpathian nappes and northwestwards under the Lower Carboniferous Culm facies. Upper Viséan siliciclastic sediments of the Culm facies (Variscan flysh) overlie the carbonates of the Hranice Paleozoic. Mesozoic left its sediments in the territory of Hranice karst not only as paleokarst infillings of depressions and cavities , but also within Outer Carpathian flysh nappes (together with Paleogene). The position of the Hranice Paleozoic as a rigid block divided from the main surface part of the Moravian-Silesian Variscides and surrounded with Miocene deposits of the Carpathian foredeep plays dominant role in the paleokarst history of the area. The role of the Pliocene fluvial and lacustrine deposits in the Hranice Paleozoic and surroundings was underestimated in the past and a revision and redefinition is prepared.

The scenario of paleokarst periods and phases presented in this paper fits well with the general synthesis submitted for Bohemian massif by Bosák (1995). Local differences from Moravian karst are especially in the oldest, Upper Devonian karstification, while the Cretaceous and Miocene history was common for the whole Central European area.

Upper Devonian karstification phase

Zbrašov aragonite caves are developed in coarse-grained and fine-grained crinoidal calciarenites, locally calcirudites (Vilémovice limestone member of the Macocha formation) and in overlying laminated and nodu-
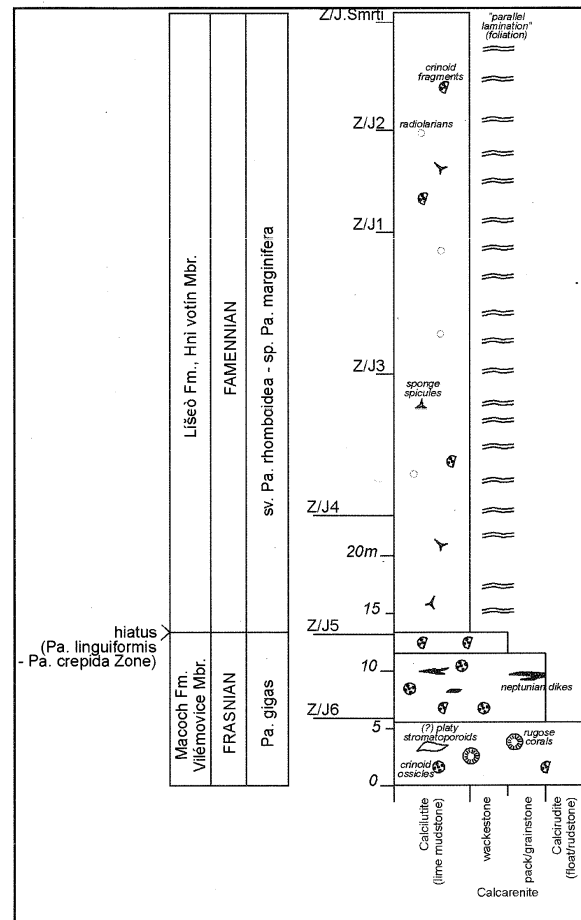
Fig.1 Stratigraphic and lithologic section in the caves perpendicular to cleavage and bedding.

lar calcilutites (Hněvotín member of the Líšeň formation). Section across the cave perpendicular to cleavage and bedding was sampled by O. Bábek for conodonts (Havíř-Bábek-Otava, 2004). Relatively long hiatus including the end of Frasnian and a part of Lower Famenian (conodont zones Pa. Linguiformis up to the upper part of Pa. Crepida) developed between

360

Vilémovice and Hněvotín members. There were probably consequences between the hiatus and origin of cavities later filled with Famenian sediment. The cavities could originate due to emergence and karstification or as classical neptunic dykes, ie. By brecciation of the rock caused by tectonic events. Later on (zone Pa. Rhomboidea, upper part of the Lower Famenian) the deposition continued in the facies of relatively deep water pelagic carbonates.

We consider the Frasnian - Famenian interruption of carbonate deposition as a primary discontinuity within the carbonate sedimentary column. All following paleokarst periods and phases (Cretaceous, Miocene, Quaternary) used the weakened zone for karstification processes including deposition of specific sediments.

Cretaceous karstification phase

There is widely distributed interregional paleokarst of this age in Central Europe (Bosák 1981, 1995). This is the first attempt to describe and prove the Rudice Formation sediments filling the cavities of the Hranice karst. The sediments of specific colors and properties were noticed and described by several authors (e.g. Dvořák 1957), but they were not mineralogically studied and compared with the type locality of the Rudice Formation. The sediments of the Rudice Formation were many times described and even analyzed from the borehole cores near Hranice and Teplice, but they were mostly assigned to a special facies of Miocene. The chemical analyses, especially ratios of aluminium and natrium oxides exclude such solution. The kaolinic clays and sands are products of quite different - subtropical and tropical humid paleoclimate.

Comparison of Cretaceous and Miocene paleokarst deposits

M	M	RF	Q		RF	RF	RF
16,4	3,9	2,4	7	SiO$_2$/Al$_2$O$_3$	2,2	64	10,9
8,2	26	236	15	Al$_2$O$_3$/Na$_2$O	120	152	801
2,34	5,2	40	3,5	K$_2$O/Na$_2$O	3,1	3	4
0,41	0,2	0,2	0,3	K$_2$O+Na$_2$O/Al$_2$O$_3$	0	0,03	0,01
24	5,2	6,2	0,9	CaO/MgO	1,6	0,4	4

Hranice karst   Moravian karst

Fig. 2 Comparison of oxide ratios in the sediments (both clays and sands) of Miocene (yellow) and of the Rudice Formation (green).
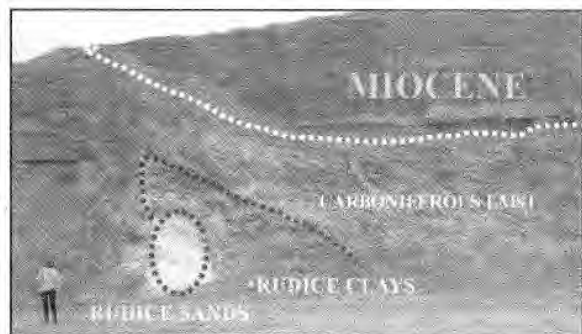
Fig. 3 Situation of the paleokarst deposits on the Hranice Paleozoic, Skalka quarry, etage 340 m a.s.l., southern wall.

To distiguish the sands of the Rudice formation from those of Miocene age the analyses of translucent heavy mineral assemblages were compared. There are substantial differences in composition, because characteristic minerals for the Rudice Formation sands are staurolite, kyanite, tourmaline and kyanite, while Miocene sands generally are typical by dominance of garnets. Such situation is generally comparable with the

Moravian Karst and again it reflects different paleoclimatic conditions during weathering, transport and deposition of paleokarst infillings on Cretaceous and Miocene.

Miocene karstification period

Karpatian and Lower Badenian transgressions finished long period of karstification and brought wide variety of sediments on highly diversified karst surface of Paleozoic carbonates. The pre-Miocene surface digitalized from thick net of boreholes drilled during the survey for Cement works is full of paleo-valleys and sinkholes, often organized in lines. The sedimentary fill ranges from coarse gravels and conglomerates through sands and sandstones to clay and sclaystones. There are many places with relics of boring activity of organisms (e.g. Gastrochenolites) which reflects high energy litoral environment of deposition. Abundant relics of Miocene fossils were found in cavities of the Skalka quarry and Chlamys shells were documented from the Zbrašov aragonite caves and Hranice abyss.
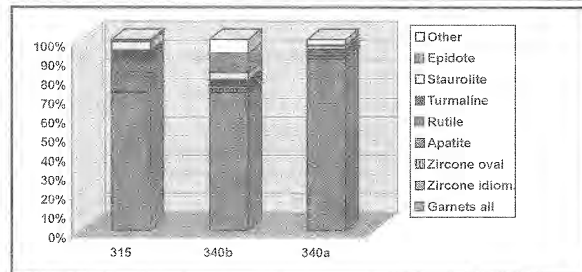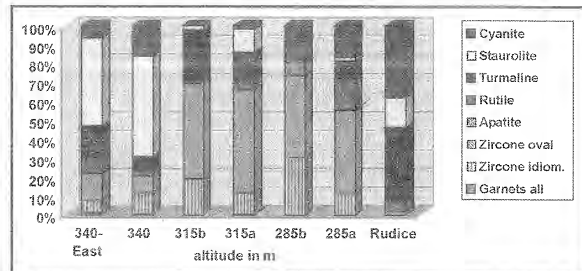
Fig. 4 Comparison of translucent heavy mineral assemblages of sands from the Rudice Formation - upper diagramm and of the Miocene sands - lower diagramm.
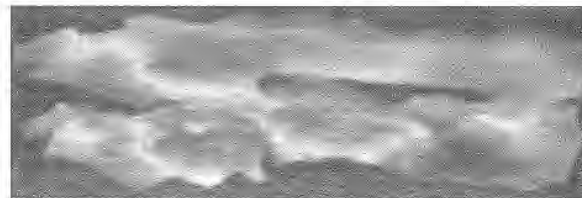
Fig. 5 The paleorelief of the Hranice Paleozoic before the Miocene transgression (lower part) and of the recent surface (upper part). The width of the sketch is approximately 4 km. Note the huge paleovalley on the right and numerous sinkholes on the left.

Generally the distribution of sedimentary fill of paleokarst cavities is quite complicated and only locally the superposition is clearly visible (see Fig.). Foraminiferal assemblages described by Petrová in Otava et al. 2004 from Skalka quarry, etage 340 m a.s.l. and from some boreholes belong to Karpatian. Palynomorphs of Lower Badenian age were identified from siltsones filling the depression on etage 300 m a.s.l. of the Skalka quarry (Doláková 2004). Termophilic elements as Sapotaceae, Engelhardia and Platycaria were accompanied by representatives of marine dinoflagelats. There was a high share of redeposited creataceous species derived from Carpathian nappes in the assemblage of palynomorphs.
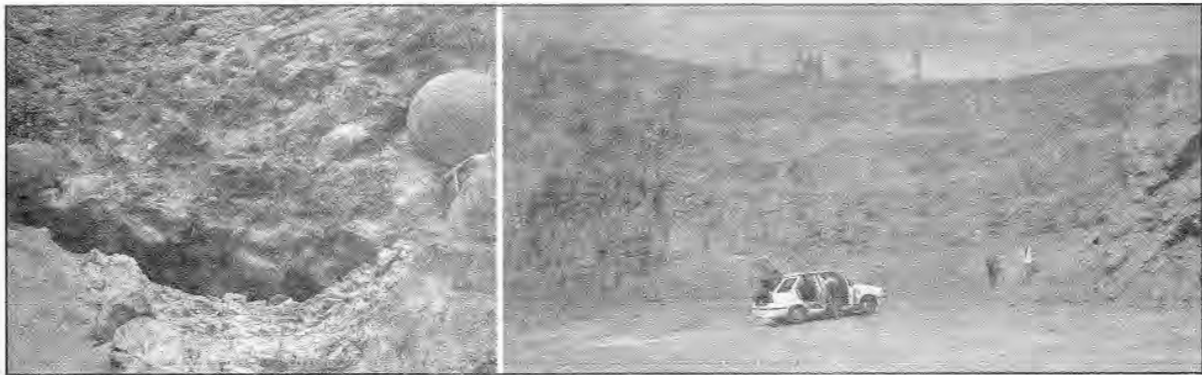
Fig. 6 Examples of the lithology of Miocene infillings. Left: bouldery conglomerate from Černotín, right: gravel (brown) and siltstone (grey) from Skalka quarry, etage 300 m a.s.l. view to the north, situation in summer 2003.

References

Bosák, P. (1981): The development of the Lower Cretaceous karst. A comparison with the plate tectonics.- Proc. 8th Int. Speleol. Congr., Bowling Green, 1: 170-173.

Bosák, P. (1995): Paleokarst of the Bohemian Massif in the Czech Republic: an overview and synthesis.- Int. J. Speleol., 24 (Phys.). 1-4:3-39.

Doláková, N. (2004): Palynological studies of cave sediments of Moravian karst areas.-3rd. National Speleological Congress, Czech Speleological Society, abstracts of papers: 13-14. Sloup

Dvořák, J. (1957): The surf reliéf of the Tortonian sea in the area of the Devonian of Hranice (Moravia). - Čas.Mineral.Geol., II, 2: 120-127. Praha.

Havíř, J.- Bábek, O. - Otava, J. (2004) : Relation of structures, stratigraphy and karstification in the Zbrašov Aragonite Caves. - Geol. Výzk. Mor.Slez. v r. 2003: 46-50, Brno.

Otava, J. et al. (2004): Explanatory Booklet and Basic Geological Map of the Czech Republic 1:25 000 Map sheet

25-123 Hranice. Czech Geological Survey, Praha.

O-116

Cosmic Rays, Solar Luminosity or Orbital Variations Drive the Earth's Climate?-Speleothem Arguments.

Y. Shopov, D. Stoykova

University Center for Space Research and Technologies, University of Sofia, Bulgaria.

Abstract

We studied Cosmic Rays, Solar Luminosity and Orbital Variations as potential driving forces of the Earth's Climate. Theoretical curves of the orbital variations of the solar insolation (SI) explain only 1/2 of the real variations of the SI due to a number of incorrect presumptions made by the Milankovitch theory. They contain also variations of the solar luminosity and Earth parameters. For quantitative correlation is necessary to use experimental records of the solar insolation. Speleothem luminescence is still the only proxy producing such records. Luminescence solar index represents solar insolation variations on the Earth's surface, so is the most appropriate solar proxy for study of the connection between Earth's climate and solar activity. Therefore, we used luminescent speleothem solar insolation proxy records from Jewel Cave, South Dakota, US and from Duhlata cave, Bulgaria 10 000 km apart. Both these records coinside in the frames of their dating errors. This confirms, that both they represent solar insolation (which is global) rather that the local paleotemperature. These records exhibit a very rapid increasing in solar insolation at 139 kyrs +/- 5.5 kyrs (2 sigma error) responsible for the termination II. This increasing is preceding the one suggested by the Orbital theory with about 10 kyr. We extracted the orbital components from the solar insolation records by a band-pass Tukey filtration set for the frequencies of 41, 23 and 19 kyrs of the orbital cycles. Solar luminosity variations were extracted from the solar insolation proxy records by subtracting of the sum of the orbital variations from the original luminescent records. A link between cosmic rays intensity and cloud cover has been discovered recently. It suggests that cosmic rays serve as nucleation centers for condensation of the water in the clouds. This suggests a strong positive correlation between the solar activity (especially solar luminosity variations) and the global temperature. Solar luminosity variations correlate with the solar wind strength. Stronger solar wind produces lower cosmic rays flux and lower cloud cover. The lower cloud cover produces higher sky transparency and higher solar insolation at the Earth's surface and the reverse. So cosmic rays-cloud cover mechanism multiply the solar luminosity variations in the solar radiation (insolation) at the Earth's surface. We found a cycle of 11 500 years producing variations of +/- 3.6 % of the solar radiation (insolation) in our experimental records. Involving the cosmic rays mechanism it can be produced by much smaller variations of the solar luminosity. This most powerful solar cycle is as intensive as most Milankovitch cycles and can produce climatic variations with intensity comparable to that of the orbital variations. Known decadal and even century solar cycles have negligible intensity (100 times less intensive) relatively to this cycle. Solar luminosity and orbital variations both cause variations of solar insolation affecting the climate by the same mechanism. Their superposition is producing the observed shifting of the Termination-II. So the well known splitting and shifting of the glaciations relatively to the theoretical orbital variations curves appear to be result of solar luminosity variations.

O-117

Decadal and Century Climatic Cycles in North Italy Derived from High- Resolution Luminescence Speleothem Records

D. Stoykova, Y. Shopov, L. Tsankov, U. Sauro, A. Borsato, F. Cucchi, P. Forti, S. Frisia
University Center for Space Research, Faculty of Physics, University of Sofia, 1164 Sofia, Bulgaria

Abstract

We present here an attempt of reconstructing climatic cycles in North Italy during the Holocene and Late Pleistocene from luminescence of speleothems from cave Savi near Trieste, N. Italy. We obtained 720 images of fluorescence and phosphorescence of speleothems from 10 caves from a S-N transept of Italy. We choose the best of them to produce high- quality records of environmental changes in Italy. Amongst all samples only speleothems (stalagmites and few flowstones) from Savi cave (North Adriatic coast near Trieste) were suitable for preparation of long high- resolution luminescence paleoclimatic records. We dated a speleothem from cave Savi with 15 ICP-MS TIMS-U/Th dates form 1.317 to 16.484 kyrs B.P. with (2 s) error ranging from +/-97 to +/-480 years. We measured 3 paleoluminescence records from this stalagmite: The longest luminescent record covers last the 14430 ±176 years (2s error) with a time step from 1.11 to 12.70 years. We prepared also a composite record consisting of 81000 data points, which has been compiled from 39 overlapping scans (of 4800 data points each). It covers the last 5005.2 ±140 years (2s) (the upper 80 mm. of the sample) including several hiatuses. The resolution of the record varies from 9.9 days to 33.9 days. The highest resolution composite record covers the last 2028 ±100 years (2s) (the upper 20 mm. of the sample) with several hiatuses. This composite record consists of 40106 data points and has been compiled of 16 overlapping scans (of 4800 data points each). It has resolution from 15.6 days to 19.9 days. It allows precise measurements of the annual growth rate of the speleothem. It varies from 2.2 to 45.4 ±0.5 microns/year from its mean value of 6.36 microns/year. Obtained record covers 2028 years taking into account hiatuses in the record. This record represents mainly the annual rainfall at the cave site. We used a new special real- space periodogramme analysis algorithm to calculate the intensity of the cycles of the annual precipitation at the cave site. Resulting periodogramme demonstrates that the strongest cycles of the annual rainfall in the region of Trieste, Italy are with duration of about 300 and 55 years. Precipitation cycle with duration of 300 years has been detected by other authors as well but its origin is still unclear. We studied variations of the length of these cycles with time by evolutive power spectral analysis. We used the same digital analysis to calculate the intensity of the cycles of the speleothem luminescence (representing cycles of solar radiation or air temperature). Obtained power spectra demonstrate that the strongest cycles of the soil temperature in the region of Trieste, Italy are with duration of about 11, 22 and 70 years. These are well known solar cycles, which drive temperature changes in some climatic regions. We studied variations of the length of this cycles with time by evolutive power spectral analysis.

O-118

The Brazilian Governmental Experience in a question of on protecting Brazilian speleological heritage

R. de Cássia Surrage de Medeiros, R. J. Calembo Marra
IBAMA - Brazilian Institute for the Environment and Renewable Natural Resources- Brasília/Brazil

Abstract

Brazil has a great speleological potential, still little studied. Caves are known to exist in all Brazilian states, presenting a great lithological diversity. In addition to the typical limestone, among the presently 3.944 registered caves there is great occurrence of granite, gneiss, schist and sandstone. However, there is much more. These fascinating environments of rare beauty are eventually targets to non-sustainable economic activities and predatory actions generated by the almost complete lack of knowledge about the richness and importance of these ecosystems. This picture has been changing over the last 10 years thanks to governmental action based on progressive improvement of legislation that guarantees protection for the Brazilian speleological heritage. Backed by solid regulations, the exploration and conservation of the Brazilian caves are challenges to be faced. Created during the commemorations of the 1997 Environment Week, the CECAV (National Center for the Study, Protection and Management of Caves) fulfills the expectations of the speleological community for the protections of Brazilian caves. Functioning nationwide, this Center is an unit of IBAMA - Brazilian Institute for the Environment and Renewable Natural Resources, subordinated to the Ecosystems Directory - DIREC. Its purposes are to propose, regulate, supervise and control the use of speleological heritage, as well as to encourage inventories, studies and research contributing to the knowledge of Brazilian caves. The CECAV's objectives are to bring into effect the conservation principles for Brazilian caves and encourage their appreciation by the community; to collaborate protecting the archaeological sites and critical areas, as well as to promote studies and researches contributing to our speleological knowledge; to establish a National Register Speleological Information (CANIE) to compile and systemize the existing and forthcoming information; to encourage the protection of caves through planned tourism, and by providing technical support for the implementation of projects and management plans compatible with this environment; to promote environmental education programs directed to enhance public appreciation and to assure the suitable socio-economic use of caves; to train personnel for the administration, study and research of speleological sites and to publicize the scientific, historical, cultural, economic and social importance of caves, as an participant in their conservations. The protection of the caves'valuable and fragile environment depends on the joint efforts of the entire brazilian society, speleological groups and institutions around the world. The development of partnerships allows the optimization of funds, uniting conservation efforts. For this purpose, CECAV has legal competence to execute agreements, partnerships, terms of technical collaborations, contracts with public, and private institutions - national and international, envisioning the protection, conservation and appreciation of the Brazilian governmental and non-governmental institutions for Brazilian caves. The CECAV has great interest in developing research activities in collaboration with foreign institutions, to deepen our knowledge of cave ecosystems and their management.

O-119

Demonstrations and observations of cave animals in show caves

J. Dumer, A. Mihevc

ZRC SAZU, Karst Research Institute

Abstract

Cave animals are important components of karst underground environments. Because of limited conditions, they are prevailingly small, rare, adapted to harsh conditions in various ways and vary sensitive to smallest underground climatic, weather and other environmental changes. Cave animals are excellent indicators of the karst underground. The listed makes cave animals very interesting and useful, but, at the same time, most vulnerable and therefore very difficult points of curiosity in show cave programs. Experiences have shown that it is very difficult to maintain regular environments for captured animals in terrariums. Continuous catching of the animals for the purpose is questionable by itself.

Stresses for animals in captivity during highlighted demonstrations are intolerable. Experiments in show caves Dimnice and Vilenica have shown that carefully chosen feeding places by the trials, with free migrations of animals, are better options. It also showed that short observations of the living animals are enough to attain education goals if combined with use of models, pictures and other didactic materials, distant from the shortly observed animals. High interests for the specifics and the vulnerability of cave animals could be supported and used with offers of different materials (postcards, souvenirs, jewellery, posters, presentations.) and projects (playgrounds with enlarged models of animals, exhibitions, workshops.) outside the show caves.

O-120

Evaluating show cave potential in Lebanon

M. Metni, J. Taouk, K. Moarkech

Speleo Club du Liban

Abstract

This paper presents an overview and synthesis for some of the studies conducted by the Speleo Club du Liban that aimed at evaluating the show cave potential in some of Lebanon's caves. These studies have revealed that although it was not economically and/or technically feasible in many instances to rehabilitate the caves for show, these caves could still be highly beneficial to local communities in terms of education, awareness and even tourism.

O-121

Some basic principles for the development of show caves: the "Frasassi Charta"

Arrigo A. CIGNA *UIS- ISCA*

Fraz. Tuffo, *I-14023 COCCONATO (Asti), Italy*

Abstract

It was deemed convenient to collect some basic principles concerning the development of show caves on account of their increasing number being developed all over the world. Both the actions to be taken before the beginning of the development and those to be carried on successively, are here considered.

These principles, which have been already delivered in Frasassi, Italy, in 2004, are here reported for discussion and a possible adoption as an ethic code.

Keywords: show caves, ethics, environmental protection.

Introduction

The development of tourist caves started some centuries ago, but recently, i.e. in the very last decades, the number of caves considered for their development into show caves increased largely. Rather often such caves do not have the intrinsic requirements which are essential for their development. In this case the risk of a waste of money and a useless modification of the environment of a wild cave could become the obvious consequence.

Existing show caves sometimes are managed not in full agreement with the present view of the protection of the environment and the safety of the public. Also if this case is not so frequent, their case must be taken into account for the implementation of the most recent principles envisaged for show caves.

The development of show caves

It is widely accepted that an Environmental Impact Assessment should be carried out before starting any activity in a wild cave to be developed into a show cave. In particular a survey of the most relevant climatological parameters (as temperature, relative humidity and CO_2) is recommended for a time span of four seasons. Unfortunately this operation, which should provide a "zero level", is far from being widespread. More usually the monitoring is established only after the development. In this way the evaluation of the impact becomes more difficult but, in most cases, not impossible.

The general layout of an Environmental Impact Assessment can usually be divided into three steps:

- Preliminary Environmental Review
- Initial Environmental Evaluation
- Comprehensive Environmental Evaluation

In the case of the development of a new show cave, the first step, i.e. the "Preliminary Environmental Review" should include not only a rough examination of the cave (and vicinity) environment but also a evaluation

of the profit based on the best available guess. In fact it is possible that a development, which is acceptable, in principle, from the point of view of cave equilibria, has not a positive economic return. In that case the whole process must be stopped immediately because the waste of money would also imply no return at all from the management of cave. Consequently the negative impact (also if small) due to the structures installed into the cave would not be counterbalanced by any advantage.

Once the feasibility is ascertained, an "Initial Environmental Evaluation" may as well be conducted together with the "Comprehensive Environmental Evaluation" in order to obtain a global information on the whole cave ecosystem, its natural equilibria and an evaluation of the visitors' capacity. Such a visitors' capacity can be defined as the maximum number of visitors acceptable in a time unit under defined conditions, which does not imply a permanent modification of a relevant parameter (Cigna, 1989; Cigna & Forti, 1990).

The preparation of the frasassi charta

The idea of establishing a document, which could be adopted as a recommendation for a minimum of actions to be carried out for the development of show caves, was firstly presented at the ISCA meeting in September 2004, organised for the 30th anniversary of the opening to the public of the Frasassi cave (Ancona, Italy). Successively the document was also presented in November 2004 to the participants to "Frasassi 2004", a large meeting of the Italian speleologists.

Therefore this document reached many persons and obtained positive reactions. It is convenient to reassure the management of show caves that the document presented here with the scope of being adopted as a strong recommendation supported by the UIS Department of Protection and Management has the cope of providing them with a useful tool to achieve the best level of cave management at the same time of the best protection of the cave environment and a suitable level of safety for tourists.

Finally it must be emphasised that the text of the "Frasassi Charta" here reported, is the result of a number of contributions from many colleagues whose intervention was instrumental for this purpose.

Frasassi Charta

Before developing a wild cave into a show cave, a careful balance of costs and benefits must be carried on by taking into account any relevant factor.

Then, the distribution of the climatic parameters in natural conditions should be evaluated possibly during one year by means of a monitoring network.

Any facility inside the cave should be obtained by avoiding as much as possible any local disturbance.

Materials as concrete, stainless steel and plastics should preferably be used for any structure inside the cave. In particular organic material as wood and different metals should never be used.

The electric lighting should consists in a safety network (with uninterruptible power supply) and light sources for local views.

Light sources should have an emission spectrum with the lowest contribution to the absorption spectrum of chlorophyll (around 440 and 650 nm). Such sources should be installed at a distance from any part of the cave to avoid both the growth of lampenflora and any damage to formations and rock paintings; such lights should be switched on possibly only when useful for visitors.

Any new access to the cave must be provided with an efficient system (doors, etc.) to avoid any change in the air circulation.

A monitoring network of the cave climate (temperature, humidity, carbon dioxide, and, if necessary, radon) should be installed to check any disturbance to the natural equilibrium. Air flow (in or out) should also be monitored.

The cave visitors' capacity (defined as the maximum number of visitors acceptable in a time unit under defined conditions which does not imply a permanent modification of a relevant parameter) should never be exceeded. Round circuits, instead of "to-and from", could reduce the time spent into the cave by visitors. Such round circuits must obey the requirements reported above.

The show cave management in order both to evaluate the results obtained by the monitoring network and to develop further researches should provide a scientific commission composed by experts of the cave environment.

The cave guides should be educated to inform correctly the public about the cave environment. Some information on both other show caves as well as the speleological research should be provided.

References

Cigna A.A., 1989 - *La capacità ricettiva delle grotte turistiche quale parametro per la salvaguardia dell'ambiente sotterraneo - Il caso* delle Grotte di Castellana. Atti XV Congr. Naz. Speleol., Gruppo Puglia Grotte - Amm. Comunale Castellana Grotte: 999/1012.

Cigna A.A. & Forti P., 1990 - La V.I.A. delle grotte turistiche. The E.I.A. of a tourist cave. VIA, l'Arca Edizioni, Milano, 4 (16): 42-53.

365

O-122

Ecological researches in show caves of Romania

O. Moldovan
"Emil Racovitza' Speleological Institute, Cluj, Romania

Abstract

Show caves of Romania are of special interest for the researchers of the Speleological Institute. Our studies focused especially on the direct and indirect anthropic impact on the cave adapted fauna. Topoclimatic measurements and monthly observations of the fauna dynamics were undertaken in two of the most important show caves of north-western Romania. Results are compared to visitor's fluctuation and conclusions enhance the importance of monitoring and limiting the number of visitors/day and the number of visitors/visit.

O-123

Glyphada ou le rêve des fistuleuses noyées de Diros

Jean-Jacques Bolanz, Luigi Casati, Patrick Deriaz, Vassili Giannopoulos

Avertissement : cet article est un condensé de la communication présentée au congrès international de spéléologie à Athènes en 2005. Faute de place, il n'est pas possible de publier l'intégralité de ce texte.

Introduction
Situation géographique

Les grottes de Diros sont situées en Laconie, au sud du Péloponnèse, près du village de Pirgos Dirou. Les villes les plus proches sont Githio et Kalamata, cette dernière est atteignable par avion.

Situées à côté de la plage du golfe de Diros, ces grottes sont au nombre de trois, très proches les unes des autres: Glyphada (appelée aussi Vlychada), Alepotripa et Kataphygui. Les deux dernières sont fermées, contenant de très importants restes archéologiques. Alepotripa, après avoir été ouverte aux visiteurs pendant quelques années est actuellement fermée au public, sauf un petit musée récemment conçu. Le travail de recherche se poursuit de manière permanente à Alepotripa qui a été longtemps habitée par des hommes du Néolithique. Kataphygui n'a pas encore été fouillée systématiquement.

Historique des explorations

Signalées depuis longtemps par des explorateurs locaux ou étrangers, ce n'est que dans les années 50 que la Société Spéléologique de Grèce (SSG) en a commencé l'exploration systématique. Il est admis que le premier explorateur aurait été un navigateur local, P. Arapakis, en 1900. A. et J. Petrochilos en ont exploré 1'600 m, dont 300 m de galeries sèches entre 1939 et 1960. En 1966, un total de 3'100 m avaient été explorés. En 1970, les premières explorations sous-marines (E. Papagrigorakis) firent découvrir encore 300 m de siphons, portant le développement total à 3'400 m. En 1982, 1'500 m de galeries supplémentaires (galerie de la Panthère) ont été découvertes, portant le développement aux alentours de 5'000 m. La première description de la cavité est due à E. Kapetanakos. A. Petrochilos a exploré et étudié la grotte et en a dressé la topographie. Dès 1961, à la suite des explorations de la SSG, une partie touristique a été aménagée par les autorités de Diros. Depuis 1967, c'est l'Office National du Tourisme qui a complété l'aménagement et a pris le contrôle de la grotte. Plus de 300'000 touristes la visitent durant toute l'année.

Les expéditions

Entre 1989 et 2004, six expéditions internationales ont exploré et topographié Diros. Les participants, spéléos et plongeurs, sont Grecs, Italiens, Français et Suisses. Vassili Giannopoulos a obtenu les permissions nécessaires.
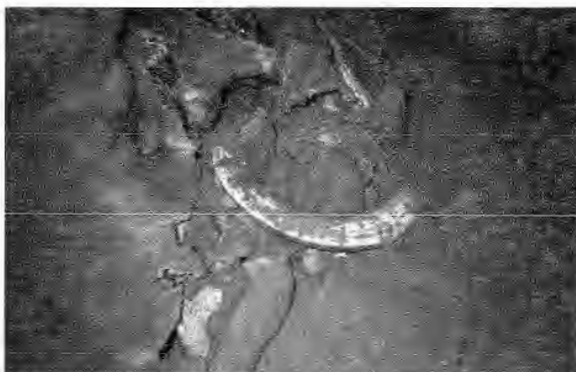
Fig. 1: Ossements d'hippopotame (photo P. Deriaz)

Fig. 2: Progression en plongée (photo L. Casati)

Les deux premières expéditions, en 1989 et 1991, furent des prises de contact fascinantes d'une semaine. Il y avait des siphons qui s'ouvraient partout. Ayant dès le début systématiquement topographié nos découvertes, nous avons cependant rapidement été incapables de les positionner précisément sur la topographie existante, due à la Société Spéléologique de Grèce et datant des années 60. La multiplication et l'enchevêtrement des siphons exigeait une nouvelle topographie de surface.

En 1992 et 1994, les expéditions comprenaient non seulement des plongeurs, mais surtout des topographes et un photographe, qui ont travaillé près de deux semaines à établir une nouvelle topographie de la partie touristique de la grotte, ainsi que des galeries sèches et noyées. Au total, 6'445 m de topographie.

Enfin, en 2003 et 2004, les deux dernières expéditions ont permis de compléter l'exploration et la topographie, l'une dans les siphons ZZorba et de la Panthère et l'autre dans les 4 Disques: le siphon en Rouge et Blanc. Le total topographié est de 12'436 m. Il reste quelques centaines de mètres déjà explorés et non encore topographiés.

Il est frappant de constater qu'il n'y a aucun chiffre global concernant les premières, mais seulement des chiffres concernant les topographies effectuées. Cela vient de l'importance énorme de la topographie dans un réseau tellement compliqué, et enchevêtré. On sait pourtant qu'en 1994, 2003 et 2004, il y eut 3'343 m de premières, dont 3'194 m de siphon et 149 m exondés.

Description globale sommaire de la partie exondée

La plus grande partie des galeries présentent de l'eau dont la profondeur varie de quelques centimètres à plusieurs mètres de profondeur. Une autre partie sont des galeries sèches. Le reste qui tend à prendre de l'importance au fil des découvertes sont les siphons.

Le point haut est à +34 m et le point bas à -78 m par rapport au niveau

Fig. 3: Navigation dans la galerie touristiques (photo R. Wenger)
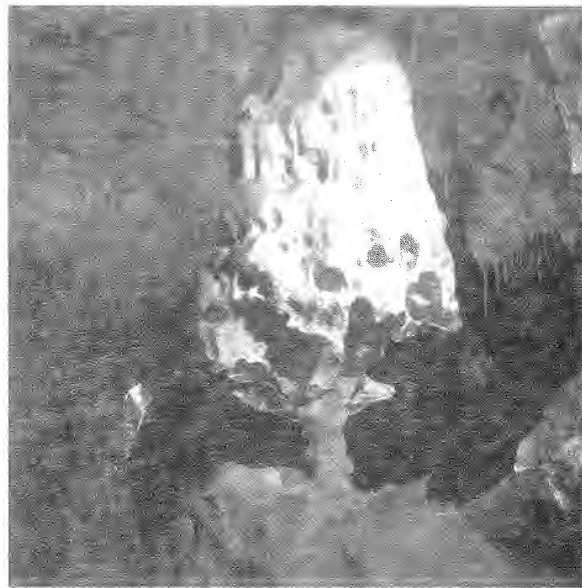
Fig. 5.: Concrétions dans la galerie de la panthère (photo R. Wenger).
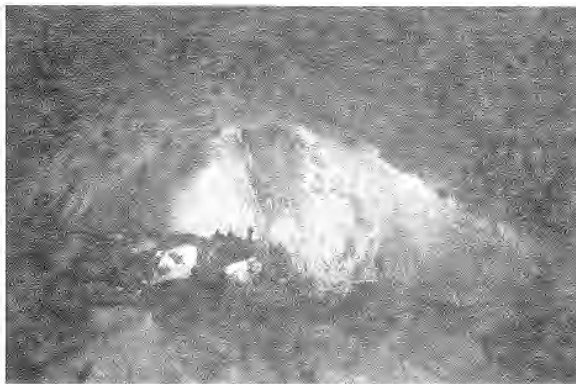
Fig. 4: La salle des Mégalotchèques (photo R. Wenger)
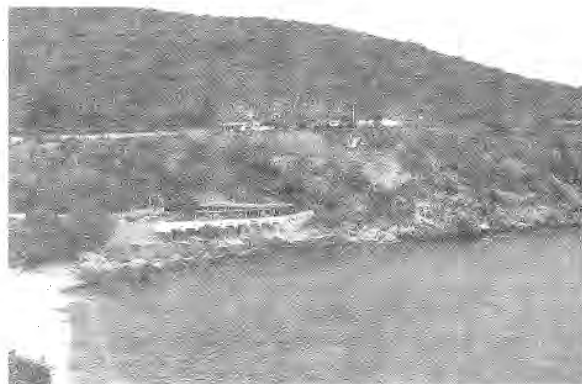
Fig. 6: l'entrée de la grotte de Diros (photo P. Deriaz)

de l'eau, une dénivellation totale de 112 m.

Le circuit touristique constitue une première partie identifiable. Il est prolongé au sud-ouest par la galerie ZZorba et de la Panthère et au sud-est, parallèlement à la Panthère, par la galerie et siphon des 4 Disques. Au sud de la partie touristique, près de la sortie artificielle on trouve la galerie des Mégalotchèques.

Description globale sommaire de la zone noyée

Il y a des zones noyées un peu partout et dont certaines correspondent partiellement avec des zones exondées, ce qui ne facilite ni la topographie ni la compréhension. On peut pourtant reconnaître une première série de siphons dans la zone d'entrée, dont certains se dirigent vers la mer. Sous le Grand Océan se trouvent des siphons descendant jusqu'à 78 mètres de profondeur. A l'extrémité de la visite touristique, entre la galerie de la Panthère et celle des 4 Disques, se trouve un invraisemblable enchevêtrement de siphons. La galerie des 4 Disques se continue par des siphons et une dernière zone se trouve sur le parcours aquatique menant à la galerie de la Panthère: dont la salle des merveilles qui atteint 40 m de profondeur pour des volumes importants.

Remarques en forme de conclusion

1 Vassili Giannopoulos a trouvé un grand nombre d'ossements dans plusieurs endroits de la grotte. Une analyse complète est publiée dans sa thèse, rédigée en grec.

Il a trouvé 107 os d'hippopotame, dont une colonne vertébrale complète, 9 os de fouine, 1 os de gazelle (dama dama), 1 os de ruminant, 2 os d'aves, 8 os de léopard, 6 os de hyène tachetée, 1 os de lion des cavernes et 1 os de phoque noir.

Une datation des stalagmites qui se sont formés sur les os a été faite et indique 31'650 ans avec plus ou moins 550 ans d'erreur.

A. Petrochilos signale que des os d'hippopotame et de bœufs préhistoriques avaient été trouvés au fond du dernier lac avant la galerie de la Panthère, c'est-à-dire à un endroit complètement différent et éloigné des endroits de nos découvertes .

Un article de synthèse est prévu sur les découvertes d'ossements.

2 Les températures relevées en plongée varient entre 16 et 19 degrés. A -70, une série de mesures indique 17 degrés. Dans la région du Grand Océan, les longues périodes de décompression ont permis de remarquer 19 degrés à -12 m, 18 degrés jusqu'à 9 mètres et 16 degrés en eau plus douce à 6 et 3 mètres. Il est intéressant de constater
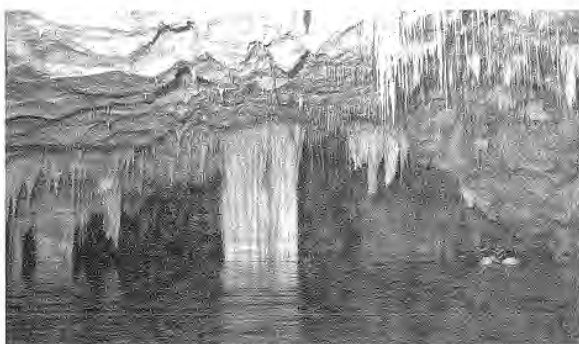
Fig. 7: sur le chemin de la galerie de la Panthère (photo P. Deriaz)

Fig. 9: Le lac de la Panthère (photo P. Deriaz)
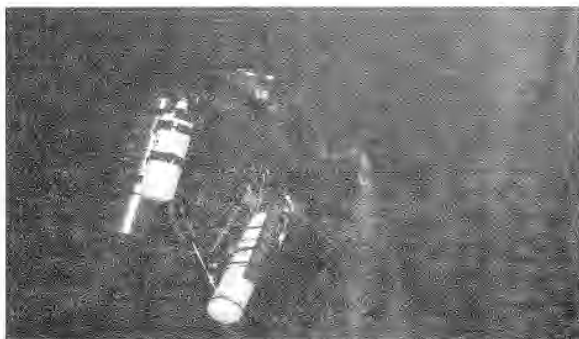
Fig. 8: Progression dans le siphon des quatre disques. Remarquez le recycleur, le long cylindre sur le dos du plongeur. (photo P. Deriaz)

que la température des eaux indiquée par A. Petrochilos en 1984 est de 12 degrés, température que nous n'avons jamais rencontrée.

3 Les concrétions trouvées à 72 m de profondeur au fond du grand puits ont été les plus profondes de Grèce, jusqu'à ce que la même équipe trouve des concrétions à plus de 100 m de profondeur au lac de Vouliagmeni. Elles sont les preuves de la différence de niveau avec la mer qui existait au moment de leur formation. Les spécialistes divergent quand à savoir si c'est la terre qui s'est enfoncée ou la mer qui est montée. Certains affirment que les deux phénomènes en sont la cause ensemble.

4 Nous n'avons pas trouvé trace des 500 l par seconde cités par Maire, près de l'ancien débarcadère. Par contre, dans le Grand Océan, à 3 et 6 m de profondeur, on peut observer un tout petit courant se dirigeant vers la mer.

5 Quelques spécimens de petits animaux vivants trouvés dans l'eau ont également été recueillis à fin d'identification.

6 La présence d'anguilles à l'extrémité de la galerie touristique a été vérifiée à plus d'une reprise.

7 En dépit des pluies torrentielles (mais oui) le niveau de l'eau dans la partie touristique n'a pas varié de manière significative. Par contre les passages aquatiques conduisant à la galerie des Mégalotchèques se sont transformés en siphons.

Des variations de 30 cm ont été remarquées au débarcadère et correspondent probablement au phénomène de marée.

8 Il a été trouvé du sable, semblable à celui de la plage, au fond d'un des siphons allant justement en direction de la mer.

Hypothèses

A la lumière des découvertes et de la topographie actuelle, on peut émettre les hypothèses suivantes:
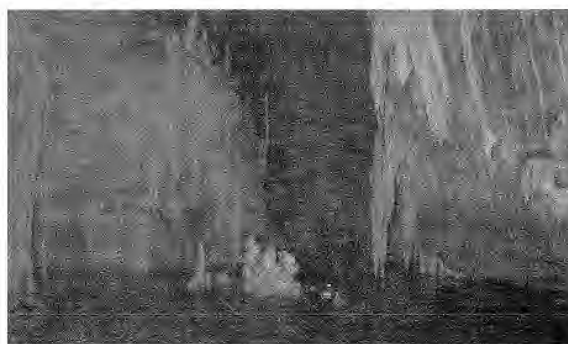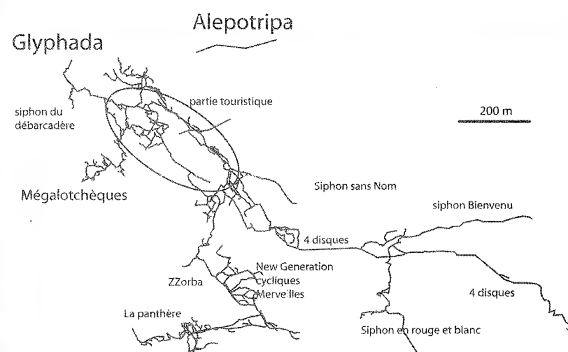
1) Un axe principal constitué de la galerie des 4 Disques et du Grand Océan a été creusé par une rivière souterraine avec enfouissement progressif jusqu'à plus de 70 m de profondeur. L'écoulement a dû être rapide à certaines époques, le super canyon de -70 est souvent bloqué par des éboulis à différentes hauteurs.

2) Un axe secondaire parallèle au premier se dessine, constitué de la galerie ZZorba, du début de la galerie touristique et de la sortie touristique.

3) Ces deux axes longitudinaux sont coupés par trois axes transversaux: la galerie des Mégalotchèques qui se poursuit vers la zone d'entrée, la fin de la visite touristique constituerait le deuxième axe transversal et les siphons Sans Nom et en Rouge et Blanc le troisième.

Bibliographie:

PETROCHILOS, J. (1953): Sur l'histoire du Quaternaire de la presqu'île de Mani. I Congrès intern. de spéléologie, Proceed. 2: 257-260, Paris.

PETROCHILOS, J. (1957-1958): Paleontologika evrimata is to spileou Glyphada, 25, Bulletin de la Société Hellénique IV, 4: 289-304.

PETROCHILOS, J. (1958): Spileogikai erevnai is tin periochi Dirou Laconias, Athina.

PETROCHILOS, J. (1961): Recherches Hydrogéologique dans la région de Diros en Laconie. III Congrès intern. de spéléologie, Vienne.

PETROCHILOS, A. (1963): Le fleuve souterrain de Glyphada au Péloponnèse. N° 25, IV Coll. intern. de spél., Premier en Grèce, Athens: 62-77.

EXPEDITION SPELEOLOGIQUE HELLENO-TCHEQUE (1966): Résultats des travaux à la baie de Diros. Bul. Soc. Spéléol. Grèce IX 5-6: 155.

PAPATHANASSOPOULOS G. (1971): Spilea Dirou 1971: 4, 289-304.

368

PAPATHANASSOPOULOS G. (1972): Spilea Dirou 1971. Archaeol. Deltion (chronika): 251-253.

PETROCHILOS, A. (1984): Les Grottes de Grèce: 11-19.

MANDOUVALOS, Y. (1981): Grottes-Pyrgos-Monuments Byzantins: 15-34, Athènes.

PETROCHILOS, A.: The Diros caves of Mani: 22-32.

MAIRE, R. (1990): La haute montagne calcaire: 68-106.

BASSIAKOS, J. E. (1993): Dating of fossils from caves and speleo-thems: Evidence from electron spin resonance technique, the study of underground karst morphology and the relevant radiometric and geological conditions in speleo environments of Diros, Mani. Athens.

BOLANZ J.-J. (1995): Explorations 1989-1994 à Glyphada (Diros). Actes Congrès de la Société Suisse de Spéléologie, 1995: 222-228.

O-124

Exploration et topographie du lac Vouliagmeni

P. Deriaz, L. Casati, J.J. Bolanz, V. Giannopoulos

Prometeo richerche

Résumé

Le lac de Vouliagmeni se trouve près d'Athènes en Grèce.

Les résultats des explorations en plongée menées de 1989 à 2004 sont présentés. Le réseau des siphons explorés atteint 4'558 m, dont 3'860 m topographiés. Si le point bas se situe à 112 m, la profondeur moyenne est de 75 m. Le réseau semble s'ordonner autour d'une énorme salle noyée de 800 m de long, 60 à 150 m de large et 30 à 40 m de hauteur, dont le plafond se trouve entre 60 et 90 m de profondeur. De grosses concrétions se trouvent à 105 m de profondeur: ce sont les plus profondes à ce jour en Grèce. A plus de 700 m de l'entrée et 100 m de profondeur, des concrétions, une sorte de varech fossilisé, ont été ramenées et analysées. Les prélèvements d'eau et de température n'ont pas donné de résultats significatifs. Des mesures de protection ont été prises par les autorités, le parcours de la grotte se situant sous des zones construites de Vouliagmeni.

1. Eléments géologiques

Introduction

Le bassin d'Athènes mesure 22 km de long du nord-est au sud-est et 11 km de large. Il est limité au nord par le mont Pendelikon, à l'est par le mont Ymittos, à l'ouest par les monts Parnis et Egaleo et au sud / sud-est par la mer de Saronique. La doline de Vouliagmeni se trouve à 21 km au sud d'Athènes, dans la partie sud du mont Ymittos.

Etudes préalables

Bien qu'elle se trouve tout près d'Athènes, peu d'études ont été faites concernant ce phénomène karstique. Le premier qui s'est occupé de cette doline est le professeur A. Christomanos, qui, en 1889, a décrit le trajet d'Athènes à Vouliagmeni, la morphologie de la région ainsi que les qualités curatives des eaux du lac - source de Vouliagmeni.
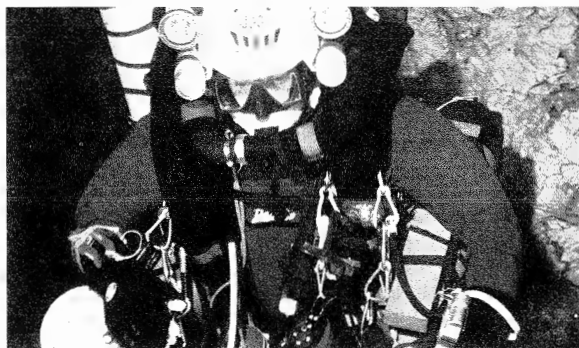
Les données historiques de Strabon, de Lausanias (IIe siècle apr. J.-C.) et de Stefano Vizantios (VIe siècle apr. J.-C.) ne font pas mention du lac de Vouliagmeni, ce qui prouve qu'il n'existait pas à cette époque. D'autre part, les recherches géologiques, comme celles de A. Zamani, qui ont été faites sur les conglomérats aboutissent à la conclusion que la doline s'est formée au cours des derniers 1500 ans.

Géologie

La doline de Vouliagmeni est un effondrement qui s'est formé sur les «marbres inférieurs». Steinman (1890) a étudié les coraux trouvés dans les marbres inférieurs d'Ymittos et les a définis comme «Calamophyllia» qui se trouvent du Trias jusqu'au Crétacé. Negris (1919) a trouvé dans la même roche le fossile «Gyroporella Vesiculifera» du Trias. Yaber (1929) a reconnu l'algue «Diplora» du Trias dans le marbre supérieur d'Ymittos. Dans le marbre inférieur, le Dr. E. Gasche a déterminé le sous-genre «Macroporella» qui est caractéristique du Trias et du Jurassique. Le même fossile a été identifié dans le marbre supérieur par Petrascheck - Marinos (1953). De tout cela on peut conclure, en suivant Lepsius, que les couches azoïques peuvent être placées chronologiquement dans le Mesozoïque inférieur (Trias et Jurassique).

Morphologie

La forme de la doline de Vouliagmeni est ellipsoïde, le grand axe allant du sud-est au nord-ouest. Sa longueur est de 210 mètres pour une largeur de 160 mètres. Dans la partie nord / nord-ouest de la doline se trouvent deux lacs avec de l'eau saumâtre. Leur formation est due à l'effondrement du plafond de la grotte qui se trouvait à la place de la doline d'aujourd'hui et qui était remplie d'eau. D'après nos premières observations, l'eau ne remplissait que partiellement la grotte, laissant une partie exondée. C'est la faible épaisseur du calcaire du plafond de la salle, combinée avec ses

369

Fig. 1: Luigi au retour d'une plongée (photo Chiquita)

Fig. 2: La vasque d'entrée (photo P. Deriaz)

Fig. 3: Coupe projetée de la grotte de Vouliagmeni d'après Toporobot. A gauche, les cavités qui partent depuis le lac.

grandes dimensions qui ont facilité l'instabilité puis l'effondrement du plafond, probablement lors d'un tremblement de terre pas nécessairement de grande amplitude.

Le grand lac a 140 mètres de long et 55 mètres de large avec une profondeur maximum de 12 mètres. Le petit lac mesure 20 mètres par 15 et a une profondeur maximale de 9 mètres.

Leur surface se trouve à 40 cm au-dessus du niveau de la mer toute proche (50 m). Cette différence est due d'une part à l'eau douce qui alimente le lac et d'autre part à l'étroite bande de calcaire qui sépare le lac de la mer, empêchant une vidange immédiate de l'eau du lac dans la mer, sans pourtant empêcher le mélange de l'eau salée et de l'eau douce. On a observé que l'arrivée principale de l'eau douce se fait par la grotte karstique noyée qui subsiste et dont l'entrée se trouve dans la partie nord-ouest du grand lac.

La température des eaux du lac augmente au fur et à mesure qu'on s'approche de l'entrée de la grotte, pour se stabiliser entre 25 et 27 degrés à 30 mètres de profondeur, dans la grotte. Le mélange des eaux salées et des eaux douces plus chaudes s'observe également à cette profondeur. Cela soutient l'hypothèse que les eaux douces proviennent des plus grandes profondeurs et que leur température est influencée par l'arc volcanique.

Enfin, il faut noter que toute la région du lac, avec le gouffre Germanica, les deux dépressions au nord du lac situées dans l'axe de la grotte noyée ainsi peut-être que le «puits» aspirant Pigadi, situé dans la mer, à quelque 500 mètres du lac de Vouliagmeni constituent un complexe karstique du plus haut intérêt scientifique, dont l'étude n'est qu'amorcée.

2. Résumé des expéditions

C'est en 1989, à l'invitation de Vassili Giannopoulos, responsable de la section de spéléologie au Ministère de la culture que commencent, sur un coup de cœur, les expéditions à Vouliagmeni. Elles se continuent en 1991 et 1992. Dès 1993, elles prennent une dimension plus importante, à la fois parce que nous réalisons l'énorme potentiel de cet ensemble de cavités réparties autour du lac de Vouliagmeni et par l'intérêt et le soutien matériel accordé par le maire de Vouliagmeni et le Ministère de la culture. Les expéditions se poursuivirent en 1995, 1996, 1997, 2000, 2001 et 2004.

Lorsque les explorations ont commencé, nous n'avons trouvé aucun fil en place et aucune topographie. Des plongeurs non spéléo s'y étaient noyés. Les profondeurs atteintes se situaient aux environ de 40 mètres. Il faut aussi dire que la plongée spéléo en était à ses balbutiements: le premier stage pour plongeurs spéléo en Grèce a été organisé par V. Giannopoulos en 1989.

3. Description des cavités du lac de Vouliagmeni

L'ensemble du système fait partie d'un site touristique privé et exploité toute l'année. Situé à quelques kilomètres d'Athènes, en direction du cap Sounion, la petite ville de Vouliagmeni compte parmi les endroits touristiques les plus luxueux de Grèce. La bonne société de Vouliagmeni et

Fig. 4: La fenêtre à -45 m (photo Chiquita)

des environs vient s'y baigner ou simplement boire un verre jusque tard le soir.

Toutes les grottes se trouvent autour du plus grand des lacs, au pied des falaises orientées au nord et à l'est, sauf la grotte de Germanica, dont l'entrée se trouve sur le plateau dominant le lac, et le siphon aspirant de Picadi dans la mer, en direction de Sounion. De gauche à droite, on trouve la grotte du Parking, ainsi appelée, car elle se développe sous le parking extérieur. On y passe dessus lorsque l'on pénètre dans le site. On trouve ensuite la grotte du Canyon, car elle s'ouvre dans un passage entre la falaise et un gigantesque bloc détaché de celle-ci, puis la grotte du Tonneau. Ces grottes ne dépassent pas 50 m de longueur et descendent seulement de quelques mètres. Aucune n'a de suite. La grotte principale s'ouvre en plein nord, sous une surface d'eau séparée du lac, de 10 m de diamètre. Puis, en allant vers l'est, on trouve le siphon des Américains qui se développe sur 116 m, finissant à -57, le siphon de l'Horloge et encore un autre tout petit siphon à droite de l'Horloge.

La salle principale est précédée d'une sorte d'antichambre encombrée de rochers effondrés, avec quelques départs à gauche et à droite. A -35, il y a trois ouvertures sur la salle principale, dont une aisément passable, même avec des bouteilles relais et un propulseur. On se trouve alors au plafond d'une salle d'effondrement dont on ne perçoit que quelques éléments. Si l'on prend par la gauche, après un début accidenté, on suit une paroi de 20 à 30 m de haut. A un ou deux endroits, on passe derrière cette paroi. Le fond se trouve à 80 m de profondeur. Si l'on prend par la droite, on suit également une paroi, mais avec des décrochements plus nombreux qui font penser à des départs de galeries. Quand on les explore, on est invariablement ramené dans la salle principale après avoir été dans un cul de sac. Si l'on prend par la droite, sans suivre tous les pseudos départs, on aboutit à 450 m, à un rétrécissement entre le fond et le plafond (20 m), un endroit encombré de gros blocs qui marque la fin de la première partie de la salle. Un peu avant cet endroit, une colonne de 20 m de diamètre joint le fond et le plafond. La deuxième partie de la salle est plus profonde, avec un plafond à -80 et le fond à -112. Une colonne de 140 m de circonférence joint le plafond et le fond. Ici se rejoignent les explorations partant de droite et de gauche, sans qu'un passage plus au nord n'ait été trouvé. D'innombrables plongées ont permis de se faire une idée de cette salle, mais il est évident que personne à ce jour ne peut en donner une description absolue, car la vue d'ensemble est impossible, faute de lumière capable de percer les énormes distances entre les parois.

4. Historique et problématique des découvertes

La première approche de Vouliagmeni a eu lieu en 1989. Conduits par V. Giannopoulos, nous faisions un recensement des possibilités d'exploration des siphons en Grèce. En deux jours et 4 plongées, nous avions dépassé les limites alors connues du lac de Vouliagmeni.

En 1991, après quelques jours d'exploration et de topographie, nous étions à 80 m de profondeur et imaginions explorer un siphon classique,

Fig. 5: Déplacement en propulseur dans la vasque d'entrée (photo Chiquita)

Fig. 6: Vue du lac de Vouliagmeni (photo Béatrice del Oro).

avec une suite de salles et de galeries. Une première stalactite avait été trouvée à 55 m. La topographie indiquait déjà que des maisons de Vouliagmeni étaient bâties sur le siphon.

Les expéditions de 1992 et 1993 permettent de continuer les découvertes, mais c'est à partir de 1993 que les expéditions prennent plus d'ampleur, en particulier grâce au soutien financier de la commune de Vouliagmeni et du Ministère. En effet, les gaz commencent à coûter très cher, ainsi que le matériel plus spécialisé, comme les propulseurs.

Ce n'est qu'à partir de 1995 que la vision d'une grande salle unique remplace la vision classique d'un réseau de galeries et de salles. La manière de topographier s'adapte à cette nouvelle vision.

Dès le début de l'exploration, l'équipe a été internationale. Il aurait été difficile de trouver toutes les compétences nécessaires dans un seul pays. Vassili Giannopoulos, Luigi Casati, Jean-Jacques Bolanz et Patrick Deriaz ont constitué l'épine dorsale de l'équipe d'exploration et de topographie. Auxquels se sont adjoints de nombreux plongeurs grecs, français (dont Marc Douchet), slovènes, suisses et italiens.

Les permissions, pas toujours simples à obtenir, ont été l'affaire de Vassili Giannopoulos. Il a également été la cheville ouvrière de la recherche de sponsoring.

L'immensité de la salle, la profondeur et la longueur des plongées ont été autant de difficultés à apprivoiser et surmonter. Psychologiquement, lorsqu'on se trouve à la fenêtre de -35, face à l'immensité du vide et du noir… ça fait de l'effet, surtout au début. Un plongeur spéléo est souvent plus habitué à des espaces restreints, voire des étroitures, plutôt qu'au vide qui paraît sans fin.

L'équipe a aussi dû s'adapter à la profondeur et à la distance. En effet, chevaucher un propulseur à 1 m du sol d'une galerie n'offre pas les mêmes risques que de le chevaucher à quelques mètres sous le plafond, en ayant 20 à 30 m de vide sous soi et un maigre fil qu'il s'agit de ne pas quitter des yeux. Il est en effet inimaginable de penser retrouver un fil dans cette immensité.

Jusqu'en 2001, toutes les plongées étaient faites avec un matériel «classique»: bouteilles de 20 l et détendeurs conventionnels. Il y avait donc sous l'eau et hors de l'eau une débauche de bouteilles et de matériel. Ce n'est qu'en 2004 que le circuit fermé fut utilisé par Luigi, réduisant très considérablement le nombre et la grosseur des bouteilles nécessaires et le coût des mélanges gazeux.

Des sécurités supplémentaires étaient une cloche immergée dans la vasque et un caisson de décompression de secours sur le bord du lac. Il n'y a eu aucun accident à signaler durant les 15 ans d'exploration, même s'il y a eu quelques incidents qui furent bien maîtrisés. Le caisson n'a jamais été utilisé.

5. Résultats chiffrés

420 mètres d'explorations en 2001 et 175 m en 2004 portent la lon-

gueur totale explorée à 4'558 m, dont 3'860 m sont topographiés[1]. Le point le plus bas se trouve à 112 m de profondeur. Ces nouvelles explorations se situent au-delà de la zone de l'éboulis, à 450 m de l'entrée (400 m de la fenêtre) et dans la zone profonde du début de la paroi gauche. La topographie, enfin bouclée au plafond, confirme que nous sommes dans une gigantesque salle de 800 m de longueur, de 60 à 150 m de largeur et de 30-40 m de hauteur, soit plus de 2 millions de m[3].

La topographie de la salle est maintenant terminée au niveau du plafond (ou 4-5 mètres en dessous). Les seules galeries significatives non topographiées se situent à plus de 100 m de profondeur. Pour la galerie du Varech, cela est sans importance, car il n'y a pas de continuation. La galerie du Visionnaire n'est pas entièrement topographiée. La partie se trouvant à plus de 100 m de profondeur si elle n'est pas topographiée est reliée à deux points topos connus.

Des concrétions (varech) ont été ramenées pour la troisième année du fond de la grotte en vue d'analyses et de datation. S'il se confirme qu'il s'agit de concrétions ne pouvant se former qu'en présence de lumière, se trouvant à 730 m de l'entrée, il ne reste plus qu'à supposer qu'il fut un temps où la lumière pénétrait à cet endroit et que cette entrée de lumière est actuellement fermée.

6. Indications techniques (2001)

Il y a eu un total de 131 plongées dont 21 ont duré plus 2 heures, 7 plongées topo (730 m dont 510 m utilisables), 3 plongées d'exploration (420 m) et 16 plongées photo à 2 plongeurs. Les combinaisons étanches avec sous-vêtements légers n'ont été utilisées que pour les longues plongées, l'eau étant à une température de 23 à 26 degrés[2].

Des mélanges hélium légers (giclettes avec 10 à 30 % d'hélium) ont été utilisés pour la presque totalité des 21 plongées conséquentes ne dépassant pas 80 m de profondeur et/ou 700 m de longueur. Pour les pointes

Fig. 7: topographie de la grotte de Germanica, située sur la colline au-dessus de Vouliagmeni. Cette cavité a été plongée jusqu'à -45 m. L'exploration est à continuer. Le principal problème est de trouver des porteurs. La cavité a une température de 28°.