January 1999

1999: Ninth International Symposium on Vulcanospeleology Catania, Italy, Sept 11-19, 1999

Symposium on Vulcanospeleology International

CENTRO SPELEOLOGICO ETNEO

INSIDE VOLCANOES

Proceedings of the IXth International Symposium on Vulcanospeleology

CATANIA (ITALY) SEPTEMBER 11-19, 1999

INSIDE VOLCANOES

PROCEEDINGS

OF THE

IXth INTERNATIONAL SYMPOSIUM

ON VULCANOSPELEOLOGY

OF THE I.U.S.

SEPTEMBER 11-19, 1999

CATANIA (ITALY)

EDITED BY: CENTRO SPELEOLOGICO ETNEO
EDITORIAL STAFF: NICOLA BARONE, RENATO BONACCORSO AND GIUSEPPE LICITRA
PAGING UP, GRAPHICS AND DIGITAL FORMAT ORGANIZATION: RENATO BONACCORSO

INDEX

FOREWORD

The IX International Symposium on Vulcanospeleology was held in Catania from the 11th until the 19th of September 1999, and was organised by Centro Speleologico Etneo (C.S.E.) for celebrating the 15th anniversary of its foundation. The event was patronised by the International Union of Speleology (U.I.S.), by Società Speleologica Italiana (S.S.I., Italian Speleological Society), by Central Speleological Committee for Speleology of the Club Alpino Italiano (C.A.I., Italian Alpine Club) and by Federazione Speleologica Regionale Siciliana (F.S.R.S., Sicilian Regional Speleological Chapter), and several institutional bodies (Province and City of Catania, Regional Park of Etna, Provincial Tourist Council, National Research Centre, University, Superintendence for Cultural and Environmental estates, etc.) collaborated for its success. Over sixty people did register and attend the Symposium, coming from all over the world, including Japan and Tasman Island; a great selection of original contributes was presented during the scientific sessions, dealing with the several topics of Vulcanospeleology and its related disciplines.

Two additional and very important events were performed in connection with the main Symposium event: an exhibition and the publication of a volume, both titled «*Inside the Volcano – The Caves of Etna*». The exhibition displayed an unusual and fascinating approach to the underground environment focused on Etna volcanic caves, through an original and accurate iconographic and descriptive *excursus* supported by very rare archaeological findings, ancient books and engraved illustrations, mineral and rock samples, etc; the volume contains original papers contributed by Italian and foreign scholars of the various involved disciplines and offers an exhaustive panorama of Etna territory, though it also concerns general topics connected with Vulcanospeleology. Both activities benefited from the significant organisational and financial support of the Park of Etna.

The scientific sessions were preceded and followed by several pre- and post-Symposium excursions to caves and areas of volcanic, speleological and tourist interest in Sicilian mainland and in the Eolian Islands; in addition a general excursion took almost all participants up to the rim of the central crater of Etna, after a coach plus 4WD minibus ride from sea level to the top through its fascinating slopes, including an exceptional visit to the Volcanology Observatory and its scientific installations. All vulcanospeleological excursions were described in detail by a 46-pages guide in Italian and English, containing also geological information on the area. Its publication and distribution was financed by the National Group for Volcanology (GNV). In addition all scientific sessions, the general Assembly of the UIS Commission for Vulcanospeleology, and the Round Table on Volcanic Parks at Symposium's end, were supported by an excellent simultaneous translation service Italian-English and v.v., supplied and financed by the Provincial Tourist Council of Catania, in order to enable all participants to attend all presentations and debates without any linguistic problem.

In conclusion, it was an event at very high level, and we immodestly rely that it was performed at its best. Alas its follow-up was not at the same level, due to the heavy delay in Proceedings fulfilment. We feel sorry and embarrassed by this mischance, and trust that this CD-ROM (that we consider an anticipation of the Proceedings volume) can at least smoothen the long wait. The responsibility for this heavy delay could be easily charged to third parties (Authors, institutions that bid themselves to print the Proceedings, etc), or we could take on ourselves the entire responsibility. Yet, the undeniable reality is that more than five years have passed by and the Proceedings have not been printed. We therefore tender to all concerned parties our sincerest apologies for this long, though involuntary delay, as well as we hope that the CD-ROM will be followed as soon as possible by its cartaceous version, which should be financed and performed by the National Institute of Geophysics and Volcanology (INGV).

We heartily thank the numerous participants, that trusted in our skill and determined the success of the event by reaching Catania from the four corners of Earth, as well as we gratefully acknowledge all financing institutions, sponsors, organisations, commercial business and individuals, whose support made the event possible.

Acknowledgements

The IX Symposium on Vulcanospeleology was patronised by:

- Union Internationale de Spéléologie (U.I.S.), International Commission on Vulcanospeleology
- Italian Speleological Society
- Italian Alpine Club, Central Speleological Commission
- Regional Sicilian Speleological Chapter.

and was sponsored by:

- Regional Province of Catania, Assessorship for the Environment;
- City of Catania, Assessorship for Culture and School Policies; Assessorship for the Environment;
- City of Linguaglossa
- City of Lipari
- City of Milo
- City of San Gregorio di Catania
- Regional Park of Etna
- Provincial Tourist Council (A.A.P.I.T.) of Catania
- International Institute of Volcanology.
- National Volcanology Group (GNV)
- Sicilian Regional Superintendence for Cultural and Environmental Estates, Archaeological Dept. of Catania.

We are indebted with the following institutions and firms, which contributed to the fulfilment of the event by their financial and/or organisational support:

- Regional Province of Catania (hosted all scientific and related sessions of the Symposium, and the exhibition, in the premises of the convention centre «Le Ciminiere», free of charge).
- Provincial Institutional Tourist Council of Catania (offered and financed the simultaneous translation [professional interpreters, technical hardware and hostess assistance] during all scientific and related sessions of the event; financed transportation [coaches and 4WD mini-buses] and tourist guide assistance for the general excursion to Mt. Etna, and offered the cocktail party during the opening ceremony of the exhibition).
- National Volcanology Group (GNV) (financed and printed the guide of the pre- and post-Symposium excursions).
- International Institute of Volcanology - CNR (IIV) (hosted the participants to the general excursion on Etna in the premises of its Volcanological Observatory at Etna North).
- Sicilian Regional Superintendence for Cultural and Environmental Estates, Archaeological Dept. of Catania (organised, financed and fulfilled the archaeological section of the exhibition).
- City of Catania, Assessorship for Culture and School Policies and Assessorship for the Environment (co-financed the exhibition; hosted, free of charge, the introduction to the public of the volume «*Le Grotte dell'Etna*» at the convention hall of the City Assessorship for Boroughs and Youth Policies, and offered the relevant cocktail party).

- City of Linguaglossa (welcomed the participants to the general excursion at the City Hall and offered a welcome drink with local pastries).
- City of Lipari (supplied a complimentary guided coach-tour of the island of Lipari to the participants of the excursion C).
- City of Milo (welcomed the participants to the excursion E – Caves of Serracozzo - at the City Hall and offered a complimentary rustic snack with local wine tasting).
- City of San Gregorio di Catania (the Mayor met the participants to the excursion B - Immacolatella Caves - at the cave area and offered a complimentary rustic snack).
- Association for Tourist Implementation of Linguaglossa (hosted the participants to the general excursion in its premises, and offered refreshment and a movie projection on Etna activity).
- Sicilian Regional Forest Service (hosted all participants and offered a rustic lunch at the Forest Refuge «Pirao», during the general excursion to Mt. Etna).
- BANCA AGRICOLA POPOLARE DI RAGUSA (financed and sponsored the participant's badges and the nylon bags containing the participants' portfolio).
- TORRISI Coffee Company of Catania (managed a coffee stand for complimentary «*espresso*» service during all scientific and related sessions of the event).
- CONDORELLI Pastries and Sweets factory, Belpasso (offered complimentary nougat boxes to all participants).

A special mention is deserved by the Regional Park of Etna, as its extended and considerable operational and financial support was crucial for the organisation and the implementation of the event. Besides the co-funding of the exhibition, the Park financed and printed the volume «*Le Grotte dell'Etna*», granted the funds for the printing, and posting in the whole Province of Catania, of the official poster of the Symposium; financed all printing and mailing expenses for the three circulars sent to participants, and offered the farewell banquet at a renowned pub-restaurant downtown in Catania.

We sincerely thank the following persons for their hearty and disinterested collaboration:

- Dr. Salvatore Caffo and Dr. Luciano Signorello, respectively Volcanology and Organisational Officers of the Park of Etna. They assisted us disinterestedly during the whole organisation, preparation and implementation of the Symposium like friends of ours, rather than officers of the supporting institution, met all requests of ours, though extemporary, and cooperated at their best for the success of the event.
- Dr. Francesco Privitera, Archaeologist and officer of the Regional Superintendence for Cultural and Environmental Estates, Archaeological Section of Catania. He assisted us during the organisation of the event and the preparation of the exhibition, by personally implementing its archaeological section and lending the displayed archaeological findings, and volunteered his complimentary assistance for the visit to the City Museum of Adrano, during the excursion D – railway tour of Etna.
- Prof. Paolo Forti, Director of the Italian Centre for Speleological Documentation (CIDS) "Franco Anelli" of Società Speleologica Italiana and past-President of SSI and UIS. He put at our disposal the collection of ancient volumes and engravings of the Library, dealing with Volcanology, volcanic caves of Etna and the Cave of Fingal, that was displayed in the exhibition. He also directed and moderated the Round Table on Volcanic Parks.
- Dr. Franz Riccobono, antiquarian, writer and owner of the homonymous collection of ancient volumes and engravings dealing with Etna. He lent almost his entire

collection, which was displayed in the section "*Travellers and Myths*" of the exhibition.

- Prof. Renato Cristofolini (Inst. of Earth Sc., Univ. of Catania); Dr. William R. Halliday (Honorary President of the UIS Commission on Volcanic Caves); Dr. Jan-Paul Gustaav van der Pas (President of the UIS Commisssion on Volcanic Caves); Dr. Harry Pinkerton (Dept of Environmental. Sc., Univ. of Lancaster UK); Prof. Hubert Trimmel (President Emeritus of the UIS). Directed and moderated in faultless and competent manner the various scientific sessions of the Symposium. Dr. v.d.Pas also presided at the General Assembly of the UIS Commission on Vulcanospeleology.
- Mrs Roxanne McDermott, fellow of our Group in the Seventies, now living on the Alps. She came to Catania at her own expenses and volunteered her complimentary and friendly assistance during the whole period 11-19 September, for any kind of organisational and linguistic needs: Secretary problems, unexpected translation performances, assistance to participants (even for shopping), and so on. Everybody appreciated her assistance, as she loosened many knots…

and the following institutional officers that offered us their precious assistance:

- Dr..Attilio Bruno, manager of the convention centre "Le Ciminiere".
- Mrs Sonia Calvari, volcanologist, International Institute of Volcanology of N.R.C.
- Mr Giuseppe Failoni, engineer, officer of the City of Catania.
- Dr Giovanni Frazzetta, Director, International Institute of Volcanology of N.R.C.
- Dr Pietro Giovanni Litrico, officer of the Forest Service of the Sicilian Region.
- Dr Paolino Maniscalco, Alderman of the City of Catania.
- Dr.Gaetano Perricone, official press officer, Regional Park of Etna.
- Dr.Giuseppe S. Pulvirenti, Alderman of the Regional Province of Catania
- Dr.Filippo Sapienza, officer of the Regional Province of Catania
- Mrs Tomaselli, officer of the Provincial Tourist Council (A.A.P.I.T.) of Catania.
- Dr.Francesco Vinci, Director, Regional Park of Etna.
- Dr Alfio Zappalà, officer of the Regional Park of Etna.

We also thank the following institutions and commercial enterprises, for the supply of excellent services at very low rates and tariffs:

- COUNCIL FOR UNIVERSITY SERVICES, Catania (exceptionally hosted the requesting participants at the Student's College # 1 of Catania University, in the town centre, at student's rates).
- VALGIULIA Ltd. (prepared and printed all photographic and descriptive panels of the exhibition «Inside the Volcano – the Caves of Etna»).
- STAR Company Inc., Linguaglossa (supplied complimentary alpine guide's service and granted ultra-reduced 4WD mini-bus fares for the general excursion to the top of Etna).
- P.A.M. Inc., Coach Company, Mascalucia (supplied all coach and mini-bus transportation during the various tourist and speleological excursions at very low rental rates).
- LA BUCA INN, Taormina (supplied at reduced price an excellent lunch to the participants to excursion J – Cyclopes Riviera and Taormina).
- LA PAGLIA INN, Catania (supplied at reduced price an excellent typical lunch to the participants to excursion K – Monumental tour of Catania).

- Restaurant SCRIBANO, Randazzo (supplied at reduced price an excellent lunch to the participants to excursion D – Railway tour of Etna).
- Restaurant-Pizzeria KASBAH, Lipari (supplied all bag lunches for the whole excursion C at discounted price).
- Cafeteria WUNDERBAR, Taormina (supplied an almost complimentary aperitif party, in *open-bar* style, to the participants to excursion J – Cyclopes Riviera and Taormina).
- Cafeteria EUROPA, Catania (supplied an excellent and very cheap cocktail service for the inauguration of the exhibition and for the introduction of the volume «Le Grotte dell'Etna»).
- MANU Viaggi, Travel Agents in Catania (supplied tourist assistance to foreign participants: reservations, ticketing, etc, before and during the Symposium, and the mandatory technical assistance for the tourist excursions).

In addition, we willingly acknowledge the friendly and collaborative mood that inspired the following suppliers during their professional performances:

- Mrs. Vanna Laura Scalia and Mrs. Alessandra Perricone, professional interpreters. They performed an excellent and appreciated simultaneous translation (Italian-English and v.v.) of all scientific sessions of the Symposium, Commission's Assembly and Round Table, far beyond their job duties and our expectancies.
- Mrs Giusi Belfiore, professional tourist guide, led in excellent way and friendly mood the excursion J to Riviera dei Ciclopi and Taormina, and the Catania City tour K.
- Mr Ermanno Spampinato, professional tourist guide, led the excursion D, railway tour of Etna, at full participants' satisfaction.
- Mrs Elisabeth Curie, professional tourist guide in Lipari, led an accurate rove to Volcano's crater rim in Vulcano Island, and the tourist visit to the citadel and Archaeological Museum of Lipari, beyond any participants' demand, and volunteered complimentary off-duty tourist assistance to Anna and Siggi, solving their flight problems for their trip back to Iceland.

Last but not least, almost all C.S.E. fellows and friends (a great deal indeed) deserve a hearty acknowledgement for their voluntary and disinterested cooperation for a soft and regular progress of the numerous scheduled events and a successful implementation, fulfilment and conclusion of «*the last vulcanospeleological event of the Millennium*». We are reluctant to mention any of them, as all of us knew that the event involved C.S.E.'s imagine itself and willingly cooperated, and don't want to forget anyone, whose personal support was an invaluable brick for the success of the Symposium. Yet it is impossible to not mention the basic support given by the Organising Committee members: Renato Bonaccorso, Giuseppe M. Licitra, Giuseppe Puglisi and Giancarlo Santi, as no event could have been performed without their irreplaceable cooperation. And the Organising Committee as a whole is deeply grateful and indebted with all fellows and friends that cooperated in the several organisational phases and during the implementation of the event, which could not be performed without their support.

Nicola Barone
Chairman of the Organising Committee
Of the IX International Symposium
On Vulcanospeleology

THE IX SYMPOSIUM ON VULCANOSPELEOLOGY
A BET

History of the ninth century reports that the tyrant of Kairouan, Zjiadet Allah, manned an army of one hundred thousand soldiers for invading and conquering Sicily, which, for the time being, was ruled and defended by the Byzantines. The army, led by the old Zjiadet's advisor Ased Ibn-el-Furat, nicknamed "*the Lion*", disembarked at Ras el Belat (Cape Granitola, near Mazara del Vallo) on the night of 16 June 827 a.D. As well as the last soldier put his foot ashore, Ased commanded to set the whole fleet on fire. «*We don't need any escape means*», the Lion said: «*we'll settle here, or die, that's a must!* ». The Arabs conquered Palermo in 831 and ruled Sicily until 1072, when Roger the Norman defeated them and conquered the island back on behalf of the Christian community.

The organisation of the IX Symposium on Vulcanospeleology was an actual bet. We had already scored more than a decade of intense activity, from the establishment in 1984 of our Centro Speleologico Etneo, perhaps the most active group in Europe, for Vulcanospeleological researches and explorations. When the fifteenth anniversary came into sight, we started discussions on how to celebrate this important target, and the idea of a Symposium began to sprout and tickle our minds. «*A hard engagement*», said someone, «*involving a lot of experience and knowledge!…*». «*We already organised two such Symposia, in 1975 and in 1983*», I replied, «*therefore we have more than the experience we need: the label was different, but people and minds are unchanged, we are still the same guys*». «*A well organised event involves a lot of money*», someone added, «*and today swarms of competitors in the naturalistic field challenge for increasingly scanty grants and sponsorships*».

I reported to my fellows the anecdote of Ased the Lion, and closed my argumentation: «*Let's approve a Symposial celebration, as a starting point, and the whole balance will follow*». It was the year 1996. A restricted committee was formed: Nicola Barone, CSE chairman, was appointed as Symposium Committee chairman, in charge for general coordination and for finding any kind of sponsorship and grant; Renato Bonaccorso, treasurer, had to coordinate all Secretary, bureaucratic and technological work, whereas I myself – the official "*graphomaniac*" of the Group – was committed with the scientific aspect of the event: my task was to get in touch and carry on contacts with all possible contributors throughout the world, to plead for original contributes on Vulcanospeleology and related topics, and arrange same into a symposial schedule. In addition, I planned and assembled all scientific, recreational and technical steps of the whole event into an organic framework, thanks to my professional expertise in the tourist and convention field. Anyone of us, in addition, had to cooperate with his fellows in their respective tasks. The Committee also benefited by the collaboration of our fellows Giuseppe Puglisi (Volcanology researcher at the National Research Council), who liaised with the local scientific environment, and of Giancarlo Santi (journalist), who took care of all press and editorial problems. Two additional and very important events must be mentioned, organised by our group in connection with the Symposium and coordinated by Nicola Barone with Renato Bonaccorso's and Luciano Signorello's (Park of Etna) collaboration: the publication, after more than one year work of the entire group, of the volume «*Le Grotte dell'Etna*» (The Caves of Etna), edited by our fellow Giancarlo Santi and published by the Park of Etna, and introduced to the public at the eve of the scientific sessions; and the very successful Exhibition on the same topic, inaugurated two days before the Symposium, and open to the public until mid January 2000.

One only nugget threatened the gear of our programs: Jim Simons, CEGEA's Chairman, submitted to Bill Halliday (Commission's chairman at that time) his proposal for a Symposium, the VIII one, to be held in Nairobi in 1998 Spring, just a handful of days before us, and he was absolutely prevented from shifting his event to the next century, due to financial, organisational

and strategic reasons, whereas the year 1999 was a must for us. We therefore announced our proposal to organize our Symposium, the IX one, in the second half of 1999, regardless of the short interval between the two events. September 1999 came on and passed by, and I immodestly believe that the IX Symposium was perhaps the most successful and well-organised event in the history of the Symposia on Vulcanospeleology. I do not want to report the feverish days that preceded the event, the sessions, the excursions, the thousand things that had to be checked and implemented. All participants remind and can witness the success of our Symposium, whereas no subsequent description can render the enthusiastic atmosphere, that all of us breathed in those days, to who missed the event. Alas the brief interval after the Nairobi Symposium involved some inconvenient. Several contributors to the VIII Symposium, that had announced further papers for the IX one, plead additional time for arranging their written presentations, after the symposial discussion.

The follow-up, for getting the final papers, took lots of time, and several contributors did never submit their final written work. Someone replied to our reminders, and declared that he withdrew the presentation or missed the time, or the… concentration, for preparing a written presentation, someone else simply disregarded our repeated pleads. Moreover, the formats (if any – some were simply written…) of all submitted contributes were different one from another, regardless of the submitting directions in our 2nd circular, and we had to work hardly – up to a few days ago – to homogenise everything in the same format. In addition, the Area della Ricerca of CNR, that had officially sponsored the publication of the Proceedings (and for this reason had been adequately mentioned in all Symposium communications and prints), withdrew its sponsorship abruptly and without any explanation or reason whatsoever. Last but not least, the subsequent INGV's (National Institute for Geophysics and Volcanology) proposal to fund the Proceedings, repeatedly delayed, remained an ineffective rather than generous proposal, which only added further delay to the publication. Maybe the INGV will actually materialise a cartaceous version of the Proceedings in a more or less next future; yet we may not waste additional time.

Today we recognise that no reasons at all can be put forth for further delaying the publication of the received papers: we owe it to all people who entrusted us. The X Symposium in Iceland and the XI one in the Azores approached and already passed by, and we are unwilling to face any further – and fully justified – recrimination. Therefore we… unearthed our "*Proceeding funds*", wisely sat aside at the end of the event, and a digital edition of the Proceedings is coming to light at our own expenses and care, and since technology is rapidly evolving day by day, the CD-ROM issue we are presenting is fully justified. <u>All</u> contributes mentioned in the pre-prints are reported. The simple abstracts produced by the authors replace the missing papers, regardless of the reason for which the original paper was not produced (once more I beg to point out that <u>no paper at all</u> was lost at our side, as rumoured during the X Symposium. I only suggested a possible loss in the mail, in my last urging communication to contributors, just to avoid an impolite and disrespectful request like «*time has been consumed to the bottom, don't add further delay and rush your paper!*»), whereas some local contribute appears only in Italian instead of English, since the author(s) did never produce the relevant English version.

More than five full years have passed by from September 1999, and at last these Proceedings are coming to light. We cannot but sincerely apologise for this very long, though involuntary delay, and rely that our efforts for a deeper knowledge in Vulcanospeleology will be appreciated by the most of our readers. It is not my job to thank who supported the success of the Symposium and made possible the publication of the Proceedings, Nicola will do it, and I support his acknowledgements. Though, I cannot but mention the invaluable contribute that two individuals gave to the event and to the Proceedings as a whole: Nicola Barone, chairman of C.S.E. and of the Organising Committee, coordinator of the Exhibition and editorial coordinator of the volume «*Le*

Grotte dell'Etna», and Renato Bonaccorso, Committee member. Nicola completely disregarded home, family, job, and yearly vacations for almost three years, and entirely devoted his energies to do, press, plead, coordinate, and solve the hundreds of needs and problems we met during the organisation, and to flatten any unforeseen nugget that menaced the regular course of the Symposium. Only his steady determination and smooth mode succeeded and crushed even the hardest obstacles, by ascending staircases, knocking at doors, closing agreements… Well, a detailed description of all Nicola's operations would be a hard, almost impossible task. Let me only say that I myself first promoted the organisation, and then planned the Symposium; all of us worked hard, but Nicola's action was irreplaceable for implementing and fulfilling it. As to Renato… His attitude and expertise and patience was determinant in coordinating and managing all bureaucratic tasks before, during and after the event, as well as his personal unselfish work for assembling, formatting and paging up all Proceedings material was determinant for the Proceedings issue. No publication could have been possible without his irreplaceable contribute. Now our task has almost come to an end. The IX Symposium on Vulcanospeleology was an actual bet, a damned fascinating bet, and now we can say that we fulfilled it.

Giuseppe M. Licitra
Member of the International Commission
on Vulcanospeleology of the U.I.S. and
member of the Organising Committee of the
IX Symposium on Vulcanospeleology

Organising Committee

Nicola Barone
Renato Bonaccorso
Giuseppe M.Licitra
Giuseppe Puglisi
Giancarlo Santi

Secretary

Renato Bonaccorso

Collaborators

Giuseppe Calcagno
Silvia Carciotto
Giuseppe Conti
Alessandra Di Salvo
Maria Letizia Gagliano
Giuseppe Garozzo
Gaetano Giudice
Gino Gulli
Francesco Leone
Angelo Leotta
Giulia Li Destri
Marco Liuzzo
Antonio Marino
Carmelo Marino
Roberto Maugeri
Margherita Mirone
Francesco Petralia
Franco Politano
Angela Privitera
Laura Saitta
Fabio Santonocito
Francesca Santonocito

ATTENDINGS

s.n.	Surname	Name	Group or Institution	Town	Country
1	Antognini	Marco	Società Svizzera di Speleologia - Sezione Ticino	Ponte Capriasca	Svizzera
2	Bani	Marco	Sezione Speleologica CAI SSI Città di Castello	Città di Castello	Italia
3	Barone	Nicola	Centro Speleologico Etneo	Catania	Italia
4	Bonaccorso	Renato	Centro Speleologico Etneo	Catania	Italia
5	Brettschneider	Hans-Helmut		Bad Homburg	Germania
6	Buzzini	Roberto	Società Svizzera di Speleologia - Sezione Ticino	Locarno	Svizzera
7	Caffo	Salvatore	Parco dell'Etna	Nicolosi	Italia
8	Calvari	Sonia	Istituto Internazionale di Vulcanologia CT	Catania	Italia
9	Caruso	Domenico	Università degli Studi di Catania Dipartimento di Biologia	Catania	Italia
10	Coltelli	Mario	Istituto Internazionale di Vulcanologia CT	Catania	Italia
11	Corsaro	Rosanna	Istituto Internazionale di Vulcanologia CT	Catania	Italia
12	Cristofolini	Renato	Università di Catania Dip. Scienze della Terra	Catania	Italia
13	Cucuzza Silvestri	Salvatore		Catania	Italia
14	De Swart	Dick	Speleo Nederland	Schoonhoven	Holland
15	De Swart	Herman	Speleo Nederland	Leiden	Holland
16	De Waele	Jo	Dipartimento Scienze della Terra Università di Cagliari	Monserrato	Italia
17	Forti	Paolo	Istituto Italiano di Speleologia	Bologna	Italia
18	Gaàl	Ludovit	Slovak Enviromental Agency	Rimavska Sobota	Slovakia
19	Girelli	Luca	Sezione Speleologica SSI - CAI Città di Castello (PG)	Città di Castello	Italia
20	Giudice	Gaetano	Centro Speleologico Etneo	Catania	Italia
21	Groenendijk	Ton	Speleo Nederland	Delft	Holland
22	Halliday	William R.	Hawaii Chapter, National Speleological Society	Nashville	USA
23	Honda	Tsutomu	Mt. Fuji Vulcanospeleological Society	Tokyo	Japan
24	Iommarini	Fania	Società Svizzera di Speleologia - Sezione Ticino	Leontica	Svizzera
25	Jonsson	Siggi	Icelandic Speleological Society	Reykjavik	Iceland
26	Kashima	Naruhiko	College of Agriculture, Ehime University	Matsuyama City	Japan
27	Kempe	Stephan	Hawaii Speleological Survey	Dieburg	Germania
28	Kueppers	Ulrich		Waakirchen	Germania
29	Laprocina	Enrica		Monfalcone	Italia
30	Leotta	Angelo	Centro Speleologico Etneo	Catania	Italia
31	Licitra	Giuseppe	Centro Speleologico Etneo	Catania	Italia
32	Liuzzo	Marco	Centro Speleologico Etneo	Catania	Italia

ATTENDINGS

s.n.	Surname	Name	Group or Institution	Town	Country
33	Madonia	Paolo	Nisida	Palermo	Italia
34	Marino	Antonio	Centro Speleologico Etneo	Catania	Italia
35	Martin Esquivel	Jose	Canary Goverment	Tenerife	Espana
36	Martinaglia	Floriano	Società Svizzera di Speleologia - Sezione Ticino	Cadro	Svizzera
37	Maugeri	Roberto	Centro Speleologico Etneo	Catania	Italia
38	Middleton	Gregory J.	Sydney Speleological Society, IUS Commission on Vulcanospeleology	Sandy Bay	Australia
39	Ogawa	Takanori	Speleological Society of Japan	Chiba City	Japan
40	Panzica La Manna	Marcello	Assessorato Regionale Territorio e Ambiente	Palermo	Italia
41	Patti	Andrea	Agharti	Pedara	Italia
42	Pinkerton	Harry	Environmental Science Dept. Lancaster England	Lancaster	United Kingdom
43	Politano	Francesco	Centro Speleologico Etneo	Catania	Italia
44	Privitera	Angela	Centro Speleologico Etneo	Catania	Italia
45	Privitera	Francesco	Soprintendenza ai BB. CC. AA. CT	Catania	Italia
46	Puglisi	Giuseppe	Istituto Internazionale di Vulcanologia CT	Catania	Italia
47	Renghi	Silvia	Sezione Speleologica SSI - CAI Città di Castello (PG)	Città di Castello	Italia
48	Santi	Giancarlo	Centro Speleologico Etneo	Catania	Italia
49	Santonocito	Fabio	Centro Speleologico Etneo	Catania	Italia
50	Stephenson	Jon	James Cook University	Townsville	Australia
51	Trimmel	Hubert	Federation of Austrian Speleologist - UIS (Past-President)	Wien	Austria
52	Van Der Pas	Jan-Paul	Speleo Nederland	Schimmert	Holland
53	Watts	Robert		Talbot Campus Poole	United Kingdom
54	Wood	Christopher	Bournemouth University	Bournemouth	United Kingdom
	ADHERENTS				
55	Barcelos	Paulo	Os Montanheiros S.E.E.		Azzorre (Portogallo)
56	Benedetto	Carlos	Instituto Argentino de Investigaciones Espeleologicas	Malargue	Republica Argentina
57	Comar	Maurizio	Società di Studi Carsici "A. F. Lindner" - Fogliano (GO)	Pieris	Italia
58	Grassi	Lorenzo	Gruppo Grotte Roma Niphargus		Italia
59	Muntoni	Alberto	Dipartimento Scienze della Terra Università di Cagliari	Cagliari	Italia
60	Perna	Giuliano		Villazzano	Italia
61	Piciocchi	Alfonso			Italia
62	Sabroux	Jean-Christophe	Institut de Protection et de Surete Nucleaire	Gif-sur-Yvette cedex	France
63	Szakacs	Alexandru	Institutul Geologic al Romaniei	Bucaresti	Romania

INSIDE VOLCANOES

IX INTERNATIONAL SYMPOSIUM ON VULCANOSPELEOLOGY OF THE I.U.S.

UNDER THE PATRONAGE OF THE

INTERNATIONAL UNION OF SPELEOLOGY

ROUND TABLE DISCUSSION
ON
«SPELEOLOGY AND ENVIRONMENTAL CONSERVATION IN VOLCANIC PARKS»

SEPTEMBER 11-19, 1999

CATANIA (ITALY)

GENERAL

PROGRAM

PRE-SYMPOSIUM

CONVENTION AND FAIR CENTER «*le Ciminiere*» (Piazzale Asia)
----

10 SEP (fri) 09:00 - 12:00 – Opening of the Secretary; arrivals and registrations.
15:00 - 18:00 – Opening of the Secretary; arrivals and registrations.
21:00 - 23:00 – Registration of late arrivals at CSE's seat, via Cagliari 15

11 SEP (Sat) 07:00 – departure of the optional vulcanospeleological excursion **A** (Grotta Cutrona in Valle del Bove)
09:00 - 12:00 – Opening of the Secretary; arrivals and registrations.
15:00 - 18:00 – Opening of the Secretary; arrivals and registrations.
18:30 - 20:00 - The President and the Prefect of the Province of Catania inaugurate the Exhibition «Le Grotte dell'Etna», which will be open to the public until 31/10/99. Refreshment.

12 SEP (Sun) 08:30 – Departure for the optional vulcanospeleological excursion **B** (Caves of Piano Immacolatella, in the territory of San Gregorio di Catania)
09:00 - 12:00 – Opening of the Secretary; arrivals and registrations.
15:00 - 18:00 – Opening of the Secretary; arrivals and registrations.

MEETING HALL OF THE CITY ASSESSORSHIP FOR BOROUGHS AND YOUTH POLICIES - VIA TOMASELLI 29

19:00 - 20:00 - Presentation to the public of the volume «Le Grotte dell'Etna», produced by Centro Speleologico Etneo and published by the Park of Etna. The Mayor of Catania and the Alderwoman for Culture will attend to the event. Refreshment.

SIMPOSIUM

13 SEP (Mon) 09:00 - 12:00 – Opening of the Secretary; arrivals and registrations.
15:00 - 18:00 – Opening of the Secretary; arrivals and registrations.
09:00 - 10:40 – Lectures in the Conference Hall
10:40 - 11:10 – Coffee break
11:10 - 13:00 – Lectures in the Conference Hall
13:00 - 15:00 – Interval
15:00 - 16:40 – Lectures in the Conference Hall
16:40 - 17:00 – Coffee break
17:00 - 18:50 – Aula; presentazione lavori
20:30 - Slide projection on «Etna eruption 1991-93», by Dr. Romolo Romano, volcanologist and researcher of the I.I.V.

Accompanying persons, 08:30: Departure for the optional tourist excursion **J** (Ciclopes' Riviera, Acireale and Taormina)

14 SEP (Tue) 09:00 - 12:00 – Opening of the Secretary; arrivals and registrations.
15:00 - 18:00 – Opening of the Secretary; arrivals and registrations.
09:00 - 10:40 – Lectures in the Conference Hall
10:40 - 11:10 – Coffee break
11:10 - 13:00 – Lectures in the Conference Hall
13:00 - 15:00 – Interval
15:00 - 16:40 – Lectures in the Conference Hall
16:40 - 17:00 – Coffee break
17:00 - 19:00 – Aula; presentazione lavori
20:30 – Optional social pizza at some restaurant downtown.

Accompanying persons, 10:00-13:00: Complimentary excursion **K** (on foot), offered by the Organising Committee in collaboration with the Superintendent of the Province of Catania for Cultural, Archæological and Environmental Estates (guided visit to the historic centre of Catania). Optional lunch at a typical Sicilian «*putìa*» (inn) in the fish market (Trattoria La Paglia).

15 SEP (Wed) 08:45 - Departure for the **general excursion** to the northern flank of Etna: meeting with the Mayor of Linguaglossa and complimentary drink; visit to the Ethnologic Museum of Linguaglossa, where the Chairman of Pro-Loco will offer a complimentary wine tasting with roasted chick-peas; stop at Rifugio Pirao, where the Forest Dept. will host the party and collaborate for a rustic lunch with local specialties; excursion to the crater area by STAR Co.'s 4WD mini-buses and guided visit to Etna Volcanologic Observatory at Monte Pizzi Deneri. Expected return back to Catania at about 21:00.

16 SEP (Thu) 09:00 - 12:00 – Opening of the Secretary; arrivals and registrations.
15:00 - 18:00 – Opening of the Secretary; arrivals and registrations.
09:00 - 10:40 – Lectures in the Conference Hall
10:40 - 11:10 – Coffee break
11:10 - 11:30 – Slide projection «Glimpses of Etna», by H. Mueller
11:30 - 13:00 – General Assembly of the IUS Commission; debate, motions, conclusion.

ROUND TABLE DISCUSSION
CONVENTION AND FAIR CENTER «*le Ciminiere*» (Piazzale Asia)

15:30 - 19:00 – Round Table discussion on «SPELEOLOGY AND ENVIRONMENTAL PROTECTION IN VOLCANIC PARKS». Official lectures, replies, debate conclusion.
21:00 - Farewell banquet at the restaurant-pub «al 17», Piazza Duca di Genova (Porto borough).

POST-SYMPOSIUM

CSE'S SEAT, VIA CAGLIARI 15 – PH./FAX 095437018
----
17 SEP (Fri) 07:15 – Departure for the optional excursion **C** (3dd - Islands of Lipari and Vulcano),
07:40 – Departure for the optional excursion **D** (1d - Tourist tour of Etna by Circumetnea train)
08:00 – Departure for the optional excursion **E** (1d - Visit to Grotta di Serracozzo)
18 SEP (Sat) 07:00 – Departure for the optional excursion **F_1** (1d - Grotta dei Tre Livelli, Grotta KTM)
19 SEP (Sun) 08:00 – Departure for the optional excursion **H** (1g - Grotta dell'Intraleo).

SCHEDULES

OF

TOPICS, PAPERS AND

SESSIONS

SCHEDULE OF TOPICS AND PAPERS

VULCANOSPELEOLOGY ON ETNA AND IN ITALY	VULCANOSPELEOLOGY IN THE WORLD	NEW CONCEPTS IN VULCANOSPELEOLOGY	HISTORY, ARCHÆOLOGY, ARTIFICIAL CAVES
A) Bonaccorso R., Maugeri R. - Top ten caves on Mt. Etna. Cadastrial files	**J) Forti Paolo et al**. - Minerogenesis in some volcanic caves of Kenya	**S) Honda Tsutomu** - Classification of lava tree molds wit/without remelted inner surace…	**AA) Patti A. et al.** - On the ancient Mother Church of Mompilieri, Etna, Italy
B) Calvari S. et al. - Formation of a complex tube network: the 1999 Etna eruption	**K) Gaàl Ludovìt** - Syngenetic volcanic caves in the West Carpathians	**T) Calvari S., Pinkerton H.** - Morphology of Etna lava tubes: insights for lava flow emplacement mechanisms	**AB) Politano F., Santonocito F.** - The Ruins of the ancient "*Campanarazzu*", buried...
C) Corsaro R. et al. - Features of Etna Lava Stalactites	**L) Honda Tsutomu et al.** - Results of survey on Ganno-ana system: example of co-existence...	**U) Coltelli M. et al.** - Cross-section measurement of 1991-93 eruption lava tube	**AC) Privitera F.sco** - Archeological findings in the caves of Mt Etna
D) Marino Antonio - Secondary mineralizations at Grotta del Fumo	**M) Jònsson S. et al.** - 2nd Speleological expedition to Surtsey	**V) Halliday William R.** - Conduit flow of water in volcanic pseudokarsts	**AD) Puglisi G., Santi G.** - Studies on volcanic caves during the past centuries
E) Giudice G., Privitera A. - The Grotta del Fumo-Macchia Gialla-Grotta dell'Arco system	**N) Kempe Stephan et al**. - Geology of the Huehue Tube (eruption 1801) and the Puhia Pele channel…	**W) Honda Tsutomu** - Investigation on Hydrodynamic interaction between tree and lava…	**AE) Santi Giancarlo** - Etna caves and XVIII century visitors
F) Leotta A., Liuzzo M. - Fracture caves on Mt. Etna	**O) Jònsson S. et al.** - Checklist and distribution of Icelandic lava caves	**X) Kempe Stephan** - Mapping lava flows by surveying lava tubes; example: Aila'au...	**AF) Politano Franco** - Artificial caves in lava flows
G) Liuzzo Marco - Study on volcanic cave concretions formed during the 1991-93 eruption of Mt. Etna	**P) Jònsson S. et al.** - New minerals from Icelandic lava caves and selected…	**Y) Kempe Stephan** - The Genesis of isolated lava caves on Hawai'i	**AG) Santi Giancarlo** - Myths and legends on Etna caves
H) De Waele J., Muntoni A., - On some volcanic caves of Sardinia, Italy	**Q) Middleton Gregory** - Lava Caves of Grande Comore, Indian Ocean: further investigations…	**Z) Stephenson Jon** - Emplacement of tube fed lavas and tube development…	**AH) Halliday William R. -** A short history of Vulcanospeleology
I) Madonia P., Casamento G. - Basaltic canyons on Mt. Etna	**R) Martìn Esquivel J.** - The Viento Cave. A volcanic lava tube of Canary Islands		

SCHEDULE OF TOPICS AND PAPERS

BIOLOGY	CONSERVATION	*IN ABSENTIA*, POSTERS
AI) Caruso Domenico - Fauna of Etna caves: description and considerations	**AJ) Caffo S., Marino A.** - Monitoring of Grotta del Gelo (Frost Cave)	**AP1) Benedetto Carlos** - Volcanic Caves in Argentina *IN ABSENTIA*
	AJ1) Marino A. - Grotta del Gelo and its glacial phenomenon	**AP2) Grassi L. et al.** - Devil's Pit at Monte Venere, the only Latial volcanic cave… *IN ABSENTIA*
	AK) Halliday William R. - Volcanic Show Caves in the World	**AP3) J.C.Sabroux et al.** – Radon monitoring in a geothermal ice cave of Mt. Erebus … *IN ABSENTIA*
	AL) Middleton Gregory - Conserving the Lava Caves of Mauritius: the Caves of...	**AP4)Szakacs Aleksandru** - Vulcanocarst: a Romanian contribution to Speleology, *IN ABSENTIA*
	AM) Wood Christopher - A rationale for the protection of volcanic caves	**AP5) Calvari S. et al.** – Main morphologic features of Etna lava tubes *POSTER*
	AN) Stephenson Jon – Guided tourism at Undara caves. North Qeensland.	**AP6) Patti A. et al.** – On the ancient Mother Church of Mompilieri, Etna, Italy *POSTER*
	AO) Halliday William R. – Speleology in volcanic parks	**AP7) Politano F., Santonocito F.** – The Ruins of the ancient "*Campanarazzu*", buried... *POSTER*
		AP8) Perna G. - Marine caves in basalts 1:Fingal's Cave in the Island of Staffa, Hebrides, Scotland - *POSTER*
		AP9) Perna Giuliano - Marine caves in basalts 2 - *POSTER*

SCHEDULE OF SESSIONS, LECTURERS AND ROUND TABLE DISCUSSION

SESSION	MONDAY 13/09/99		TUESDAY 14/09/99	
morning 1	**Chairman: Prof. Hubert TRIMMEL**		**Chairman: Dr. Harry PINKERTON**	
	Topic: Vulcanospeleology on Etna and in Italy		***Topic: New concepts in Vulcanospeleology***	
	09:00	**A**) Maugeri Roberto	09:00	**S**) Honda Tsutomu
	09:25	**B**) Calvari S. + Pinkerton H.	09:25	**T**) Calvari Sonia
	09:50	**C**) Corsaro Rosanna	09:50	**U**) Coltelli Mauro.
	10:15	**D**) Marino Antonio	10:15	**V**) Halliday William R.
10:40 / 11:10	COFFEE BREAK			
morning 2	**Chairman: Prof. Hubert TRIMMEL**		**Chairman: Dr. Harry PINKERTON**	
	Topic: Vulcanospeleology on Etna and in Italy		***Topic: New concepts in Vulcanospeleology***	
	11:10	**E**) Giudice Gaetano	11:10	**W**) Honda Tsutomu
	11:35	**F**) Leotta Angelo	11:35	**X**) Kempe Stephan
	12:00	**G**) Liuzzo Marco	12:00	**Y**) Kempe Stephan
	12:20	**H**) De Waele Jo	12:20	**R**) Martìn Esquivel José
	12:35	**I**) Madonia Paolo	12:50 / 13:00 - Time left for discussion	
13:00 / 15:00	BREAK			
afternoon 1	**Chairman: Dr. William R. HALLIDAY**		**Chairman: Prof. Renato CRISTOFOLINI**	
	Topic: Vulcanospeleology in the World		***Topic: History, Archæology, Artificial caves***	
	15:00	**J**) Forti Paolo	15:00	**AA**) Patti Andrea
	15:25	**K**) Gaàl Ludovìt	15:25	**AB**) Santonocito Fabio
	15:50	**L**) Honda Tsutomu	15:50	**AC**) Privitera Francesco
	16:15	**M**) Jònsson Sveinn Sigurður	16:15	**AD**) Puglisi Giuseppe
16:40 / 17:00	COFFEE BREAK			
afternoon 2	**Chairman: Dr. William R. HALLIDAY**		**Chairman: Prof. Renato CRISTOFOLINI**	
	Topic: Vulcanospeleology in the World		***Topic: History, Archæology, Artificial caves***	
	17:00	**N**) Kempe Stephan	17:00	**AE**) Santi Giancarlo
	17:25	**O**) Jònsson Sveinn Sigurður	17:25	**AF**) Politano Franco
	17:40	**P**) Jònsson Sveinn Sigurður	17:50	**AG**) Santi Giancarlo
	18:00	**Q**) Middleton Gregory J.	18:15	**AH**) Halliday William R.
	18:25	**Z**) Stephenson Jon	***Topic: Biology in volcanic caves***	
(*) Paper lectured by GRASSO Rosario, on behalf of CARUSO Domenico			18:40	**AI**) Caruso Domenico (*)

SCHEDULE OF SESSIONS, LECTURERS AND ROUND TABLE DISCUSSION

SESSION	THURSDAY 16/09/99	
morning 1	**Chairman: Dr. Jan Paul VAN DER PAS**	
	Topic: Conservation	
	09:00	**AJ, AJ1**) Marino Antonio
	09:25	**AK**) Halliday William R.
	09:50	**AL**) Middleton Gregory J.
	10:15	**AM**) Wood Christopher
10:40 / 11:10	COFFEE BREAK	
morning 2	**Chairman: Dr. Jan Paul VAN DER PAS**	
	11:10	***Müller's slides on Mt. Etna***
	from 11:30 - General Assembly of the Commission on Volcanic Caves of the IUS, under Chairman Van Der Pas' direction. Debate, Motions, Conclusion	
13:00 / 15:00	BREAK	
afternoon	**ROUND TABLE DISCUSSION ON SPELEOLOGY AND ENVIRONMENTAL CONSERVATION IN VOLCANIC PARKS**	
	Chairman: Paolo FORTI	
	Official speakers:	
	Francesco **VINCI** (Etna Park)	
	Nicola **BARONE** (Centro Speleo. Etneo)	
	Alfonso **PICIOCCHI** (Vesuvius Park)	
	William R. **HALLIDAY** (Hon.Ch.Comm.IUS))	
	Christopher **WOOD** (Conservation Teacher)	
	Time per Speaker: 20 minutes	
	Time per debater: 10 minutes	
	Debate, Conclusion	
	Starting time 15:30 - Expected end 19:00	

AUTHORS LIST

s.n.	Author	presented papers				
1	Amantia A.	7 - AP5				
2	Battiato M.L.	7 - AP2				
3	Benedetto C.	7 - AP1				
4	Bonaccorso R.	1 - A				
5	Bozzo E.	3 - U				
6	Caffo S.	6 - AJ				
7	Calvari S.	1 - B	1 - C	3 - T	7 - AP2	
8	Cappa G.	7 - AP2				
9	Caruso D.	5 - AI				
10	Coltelli M.	3 - U				
11	Corsaro R.	1 - C				
12	De Waele J.	1 - H				
13	Faivre-Pierret X.R.	7 - AP3				
14	Felici A.	7 - AP2				
15	Forti P.	2 - J				
16	Gaàl L.	2 - K				
17	Galli E.	2 - J				
18	Giudice G.	1 - E				
19	Grassi L.	7 - AP2				
20	Halliday W.R.	3 - V	4 - AH	6 - AK	6 - AO	
21	Honda T:	2 - L	3 - S	3 - W		
22	Izquierdo *I.*	2 - R				
23	Jònsson S.S.	2 - M	2 - O	2 - P		
24	Kempe S.	2 - N	3 - X	3 - Y		
25	Leotta A.	1 - F				
26	Lerch C.	2 - N				
27	Licitra G.M.	4 - AF				
28	Liuzzo M.	1 - F	1 - G			
29	Lombardo S.	3 - U				
30	Love G.	2 - M	2 - O	2 - P		

AUTHORS LIST

s.n.	Author	presented papers				
31	Madonia P.	1 - I				
32	Marino A.	1 - D	6 - AJ	6 - AJ1		
33	Martin J.L.	2 - R				
34	Maugeri R.	1 - A				
35	Mecchia G.	7 - AP2				
36	Merlanti F.	3 - U				
37	Middleton J.C.	2 - Q	6 - AL			
38	Muntoni M.	1 - H				
39	Neri M.	1 - B				
40	Oberwinder M.	2 - N				
41	Ogawa T.	2 - L				
42	Palmeri A.	1 - I				
43	Patti A.	4 - AA	7 - AP6			
44	Perna G.	7 - AP8	7 - AP9			
45	Pinkerton H.	1 - B	3 - T			
46	Piro M.	7 - AP2				
47	Politano F.	4 - AA	4 - AB	4 - AF	7 - AP6	7 - AP7
48	Pompilio M.	1 - C				
49	Privitera A.	1 - E				
50	Privitera F.	4 - AC				
51	Puglisi G.	4 - AD				
52	Richon P.	7 - AP3				
53	Rossi A.	2 - J				
54	Sabroux J.C.	7 - AP3				
55	Santi G.	4 - AD	4 - AE	4 - AG		
56	Santonocito F.	4 - AA	4 - AB	7 - AP6	7 - AP7	
57	Stephenson J.	3 - Z	6 - AN			
58	Szakacs A.	7 - AP4				
59	Tabacco I.	3 - U				
60	Wood C.	6 - AM				

SCHEDULES
OF THE
TOURIST EXCURSIONS

EXCURSION «C» - ÆOLIAN ISLANDS (LIPARI and VULCANO)

FRIDAY 17 SEPTEMBER 1999

07:00 Meeting at Piazza Abramo Lincoln; delivery of lunch-bags.
07:15 Departure toward Milazzo by private coach.
10:00 Arrival to Milazzo.
10:15 Embarkation on the SIREMAR «ISOLA DI STROMBOLI» hydrojet ferry.
10:30 Departure toward Lipari.
11:40 Arrival to Lipari, disembarkation at Marina Lunga port and delivery of luggage to the hotel van. Transfer on foot to the hotel and accommodation. Time at leisure.
14:20 Meeting with the guide, Mrs Helga Jung.
14:30 Departure by coach for the complimentary island tour, offered by Lipari Municipality. The tour will touch the fishermen's villages of the western coast, San Calogero's Spas, dating back to Micenean age (3500 ybp), the pumice quarries at Canneto.
17:30 Return to the hotel, and transfer on foot to the City Hall.
18:00 Meeting with the Mayor of Lipari, who will welcome the party in the island and will offer a drink and complimentary brochures concerning the Æolian archipelago.
19:00 Time at leisure for a stroll downtown, an ice cream, an optional dinner or pizza in the numerous inns of Æolian headtown. Overnight.

SATURDAY 18 SEPTEMBER 1999

08:00 Transfer on foot to Marina Corta port, and meeting with the licensed guide, Mrs Elisabeth Curie (*); delivery of lunch-bags.
08:30 Embarkation on SIREMAR's hydrofoil to Vulcano.
08:40 Disembarkation at Vulcano, Porto Levante, and guided visit to the large crater named «*la Fossa*» (the Hole); visit to the numerous phenomena of minor volcanism (fumarolic emissions of sulphur and water steam, submarine boiling water-springs, boiling mud springs) and to the small Grotta dell'Allume, hosting secondary mineralizations. Time at leisure for the lunch.
15:00 Meeting at SNAV's hydrofoil wharf at the port of Vulcano.
15:15 Embarkation toward Lipari.
15:25 Arrival to Lipari, Marina Corta port. Transfer on foot to the hotel. Time at leisure for rest, individual activities and/or optional excursions, shopping. Optional dinner, overnight.

SUNDAY 19 SEPTEMBER 1999

08:30 Delivery of luggage to the hotelkeeper, and transfer on foot to Piazza Mazzini; meeting with the licensed guide, Mrs Elisabeth Curie (*).
09:00 Guided visit to the Citadel of Lipari and to the Archæological Æolian Museum.
11:30 Transfer on foot to Lipari, Marina Lunga port, through the characteristic Via Meligunis.
11:45 Withdrawal of luggage (carried to the port by the hotel van) and delivery of lunch-bags; embarkation on SIREMAR's «ISOLA DI STROMBOLI» hydrojet ferry.
12:00 Departure toward Milazzo.
13:10 Arrival to the port of Milazzo, disembarkation, transfer to the private coach.
13:30 Departure toward Messina.
14:15 Arrival to Piazza della Repubblica in Messina (Central State Railway Station; Bus Terminal). Prosecution of individual journey by train, or by Ditta Cavalieri's liner coach for those departing from Reggio Calabria airport. The remainder party reaches Catania by the private coach.
16:00 Arrival to Catania, Piazza Abramo Lincoln. End of the excursion.

(*) Mrs Curie will describe in Italian, French and German language, the itinerary at Vulcano, and the visit to the Citadel and to the Æolian Museum; no licensed English speaking guide is available on Saturday 18 and Sunday 19.

Suggested restaurants in Lipari: «Kasbah» (Via Maurolico), «al Vicoletto» (Vicolo at Via V. Emanuele), «Filippino» (Piazza Mazzini); average cost 40.000 to 60.000 ITL for fish based menu (without wine or with local lose wine).

EXCURSION «D» - RAILWAY TOUR OF ETNA BY *CIRCUMETNEA* TRAIN

FRIDAY 17 SEPTEMBER 1999

07:40 Meeting with the licensed English speaking guide, Mrs Giovanna Farruggia, at the Cafeteria of the FCE Railway Station «BORGO».
07:50 Departure toward Adrano by the train Catania-Randazzo.
08:55 Arrival to Adrano Station, and meeting with the Superintendence Archæologist, Mr. Francesco Privitera. Transfer to the Norman Castle and visit to the Ætnean Archæological Museum, with prehistorical findings of Hybla Mayor and the territory of Etna.
12:15 Departure toward Randazzo.
13:10 Arrival to Randazzo.
13:20 Lunch at Scrivano Restaurant, with pore fungus and grill based courses. Non-subscribers for lunch will re-join the party at the Railway FCE Station. Those wishing to join the party for lunch may apply the guide for the vouchers (ITL 30.000 per person).
14:00 Visit on foot to the medieval borough with its churches of St Maria (Norman), St. Nicholas (Greek) and St. Martin (Lombard), the City Hall (a XVIII century monastery and cloister), the Castle with Museo Vagliasindi, the Royal Palace, Clarentano Mansion, the narrow stone paved lanes, the cosy courts.
16:30 Departure by FCE train toward Giarre.
17:30 Arrival to Giarre. Time at leisure for a cup of coffee.
18:10 Departure toward Catania by FS Railways train # R.12765.
18:45 Arrival to Catania Central Railway Station. End of the excursion.

===000===000===

EXCURSION «J» to the CICLOPES' RIVIERA, ACIREALE and TAORMINA

MONDAY 13 SEPTEMBER 1999

08:15 Meeting with the licensed guide, Mr Giacomo Mazza, at Piazza Abramo Lincoln.
08:30 Departure from Catania by mini-bus. Slow ride along the seaside road with stop at Aci Castello (Norman Castle) and Aci Trezza (the Cyclopes' Faraglioni).
09:15 Arrival to Acireale. Visit to the Cathedral, the Biblioteca (library) Zelantea, further remarkable monuments and highlights.
12:00 Arrival to Taormina, Porta Messina. A stroll on foot through the Corso will bring the party to Piazza IX Aprile, for admiring the panorama of Etna and the God's Bay, while sipping a complimentary drink at Wunderbar's, the most traditional cafeteria and tea-room downtown.
13:00 Lunch at the garden of "*la Buca*", with excellent fish-based courses prepared by the Chef Antonino Intelisano. Participants that don't want to attend to the restaurant lunch, will meet the party again at Piazza Santa Caterina (Palazzo Corvaja corner) at 14:30. The non-subscribers wishing to join the party may apply the guide for the vouchers (ITL 35.000 per person).
14:30 Guided visit to Taormina monuments: the Roman-Greek Theatre, the Odeon, the medieval Palazzo Corvaja, St. Catherine's Church, the Roman Gymnasium (improperly named "*le Naumachie*"), the City Hall, the XV century Cathedral. Time at leisure for a cup of ice cream, resting at some downtown cafeteria, or for shopping or strolling along the Corso.
17:30 Meeting at Porta Messina with the mini-bus and departure toward Catania.
18:20 Arrival to Catania, Piazza Abramo Lincoln. End of the Excursion.

EXCURSION «K» - GUIDED VISIT TO CATANIA HISTORIC CENTRE

TUESDAY 14 SEPTEMBER 1999

09:30 Meeting with the English speaking licensed guide, Mrs Giovanna Farruggia, and the Superintendence Archæologist, Mr. Francesco Privitera, at Piazza Duomo (Palazzo dei Chierici corner at Porta Uzeda.

The visit (on foot) will start from the Cathedral of St. Agate, a baroque realisation on medieval remains survived to the 1693 earthquake (Norman transept and apses); then the Central University Palace, and many more highlights (Roman Amphitheatre, Church of St. Francis, Roman-Greek Theatre, Odeon, Benedictine Monastery at Piazza Dante, Via Crociferi, Terme (Spas) della Rotonda, the Castle, Terme dell'Indirizzo, the Fish Market.

12:45 The walk ends at the Fish Market, where subscribers will have a fish based lunch, Catania style cuisine, at the old typical inn «Trattoria La Paglia». Those wishing to join the party may apply the guide for the vouchers (ITL 40.000 per person).

===000===000===

VULCANOSPELEOLOGICAL EXCURSION «E» - GROTTA DI SERRACOZZO

FRIDAY 17 SEPTEMBER 1999

18:00 ON ITS WAY BACK TO CATANIA, THE PARTY WILL BE HOSTED BY THE CITY ADMINISTRATORS OF MILO, FOR A WELCOME SPEECH AND A RUSTIC WINE TASTING.

===000===000===

TOUR LEADERS OF THE PLANNED (VULCANOSPELEO & TOURIST) EXCURSIONS

EXCURSION "**A**" - SAT. 11/09/99	- Marco LIUZZO (Vulcanospeleologist)
EXCURSION "**B**" - SUN. 12/09/99	- Angelo LEOTTA (Vulcanospeleologist)
EXCURSION "**J**" - MON. 13/09/99	- Giacomo MAZZA (Licensed tourist guide)
EXCURSION "**K**" - TUE. 14/09/99	- Giovanna FARRUGGIA (Licensed tourist guide); - Francesco PRIVITERA (Archæologist)
EXCURSION "**GEN**" WE 15/09/99	- The whole Centro Speleologico Etneo
EXCURSION "**C**" - Fri/Sun 17-20/09	- Giuseppe M. LICITRA (Tour leader) - Helga JUNG (Tourist guide) - Elisabeth CURIE (Licensed tourist guide)
EXCURSION "**D**" - FRI 17/09/99	- Giovanna FARRUGGIA (Licensed tourist guide); - Francesco PRIVITERA (Archæologist)
EXCURSION "**E**" - FRI 17/09/99	- Marco LIUZZO (Vulcanospeleologist)
EXCURSION "**F_1**" SAT 18/09/99	- Giuseppe GAROZZO (Vulcanospeleologist) - Sonia CALVARI (Volcanologist)
EXCURSION "**H**" - SUN 19/09/99	- Angelo LEOTTA (Vulcanospeleologist)

The excursions "**F_2**" and "**G**" were cancelled for lack of subscriptions.

PAPERS

Vulcanospeleology on Etna and in Italy

TEN OF THE MOST INTERESTING CAVES ON MOUNT ETNA. CADASTRIAL FILES

Renato Bonaccorso and Roberto Maugeri

Centro Speleologico Etneo, via Cagliari 15 - 95127 Catania, Italy

Abstract

This paper contains the cadastrial data of ten of the most interesting caves on Mt.Etna.
The choice has been based upon the dimension, shape, geological features, archaeological findings or other peculiar characteristics. Some of them present more than one interesting characteristic like Grotta del Santo chosen for its labyrinthical shape and also important for its archaeological findings; Profondo Nero is an interesting fissure cave, the longest on Mt.Etna. Grotta del Lago chosen for its water deposit that freezes during the winter. Among more than 250 caves being explored on Mt.Etna only Grotta del Gelo, has a water deposit while snow deposits are more common. Grotta dei Tre Livelli is the longest lava tube on Mt. Etna having the biggest difference in level between the top and the bottom. Grotta Catanese I is not very long but a part of it is the biggest lava tube among the Etnean caves. To Grotta Petralia belongs one of the most important archaeological cave site and it is the longest lava tube near the sea level. An example of cave usage in more recent periods is Grotta dei Ladri used as a snow deposit during the summer. For this reason it was modified in order to achieve a better use. Grotta degli Archi is one of the best example of lava tube starting from the base of a crater: a lava channel partially covered and associated with an underneath lava tube. Grotta di Serracozzo instead is one of the best example of a cave starting from a eruptive fissure. Grotta Cutrona had a very interesting secondary mineral deposit with some rare minerals that were formed during the cooling of the cave after its formation. However these minerals were destroyed when the cave became colder and rain water entered inside.
Other interesting caves have been excluded since well described in other papers.

Introduction

On Mt. Etna more than 250 lava caves are known, mostly are lava tubes, while the others are eruptive fractures and very few of them created by erosion. All these caves present similar morphological features, but some of them can be selected as representative due to some peculiar characteristics.
The following files are ordered according to the cave length.
Coordinates are given in ED1950.

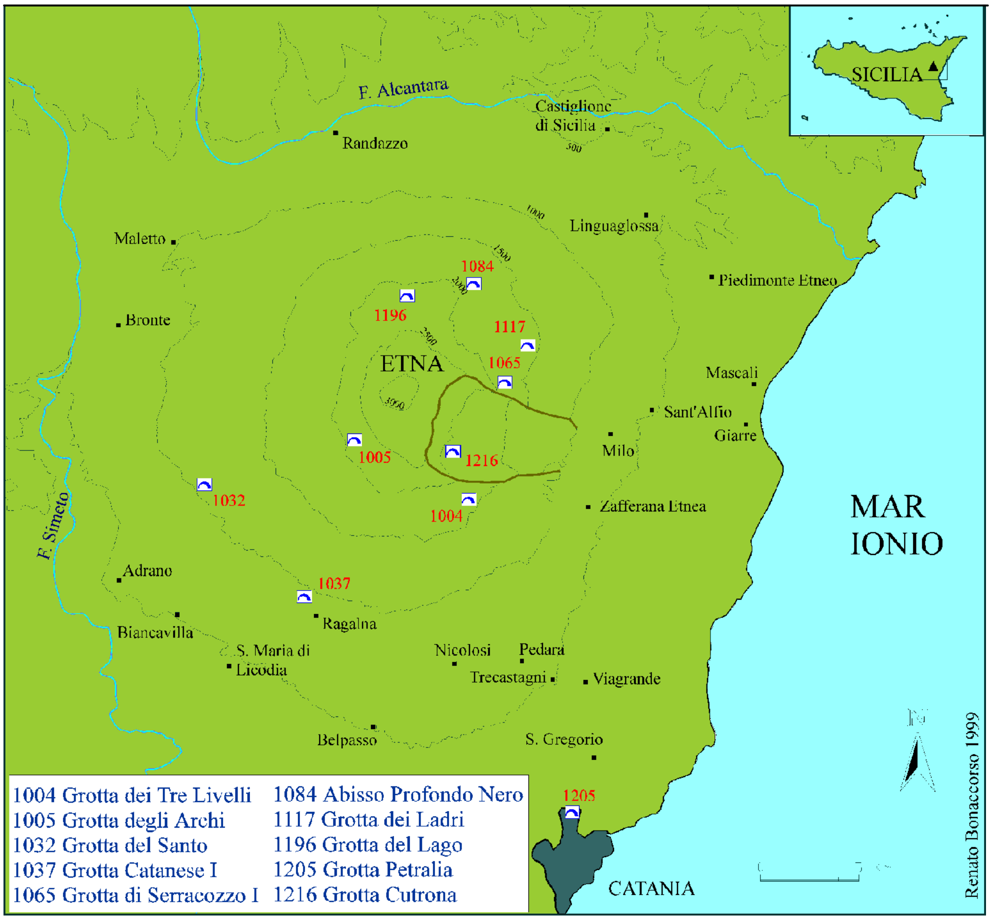
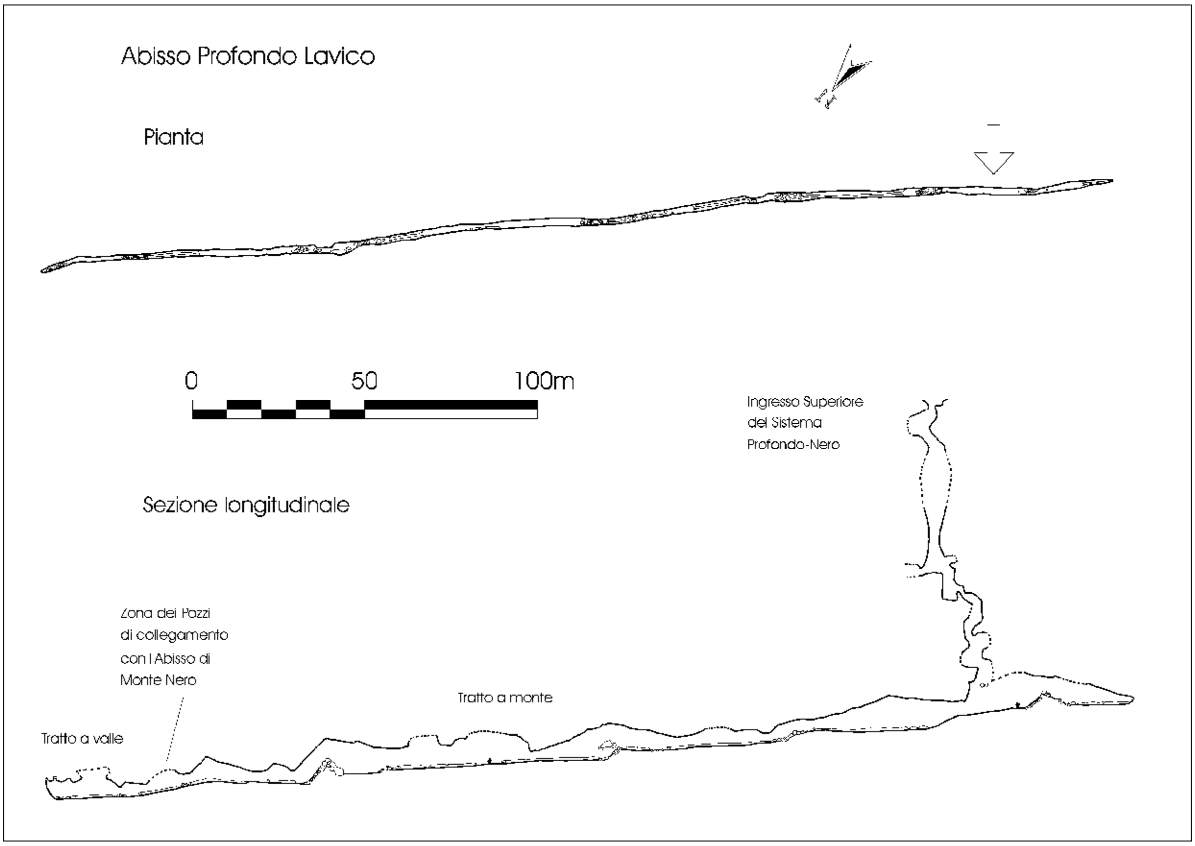
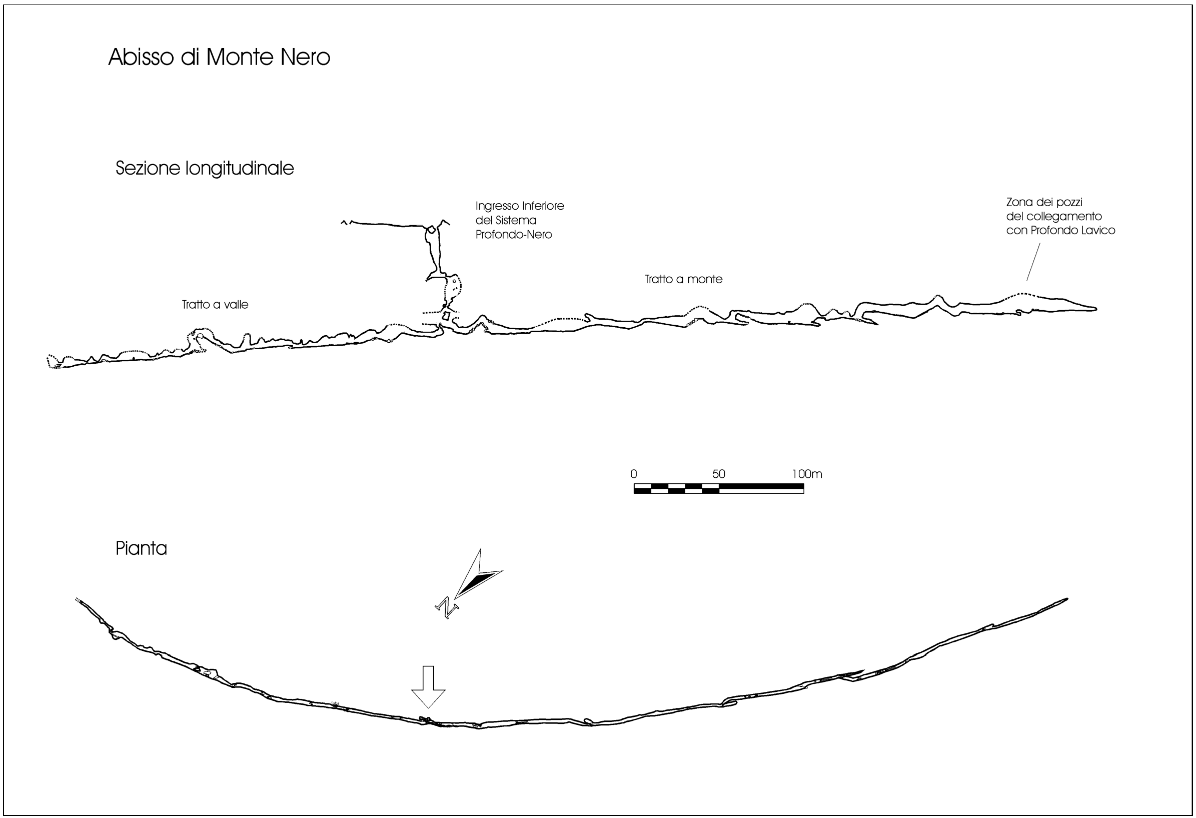


Fig 1. – The map shows the locations of the cavities which are the object of this work.

ABISSO PROFONDO NERO

- *Cadastrial number:* SICT 1084
- *Other names:* Pozzi dell'Eruzione del 1923
- *Location:* Bocche del 1923
- *I.G.M.map:* Serie 25, Foglio 613, Sezione III, Linguaglossa, Ediz. 1993
- *Longitude:* High entrance 15° 01' 40" E; Low entrance 15° 02' 07" E
- *Municipality:* Castiglione di Sicilia
- *Year of eruption:* 1923
- *Total lenght:* >1170 m
- *Total depth:* 174 m
- *Height:* 1995 m, 1900 m
- *Latitude:* 37° 48' 13" N; 37° 48' 29" N
- *References:* Giudice e Scalia, 1994, 161-171; Centro Speleologico Etneo, 1999, 267-270; Forti e Marino, 1995, vol I, 92-100.
- *Survey:* Profondo Lavico (1992-94) V. Biancone, A. Caflisch, G. Giudice, F. Leone, A. Privitera, C. Monaco - Monte Nero (1992-94) A. Caflisch, A. Cariola, G.Giudice, F. La Rosa, F. Leone, A. Leotta, M. Liuzzo, A. Marino, A. Privitera, F. D'Agata, R. Maugeri, R. Petralia.
- *Drawing:* G. Giudice, R. Maugeri


Abisso Profondo Lavico
Pianta
0
50
100m
Ingresso Superiore
del Sistema
Profondo-Nero
Sezione longitudinale
Zona dei Pozzi
di collegamento
con l Abisso di
Monte Nero
Tratto a monte
Tratto a valle


Abisso di Monte Nero
Sezione longitudinale
Ingresso Inferiore
del Sistema
Profondo-Nero
Zona dei pozzi
del collegamento
con Profondo Lavico
Tratto a monte
Tratto a valle
0
50
100m
Pianta

Location

This cave is situated along the eruptive fracture created in 1923 long the NE flank of Mt. Etna near Mt. Nero.

Description

This is not a lava tube but an eruptive fracture that a breakdown divided in two main sections each of which has its own entrance: Abisso di M. Nero and Profondo Lavico.
It is the biggest eruptive system surveyed on Mt.Etna and one of the most preserved.
It was explored and surveyed for more than 1 km and is the longest lava cave on Mt.Etna. The average depth is about 50 m and average width is only 2 meters. Some secondary minerals were found inside. One of them was the Portlandite, a very rare mineral never found in a cave (Forti & Marino, 1990).
The main entrance is situated in a little *hornitos* (little ash cone) long the fracture system of 1923. After a 30 m pit there is a big lava block covered by ash. Going NE there is another pit of 35m and then the fissure bottom. From this point going down toward NE the fissure is about 250 m long, instead going up toward SW is about 800 m long.
Long the fissure, the floor is formed by two big lava rolls joined together. The walls are rather parallel and the distance from each other is about 2 m and are covered by a lava layer that is thick in some part and in others only few centimetres thin. In some areas the collapse of lava layers obstructed the way so that climbing becomes necessary making the exploration dangerous.

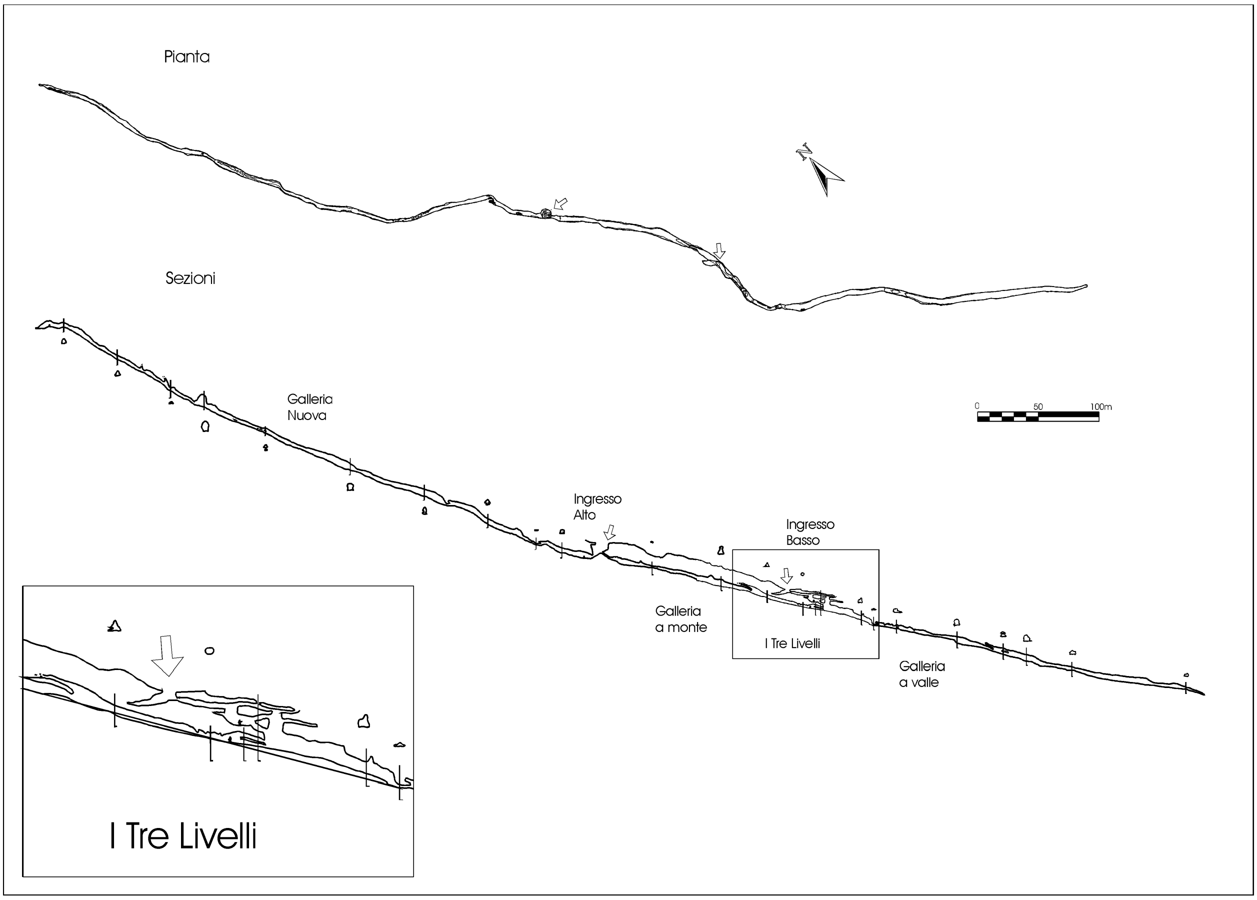

2


3

Fig. 2 - The eruptive fracture (G. Giudice).
Fig. 3 - Topographic survey of the fracture (G. Giudice).

GROTTA DEI TRE LIVELLI

- *Cadastrial number:* SICT 1004
- *Other names:* Galleria dei Pipistrelli
- *Location:* Contrada Casa del Vescovo
- *I.G.M.map:* Serie 25, Foglio 625, Sezione IV, Sant'Alfio, Ediz. 1993
- *Longitude:* High entrance 15° 01' 57" E
  Low entrance 15° 02' 01" E
- *Municipality:* Zafferana Etnea
- *Year of eruption:* 1792-93
- *Total lenght:* 1150 m
- *Total deptht:* 304 m
- *Height.:* 1675 m, 1625 m
- *Latitude:* 37° 42' 07" N
  37° 42' 02" N
- *References:* F. Brunelli, B. Scammacca, 1975, 30-31; R. Corsaro, G. Giudice, 1991, 56-59; R.Corsaro, G.Giudice, G. Puglisi, 1995, I, 66-76; Centro Speleologico Etneo, 1999, 286-289.
- *Survey:* (1990) A. Caflisch, F. D'Agata, A. Di Paola, G. Giudice, A. Leotta, A. Liotta, A. Marino, A. Privitera, C. Privitera, G. Puglisi, N. Scalia
- *Drawing*: R. Bonaccorso, G. Giudice.



Location

The Tre Livelli cave is located on the southern flank of Mt. Etna, at Contrada Casa del Vescovo, and is reached driving along the provincial road 92, which connects Zafferana Etnea to Rifugio Sapienza. The entrance is next to the road, at about 13.5 km from Zafferana Etnea or 5 km from Rifugio Sapienza.

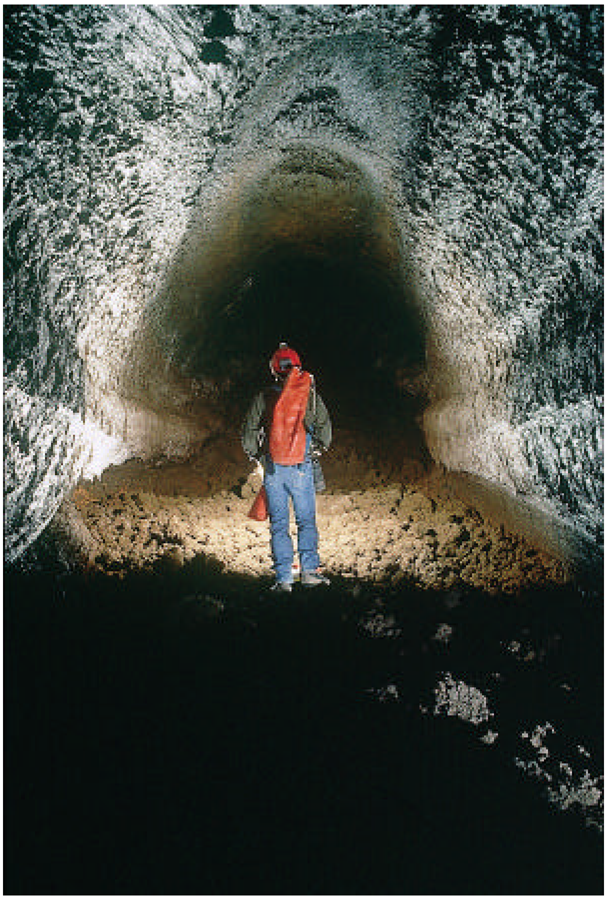
Description

This is the most important lava tube on Mt. Etna and it was also the main channel of the 1792-93 eruption. Its total length is 1150 m and it's the longest being the others less than 1000 m. Also the

difference in level between the top and the bottom is the highest, 304 m. Probably this is due to the duration of the eruption, 370 days, and its development on the upper part of the flow which is steeper than the lower part where other smaller caves are known. The slope of this cave with its 40° is unusual for lava tubes on Mt. Etna and also in the world.

The name Grotta dei Tre Livelli (Three Levels Cave) was chosen since, near the main entrance, there are three different overlapping levels (although in a short stretch the lower level is further divided).

The entrance is located on the roof of the upper tube which can be followed for a few meters before reaching the middle-level. The merging of these tubes creates a step (6 m) indicating a flow capture. In this point a speleological metallic ladder or a rope is needed. The middle tube is larger than the upper one and characterised by many rocks on the floor. A few meters ahead another 2 m step leads into the lower tube. This can be visited for about 350 m downward and 750 m upward. After a narrow passage, the lower part shows a wide section and a constant slope. The floor is made of clinkers with huge blocks. While going upward, the first 150 m are characterised by a narrow path, where lateral banks of lava often produce key-hole shaped sections. After another narrow passage, situated at the base of a depression, in correspondence of the second entrance, the tube continues for about 40 m and then it seems to end. On the right side a narrow dug passage, 4 meters long, allows to overcame this obstruction. From here the slope increases significantly, reaching 40° in the upper part. In this steep portion there is the passage between a lava tube and the eruptive fissure. The section becomes narrower, the lateral walls are more vertical and the height of the roof gradually increases as far as the point of lava emission.


4


5

Fig. 4 - The upper portion of the cave from the entrance (G. Giudice).
Fig. 5 - The connection between two levels near the entrance (F. Barbagallo).

GROTTA DEL SANTO

- *Cadastrial number:* SICT 1032
- *Other names:*
- *Location:* Contrada Diamante
- *I.G.M.map:* Serie 25, Foglio 624, Sezione I, Monte Etna, Ediz. 1993
- *Longitude:* 14° 52' 35" E
- *Municipality:* Adrano
- *Year of eruption:* Preistorica
- *Total lenght:* 924 m
- *Total depth:* 44 m
- *Height:* 1043 m
- *Latitude:* 37° 42' 37" N
- *References:* Bella, Brunelli, Cariola e Scammacca, 1982, 239-240; Greco, 1995, 247; Lo Giudice e Privitera, 1982, 2-10; Petronio Russo, 1880, 85; Santangelo, 1952, 55; Centro Speleologico Etneo, 1999, 230-233.
- *Survey:* (1984) F. Andronico, R. Corsaro, F. Fanciulli, V. Fazio, A. Liotta, A. Mazzullo, S. Milazzo, R. Squadrito - (1998) R. Bonaccorso, O. Cavallaro, G. Garozzo, G. Giudice, F. Leone, A. Leotta, G. Licciardello, A. Marino, L. Musumeci, R. Pelleriti, A. Privitera, A. Sauca.
- *Drawing:* R. Bonaccorso

Location

This cave is situated on the western flank of Mt. Etna near Adrano.

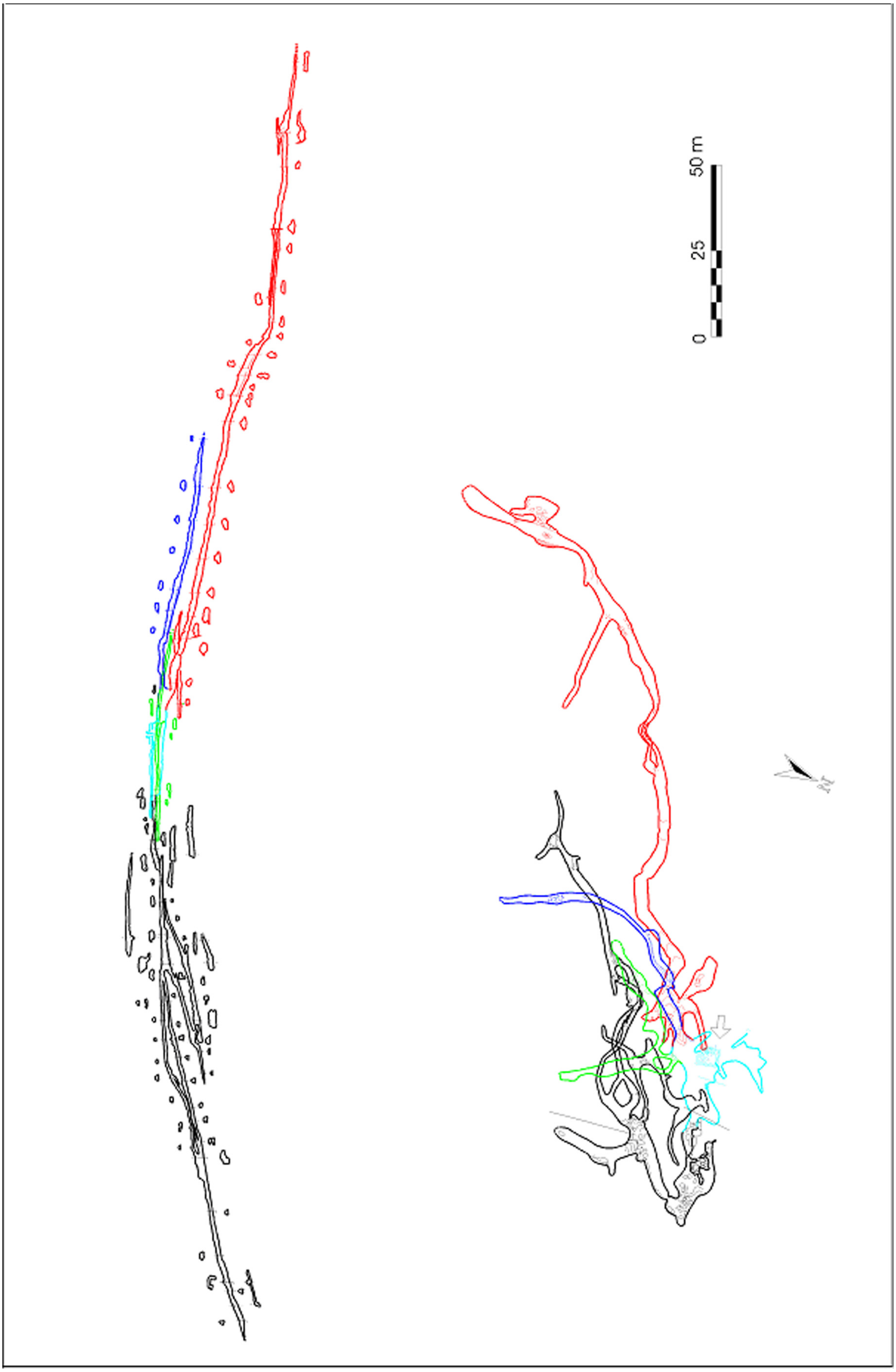
Description

Grotta del Santo is one of the longest caves on Mt. Etna (its total length is more than 900 m). It is composed by many narrow tubes superimposed and joined each other giving to this cave a labyrinthic shape. The entrance is formed by some rock steps. There is a main chamber, quite large, with a little altar dedicated to the Saint Nicola Politi who lived here in XII[th] century. The legend tells that the Saint went in this cave just one day before his marriage and lived there for three years from 1134 to 1137. From the entrance five galleries start. The two main tubes have the same orientation NNE-SSW while the others have many different directions.
The developing of this cave was probably in a flat area where these little tubes were formed like in a delta of a river.
The age of this cave is prehistoric and some pottery was discovered inside probably dating back to the Malpasso culture, last phase of the Copper Age (PRIVITERA, 1999). The entrance is on a little outcrop of prehistoric lava and surrounded by more recent lava flows, maybe 1595.


6

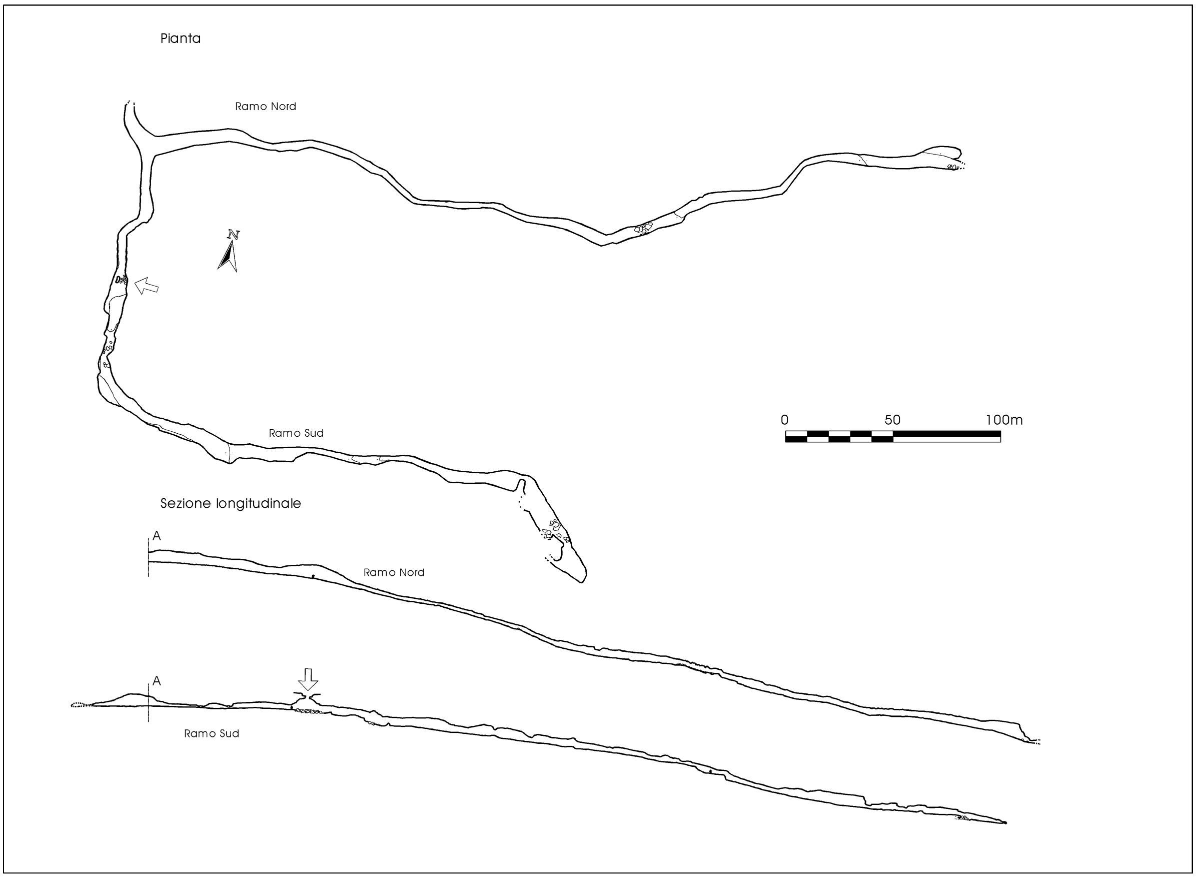

7

Fig. 6 - Entrance room: on the left the votive altar (R. Maugeri).
Fig. 7 - The B2 branch spot in which the two lava tubes are reunite (R. Bonaccorso).



GROTTA CUTRONA

- *Cadastrial number:* SICT 1216
- *Other names:* Grotta MC1 Grotta
- *Location:* via Liardo
- *I.G.M.map:* Serie 25, Foglio 625, Sezione IV, Sant'Alfio, Ediz. 1993
- *Longitude:* 15° 01' 23" E
- *Municipality:* Zafferana Etnea
- *Year of eruption:* 1991-93
- *Total Lenght:* 870 m
- *Total deptht:* 97 m
- *Height:* 1860 m
- *Latitude:* 37° 43' 09" N
- *References:* Forti, Giudice, Marino e Rossi, 1994, 125-151; Giudice e Leotta, 1994, 213-230; Centro Speleologico Etneo, 1999, 304-308.
- *Survey:* (1990) (1994) A. Caflisch, G. Giudice, F. Leone, A. Privitera
- *Drawing*: G. Giudice, R. Maugeri.



Location
This cave is situated on the East flank of Mt.Etna, inside "Valle del Bove" near Serra Vavalaci.

Description
This cave was formed during the 1991-1993 eruption in Valle del Bove. It was explored just one year after the eruption when inside there was a temperature of about 30-40°C. In some parts the temperature was over 70°C and, naturally, were not explored. The most interesting things founded in this cave were the beautiful speleothems composed by different types of salts, melted by rainwater while dripping from the upper layer, and by aerosol from gases released during the cooling of lava. Their formation is possible only under particular conditions of temperature and humidity, and, when these conditions change with the cooling of the rocks, the rainwater destroys the speleothems melting their salts. These type of speleothems were first observed by our cave group in the lava tubes of 1983 eruption and then destroyed by the 1985 lava flow.
The cave is a long U shaped tube with its branches oriented toward East.

The entrance is on a roof collapse in the middle of the tube in its southern branch (300 m long) hence a metallic ladder (10 m) or a rope is needed. The shape is variable being wider in the flat parts and narrower in the steepest parts. The ending part is wide and it closes by the lowering of the ceiling.
The northern gallery is about 500 m long. From the entrance going northward there is a crawling passage. After this passage there is a wide gallery going toward NW and 25 m long while the rest of the cave develops eastward. This gallery was found plenty of mineralization but today only a white heap remains long a short part of this gallery. The tube ends with a breakdown.


8


9

Fig. 8 - Highly concretioned gallery (R. Bonaccorso).
Fig. 9 - A “fantasy shaped” salt concretion (R. Bonaccorso).

GROTTA PETRALIA

- *Cadastrial number:* SICT 1205
- *Other names:* Grotta Leucatia
- *Location:* via Liardo 17
- *I.G.M.map:* Catania, Foglio 270, Quadrante IV, Orient. SE, Ediz. 1971
- *Longitude:* 15° 05’ 07” E
- *Municipality:* Catania
- *Year of eruption:* Prehistorical
- *Total Lenght:* 518 m
- *Total depth:* 21 m
- *Height:* 138 m
- *Latitude:* 37° 31’ 59” N
- *References:* Privitera, 1994, 17-35; Privitera, 1999, 85-104; Centro Speleologico Etneo, 1999, 176-179.
- *Survey*: (1990) R. Bonaccorso, A. Caflisch, G. Calabretta, F. D’Agata, G. Giudice, G. Gulli, R. Maravigna, A. Marino, A. Privitera, C. Privitera.
- *Drawing*: R. Bonaccorso, G. Giudice

Location
The entrance of this cave is situated in a private garden in Catania, Via Liardo 17.

Description
This cave is long more than 500 m and it develops under the urban area of Catania. It is the longest cave at such a low altitude but its main feature is the discovery of the most important archaeological site with a lot of pottery and some burials. This site was found intact without any tampering. The entrance is near one extreme of the cave. The access is by a concrete staircase. Here the tube is wide and it was used as an air-raid shelter during the II World War so that only

few prehistoric pottery were found. Going East the tube is only 30 m long and it is wide and high. Going West the tube becomes low and, after a narrow passage, there is the first breakdown 20 m long. Walking upon the blocks, at the end of the gallery, a narrow and short passage allows the access to the rest of the cave. Until its discovery the remaining part of the cave was preserved for centuries. Few meters ahead the gallery becomes wide and high and the floor is flat. Here tombs, human bones and broken pottery were found. The pottery was broken maybe because of the poor manufacture or ancient rituals. Now they are collected and catalogued by the archaeologists. After 300 m and three breakdowns there is a depression due to a capture phenomenon of the lava flow. Going down there is a crawling gallery containing prehistoric pottery and human bones. This low gallery ends in the west part of the cave next to a recent breakdown probably due to building works. The main gallery becomes lower and ends in the eastern part of the same breakdown after an area characterised by stone fences probably used for rituals. A very narrow passage, that is not possible to cross, connects the eastern side to the western.

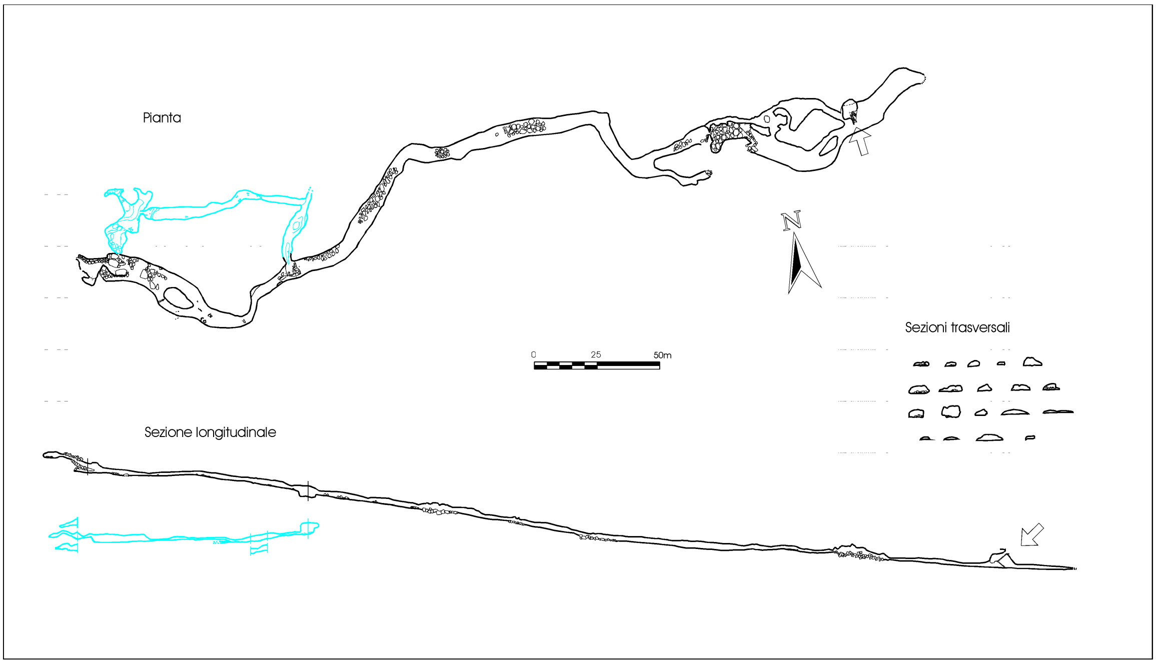
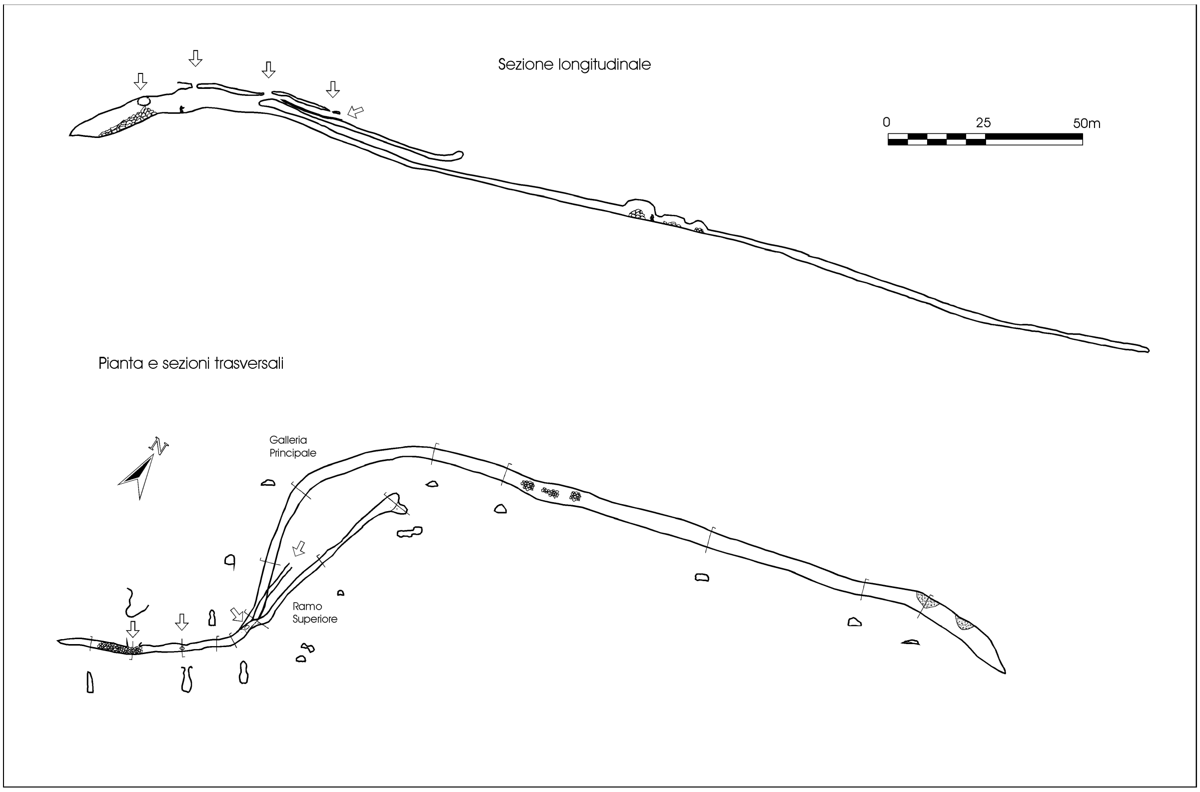


Fig. 10 - Big fluvial pebble into the cave (R. Maugeri).

Fig. 11 - Evidences into the western hall (R. Maugeri).

GROTTA DI SERRACOZZO I

- *Cadastrial number:* SICT 1065
- *Other names:*
- *Location:* Contrada Serracozzo
- *I.G.M.map:* Serie 25, Foglio 625, Sezione IV, Sant'Alfio, Ediz. 1993
- *Longitude:* 15° 03' 26" E
- *Municipality:* Milo
- *Year of eruption:* 1971
- *Total lenght:* 350 m
- *Total depth:* 60 m
- *Height:* 1840 m
- *Latitude:* 37° 45' 28" N
- *References:* Barone, Priolo A., Priolo G., Sanfilippo, Scammacca; 1994, 376; Cavallaro e Licitra, 1975, 245-248; Rittmann, Romano, Sturiale, 1971 e 1973, 418-430; Centro Speleologico Etneo, 1999, 282-283.
- *Survey:* (1975) F.Cavallaro, A. Di Paola, G. Montana
- *Drawing:* R. Bonaccorso, F. Cavallaro



Location

The cave is situated on the East flank of Mt.Etna, in “Contrada Serracozzo” area.

Description

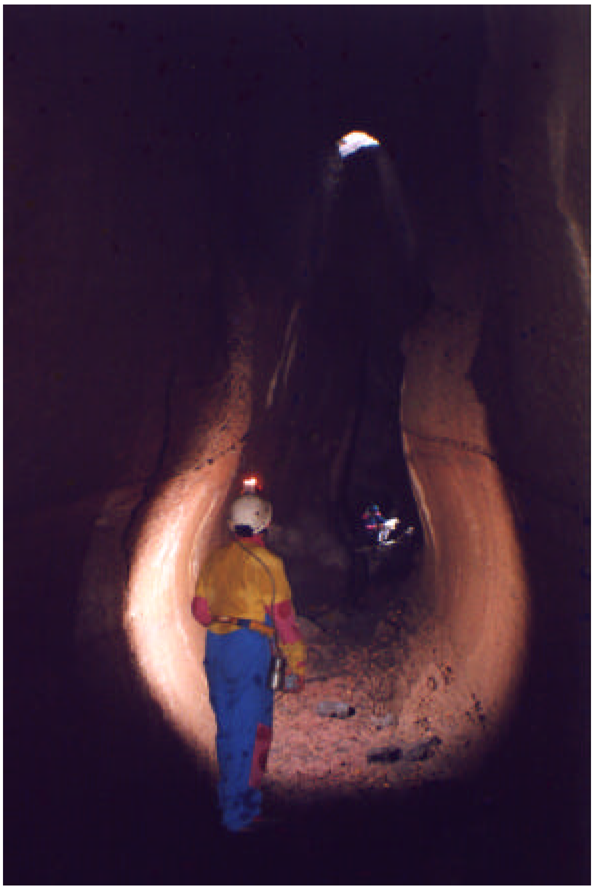
This cave, formed during the 1971 eruption, is a beautiful example of lava tube starting from an eruptive fracture (50 m long) that can be partially visited. There is a clear boundary between the fracture and the lava tube. The cavity is "S" shaped and the entrance is possible through a collapsed wall of the fissure situated where the lava started. The section of this part has a keyhole shape. The main tube is long about 300 m with a difference in level of about 60 m.

From the entrance the fissure goes toward SW inside the mountain for about 20 m. Most part of it is covered by the debris of the collapse.

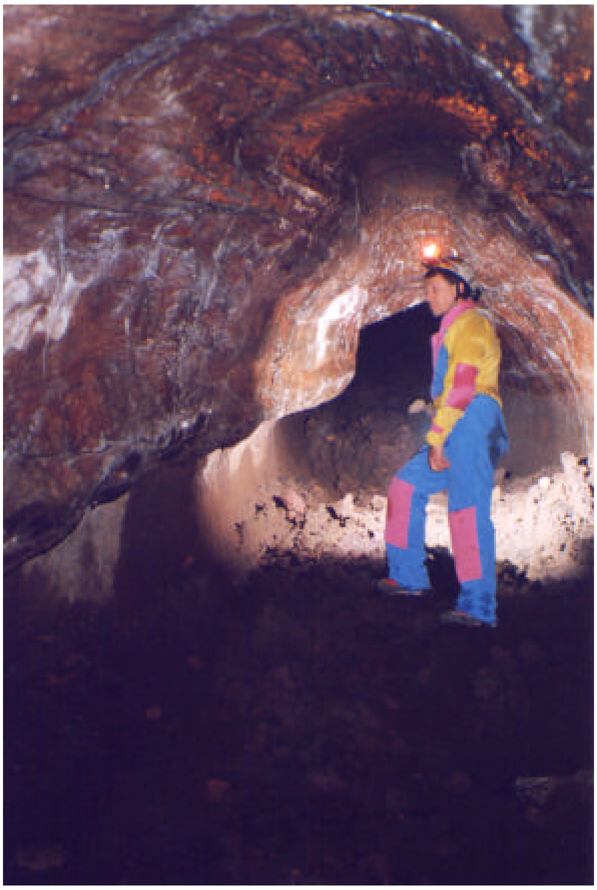
From the entrance, going toward NE the floor is about 3 m lower than the debris cone. After about 30 m the cave turns left. In this point the fracture ends and three tubes, having different directions, begin from the fracture.

The main gallery turns northward and, after 40 m, toward ENE for about 200 m until it closes. The width is from 2 to 4m and the height from 1 to 4m so that the shape is generally squeezed. There are some collapses. The ending part is obstructed by volcanic sand conveyed by the waters.

The other two galleries are narrow and short and can be easily reached from outside through a little collapse of the roof. One is about 50 m long, the other is about 20 m long.



12

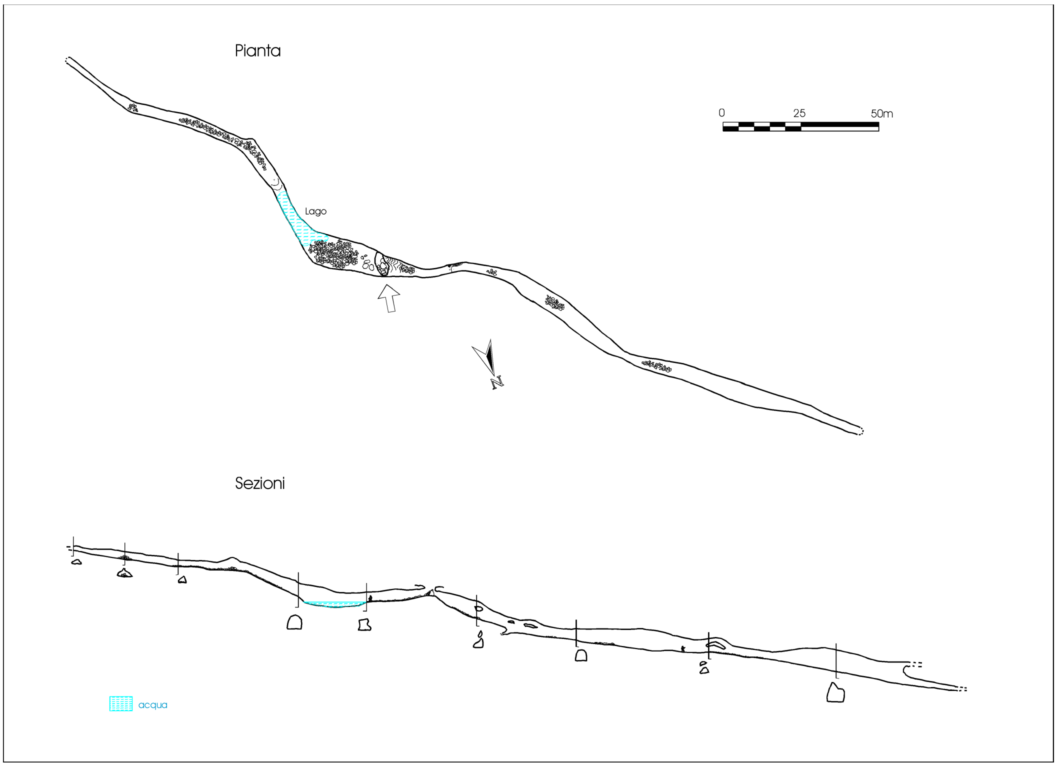


13

Fig. 12 **-** The characteristic morphology of the tube in the higher portion of the cave (R. Bonaccorso).
Fig. 13 **-** A section of the main conduit (R. Bonaccorso).

GROTTA DEL LAGO

- *Cadastrial number:* SICT 1196
- *Other names:* Grotta dei pecorai
- *Location:* Sciara del Follone
- *I.G.M.map:* Serie 25, Foglio 612, Sezione II, Randazzo, Ediz. 1993
- *Longitude:* 14° 59’ 53” E
- *Municipality:* Randazzo
- *Year of eruption:* 1614-24
- *Total lenght:* 288 m
- *Total depth:* 41 m
- *Height:* 2130 m
- *Latitude:* 37° 48’ 13” N
- *References:* Barone, Priolo A., Priolo G. Sanfilippo e Scammacca, 1994; Centro Speleologico Etneo, 1999, 250-251.
- *Survey:* (1994) A. Balsamo, A. Leotta, S. Raciti, N. Scalia
- *Drawing:* A. Balsamo, R. Bonaccorso



Location
This cave is situated on the northern flank of Mt. Etna in the “Sciara del Follone” area.

Description
This cave is less than 300 m long but it is interesting for its permanent water deposit used by shepherds to water the flocks. In winter this deposit is frozen for the low temperature reached at the opening level of the cave. Only another cave, Grotta del Gelo, described in other papers in this volume, has a similar deposit frozen all over the year. Grotta del Lago is higher than Grotta del Gelo and it is in the same area but, different conditions, as a constant air flow, melt the ice during the summer.
The entrance is by a roof collapse at about one third of the cave. Going upward, after a breakdown, there is the little “lake”, about 15 meters long with a depth of 50 centimetres. After the lake there is another breakdown. This part is long about 130 m and at the end it is so narrow that the passage is not possible but a connection with the surface produces a constant air flow.
Going downward from the entrance, there are short and overlapping levels. This part, about 170 m long, is larger than the other with the exception of the ending section where it closes becoming narrower.


14


15

Fig. 14 - The iced lake (G. Tomasello).
Fig. 15 - The two levels of the lower section (G. Tomasello).

GROTTA DEGLI ARCHI

- *Cadastrial number:* SICT 1005
- *Other names:* Grotta di Monte Pecoraro
- *Location:* Bocche eruttive del 1607
- *I.G.M.map:* Serie 25, Foglio 624, Sezione I, Monte Etna, Ediz. 1993
- *Longitude:* High entrance 14° 58' 03" E; Low entrance 14° 57' 52" E
- *Municipality:* Biancavilla
- *Year of eruption:* 1607
- *Total lenght:* 284 m
- *Total deptht:* 73 m
- *Height.:* 2075 m, 2010 m
- *Latitude:* 37° 43' 43" N; 37° 43' 43" N
- *References:* Andronico, 1930, 211; Brunelli e Scammacca, 1975 31-32; De Roberto, 1881; Miceli, 1933; Poli, 1959a, 6; 1959b, 7; Sartorius, 1880, II, 109; Centro Speleologico Etneo, 1999, 225-227.
- *Survey:* (1999) R. Bonaccorso, G. Calcagno, F. Leone, P. Nastasi
- *Drawing*: R. Bonaccorso.

Location

This cave is situated on the SW flank of Mt. Etna near the Galvarina Refuge.

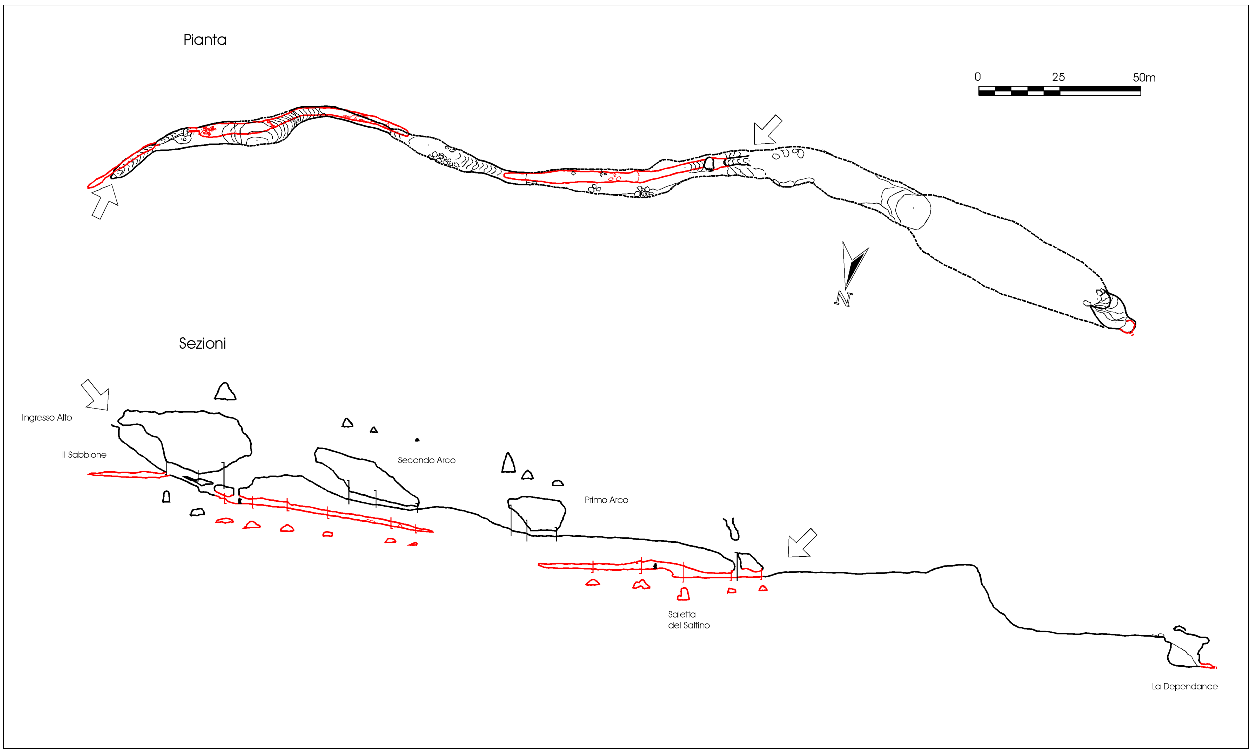
Description

Grotta degli Archi is an important lava tube associated with eruptive fracture and cones.

There are two overlapping levels formed by a lava channel and a lava tube. The upper level starts from the base of a little cone and then continues downward alternating beautiful lava channels with short lava tubes whose sections look like arches and give the name to the cave (Arches Cave). This level is long about 350 m but most of it is open.

Underneath there is another lava tube accessible from both ends but obstructed in the central part for the joining of the floor and the ceiling. The higher entrance, situated under the arch next to the cone, consists of a slope leading to a lava cave 100 m long. Another slope, situated on the lower part of the channel, leads to the lava tube that can be explored for about 70 m to the obstruction after a climbing of 3 m.

About one hundred years ago, this cave was probably used as a snow deposit.



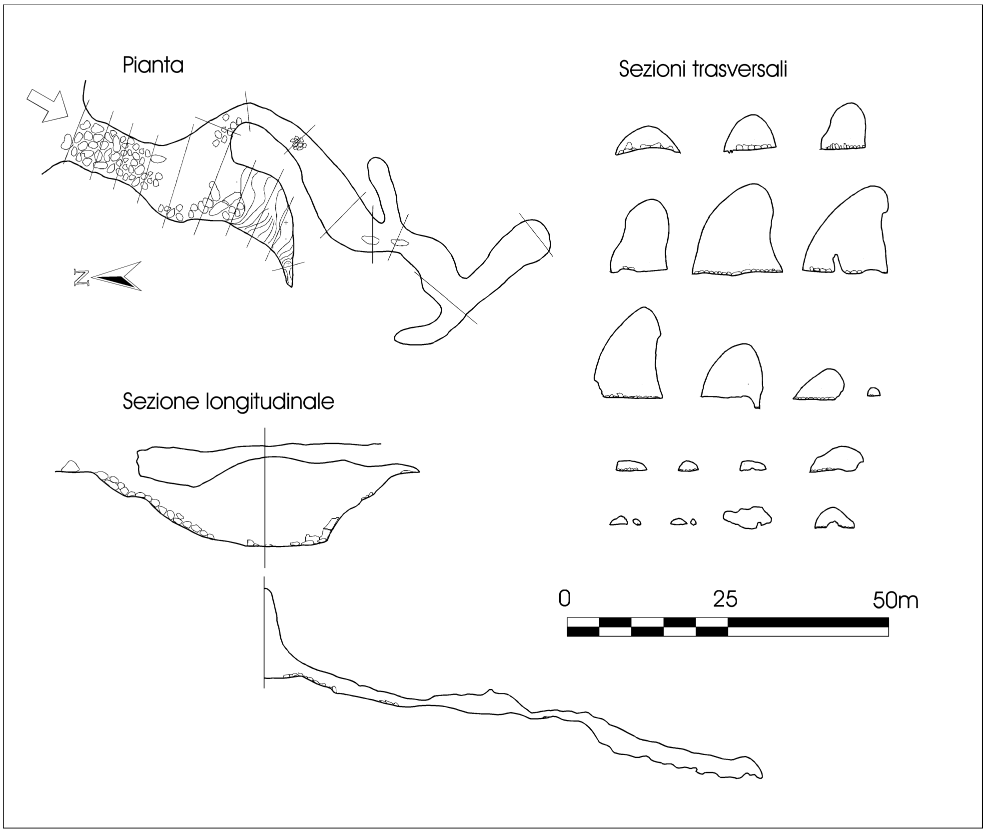

16


17

Fig. 16 - Grotta degli Archi. The first arch (M. Liuzzo).
Fig. 17 - Grotta Catanese I. The entrance (R. Bonaccorso).

GROTTA CATANESE I

- *Cadastrial number:* SICT 1037
- *Other names:*
- *Location:* Passo della Catanese
- *I.G.M.map:* Serie 25, Foglio 624, Sezione II, Adrano, Ediz. 1993
- *Longitude:* 14° 56' 21" E
- *Municipality:* Ragalna
- *Year of eruption:* Storica non datata
- *Total lenght:* 145 m
- *Total depth:* 27 m
- *Height:* 905 m
- *Latitude:* 37° 35' 58" N
- *References:* Brunelli e Scammacca, 1975; Bella, Brunelli, Cariola, Scammacca, 1982, 245-246; Centro Speleologico Etneo, 1999, 220-221.
- *Survey:* (1976) Centro Speleologico Etneo
- *Drawing:* R. Bonaccorso, A. Laudani

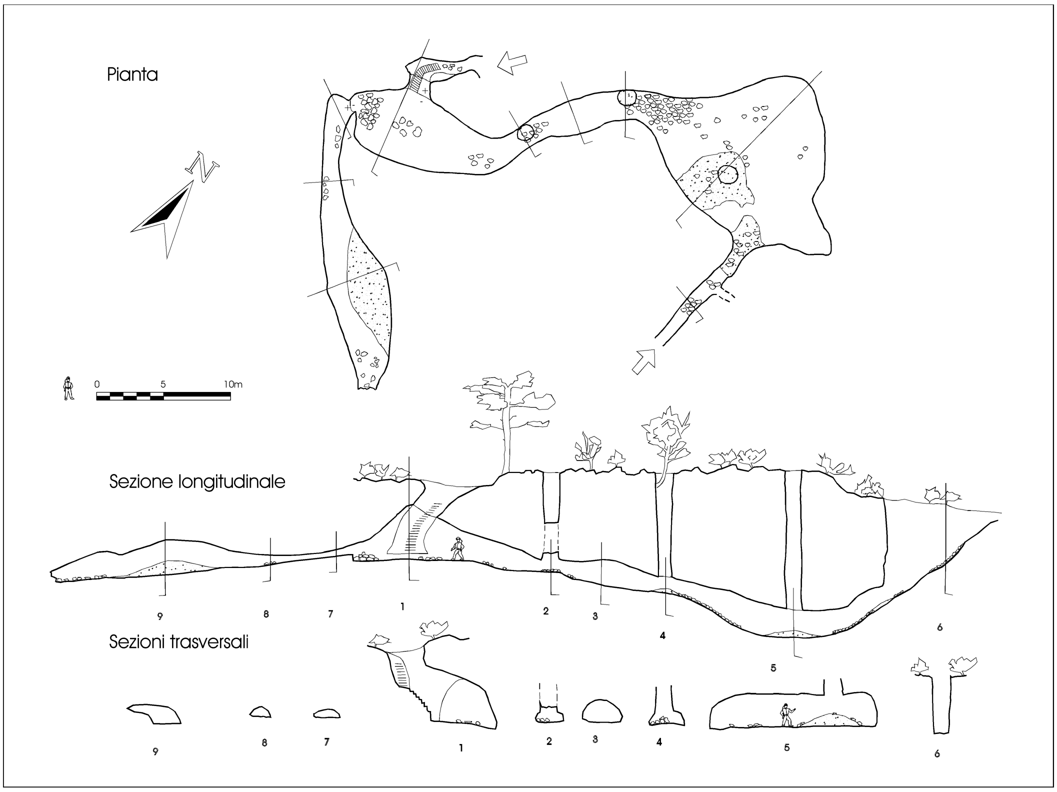


Location
This cave is situated on the south flank of Mt.Etna near Ragalna town.

Description
This cave is only 145 m long but a part of it is the largest lava tube on Mt. Etna. The entrance is on a great collapse and maybe in the past the tube was longer. Going downward over the blocks there is the main tube 13 m high, large more than 10 m and 25 m long. It is closed by a fall of lava coming from the ceiling. The remaining part of the cave, developing as a branch of this channel and starting from its lower area, presents smaller dimensions.
Nearby the collapse zone, another cave, Grotta Catanese II, opens as a further branch of the main tube.
The age of the eruption that formed this cave is unknown but it is believed to be historical.
The name of this cave comes from a legend which tells about a woman from Catania who was killed by brigands in order to put a spell on the booty hidden in this cave. Now the only way to find the booty is to kill someone in the cave!

GROTTA DEI LADRI

- *Cadastrial number:* SICT 1117
- *Other names:* Grotta dei Briganti o della Neve
- *Location:* Piano delle Donne
- *I.G.M.map:* Serie 25, Foglio 625, Sezione IV, Sant'Alfio, Ediz. 1993
- *Longitude:* 15° 04' 20" E
- *Municipality:* Sant'Alfio
- *Year of eruption:* Preistorica
- *Total lenght:* 59 m
- *Total depth:* 4 m
- *Height:* 1547 m
- *Latitude:* 37° 46' 21" N
- *References:* Barone, Di Paola, Fanciulli, Marino, Maugeri, 1989,16-17; Cantarella, 1985, 7; Houel, 1784, II, 81-82; Centro Speleologico Etneo, 1999, 276-277.
- *Survey:* (1988) N. Barone, A. Di Paola, F. Fanciulli, A. Marino, R. Maugeri
- *Drawing:* R. Bonaccorso, F. Fanciulli



Location
This cave is situated on the East flank of Mt. Etna on the Mareneve road (Km 19).

Description
The legend of this cave tells that it was used by brigands as a refuge. The wells connecting the cave to the surface were used to hide their booty which was taken back walking through the easiest accesses. But in reality this little lava cave was used as a snow deposit. Other little caves on Mt. Etna were used for such a purpose but this cave was also modified to achieve a better use. The use of this cave was depicted by J. Houel (Houel 1784) in the *Grotte à la néige* painting.
Three wells were dug in order to fill the cavity of snow. One of them is closed by debris but the others are still open.
This cave has two easy entrances. One entrance was modified with some steps carved in a wall, the other was carved in the basalt to create a steep slope.
A date (1776) can be read by the entrance of the slope which gives access to a large and low chamber. One of the wells reaches this point were there is a little debris cone. Climbing the debris

westward a narrow gallery leads to the second well with a tree inside. At the other end of the gallery (about 10 m long) another large chamber (showed in the *Grotte à la néige*) gives access, eastward and after a narrow passage, to a little gallery (20 m long), northward to the exit with the steps carved in the basalt.

18

19

Fig. 18 - A corner of the Thieves Hall (G. Tomasello)
Fig. 19 - Houel Room: the stairs carved in stone (R. Bonaccorso).

References

- ANDRONICO D., 1930: *L'Etna e le sue meraviglie*, Catania.
- BARONE N., DI PAOLA A., FANCIULLI F., MARINO A., MAUGERI R., 1989: *La Grotta dei Ladri*, Economia Siciliana 40, I Semestre 1989: 16-17.
- BARONE N., PRIOLO A., PRIOLO G., SANFILIPPO G., SCAMMACCA B., 1994: *Grotte vulcaniche di Sicilia, notizie catastali: terzo contributo (da Si CT 51 a Si CT 75)*. Boll. Acc. Gioienia di Sc. Nat., 27, (346): 367-398, Catania.
- BELLA V., BRUNELLI F., CARIOLA A., SCAMMACCA, 1982: *Grotte vulcaniche di Sicilia, notizie catastali: secondo contributo (da Si CT 26 a Si CT 50)*, Boll. Acc. Gioenia di Sc. Nat., 15, (320): 229-292, Catania.
- BRUNELLI F., SCAMMACCA B., 1975: *Grotte Vulcaniche di Sicilia (notizie catastali)*, G.G.C. – C.A.I. Sez. dell'Etna, Catania.
- CANTARELLA F. 1985:, *La Grotta dei Ladri*, Il Prometeo 4, Settembre 1985: 7.
- CAVALLARO F., LICITRA G. M., 1975: *Scheda per l'escursione del 26.8.1975 alla Grotta di Serracozzo I*, in Atti Settimana Speleologica Catanese e Seminario sulle grotte Laviche, Gruppo Grotte Catania e Club Alpino Italiano, Catania.
- CENTRO SPELEOLOGICO ETNEO, 1999: *Dentro il vulcano. Le grotte dell'Etna*, Parco dell'Etna, Catania.
- CORSARO R., GIUDICE G., 1991: *Quasi record ai Tre Livelli*, in.Speleologia Anno XII, n.24
- CORSARO R., GIUDICE G., PUGLISI G., 1995: *Sistema 3 Livelli – KTM: Studio comparato di una colata con gallerie di scorrimento lavico*, Atti I Conv. Reg. di Speleol. della Sicilia, vol. I, Ragusa.
- DE ROBERTO F., 1881: *Cronache per il "Fanfulla"*, a cura di G.Finocchiaro Chimirri, Milano, 1973.
- FORTI P., GIUDICE G., MARINO A., ROSSI A., 1994: *La Grotta Cutrona (MC1) sul Monte Etna e le sue concrezioni metastabili*. Boll. Acc. Gioenia Sci. Nat. V.28, n.348, p.125-151.
- FORTI P., MARINO A., 1995: *Nota preliminare su un ritrovamento di un nuovo minerale di grotta nei "Pozzi dell'Eruzione del 1923 (Si Ct 1084)*. Atti I° Convegno Regionale, Ragusa 1990, vol. I, 92-100.
- GIUDICE G., SCALIA N., 1994: *La frattura eruttiva di Profondo-Nero*, Boll. Acc. Gioenia di Sc. Nat., 27. 348.
- GIUDICE G., LEOTTA A., 1994: *La Grotta Cutrona (MC1)*, Boll. Acc. Gioenia di Sc. Nat., 27. 348.
- GRECO, 1995: *I Santi Patroni di Sicilia*, Dario Flaccovio Editore, Palermo.
- HOUEL J., 1784, *Voyage pittoresque des Isles de Sicile, de Malte et de Lipari*, Paris.
- LO GIUDICE R., PRIVITERA M., 1982: *Contributo alla conoscenza della bioflora cavernicola dell'Etna*. Archivio botanico.
- MICELI F., 1933: *Le grotte dell'Etna*. Rivista del C.A.I., sezione dell'Etna, Catania, numero unico.
- PETRONIO RUSSO S., 1880: *Della vita e del culto di San Nicolò Politi*, Messina.

- POLI E., 1959 (a): *Sulla genesi di alcune grotte dell'Etna*. Boll. Acc. Gioienia Sc. Nat. IV. 5 (1): 1-17.
- POLI E., 1959 (b): *Genesi e morfologia di alcune grotte dell'Etna*. Boll. Soc. Geogr. Ital., 9/10: 3-14.
- PRIVITERA F., 1994: *Esplorazione archeologica della Grotta Petralia*. Boll. Acc. Gioenia di Sc. Nat. 27, (348): 17-35, Catania.
- PRIVITERA F, 1999, *Le Grotte etnee nella preistoria, in "Dentro il vulcano - Le grotte dell'Etna"*, 85-104.
- RITTMANN A., ROMANO R., STURIALE, 1971: *L'eruzione etnea dell'aprile-giugno 1971*, Atti Acc. Gioenia di Sc. Nat. in Catania, S. VII, VIII.
- RITTMANN A., ROMANO R., STURIALE, 1973: *Some considerations on the 1971 Etna eruption and on the tectonophysics of the Mediterranean area*, Geol. Rund., B. 62, H. 2.
- SANTANGELO A., 1952: *San Nicolò Politi*, Catania.
- SARTORIUS VON WALTERHAUSEN W., 1880: *Der Aetna*, Lipsia.

FORMATION OF A COMPLEX TUBE NETWORK: THE 1999 ETNA ERUPTION

Sonia Calvari [*]*, Marco Neri* [**] *and Harry Pinkerton* [***]

* Istituto Internazionale di Vulcanologia, Piazza Roma 2, 95123 Catania - Italy
** Istituto Nazionale di Geofisica – Sistema Poseidon, Via Vigna Murata 6, Roma - Italy
*** Environmental Science Department, Lancaster University, Lancaster LA1 4YQ – United Kingdom

Abstract

The 1999 Etna eruption began on the 4th February, and is still going on as of August 26, 1999. The eruption started with strombolian activity at the South-East Cone (SEC), and with the opening of a fissure on the southeastern flank of this cone. Lava discharged from the lower part of the fissure flowing E and SE towards the Valle del Bove (VDB). The 35-65° slope of the western VDB wall decreased the advance rates of the lava flows. Flow fronts into the VDB propagated until the 10th March, when they attained 1970 m asl and the maximum length of 2.8 km.

The resulting lava flow field can be subdivided into two parts: the upper flow field, from the base of the SEC to the VDB rim, and the lower flow field, beyond this margin. The emplacement of the lava flow field during the 1999 eruption can be subdivided into at least five phases on the basis of the observed morphological changes.

The first phase was between February 4 and March 10, 1999, and was essentially characterized by lengthening of the lava flow field. During this phase there were few ephemeral vents in the upper and middle flow field, and tube systems developed along arterial aa lava flows.

The second phase lasted between March 11 and April 15, causing widening and little thickening of the flow field. Flows were active both on the upper and lower flow field. Flow fronts in the lower part widened, and the entire flow thickened through overflows. Many ephemeral vents formed in the upper and lower flow field.

During the third phase, which lasted between April 16 and May 15, the active lava flows were confined to the Valle del Bove, causing a considerable increase in thickness of the lower flow field. Lava tubes remained apparently stable without increasing in length.

This trend was interrupted by the start of the fourth phase, between May 16 and June 6, when activity resumed on the upper flow field through new breakouts along the chain of hornitos. Thickening of the upper flow field and lower flow field was marked by formation of many tumuli both on the upper flow field and along the western wall of the Valle del Bove. Due to a decrease in effusion rate, previous tubes have been deactivated and new, smaller tubes formed at an upper level into the flow field giving a stacked tube system.

A probable decrease in the effusion rate produced the start of the fifth phase, from June 7 onwards. Flows and vents beyond the western wall of the Valle del Bove disappeared completely. Only the upper flow field was active, producing many new tumuli, which increased the thickness of the upper flow field. Effusion rate decreased from previous 3-5 m^3/s to 0.07 m^3/s.

FEATURES OF ETNA LAVA STALACTITES

Rosanna Corsaro, Sonia Calvari and Massimo Pompilio

Istituto Internazionale di Vulcanologia, Piazza Roma 2 - 95123 Catania, Italy

Abstract

Lava stalactites are one of the most spectacular features observed into lava tubes. While some stalactites form from mineral precipitates at the end of eruptions (1), the majority form in response to thermal and mechanical processes during flow and subsequent drainage. Stalactites on Etna have shapes and sizes that differ significantly from some of their Hawaiian counterparts. For example, the delicate, worm-like structures found on the roofs of lava tubes on Hawaii (2) have not been observed on Etna.

On Etna, Calvari and Pinkerton (3) have distinguished four kinds of stalactites, of which there are excellent examples on the walls and roof of the Tre Livelli and Cassone tubes. Stalactites with very smooth surfaces form on ridges that are elongated in the flow direction. These stalactites are typically red in colour, and they are considered to form by remelting by gases accumulating below the roof (2, 3, 4). On Etna they are typically up to a few centimetres long and at most 2 cm wide at the base, and they are conical in shape. Another type is rough, grey in colour and spiky, and it is usually found in constrictions of the tube. This second group of stalactites was also recognised by Jaggar (2). They are generally less than 0.5 cm wide, a few centimetres long, and they are considered to have formed where lava completely filled a tube and then drained, either partially or completely. The resulting stalactites record the dribbling of lava from the roof. The spiny nature of these stalactites is due to the presence of crystals (mainly plagioclase) and small amount of interstitial glass. The third group of stalactites are morphologically similar, and they form when part of the roof or wall lining drops or rolls off, leaving rough ‘pull-apart’ stalactites. The final type of stalactite, which is not very common, is characterized by bulbous shapes. Thin sections reveal that they are composed of multiple layers with an external boundary marked by a very thin film of oxides. We interpreted these as stalactites that have been repeatedly coated by lava. Here we present some measurements performed on three different kinds of lava stalactites sampled inside the Tre Livelli Tube which formed during the 1792-1793 Etna eruption.

References

- GIUDICE G. AND LEOTTA A., 1995. *Le alchimie di un vulcano: la Grotta Cutrona*. Speleologia 33, 14-20.
- JAGGAR T. A., 1931. *Lava stalactites, stalagmites, toes, and “squeeze-ups”*. The Volcano Letter 345, 1-3.
- CALVARI S. AND PINKERTON H., 1999. *Lava tube morphology on Etna and evidence for lava flow emplacement mechanisms*. Jour. Volc. Geoth. Res., 90, 263-280.
- KAUAHIKAUA J. ET AL., 1998. *Observations on basaltic lava streams in tubes from Kilauea Volcano*, Hawai’i. Jour. Geoph. Res., 103, 27303-27324.

SECONDARY MINERALIZATIONS INSIDE GROTTA DEL FUMO – SMOKY CAVE – (1991/93 ETNA ERUPTION)

Antonio Marino

Centro Speleologico Etneo, via Cagliari 15 - 95127 Catania, Italy

Abstract

Grotta del Fumo, which is located in the high area of 1991/93 Etna lava flow, six years after the end of the volcanic phenomenon, still keeps, upstream its entry, a temperature of 40°C and continuous vapour emission flowing in the high part of the gallery. On the contrary the temperature and humidity are lower in the area close to the floor. In this environment, in the area preceding it and in the tube downstream the entry, where the internal temperature has already reached the external yearly average values (±5°C), salt secondary mineralizations, which are typical of ending eruption, are still present.
Three specimens were examined. They were drawn in three different parts of the tube: the first in the smoky gallery, the second in the preceding area and the last one downstream, directly below the entry. The presence of those minerals, that is Thenardite, Halite and Gypsum, which are usually found in these post-eruptive environments, was noticed. However in the first specimen the presence of tiny crystals of Celestine (30–40µ) associated with Halite was also noticed. This compound was previously not found in other deposits. If there is the chance to examine closely these deposits, more information about the composition of gaseous emissions, which still continue to come out from the eruptive fissure, will probably be obtained.

Introduction

Only in the last years, the study of lava flow secondary minerals, that is those which are directly not part of lava mineralogical composition has been exciting interest in the scientific environment. These minerals can be found, during the eruption or after it, near the “fumarole” which are located along the lava tube and inside the volcanic cave, but at least one year later the end of the effusive manifestation, that is when the temperature almost decreases to atmospheric values. They are in the shape of stalactites, patina, masses, flows etc… which cover, sometimes completely, the cavity surface.
After many analysis inside the new caves, it was possible to understand that, when the values of the inside temperature are next to those outside (45-35 °C), gas and residual magmatic vapour condense forming a large quantity of salt deposits (mainly sulphate minerals and chlorides of Na and Ca) which, when the temperature definitively stabilise to external average values, thanks to the high relative humidity, dissolve leaving only few traces.

Fig. 1 - The lava flow in the first days of eruption (12–29–1991).

Grotta del Fumo

The 1991/93 lava flow (fig. 1) came out from a fissure cracked on the west side of Valle del Bove, at an altitude of about 2400 metres and it flowed along a gully facing the bottom of the valley before becoming wide on the valley extend. In its first part it created a rectilinear canal, which is deep and very inclined, and almost close to form a long gallery, although it is open in three parts which let gas and vapour emission. The entry, which is located upstream the other two, emitted smoke for a long time. Two years later the end of the eruption we went inside this chasm and we could notice that downstream the temperature had already reached normal values and there were not evident concretions. On the contrary, from the gallery upstream leading to the eruptive fissure, a sort of vapour, which was still keeping high temperature, was coming from. It was flowing along the roof of the gallery where its height decreased to about one metre.
This is why it was called Grotta del Fumo (fig. 2). Temperature in the high part of the small gallery was still very high (about 80 °C). On the contrary, on the floor the temperature was close to 40°C. this situation let the formation of salt compounds only on land; on the contrary, on the roof there were still not concretions. To proceed into the lava tube was not possible for other four years, that is until when, in 1999, roof temperature decreased to 50 °C and on the floor it reached 30°C.

Although the inside conditions improved, even if to entry the cave was quite difficult because of the detritus sliding down which quite closed the entry, we moved forward only for few metres. In fact, over the area of one metre in height, the gallery grows to a height of two metres, but it is always full of vapour at temperature of 40°C and with 100% of humidity. We had difficulty in breathing properly and so we stop there just for few minutes. We could just see that the tube was longer. We wait that the temperature and humidity decrease further on to go over to verify the right length of the lava tube, unless the detritus completely close the narrow passage which still exist obstructing the way.

Fig. 2 - The well–shaped entry of the Grotta del Fumo

Previous Observations

Inside the numerous cavities deriving from the 1991/1993 eruption we observed the presence of mineralising deposits, which were white or variously coloured because of the presence of other elements, which were included at a molecular level inside the most abundant compounds: Thenardite (sodium sulphate), Halite (sodium chloride) and Gypsum (calcium sulphate).
The first to be examined were those which were found inside Grotta Cutrona (Cutrona Cave), in Valle del Bove (Forti et al., 1994). During the next years other descriptive studies of speleothemes have been carried out in other cavities of lava flow (Grotta del salto della Giumenta, Grotta della Macchia gialla, Grotta dell'arco, etc…).

Secondary Mineralizations inside Grotta del Fumo

During 1998 and 1999 summer seasons, salt deposits were drawn inside Grotta del Fumo: one in the area downstream the entry, which is closed by a landslide and possible to reach only by the second entry (Grotta della Macchia gialla – Yellow Spot Cave), where the temperature stabilised to the external yearly average one (±5 °C). Other two specimens were drawn inside the smoky gallery: one from the floor of the low gallery (fig. 3) and the other from the small balcony on the left side of the anterior high gallery.

Fig. 3 - The low cave where sample n.1 has been taken.

The specimens were catalogued according to the direction of lava flow:
N.1 – this specimen was drawn inside the low gallery: it is made up of a small stalagmite mass whose colour is translucid white.
N.2 – this specimen was drawn in the high gallery on the small balcony on the left side: it is made up of white-yellowish efflorescence.
N.3 – this specimen was drawn at the entry of the gallery, downstream: it is made up of a small stalagmite mass whose colour is semi-transparent white.

The analysis was conducted at the International Institute of Volcanology (I.I.V.) of Catania in collaboration with Dr. Massimo Pompilio.

Specimen n.1 is mainly made up of Halite (NaCL) mixed with micro crystals of Celestine ($SrSO_4$), 30–40µ length (fig. 4)

Specimen n.2 is made up of Thenardite (Na_2SO_4)

Specimen n.3 is made up of Thenardite (Na_2SO_4) and Halite (NaCL)

The minerals which are present in the three specimens, but Celestine, had already been found inside the other new cavities of Mount Etna.

Celestina enlarges the range of compounds which are present inside the secondary mineralizations of Etna caves. Its presence could be linked to the persistence of magmatic vapour which, over six years after the end of the eruption, continues to come out not only depositing the usual substances, but, probably, also new compounds. It is not a coincidence the finding of Celestine in the specimen which was drawn in the low gallery, where the deposit are more recent.

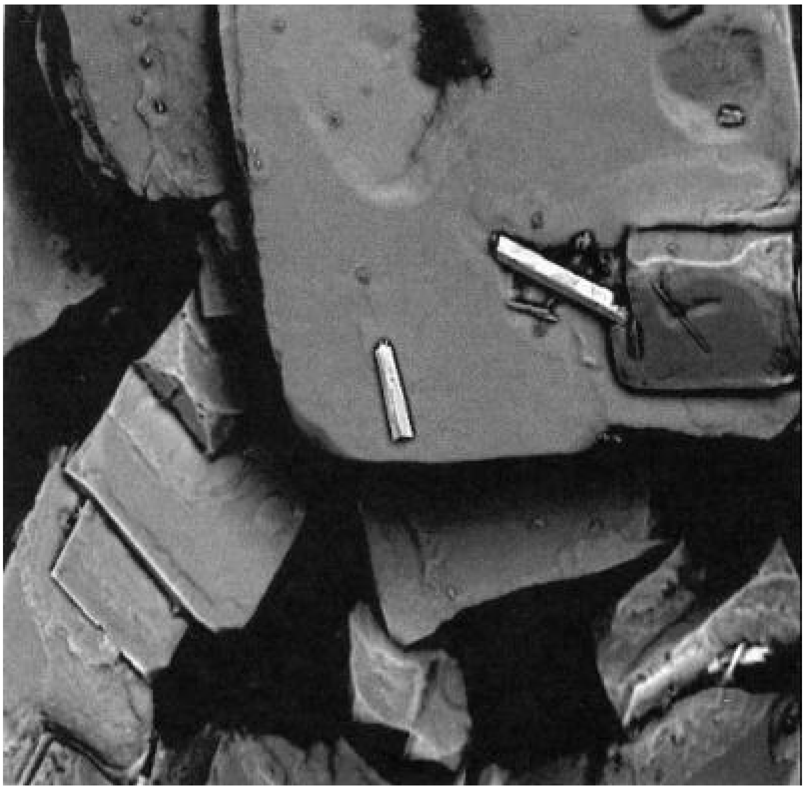


Fig. 4 - Celestine crystals ($SrSO_4$) 30–40 µ on to Halite crystal.

Conclusion

For a better understanding of the problem, the research should be deepened drawing new specimens and surveying the temperature, which would give us more information about the evolution of the phenomenon and the formation of new minerals. However the difficulty of reaching the cave and the lack of specific instruments has prevented us from making a constant monitoring of the phenomenon, which still keeps its scientific interest. We hope to achieve, in collaboration with Organisations and Institutes of research, a complete knowledge of the phenomenon.

Acknowledgements

My thanks to Dr. Massimo Pompilio of I.I.V. of the CNR for the collaboration in the analysis of the specimens and Dr. Leone for translation from Italian to English.

Bibliography

- FORTI, P., GIUDICE, G., MARINO, A., ROSSI A., 1994, *La grotta Cutrona (MC1) sul Monte Etna e le sue concrezioni metastabili,* Proceedings of the II Conv. Reg. di Speleologia, Catania, I 1994, Boll. Acc. Gioenia S.N., vol. 27, n. 348, pp. 125-151;
- HILL, C.A., FORTI, P., 1986, *Cave minerals of the World*, NSS Hunstville, pp. 1-238.

THE SYSTEM GROTTA DEL FUMO - MACCHIA GIALLA – GROTTA DELL’ARCO

Gaetano Giudice and Angela Privitera

Centro Speleologico Etneo, via Cagliari 15 - 95127 Catania, Italy

Summary

This paper describes the explorations of the galleries located in the upper part of the 1991-93 eruptive fissure. During 1994 three caves were discovered in the main tunnel of the lava flow, named Grotta del Fumo (2375 m asl), Macchia Gialla (2275 m asl) and Grotta dell’Arco (2220 m asl), but only in the spring of 1995 it was possible to reach the lava tube from the shaft of Macchia Gialla, because of the high values of Rh and temperature recorded before. Later it was possible to partially explore the Grotta del Fumo, where salt depositions were found on the floor and a continuous flow of steam was observed on the roof. This steam had a temperature of about 57°C, which restrained further explorations. Finally, the Grotta dell’Arco was explored, but it was impossible to descend a shaft in the bottom part because temperature and Rh inside were still too high. Already in 1995 the three caves were connected after digging for a few days, but only in the spring of 1997 the bottom of the system was reached. We descended the shaft and discovered the final room, totally clogged and with ambient temperature above 30°C and Rh of 100%. More recently, in the summer of 1999, the upper limit of the system was surpassed in the Grotta del Fumo, probably reaching the zone connecting the lava tube with the 1991-93 eruptive fracture. On the same occasion we also descended for few meters inside the uppermost part of the same fracture. Furthermore, during this last recognition we observed both the persistence of the steam flow and the increase in salt deposition. On the basis of these observations, and considering the long time span since the end of the eruption (more than 6 years), a preliminary hypothesis on the dynamics of the phenomena is attempted.

Approach

Following the track that starts from the Strada Provinciale 92 about 1 km east of the Rifugio Sapienza, on the direction towards Zafferana Etnea, the Schiena dell'Asino, on the SW edge of the valle del Bove, is reached in about 1 hour walk. Here is a tombstone, named Lapide Malerba. From this point onward the track leads into the Valle del Bove, maintaining the same altitude. After crossing the Canalone della Montagnola the track goes up and down to finally reach the upper part of the 1991-93 lava flow, which is clearly visible on the right because it is darker than the other flows around.

Once approached the 1991-93 lava flow, climbing up to the altitude of 2375 m, the Vent of the Grotta del Fumo is visible.

The total time of the approach is about 3 hours.

History of the explorations and description of the cave

From the fissure that opened in December 1991 at 2400 m of altitude in the western side of the Valle del Bove a huge quantity of lava flowed along the steep slope below forming a deep lava channel. In a short time the external part was consolidated, thus forming a so called lava tube.

Many fissures remained open in the tube roof, and from these both vapours and fragments of lava were emitted.

At the end of the eruption, in March 1993, three windows were still present from which sprung a lot of vapour.

In January 1994 tree members of the Centro Speleologico Etneo explored the lava flow, searching for possible access points to the lava tube. Three caves were eventually discovered in the main tunnel of the lava flow, the Grotta del Fumo (2375 m asl), the Macchia Gialla (2275 m asl) and the Grotta dell'Arco (2220 m asl). It was only in the spring of 1995 that the lava tube from the shaft of Macchia Gialla could be approached, because of the high values of Rh and temperature recorded until then. Later it was possible to partially explore the Grotta del Fumo, in which salt depositions were found on the floor and a continuous flow of steam was observed on the roof. Steam had a temperature of about 57°C, which restrained further explorations. Finally, the Grotta dell'Arco was explored, but it was impossible to descend a shaft on the bottom part of the cave because temperature and Rh inside of it were still too high. Already in 1995 it was possible to connect the three caves after digging for a few days, but only in the spring of 1997 was the bottom of the system reached, descending the shaft and discovering the final room. It was totally clogged and had ambient temperature above 30°C and Rh of 100%. More recently, in the summer of 1999, the upper limit of the system was surpassed in the Grotta del Fumo, probably reaching the zone connecting the lava tube with the 1991-93 eruptive fracture. On the same occasion the uppermost part of the same fracture could be visited, although only for a few moments because of the prohibitive ambient conditions (temperature above 42°C and Rh of 100%). Furthermore, during this last recognition both the persistence of the steam flow and an increased salt deposition were observed.

The total length of the system is about 450 m, and its depth is about 200 m.

The average slope of the tube is remarkable, being about 40 degrees. From a morphological point of view this cave is a typical lava tube with high slope, similar to the upper part of the tube of the Tre Livelli (Corsaro et al., 1995), with cross section often shaped like that of a pagoda, that is large at the bottom and narrow at the top.

The peculiarity of this cave lies on the phenomena observed in its upper part, just upslope of the Grotta del Fumo entrance. There (see detail in Figure 2) the tube changes its slope abruptly, which then remains below 5 degrees. On moving further up along the tube, passed the entrance, a large tunnel about 30 m long is reached. There lava balconies on both walls testify flowing morphologies (reogenetic), and indicate a quite constant level of lava that partially invaded the cave for a sufficient period of time.

In 1995 the ceiling of this tube was found covered with hot vapour that flowed over it like a river. The stream of vapour was about 2 meters above the tube floor and was directed towards the entrance of the tunnel, forming a sort of smoky chimney in the entrance shaft. Underneath the bottom of the vapour stream temperature was 25°C and Rh was 73%.

The upper part of the tube is narrower, being a cylindrical cuniculus with radius of less than one meter. In the spring of 1995 temperature inside this cuniculus was 58 °C in the vapour stream, whereas it was about 40°C near the floor. Due to such unfavourable ambient conditions, only 10 meters of cuniculus were explored in that occasion. The gas stream seemed to be composed principally of water vapour and CO_2 (measured CO_2 concentration of about 1% vol.), with traces of CO.

- Cadastral number: SICT 1236	- Commune: Zafferana Etnea
- System of Grotta del Fumo, Macchia Gialla, dell'Arco	- Year of eruption: 1991-93
- Location: Sasso del Goliardo	- Development: 450 m
- Map: I.G.M.: Serie 25, Foglio 625, Sezione IV, Sant'Alfio, Ed. 1993	- Total deepness: 200 m - Altitude: 2375 m, 2275 m, 2220 m
- Fumo Longitude: 15° 00' 52" E	- Latitude: 37° 43' 40" N
- Macchia Gialla Longitude: 15° 00' 57" E	- Latitude: 37° 43' 39" N
- Arco Longitude: 15° 01' 01" E	- Latitude: 37° 43' 38" N
- Survay: (1999) G.Garozzo, G.Giudice, A.Marino, A.Privitera, G.Tomasello	- Park zone: A

Table 1: Cadastral data

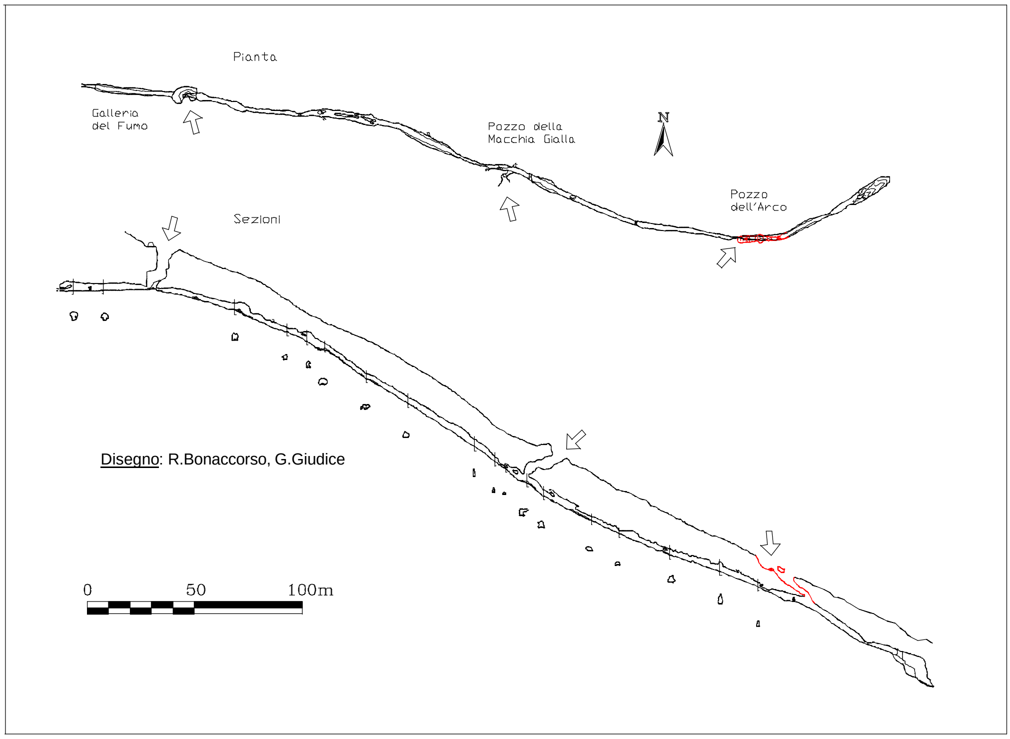


Fig. 1

Beneath the vapour level abundant deposition of salt speleothems was found, in all similar to that observed in 1994 in the Grotta Cutrona (Giudice & Leotta, 1994; Forti et al., 1994).

Only in the summer of 1999 was the cuniculus surpassed, leading to a room invaded with vapour at temperature above 42°C and Rh of 100%. From this room (about 3 meters of diameter) a little cave continued with a high slope, and a massive flow of hot vapour came out of it. The exploration was stopped there, because more adequate equipment was needed and it was impossible to resist in that atmosphere for more than a few minutes.

In that occasion it was observed that compared to 1995 temperature in the cuniculus had decreased to about 40°C in the vapour, and to 23°C underneath, whereas near the entrance of the large cave measured temperature was 13°C. Furthermore, minerals deposition was still active in the cuniculus, and new blue coloured stalagmites were observed.

The morphology of the upper part of the cave and the altitude reached, same as that of the 1991-93 vent (at least in the central and terminal phase of that eruption), gave the impression that the connection between the 1991-93 eruptive fissure and the emission point of the lava flow had been reached. A similar morphology is also observable in the upper part of the Grotta dei Tre Livelli (Corsaro et al., 1995).

The 1999 exploration could not be completed because of large collapses at the base of the entrance shaft, and a short period of digging was needed. Unfortunately it is probable that this problem will occur more and more frequently in the future, because of large rock and sand falls from the slope above the entrance, especially during the spring when snow melts. Further, it was impossible to reach the lower gallery from this entrance, because the passage was buried by rock collapse. Now to visit this part of the cave it is necessary to enter from the Macchia Gialla shaft. The cave above this shaft has some peculiarities: it is narrow, extremely deep, very high (above 6 meters in many places) and with its walls striated by lava flow erosion, that further deepened the floor constituted of small piroclastic materials.

Under the Macchia Gialla shaft a short narrow passage (excavated in 1995) leads to the Galleria dell'Arco, below the Grotta dell'Arco entrance, which is the lowest of the system. From here the tunnel becomes larger but again very steep. In 1995 the exploration was stopped over a shaft about 10 metres deep, from which a stream of hot vapour (above 50°C) flowed.

Only in the spring of 1997 was it possible to reach the actual bottom of the system in a room closed “a cul de sac”, surpassing the shaft (a rope is needed). During this exploration vapour’s temperature was still over 30°C.

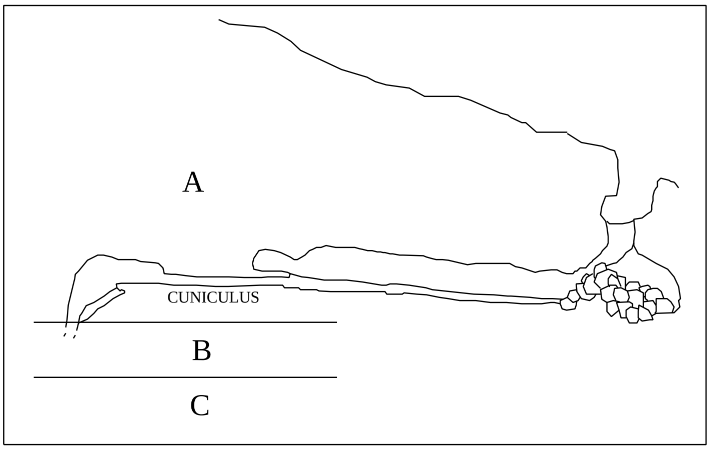


Fig. 2

Observations And first hypothesis on the dynamic evolution of speleothems

The comparison between the physico-chemical conditions found in 1995 and those in 1999 inside the Grotta del Fumo suggests us a possible way to explain the observed phenomena. We take into account especially the observations related to the cuniculus indicated in Figure 2. In this site steam was ever present, with the stream directed towards the entrance. Inside the vapour, near the cave ceiling, neither in 1995 nor in 1999 considerable incrustation was found, whereas near the floor, out of the vapour, a lot of speleothems were observed in both explorations.

Between 1995 and 1999 temperature in several points of the cave decreased by 15-20°C. In 1999 the temperature near the entrance of the cave was about 13°C, and this causes vanishing of almost all of the incrustations in this site. Conversely, only minimal changes in speleothems occurred in the cuniculus. Unfortunately, no observations are available for the inner part of the cave before 1999.

We assume that initially, that is immediately after the end of the 1991-93 eruption, the whole mass of new lava was very rich in salts, especially sodium chloride (P.Forti et al., 1994), and water could not infiltrate because rock temperature was above 100°C.

Cooling of the surface of the new lava after a certain period allowed water to penetrate down to a certain depth, for example the limit between A and B zones of Figure 2, and to dissolve salts. If along its descent a cave with opportune conditions of temperature and humidity is met, the solution may deposit dissolved salts originating incrustations. This situation is perfectly represented in what observed in zone A of Figure 2. It is easy to consider that rain water infiltration, after the rainy season, causes the decrease in salt concentration in the new lava, starting from the most superficial zone. In this zone the contribution to development of speleothems (in a cave incidentally encountered) is generally irrelevant. On the contrary, water will again dissolve salt of speleothems, so the concretions will vanish rapidly. This phenomenon was largely observed both in the Grotta Cutrona (Giudice & Leotta, 1994) and in the Grotta del Salto della Giumenta.

After the first phase in which the superficial zone is depleted in salt content, water can continue its downward infiltration encountering and dissolving salt in deeper zones of the lava flow, such as zone B of Figure 2, that are still rich in salt. Other deeper zones remain with initial salt concentration, as they are not yet cooled sufficiently. If a lava tube is situated in such a zone (B), salty water may produce concretions, but it may also vaporize and this vapour may transport a certain amount of salt (in the form of aerosol). This salt may be transported again towards the exit:

in fact the density of air inside the cave, warmed by the still hot deep rocks, will be lower than that of external air so as to produce an upward motion of air in the tube (which was effectively observed). Motion of this warm air will suck down fresh external air through cracks and fissures, ever abundant in new lava. On moving upward, aerosol may encounter relatively cold rocks and deposit part of the transported salt, hence contributing to the increase of incrustations. This particular kind of deposition was first envisaged by P.Forti (P.Forti et al., 1994), but this author suggested that aerosol was of primary origin (i.e., from fumarole vapours), while we believe that it is also due to water infiltration in new lava, dissolution of the salt present and then vaporisation in hypogean environment.

The strong air flow present in narrow passages, as in the case of the cuniculus considered in this study, facilitates and accelerates aerosol deposition. Water condensed on the ceiling of the cuniculus cannot produce deposition here because humidity is too high. However, dripping of water still meets appropriate conditions to create concretions: for this reason only the floor has been found covered with salt depositions.

It is possible that still in 1999 zone A conserved a sufficient concentration of salt, so a little contribution to deposition may come from a normal mechanism, similar to that described for the first phase (zone A, 1995) of the phenomena.

We believe that both mechanisms, gravity and aerosol deposition, contribute to generation of speleothems. At the beginning the first one has a preponderant role because the conditions are more favourable, while after rainy seasons the importance of the second mechanism increases and probably at a certain point becomes the only factor in salt deposition. Inevitably, at the end the speleothems will vanish totally.

In conclusion, we describe a simple experimental device that could give us some information on real contribution of aerosol mechanism. It consists of a little pipe placed on the floor with its longest axis parallel to the axis of the cuniculus and containing a small obstacle that simulates a stalactite. Deposition of salt inside the pipe in this case is only due to aerosol transport, whereas externally both are possible causes of deposition.

Unfortunately, it is quite certain that in the future it will become increasingly difficult to enter the lava tube, because of frequent rock collapses on the shaft entrance and accumulation of sand transported by water produced by melting of the snow. A long and hard work of excavation and consolidation would be necessary to assure the access to the lava tube without problems, but the great distance of the tube from the road track and the difficulties of approach could severely thwart this project.


3

Fig. 3 - Grotta del Fumo: Entrance shaft

Fig. 4 - Grotta del Fumo: Speleothems at the entrance of the cuniculus


4

5


6


7


8


9


10

Fig. 5 - 1991-93 vent and lava flow: 1-Grotta del Fumo 2-Macchia Gialla 3-Grotta dell'Arco
Fig. 6 - Grotta del Fumo: Speleothems and vapour in the cuniculus in 1995
Fig. 7 - Grotta del Fumo: Gallery in 1999
Fig. 8 - Grotta del Fumo: Speleothems and vapour in the cuniculus in 1999
Fig. 9 - Grotta del Fumo: Vapour in the gallery in 1995
Fig. 10 - La Macchia Gialla: Entrance shaft in 1999

References

- CORSARO, R., GIUDICE, G., PUGLISI, G, 1995, *Il sistema Tre Livelli Ktm: Studio comparato di una colata con gallerie di scorrimento lavico*; Atti del I convegno regionale di speleologia della Sicilia; Ragusa, Italy 1990; vol. II, pp. 66-76.
- GIUDICE, G., LEOTTA, A.,1995, *La Grotta Cutrona (MC1)*; Atti del II Convegno Regionale Siciliano di Speleologia, Catania, Italy, 1994, Bollettino dell'Accademia Gioenia di Scienze Naturali, Catania; vol.27, # 348, pp. 213-230;
- FORTI, P., GIUDICE, G., MARINO, A., ROSSI, A.,1995, *La Grotta Cutrona (MC1) sul Monte Etna e le sue concrezioni metastabili*; Atti del II Convegno Regionale Siciliano di Speleologia, Catania, Italy, 1994, Bollettino dell'Accademia Gioenia di Scienze Naturali, Catania, Italy; vol.27, # 348, pp. 125-151;

FRACTURE CAVES ON MT. ETNA

Angelo Leotta and Marco Liuzzo

Centro Speleologico Etneo, Via Cagliari 15 - 95127 Catania, Italy

Summary

This paper reports fhe results of the explorations implemented by Centro Speleologico Etneo in fracture caves on Mt. Etna, during the last decade. The specific morphologies of each cave were compared with the homologues of other explored caves, and analogies were ascertained both in shapes and sizes. Further comparisons were also carried between fracture caves and relevant contained speleothems, on one hand, and the specific features of the flows originated by such fractures, on the other hand.

The eruptive fractures on the northwestern flank of Etna were also analysed, in the light of the structural regional trends and of the resulting flow typologies.

STUDY ON THE CONCRETIONS OF LAVA TUBES WHICH WERE FORMED BY THE 1991-93 ERUPTION ON MOUNT ETNA.

Marco Liuzzo

Centro Speleologico Etneo, Via Cagliari 15 - 95127 Catania, Italy

Abstract

The 1991-93 lava flow on Mount Etna created many lava tubes all over its length. The spelaeologists of Centro Speleologico Etneo explored them as soon as the internal temperature let it. Cutrona Tube was the first one to be inspected. Concretions of different minerals were discovered in it. Among them there were some which had never been found in literature. The next step was a careful examination of two other tubes, which were born by the same eruption. The aim of our research was to collect a wide set of specimens of mineralogical species and to conjecture about the genetic processes, which originated them. Two different methods were used to conduct the analysis of concretions: traditional X-ray powder diffraction and IR spectroscopy. The purpose of this double analysis was to compare and evaluate the efficacy of the second method applied to this kind of research. According to previous studies the discovered concretions are mainly made up of Halite. The imposing concretions, which are present in the lava tubes formed by the 1991-93 eruption, are considered deeply connected to pneumatolytic phenomena acting inside lava itself, that is linked to the fumaroles without roots.

Introduction

Mount Etna is a volcano with a complex structure. It rises from Catania plain and its summit is at, about, 3300 metres.

On 14 December 1991 an eruption started. It lasted sixteen months and ended in March 1993. An eruptive fissure cracked on the west high wall of Valle del Bove, at an altitude of about 2400 metres. The lava flow, which came out of it, nearly reached Zafferana build-up area, a piedmont town located on the east face of the Etna. The lava flow reached a length of about 8.5-km. When the eruption ended, the members of Centro Speleologico Etneo carried on an intense exploration of lava tubes. They discovered many tubes, but only a few numbers of them could completely be explored because of their high temperature.

According to the physico-chemical features of lava and the topographical peculiarities of land, along the lava flow many lava tubes took form. All the lava tubes explored are the result of ‘a-‘a lava flow, the same kind as most other tubes present on Etna (Licitra, 1983).

Cutrona tube (MC1) was the first tube to be completely explored. An intensive phenomenon of concretions was discovered inside it (Forti et al., 1994). Later, after the good result of the first exploration, new inspections were conducted in other lava tubes originated from the same lava flow, among others: Grotta del Fumo (see Fig.1) and S.G.2 tube. They are respectively upstream Cutrona tube, near the eruptive fissure and downstream the same tube, scantily under Salto della Giumenta in Val Calanna. Because of the thermic conditions, the inspections of these tubes was impossible for a very long time.

Fig. 1 - Schematic map of Etna territory, location of the 1991-93 lava flow and of the analysed tubes.

More than a year after the end of the eruption rich amount of concretions were found in these tubes, although it was not comparable to that found in Cutrona tube.
The tubes, where the analysis were conducted, are located at different distance from the vents of the 1991-93 eruption: Grotta del Fumo partly coincides with the eruptive fissure (see Fig. 4), S.G.2 tube is located at 5.5 km from this eruptive fissure and Grotta Cutrona, whose presence had already been determined, is located between them. This is why the author decided to analyse the possibility of a mineralogical variation in the examined concretions according to the different distances from the eruptive fissure. The next step was the concrete analysis of the set of mineralogical specimens by means of X-ray powder diffraction and IR spectroscopy.

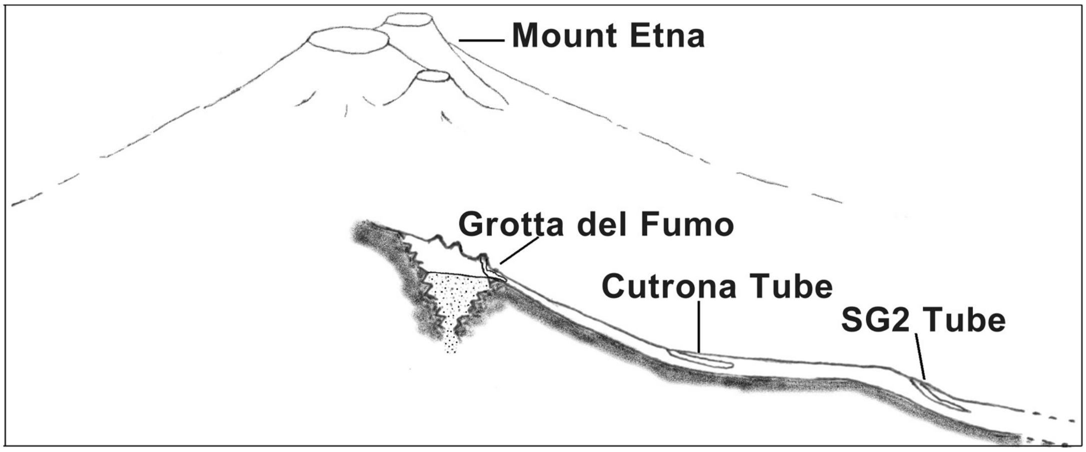
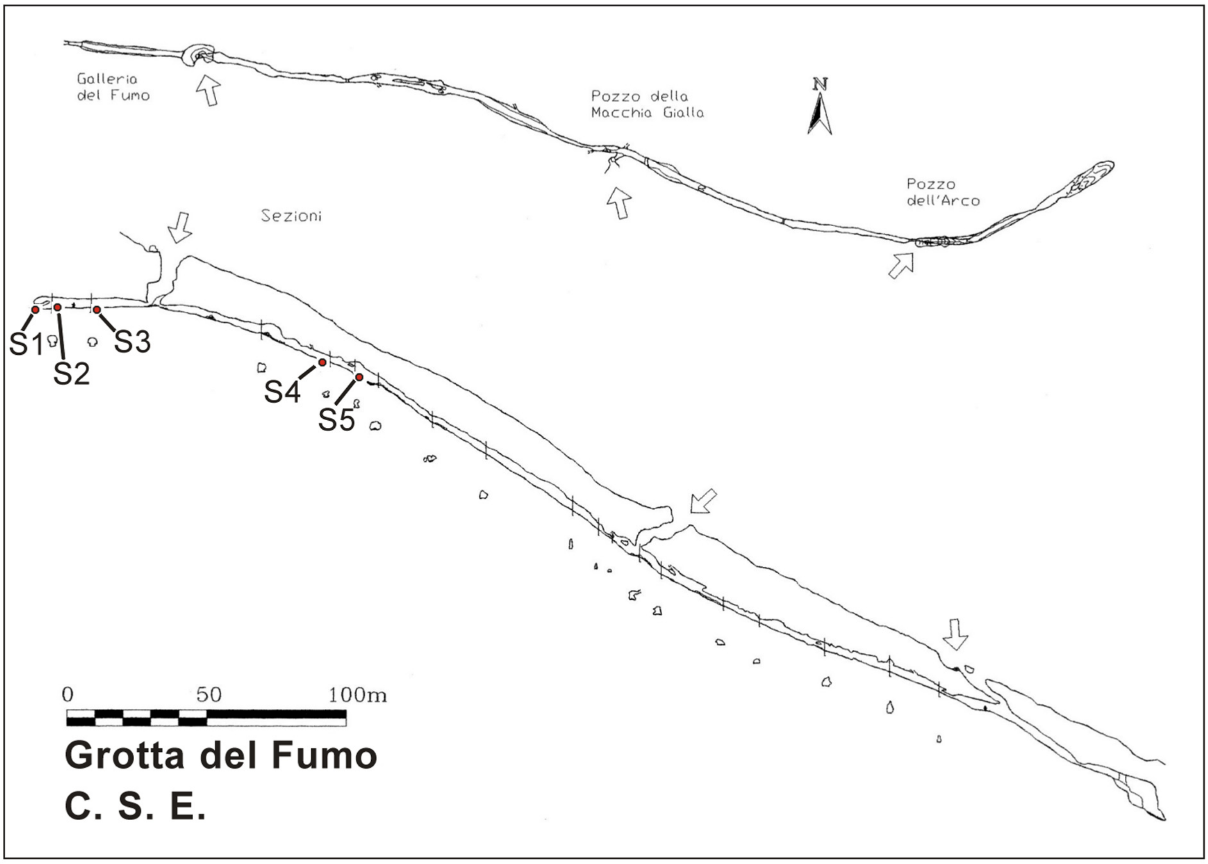


Fig. 2 - Schematic cutaway of the 1991-93 lava flow; it is important to highlight the partial overlap between Grotta del Fumo and the eruptive fracture.



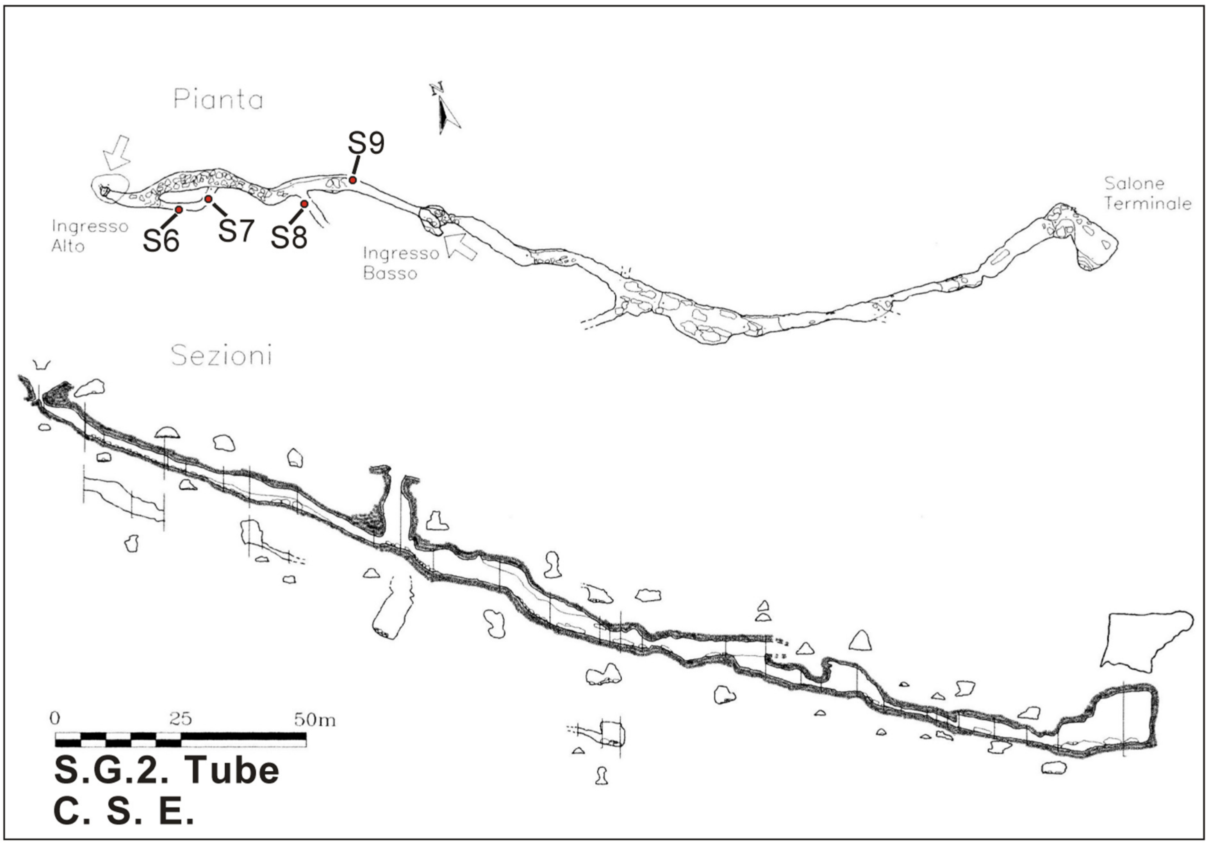


Fig. 3 - G. del Fumo and G.S.2 tube topography. The red marks indicate the places where the specimens were drawn. The abbreviations stand for the used specimens.

Specimen descriptions

The set of specimens was constituted according to the organoleptyc and morphochromatic features of concretions. The specimens were drawn from different places of each tube.
The descriptions of the specimens, which were picked up in the two described tubes, is as follows:

High Valle del Bove - Grotta del Fumo (see Fig. 3) - survey of 5 June 1995

Specimen 1: it is made up of clot-shaped aggregates which seem like the sea salt. It is wet at the touch and vitreous in its appearance. It does not taste too salty.

Specimen 2: it is made up of crusty concretion, which sometimes are coralloid. It is of milk-white colour and salty taste. It can easily be turned into dust (always white). It is anhydrous at the touch.

Specimen 3: it is made up of spheroidal aggregates of translucid orangey-red colour. It is salty and wet.

Specimen 4: it is a light brown crusty concretion. It is salty and dry.

Specimen 5: its colour is translucid milk-light. It is made up of spheroidal aggregates which are wet. They are covered of a patina, which is made up of spheroidal impurities (but milk-white inside). It is salty.

Salto della Giumenta - S.G.2 tube (see Fig. 3) - survey of 11 November 1995

Specimen 6: it is a milk-white concretion. This one is a stalactite rich in vesicles resulting from percolation. The stalactites are cannulae growing in length. They can have a smooth surface or they can be rich in globular protuberances, which are very often split.

Specimen 7: it is a coral-shaped milk-white concretion, vaguely resembling small ferns.

Specimen 8: pulverulent, white, white-grey concretion. It was found on the south branch where a strong hot current of air is present. The concretions seem to be made up of small globular flocks, which resemble the mould.

Specimen 9: it was found in the final part of the south branch where there was little or no air current (already at low temperature). The concretion is milk-white with vitreous brightness. Its innermost part is more similar to the transparent vitreous salt.

Analysis methods

The specimen analyses were carried out by means of infra-red spectroscopy (IR) and x-ray powder diffraction. The latter represents one of the most common and reliable methods of research in the field of mineralogical diagnostic. On the contrary, IR spectroscopy is commonly not used for this kind of analysis. However it was used in this specific case because it has a number of advantages, among which the fast performance and the need of small quantity of mineral: only 2 mg of concretion, for each specimen, were used.
The specimens were powdered and analysed by means of both research techniques.
A Philips diffractometer, which was equipped with a Bragg-Brentand geometry goniometer PW1130([1]), was used for the diffraction patterns. On the same specimens IR spectra were also obtained by means of Fourier transform infrared (FTIR) spectroscope, trademark Perkin-Elmer, mod.1710 (1) to survey the IR spectra in the interval of wave-length between 4400 and 400 cm^{-1} (2,27- 25 μm). The technique of KBr tablet was used to obtain the transmittance spectra. KBr tablets of 600 mg were prepared. They were pressed at 8 $tonn/cm^2$ per 1,5 min., so that the

[1] The diffractometer belongs to the Institute of Chemistry of the University of Catania. The spectroscope belongs to the Institute of Astronomy of the University of Catania.

background spectrum was surveyed and compared to the tablet holding the specimen to analyse. This tablet was obtained mixing little quantity of specimen (about 2 mg) with about 600 mg of KBr powder to obtain a tablet whose mass and thickness could be compared to those of only KBr.

According to the results of the applied analyses, the respective diagrams (Fig. 4), per each specimen, were drawn. The results are synthesised on Table 1.

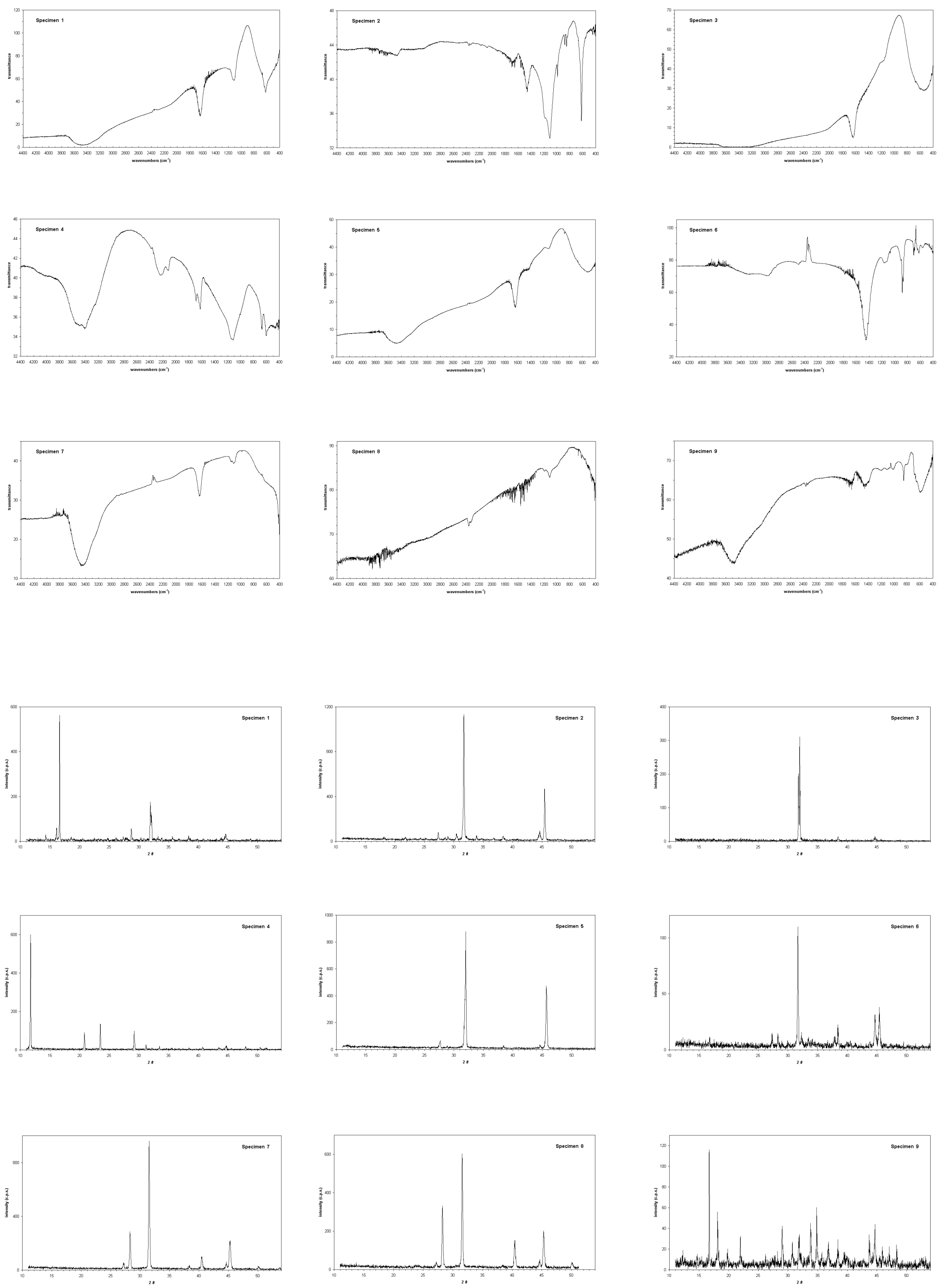


Fig. 4 - IR spectra and specimen diffraction patterns.

	TABLE 1		
SPECIMENS		*IR METHOD*	*XRD METHOD*
Grotta del Fumo	Specimen 1	probably Epsomite ($MgSO_4.7H_2O$)	No recognisable bands.
	Specimen 2	Carbonate mineral (probably unstable $CaCO_3$) + $MgSO_4$.The specimen is anhydrous	Halite
	Specimen 3	Abundance of water and no recognisable bands.	No recognisable bands.
	Specimen 4	Gypsum	Gypsum
	Specimen 5	No visible bands	Halite
S.G.2 tube	Specimen 6	Carbonate mineral + Sulfate mineral (probably of Mg)	Halite + Thenardite
	Specimen 7	No visible bands	Halite + Sylvite
	Specimen 8	No visible bands	Halite + Sylvite
	Specimen 9	No visible bands	Trona

Table 1. Results of the specimen analyses and comparison of the two methods of research.

Analysis results

The results of the analyses have allowed to identify the most widespread kind of lava tube minerals described in literature. Among others, Halite (the most abundant), Gypsum, Sylvite (which is always joined with Halite), Thenardite and Trona (the last two minerals in smaller quantity) were found. There were not found new and rare species. This is probably connected to the late investigation of the above mentioned tubes. They were explored more than a year after the end of the eruption, that is after a rainy season which can have caused the washing away of those concretions (extremely soluble) which were present in the first phases of concretioning, but in small quantity. On the contrary, only the abundant species held out this process.
To confirm this theory, some specimens were drawn in dry areas and others where the percolation of meteoric water was very active. The latter were wet and deliquescent ([2]).
The specimen 3 resulted the richest in water. To identify its mineralogical species, by means of both RX and IR, was impossible. The IR technique was ineffective because the instrument could only survey the IR of wave-length between 4400 and 400 cm^{-1}. In this range the most abundant salts, which were found in the explored tubes, (Halite and Sylvite), were transparent, that is they have not characteristic absorption band. This technique, however, was useful to identify water in minerals and, summarily, to estimate its quantity. This allowed to compare specimen 3 with specimen 2, which, according to the result of RX exam, was made up of NaCI (Fig. 5).
The IR spectrum of specimen 2 (green, Fig. 5) showed the lack of water, which, on the contrary, was abundantly present in specimen 3 (red). In the latter the presence of a wide absorption band in the spectral range between 3700 and 3200 cm^{-1} and a pick at about 1640 cm^{-1} were observable. These bands characterise the water because they are respectively caused by stretching O-H and bending H-O-H.
Afterwards two other specimens were obtained by specimens two and three. One was specimen 3a (black in the figure) which was the result of specimen 3 dried in thermostatic

[2] It is important to consider that the tube located at the highest altitude (about 2150 metres above sea level) is inside an area where, according to the topographical features of land, the snow is present until July.

stove at 40 °C ([3]) for seven days and then dried again, at the same temperature, for one day after the pulverisation. The other was the specimen 2a (blue) which was the result of specimen 2 exposed to wet environment for about four hours. According to the comparison of the two spectra, the compositions of the two specimens seems to be comparable. The absorption of water in specimen 2 modifies the form of the spectrum mainly causing the mixing of the two picks between 900 and 800 cm^{-1} in one pick. At the same time the well-defined pick at 620 cm^{-1} of specimen 2 tend to lose its appearance. On the whole there is an overlap between the spectra of specimen 2a and 3.

Although the specimen 3a was dried, it still kept a large quantity of water. There is an interesting phenomenon to highlight, that is the appearance of a new pick at 1150 cm^{-1} (comparable with those of 2 and 2a). On the spectrum of specimen 3a an anomalous pick appeared at about 2350 cm^{-1}. However it is not relevant because it represents the atmospheric CO_2, which changes for each analysis. This means that the quantity of CO_2 present during the background-spectrum acquisition was different.

To sum up: because of the lack of information resulting from the RX analysis of specimen 3 and according to what is perceptible from the organoleptic characteristic of this specimen, the author supposes that the specimen 3 is mainly made up of water-imbibed Halite.

We should spend some more words about IR spectroscopy before ending the discussion. According to the results of the specimen analyses, IR spectroscopy has not always given definitive answers about the mineralogical species that constitute the concretions.

This is probably due to the kind of instrument which was used for the analysis: a better result is thinkable by means of such models which can operate a spectrum analysis that reaches 45 cm^{-1} (222,2 μm). The diffraction was not more effective to solve the mineralogical data. This is why the author considers IR spectroscopy applied to mineralogical analysis a helpful means when it is associated with the diffraction. This is also why it needs new examinations.

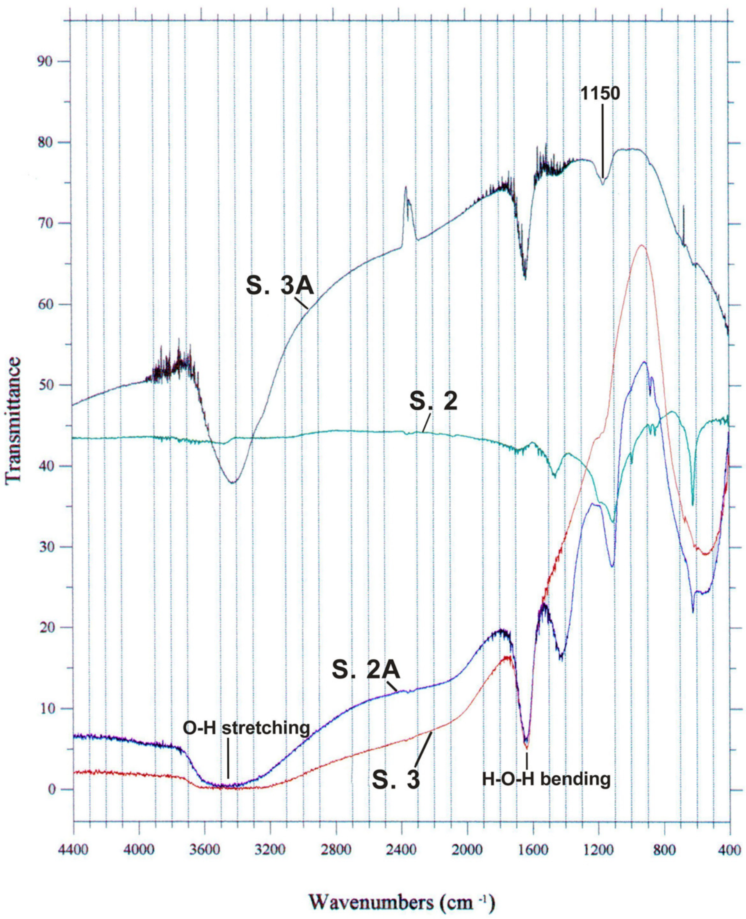


Fig. 5 - IR spectra for the comparison of specimens 2, 3 and of the modified specimens (see text) 2A and 3A.

[3] The temperature was chosen as the compromise between the need to “make ” as much as possible water “evaporate” from the specimen and the necessity not to cause phase transition to the specimen whose composition was still unknown.

Genetic hypotheses

The considerable quantity of concretions is one of the main characteristics of just formed lava tubes.

Because of the relative abundance of chlorides, main features of these concretions, deep contributions of sea water to Etna volcanic structure were considered possible (Forti et al. 1994). The author thinks, on the contrary, that the presence of these salts is linked with the phenomenon of lava degassing, as well as of "pneumatolytic differentiation" processes (Rittman, 1976) or "gaseous transfer" (Fenner), which concerns the magma in volcanic environment and whose effect is the concentration of sublimates, particularly the haloid. In the magmatic system, pressure and temperature are the parameters governing the formation of sublimates. They allow a first separation of gas, as an independent phase of magma and then its transport to surface with precipitation in volcanic areas with fumarole activities.

In our case the process would be concerning with the lava which is coming out of eruptive vents and consequently it would be subject to P and T different from those of magmatic systems. It is possible to suppose that the mechanism of tube salt formation is connected to the degassing of those gases which are still in the lava, that is those gases which cause the formation of "fumarole without roots"([4]). The quantity of gas which is present in this lava is decreased by the large loss in vent areas (Swanson and Fabbi, 1973; Peterson and Swanson, 1974). Probably their composition is largely depleted of volatile elements. However, these are still able to aid the displacement of some solid phases, which, because of adhesion to gases, make a system less dense than the liquid in which they are dipped. This causes the coming out of gas bubbles from the vesicle formation phase to the last fumarole manifestations in the last phases of cooling. There is a P and T variation in gas bubbles when they reach the interface lava/air during their journey from inside lava to outside. Because of the fact that generally the reactions of formations of metal halogen compounds are endothermic, the elements moved by gas are handed over.

This process causes a lava "leaching" resulting in the concentration of minerals on the surface and, consequently, in their accumulation. This mechanism continuously acts inside lava tube aiding the deposition of minute minerals in the fissures, in the vesicles of the vault and of the tube walls. It also acts in the whole environment where gas interacts with the outside.

The hot gaseous mass, which takes with itself all the chemical components of the potential minerals, is defined "mineralising convoy" (Gottardi, 1978). In it (that is aerosol) the elements which later create the tube minerals either by direct precipitation or by alteration phenomena in water or air can be found. For example, the presence of S (surveyed inside Grotta Cutrona by Forti et al., 1994) is linked to air exposure of sulphydric acid in watery solution because the air oxygen oxidizes it at S.

Another example of metals kept in the gaseous phase as haloid (particularly as chlorides) is:

$$\underset{\text{(gas)}}{2FeCl_3} + H_2O \leftrightarrow \underset{\text{(hematite)}}{Fe_2O_3} + 6HCl$$

According to the common chemism of Etna lava, example of molecules that take part to the crystallization and of those that migrate to the gas coming out trough fumaroles are:

$$\underset{\text{Ab}}{2NaAlSi_3O_8} + \underset{\text{Di}}{CaMgSi_2O_6} + \underset{\text{Ol}}{5Mg_2SiO_4} + \underset{\text{gas}}{2HCl} \leftrightarrow \underset{\text{An}}{CaAl_2Si_2O_8} + \underset{\text{En}}{11MgSiO_3} + \underset{\text{gas}}{2NaCl} + H_2O$$

[4] They are generally polluted by the "resurgent gas". This is the name which characterises the gas resulting from organic substances and /or soil which are covered by lava flow. The case of 1991-93 eruption is different. In fact it is inside Valle del Bove where it covered the lava fields of previous eruptions; in the high Valle del Bove, particularly, there was not vegetation or thick soil.

or

$$\underset{Ab}{2NaAlSiO_8} + \underset{Di}{CaMgSi_2O_6} + \underset{Gas}{HCl} \leftrightarrow \underset{An}{CaAl_2Si_2O_8} + \underset{En}{MgSiO_3} + \underset{Qz}{5SiO_2} + 2NaCl + \underset{Gas}{H_2O}$$

the equilibrium of such reactions moves towards the right side when the pressure decreases with consequent escape of gas.
Now we can identify four phases, which turn the minerals that are produced by the pneumatolytic concentration into tube concretions:
1. the minerals, because of lava degassing during the cooling, are deposited on every side of lava. The salts resulting from this operation accumulate in minute crystals in the cavities, in the fissure and on the surface of the just formed lava. They could be modified by the exposure to air and humidity;
2. when the temperature decreases under 100°C, letting the circulation of water as liquid phase, the previously produced salts are mobilised by the meteoric water and moved to the internal part of the cavity trough many fissures which are present in the lava tunnel;
3. afterwards there is one more elaboration by pseudo-Karst processes, which start inside the cavity. They cause the precipitation with the same mechanism acting in the caves which are really Karst. They form different typologies of speleothems;
4. later the deposition can take place inside the tube by direct precipitation, that is by aerosol coming out from the fissures of the cavity and from those parts of lava flow which still have a high temperature. This does not imply the passage by the phase of solubilization in meteoric water. In this case, because of strong air current (aerosol current), the deposits can create some weak filiform concretions. They grow over old concretions, which were formed following the mechanism discussed at point 3.

Conclusion

Lava tube concretions, which are formed in the first phases of cavity cooling, hold out for little time after their formation. Because of their being soluble and metastable, they hardly leave traces of their past existence. They are immediately washed away by the meteoric water which acts in the tube. The result is, by contrast with the imposing phenomenon, a poor scientific production about the genesis of first-formation concretions.
Our research has allowed locating salts, whose presence inside Cutrona tube and other tubes had already been recorded. In fact no new mineralogical species was found. We can deduce that the chlorides are those minerals which are largely formed.
The relative poverty in mineral species, compared with the relative abundance of the phenomenon, is linked with the late exploration of new tubes, which had already been subject to the seasonal rains. The only preserved species were those which were present in larger quantity.
The possible genesis of the various mineralogical species is linked with the pneumatolytic differentiation which lead to the concentration and, consequently, to the accumulation of pneumatophil elements, particularly haloids.
A progressive impoverishment of the mineralising convoy when the distance from the vents increases could determine a variation in the chemism of the concretions which are located at different distances from the effusive vents. This is only a hypothesis, because according to our date it is impossible to get such kind of conclusions. Of course a future geochemical analysis of the gases coming out from the fissures of lava flows is necessary. The sampling should concern the whole length and should be periodic, so that the necessary comparisons can be made.
An analysis of lava flow chemism is also necessary to determine the schematic equations of the reaction taking place between lava and liberated gas. It is also useful to compare these results with those concerning other tubes.

Acknowledgements

I am very grateful to Prof. G. Strazzulla for the suggestions and the loan of the instruments, which are of the Institute of Astronomy, and to Dr. N. Gulino for the instruments of the Institute of Chemistry. My special thanks also to Dr. G.Cimino for having collaborated in the analysis, for the suggestions and for the critical reading of this paper.

Bibliography

- FORTI P., GIUDICE G., MARINO A., ROSSI A. - *La Grotta Cutrona (MC1) e le sue concrezioni metastabili*; Atti del II Convegno Regionale Siciliano di Speleologia - Area della Ricerca di Catania CNR - Catania 1994.
- GOTTARDI G. - *I Minerali* - Boringhieri - 1978.
- LICITRA G. M. - *Ipotesi dinamica sulla formazione delle gallerie di scorrimento lavico* - Atti IV Symposium Internazionale di Vulcanospeleologia - Catania 1983.
- PETERSON D. W. AND SWANSON D. A. - *Observed formation of lava tubes, during 1970-71 at Kilauea Volcano, Hawaii*. - Studies in speleology - William Pengelly Cave Studies Trust Ltd., London. 1974, vol. 2, part. 6, 209-222. Atti Seminario sulle grotte laviche. Catania 1974.
- RITTMANN A. - *I Vulcani e la loro attività* - Cappelli Editore - 1972.
- SWANSON D. A. E FABBI B. P. - *Loss of volatiles during fountaining and flowage of basaltic lava at Kilauea Volcano*, Hawaii. J. Res. U.S. Geol. Surv.,1; 649-658.

ON SOME VOLCANIC CAVES OF SARDINIA (ITALY)

Jo De Waele and Alberto Muntoni

Dipartimento di Scienze della Terra dell'Università di Cagliari, Via Trentino 51, 09127 CAGLIARI e-mail: geoam@unica.it

Abstract

Volcanic Tertiary activity in Sardinia has started in the South about 60 Ma ago, but the most important volcanic period goes from 32 Ma to 13 Ma, and is related to the Oligo-Miocene rifting of the Sardinian-Corsican microplate. From 13 Ma to about 5,5 Ma no important volcanic events occur, but due to the opening of the Southern Thyrrenian Sea, a new volcanic cycle starts (5,5-0,1 Ma), with the formation of the so-called "Giare", basaltic highflats, and of the Campidano Graben.
On the island are known almost 100 volcanic caves, mostly of secondary origin, but some of these are of reogenetic and pneumatogenetic origin.
In this article the Authors present the most interesting lava caves of Sardinia. Some of these caves, because of their primary origin and of their rarity, represent one of the less known speleological particularities of the island, and therefore these should be appropriately protected.

Introduction

In these last years the volcanic tertiary complex in Sardinia has been studied in detail, with the determination of the absolute ages, the palaeomagnetism, the petrographic stratigraphy, but nevertheless the strictly volcanogenic aspects of the different rocks have never been thoroughly taken in consideration; the aim of this work is to put in evidence the existence of primary volcanic caves in Sardinia, describing their morphology and explaining their formation.
In Sardinia non-carbonatic caves aren't easy to encounter; many caves develop in volcanic rocks, most of which have an exogenic and secondary origin (eolic, fluvial, tectonic, etc.). There are some rare examples of rheogenetic volcanic caves that present singular characteristics. The most interesting of all these caves in volcanic rocks of Sardinia will be described.

Tertiary volcanism in Sardinia

The first tertiary volcanic activity in Sardinia occurs in the Sulcis area; in this region can be found alkaline volcanic rocks, appearing as *sills*, interposed by sediments of the Upper-Palaeocene to Under-Eocene (ASSORGIA et al., 1992). The age of these volcanic rocks is determined between 62.1 and 60.2 Ma (MACCIONI et al., 1990). Probably this volcanic activity is related to the laramic-pyrrennean tectonic cycle, that manifested itself in Sardinia only during the early phases (BARCA et al., 1997).
Later on, beginning from 32 Ma, Sardinia has been interested by important geodynamic and tectonic events, responsible for the opening of the North-Western Mediterranean and connected to the drifting of the Sardinian-Corsican microplate; due to these phenomena starts a new volcanic cycle of prevalently calc-alkaline character that has been related to the subduction of oceanic lithosphere underneath the Sardinian-Corsican microplate (COULON, 1977; BECCALUVA et al., 1987).
In Sardinia the geodynamic trend of this movement is characterised both by distensive and compressive tectonic phases and therefore, the volcanic products related to these cycles are alternatively basic and acid.

Recently LECCA et al. (1997) have proposed a stratigraphy that isn't based on the distinction between different volcanic events, but on the chronology of all the volcanic products in general, without distinguishing sequences.
ASSORGIA et al. (1997) instead, classify these volcanic rocks in four series that outcrop in particular in Northern Sardinia, but nevertheless also in different localities in Southern Sardinia.
Today most Authors collect these volcanic terms in four different sequences that represent a cyclic character for what concerns chemistry; from the oldest to the most recent we have:
LOWER BASIC LAVA SEQUENCE (LBLS): outcrops in Central-West and South Sardinia, and is characterised by lava with an intermediate to basic chemistry, related to a Peléan volcanic activity. These rocks generally present a dome structure at which are associated often pyroclastic sediments. The K/Ar age of this sequence varies from 32 to 23 Ma.
LOWER ACID EXPLOSIVE SEQUENCE (LAES): in this sequence converge all lithologies with acid-intermediate chemistry that overlie in concordance the earlier described volcanic rocks. The sequence is characterised by lava flows, pyroclastites and high grade temperature ignimbrites. The K/Ar age is given between 23 and 20 Ma. This sequence outcrops in several parts of Central-Sardinia.
UPPER BASIC LAVA SEQUENCE (UBLS): outcrops prevalently in West-, Central- and South-Sardinia. These volcanic rocks are composed of andesites and basalts that have been deposited by means of lava flows and pyroclastic sediments, both subaqueous and subaerial, or as lava domes and associated explosive phreatic-magmatic products. Their K/Ar age goes from 19 to 16 Ma.
UPPER ACID EXPLOSIVE SEQUENCE (UAES): this sequence is characterised by ignimbritic, pyroclastic and lava-like rocks. These products are riolitic and dacitic (with rare episodes of pyroclastic sedimentation with Sanidine), sometimes commenditic (Sulcis), and represent the last eruptive activities related to the calc-alkaline Sardinian volcanic cycle. Their K/Ar age varies between 17 and 13 Ma.
With the end of the calc-alkaline cycle, about 13 Ma ago, a long volcano-tectonic quiescence reigns over Sardinia. Only about 5,5 Ma ago a new volcanic cycle of alkaline type starts, and goes on with various grades of intensity up until 0,2-0,1 Ma ago (BECCALUVA et al., 1985). This volcanic cycle has been ascribed to the opening of the Southern Thyrrennian Sea, related to a large scale expansive geodynamic context (BECCALUVA et al., 1977), that has also caused the formation of the Campidano Graben in East Sardinia (PECORINI et al., 1969) and the great volcanic table-like mountains, locally known as "Giare", in Central Sardinia.
The most abundant products of this cycle are alkaline and sub-alkaline basalts that outcrop in a rather discontinuous way in several parts of the Island (mostly in Central and Northern Sardinia). Besides these basalts sometimes more evolved types of volcanic rocks can be found, such as phonolites (in the Montiferro volcanic complex, West-Sardinia), rhyolites, dacites and trachytes (at Monte Arci and Monte Fortuna in Central-West-Sardinia) and latites and trachytes (at Capo Ferrato, East-Sardinia) (BROTZU et al., 1975).
Most of these volcanic rocks although represent lava flows that often form great tabular mountains (ASSORGIA et al., 1983).
The most important volcanic rocks for what concerns this work are the basalts, because these represent the main characteristics for the formation of syngenetic volcanic caves at the end of the eruption.

Caves in the volcanic rocks of the calc-alkaline cycle (Oligocene-lower-middle-Miocene)

As has been explained in the previous chapter this volcanic cycle is characterised by both basic and acid rocks. Only little caves have been found in the basic volcanic rocks, while in the acid-intermediate lava's are known several interesting caves, most of which of secondary origin and created by wind or water erosion.

These pyroclastic rocks, mostly characterised by scarcely consolidated ignimbrites, present various erosional cavities especially in Central-Sardinia, but also in the SW (Monte Su Crobu, Carbonia, Sulcis), or great fractures successively eroded by the wave motion (Capo Marargiu-Bosa, Island of San Pietro). Some of these caves, as for example the Cave of the Pelicans (Bosa), show a significant development and are well decorated by limestone concretions, due to a Miocene limestone cover upon the volcanic rocks (PIRAS et al., 1995).
The great wind-erosion caves of Central-Sardinia are normally used by the shepherds and can also represent great archaeological interest. At Montresta, Villaperuccio and Bonorva are documented vast underground settlements or necropolis formed by both natural and artificial caves in rhyolites, ignimbrites and other fragile volcanic rocks.

Caves in the volcanic rocks of the alkaline cycle (Pliocene-Pleistocene).

Volcanic rocks of the alkaline cycle outcrop in many parts of Sardinia, even though little caves are known from these rocks, probably due to a lack of speleological exploration.
Although these lavas are very abundant, only some types of these rocks are suitable for the formation of volcanic caves, depending on temperature and viscosity. For what concerns the Island especially basalts are likely to have the right characteristics for the formation of lava tubes. Basalts in fact, have a high fluidity and are likely to flow for several miles, causing the formation of tunnels that can be explored once the eruption ends.
In general the primary lava caves that will be described in this work are of two types: lava tubes or rheogenetic caves and bubble or pneumatogenic caves (CONDARELLI D., 1972; RITTMANN A., 1975).
The first are formed when, during the flowing of the lava, the external parts solidify, forming first lava channels, then lava tunnels, that stay active until the alimentation stops.
The latter have a much more simple formation when the gases, that come out of the liquid lava, are trapped underneath a semi-solid peel of lava, creating a spherical chamber.
The volcanic caves of the Island are not very important from a speleological point of view, being characterised by small developments and lacking of concretioning.
In what follows we have described the most important of these volcanic caves, separated on a geographical scale.

Short description of the caves in volcanic rocks

In what follows are described some of the most interesting primary and secondary volcanic caves of Sardinia. Along with the name of the cave, between brackets is given the official register number followed by two letters that stay for the region (SA=Sardinia) and two for the province (SS=Sassari, CA=Cagliari, NU=Nuoro or OR=Oristano). These numbers refer to Fig.1 in which are represented the volcanic outcroppings in Sardinia and the location of the caves described in this work.
Close to Torralba, on the homonymous mountain, exists the "Grotta di Monte Oe" (57 SA/SS), formed by wind erosion in trachy-andesites of the calc-alkaline volcanic cycle. This subcircular room of about 15 meters in diameter, is used by the local shepherds (BARTOLO G. et al., 1994).
At Cossoine a little cave called "Ucca de su Vicariu" (1414 SA/SS) is formed on some fractures in calc-alkaline volcanic rocks (BARTOLO G. & FADDA A.F., 1998). In the same area are known other secondary volcanic caves, signed on the geographic maps.
Near Montresta (SS), in the trachy-andesites of the calc-alkaline volcanic cycle, has been reported the little cave named "S'istampu de Pippetto" (1412 SA/SS) (MELE E., 1997), composed of an 8 meter pitch that ends in a subcircular room. The genesis of this cave is due to water erosion along some small fractures close to the entrance.

In the territory of Villanova Monteleone is known the cave called "Pentuma de Pala Umbrosa" (574 SA/SS), that is formed on a fracture in Miocene trachy-andesites (MELONI A., 1985). Reaching a development of about 40 meters, the cave has a pure tectonic origin, and is inhabited by a colony of bats.
More to the South, in the region of Cuglieri, Scano Montiferro, Magomadas, Mogoro, Sennariolo, Bosa etc. are known the most interesting lava caves of Sardinia: these caves are "Sutterru de Murada" (163 SA/OR), "Monte Santu" (206 SA/OR), "Cappas" (2 caves: 181 and 1933 SA/OR), "s'Istampu de Ziu Nanni" (224 SA/NU), "Ispelunca de Nonna" (226 SA/OR), "Coro Malzu" (2 caves: 255-256 SA/OR), "Terra di San Giovanni" (1939 SA/NU), "Motzo" (2 caves 1940-1941 SA/NU) and "Baraggiones" (1942 SA/OR) (FURREDDU P.A. & MAXIA C., 1964; MELONI A., 1986; SPELEO CLUB DI CAGLIARI, 1986).
Most of these caves are formed in the basalts and the phonolites of the Montiferro volcanic complex. "Sutterru de Murada" (163 SA/OR) is a lava tunnel of 40 meters length revealing clear lava flow features, ropy lava and two entrances. More interesting is the "Cappas 1" cave (181 SA/OR), with its length of about 120 meters the longest primary lava tunnel cave of the Island. It has an entrance due to collapsing of the roof, and develops in two directions (FURREDDU P.A. & MAXIA C., 1964). The vertical cave "s'Istampu de Ziu Nanni" (224 SA/NU) is formed on some fractures near the vertical wall of a basaltic flow (MELONI A., 1985) while "Ispelunca de Nonna" (226 SA/OR) is the relic of a gas bubble, which roof has collapsed (SPELEO CLUB DI CAGLIARI, 1986). The caves "Baraggiones" 1942 SA/OR) and "Voragine di Coro Malzu" (256 SA/OR) instead are formed on great vertical faults and develop in horizontal for 50 meters. The first cave is interesting for the presence of a bat colony. Of secondary origin is the "Monte Santu cave" (206 SA/OR), formed by water erosion in ignimbrites and almost 100 meters in development (FURREDDU P.A. & MAXIA C., 1964).
Of marine erosion origin are the numerous caves along the Capo Marargiu coast (Bosa). The most interesting of these is the Cave of the Pelicans (1270 SA/NU), composed of two distinct branches both formed on faults. The total development reaches 160 meters, partly submerged, and in the dry branch are present several calcareous concretions and a bat colony (PIRAS V. & PANI D., 1995). Close to the Corona Niedda island, in the context of a submerged caldera, is known another submarine lava cave, probably the relic of an ancient lava tunnel (PIRAS V., 1995, personal communication).
Near the villages of Nurri and Orroli, above Palaeozoic sediments, Jurassic and Miocene limestones, outcrops a vast basaltic plain with several lava caves: "Su Fossu Corroga" (761 SA/NU) (BARTOLO G. et al., 1995), "Baraci" (3 caves: 1947-1949 SA/NU), "Rutta de Su Cannoni" (2002 SA/NU), and "Gurti Acqua" (2 caves: 2009 SA/NU and 2027 SA/NU) (SPELEO CLUB DI CAGLIARI, 1986). The first is characterised by a little pitch and a 20 meter wide chamber, developed on the contact between the basal lava conglomerate and the lava flow. The genesis of this cave is due to water erosion of the basal clayey volcanic breccia and the subsequent collapse of the roof. From a cave dwelling fauna point of view the presence of an important bat colony has enhanced the development of a rich animal population (Pseudoscorpiones, Diplura, Speleomantes, etc.). The "Baraci" and "Cannoni" caves are small shelters of secondary origin (wind and water erosion) while the "Gurti Acqua" caves are the relic of a single lava tunnel with clear lava flow features. In both caves, distant one from another about 10 meters, have been noticed ropy lava and gas bubble prints.
In the basaltic outcrops near Orroli have been reported several caves: "S'Inginnu" (4 caves: 561-563 and 565 SA/NU) (GRUPPO GROTTE CAI CAGLIARI, 1982; BARTOLO G. & FADDA A.F., 1998). Even though all of these are relatively small in size, they are interesting for the presence of ropy lava, columnar jointing on the outside wall above the caves, the basal lava conglomerate and several lava flow features. Furthermore in many of these shelters have been found remains of pottery of 4000 years ago.

Of great archaeological interest is the cave called " Caombus" (1654 SA/OR) near Morgongiori, formed on an open fracture in the basalts of Monte Arci (LECIS A. & MUZZETTO G., 1989). In this tectonic cave, with a development of almost 200 meters, has been discovered a so-called "sacre-pit", for the devotion of water, together with the ancient stairs, dated about 4000 years ago. Not far away from "Caombus" is reported another tectonic lava cave, "Is Benas" (291 SA/OR), of no particular interest (FURREDDU P.A., MAXIA C., 1964).
In the Sulcis area, close to the city of Carbonia, many caves are known in the Monte Crobu rhyolitic mount. All of these are mainly formed by wind erosion and hydrolysis of the silicates along the fractures, and some reach developments of several tenths of meters. These caves have been used in ancient times as burial places or as shelters.
One of the most interesting volcanic areas in Sardinia for what concerns caving is the San Pietro Isle and the nearby Sant'Antioco Isle, composed of Miocene volcanic rocks (commendites and liparites) of the calc-alkaline cycle. CAPPA G. (1974) describes as much as 70 caves on San Pietro Island, mostly of marine and structural origin, some of which have a development of almost 70 meters. Among the marine caves can be remembered these called "del Bue Marino" (14 SA/CA), "Marine" (54 SA/CA), "delle Oche" (67 SA/CA), "Enea" (1844 SA/CA), "Sa Xitta" (1845 SA/CA), "Punta delle Colonne" (3 caves: 1846-1847-1848 SA/CA), "delle Colonne" (2 caves: 1849-1850 SA/CA), "Geniò" (2 caves: 2094-2095 SA/CA)). Formed by wind erosion in the commendites are the caves "Commende" (29 SA/CA) and of "Bricco Patella" (not classified) (CAPPA G., 1974; BARTOLO G. & FADDA A.F., 1998).
On the island of Sant'Antioco only two volcanic caves, both of wind erosion origin and with less than 10 meters of development, are known: "Luttoni Biancu" (2079 SA/CA) and "Gruttiacqua" (2080 SA/CA) (SPELEO CLUB DI CAGLIARI, 1986).
In East Sardinia, nearby the village of Barisardo, has been explored one of the longest secondary lava caves of the Island, "Sa Ucca ‘e Su Vulcanu" (1283 SA/NU), with its 132 meters of length. This cave, developed close to the border of the Pliocene-Pleistocene basaltic high plain locally known as "Teccu", is formed on several orthogonal faults that opened in recent times (BARTOLO G. & ZANDA G., 1995).
To end this long list of caves in volcanic rocks, it is interesting to mention some caves known by local people to be the "mouth of volcanoes": the great shafts of "Golgo" (63 SA/NU) and "Genna s'Armentu" (421 SA/NU) at Baunei, and the "Ucca de Mammuscone" at Cossoine (180 SA/SS). The speleological exploration of these caves, that have their entrances in basaltic rocks, has immediately shown their karstic origin, being formed by inverse erosion of the underlying limestones (respectively Jurassic and Miocene in age) and the subsequent collapse of the basaltic cover (FURREDDU P.A., MAXIA C., 1964; DE WAELE J. et al., 1995; MUCEDDA M., 1985).

References

- ASSORGIA A., MACCIONI L., MACCIOTTA G., 1983, *Carta geopetrografica del vulcanismo pliocenico della Sardegna centro-meridionale*; S.E.L.C.A. editor, Firenze; *1:50.000.*
- ASSORGIA A., FADDA A., GIMENO A., TORRENTE V., OTTELLI L., SECCHI F. A., 1992, *Le successioni ignimbritiche terziarie del Sulcis (Sardegna Sud-Occidentale);* Mem. Soc. Geol. It., Roma; # 45, pp. 951-963.
- ASSORGIA A., BARCA S., SPANO C., 1997, *A synthesis on the Caenozoic stratigraphic, tectonic and volcanic evolution in Sardinia (Italy)*; Boll. Soc. Geol. It., Roma; # 116, pp. 416-420.
- BARCA S. & COSTAMAGNA G. L., 1997, *Compressive “Alpine” tectonics in western Sardinia: Geodynamic consequences*; C. R. Acad. Sci. Paris; # 325, pp. 791-797.
- BARTOLO G., FADDA A.F., 1998, *Sardegna il mondo sotterraneo*; Coedisar editor, Elmas; 300 p.

- BARTOLO G., RATTU M., ZANDA G., 1994, *Ulteriori grotte per il Catasto*; Speleologia, Milano; # 30, pp. 118-119.
- BARTOLO G., ZANDA G., 1995, *Sa Ucca de Su Vulcanu*; Speleotranxsfer, Milano; # 1, p.3.
- BARTOLO G., ZANDA M., RATTU M., 1995, *Su Fossu 'e Corroga*; Speleologia, Milano; # 33, p.91.
- CAPPA G., 1974, *Nota informativa sulle cavità nell'Isola di S.Pietro (Sardegna)*; Rassegna Speleologica Italiana, Milano; # 11(1), pp. 73-76.
- BECCALUVA L., DERIU M., MACCIOTTA G. SAVELLI C., VENTURELLI G., 1977, *Geochronology and magmatic character of the Pliocene-Pleistocene volcanism in Sardinia (Italy)*; Bull. Volcanol.; # 40, pp. 1-16.
- BECCALUVA L., CIVETTA L., MACCIOTTA G., RICCI C. A., 1985, *Geochronology in Sardinia: results and problems*; Rend. Soc. It. Min. Petr.; # 40, pp. 57-72.
- BROTZU P., FERRINI V., MORBIDELLI L., TRAVERSA G., 1975, *Il distretto vulcanico di Capo Ferrato (Sardegna sud-occidentale)*; Rend. Sem. Fac. Sc. Univ., Cagliari; # 45(3-4), pp. 119-144.
- CONDARELLI D., 1972, *Le grotte vulcaniche, loro genesi e morfologia*; Rassegna Speleologica Italiana, Como; # 11(2), pp. 29-31.
- COULON C., 1977, *Le volcanisme calco-alcalin cenozoique de Sardaigne (Italie). Petrographie; Geochimie et Génèse des laves andésitiques et des ignimbrites-signification geodinamique*; Thèse Doct. 3 Cycle Univ. Aix-Marseille III; 288 pp.
- DE WAELE J., GRAFITTI G., LOCCI C., PISANO M., SPIGA R., 1995, *Attuali conoscenze speleologiche nel Supramonte di Baunei*; Monografia di Anthéo, Cagliari; # 4, 88 p.
- FURREDDU P.A., MAXIA C., 1964, *Grotte della Sardegna*; Fossataro editor, Cagliari; 310p.
- GRUPPO GROTTE CAI CAGLIARI, 1982, *Su Cannoni de Pardu S'inginnu - Grotta Genniau*; Speleologia Sarda, Cagliari; # 42, pp. 11-15.
- LECCA L., LORIS R., LUXORO S., MELIS E., SECCHI F., BROTZU P., 1997, *Oligo-Miocene volcanic sequences and rifting stages in Sardinia: a review*; Per. Min.; # 66(7), pp. 7-61.
- LECIS A., MUZZETTO G., 1989, *Sa Grutta de Is Caombus*; Speleologia Sarda, Cagliari; # 69, pp.19-22.
- MACCIONI L., MARCHI M., SALVADORI A., 1990, *Eocene alkaline lamprophyre in south-western Sardinia (Italy)(new occurrence).* Rend. Sem. Fac. Sc. Univ. Cagliari; # 60, pp. 217-231.
- MELE E.,1997, *S'Istampu 'e Pippetto*; Speleomantes, Sassari; # 0, pp. 45-46.
- MELONI A., 1985, *Sa Pentuma de Sa Pala Umbrosa*; Speleologia Sarda, Cagliari; # 53, pp. 6-7.
- MELONI A., 1986, *S'Istampu 'e ziu Nanni*; Speleologia Sarda, Cagliari: # 59, pp. 25-26.
- MUCEDDA M., 1985, *La grotta Sa Ucca 'e Mammuscone di Cossoine*; Bollettino del Gruppo Speleologico Sassarese, Sassari; # 9, pp. 38-44.
- PECORINI G., POMESANO CHERCHI A., 1969, *Ricerche geologiche e biostratigrafiche sul Campidano meridionale (Sardegna).* Mem. Soc. Geol. It.; # 8, pp. 421-451.
- PIRAS V., PANI D., 1995, *Le grotte marine di Capo Marargiu*; Sardegna Speleologica; # 8, pp. 15-22.
- RITTMANN A., 1975, *La formazione delle grotte vulcaniche*; Atti del Seminario sulle Grotte Laviche, Catania, 1977; pp. 87-100.
- SPELEO CLUB DI CAGLIARI, 1986, *20 anni nelle grotte della Sardegna*; Guido Bartolo editor, Cagliari; 239 p.

THE BASALTIC CANYONS OF MOUNT ETNA

Paolo Madonia and Adelina Palmeri

Al Qantara, Via A. Di Giovanni 14, 90100 Palermo, e-mail: alqantara@europe.com

Abstract

Present work deals with the description of the two basaltic canyons of Alcantara river and Simeto river, respectively located NE and W the Mount Etna Volcano.
The authors describe the main hydrological, geological, morphological and naturalistic features of the canyons; a final section is specifically dedicated to water pollution and environmental protection problems.
The discussion of the above mentioned themes highlights two important conclusions:
1. The morphology of the Simeto canyon is very similar to other karst canyons of Sicily (Pollina river or Faguara creek, in the Madonie Mounts);
2. Water pollution of Simeto rivers is very dramatic and absolutely incompatible with the presence of two natural reserves that theoretically should protect this area

Introduction

The Mount Etna Volcano is borded, eastward and westward, by two of the main rivers of Sicily, respectively the Alcantara and the Simeto rivers that, eroding the quaternary lava flows encountered along their courses, have generated two of the most important canyons of the island (see Fig.1).
These two features are of great naturalistic interest, so they have been protected by sicilian governments by the institution of two natural reserves.
In particular, as it happens in other karst areas, where canyons and caves constitute unique natural systems which development is driven by strictly related geomorphological processes, the Mount Etna Volcano represents a very complex pseudokarst system, where underground and surface features sometimes present peculiarities due to their lithological origin, but in other cases they show a strong morphological convergence with limestone karst morphologies.
Despite their importance, the scientific knowledge of these areas is very poor and one of these, the Simeto river canyon, presents a lot of environmental problems due to water pollution and illegal solid material discharge.
The aim of the present work is to contribute to the general scientific knowledge of these two environmental systems, discussing their hydrological and geological-geomorphological characteristics and focusing the attention over the environmental preservations problems.

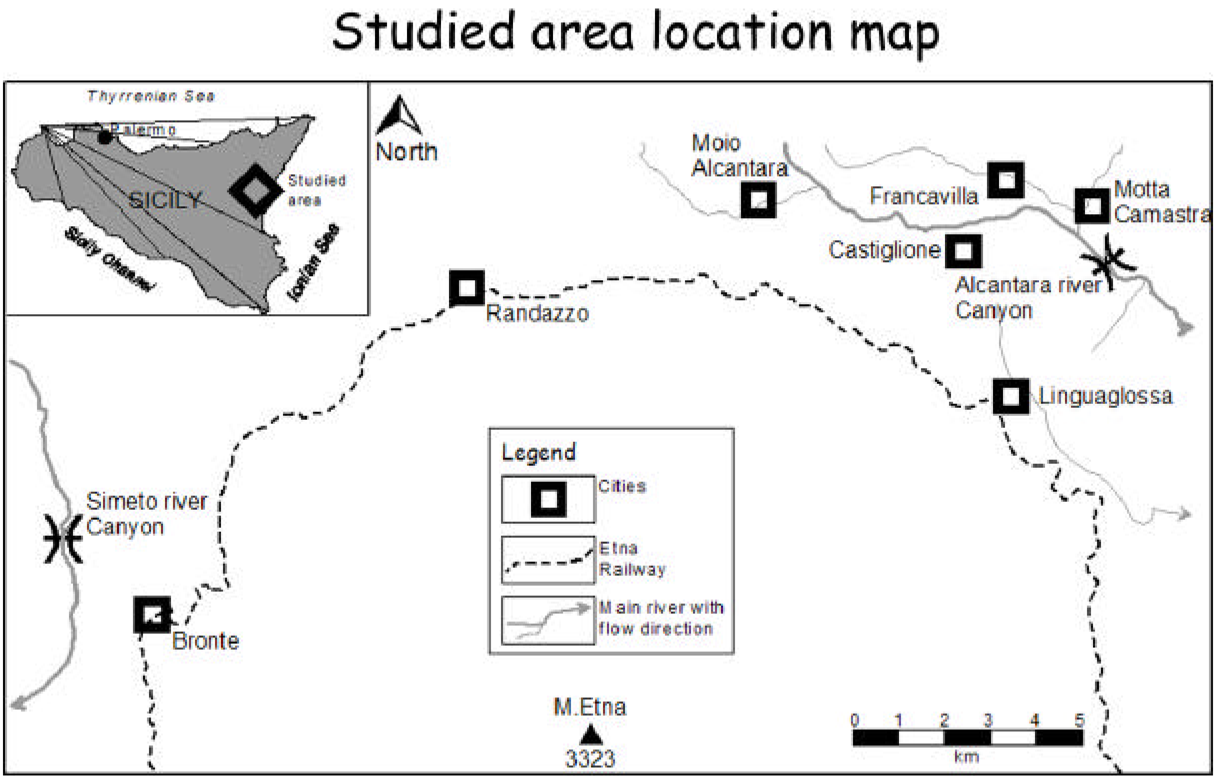


Fig. 1 - Studied area location map.

Hydrology of Alcantara and Simeto rivers

Figures 2 and 3 shows respectively the main climatic and hydrological parameters of the studied areas, acquired in the nearest available station of the ITALIAN HYDROGRAPHIC SERVICE (1986-1994).

The yearly average distributions of rainfall amounts and temperatures are in tune with the general climatic asset of Sicily: a Mediterranean climate with a mild rainy winter season and a dry hot summer.

The effective rainfall amount, with this term defining the difference between rainfall and evapotranspiration amounts, is very low, or equal to zero, during the entire summer and part of spring and autumn. The above mentioned figures shows the average monthly values for the two rivers; evapotranspiration has been calculated using the HARGREAVES (1994) formula.

From April to September evapotranspiration losses exceed rainfall amounts, so there is no water to supply surface discharge. This theoretical situation is confirmed by the monthly values of Alcantara river flow rates (no measuring stations along the Simeto river), that shows a one month shift respect to the corresponding values of precipitation. This shift is probably due to the underground waters that are also responsible, with the anthropogenic contributions (sewer effluents), of the minimum flow rate (less then 1 m^3/s) registered during August; in the same period the Simeto river presents a discharge of two magnitude orders less only in exceptional rainy years; in a normal hydrologic year its bed is completely dry. This different hydrological summer regime is due either to the hydrogeological asset of Mount Etna Volcano, which impermeable sedimentary basements dips eastward and drives underground waters toward the Alcantara river, either to anthropogenic causes, as better discussed in the environmental paragraph.

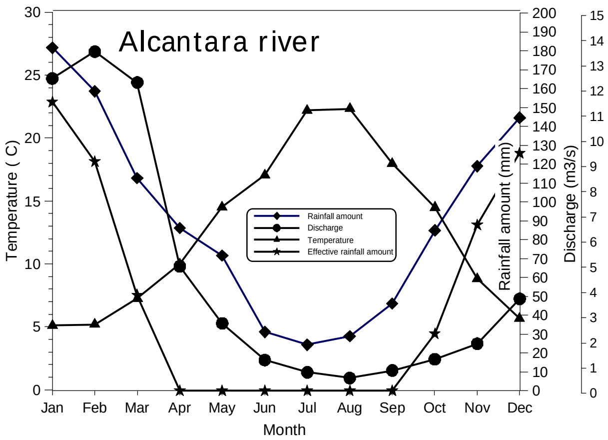


Fig. 2 - Hydrological parameters of Alcantara river (average values for the period 1986-1994).

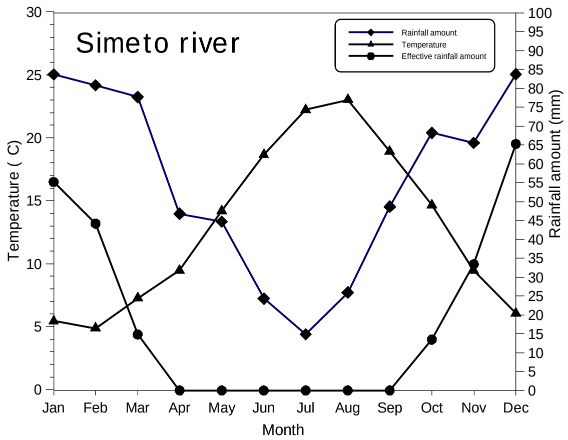


Fig. 3 - Hydrological parameters of Simeto river (average values for the period 1986-1994)

Geological and geomorphological asset of Alcantara and Simeto canyons

The geological context of the two studied canyons is showed in the figures 4 and 5, completed by the longitudinal sections presented in Fig. 6.
Both the canyons have been eroded into the Quaternary alkali basalts of the Mongibello volcanic complex (ROMANO et al., 1983): the Alcantara canyon in the Holocenic lavas (recent Mongibello), the Simeto canyon in the Pleistocenic ones (ancient Mongibello).
In both cases we can define the two features as “antecedent canyons”, because the flow direction of the rivers doesn’t vary during the crossing of the canyons themselves.
The longitudinal profiles of the two canyons are not very similar, reflecting the different mechanical properties of the lava outcroppings where they have been eroded.
The Alcantara canyon presents a series of little waterfalls, with an height no higher then 2/3 m, regularly distributed along its entire development. On the contrary, in the Simeto canyon we can found a main waterfall 8 m high just at its entrance; the longitudinal profile is then horizontal, interrupted by two minor waterfalls respectively 1 and 5 m high.
These differences are probably due to the characteristic columnar fracturing, founded in the holocenic lavas and only in a very reduced form in the ancient ones. Despite of their younger geological ages erosion rate, driven by the columnar fracturing, is faster and more homogeneous in the first ones. This is confirmed also in the Simeto canyon, where at the passage from the pleistocenic to the holocenic lavas, just at the end of the canyon itself, we assist to a sudden increase in the river bed width.
Columnar fracturing is also responsible of the semblance of the rockwalls that confine the river inside a basaltic canyon: where fracturing is present and well developed the rockwall surface is articulated in a multitude of minor surfaces with various aspects and slopes, corresponding with the faces of the polyedra formed by the fracturing system. When the columnar fracturing is absent or poorly developed, the lava outcropping is more resistant to fluvial erosion, waterfalls are generated only in correspondence of the hardest portion and the canyon rockwalls are polished in the same way we can find in a morphology developed in other lithologies like limestones, sandstones, etc.
In other words, due to the presence of a common morphogenetic agent, that is the fluvial erosion, we observe in this case a very evident morphological convergence with features formed in different lithologies.

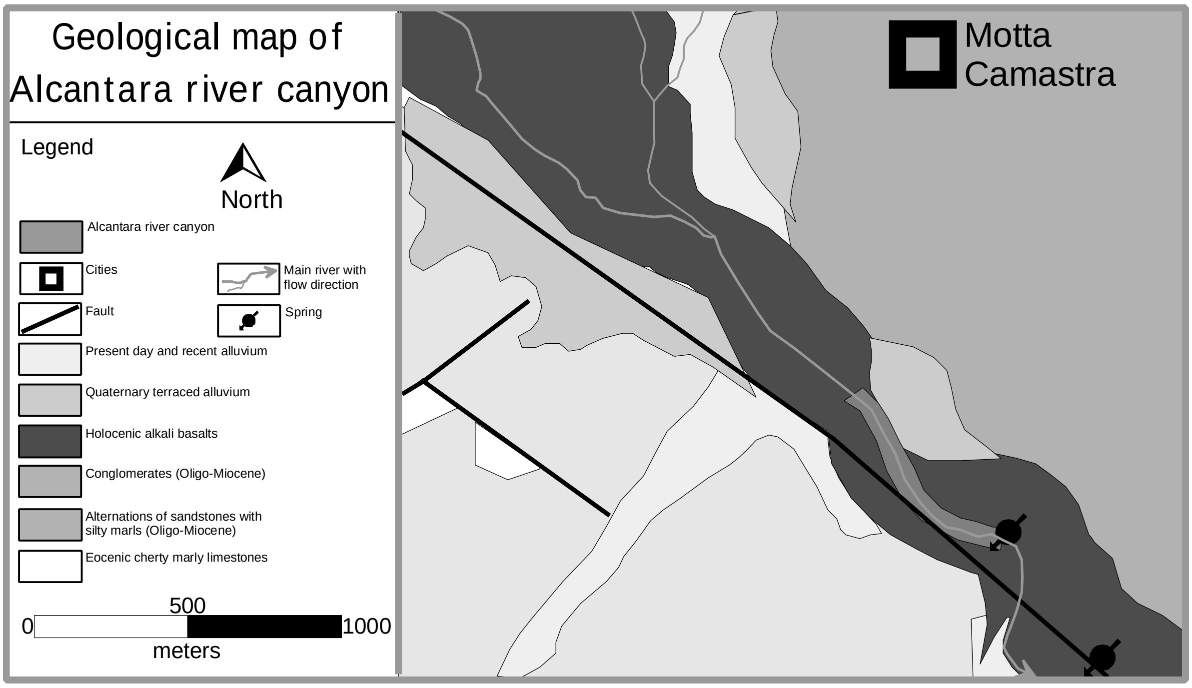


Fig. 4 - Geological map of Alcantara river canyon.

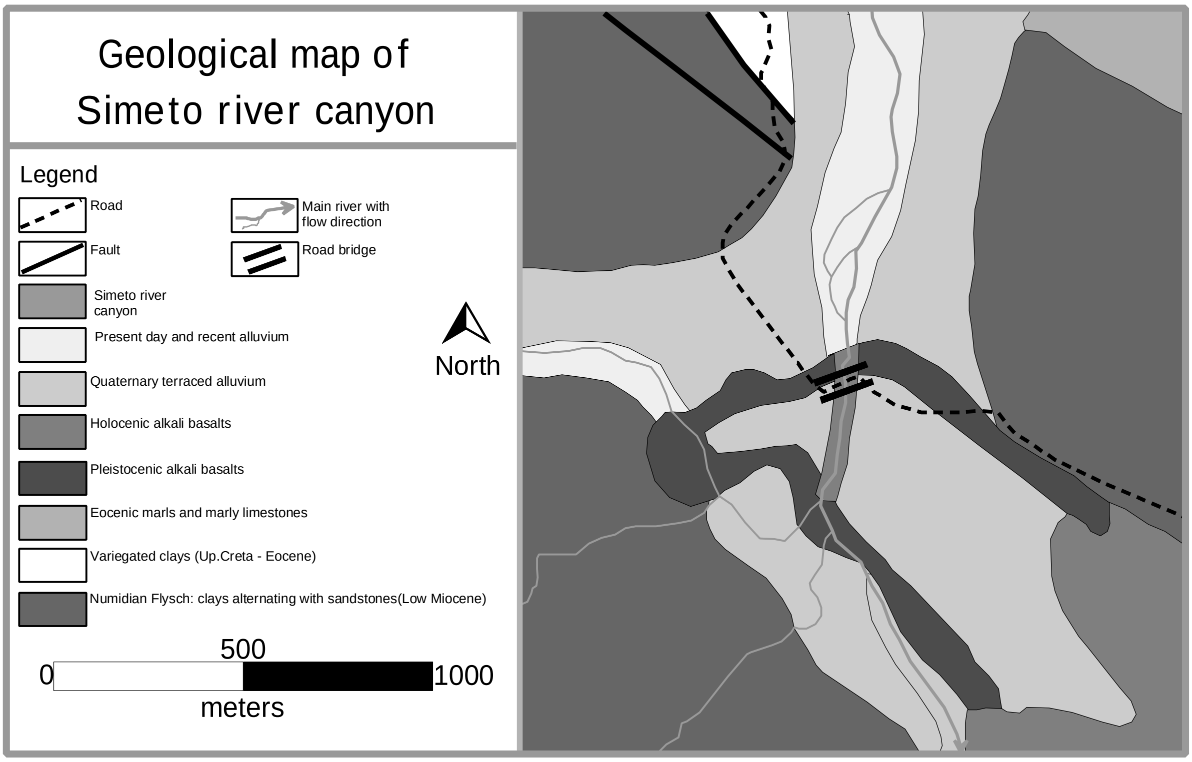


Fig. 5 - Geological map of Simeto river canyon.

Only when a peculiar characteristic of lavas, like the columnar fracturing, is present the morphological evolution of a basaltic canyon shows secondary features strictly related to its lithological nature.

We can then conclude that while the morphological evolution of lava caves is strictly related either to their lithological nature either to the very particular morphogenetic agent occurring in their formation (flow of the melted hosting rock itself), so that the resulting morphologies are to be considered as very particular karst forms, in the case of lava canyons we found features similar to other ones developed in fluvio-karst (Pollina river or Faguara creek, Madonie Mounts, Sicily)

or simply fluvial system (sandstone canyon of Vicaretto creek, Madonie Mounts), except same secondary features due to columnar fracturing.

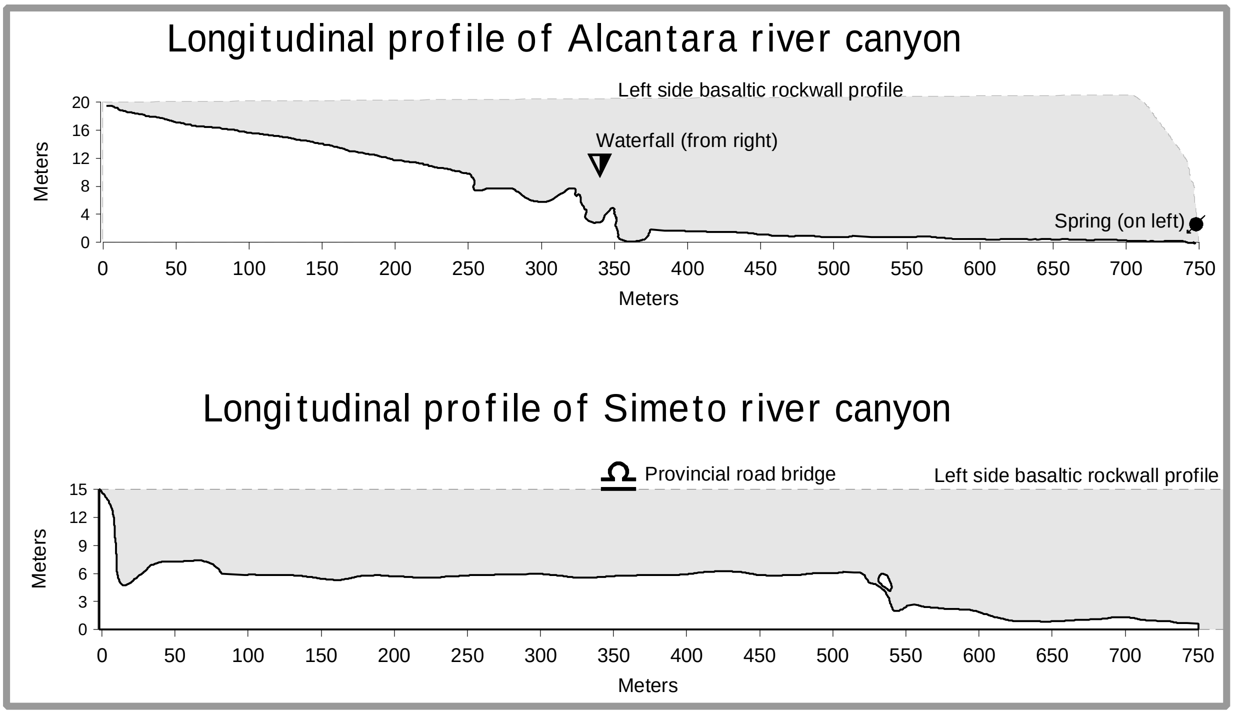


Fig. 6 - Longitudinal profiles of Alcantara and Simeto rivers canyons.

Water quality and environmental aspects

According to the sicilian legislation (regional law 14/88) governing the institution of protected areas, a transitory regime of restrictions in land use and environment protection norms is active since the insertion of the area in the Regional Plan of Parks and Natural Reserves (1991).

In particular, the Alcantara canyon is considered only of geological and geomorphological interest, the Simeto canyon has been proposed for the institution of a natural reserve for the protection of its peculiar riparial and limnic environments rich of botanical and fauna species.

Due to this different classification, only abiotic interesting components in the Alcantara canyon, very important biological aspects in the Simeto ecosystem, river water pollution control is expected to be more important in the latter area that in the former.

As showed by the data acquired during a field session conducted in August 1999 and presented in the graph of Fig.7, pollution presents dramatic level in the Simeto area despite its environmental interest.

Taking into account the italian laws about water pollution control, and in particular the D.P.R. 236/88, receipting an european community directive about maximum/minimum values of some chemical parameters in water destined to human consumption, it can be seen how in the Simeto area, except D.O. values, all the guide values, and in two cases the limit values too, are not respected in river waters.

In particular, high concentrations of nitrogen and phosphate ions are due to the wide agricultural use of chemical fertilizers in the land fields crossed by the river. Environmental pollution is augmented by the illegal discharge, from the road bridge crossing the canyon in its middle, of a big quantity of solid wastes and empty plastic tanks of pesticides and fertilizers (classified as dangerous wastes); the presence of empty tanks of a wide variety of chemical hazardous products on the river bed leads to the supposition that the same chemical species are present also in river waters, with a dramatic depletion of environmental quality of the protected ecosystem.

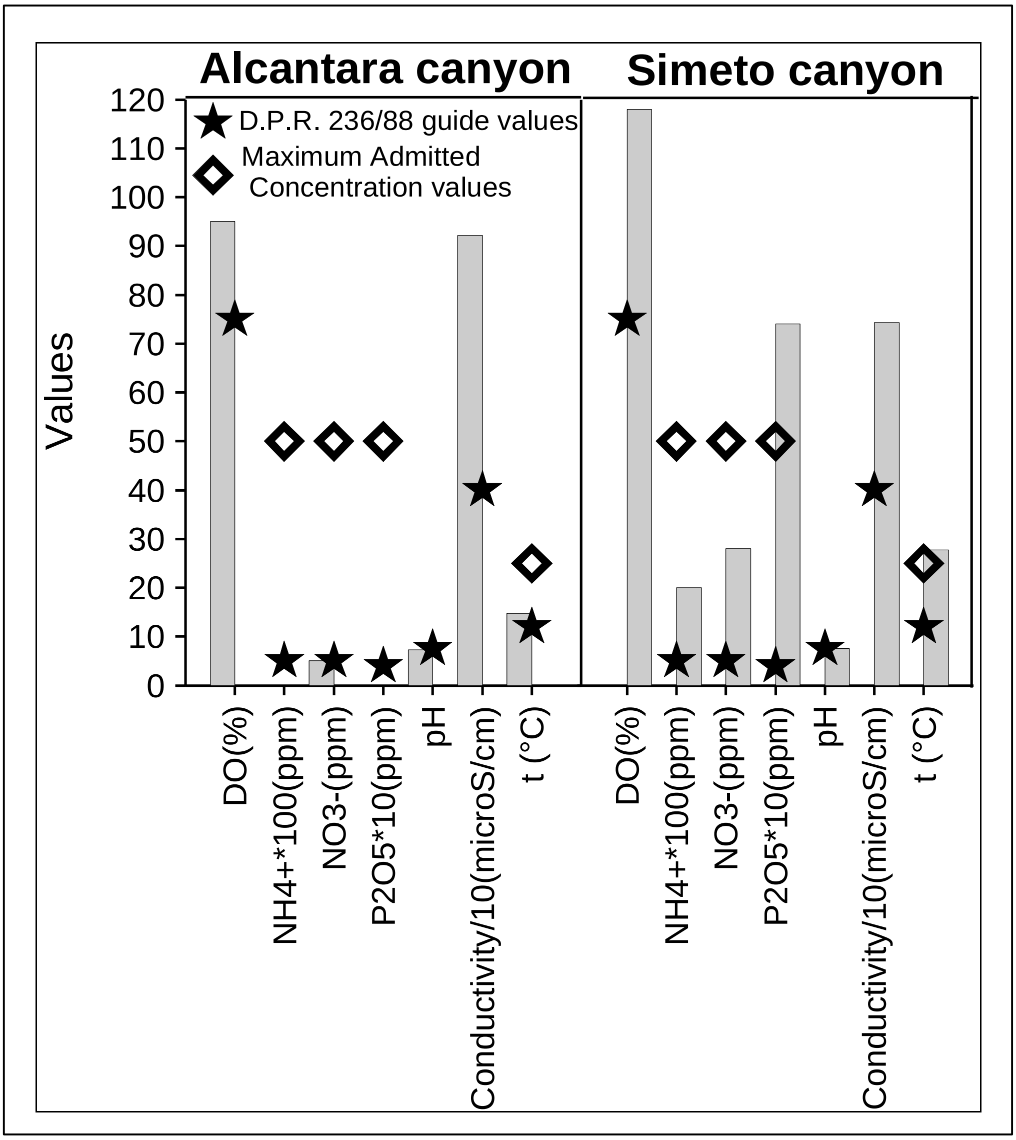


Fig. 7 - Chemical parameters of Alcantara and Simeto rivers surface waters.

As a paradox, except the visual perception of wastes, that represents on itself a negative environmental impact, the same pollution factors should cause a minor impact in the Alcantara river, where only an abiotic ecosystem is protected, but where the mitigation interventions on wastewaters discharged into the river (water purification plants treating sewer effluents of the cities located upflow the canyon) have lowered water pollution down to a reasonably low level compatible with the presence of a protected area of geological interest

Conclusions

The two studied canyons present very different characteristics, either from the hydrological either from the geomorphological points of view.

In particular, the observation of the morphological characteristics of these features leads to the conclusion that, while the morphological evolution of lava caves is strictly related either to their lithological nature either to the very particular morphogenetic agent occurring in their formation , in the case of lava canyons we found features similar to other ones developed in fluvio-karst or simply fluvial system, except same secondary features due to columnar fracturing.

Both the Alcantara and Simeto canyons, due to their environmental characteristics, have been comprised in the Regional Plan for Parks and Natural Reserves of the Sicilian Region (1991) as natural reserves to be instituted in the near future.
Surface water quality, as a result of a first field sampling session, seems to be in the case of Simeto river not compatible with the presence of a natural reserve of biotic interest.

Bibliography

- HARGREAVES G., 1994, *Defining and using reference evapotranspiration*, Journal of Irrigation and Drainage Engineering, Vol. 120, n°6
- ITALIAN HYDROGRAPHIC SERVICE , 1986-1994, *Annali Idrologici: Parte I e II*, Palermo
- ROMANO R., STURIALE C., LENTINI F., 1983, *Geological Map of Mt. Etna*, Memorie della Società Geologica Italiana, Vol. XXIII, Roma, Italia

Vulcanospeleology in the World

MINEROGENESIS OF VOLCANIC CAVES OF KENYA

Forti Paolo, Galli Ermanno** and Rossi Antonio***

* Istituto Italiano di Speleologia, Università di Bologna.
** Dipartimento di Scienze della Terra, Università di Modena e Reggio Emilia.

Abstract

Kenya is one of the few countries in which karst cavities are scarce with respect to volcanic ones, which are widespread throughout the whole country. The great variability in lava composition allowed the evolution of very different cavities, some of which are amongst the largest lava tubes of the world.

As normal for such a kind of cave, the hosted speleothems and cave minerals are scarce but important from the minerogenetic point of view. Anyway up to present no specific mineralogical research have been carried out therein.

During the 8th International Symposium on Volcanospeleology, held in Nairobi in February 1998, some of the most important volcanic caves of Kenya have been visited and their speleothems and/or chemical deposits sampled: most of them were related to thick guano deposits once present inside these cavities.

Speleothems mainly consisted of opal or gypsum, while the deposits related to guano often resulted in a mixture of sulphates and phosphates.

The analyses confirmed the great variability in the minerogenetic mechanisms active inside the volcanic caves, which consequently allow the evolution of several different minerals even if the total amount of chemical deposit is scarce.

Among the observed minerals kogarkoite, phillipsite and hydroxyapophyllite, must be cited because they are new cave minerals not only for the lava tubes of Kenya, but also for the world cave environment.

The achieved results are compared with the available random data from previous literature in order to allow an updated overview on the secondary cave minerals of Kenya.

Introduction

There has been a growing interest in volcanic caves in the last few years, not only from the explorative point of view but also for the possibility of studying minerogenetic and diagenetic processes absolutely peculiar to this environment (Forti et al 1996: Benedetto et al 1998).

During an excursion of the 8th International Symposium on Vulcanospeleology, held in Nairobi in February 1998, studies were undertaken to learn more about the minerogenetic processes that develop inside the volcanic cave and one excursionist (P.F.) had the chance to make observations and to take samples in some caves formed in the flank of some of the most important volcanoes.

Kenya is one of the few countries in which karst caves are scarce with respect to volcanic ones, which are widespread throughout the whole country. The great variability in lava composition allowed the evolution of very different caves, some of which are amongst the largest lava tubes of the world.

The collected samples have resulted more or less complete even though only limited to some of the caves visited and essentially, restricted to the small speleothems and efflorescences present on the walls and ceilings as well as to the small masses of whitish substances that had developed inside the once vast guano deposits as there been an extensive cultivation of guano between the 1960's and the1980's (Simons,1999b).

This has been the first systematic mineralogical research work undertaken in a volcanic cave in this country that have brought about the recognition of many minerals, some of which never been described before now in a cave environment.
The achieved results are compared with the available random data from previous literature in order to allow an updated overview on the secondary cave minerals of Kenya.

Experimental Methods

I) First of all an accurate exam of the samples was made by a binocular microscope for detection and separation of the different mineralogical phases.
II) The separated mineralogical phases then underwent a roentgen analysis through a powders diffractometer (Philips PW 1050/25) when the material was quantitatively sufficient and homogeneous or with a Gandolfi camera (Ø 114mm, exposition time 48 h), when the material was scarce or heterogeneous. The following conditions were observed in both cases: 40Kv tube and 20mA, radiation CuKα, λ = 1.5418 Å, with Ni filter. Natrolite has been determined by single-crystal precession photographs and a Siemens P4P rotating-anode single-crystal diffractometer (graphite-monochromatized Moka radiation, 52kV, 140mA) equipped with XSCANS software (Siemens 1996).
III) The same samples utilised for the diffractometer and the Gandolfi camera also had images made by an electronic microscopic with semi-quantitative chemical analysis through an scanning electronic microscope (SEM Philips XL40) combined to an electronic dispersion microprobe (EDS-EDAX 9900) in the Centro Interdipartimentale Grandi Strumenti (C.I.G.S.) at the University of Modena and Reggio Emilia.

The caves and studied samples

The three visited areas were: Chyulu Hills, Mount Suswa and Mount Helgon (Forti 1999) (Fig. 1).

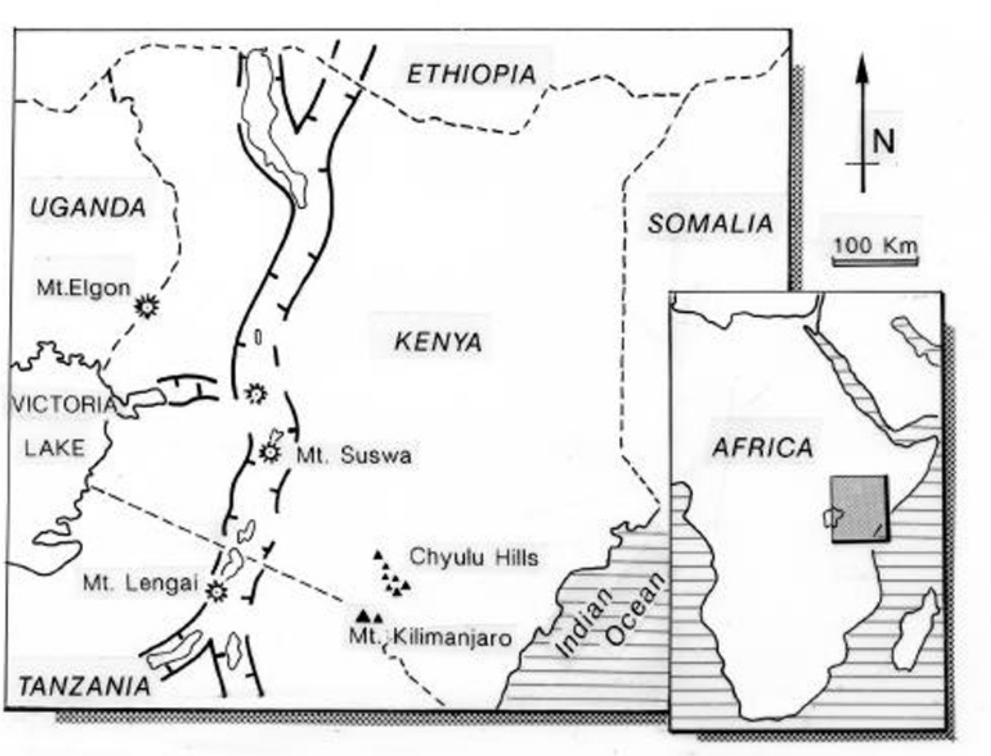


Fig. 1 – Location map for the volcanic areas in which secondary cave minerals have been sampled for the present study

CHYULU HILLS

The volcanic area in the Chyulu Hills is located south of Nairobi near the Tanzanian border, practically at the foot of Mount Kilimanjaro, where the volcanic area covers a surface of more than 2000 Km^2, and peaks up to 2175 m.

Mathaioni Cave

The Mathaioni cave was the first visited: it is one of the largest caves in the area, reaching a development of more than 1.9 km. The cave is developed on two levels and contains lava stalagmites, that could be the largest in the world (and more than three meters high),with some other beautiful re-melting stalagmites. This lava tube was discovered by Jim Simons in the 1960's (Simons, 1974) and was exploited for more than ten years for the imposing deposits of guano it contained ,which were three meters thick in some areas .At the moment there is almost no trace of guano in the cave, beside the small puddles of semi-liquid substance present in the lower branches and some earthy whitish coloured deposits of scarce consistence on the cave walls and floors where once there was guano. The sample of these sediments (EG1) under binocular observation has revealed a friable earthy material, light brown in colour, formed by minute prismatic tabular crystals of gypsum (Fig. 2 and Tab. 1a), as confirmed both in the diffractometric and EDAX analyses.

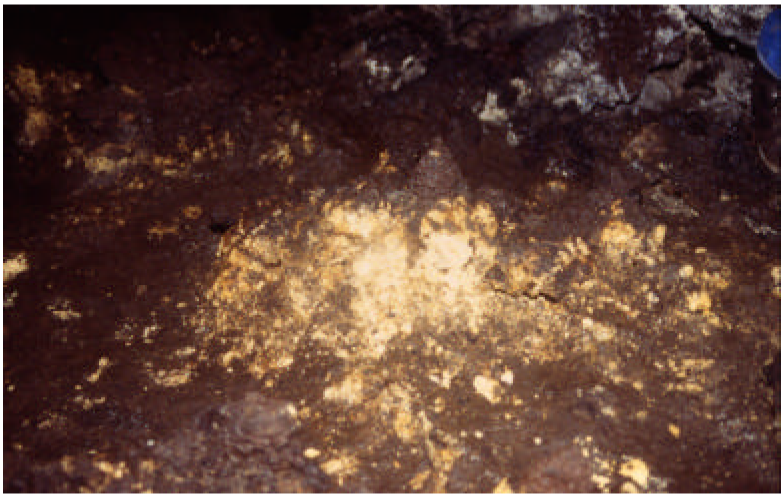


Fig. 2 – Mathaioni cave: white-pale yellow masses, developed at the contact between guano and the cave floor

Fig. 3 – Shetani cave: opal formations

Leviathan Cave

A brief visit to the central sector of the famous Leviathan Cave was organised the next day. This cave was discovered in 1975 and rapidly became the deepest longest lava tube in Africa with a an extension of 12.5 km and almost 479 m difference in level (Simons, 1998). Due to lack of time it was not possible to collect any samples from this cavity also known for the presence of beautiful opal concretions (stalactites and stalagmites) with colours varying from white to yellow (Simons 1998).

Shetani Lava Cave

The last day of our visit to the Chyulu Hills was spent in the extreme south of the lava outcrop in one of the most famous natural parks of Kenya (Tsavo West) in order to visit the Shetani Lava Cave (Fig. 3). This cave opens into a pahoehoe flow that is quite recent and has a length of about 200 m. It is

a sub-horizontal lava tube with a medium of 5 m in diameter. The cavity has been partially equipped for tourists visits, basically to protect some bone deposits, where, apart from other things lies an almost complete skeleton of a rhinoceros. No samples were taken in this cave.

MT. SUSWA

The second visited area was the Suswa volcano which rises imposingly in the centre of the Rift Valley at about 90 km N. of Nairobi. The Suswa volcano is characterised by an enormous caldera (some km in diameter and a depth of more than 200 m), whose formation was caused by the collapse of the magmatic chamber. All main caves are found in a lava field on the caldera's NE border. During two days it was possible to visit some of the most important lava tubes in the zone.

Cave N° 13

The entrance displays the remains of a hut constructed in the 50's by the Mau-Mau, during the war of independence. The internal part reveals a marvellous example of "lava rope" and strange re-melting forms on the walls: it is also possible to admire some stalactites and there are beautiful translucent needles in a milk white material above a clayey deposit situated in the terminal part of the cavity. Five samples were taken in this cave.

EG 4 – It is an elongated fragment of a rope stalactite (9 x 3 cm) formed by an earthy material, cream white internally and light-brown and grey externally, very light and arranged in concentric layers with a pealed onion sheeting effect. At large magnification (Tab. 1b) it shows a spongy structure, characterised by the presence of numerous cavities. The X-ray and the chemical analysis have evidenced the presence of opals, which sometimes tend to assume the appearance of octahedron, typical of cristobalite (Tab. 1c).

EG6 – A stalactite fragment (4 x 1 cm) taken a few meters apart from the previous sample. The fragment consists of an inner core consisting of volcanic rock plenty of small cavities, which are completely covered by a thick layer of a spherulite aggregate made by porcelaneous material, the colour of which is milk white internally and dark nut on the external part. The X-ray and the EDAX analysis have evidenced that the porcelaneous material is formed by amorphous silicate, while in the vacuolar volcanic rock the presence of sanidine has been recognised.

EG7-A heterogenious material, very fragile in hygroscopic, which resulted to be one of the richest of mineralogic species. This samples was taken from the terminal part of the cavity at the top of a clayey deposit. Fragile vitreous lined crusts are present, formed by the evident union of prismatic crystals of thermanonatrite (Tab. 1d), which are only rarely present in isolated individuals (Tab. 1e). There are thin blades of trona (5 x 0.3 mm) closely associated to the thermonatrite (Tab. 1f), from colourless to pale yellow, semi-transparent, fibrous-radiate or closely woven in the form of felt. The same sample contained two spheroidal aggregates of minute blade crystals of a pale yellow-orange colour with a glassy brightness. The X-ray and the EDAX analysis have shown it to be kogarkoite (Tab. 1g). Some grains of glass, rounded isolated, with a colour varying from citrine yellow to dark grey, derived from the disintegration of the volcanic rock that forms the cave wall consists of sanidine.

EG8 – Flowstone milk white in colour, very resistant, arranged in millimetre layers that form the floor of the cave in some points. The X-ray and the EDAX analysis have shown the presence of amorphous silicate.

EG9 - Only a short distance from where the EG4 sample was taken, some aggregates in the form of a rose were removed , and consisted of gypsum blade creamy yellow crystals, partly covered by a thin layer of earthy looking light grey material found to be amorphous silicate.

EGII – It's similar to the EG4. This sample is also formed by a lithoid material, sponge-like, very light, with a varying colour from cream white in the central part to dark grey on the external part. The X-ray and the EDAX analysis have shown that also in this case it consists of amorphous silicate.

Cave N° 14

Famous for a large chamber, “The ballroom”, and characterised by a perfectly flat sand and clay floor. This cave had two samples taken and it too, has revealed to be particularly rich in mineralogic phases.
EG5A – A coralloid of about 3 cm in length, formed by a aggregate of spherulitic material from transparent to porcelaneous with an onion-like sheeting cemented by a very resistant light grey earthy material. The X-ray and the EDAX analysis have proved it to be amorphous silica. This material is characterised by the presence of numerous quite spherical cavities where the walls sometimes host minute spheroid aggregates of pseudo-hexagonal blades (Tab. 2a, b) that the X-ray and EDAX have shown to be taranakite.
EG5B – This sample consists of numerous sub-spheroids (0 < 8 mm) with the surface covered by a heterogeneous material, yellow ochre in colour. By using a binocular microscope it is possible to recognise prismatic bladed crystals of gypsum and prismatic, tabular, colourless, crystals, isolated or in aggregates of few individuals, of hannayite (Tab. 2c). These two minerals are closely associated between them and difficult to separate. The same material has evidenced a small glassy, white or ivory aggregate of radial fibrous crystals of brushite, and a earthy greyish white spheroid knot, consisting of an irregular aggregate of prismatic to tabular crystals of taranakite, more or less altered. The central core of the grains are formed either by a glassy material, ranging from colourless to honey yellow, semi-transparent, apparently compact whereas, in reality it is fractured (Tab. 2d). The X-ray and EDAX analysis have shown it to be newberyite, alone or associated to hydroxylapatite. Sometime small irregular fragments of purple coloured volcanic rock, characterised by the presence of numerous cavities are also present. The X-ray analyses of this last material has shown the presence of sanidine, as also confirmed by the EDAX analysis.

MT. ELGON

The last visited area was Mount Elgon, situated at 380 km NE of Nairobi, on the border between Kenya and Uganda, and it’s 4360 m in height make it the third highest peak in the country. This volcano is characterised by scarce lava eruptions and great explosive activity essentially in the Miocene and Pliocene period. The cone is enlarged and basically consists of volcanic ash which then become conglomerate, breccia and tuff. There are numerous caves at the foot of the mountain, ancient lacustrine deposits rich with fossilised trunks, and only partly explored even though the area has been known to the mineralogists for the presence of zeolite in the rock for more than half a century (Udluft,1928; Jèrèmine, 1934). Though these caves developed mainly in volcanic substances, they absolutely can not be considered lava caves; in fact they are the result of water flow erosion caused by their different permeability and cohesion in respect to the overhanging volcanic deposit. Many of them have been completely modified by man for the salt extraction. Three of the caves visited were Kitum Cave, Chepnyalil Cave and the Makingen Cave.

Kitum Cave

A cave to be visited at day time in order not to disturb elephants who go there at night to find salts. The vault has numerous cylindrical formed cavities formed by the dissolution of trunks of wood that was originally trapped by the lacustrine sediments. The walls of these cavities sometimes reach to one or two meters in length and a diameter of 40-50 cm, they are generally covered in beautiful calcite crystals and translucid needles of natrolite. Three samples were taken in this cave.
EG3A – It is essentially formed by glassy to transparent minute prismatic pseudo-tetragonal acicular crystals (5 x 0.25 x 0.2 mm), that the X-ray and the EDAX analysis have identified as natrolite (Tab. 2e).
EG3B – There are some stalactite fragments (Fig. 4) formed by a cylindrical internal nucleous of golden yellow calcite, wrapped in a thin layer of milk white micro-crystals of phillipsite which is partially covered by transparent prismatic crystals of natrolite.

Fig. 4 - Kitum cave: a large cylindrical void of the ceiling with calcite macrocrystal stalactites covered by natrolite, hydroxylapophyllite and phillipsite

Finally successive crystallisation formed splendid tabular tetragonal prismatic crystals of hydroxyapophyllite over the natrolite. In the same sample there are also beautiful isolated semi-transparent, from colourless to pale golden yellow rhombohedral crystals of calcite (>10 mm), often associated with a saccharoidal off-white, resistant substance (which proved to be phillipsite) and some earthy grains.

EG3C – The walls on the more internal part of the cave show evident signs of the nightly excavation activity by elephants. This is where aggregates of off-white, sericeous, bending crystals of gypsum (sericolite variety) are found (Fig. 5).

All the described samples have inside small fragments of volcanic rock, the colour of which varying from pinkish- purple to dark grey, characterised by the presence of vacuole with walls covered in a thin layer of twinned crystals of phillipsite. In some cases the phillipsite crystals are covered by semispheric masses or minute cubic crystals of halite (Tab. 2f), whereas in others the presence of an irregular spreading of celestite has been identified (Tab. 2g).

Fig. 5 – Kitum cave: gypsum (sericolite variety) inside a crack in the cave bottom

Fig. 6 - Enlargement of a stalactite of the fig.4: the natrolite, hydroxylapophyllite and phillipsite aggregates cover the internal calcite core, which outcrop in the tip as large crystal.

Chepnyalil Cave

A cave of great archeological interest due to the rock paintings on the walls near the large entrance while the flooring is literally covered in crude bone and rock utensils and even, though less frequent, ceramic fragments. The wall provided a rock fragment of a pseudo-cylindrical shape (8 x 5 cm) made of splendid prismatic crystals, glassy, light brown in colour, isolated or weakly plaited to natrolite on the surface or again strongly cemented to become a highly resistant and compact underneath. Tabular crystals of hydroxyapophyllite are present in the interstice, almost always covered over by a thin rosy-white glaze.

Makingen Cave

The last cave visited was the Makingen Cave,which is located about a km from the last one. The entrance to the cave is extremely spectacular with a 60 m wide mouth and 16-18 in height,with a perennial waterfall. The erosive action of the water is much more evident in this cave and the principal tunnels remind us of the normal karst ones. There is a great accumulation of fallen masses at the end of the cave similar to those present in the Kitum Cave. The bat colonies are much more numerous in this part of the cavity to those observed in the other cavities. No sample has been taken in this cave.

Discussion

Only 8 of the many secondary minerals noted in the volcanic caves of Kenya (Tab. 3) were not found in the samples analyzed in the present study, more precisely: apophyllite, aragonite, bobierrite, mendozite, mirabilite, sodium alum, thenardite and tetranatrolite. It must be said that two of these, thenardite and tetranatrolite, have been described only recently (Kashima & Ogawa, 1998) in samples taken during the same excursion in other areas but in the same caves from which those described here came from. This fact confirmed what was mentioned in the introduction about the sample collection: it was reasonably accurate but certainly the lack of time at disposition did not allow enough time to carefully observe all the secondary chemical deposits in the visited caves.

Thenardite observed by Kashima and Ogawa is probably a product from the dehydration of mirabilite, a mineral that was already known in the lava caves of Kenya (Sutcliffe1973, Simons 1998).

Among the other minerals undetected in the present study, the absence of composts like sodium alum, mirabilite and mendozite can be easily justified by the fact that the samples were taken in a period just successive to a heavy rainfall and therefore it seems reasonable that these very soluble sulphates have been completely washed away by the percolation water.

Moreover the removal of almost all the guano present in the cave for an economic exploitation is probably the reason why the bobierrite was not observed.

The aragonite described by Simons (1998) was not found simply because during the excursion there was insufficient time to get to the area where the mineral had been seen.

The last minerals not found in the present study are tetranatrolite and apophyllite, but it is highly probable that these two silicates correspond to natrolite and hydroxyaphopyllite of this paper. Morphological and X-ray diffraction analyses cannot discriminate between natrolite and tetranatrolite, which has also been recently discredited by the Subcommittee on Zeolite Mineral Nomenclature of the IMA Committee on NEW Minerals and Mineral Names (Coombs *et al*., 1997; Artioli & Galli, 1999): discrimination may be done only by means of chemical and single crystal diffraction analyses. During the present study several pseudo-tetragonal vitreous, perfectly transparent crystals have been selected from fragments of the stalactites as well as from fragment of rock of the walls of the Kitum Cave. They have been analysed with a single-crystal precession camera and single crystal diffractometer: always they resulted natrolite, which was also confirmed by the chemical analysis.

The same may be said of apophyllite (Udluf, 1928), moreover it has to be noted that this term is assigned to a entire group of minerals, among which there is hydroxyapophyllite, the detection of which may be sure only by mean of chemical analyses.

It should be noted that the results of the present study, even though only limited to some caves has allowed to identify 12 minerals which are described for the first time in the caves of Kenya (Tab.1). This fact is surely indicative of the great mineralgenetic interest of these caves and also suggests the idea that research in this field is still far from being concluded.

Five of the minerals observed for the first time are phosphates (brushite, hannayite, hydroxylapatite, newberyite and taranakite), each have already been noted in the cave

environment: all of them are clearly related to the great guano deposits. Some of these minerals have certainly already been sampled in lava caves of Kenya, but studies carried out on them (Simons, 1998) were clearly insufficient to discriminate them.

The presence of such a high number of phosphates even after the deposits of guano have been almost destroyed when it was sold as fertiliser (Simmons 1999), leads to believe that probably, if a detailed study was conducted on these deposits before their reduction, the number of cave minerals in the lava cave of Kenya would have been much more.

The cave n.13 on Mount Suswa provided three of the minerals observed for the first time during this study: thermonatrite, trona and kogarkoite.

Thermonatrite and trona were already known cave minerals, especially in the volcanic caves (Hill & Forti 1997) and their genesis should be related to weathering of the lava flow. Instead, the kogarkoite has been noted for the very first time in a cave environment and its genesis is, however, probably similar to that of other two associated minerals: in fact their anions cations can all derive from the weathering of volcanic rock though the presence of F and S could, in this case, be put in relation to the presence of guano deposits.

The last four minerals observed for the first time in Kenya (phillipsite, hydroxyapophyllite, celestina and halite) have all been noted in samples taken from the Kitum Cave on Monte Helgon.

The genesis of all these minerals is to be put in relation of the weathering effect from the percolation waters inside the volcanic breccia and tuff in which the cave developed. The rainwater seepage, in fact, was easy inside the breccia and tuff because they have trapped large tree trunks, that, as a result of their permanence before destruction, have left oblong imprints, often connected between them (Fig.4).

Phillipsite and hydroxyapophyllite are silicates widespread in the volcanic rocks but they are here reported, for the first time in the world, as cave minerals.

In this case their environment of development is so particular as to identify them as real and true cave minerals. In fact, these two minerals together with natrolite form the external structure of some macro-crystalline calcite stalactites (Fig. 5). Their genesis and evolution are probably related to the first moment of seepage of rainwater inside the still warm volcanic rock; the fluids in fact, may have permitted the mobilisation of ions necessary for the formation of these minerals and to their successive deposits inside the spaces generated by the decomposition of trapped trees.

Final Remarks

Although the sample collecting was of course performed in a hurry and incomplete, the present paper offered the possibility to increase the relative knowledge about secondary minerals developed in the lava caves of Kenya, now being 22.

It must be remembered that the sample collection and therefore the study of minerals has only regarded a small part of the volcanic caves actually known in Kenya, so it is fairly probable that the real number of secondary minerals truly present is much superior and so new and systematic research should be conducted in the caves of this country.

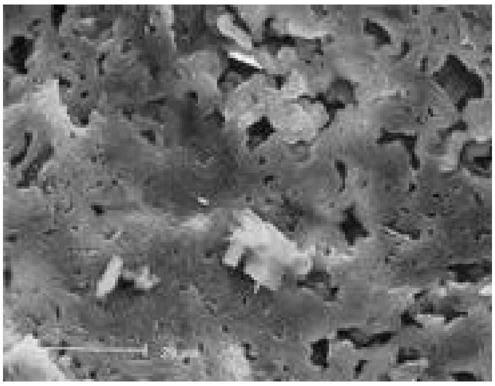
Considering the twelve minerals observed for the first time in these caves, note that 3 (hydroxyaphophyllite, kogarkoite and phillipsite) result in being completely new to the caves in general.

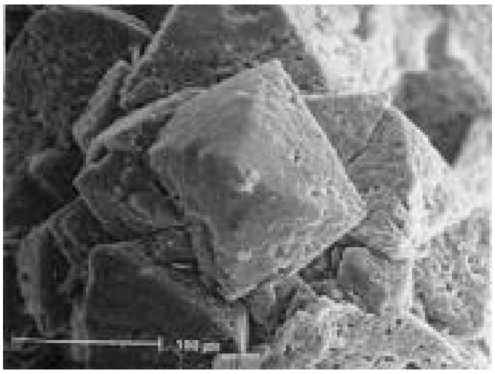
This would confirm what has only recently been brought to light and that is, though at first sight the volcanic caves lack secondary chemical deposits, they are among the underground environment more important for the formation of secondary mineralization.

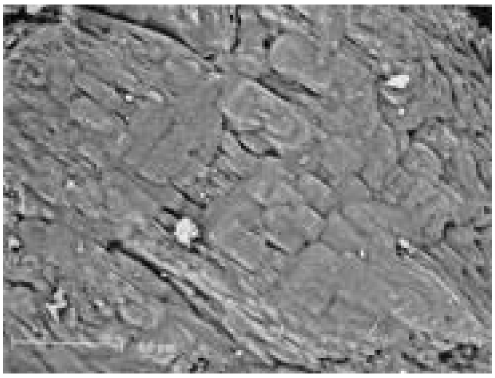
Hopefully an international team will be settled up in the near future in order to co-ordinate researches and studies on genetic processes and mechanisms allowing the development of secondary mineralization inside the volcanic caves.

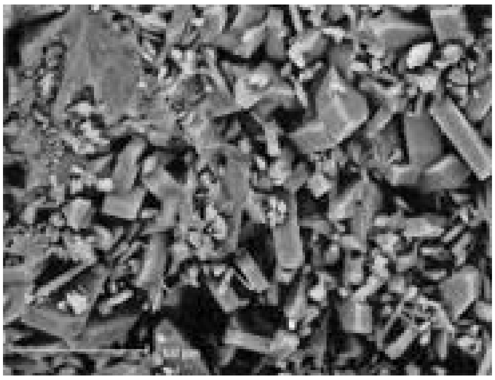
Tab. 1 – SEM images

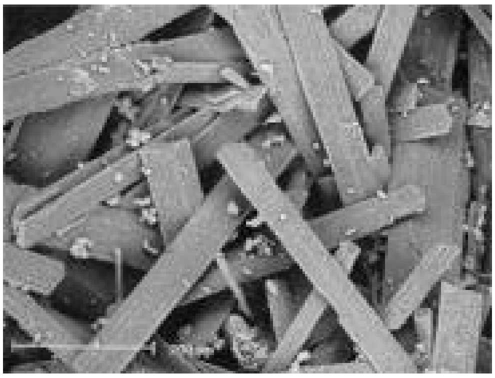

a


b


c


d


e


f

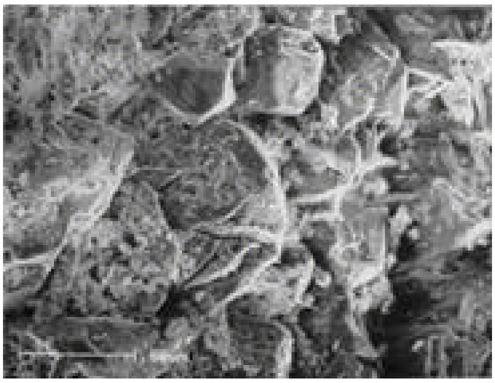

g

a) gypsum from Mathaioni cave, Chyulu Hills;
b, c) opal from Cave n°13, Mt. Suswa;
d, e) thermonatrite from Cave n°13, Mt. Suswa;
f) trona from Cave n°13, Mt. Suswa;
g) kogarkoite from Cave n°13, Mt. Suswa.

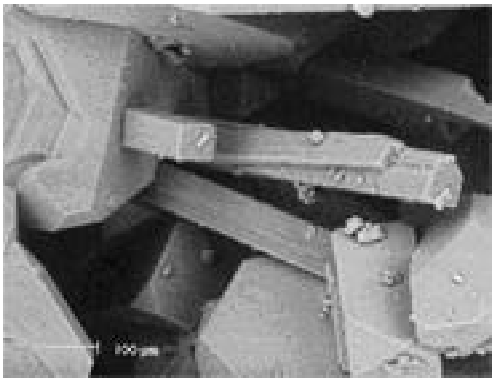
Tab. 2 – SEM Images.

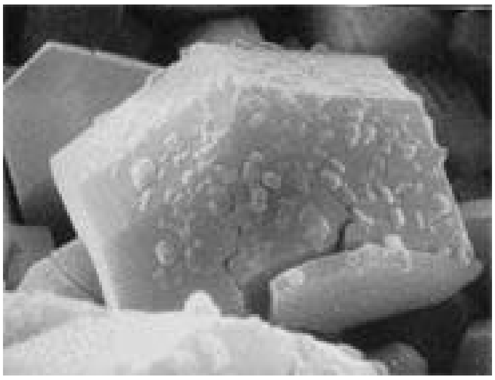

a

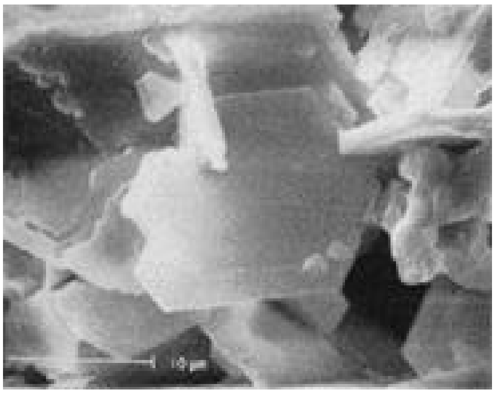

b


c


d


e


f


g

a, b) taranakite from Cave n°14, Mt. Suswa;
c) hannayte from Cave n°14, Mt. Suswa;
d) newberyite from Cave n°14, Mt. Suswa;
e) natrolite and hydroxyapophyllite from Kitum Cave, Mt Helgon;
f) phillipsite with halite from Kitum Cave, Mt Helgon;
g) celestine over phillipsite from Kitum Cave, Mt Helgon.

Tab. 3. The secondary minerals in volcanic caves of Kenya : an asterisk in the first column identifies the minerals observed in the present study

	Mineral	Chemical Formula	Crystal System	Habit or mode of occurrence[I]	References
	Apophyllite	$KCa_4[Si_8O_{20}(F, Na, OH)]\cdot 8H_2O$	Hexagonal	Prismatic crystal	Udluft (1928)
	Aragonite	$CaCO_3$	orthorhombic	Small clusters of flowers	Simons (1998)
	Bobierrite	$Mg_3(PO_4)_2\cdot 8H_2O$	monoclinic	Small radiating acicular crystals	Simons (1974, 1976)
*	Brushite	$CaH(PO_4)\cdot 2H_2O$	monoclinic	*Radial aggregates of thin needles*	
*	Calcite	$Ca\ CO_3$	trigonal	*Rhombohedral crystals,* stalactites, stalagmites	Udluft (1928), Jérémine (1934), Sutcliffe Sutcliffe (1973)
*	Celestine	$SrSO_4$	orthorhombic	*Small zig-zag shaped coating*	
	Collophane[II]	$Ca_5(PO_4)_3(OH, F, Cl)$	amorphous	Secondary stalactites	Simons (1998)
*	Gypsum	$CaSO_4\cdot 2H_2O$	monoclinic	*Bladed or acicular curved crystals*	Simons (1974), Kashima & Ogawa (1998)
*	Halite	NaCl	cubic	*Small spots or cubic crystals*	
*	Hannayite	$Mg_3(NH_4)_2H_4(PO_4)_4\cdot 8H_2O$	triclinic	*Transparent prismatic crystals*	
*	Hydroxyapophyllite	$KCa_4Si_8O_{20}(OH)\cdot 8H_2O$	tetragonal	*Tetragonal prismatic crystal*	
*	Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	hexagonal	*Small plate-like masses*	
*	Kogarkoite	Na_3FSO_4	monoclinic	*Aggregates of small bladed crystals*	
	Mesolite [III]	$Na_2Ca_2[Al_6Si_9O_{30}]\cdot 8H_2O$	orthorhombic	Prismatic crystals	Udluft (1928)
	Mesotype (=natrolite)	$Na_2[Al_2Si_3O_{10}]\cdot 2H_2O$	orthorhombic		Jérémine (1934)
	Mirabilite	$Na_2SO_4\cdot 10H_2O$	monoclinc	Curved crystals, efferescences	Sutcliffe (1973), Simons (1998)
	Mendozite	$NaAl(SO_4)_2\cdot 16H_2O$	monoclinc	Blisters	Sutcliffe(1973), Simons (1998, 1999a)
*	Natrolite	$Na_2[Al_2Si_3O_{10}]\cdot 2H_2O$	orthorhombic	Prismatic crystals	Udluft (1928), Sutcliffe(1973)
*	Newberyite	$MgHPO_4\cdot 3H_2O$	orthorombic	*Plate-like masses of fractured crystals*	
*	Opale	$SiO_2\cdot nH_2O$	amorphous	*Stalactites, Stalagmites*	Simons (1974,1998)
*	Phillipsite	$K_2(Ca_{0.5},Na)_4[Al_6Si_{10}O_{32}]\cdot 12H_2O$	monoclinic pseudo-orthorhombic	*Pseudo-tetragonal twinned crystals*	
	Sodium Alum	$NaAl(SO_4)\cdot 12H_2O$	cubic	Efflorences	Simons (1998)
*	Taranakite	$H_6K_3Al_5(PO_4)_8\cdot 18H_2O$	trigonal	*Nodule of prismatic bladed crystals*	
	Tetranatrolite	$(Na,Ca)_{16}[Al_{19}Si_{21}O_{80}]\cdot 16H_2O$	tetragonal	White acicular frostwork	Kashima & Ogawa (1998)
*	Thermonatrite	$Na_2CO_3\cdot H_2O$	orthorhombic	*Thin crusts of prismatic crystals*	
	Thenardite	Na_2SO_4	orthorhombic	Pale yellowish soft cave powder	Kashima & Ogawa (1998)
*	Trona	$Na_3H(CO_3)_2\cdot 2H_2O$	monoclinic	*Thin blade-shaped laths*	

Notes: [I] In italics those from this work; [II] Term used for massive fine-grained members of the apatite group, usually carbonate-fluorapatite or carbonate-hydroxylapatite; [III] M.H.Hey (1931) abstracting the Udluft's paper writes" The author terms the calciferous material mesolite, but his optical data show it to be natrolite".

References

- ARTIOLI G., GALLI E. (1999) *Gonnardite: Re-examination of Holotype material and discreditation of tetranatolite.* Amer. Mineral., 84, 1445-1450.
- BENEDETTO C., FORTI P., GALLI E., ROSSI A. (1998) *Chemical deposits in volcanic caves of Argentina.* Proc. 8th Int. Symp. on Vulcanospeleology, Int. J. Speleol., 27B (1/4), 155-162.
- COOMBS D.S., ALBERTI A., ARMBRUSTER T:, ARTIOLI G., COLELLA C., GALLI E., GALLI E., GRICE J.D., LIEBAU F., MANDARINO J:A:, MINATO H., NICKEL E.H., PASSAGLIA E., PEACOR D.R., QUARTIERI S., RINALDI R., ROSSm., SHEPPARDD R.H., TILLMANNS E., VEZZALINI G. (1997) *Recommended nomenclature for zeolite minerals: report of the subcommittee on zeolite of Iinternational Mineralogical Association, Commission on New Minerals and Mineral Names*. Canad. Mineral., 35, 1571-1606.
- DAVIES G.J. (1999) *"Hades" a Remarkable Cave on Oldoinyo Lengai in the East African Rift Valley.* Proc. 8th Int. Symp. on Vulcanospeleology, Int. J. Speleol., 27B (1/4), 57-67.
- FORTI P. (1994) *Cave minerals in Volcanic Caves.* Atti I Encontro Int. de Vulcanoespeleologia das Ilhas Atlanticas, Terceira, Acores, 1992, 91-98.
- FORTI P. (1998) *Le Grotte Laviche del Kenya*. Sottoterra, 105, 46-55.
- FORTI P., PANZICA LA MANNA M., ROSSI A., (1996) *The peculiar mineralogical site of the Alum cave (Vulcano, Sicily)* 7th Int. Symp. on Vulcanospeleology, Canarie 1994, 35-44.
- FORTI P., GIUDICE G., MARINO A., ROSSI A., (1996) *The MC1 cave on the Mt. Etna and its peculiar metastable speleothems.* 7th Int. Symp. On Vulcanospeleology, Canarie 1994, 33.
- GLOVER P.E., GLOVER E.C., TRUMP E.C., WATERIDGE L:E.D. (1964) *The Lava Caves of Mount Suswa, with Particular Reference to their Ecological Role.* Studies in Speleology, 1(1), 51-67.
- HEY M.H. (1931) Abstract of the paper *Zeolithe als Fossilisationsmaterial* by H. Udluft. Mineral. Abstr. (1931), 4 (1-4), 374.
- JÉRÉMINE E. (1934) *Note sur les zéolites des Monts Lubur et du Mont Elgon.* Bull. Soc. Franc Minéral., 57, 240-243.
- KASHIMA N., OGAWA T. (1998) *Speleo-minerals in Volcanic Caves of Kenya, East African Rift Zone.* J. Speleol. Soc. Japan, 23, 46-52.
- SIEMENS (1996) *XSCANS: X-ray Single Crystal Analysis System – Technical reference.* Siemens instruments.
- SIMONS J.W.E. (1974) *The lava caves of the northern Chyuly Hill, Kenya*. Studies in Speleology, 2 (6), 238-255.
- SIMONS J.W.E. (1976) *Leviathan Cave, a Major Lava Tube in Kenya*. BCRA Bull., 14, p.23-25.
- SIMONS J.W.E. (1998) *Volcanic Caves of Kenya*. A guide for the8th Int. Symp. on Vulcanospeleology. Nairobi, Kenya, February 1998, 37 pp.
- SIMONS J.W.E. (1999a) *Volcanic caves of East Africa. An overview.* Proc. 8th Int. Symp. on Vulcanospeleology, Int. J. Speleol., 27B (1/4), 11-20.
- SIMONS J.W.E. (1999b) *Guano mining in kenyan lava tunnel-caves.* Proc. 8th Int. Symp. on Vulcanospeleology, Int. J. Speleol., 27B (1/4), 33-51.
- SUTCLIFFE A.J.(1973) *Caves of the East African Rift Valley*. Trans. Cave Res. Group of G.B., 15 (1), 41-65.
- UDLUFT H. (1928*) Zeolithe als Fossilisationsmaterial.* Arrkiv Kemi Min. Geol., 9 (33), 15 pp., 2pls.

SYNGENETIC VOLCANIC CAVES IN THE WESTERN CARPATHIANS

Ludovit Gaál

Slovak Environmental Agency - 974 01 Banská Bystrica, Slovakia

Summary

The Northern and Western part of the Carpathians arch, known as the Western Carpathians, extends in the territories of Slovakia, southern Poland, Northern Hungary and the eastern part of Czech Republic. That is a result of the Alpine orogenic cycle. In the termination of Alpine orogeny, volcanic activities in Tertiary and Quaternary resulted from the subduction in the back part of the Carpathians arch. During the Middle Miocene some large stratovolcanoes of acide and intermedial alcali-calcareous volcanic rocks were formed. Later, in Pliocene and Pleistocene the volcanism had a basic character with alcali basalts in Southern (rarely in Middle) Slovakia and Northern Hungary.

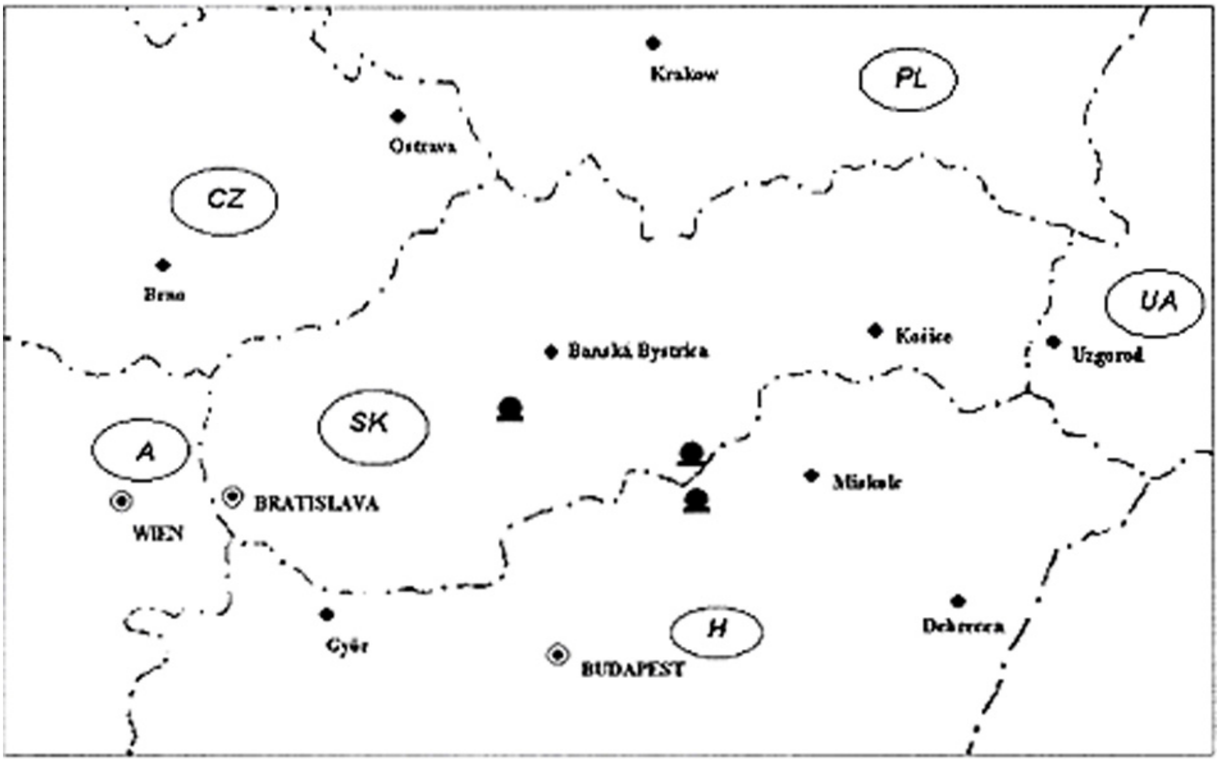


Fig. 1. Situation of the volcanic caves in the Western Carpathians.

Although the syngenetic volcanic caves also in andesite are mentioned, its syngenetic origin is not proven explicitly, because its primary features are wiped out by weathering processes.

On the other hand, the young volcanic structures of Pliocene-Quaternary basalts preserve sufficiently enough syngenetic volcanic caves with their microforms. These caves in following places are known: Ragác hill in Cerova vrchovina mountains (Southern Slovakia), Putikov vršok in the Štiavnické vrchy (Middle Slovakia) and Kis-ko hill in Northern Hungary.

There are 3 small gas cave known in scoria-cone of Ragác (Ebeczkého jaskyna with the length of 17 m, Ragácsky komín - 6,2 m and Ragácska studna with the depth of 9,3 m). Putikov vršok is the youngest volcanic structure in Slovakia (0,53 +- 0,16 Ma). The gas cave named Sezam with the length of 26,4 m is known in basalt agglomerates of this scoria-cone.

Kis-koi-bazaltbarlang with the total length of 30 m and the depth of 15,6 m is a vertical volcanic cave into eruptive fissure. The residues of lava coatings and lava stalactites occurs in the wall of the conduit.

The Northern and Western parts of the Carpathians belt, known as the Western Carpathians, extend in the territories of Slovakia, Southern Poland, Northern Hungary and the Eastern part of the Czech Republic. The mountain range is a result of the Alpine orogenic cycle. Therefore the sediments of Tethys realm are its main building elements (mainly Mesozoic and Tertiary shales, sandstones, limestones, dolomites). The older (Paleozoic perhaps Proterozoic), mainly crystallic and magmatic rocks at smaller places in core mountains and as denudation relics in older (Hercynian and Caledonian) structures are situated. In the termination of Alpine orogeny, volcanic activities in Tertiary and Quaternary were a result of subduction and the collision of the Carpathian belt with the margin of the European plate in Neogene (LEXA et al. 1993). During the Middle Miocene some large stratovolcanoes were formed in Middle and Eastern Slovakia and Northern Hungary. They are composed of acide and intermedial alcali-calcareous volcanic rocks (andesites, rhyolites, diorites, dacites). Later, in Pliocene and Pleistocene the volcanism had a basic character with alkali basalts in Southern (rarely in Middle) Slovakia and Northern Hungary.

In Miocene andesites in Northern Hungary some little caves were researched by ESZTERHÁS, which may have been origin of a volcanic explosion or exhalation (for example *Csódi-hegyi-barlang* in Visegrádi Mountains, *Kámori-rókalyuk* and *Rózsabánya andezitürege* in Börzsöny Mts, *Vidróczki-barlang* in Mátra and *Felso-barlang* in Tokaj Mts. - see ESZTERHÁS - GAÁL - TULUCAN, 1996). In the summer of 1999 I visited *Vidróczki-barlang* with the length of 5,1 m and *Függo-koi-barlang* (3,5 m) in Mátra Mountains. Both horizontal undergroud cavities in compact andesites are situated near the volcanic center, therefore we do not elimine their syngenetic origin. However, absence of its primary features (wiping out by weathering processes) do not allow us to make explicit conclusions.

On the other hand syngenetic volcanic caves with their microforms are evidently preserved in the young volcanic structures of Pliocene-Quaternary basalts. From this volcanism some small scoria-cones with lava flows, diatremas, necks and residues of maars remains. The caves only in 3 localities occur: Ragác Hill in Cerova vrchovina Mountain (Southern Slovakia), Putikov vršok Hill in Štiavnické vrchy (Middle Slovakia) and in Kis-ko Hill in Northern Hungary.

Ragác

Ragác is a small scoria-cone with the height of 250 m (536 m altitude) near village of the Hajnácka in Cerová vrchovina Mountain. At present there are remains of only NE part of the original volcanic cone with the diameter of about 1 km. The crater is not preserved. The summit region is formed by agglomerates, agglutinates and lapilli tuffs with 3 dikes of basalt. In the southern part of the Ragác is a 2,5 km long lava flow extends, which originated from the lower part of this scoria-cone. The age of the alcali nefelinite basanit of the lava flow is 1,39 +- 0,12 Ma (determined by K/Ar method, BALOGH - MIHALIKOVÁ - VASS 1981). The lava flow has a arch-like shape, because it flowed around the eastern part of older maar structure. In limnic tuffits of the crater lake of this maar Upper Pliocene mammals were found (mainly tapires, rhinoceroses, mastodontes - KUBINYI 1863, KORMOS 1934, FEJFAR 1958 and others).

The volcanism in the Ragác had a highly explosive character. In volcanoclastic rocks of the summit numerous small explosive cavities occur with the diameter of some cm to 1 m. In this part 3 gas caves are known. They were formed by fumarola processes - exhalations of volcanic gases and vapours in basalt volcanoclastics (agglomerates, agglutinates) during volcanic eruptions or shortly after them. Fumarolas were probably of high temperature (100-900 °C). Various minerals sometimes sublimated from ascending vapours. The morphological shapes of these chimnies are not regular, often with small hollows and cavities.

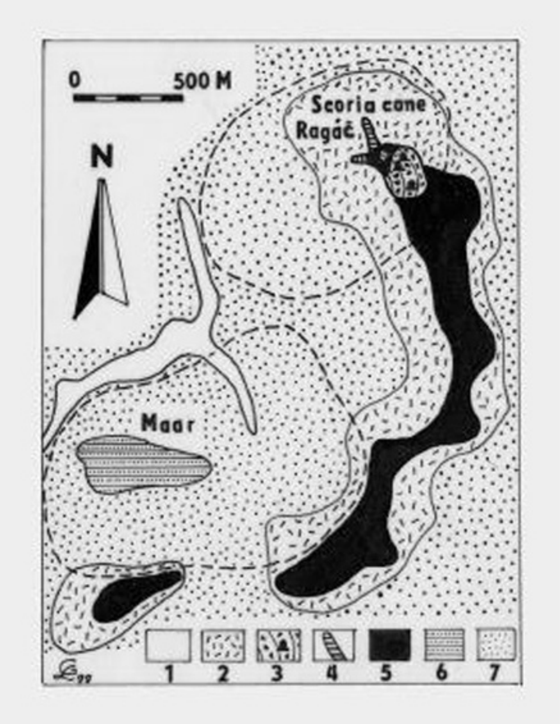


Fig. 2. Geological situation of the Ragác hill. After D. Vass - V. Konecný, 1992, modified by L. Gaál. The supposed original volcanic structures are marked by disturbe lines. Explanations: 1. Alluvium of the streams, 2. Slope sediments with the fragments of basalt (Quaternary), 3. Agglomerates and agglutinates of basalt with occurance of the gas caves, 4. Basalt dikes, 5. Lava flow (3-5 Pleistocene), 6. Tuffs and lapilli tuffs of maar (Upper Pliocene), 7. Sandstone (Lower Miocene).

Ebeczkého jaskyna (Ebeczky´s cave) is a typical gas cave on the southern slope of Ragác Hill, at an altitude of 495 m. The horizontal underground corridor is accessible with a horizontal and a vertical entrance. The total length of the cave is 17 m, the width is 1-3 m, the height of top is 1-2 m. Some sidelong prominences and hollows stick out from underground corridor. In the back part of the cave in 1990 a vertical chimney was discovered, its origin was proved by explosion of ascending gases (GAÁL - ESZTERHÁS 1990). The origin by gases of this cave was mentioned by JUGOVICS (1944), but PILOUS (1982) considered it as a weathering cave. Some thin crusts of mixture of calcite and gypsum are between the dark volcanic bombs in many places of the cave walls (by X RD analysis made by Geological Institute of the Slovak Academy of Sciences, Banská Bystrica), from which small pisolites secondarily originated. The gases probably exploded near the surface of the volcanic cone as a consequence of a sudden decrease of hydrostatical tension. There are several small explosion cavities around the cave with a diameter about 1 m.

Fig. 3. The gas cave „Ebeczkého jaskyna“. Photo by Jozef Gaál.

Ragácska studna is situated under the summit cliff of the scoria-cone of Ragác Hill. It is a vertical conduit with a diameter of 1,5 m, formed in agglomerates of vesicular basalt bombs and lapilles. Its depth was 3,8 m, but during our new research it was deepened to 9,3 m in 1999 (in older literature mentioned also 15 m - JUGOVICS 1944). In the past, its origin was explained differently: by volcanic exhalations (JUGOVICS 1944), as a volcanic crater (KLINDA 1977), as an artificial shaft (PILOUS 1982, VÍTEK 1983) and again as a volcanic exhalation chimney (GAÁL - ESZTERHÁS 1990). Its origin by fumarola processes support several features, mainly its irregular course in the lower part of the chimney (discovered during research in 1999). According to morphological shape of surrounding cliffs we can deduce a existence of explosive cavity above the present entrance of conduit. Therefore the conduit could represent a rest of intake channel of gases.

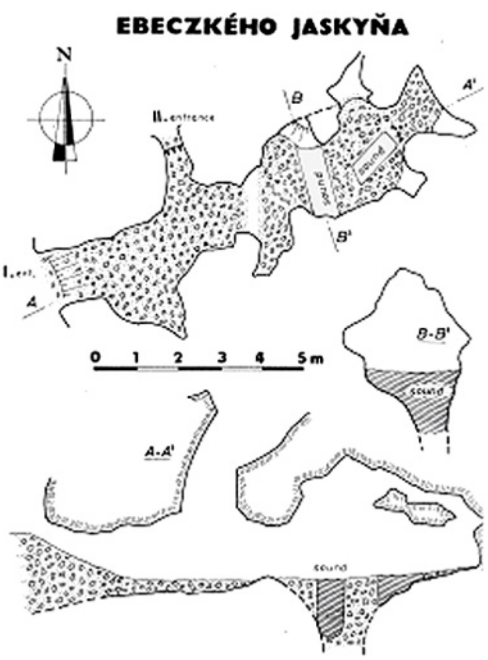


Fig. 4

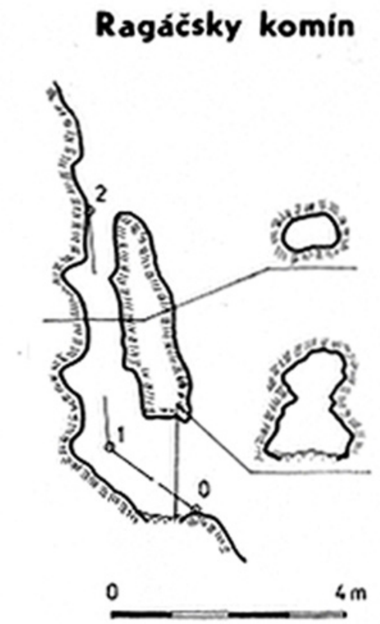


Fig. 5

Ragácsky komín is a small open volcanic conduit, described by GAÁL - ESZTERHÁS (1990) under the north-eastern wall of the summit cliff of Ragác. It has two entrances: the lower is larger (1,8 x 1,4 m) and oriented horizontally, the upper one is vertical (0,5 x 0,4 m). The lenght of the conduit is 6,2 m. It originates in agglomerates and agglutinates of vesiculare basalt bombs. There are some other small hollows and cavities around this conduit, what proves highly explosive character of the volcanism.

Putikov vršok

It is a small scoria-cone with the lava flow of nepheline basanites in the SW part of the large Miocene andesite-rhyolite stratovolcanic stucture named Štiavnica in Štiavnické vrchy mountains (Central Slovakia). The age of basanite from lava flow near Nová Bana is 0,53 +- 0,16 Ma (KANTOR - WIEGEROVÁ 1981) and it represents the youngest volcanic structure in Slovakia. The lava flow the Pleistocene terrase of Mindel-Riss age particularly covers.

Sezam is a similar gas cave as Ebeczkého jaskyna. Its entrance is relatively large (1,9 x 1,7 m) in altitude of 450 m. Its total lenght is 26,4 m, depth 14,6 m (GALVÁNEK - GAÁL, 1995, GAÁL 1996). From the horizontal corridor a vertical conduit extends with a depth of 10 m. It has irregular course with many small sidelong hollows and cavities. The cave originates in agglomerates of brown-red volcanic bombs, breccias and lava coatings, which formed the filling of the crater wall.

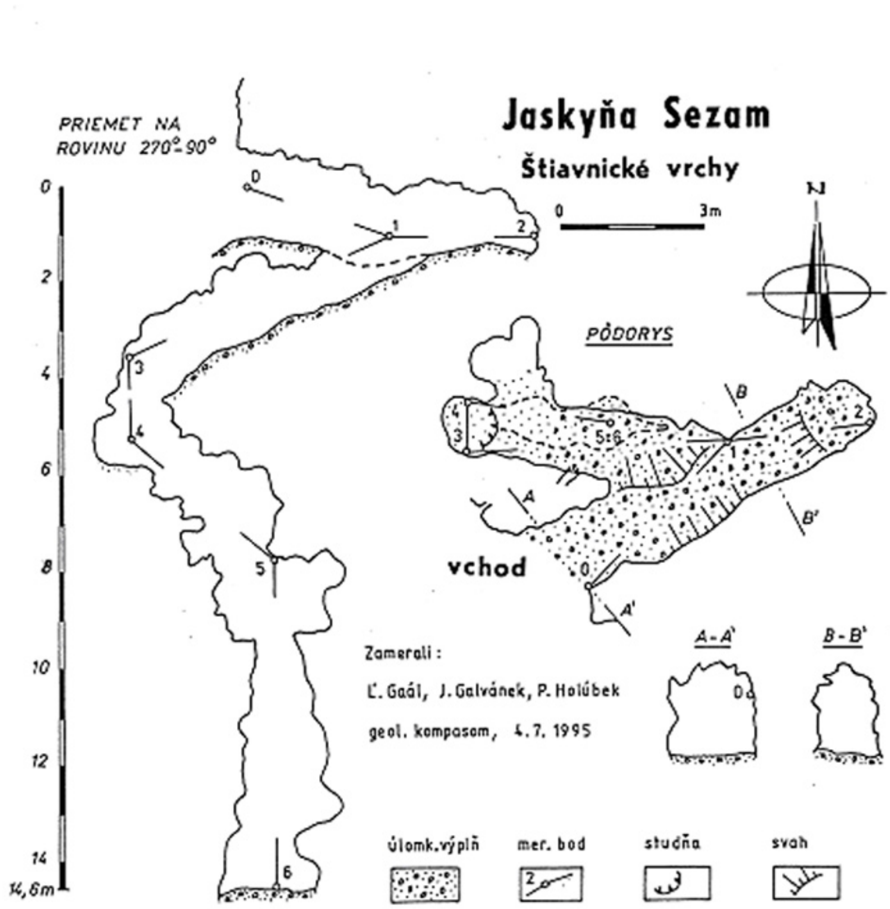


Fig. 6

Kis-ko

Kis-ko is a small hill with a basalt cliff near village Szilaspogony, 12 km east of the town of Salgótarján in Northern Hungary. The cliff represents a residue of diatrema with the height of 30 m at the altitude of 381 m. The diatrema consists of agglomerate and agglutinate of basalt with some basalt dikes. In the middle of diatrema, there is a uniquely preserved open vertikal volcanic conduit named Kis-koi-bazaltbarlang.

Kis-koi-bazaltbarlang was described by JUGOVICS (1942), OZORAY (1960), SZENTES (1971) and was mapped by ESZTERHÁS with the total lenght of 30 m and the depth 15,6 m (GAÁL - ESZTERHÁS, 1990). The vertical conduit has a crack shape in direction NNW-SSE (335°-155°) with the length of 11,5 m. The entrance is small and narrow, but the dimension of the conduit widens with its depth. The bottom part is 4,5 x 6 m wide. This space is accessible through an artificial tunnel mined in 1910. There are several stacked cavities and separated narrow and short intermediate passages in the conduit. The traces of lava flows, residues of lava coatings and lava stalactites occurs in the wall of the conduit.
According to the shape of the conduit and its typical volcanic features we can deduce its origin as a vertical cave within eruptive fissure. The lava penetrated into the eruptive fissure in finish of eruptions, had low energy, therefore is not effuse on the surface. It was quickly cooled by the contact with the surrounding damp sandstones, but it´s inner hot part flows down into the innermost part of the fissure. The similar forms was described for example from Etna (LEOTTA - LIUZZO 1998). The solid linings of the lava in the conduit wall was preserved to present and conserved the fissure before collapse.

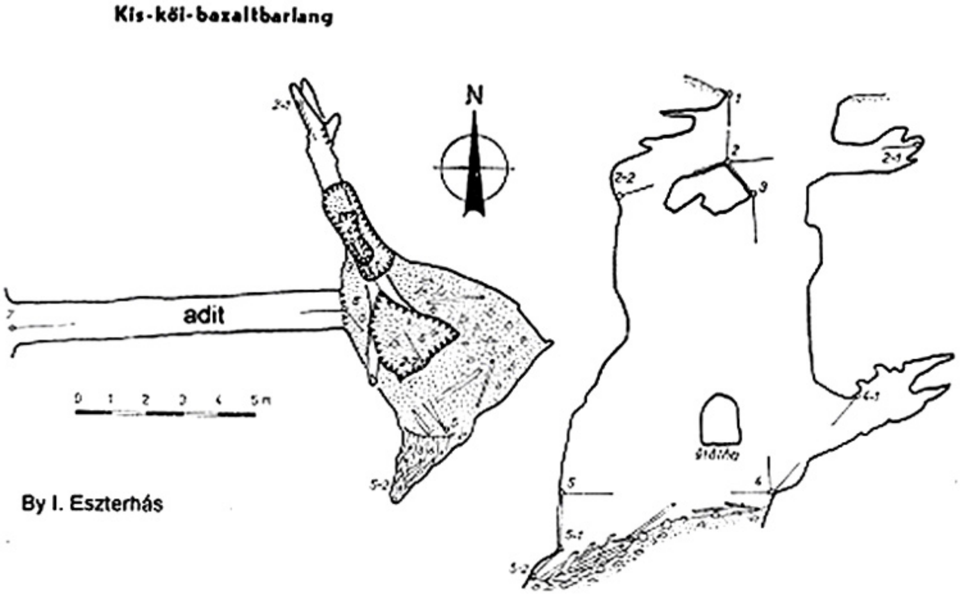


Fig. 7

About 400 caves (about 100 in Slovakia and 300 in Hungary) are known in young volcanic rocks (andesite, dacite, rhyolite, basalt and its volcanoclastics) in Western Carpathians, but the most of them are originated by slope movement (fissure caves, boulders caves) and by weathering or by other postgenetic processes. The syngenetic volcanic caves are very rare in this area, therefore they are of a great morphological, geological and mineralogical importance. They demand adequate protection and management.

References

- BALOGH, K., MIHALIKOVÁ, A., VASS, D., 1981: *Radiometric dating of basalts in Southern and Central Slovakia.* Západné Karpaty, Geol. 7, Bratislava, pp. 113-126.
- ESZTERHÁS, I., GAÁL, L., TULUCAN, T., 1996: *Caves in the Volcanic Rocks of the Carpathian Ranges*. In: Proceed. of the 6th Int. Symp.on Pseudokarst, Galyateto 1996, Publ. Isztimér, pp. 136-157.
- FEJFAR, O. 1964: *The Lower Villafranchian Vertebrates from Hajnácka near Filákovo in Southern Slovakia.* Rozpr. Ústr.úst.geol., 30, Praha, pp. 1-115.
- GAÁL, L., 1996*: Nové jaskyne v bazaltoch Slovenska s dôrazom na ich prírodovedecký a kultúrno-historický význam.* In: Kras a jaskyne, Proceed. of Confer. 1995, Liptovský Mikuláš, pp. 57-62.
- GAÁL, L., ESZTERHÁS, I., 1990*: Pseudokrasové jaskyne Cerovej vrchoviny - otázky genézy a rozšírenia.* Slovenský kras, 28, Liptovský Mikuláš, pp. 71-102.
- GALVÁNEK, J., GAÁL, L., 1995: *Nová sopecná jaskyna na Slovensku*. In: Preserving of Pseudokarst Caves. Proceed., Rimavská Sobota-Salgótarján, pp. 104-109.
- JUGOVICS, L., 1942: *Salgótarján és Bárna környékén eloforduló bazaltok és bazalttufák.* Magyar Kir.Földt.Int. Évi jel. 1936-1938-ról. Budapest, pp. 957-969.

- JUGOVICS, L., 1944: *Adatok a nógrád-gömöri bazaltterület ismeretéhez.* Magy.Kir.Földtani Int. Évi jel., Függelék 4, 6, Budapest, pp. 277-328.
- KANTOR, J., WIEGEROVÁ, V. 1981: *Radiometrické veky niektorých bazaltov Slovenska podla 40 Ar/40 K metódy.* Geologica Carpathica 32, 1, Bratislava, pp. 29-34.
- KORMOS, T., 1917: *Az ajnácskoi pliocén rétegek és faunájuk*. Magy.Kir.Földt.Int. Évi jel. 1915-rol, Budapest, pp. 524-541.
- KUBINYI, F., 1863: *Az ajnácskoi osemlosök.* Magyarhoni Földtani Társ. Munkái, 2, Pest, pp. 77-89
- LEOTTA, A., LIUZZO, M. 1998: *The 1981 eruptive fissure on Mt Etna. Considerations on its exploration and genesis.* Intern. Journal of Speleology, 27, 1-4, pp. 147-153.
- LEXA, J. ET AL. 1993: *Distribúcia vulkanitov karpatsko-panonského regiónu v priestore a case.* In: (Rakus ed.): Geodynamický vývoj a hlbinná stavba Západných Karpát. Bratislava, Geol.ústav D. Štúra, 57-70
- OZORAY, Gy. 1960: *Nemkarsztos üregek genetikája magyarországi példák alapján*. Karszt és Barlangkut. Táj., Budapest, pp. 4-15.
- PILOUS, V. 1982: *Pseudokrasové dutiny v neovulkanitech jižního Slovenska.* Ceskoslovenský kras 32, Praha, pp. 73-84.
- SZENTES, Gy. 1971: *Caves formed in the Volcanic Rocks of Hungary.* Karszt és Barlangkut. 6, Budapest, pp. 117-129.
- VÍTEK, J., 1983: *Nekrasové jeskyne v Cerové vrchovine.* Krásy Slovenska 60, 10, Bratislava, pp. 39-40.

RESULTS OF SURVEY ON GANNO-ANA CAVE SYSTEM, EXAMPLE OF CO-EXISTENCE OF LAVA CAVES AND TREE MOLDS

*T.Ogawa, H.Tachihara, T.Oosako, R.Katsumata, Y.Nakamura, T.Watanabe, H.Hinata, T.Makita, M.Tachika, Y.Kuroishikawa, K.Nakaue, M.Satou, T.Watanabe, H.Miyashita, K.Suzuki, K.Inose, H.Murakami, M.Gomi, H.Hayakawa, K.Fujiya, K.Kawamura, A.Kokado, K.Hirano, A.Miyazaki, T.Honda **

* Mt.Fuji Volcano-Speleological Society, 3-6-1 Otsuka, Bunkyo-ku, Tokyo, 112-0012 Japan

Abstract

On the northern flank of Mt.Fuji, located Ganno-ana cave area in the lava flow of Ganno-ana which is beleived empted more than 1000 years ago. In this area, a lot of lava tree molds and lava caves have been found and investigated as pioneer by Ishihara (1925-29) at first, however not with fully systematic way. Recently, Comrnission on vulcanospeleology of Speleological Society of Japan (Ogawa/Tachihara's group,1996-1998) have surveyed this area systematically for environment protection, and found lots of tree-molds, two crater lake and lava trench in this area, and made a map of distributions of these.

Fig.l shows distribution of tree molds and location of crater lake, gas cavities and lava trench. Arrows indicated near tree molds are directions of lava flow iudged from tree molds structure which are results and registered traces of interaction between tree and lava flow. Tree molds are indicatifs of lavaflow direction, flow speed and lavaflow thickness.

Fig.2 shows the cross section of Ganno-ana cave and adiacent area observed by topological survey. Ganno-ana cave have a continuous structure with other caves and tree molds. These tree molds and lava cave and gas cavities may be resulting from lava flow from these two crater lakes. The detail inner and outer structure of tree molds are measured and the detail investigation on formation mechanism of this cave system is under being performed.

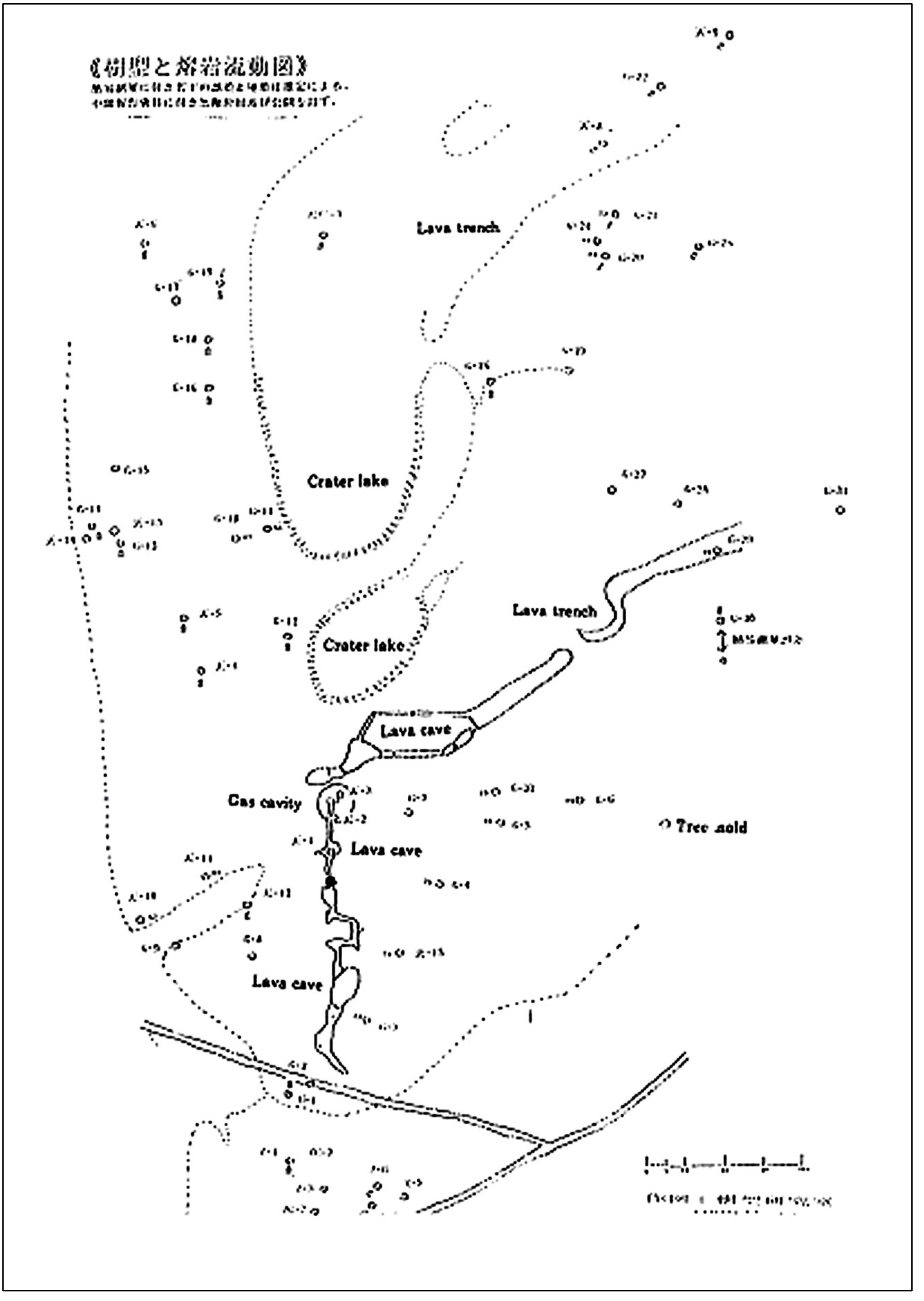


Fig. 1 – Distribution of tree molds and location of crater lakes, gas cavities and lava trench.

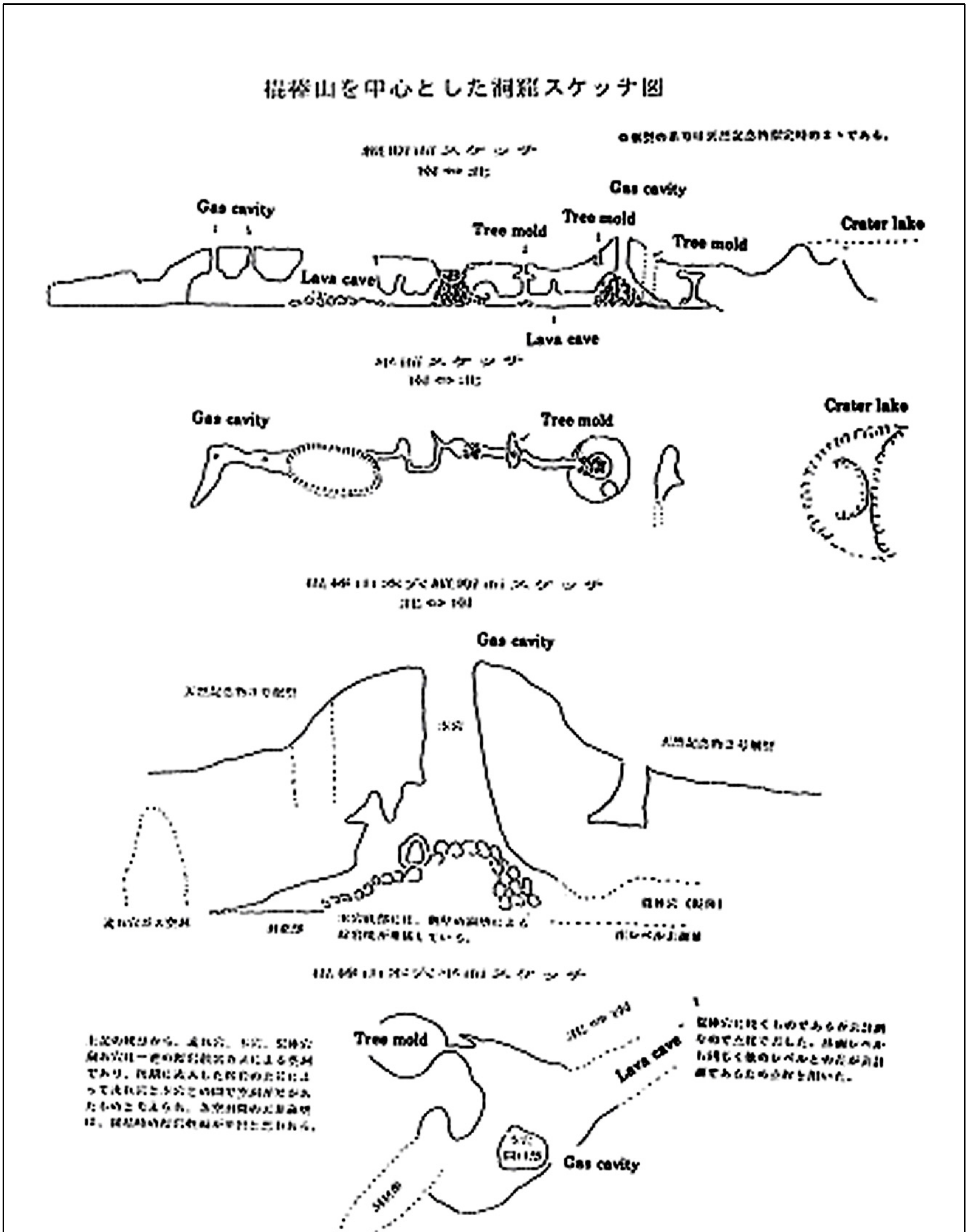


Fig. 2 – The cross section of Ganno-ana cave and adiacent area by topological survey.

SECOND SPELEOLOGICAL EXPEDITION TO SURTSEY

Sigurður S. Jónsson and Guðmundur Löve

Icelandic Speleological Society, P.O.Box 342 , 121 Reykjavík, E-mail ssjo@os.is, gl@info.is

Summary

The second ISS expedition to the volcanic island Surtsey off the South-coast of Iceland was organised in late summer 1998. Participants from the ISS were six and the expedition's planned duration was for four days.

Results of the first speleological investigations in Surtsey have been described by Jonsson & Hroarsson (1992). Seven caves were discovered of which three were surveyed and a map published of the largest cave.

Very severe weather conditions seriously inhibited the work of the second speleological expedition to Surtsey. Surveys of two caves were nearly completed but with less accuracy than could have been accomplished if conditions had allowed.

The first cave that was discovered in Surtsey, SU-01 was re-surveyed but Jonsson surveyed the cave in 1994 (unpubl.).The cave opens in to a sea cliff and by comparing the two surveys the destruction rate of the cave can be estimated. SU-01 is the only cave in Surtsey that opens out to the open sea.

One new cave was discovered inside the western crater and an unexpected connection made between the newly discovered cave and a previously known but unexplored pit, also inside the crater. A preliminary draft of the system is presented but an accurate survey awaits next expedition to Surtsey.

The underlying shaft of the hornito/crater on the northern side of the hyaloclastite crater rim was descended and explored. The shaft is 18 metres deep and ends in a semi-closed elongated eruptive fissure. The western end of the fissure is overhung by a lip of lava, sheltering the site from incoming precipitation and thus preserving an enormous quantity of mineral encrustations, some of which are water-soluble. Protruding small spiral-like crystals of mirabilite are abundant as well as crusts of gypsum with specks of fluorite and ralstonite. A preliminary draft of the volcanic conduit and fissure is presented.

Samples of mineral encrustations were collected from the largest cave, SU-03 and the cave was photographed.

Ten caves are now known in Surtsey. All have now been explored and five have been surveyed to a different level of accuracy. Further studies are needed to complete the investigations.

GEOLOGY OF THE HUEHUE TUBE (ERUPTION 1801) AND THE PUHIA PELE CHANNEL SYSTEM, HUALALAI, HAWAII

Stephan Kempe, Christian Lerch and Matthias Oberwinder

Geol.-Paleontol. Inst., TU-Darmstadt, Schnittspahnstr. 9, D-64287 Darmstadt, Germany

Abstract

Historic records suggest that the Hualalai, the only active volcano in its terminal alkali basalt phase on Hawaii, erupted last in 1801. The precise boundary of this flow, the Huehue flow, was previously confused with another flow similar in age, the Puhia Pele Flow. The flows can now be separated because an extensive tube system, with a length of 10.8 km in total, has been mapped in the Huehue Flow in the past few years by teams of the Hawaii Speleological Survey (Medville and coworkers and Kempe and coworkers).

The tube shows that the 1801 lava issued from an inconspicuous vent at an altitude of ca. 540 m a.s.l. and continued all the way to the sea, keeping to the south of the earlier Puhia Pele flow and partly covering it. The tube covers an altitude difference of 495 m and ends in a lava seal at ca. 30 m a.s.l. The main passage has a length of 6.17 km end-to-end and a sinuosity of 1.2. The Huehue Tube has 29 pukas (collapse holes), part of those already formed when the cave was still active (hot pukas). These allowed ventilation through the incising tube, causing the freezing of extensive secondary ceilings in the upper part of the tube. Puka 17 served as a rootless vent, issuing hot pahoehoe lava to the surface, straddling the Puhia Pele Flow, thereby confusing the surface picture further. In fact the upslope boundary of the smooth Puka 17 lava, where it borders at the hummocky main flow lava, was thought to mark the end of the 1801 flow originally.

Contemporary with the Huehue flow, i.e. active at the same time, was a second small vent, within 50 m of the point where the Huehue tube starts. This vent (possibly a rootless vent above a tube parallel to the Huehue tube) forms a small shield-like dome from which hot pahoehoe lava issued. This lava, termed Mystery lava, covers the upper part of the Huehue lava and interacted in various ways with the lava flowing below in the tube. The Mystery lava gradually changed downslope into prominent aa flows, which, in part, form the roof of the Huehue tube. Two small scale cave systems have been mapped in the mystery flow, Zoe’s Puka, 428 m long, and Puka 4 Cave, 292 m long, both caves are rather narrow and not very mature.

Below the Huehue/Mystery lava lies the Puhia Pele Flow. It is very different from the Huehue Flow, having a much higher gas content. This led to the buildup of a spectacular series of spatter cones and spatter ramparts at an altitude of 499 m a.s.l.. At least three of the vents are still open to a depth of over 100 m (ongoing exploration by J. Rosenfeld). Below of the spatter ramparts a spacious tube system started, the beginning of which is now collapsed into a trench. The lower part forms an about 400 m long cave, interrupted by several pukas, before it issued into an open trench. At this point the channel is filled with Mystery aa, obliterating the lower end of the cave system. The entire trench System was now mapped by our group with DGPS (Differential Global Positioning System). It extends down to about 80 m a.s.l.. In this section the trench was blocked several times, leading to the formation of short caves and causing extensive overflows. Two overflow side channels to the north were established. Twice the trench was invaded by Huehue lava from the south. Below an altitude of 80 m a.s.l. a wide lava delta formed, which again featured a central tube. This tube overflowed several times issuing wide and flat lava fields. Today only those parts of the feeding system can be seen, which evolved by breakdown above the original tube. The tube itself seems to be filled entirely by ponded lava. This is especially evident in Giant Room Cave, which is essentially one large 145 m long chamber closed at both ends by lava seals. Apparently the Puhia Pele delta must have flooded the area by at least 10 to 15 m of

lava. This large mass of hot lava cooled over a longer time period, allowing steam venting and causing the deposition of brown mineral deposits along prominent contraction cracks.
At places where thin Huehue lava fingers cross the center of the Puhia Pele flow, these brown mineralizations are seen also on the Huehue lava. This observation suggests that the distance in time between the two flows may not have been more than fifty years, possibly even less than ten years. Clearly the activity of the Puhia Pele Flow had terminated when the Huehue/Mystery lava erupted, but apparently there was still enough heat in the ponded lava to influence the weathering of the transgressed Huehue lava. We therefore suggest that the Puhia Pele Flow must have erupted at around 1780 AD ± 20 a. This date is consistent with archeological finds which we made in the Puhia Pele Cave, indicating that it has been used for a variety of purposes.

CHECKLIST AND DISTRIBUTION OF ICELANDIC LAVA CAVES

Sigurður S. Jónsson and Guðmundur Löve

Icelandic Speleological Society, P.O. Box 342, 121 Reykjavík, E-mail ssjo@os.is, gl@info.is

Abstract

Since the founding of the Icelandic Speleological Society in 1989, systematic collection of cave-data has been conducted by the society. The pioneer work of Hroarsson (1991) lay the foundations for that database and additions have been quite a few every year.

The island is 103.000 km^2 and the potential cave areas are confined to the neovolcanic zone from the Reykjanes peninsula in the southwest through Langjökull, and north to the Melrakkaslétta peninsula from Vatnajökull, with offshoot from the centre-line between Langjökull and Vatnajökull to the south towards the Vestmannaeyjar archipelago. The area covered with postglacial lava-flows; (younger than 10-13.000 years) is about 10.000 km^2. In the book *Hraunhellar á Íslandi* (Hroarsson, 1991) the author mentions about 150 caves. Today the total number of caves is 225. The total added length of all known lava-caves in Iceland is about 37 km. Numerous small caves are not listed, some caves on the list are "lost" and Icelandic speleologists like to think that there are many more out there to be discovered.

Since 1995 the ISS has tried to mark all the known caves, when visited, with a specially prepared plastic ribbon with pre-printed marking. The serial number of the cave to be tagged is marked on the ribbon using a waterproof felt-tip marker and hung up inside, in the dark zone of the cave.

A checklist of all known Icelandic lava caves is presented.

NEW MINERALS FROM ICELANDIC LAVA CAVES AND SELECTED SPELEOTHEMES

Sigurður S. Jónsson and Guðmundur Löve

Icelandic Speleological Society, P.O. Box 342, 121 Reykjavík, E-mail ssjo@os.is, gl@info.is

Abstract

Many Icelandic caves exhibit abundant mineral encrustations but a lot of work is still to be done in that field. The Icelandic caves are prone to a large quantity of precipitation nearly all year round and thereby water-soluble minerals vanish very quickly after they have formed. In several caves special conditions prevail like for instance in Surtsey, due to the low age of the lava flow, many unstable water-soluble minerals are still present. During the second ISS expedition to Surtsey, samples resembling *mirabilite* were collected. The mineral has very loosely bound molecular water, which is readily lost, when samples are removed from the cave environment. Due to the confirmed presence of the anhydrous sodium sulphate *thenardite*, a suspicion arose about the possible presence of *mirabilite*. A sample was carefully packed in a container with moist paper towel to preserve the humidity of the cave environment. Upon arrival from Surtsey the sample was immediately analysed with the Icelandic Energy Authority's XRD equipment, with several hours intervals. The presence of *mirabilite* was confirmed. A rate of the transformation from *mirabilite* to *thenardite* was also quantified to some extent.

In the cave Arnahellir on the Reykjanes peninsula, bright-green coatings on stalagmites were noted several years ago. Samples were taken from the cave and analysed with XRD. The results were rather surprising as it turned out to be *volborthite*, a copper-vanadate normally found in different environment. Later the presence of both copper and vanadium in the mineral was clearly confirmed using the Icelandic Technological Institute's Scanning Electron Microscope's EDS.

Icelandic lava caves display a vast array of speleothemes which Icelandic speleologists have had difficulty putting in global perspective. The caves Arnahellir and Jörundur in South Iceland are the two best examples of caves with extensive decorations, mostly stalagmites and stalactites, made from segregational liquid. Several examples of odd and unusual speleothemes are presented.

LAVA CAVES OF GRANDE COMORE, INDIAN OCEAN: FURTHER INVESTIGATIONS, JULY 1998

Gregory J. Middleton

Member, IUS Commission on Volcanic Caves, Sydney Speleological Society, Southern Tasmanian Caverneers. Address: PO Box 269, Sandy Bay, Tasmania 7006, Australia.
e-mail: gregmi@dpiwe.tas.gov.au

Abstract

The author initiated speleological investigations on Grande Comore in September 1997 when some fifteen lava cave entrances were located and, to varying degrees, explored and surveyed (Middleton 1998a, b).

The results of this initial work encouraged a second visit in July 1998. Exploration of most known caves was completed and a number of additional caves were located and surveyed. 28 caves have been documented with a total length of over 4,000 metres. The first known roost of the endemic fruit bat, the cave-dwelling *Rousettus obliviosus,* was located. Efforts to reach the island of Anjouan were unsuccessful, as was a search for caves on the smaller island of Moheli.

Background

The lava caves of Grande Comore, the largest island of the Comoro Archipelago in the Indian Ocean NW of Madagascar, are the result of lava flows from the active Karthala Volcano or its subsidiary vents (Fig. 1). Significant flows occurred in 1972 and 1977; the most recent (explosive) eruption was in 1991 (Chester 1993, pp. 286-289).

The impetus for investigation of these caves came from Bill Halliday, now Hon. President of the IUS Commission on Volcanic Caves, who had received a verbal report on the occurrence of lava caves on Grande Comore from the late Haroun Tazieff. Some 15 entrances to volcanic caves were investigated by the author on his initial visit in September 1997.

The author returned to the Comores on 29 June 1998 with Imran Vencapah, a cave enthusiast from Mauritius, who acted as interpreter and survey assistant. We were further assisted by Bahassani Djaffar who acted as Comoran-French translator and looked after our car and, when necessary, our ladder and rope.

The plan was first to revisit those caves that had not been fully explored/surveyed the previous year and complete this work; then to try to find others of which we had reports and, finally, to ask the local people about other caves.

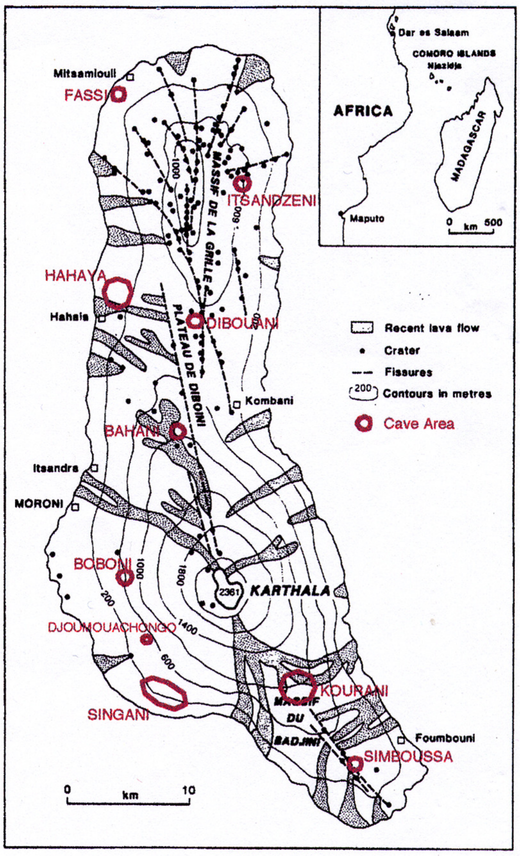


Fig. 1 - Grande Comore, showing lava flows, craters and fissures (from Chester 1993) and approximate positions of arbitrary 'cave areas' designated by the author for ease of reference.

Collaboration with CNDRS

In order to establish contact with the Centre National de Documentation et de Recherche Scientifique (CNDRS) we visited its headquarters in Moroni on 30 June. The Director was away but we were introduced to Dr Aïnouddine Sidi, Acting Director, to whom we explained our purpose and intentions. A draft copy of the author's previous report (Middleton 1998b) indicated the work already carried out. Dr Sidi invited our cooperation with CNDRS and indicated his support for our investigations. He subsequently provided us with an official letter and requested that we include a technical officer from the Centre in our team. Yahaya Ibrahim, a botanist by training, subsequently joined us and proved a most valuable member of the team.

Results of investigations

Hahaya Cave Area[1]

GPS locations were determined for the three entrances (#10 - now HH1, #11 - HH2, and #12 - HH3) although as all are within a circle of radius less than 20 m, the differences are unlikely to be real, given the c. 100 m accuracy of the instrument.

HH2: The largest of these three caves, the exploration of which could not be completed in September, was completely explored and surveyed. It was expected that this cave, which was heading directly for the main runway of the international airport (Fig 2), would have been detected and collapsed during the airport's construction. This turned out to be the case; about 90 metres beyond the fork where the initial survey had stopped, we came to rubble piles (after a further fork) in all three passages (Fig. 3). From the freshness of the rocks and scratches on them clearly due to earthmoving equipment, it was obvious that the closures were of human origin. Although expected, this was some-thing of a disappointment as this cave had the potential of another 500 m or so before possibly reaching the sea. Indeed, we found marine mollusc shells in this cave which are most unlikely to have got there by any agent other than their own efforts. We continued the survey for a grand total of 475 m (see Fig. 4).

Fig. 2 - The large passage of HH2 held considerable promise, and the potential to reach the sea.

Fig. 3 - Sealed passage in Cave HH2 under Hahaya airport, east coast, Grande Comore.

[1] For ease of reference, I propose some arbitrary cave areas - see Fig. 1. Hahaya (or Hahaïa), code HH, on the west coast in the vicinity of the airport, is the most cave-rich yet identified.

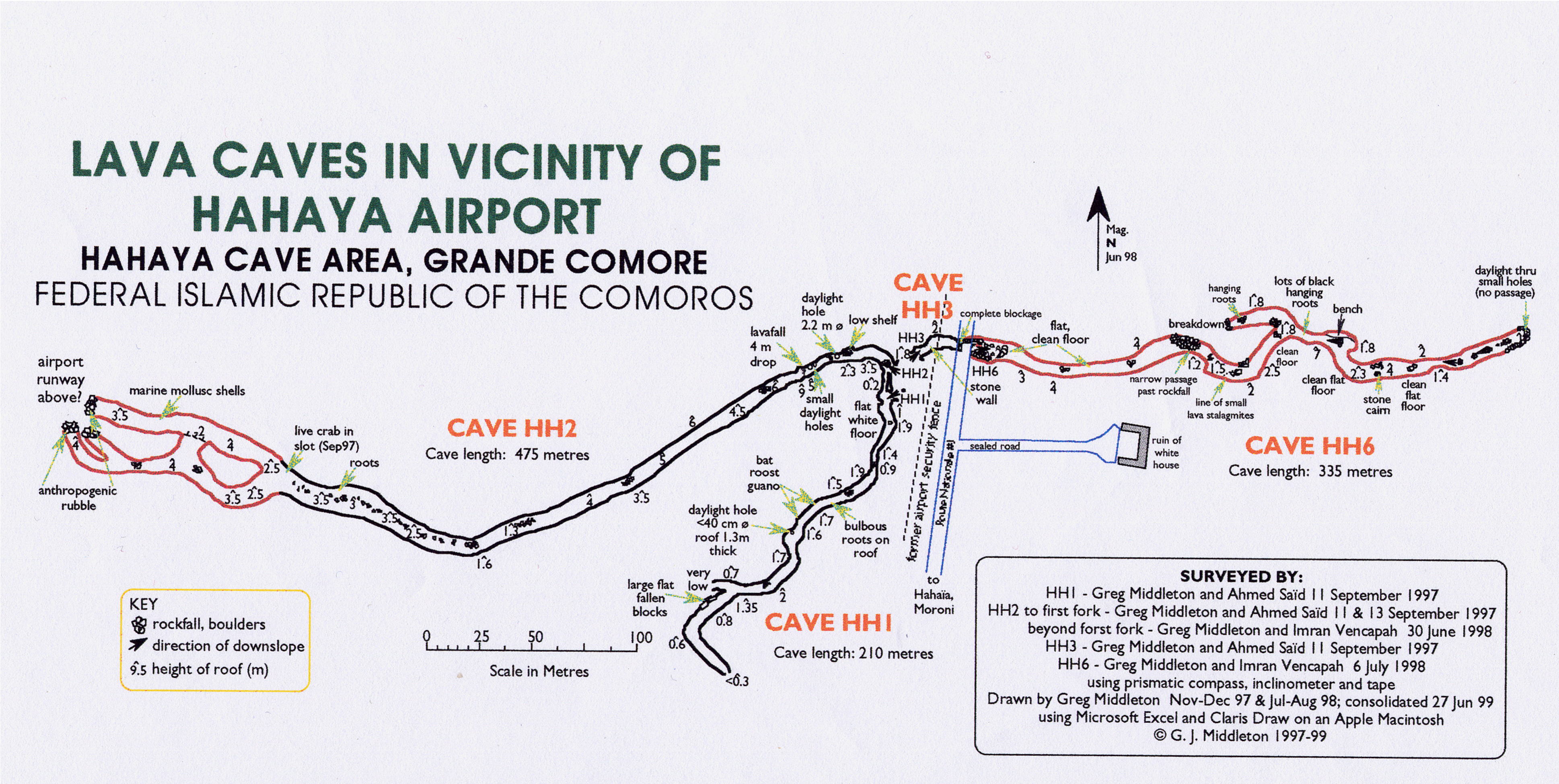


Fig. 4 – Four lava caves in the vicinity of Hahaya international airport. HH1, the major part of HH2 and HH3 were explored and surveyed in September 1997. The western most part of HH2 (beyond the first fork) and HH6 were explored and surveyed in June-July 1998. HH2 may have originally reached the sea, some 500 m to the west, but has been collapsed and filled where it runs under the airport runway.

Ngama Mhimadji-Panga Mnouka (Cave #17-18, HH8-9)

A local man, Ali Mmadi, helped us refind cave #14 [HH4] and showed us others in the vicinity: Panga Betini (#16, HH7), Ngama Mhimadji (#17, HH8: a hole about 20 m deep and 15 m in diameter, named for a type of tree, three of which grow in it) and Panga Mnouka (#18, HH9: meaning odour, though we noticed nothing unusual).

We proceeded to explore and survey from HH9. Fortunately, this connected with HH8 (see Fig. 5), obviating the need to descend that ngama, but we did not find an underground connection with HH7, though it was not far away. While surveying we collected a few snails in this cave and some cave crickets just below HH8. [The snails were subsequently identified as an endemic *Trophidophora (Ligatella)* sp. and two natives, *Subulina striatella* and *Gastrocopta microscopica*.] We came across a barn owl in the cave beyond, cowering in the darkness.

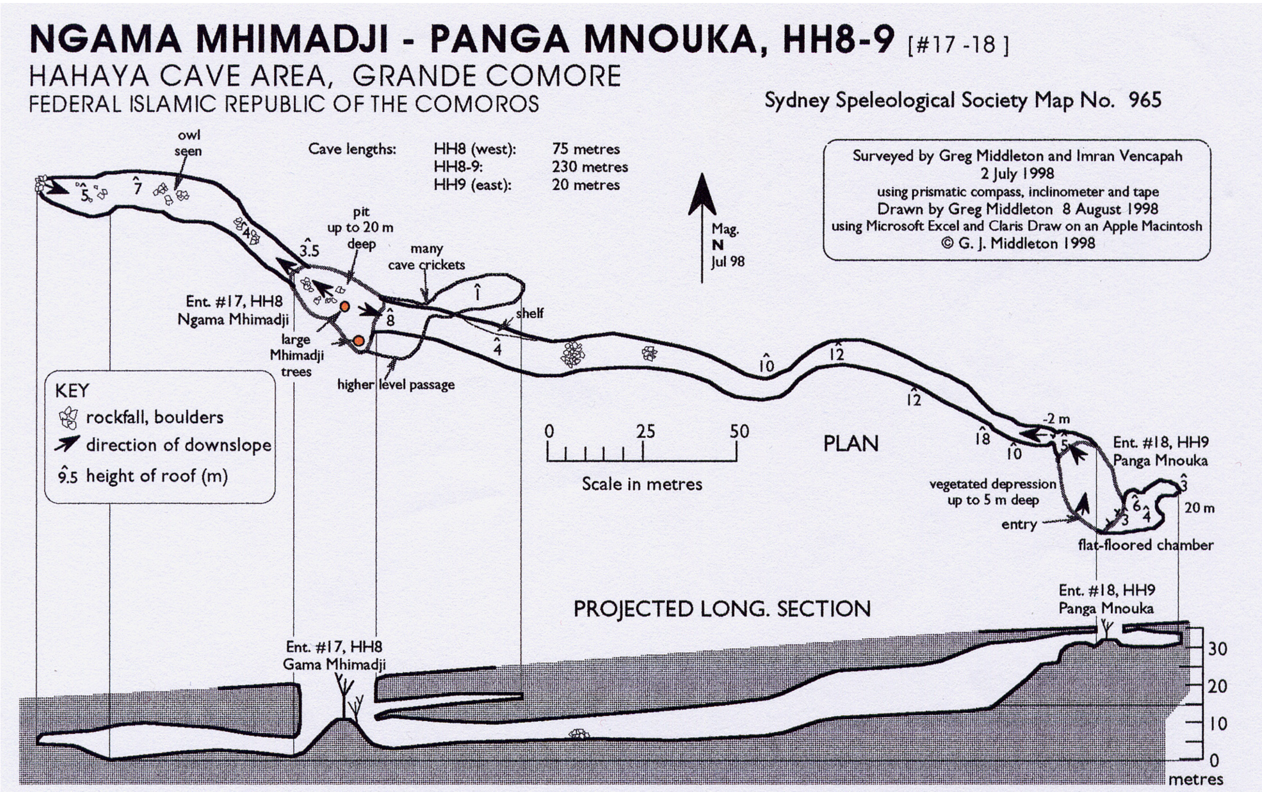


Fig. 5 – Plan and projected longitudinal sections: Ngama Mhimadji – Panga Mnouka, HH8-9, a two entrance lava tube inland of the Hahaya airport.

Panga Mhandou (#14, HH4-5)

On 3 July we returned to Hahaya area to complete the deferred survey of Panga Mhandou. Looking around the entrance chamber, I discovered there was a further section, extending to the east, I had missed last September. We surveyed this (see Fig. 6) and then walked through the cave to the entrance I had referred to as #14a [HH5] where we commenced surveying the rest of the cave. Neither of the two upper levels went very far and the more promising main passage ended in a huge mound of vesicular lava after a further 60 m. A few small insectivorous bats were seen, either solitary or hanging in small groups.

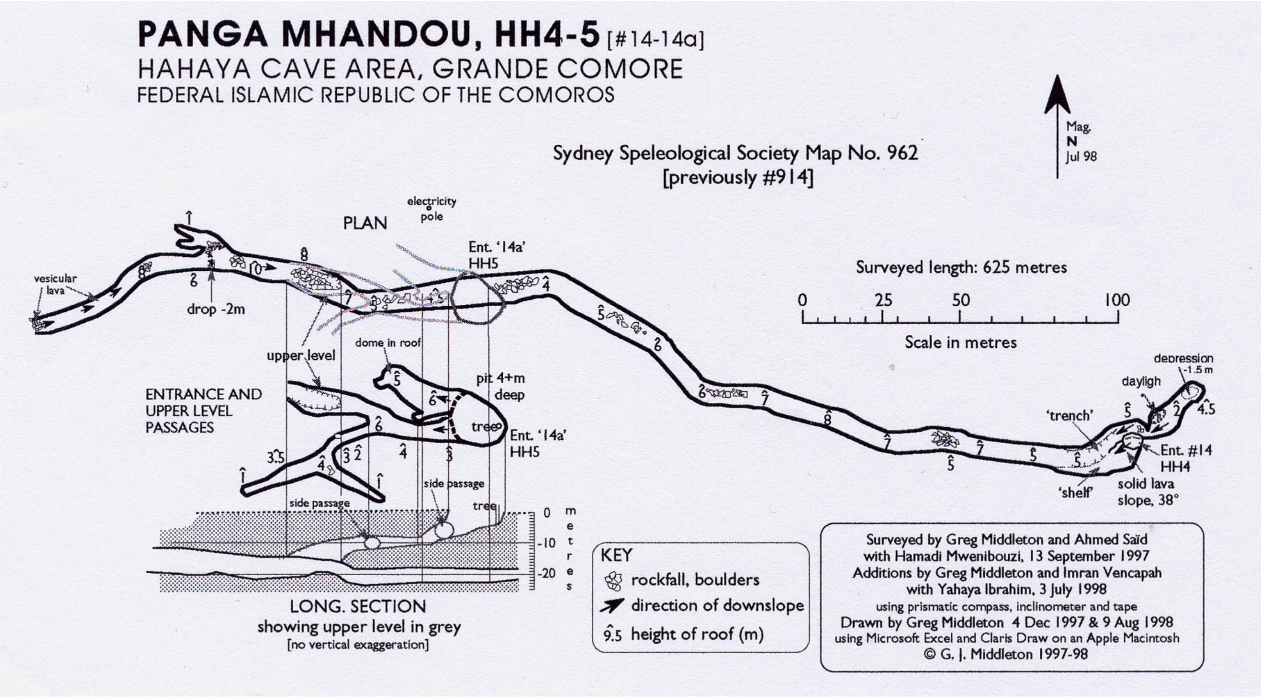


Fig. 6 – Plan of Panga Mhandou, HH4-5, in the Hahaya cave area. The lava tube between entrance HH4 and the passage connecting with HH5 was explored and surveyed in September 1997, the short section east of HH4 and that west of the passage up to HH5 were added in July 1998.

Panga Betini (#16, HH7) and following series (#21-#24, HH10-13)

Panga Betini [HH7] is entered through a hole about 4 m deep (Fig.7). The roof of the chamber at this point is extremely thin, perhaps only 30 cm.

This turned out to lead to quite a complex and interesting system, connecting directly to holes #21 [HH10] and #22 [HH11] which lead, overland along a collapsed depression, to #23-24 [HH12-13]. We surveyed all the accessible passages, which totalled 345 m for Betini and 180 m for HH12-13 (Fig. 8).

In a flat floored chamber just off the HH7 entrance chamber we were surprised to notice a number of stone circles (Fig. 9). These had clearly been placed in position by humans but the reason was not obvious. They did not appear to be fire rings as there was no accumulation of charcoal or ash in them. There were some small fragments of carbon but these seemed much more likely to be the remnants of flaming torches which would have been required for light. Possibly the stones had some religious or spiritual significance, or held water-filled gourds, but we did not notice others in other caves. There was also a low stone wall of a type we did notice in a number of caves. In the same chamber was a very fine white stalagmite. It appeared to be composed of lava and the white material may have been deposited later.

Fig. 7 - Entrance of Panga Betini.

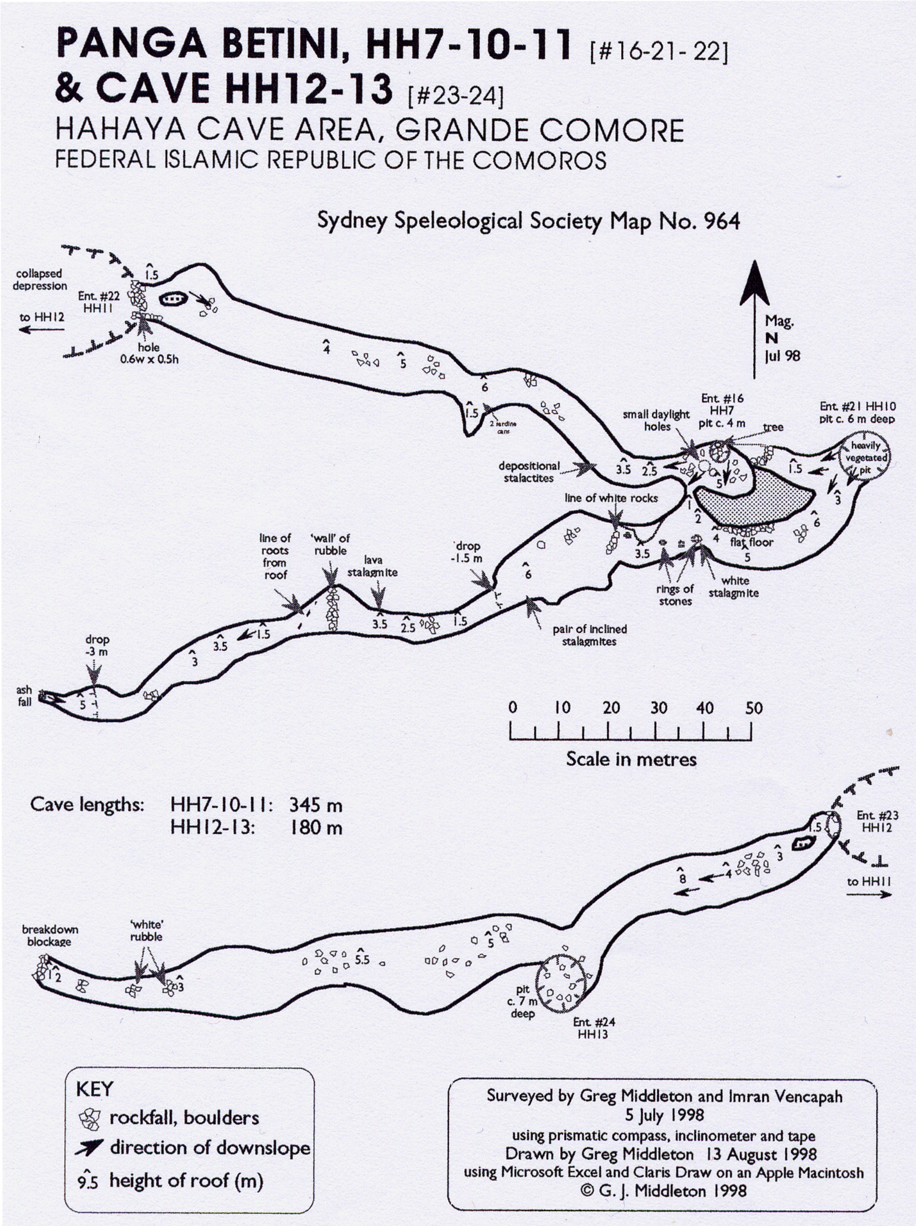


Fig. 8 - Plans of Panga Betini, HH7-10-11, and nearby HH12-13 which probably once connected to HH11 but is now separated by an elongated depression.

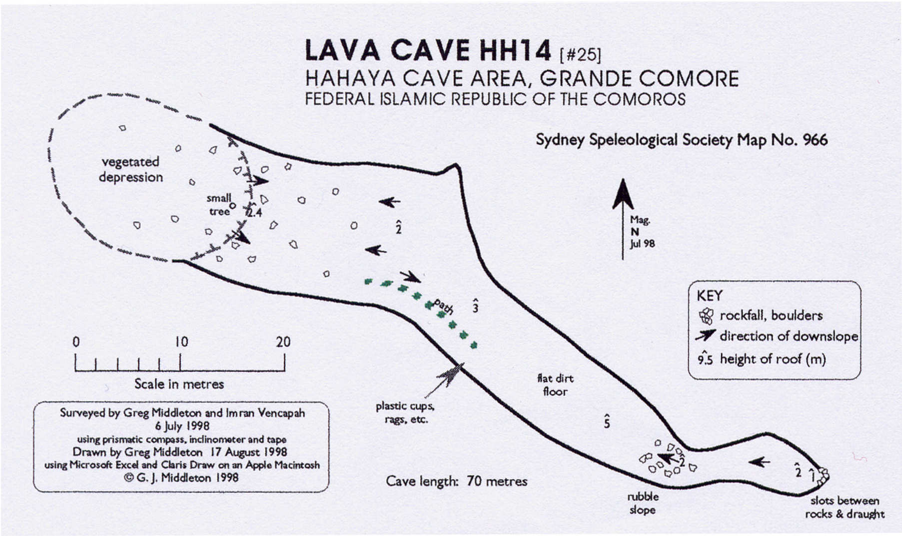
Fig. 9 - Unexplained stone circle, Panga Betini.

Caves #25 [HH14] and #15 [HH6]

Cave #25 [HH14] was surveyed (see Fig. 10). This held no surprises but we did notice bits of cloth and large numbers of plastic cups of the kind used by some airlines. There was also a well developed path to the back of the cave and someone had been using a car driveshaft to try to excavate at one point.

The last cave I had visited on my first trip, #15 [HH6], on the opposite side of the main road from HH1, 2 and 3 was surveyed. We commenced at the entrance HH3, across the road from HH6, to test my theory that this cave was actually the continuation of HH3 before it was collapsed when the main road was built.

I had noted "… it is possible that there may be a way around it [the rockfall] to the right" (Middleton 1998a, b). Indeed there is and we were able to survey on along some very spacious and clean passage until eventually we reached the inevitable blockage. In this case, however, we were able to see sunlight through small holes. Getting out at this point, however, was not possible. The cave has a length of 335 m. An unexpected find was a stone cairn about 250 m into the cave.



The survey plan is presented in Fig. 4, which also shows HH3 - clearly the former entrance to the system, before roadbuilders collapsed the passage under RN1.

Fig. 10 - Plan of the cave HH14, a small lava tube east of the Hahaya airport. Plastic cups may indicate it has been frequented by personnel from the airport.

Simboussa Cave Area: Ngama Yondzi, SB1

On 1 July we concentrated our efforts on the pits in the Simboussa and Kourani areas. Cave #2 [SB1] was easily relocated as it is beside Route Nationale 5. The pit proved to be 8 m to the top of the rubble pile and a further 6.2 m to the deepest point. We could find only one minor extension, to the south-west (see Fig. 11) in which there were some depositional speleothems, including a very fine, though short, column. There was a species of small insectivorous bat roosting on the walls, often solitary or in small groups. Not a great deal of rubbish has been dumped here, considering how convenient the hole is to the main road – though there was a motorised plough. Unfortunately a lot of medicines, including many hypodermic syringes have been carelessly disposed of in this pit.

We were told the name of the cave is Ngama Yondzi. Subsequently we learned that ‘ngama’ is equivalent to the French ‘trou’ (hole or pit).

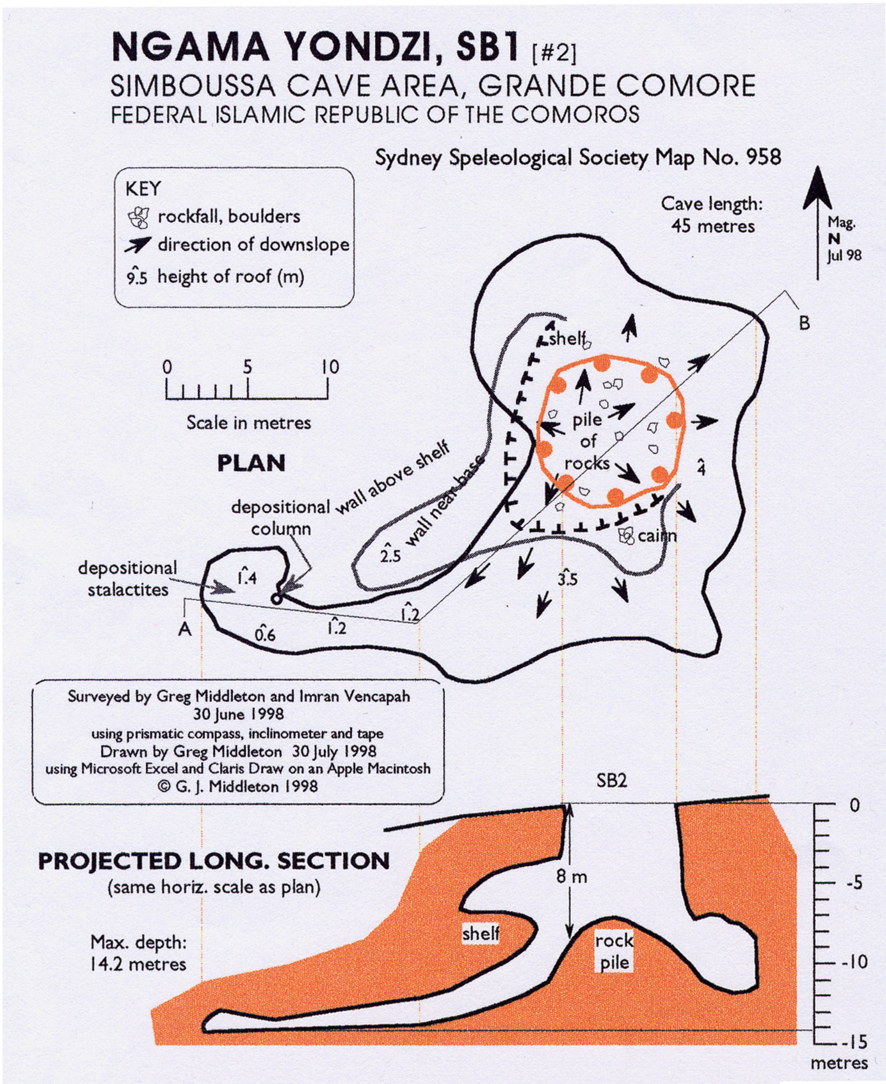


Fig. 11 - Plan and projected longitudinal section of Ngama Yondzi, SB1, “the hole in the field”, near Simboussa.

The initial 'n' is hardly sounded. Iain Walker (an Australian anthropologist working in Comoros) has subsequently suggested this is a contraction of "ngama ya hondzi" which, quite appropriately, means "the hole in the field". We also learned that a deep hole or 'abime' (Fr.) is called 'nindi', though we could not ascertain whether this is actually bigger than 'ngama' or just a different dialect.

Panga Evangadjou [SB2], Simboussa Cave Area

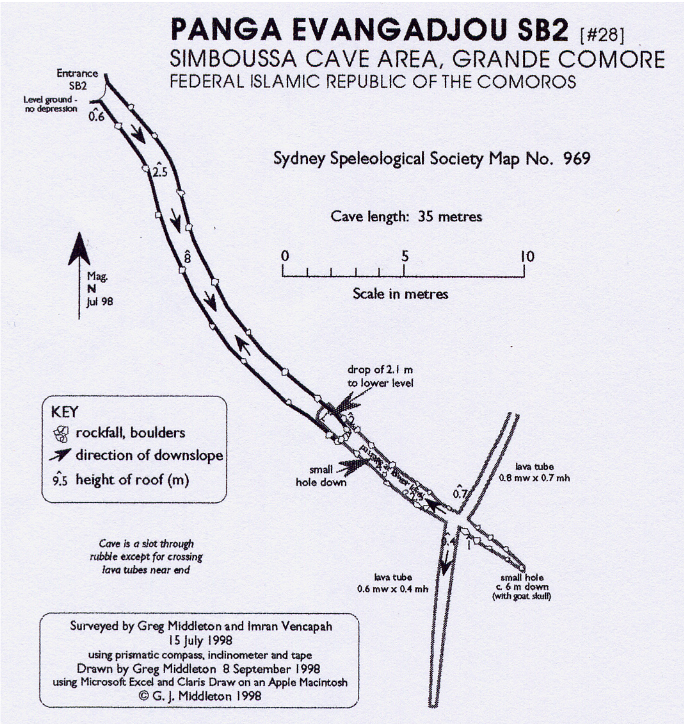


Fig. 12 - Plan of Panga Evangadjou, SB2, near the village of Simboussa. It appears to be more a crack between boulders than a true lava cave.

Whilst on Moheli we were told of a cave at Simboussa in the south of the main island so we went to search for it as soon as we returned to Grande Comore. At first, when we asked about 'pangas' we were directed to Ngama Yondzi, but when we insisted we were looking for a walk-in cave, a youth took us to the north of the village, through a series of what appeared to be small walled gardens, now largely overgrown. In one he showed us a hole, covered by palm leaves to prevent goats falling down it. SB2 turned out to be a narrow slot going steeply downward. After descending for about 10 m it rose slightly before descending again, eventually ending in a jumble of rocks. It was more a cleft than a lava tube, but towards the end a small but perfectly formed lava tube crossed the slot at right angles, tapering off at both ends (see Fig. 12). We were informed its name was Panga Evangadjou.

Kourani Cave Area: KO5 & 6

We later drove up through Nioumamilima on the road to Kourani to the road-side pits I had numbered #7 and #8 [KO5 & 6]. The ladder was attached to the car and lowered into the pit on the southern side (KO5), enabling us to descend.

This is a much smaller pit than SB1, tapering from 5 m to less than 3 m in diameter but it descends vertically for 14 m to a dirt slope which drops into a deeper narrow slot. Opening from it on the eastern side is a narrow slot with boulders wedged in it. Unfortunately the walls are inclined to flake off and there is no real floor for an undetermined depth below. As we had no way of providing any protection in this section we decided it was too hazardous to proceed. We did note, however, quite a strong, cool draught, which made conditions more comfortable than the heat on the surface. The slot was very reminiscent of Cave #6 [KO4] visited on the previous trip, a few hundred metres to the north (Middleton 1998, 1999).

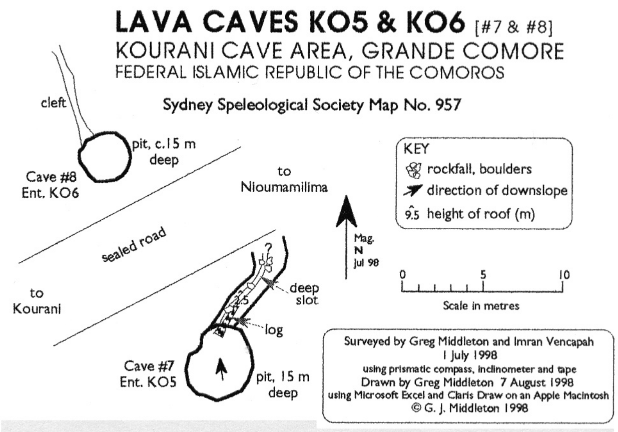


Fig. 13 - Sketch plan of the environs of entrances KO5 and 6, two pits below the village of Kourani.

The northern pit [KO6] was also rigged from the car. It was smaller at the mouth than KO5 and more heavily overgrown. Imran had only descended about 2 m when he dislodged a large mass of rock from just below the lip which fell with a thunderous crash. In view of the danger posed by such unstable conditions and the likelihood that the pit would be similar at the bottom to KO5, we decided not to proceed further with its exploration. I prepared a sketch of the locality (Fig. 13). It was noted that a distinct crevasse-like feature runs away to the north, under dense vegetation, supporting the possibility of these holes being connected with KO4 (Cave #6 – Middleton 1998a) or at least having been formed by the same event.

Singani Cave Area: Panga Pachwa Myembe (#19, SG1-2-3) and Panga La Dzahadjou (#20, SG4)

Yahaya told us of a cave near his village, Mdjoyézi, located above Singani, so we arranged to visit it. We were guided by Abdou Ahamada who cultivates around the cave and presumably owns the land. He showed us one large depression before taking us across the road to another. From the more northerly hole we could see a large depression stretching further north but were told there were no entrances from it. We descended a steep slope into Cave #19, SG1, Panga Pachwa Myembe, which Yahaya told us meant "Local Mango" Cave. We surveyed through a short passage containing many small bats, and a cow skeleton, into a steep-sided canyon (SG2, the large depression we had seen from the road) with vegetable crops. At the southern end of this was another section of cave, (SG2-3) followed by another steep-walled canyon with bananas, etc, growing in it. We climbed up a rough 'ladder' for 8 m to reach the surface, to find we had crossed under the road (see Fig. 14).

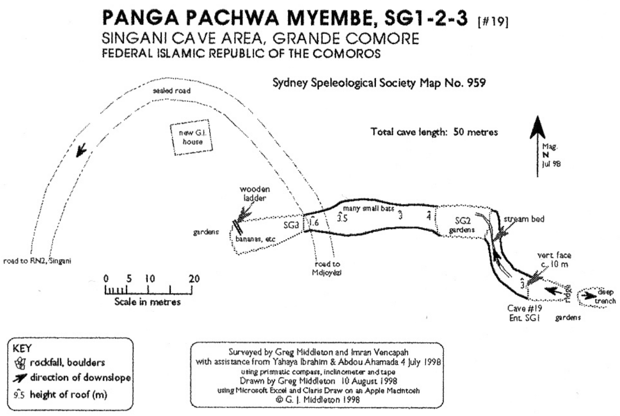


Fig. 14 - Plan of Panga Pachwa Myembe, SG1-2-3, a cave in two sections near the village of Mdjoyézi.

South of Singani, Yahaya assured us there was another, larger cave. We stopped in the village of Dzahadjou and climbed up through the village, past ancient water cisterns and up to an impressive entrance (SG4), obscured by hanging ferns of great length. Behind was a fair sized chamber up to 10 m high, the floor of which rose steeply as one went in, leading to two small holes. We ignored the lower one as too tight but Imran tackled the upper one. The small passage extended for about 70 m but was eventually blocked (see Fig. 15).

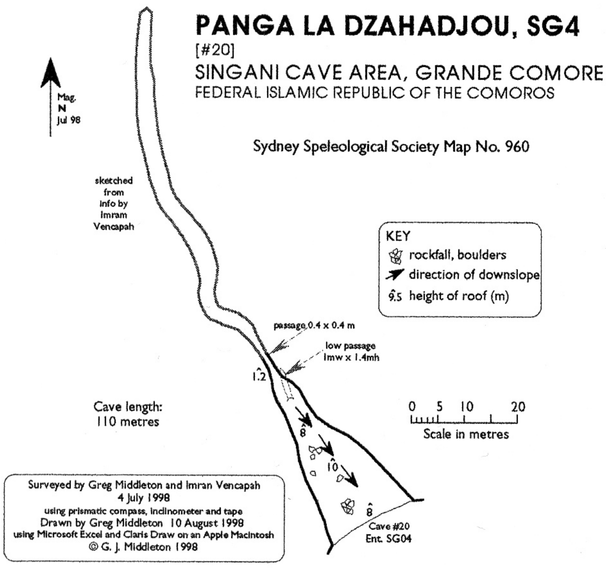


Fig. 15 - Plan of 'La Grotte Celebré de Dzahadjou' – "the cave of the village up the lava flow".

Fassi Cave Area: Panga Nyamaoui (#13, FA1)

Perhaps the most compelling reason for the author to return to Grande Comore was to complete the exploration of Panga Nyamaoui[2]. In September 1997 I had surveyed over 300 m in this cave but knew that it continued both to

[2] This name can also be written 'Nyamawi' or 'Niamaoui' but in any case, means 'bad meat'.

the east and the west. More importantly, I had recorded the presence of bats with bright, highly reflective eyes in the eastern branch - indeed, it was because of their great numbers that I had not been able to get my local guide and assistant to continue.

Further information, provided by Dr Pierre Strinati, well-known Swiss cave biologist, revealed that this bat was probably the little known endemic fruit bat, *Rousettus obliviosus.* Although I had realised it was rather large for an insectivorous species, I had not imagined it was a fruit bat because I thought it lacked the ability to echolocate - which would be essential to reach its roosting site. While this bat had been noted by the German naturalist Günther in 1879, it was not formally described until 1978, by Kock (1978). In one of few papers on this species, Reason, Trewhella, Davies & Wray (1994) have written:

> R. obliviosus *was only recently formally described and nothing is known about its ecology or population biology. …*
>
> *Unlike the* Pteropus *species which were seen flying several hours before dusk*, R. obliviosus *was not seen flying before dusk. It is not known whether this species has any echolocation abilities as seen in some other* Rousettus *species.*
>
> *There was no indication as to where* R. obliviosus *was roosting by day [on Anjouan].* Rousettus *generally roost in tombs, temples, rock crevices, garden trees, date plantations but most commonly in caves.*
>
> *… if this species is limited to forest habitat then the deforestation affecting Comoros (especially Anjouan) could have a serious impact on the status of* R. obliviosus*. Also, if roosting is limited to a few cave sites, these too may be vulnerable.*

If the bats in Panga Nyamaoui do turn out to be *R. obliviosus* this would be their first positively identified roosting site and the value of the cave as essential habitat for this species would be greatly enhanced.

Fig. 16 - Panga Nyamaoui entrance pitch. The giant Dracena provides access for the nimble.

From Fassi Alismael Yousoof guided us back to the cave in about 20 minutes. We rigged up the ladder and descended the 7.6 m to the rubble pile (Fig. 16). We resurveyed the entrance pit and continued on into the western passage. This part of the cave turned out to comprise a total passage length of 390 m, including a curious parallel passage, accessed only with difficulty via a higher level cross passage (see Fig. 17). In order to descend safely to the parallel passage we had to bring down the wire ladder and anchor it to a large rock in the cross passage.

In the partly explored eastern passage we took up the survey at the beginning of the bat roost and, despite disturbing large numbers and being showered with their urine, we pressed on into the cave. The temperature was markedly higher in this section of the cave, as was the humidity. The very large numbers of cave crickets remarked on in my initial report were still in evidence. There is no doubt that the large numbers of crickets and other insects, as well as a small snail which was present in large numbers *(Allopeas clavulinum),* owe their survival at this remote spot entirely to the excretions of the bats. Shells of the snail *Subulina striatella* were also collected but live specimens were not evident.

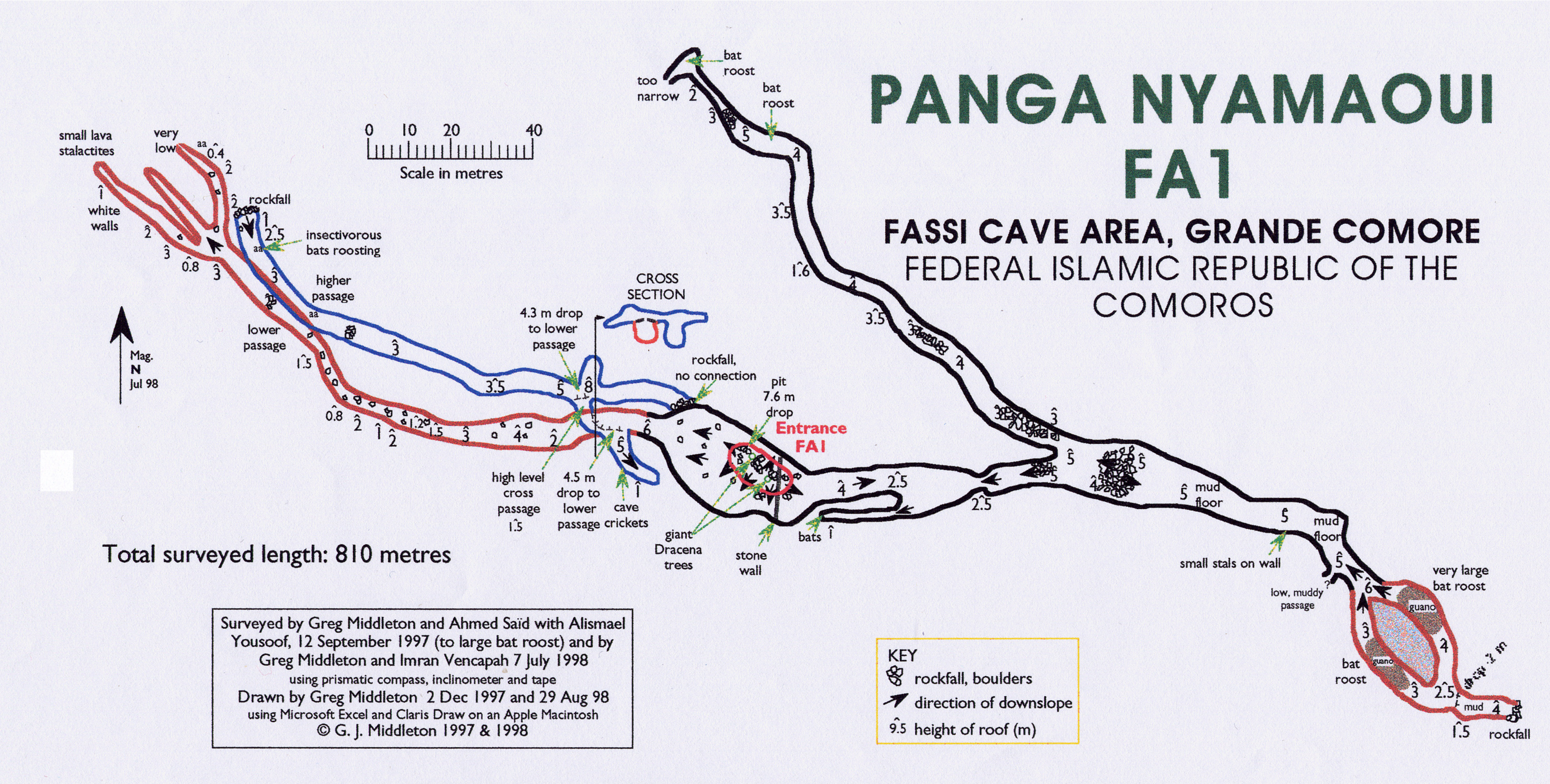


Fig. 17 – Plan of Panga Nyamaoui, inland from the village of Fassi, northern Grande Comore. The passages east of the entrance, FA1, except for the bat roost, were explored and surveyed in September 1997. The bat roost chambers and passages west of the entrance were explored and surveyed in July 1998. The bat roost is the first identified roosting site of the fruit bat *Rousettus oblivius* in the Comoros, and is the bigger of only two known.

The white patches on the floor indicated that the diet of these bats is not that of an insectivorous bat. Another notable feature of these bats was the noise they made. This was a constant high-pitched babble, rather like the sound of the human voice recorded on tape and played back at a much higher speed. These sounds may be related to their echolocation faculties which they must possess in order to safely reach and return from this roosting site.
We searched in vain for a bat skull which might provide positive proof as to the animal's species. In fact we could find only three bones, two of them clearly long bones from the arms. Hopefully these would be of some benefit in identifying the species.[3] From this site we also collected a large cricket and some snails. Unlike bat roosts in Mauritius and Madagascar, there appeared to be few cockroaches.
The survey of the eastern part (Fig. 17) shows a final length of 420 metres, giving a grand total of 810 metres for the whole cave and making it the longest thus far recorded in the Comoros.

Itsandzéni Cave Area: Panga Milembeni [#26, IZ1] and Cave #27 [IZ2].

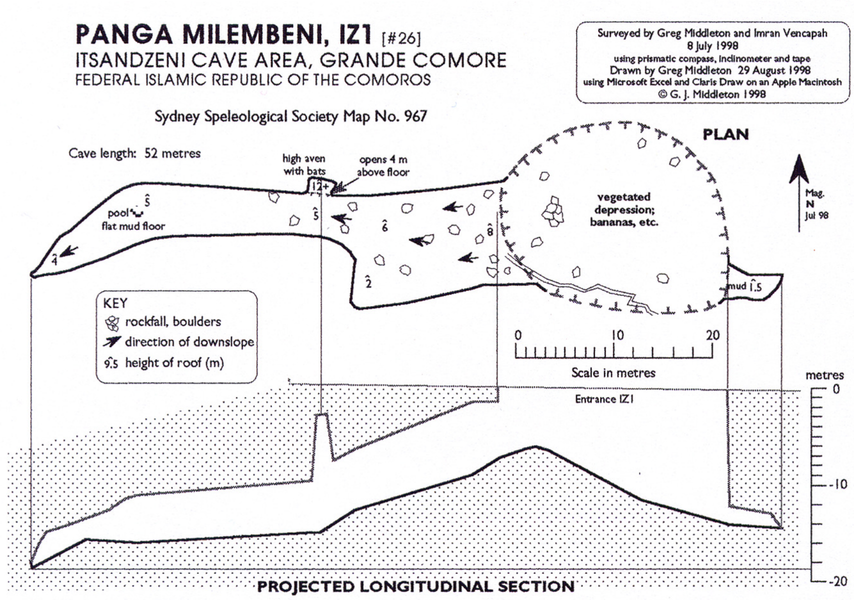


Fig. 18 – Plan and developed longitudinal section of Panga Milembeni, IZ1, north-east Grande Comore.

These caves, on the eastern side of the island, were visited with anthropologist Ian Walker and his wife, Anny. Milembeni 'grotte' is marked on the 1:50,000 road map of the island. When we got to the pit the locals assured us was Milembeni we decided the location marked on the map is somewhat too far north (it may, in fact, be the site of another cave).
Although the entrance pit was very large and looked promising, the cave turned out to be insignificant – except for the fact that a small high dome (or aven) just inside the cave is the roost of a number of bats which appeared to be the same species as those in Panga Nyamaoui. This group, however, probably only numbered a hundred or so.
On the other side of the entrance pit, which was planted with a type of yam, was only a small overhang. We surveyed the cave - see Fig. 18.
On being questioned, the locals said they knew another cave and directed us further north. This one (identified as #27 or IZ2 as we could not ascertain a name for it) consisted of a particularly deep pit with vertical walls, overhung in places and filled with a mass of vegetation - mainly huge *Dracena*s.

Fig. 19 – A huge Dracena provides easy access to Cave #27.

[3] Dr Bill Trewhella of Nottingham University has since advised that a specialist at the Royal Museum in Scotland is convinced they are *Rousettus*.

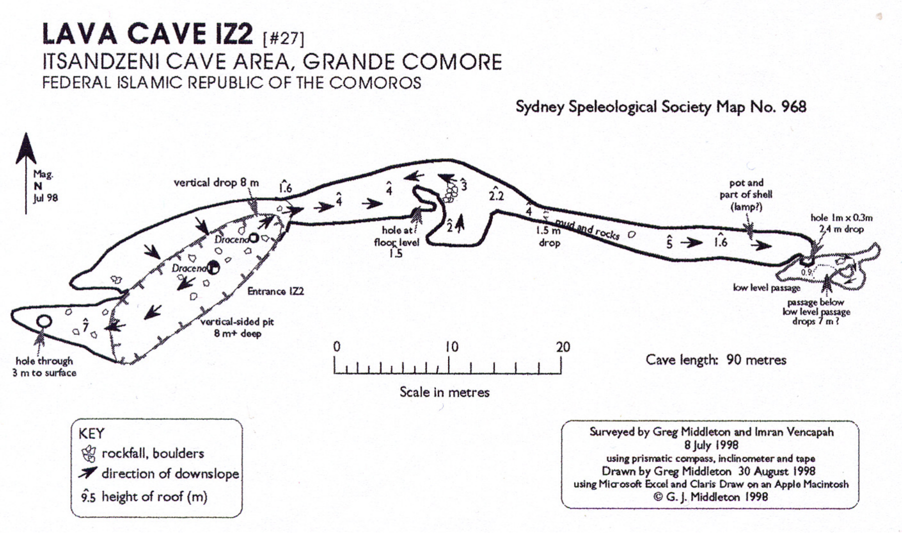


Fig. 20 – Plan of cave #27, Lava Cave IZ2, near Panga Milembeni, north-east Grande Comore.

We concluded that the *Dracena*s tend to survive in the collapsed pits either because they are susceptible to damage by cyclones and are only protected in the pits or (which I think more likely) they were cleared on the surface to make way for crops and grass, only surviving in those pits which are too deep to be safely cultivated. The biggest *Dracena* provided relatively easy access down the 8 m to the usual rubble pile (Fig 19). Here we found a true cave (see Fig. 20) which even contained an intriguing, though small, lower level. We noted an old ceramic pot in the main passage and part of a large sea shell of a type which used to be employed as oil lamps.

Boboni Cave Area: Panga Mdrashi [#29 BB1] and Panga Rajab [#30 BB2-3]

A German zoologist, Speiser (1908), described a bat parasite, *Nycteribosca gigantea*, taken from a bat of the genus *Rousettus* 'n. sp' (no doubt *R. obliviosus* described only in 1978) collected in the "Höhle bei Boboni, 640 m über Meer" on 3 August 1903. This information also came to my attention through Pierre Strinati, and I assured him I would make an effort to find what could be a most important cave - especially if it is still a roosting site of *R. obliviosus.*

Boboni, high above Moroni, was the site of a large timber mill, constructed before the turn of the century to exploit the forests high on the side of Mt Karthala. The mill was clearly abandoned many years ago but a village and its hardy inhabitants remain. The fact that this village is at 640 m a.s.l., leaves no doubt that this is the place referred to by Speiser.

Two young men agreed to show us a cave near the village. They led us in a south-westerly direction probably about 500 m to a small field. There, at the base of a stone wall, was our 29th cave entrance, BB1, a gaping hole into which people had been throwing weeds removed from their vegetable gardens. We attached the ladder to a convenient tree and

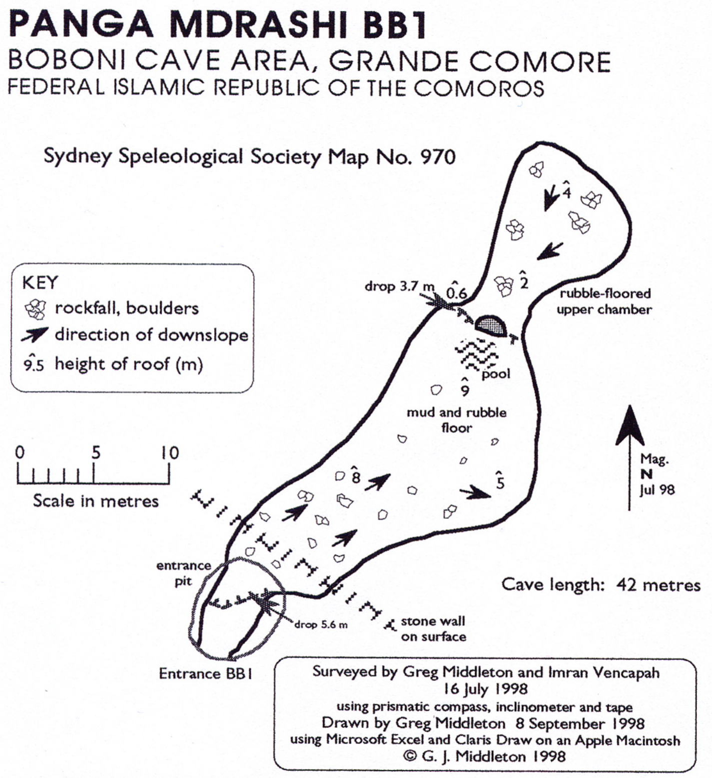


Fig. 21 – Plan of Panga Mdrashi, BB1, "incense burner cave", near Boboni.

climbed down. A steep passage led down to a lofty chamber with a mud floor and pools of water. On the far side of the chamber there was a hole in the wall almost 4 m above the floor. We climbed up and entered another, smaller, chamber with irregular roof breakdown on the floor. It didn’t go any further - and there were no signs of bats. Both chambers were very wet and large amounts of water were dripping from the ceiling over virtually the entire area of the cave. These are not conditions favoured by bats and it is most unlikely that this is the ‘Höhle bei Boboni’. The cave is known locally as Panga Mdrashi (which can be translated as ‘incense burner’) - see Fig. 21.

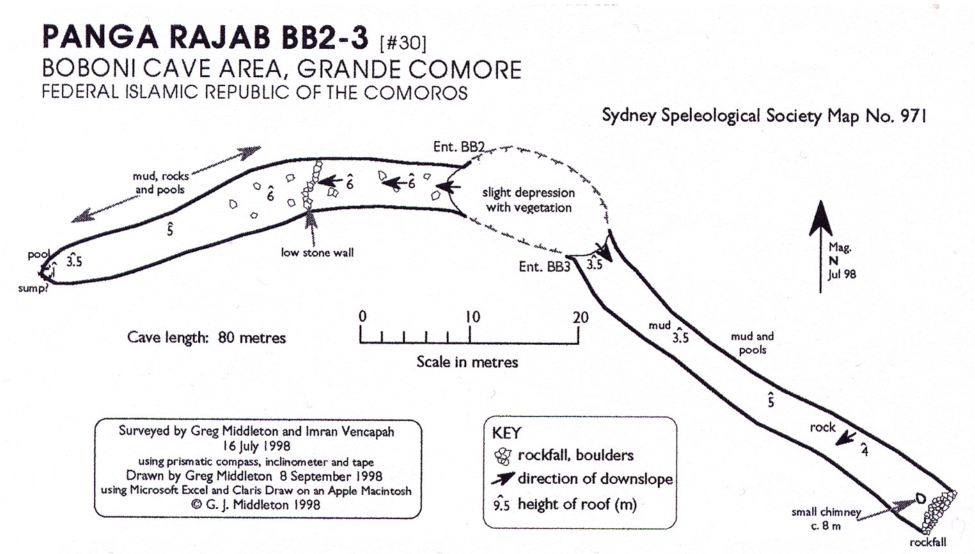


Fig. 22 – Plan of Panga Rajab, BB2-3, near the highland village of Boboni.

We were shown another cave about 740 m further from the village than BB1. Two entrances [BB2 & 3] led away from a central collapsed area and the usual rubble slopes led down into the depths. In the southern part we found another case of a stone wall having been built across the passage. The cave terminated in a sump - or at least a pool of water (if the tube continues it is too small to admit a human). The northern passage ended after a short distance in a rockfall. In neither part were there any signs of bats, either at the present time or in the recent past. This cave, our 30th, we were told, is called Panga Rajab - see Fig. 22. It seems also not to be the one recorded by Speiser (1908).

Dibouni Cave Area

After I had left Comoros, Iain Walker investigated the cave marked on the map as Pangaleraladjou. It is inland from Hahaya, via Dibouni, and only accessible by four-wheel drive. Iain described the cave as a larger version of Panga Milembeni. There is a large pit, easily entered without climbing, with overhangs north and south. The pit is about 20 m in diameter and perhaps 10 m deep. The passage to the south is 15-20 m long, about 10 m wide and 8-10 m high. It leads to a second pit which appears to have no other exit. There is no spring, as implied by the map, but a small pool which may be larger in the wet season. The passage on the northern side is about 25 m long and 10-12 m high, with a lot of roof breakdown. No bats were sighted.

Djoma la Huwanga (Hahaya Area)

Iain Walker has drawn my attention to the following interesting reference to a cave by Pierre Vérin (1994) (translated from the French):

> *The marvellous cave bears the name of Djoma la Huwanga,’the cave of the hatched egg’. It broke, and living beings came out. Their descendants settled Ngazidja, but they had forgotten the extraordinary place. Accompanied by Maurice Kraft, one of the most intrepid vulcanologists on earth, I found myself in the mysterious cave. While he was exploring a tubular gallery under the lava to the north of the runway at Hahaya, Kraft had his attention attracted by a noise that evoked the breathing of a marine monster. He led me there so that I could appreciate the unusual nature of this natural underground phenomenon. The gallery opened out a little above the level of the sea and the to-and-fro of*

the waves created a light that was sometimes transparent, sometimes blue. A beach of white sand lay at the entrance of the cave, itself filled with stalactites of cold lava, and I imagined the surprise of the Shirazis who believed themselves in paradise after having suffered what they thought was a shipwreck. But the village of Hadombwe Ilezo, that had welcomed them, was itself covered by a lava flow in 1859.

Thus, this cave is the place where the first Shirazis (Islamic ancestors of the present inhabitants) are supposed to have landed, and would be expected to have some symbolic significance for Comoriens. Whether this cave is the one referred to as HH2 in this report, or another - and whether it still opens to the sea as described, remains to be investigated.

Island of Moheli

Because of the political situation we were unable to visit Anjouan. We did visit Moheli but in five days were unable to discover any significant caves. We were shown some small sea caves but could find no lava tunnels.

Cave regions and areas of Grande Comore

Based on last year's experience and the additional information now obtained, I propose a series of "cave areas" for Grande Comore which group caves in the same locality and provide for a logical, if arbitrary, way of numbering cave entrances.

The larger scale regions are simply Grande Comore North-East, North-West, South-East and South-West. Within these, cave areas are generally named after the closest village, as follows:

Area	*Code*	*No. of entrances recorded*	*Total length (m)*
Grande Comore NE			
Itsandzeni	IZ	2	142
Grande Comore NW			
Bahani	BH	3	30
Dibouani	DB	2	45
Fassi	FA	1	810
Hahaya	HH	14	2,585
Grande Comore SE			
Simboussa	SB	2	80
Grande Comore SW			
Boboni	BB	3	122
Djoumouachongo	DJ	1	4
Kourani	KO	6	66
Singani	SG	4	160

Conclusion

The results of this second trip to the Comoros were most satisfactory, despite the disappointment of not being able to get to Anjouan and the lack of caves on Moheli. Exploration and survey of all of the caves on Grande Comore that had been only part investigated on the first trip were completed, except for #6, #7 and #8 which were considered too dangerous and #3 and #4 which were too small to enter. In addition, a further fifteen lava caves were located, explored and surveyed, bringing the total to thirty.

The discovery of the first and second known roosting sites of the small endemic fruit bat *Rousettus obliviosus* were confirmed and some invertebrate cave fauna was collected. Many interesting questions remain in relation to the lava caves of Grande Comore and the likelihood of further major discoveries is high.

References

- CHESTER D. K., 1993: *Volcanoes and Society*. Edward Arnold: London, Melbourne, Auckland,
- GREENWAY P., 1997: *Madagascar & Comoros.* 3rd Edn. Lonely Planet Publications: Hawthorn, Vic. 437 pp.
- KOCK D., 1978: *A new fruit bat of the genus* Rousettus *from the Comoro Islands*. Proc. Int. Bat Res. Conf., 4:205-216
- MIDDLETON G., 1998a: *Speleological survey of the lava caves of Grande Comore*, September 1997. J. Syd. Speleo. Soc., 42(9):201-213
- MIDDLETON G., 1998b: *Lava caves of Grande Comore, Indian Ocean: an initial reconnaissance, September 1997*. (Paper presented to 8th International Symposium on Vulcanospeleology, Nairobi, February 1998.) Int. J. Speleol., 27B(1/4):77-86.
- REASON P.F., TREWHELLA W.J., DAVIES J.G. & WRAY S., 1994: *Some observations on the Comoro rousette* Rousettus obliviosus *on Anjouan (Comoro Islands: Western Indian Ocean)*. Mammalia, 58(3):397-403.
- SPEISER P., 1908: *Die Diptera pupipara der madagassisch-maskarenischen region* [in] Voeltzkow, von A. Wissenschaftliche Ergebnisse. Bd. II. Systematische Arbeiten. p. 198.
- VERIN P., 1994: *Les Comores.* Karthala: Paris, p.58.

THE PROTECTION OF THE VIENTO-SOBRADO CAVE - A VERY LONG VOLCANIC CAVE IN THE CANARY ISLANDS

José L. Martín Esquivel [1] and Isaac Izquierdo Zamora [2]

Centro de Planificación Ambiental, Ctra. La Esperanza, Km. 0,8 - 38071 La Laguna, Tenerife
Islas Canarias - e-mail: [1] esquivel@cistia.es - [2] iizqzam@gobiernodecanarias.org

Abstract

The Viento Cave is a very long lava tube (> 20 Km) localised in Icod de los Vinos, at the north slope of Tenerife (Canary islands, Spain). The cave is formed inside a lava flow coming from Teide mountain, probably in the last thousand years. It has important morphologic and biologic feature for conservation, and because of this the regional government is promoting its protection.

Under biologic point of view, the cave is significant. It has the mayor concentration of species troglobites of the Canary Islands. Right now it has been found thirty six cave-dweller, many of them have remarkable adaptations to underground life. This fauna includes species belonging to several rare groups as blataria or homoptera, although the more abundant group are the coleoptera.

The Canary Government has elaborated a Management Plan to guarantee the conservation of this unique ecosystem. One of the goals of it is the declaration of the cave as Special Natural Reserve, a category of protection equivalent to the level IV of UICN. Similarly, at the surface it has been established a control system to be based in the impact assessment of any action that may transform it natural conditions. New building on the surface is forbidden and, at the same time, a sewage plan for the existence shelter is being implemented. Near the entrances it has been projected a Visitor Centre with slipping rooms for visiting scientist. Now, the European Union is developing a conservation program of several caves of Canary Islands, were the Viento cave is the main objective.

Introduction

Site

The Viento cave comprises a series of underground caverns that stretch for over 20km in the north of Tenerife in Icod de los Vinos. The cave is actually situated inside a solidified lava flow that ran down from the peaks of the island to the coast many years ago, although there are different opinions as to exactly when: according to Montoriol-Pous & De Mier (1974) and Wood & Mills (1977) the lava flows are only a few thousand years old, however according to Coello (1989) they may date back as much as 150,000 years.

Ever since the cave was first explored in 1891 by a group of English tourists who made the first map of part of its galleries (Sobrado) (Oromí and Martín, 1995) the length of the cave known to mankind has gradually increased and on occasions has been considered the longest volcanic cave in the world (Halliday, 1972: Wood, 1973). The “longest-cave” record is now held by other lava tunnels in Hawaii and Australia, but the Viento-Sobrado cave may yet be considered as the longest, since it has still not been fully explored.

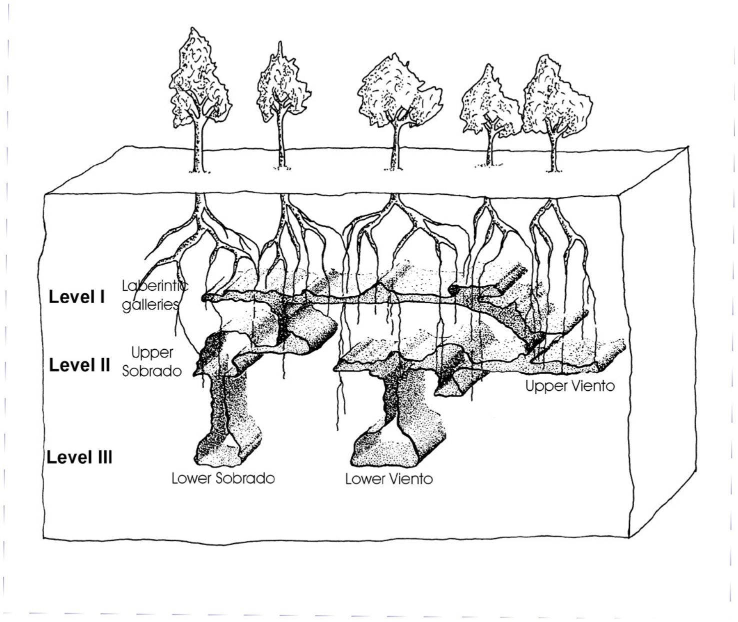


Fig. 1. Depth levels and their drops connection in Viento cave

Table I. Longitude of the different branches in Viento-Sobrado cave (including the inconnected Felipe Reventón cave)

BRANCH	DEPTH LEVEL	AUTHOR	LONGITUDE
Piquetes	II	Woods & Mills (1977)	2.080 m
Breveritas	I-II	Woods & Mills (1977)	5.582 m
Ingleses	III	Oromí (1995)	3.144 m
Belén	II	G.M. Teide	158 m
Sobrado superior	I-II	J.L. Martín, H.G. Court & A. Vera (Published in Hernández *et al*. 1995).	3.570 m
Sobrado inferior	III	Laínez (1996)	2.346 m
Petrólea	II	Zurita *et al*. (1996)	152 m
Felipe Reventón	I-II	Hernández *et al*. (1985)	3.000 m
TOTAL	I-II-III		20.032 m

The history of its different stages of discovery

A long gap followed the visit of the above-mentioned English tourists, in spite of the fact that the cave's existence was already known even before their appearance, as is clear by references dating from the eighteenth century (Castro, 1776). It was at the end of the 1960's that a group of speleologists from the Tenerife Mountain Group started exploring and charting the cave in detail (Chávez, 1970). In 1974, Montoriol-Pous and De Mier published the first topography of the cave, ascribing it a length of 6,200 metres. A few years later, a group of English geologists discovered a new network of galleries even deeper than the previous ones and increased the cave's length to ten kilometres (Wood & Mills, 1977). In 1988, local cavers managed to connect the nearby cave of Sobrado to the Viento cave, increasing the total length to 13,750 metres and shortly afterwards, in 1994 the biospeleologist Juan José Hernández Pacheco discovered a new 2,346 metre branch that

increased the cave's total underground length to over 17 kilometres. If we add to this the approximately 3 kilometres of the Felipe Reventón cave located not fifty metres away from one of the Viento-Sobrado galleries and in the same lava flow, the total underground system is over 20 kilometres long (table I)

The same speleologists who in the sixties made the first topography were also those who discovered the first animal-life, more specifically a small troglobite cockroach, which many years later was to be described as *Loboptera subterranea* (Martín and Oromí, 1987). But it was in the eighties that there was a tremendous boost to biological studies of the cave, with the discovery by researchers from the Laguna University's Speleology Research Group of a serie of new species, mainly arthropods, that made the cave one of the most important sites of cave-dwelling fauna in the whole of the palearctic region.

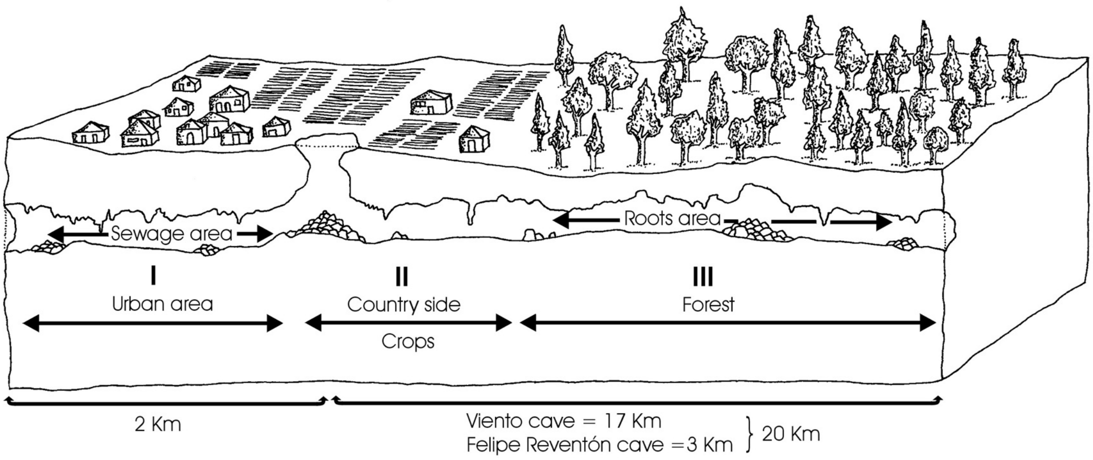


Fig. 2. Different areas of the underground ecosystem according to the nature of the surface habitat

Morphology

The cave is made up of several volcanic tubes that occasionally intersect horizontally, whilst vertically it is laid out in three different depth levels and connected by ledges or pits with drops of up to 15 m. The Ingleses and lower Sobrado galleries are the deepest. At an intermediate depth are the upper Sobrado, Petrólea, Breveritas, Piquetes and Felipe Reventón galleries and nearest of all to the surface there is a small network of fairly narrow and laberintic galleries that connect the passageways of the upper Sobrado gallery to the Breveritas gallery (fig. 1). This lay-out is probably due to the manner in which the cave was originally formed, which according to Wood & Mills (1977) was a three-stage process; first of all the deepest galleries would have been formed (III) which would have opened up to the outside through vertical "jameos" (sky-lights), that are now the shafts that connect this level to the intermediate level (II). After a period of calm in the area, volcanic activity started once again and a new flow was deposited on top of the previous one with a new volcanic tube (level II) that connected down to the lower level through the openings mentioned previously, thus joining together the intermediate and deepest levels. The level that is nearest to the surface (III) was also formed during this second flow, as another of the many

branches that arose from slope drainage below the cooled and solidified surface crust of the lava (see Wood, 1977 for an explanation of the process).
Since the cave is on a very steep slope (11%) and the volcanic tubes generally follow the direction of the slope, there is a tremendous height difference between the cave's top and its bottom of up to 478 metres according to Wood & Mills (1977) and 580 metres according to Montoriol-Pous & De Mier (1974). The average height and width of the galleries is between 2 and 4 metres.
Many of the typical geomorphological structures of volcanic caves such as lateral terraces, lava rivers, lava stalagmites, lava cascades, lava lakes, lateral benchs, etc. In more specific areas there are also interesting gypsum deposits, minerals (Moen, 1972) and cristobalite, a structure of secondary origin, which has silica as its main compound (Izquierdo *et al*. 1995).

The Ecosystem

The surface

The vegetation of the area should be a laurisilva wood, surrounded in its upper part by a Canary-island pine forest. However, this potential vegetation has mainly disappeared as a result of human settlements, farming and livestock practices and forestry. This means that vegetation today is merely what is left of the area's original potential, with a mixed pine forest (*Pinus Canariensis*) speckled with deciduous species (*Myrica faya, Ilex canariensis*, *Laurus azorica*) and heather (*Erica arborea*) on the highest part of the slope, a landscape containing different buildings located near to the crop-growing areas in the middle area and a built-up area at the bottom. The interior of the tubes are affected by the vegetation, since the roots of many of the plants growing above the cave actually penetrate into it.

The underground environment

The underground ecosystem is divided into three different areas (fig. 2) according to the nature of the surface habitat:
Area I is the place that has undergone greatest change, caused mainly by the large amounts of waste water that come from the buildings at surface level. From a fauna point of view this area can be considered as the most deprived.
Area II has an major fauna content, although there are some deteriorated areas that usually coincide vertically with buildings at surface level or places where visitors to the cave normally congregate.
Area III has the largest fauna content, since it is the best-conserved of the three areas. The majority of this area is underneath a pine forest at surface level, meaning that it contains numerous hanging roots that provide a peculiar habitat for many cave-dwelling species.
Over one hundred and fifty animal species, mainly arthropods have been found to be living in this volcanic tube (Martín, 1992; Martín *et al*, 1995; Oromí *et al*. 1995; Arechavaleta *et al*, 1999). Many are kinds of trogolophiles and trogloxenes, although 36 of them can be considered as true troglobites showing different degrees of adaptation to underground life. Fourteen of the species have only ever been found in this cave (table II). Some of them do not have any direct relations amongst surface-dwelling fauna and are only even known because just a few of their kind have been found. There are indications that species such as *Tyrannochthonius superstes* and *Canarionesticus quadridentatus* may be authentic distributive relicts (Martín, Izquierdo & Oromi, 1989) as the term was meant by Botosaneau & Holsinger (1991).
Coleopterans and araneids are the dominant groups as far as the number of troglobite species go with the interesting peculiarity that both of these groups have genus with several species living in the same cave. In some cases, such as *Dysdera*, there are as many as five troglobite species and a sixth more troglophile (*D. crocota*) living in the same area. As for the numbers of each type, there is a predominance of *Loboptera*. At some times the *subterranea* species of *Loboptera* are more

common and at others the *troglobia* – in the eighties it was the former, whilst in the nineties it was the latter.

A variety of bone remains of vertebrates that have since disappeared from the island or have even become extinct have also been found. Among the former, there are the remains of choughs (*Pyrrhocorax pyrrhococorax*) that can now only be found on the neighbouring island of La Palma (Rando & López, 1996) or the canarian houbara bustard (*Chlamydotis undulata*) that is only found in Lanzarote and Fuerteventura (Rando, 1995). As for extinct species, large numbers of remains of a giant lizards (*Gallotia simonyi*) have been found as well as a giant rat (*Canariomys bravoi*), a partridge (*Coturnix gomerae*) and a small, long-legged, short-winged bird (*Emberiza alcoveri*) (Rando & López op. cit; Rando et al. 1999).

Table II. Troglobites of Viento-Sobrado Cave

	Endemic of Viento Cave	Superficial close-relatives
Arachnida-Araneae		
Agraecina canariensis	Not	Yes
Canarionesticus quadridentatus	Yes	Not
Dysdera ambulotenta ν μ	Yes	Yes
Dysdera esquiveli μ	Not	Yes
Dysdera labradensis ν μ	Not	Yes
Dysdera volcania	Yes	Yes
Dysdera unguimmanis μ	Yes	Yes
Spermophorides reventoni	Yes	Yes
Troglohyphantes oromii μ	Not	Not
Metopobactrus cavernicolous ν μ	Yes	Not
Walkenaeria cavernicola μ	Not	Yes
Arachnida – Pseudoescorpionida		
Lasynochthonius curridigitatus	Yes	Not
Paraliochthonius tenebrarum	Not	Not
Tyrannochthonius setiger μ	Yes	Not
Tyrannochthonius superstes μ	Yes	Not
Malacostracea – Isopoda		
Trichoniscus bassoti	Not	Yes
Venezillo tenerifensis	Not	Yes
Porcellio martini	Not	Yes
Myriapoda – Diplopoda		
Dolichoiulus labradae	Not	Yes
Dolichoiulus ypsilon	Not	Yes
Myriapoda – Glomerida		
Glomeris sp.	Not	Yes

	Endemic of Viento Cave	Superficial close-relatives
Myriapoda – Chilopoda		
Lithobius speleovulcanus	Not	Yes
Criptops vulcanicus ν	Yes	Yes
Hexapoda – Blattaria		
Loboptera subterranea	Not	Not
Loboptera troglobia μ	Not	Not
Hexapoda – Homoptera		
Tachycixius lavatubus μ	Not	Not
Hexapoda – Coleoptera		
Aeletes oromii	Yes	Not
Apteranopsis outereloi ν μ	Not	Not
Domene alticola ν μ	Not	Not
Domene vulcanica ν μ	Yes	Not
Lymnastis subovatus ν	Not	Yes
Lymnastis thoracicus ν	Yes	Yes
Oromia hephaestos ν μ	Yes	Not
Speleovulcania canariensis ν μ	Not	Not
Wolltinerfia martini μ	Not	Not
Wolltinerfia tenerifae μ	Not	Not

Note: ν rare; μ vulnerable. After criteria from Recomendation nº 36 (1992) of Council of Europe

Energy flows

The main energy source for the underground ecosystem comes from the roots of surface vegetation and from small troglophile or trogloxene arthropods that access the cave through entrances, cracks or through the layer of earth that separates the cave from the surface (Martín *et al.*, 1995). In addition to lava tubes, within the lava flow there are also numerous retraction cracks that increase quite considerably the network of passageways along which the troglobites can wander. Roots are especially numerous under the pine forest and provide sustenance for troglophilic species such as the plant-eating beetle *Rhizophagus ferrugineus* or the troglobite *Tachycixius lavatubus*. When they die they become food for other saprophagous, troglophile and troglobite species which in their turn become prey for (mainly troglobite) carnivores.
The most numerous troglophiles are small dipterous of the *Megaselia* genus, the larva of which live an endogeous life in the soil layer above the cave, and when they become adults they scramble up to the surface where the imago flies off in search of food and a mate. However, during its wanderings in the soil it sometimes enters the cave where it may even mate and lay eggs if it can find excrement remains or other organic matter such as the corpse of the giant troglobite spider *Dysdera labradensis*. It is extremely common for these flies to fall prey to carnivorous beetles and araneids. *Megaselia* is extraordinarily abundant both near to the entrances and in the parts that are furthest away, whenever there is a thick layer of soil. Other species that also penetrate the cave include diplopods (*Blaniulus guttulatus*), snails (*Caracollina lenticula* and

Oxychilus alliarius) and collembola (*Acherongia huetheri*). These species and the *Megaselia* provide a significant amount of energy to the biomass, especially in the galleries nearest to the surface (Martín et al., 1995).
If we just consider the troglobite species, a comparative analysis of the biomass in the different biotypes gives rise to an inverted pyramid in which zoophaga predominate. This is an ecological contradiction which can only be explained by the abundance of troglophile and trogloxene detritovores at the base of the trophic pyramid representing the energy source upon which the underground ecosystem is based (fig 3.) This ecosystem structure is characteristic of volcanic tubes in the Canary Islands and has been found in other caves (Martín, 1992).

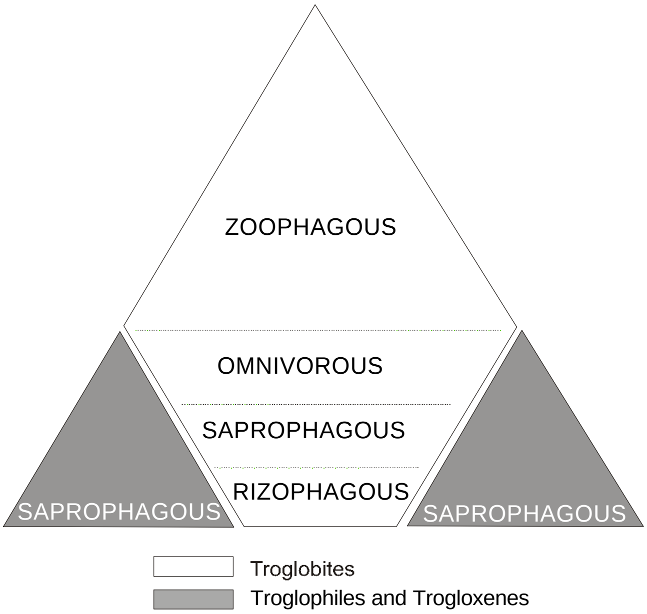


Fig. 3. Biomass and trophic levels in the underground ecosystem of Viento-Sobrado cave, after datas of Martín (1992)

Relations between the underground ecosystem and the surface environment.

As a result of the absence of primary production in the subsoil and dependency on energy from the surface, the underground ecosystem's main characteristic is its lack of energy, which has lead the most adapted species to keep their populations to a minimum and to develop peculiar lifestyles. Figure 4 shows how the use that the surface is put to may affect the underground ecosystem either directly or indirectly . In the case of direct effects, it is the presence of mankind in the cave that provides the transformation vector and as for indirect effects these are those arising from surface soil use such as building, farming practices, and waste water. This interrelation means that any conservation strategy put into operation to protect the cave must include precise regulations both on what goes on in its interior (visits and research) and what occurs at surface level (farming and urban use).

Conservation

The Viento-Sobrado cave has the greatest concentration of troglobite fauna and the largest variety of geomorphological structures of all the caves in the Canary Islands, which makes it a unique place (Oromí & Martín, 1995). However, the nearby development of harmful activities and the affluence of visitors who are attracted by the cave's own natural value are both seriously

damaging the possibility of conserving the cave's self-same natural values. The three main threats that affect the underground ecosystem are pollution, human presence and building at surface level.

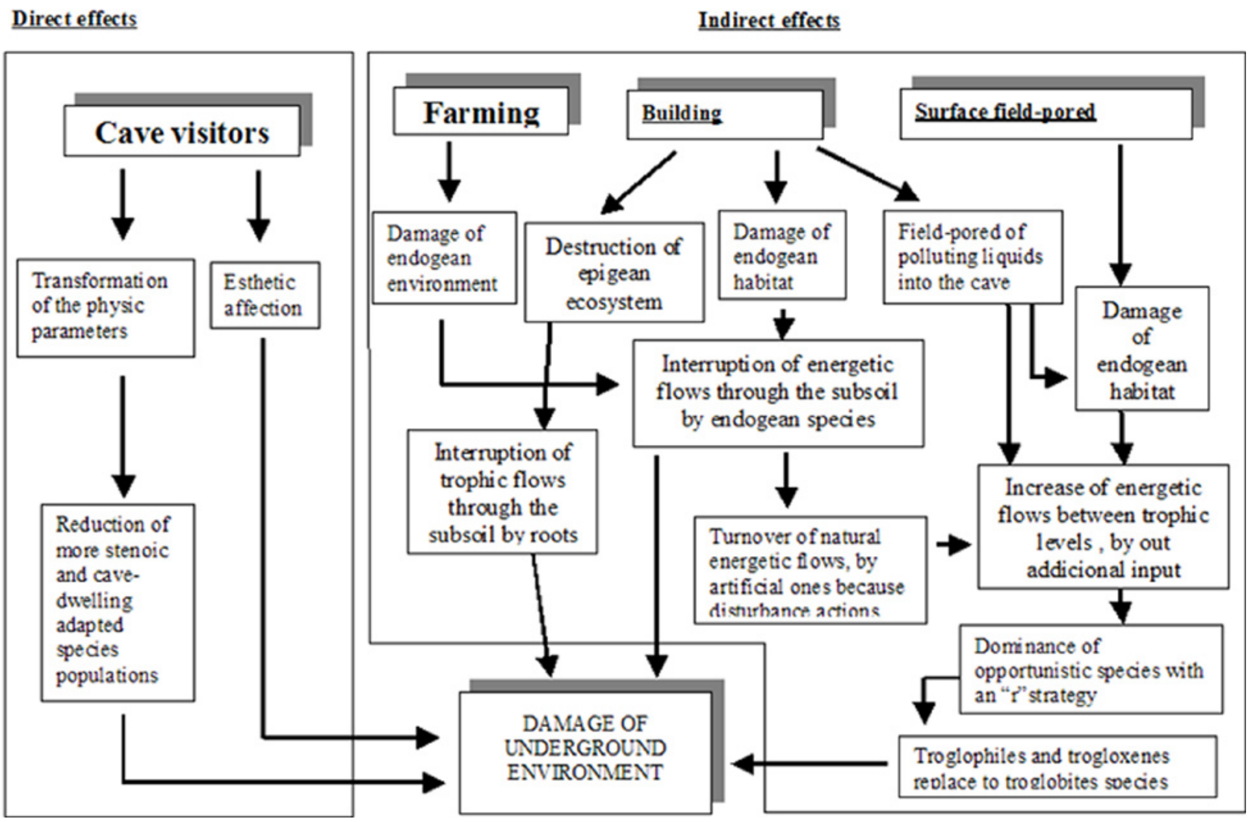


Fig. 4. Effects on underground environment of the different human uses

Pollution

The waste water that has been dumped inside the volcanic tube has profoundly affected the troglobite and troglophile fauna especially in the Piquetes gallery and the northern branch of the Breveritas gallery. In the southern branch of this gallery and also the Belén gallery this pollution only affects some areas and is less concentrated. Waste water has an excess concentration of nitrates, way above the normal level of underground water and in almost all cases is present within a 50 metres radius of surface buildings. Some polluting organochlorines such as lindane, DDT and derived metabolites have been found in the sediments of some areas of the caves. These appear due to bioaccumulation in species such as *Loboptera troglobia* and demonstrate the presence of these pollutants in trophic chains (Oromí *et al*. b, 1995). One characteristic of the fauna where the greatest levels of pollution are found is the dominance of opportunistic species with an "r" ecological strategy (troglophiles and trogloxenes) at the expense of specialists with a "K" strategy (troglobites) as occurs in the most polluted sector of the Piquetes gallery (Martín et al., 1995).

Human presence

The amount of waste within the cave is directly proportional to the frequency and number of visitors. Waste includes calcium carbide remains, batteries, paper, plastic, candles, food remains, etc. Some of the cave's walls have even been vandalised with paint.
Together with this, those who visit the cave also bring about climatic changes, which result on occasions in changes to surrounding temperature and in the air content, especially in those

galleries where there is less air circulation (Arechavaleta *et al*, 1996). This can cause temporary two to three degree temperature changes in the most frequently visited areas, which may be the reason behind their more limited amount of troglobite fauna (Martín *et al*. 1995).

Buildings

With the only exception of the surface area above the section of the cave known as “Piquetes”, the rest of the ground above the cave has been classified as non-building land by the administration. However, in recent years many buildings have been constructed on some occasions directly above the volcanic tube. Neither these buildings nor the ones located directly above “Piquetes” have a sewer system, so sewage is dumped directly onto the subsoil, causing serious ecological damage.
A second effect of urbanisation, whether it takes the form of buildings, roads or any other action that changes the surface, is that it interrupts the energy flows that support the underground ecosystem, either through the destruction of vegetation or via the elimination of the soil layer where the troglophile and trogloxene species live and which are the foodstuff for the troglobites that live underground.

What the government is doing

The Viento cave meets the criteria recommended by the Council of Europe in 1992 for selecting habitats according to their biological value (table III) and which include an urgent need for measures to be adopted to ensure that habitats are maintained in as “natural” a state as possible (Juberthie, 1995). The corresponding public nature conservation body met this need by setting up a preventive protection system called the Plan for Regulating Natural Resources. This plan contained the precise measures to be taken to eradicate any threats to natural habitats and to guarantee their conservation. This preventive system was passed by an order dated the 20th December 1994, (B.O.C, 1994) and the mentioned Plan for Regulating Natural Resources in the Viento-Sobrado cave was formally approved in a Canary-Island Government Decree (B.O.C., 1998) after a public and institutional consultation process where all the interested parties were invited to a hearing to make their comments on the Plan (Izquierdo, 1998).
The plan was approved with the go-ahead of the main social and political groups of the region and the owners of the land where the cave is located.

Table III. Staus of criteria for selecting underground habitats of biological value for the contracting parties of “Convention on the conservation of european wildlife and natural habitats” in the Viento-Sobrado cave

CRITERIA*	STATUS
Presence of species adapted to subterranean life	36 troglobites
Presence of vestigial species	To see table I
Presence of vulnerable species	To see table I
Presence of endemic species	36 troglobites and several troglophiles and trogloxenes
Presence of rare species	To see table I
Presence of bats	Not
Relatively high biodiversity	Yes
Originality of the habitat	Yes due to it volcanic origin
Scientific value	Very high
Vulnerability of habitats	Yes, due to the threatens former comented

* after Recomendation nº 36 (1992) of Council of Europe

The Plan lays down a series of measures to be directly and immediately applied and others, that will have to be developed later through new regulations. The following are the main points of the plan: (fig. 5).

The scope of the Plan is the best-preserved part of the cave and does not include the Piquetes gallery (area I in fig. 2) since it is already badly affected by decades of solid waste and sewage that have entered from outside.

A large area of the land above the cave will receive the category of “ecologically sensitive area” and any authorised use to which the land is put will have to undergo an impact study to examine any possible effect said use would have on the underground ecosystem.

Chemical fertilisers for farming, intensive livestock rearing, phytosanitary treatments, forestry treatment, reforestation using exotic species and land movement will all be strictly limited.

No building will be allowed directly above the cave nor on a 100-metre wide strip of land on either side of the cave, except for the construction of a visitors’ centre near to one of the cave’s entrances to control access and provide information about the cave and its surroundings.

A maximum of 30 people will be allowed inside the gave at any one time and groups should be less than 15 people.

No rubbish shall be dumped inside the cave.

Research and education activities will be promoted in accordance with the public use plan which should be written for the area.

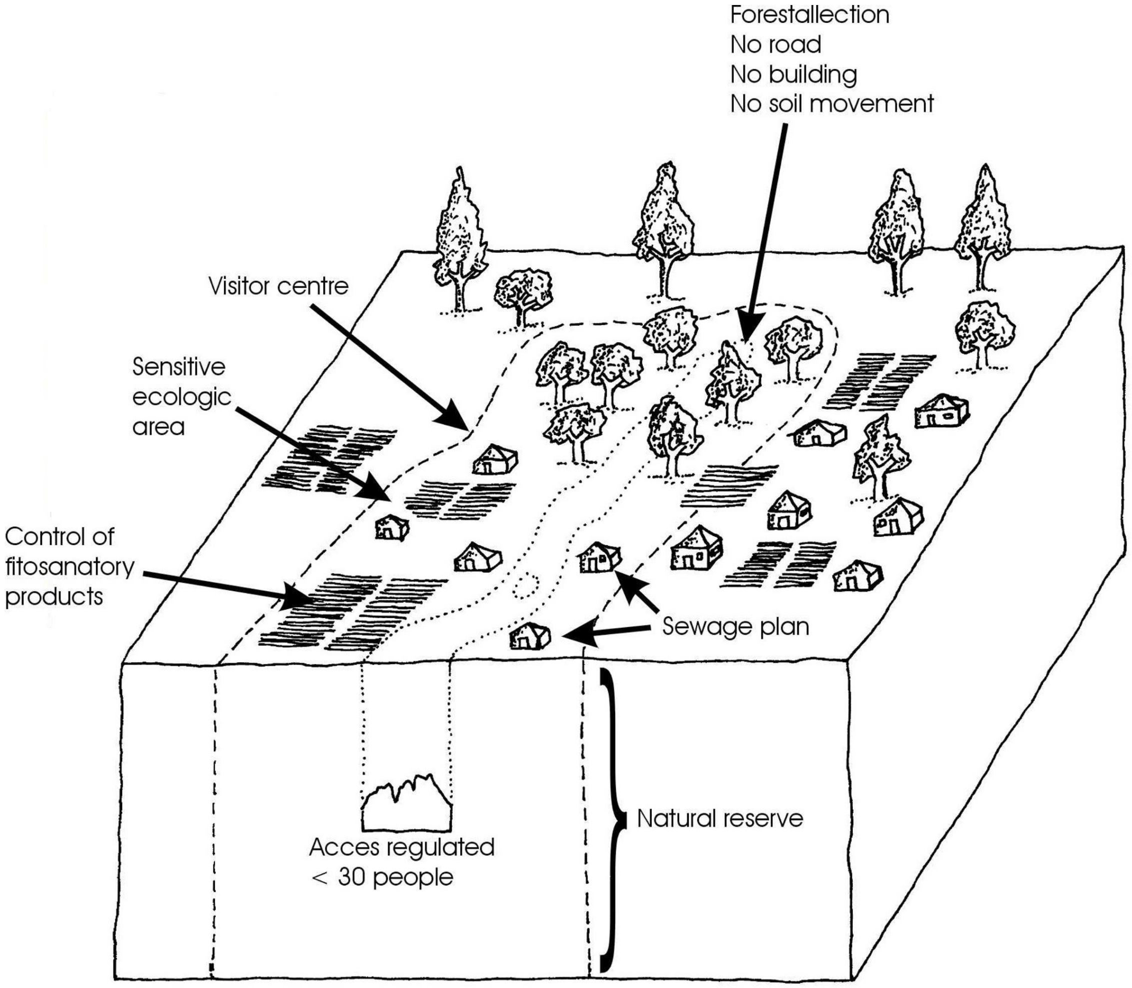


Fig. 5. Measures to be taken to eradicate any threats to underground environment and to guarantee their conservation

In the medium term it is hoped that the necessary steps will be taken in canarian parlament for the underground environment of the area designated as an ecologically sensitive area to be declared Special Nature Reserve – a category which is equivalent to level IV of the UICN's international nomenclature. In this way, the cave would become part of the Canary-Islands Network of Protected Natural Areas.
All of this is in addition to the recent purchase by the public administration of the land at the entrance to the cave, so as to effectively control the accesses in accordance with what is stipulated in the Plan for Regulating Natural Resources. A research projected subsidised by the European Union within its LIFE invested programme is also being carried out with a view to refine the conservation measures and finalise the fauna inventories.

Bibliography

- ARECHAVALETA M., P. OROMÍ, L.L. SALA & C. MARTÍN, 1996: *Distribution of carbon dioxide concentration in Cueva del Viento (Tenerife, Canary Islands)*. Proc. VII Int. Symp. Vulcanospeleol., La Palma 1994: 11-14.
- ARECHAVALETA M., L.L. SALA & P. OROMÍ C. MARTÍN, 1999: *La fauna invertebrada de la Cueva de Felipe Reventón (Icod de los Vinos, Tenerife, Islas Canarias*). Vieraea, 27: 229-244.
- BOLETIN OFICIAL DE CANARIAS, 1994: *Orden de 20 de septiembre de la Consejería de Política Territorial por la que se dispone la elaboración de un Plan de Ordenación de los Recursos Naturales en la zona de "Cueva del Viento-Sobrado", en el municipio de Icod de los Vinos (Tenerife)*. BOC nº 124: 7448-7449.
- BOLETIN OFICIAL DE CANARIAS, 1998: *Decreto 53/1998, de 17 de abril, por el que se aprueba el Plan de Ordenación de los Recursos Naturales de Cueva del Viento-Sobrado*. BOC nº 54: 4577-4583.
- BOTOSANEANU L. & J.R. HOLSINGER, 1991: *Some aspects concerning colonization of the subterranean realm-especialy of subterranean waters: a response to Rouch & Danielopol, 1987*. Stygologia, 6(1): 11-39.
- CASTRO J. B, 1776: *De una cueva que se halla en la isla de Tenerife a distancia de una milla del lugar de Icod, hacia el norte, examinada el 14 de noviembre de 1776, por Don José, Don Agustín de Bethencourt de Castro y Molina, Don José de Monteverde y Molina, y otros*. 3 pp. Sin publicar.
- COELLO J., 1989: *Marco geológico regional del Teide y Las Cañadas*. In V. Araña & J. Coello (eds.) "Los volcanes y la caldera del Parque Nacional del Teide", ICONA, Madrid: 45-63.
- CHÁVEZ A., 1970: *La "Cueva del Viento" (Icod), la mayor del mundo en terreno volcánico, con 6.182 m*. La Tarde (newspaper of Santa Cruz de Tenerife), 28 nov: 7.
- HALLIDAY W.R., 1972: *The world's longest lava tube caves*. NSS News, 30(4): 80-82
- HERNÁNDEZ J.J., A.L. MEDINA, I. IZQUIERDO, A. VERA & H. GARCÍA, 1995: *Topografía y espeleometría*. En P. Oromí (coord.) "La Cueva del Viento". Consejería de Política Territorial, Viceconsejería de Medio Ambiente: 9-14.
- IZQUIERDO I., 1998: *Fauna subterránea de la Cueva del Viento-Sobrado*. Quercus, 154: 32-37.
- IZQUIERDO I., A. MEDINA & J.J. HERNÁNDEZ, 1995: *Geomorfología*. En P. Oromí (coord.) "La Cueva del Viento". Consejería de Política Territorial, Viceconsejería de Medio Ambiente: 15-29.
- JUBERTHIE CH., 1995: *Underground habitats and their protection*. Council of Europe Press, Nature and Environment, nº 72, Strasbourg, 158 pp.

- LAÍNEZ A., 1996: *Galería Juan José Hernández Pacheco, un nuevo descubrimiento en el complejo de la Cueva del Viento-Sobrado (Icod de los Vinos, Tenerife).* Proc. VII Int. Symp. Vulcanospeleol., La Palma 1994: 69-73.
- MARTIN J.L., 1992: *Caracterización ecológica y evolución de as comunidades subterráneas en las islas de Tenerife, El Hierro y La Palma*. PhdTesis (inédit) deposited in the Dpto ob animal biology of Biology Faculty (La Laguna University). 342 pp.
- MARTÍN J.L., I. ZQUIERDO & P. OROMÍ, 1989: *Sur les relations entre les troglobies et les espèces épigées des îles Canaries.* Mémmoires de Biospéologie, 16; 25-34.
- MARTIN J. L. & P. OROMI, 1987: *Tres nuevas especies hipogeas de Loboptera Brum. & W. (Blattaria, Blattellidae) y consideraciones sobre el medio subterráneo de Tenerife (Islas Canarias)*. Ann. Soc. Entomol. Fr., 23(3): 315-326.
- MARTÍN J.L., P. OROMÍ, I. IZQUIERDO, A.L. MEDINA & J.M. GONZÁLEZ, 1995: *Biología*. En P. Oromí (coord.) "La Cueva del Viento". Consejería de Política Territorial, Viceconsejería de Medio Ambiente: 31-78.
- MONTORIOL-POUS J. & J. DE MIER, 1974: *Estudio vulcanoespeleológico de la Cueva del Viento (Icod de los Vinos, Isla de Tenerife, Canarias)*. Speleon, 21: 5-24.
- MOEN W., 1972: *Cueva del Viento minerals.* Cascade Caver, 11(3): 19.
- OROMÍ P., M. ARECHAVALETA, L. SALA Y S. SOCORRO, 1995: *Estudio de impacto ambiental del anteproyecto "Cueva del Viento*". Documento Inédito, depositado en la Viceconsejería de Medio Ambiente del Gobierno de Canarias.
- OROMÍ P. & J.L. MARTÍN, 1990: *Recorrido histórico y perspectiva actual de la espeleología en Canarias*. An. Fac. Cienc. Univ. La Laguna, Homenaje al Profesor Dr. Telesforo Bravo, I: 577-593.
- OROMÍ P., J.L. MARTÍN, 1995: *Conclusiones generales*. En P. Oromí (coord.) "*La Cueva del Viento*". Consejería de Política Territorial, Viceconsejería de Medio Ambiente: 79-91.
- OROMÍ P. & MARTÍN J.L., 1995: *Memoria histórica*. En P. Oromí (coord.) "*La Cueva del Viento*". Consejería de Política Territorial, Viceconsejería de Medio Ambiente: 5-8.
- RANDO J.C., 1995: *Restos de Hubara, Chlamydotis undulata (Jacquin, 1784) (Aves: Otididae), en la Cueva del Viento (Tenerife, Islas Canarias).* Vieraea, 24: 192.
- RANDO J.C. & M. LOPEZ, 1996: *Un nuevo yacimiento de vertebrados fósiles en Tenerife (Islas Canarias*). Proc. VII Int. Symp. Vulcanospeleol., La Palma 1994: 171-173.
- RANDO J.C., M. LÓPEZ & B. SEGUÍ, 1999: *A new species of extintc flightless passerine (Emberizidae: Emberiza) from the Canary Islands.* The Condor, 101(1): 1-13.
- WOOD C., 1973: *Cueva del Viento confirmed to be the longest lava tube cave in the world.* J. Shepton Mallet Caving Club, 5(6): 3-7.
- WOOD C., 1977: *The origin and morphological diversity of lava tube caves*. Proc. 7th Int. Congr. Speleol. Sheffield (England). 440-444.
- WOOD C. & T. MILLS, 1977: *Geology of the Lava Tube Caves around Icod de los Vinos, Tenerife (Report of the expedition to Tenerife from the Shepton Mallet Caving Club in 1973 and 1974).* Trans. British Cave Res. Assoc., 4(4): 453-469.
- ZURITA N., L. SALA, M. ARECHAVALETA, E. MUÑOZ & P. OROMÍ, 1996: *Cueva de Petrólea, a newly discovered branch of Cueva del Viento system: survey and fauna.* Proc. VII Int. Symp. Vulcanospeleol., La Palma 1994: 121-125.

New concepts in Vulcanospeleology

CLASSIFICATION OF LAVA TREE MOLDS WITH/WITHOUT REMELTED INNER SURFACE ACCORDING TO ITS FORMATION PROCESS

Tsutomu Honda

Mt.Fuji Volcano-Speleological Society, 3-6-1 Otsuka, Bunkyo-ku,Tokyo, 112-0012 Japan

Abstract

Lot of classifications of lava tree mold have been proposed by various investigators such as Ishihara (1929), Hamano (1993), Tanaka (1995) and Ogawa (1996) according to its features and structures. Makita (1997) made a table of comparison of these classifications. Recent investigation on lava tree mold of Kashiwa-bara area on the flank of Mt. Fuji performed by the group of Ogawa and Tachihara (1997) brought a lot of new discoveries and findings on the structure and formation process of lava tree mold and remelted inner surface of hollow related to lava tree mold. Tachihara (1998) is then proposing more improved classification according to their observation, however, still based on features and structures of lava tree molds.

The author would like to propose different classification concept based on its formation process, which was presented in the previous paper (1998). The complete process of lava tree mold with remelting layer formation are 1) crust formation around the tree, 2) destruction of crust by pressure of water vaporization in the tree, 3) hydrogen and carbon mono-oxide production by chemical reaction between vapor and carbonized tree, 4) and again a destruction of crust boundary with atmosphere, 5) and finally gas burning by mixing of oxygen in air, leading to remelting of surface of hollow.

Classification of tree molds types was carried out according to this process with incomplete termination or with some parasitic phenomena as shown in Fig. l.

Further, other possible effects such as lava cave formation initiated by gasification of living tree, etc., extraporated from this basic process were discussed .

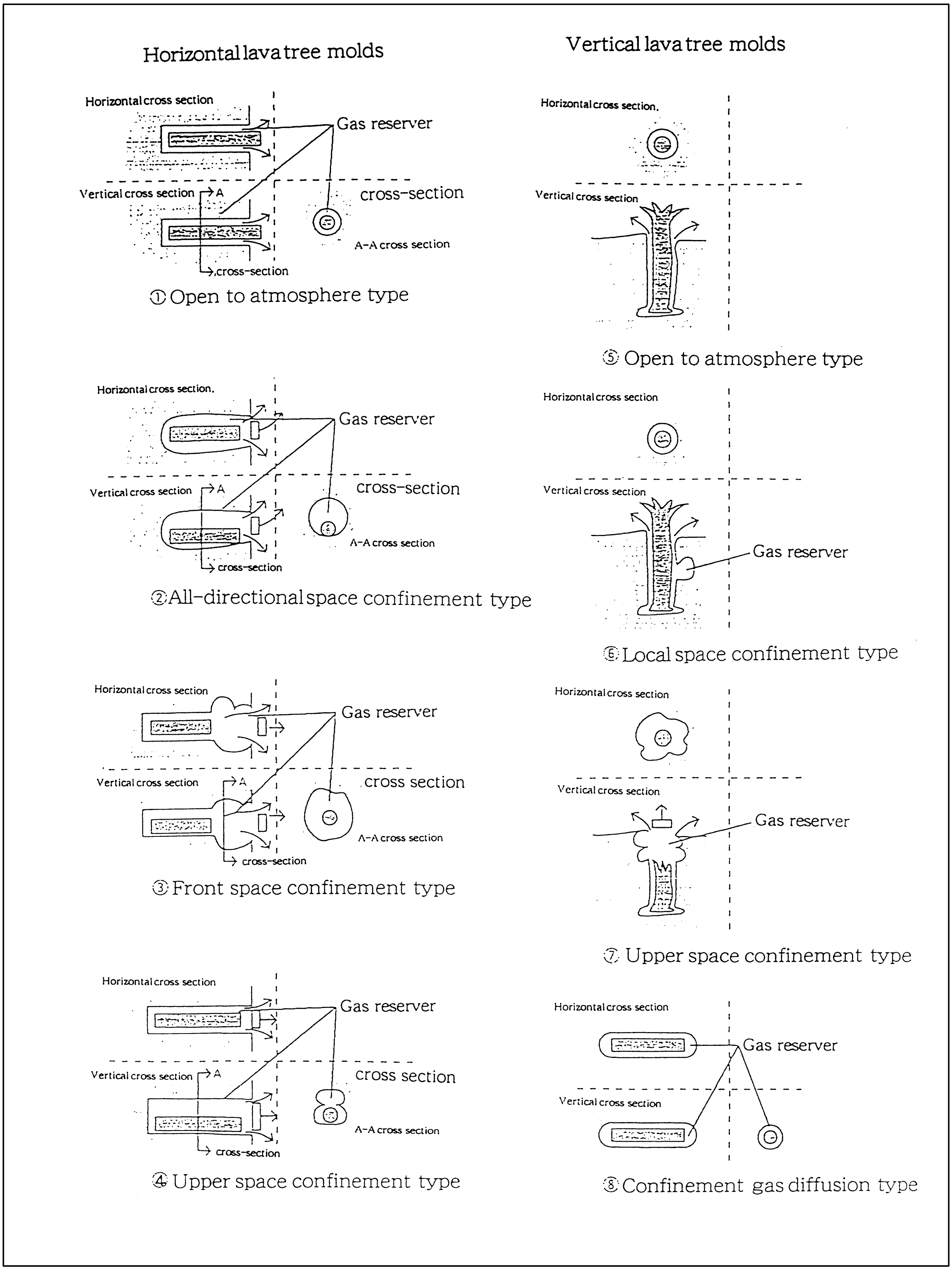


Fig. 1 - Classification of lava tree molds by its formation process.

MORPHOLOGY OF ETNA LAVA TUBES : INSIGHTS FOR LAVA FLOW EMPLACEMENT MECHANISMS

Sonia Calvari and Harry Pinkerton***

* Istituto Internazionale di Vulcanologia, Piazza Roma 2, 95123 Catania, Italy
** Environmental Science Department, Lancaster University, Lancaster LA1 4YQ, U.K.

Abstract

Lave tubes play a pivotal role in the formation of many lava flow fields. A detailed examination of several compound ‘a‘a lava flow fields on Etna confirmed that a complex network of tubes forms at successively higher levels within the flow field, and that tubes generally advance by processes that include *flow inflation* and *tube coalescence*. *Flow inflation* is commonly followed by the formation of major, first-order ephemeral vents, which, in turn, form an arterial tube network. *Tube coalescence* occurs when lave breaks through the roof or wall of an older lava tube; this can result in the unexpected appearance of vents several kilometres downstream. A close examination of underground features allowed us to distinguish between ephemeral vent formation and tube coalescence, both of which are responsible for abrupt changes in level or flow direction of lava within tubes on Etna.

Observations of active ‘a‘a lava flows emplaced during the 1991-93 eruption suggested that inflation of the flow fronts of mature ‘a‘a lava flows was an important aspect of tube formation (1). This statement is confirmed by features that we observed underground. A striking feature in many etnean lava tubes is the association of large chambers with narrow passages. We interpret these features as the product of flow inflation in the frontal zone, followed by opening of first-order ephemeral vents on the snout region. This suggests that the production of multiple flows connected by secondary vents is an essential mechanism of tube growth on Etna. This process can be observed on the surface where new, long-lived vents open at the margins of previously inactive ‘a‘a lava flows, and underground as multiple linings and lateral benches.

Tube coalescence is an important process during the emplacement of long-lived flows. This occurs when an upper tube drains into a previous, lower tube because of roof collapse. The re-occupation of a deeper and possibly longer tube may cause a re-activation of distal parts of the flow field, and a consequent increase in flow field length. The possibility of new flows breaking through the roofs of previously inactive tubes has important consequences in hazard assessment. Our surveys indicate that a crust thickness of 0.5 m is the minimum required for ‘a‘a lava flows, and we propose a simple formula to calculate roof stability for a typical etnean ‘a‘a lave flow.

In conclusion, our underground surveys help to confirm (1) that subterranean effusive processes play en important role in the development of ‘a‘a flow fields. They show how tube inflation and coalescence can result in considerable lengthening of lava flow fields beyond the distance that can be attained by channel-fed lava flows. This work has clear implications for hazard assessments during future effusive eruptions on Etna. Finally, in view of the ease with which lava can break through the roofs of lava tubes, we consider that the process of tube coalescence may be an integral part of tube development, not only on Etna, but also on other basaltic volcanoes.

References

CALVARI S. AND PINKERTON H., 1998. *Formation of lava tubes and extensive flow field during the 1991-93 eruption of Mount Etna*. Jour. Geoph. Res., 103, 27291-27302.

CROSS-SECTION MEASUREMENT OF THE 1991-93 ERUPTION LAVA TUBE

Coltelli M., Bozzo E.**, Lombardo S.**, Merlanti F.** and Tabacco I.****

* Istituto Internazionale di Vulcanologia, C.N.R., piazza Roma 2, 95123 Catania, Italy
** Dipartimento di Scienze della Terra, viale Benedetto XV 5, 16132 Genova, Italy
*** Dipartimento di Scienze della Terra, via Cicognara 7, 20129 Milano, Italy

Abstract

An electromagnetic survey on Etna was performed in June 1992, to study the features of the lava tube feeding the lava flows in Valle del Bove.
Measurements were carried out along profiles established on a smoothed area above the lava tube at 2000 m a.s.l. Ground probing radar, very low frequency electromagnetic inductive and magnetometric techniques were employed. The aim of the experiment was to measure the cross sectional area of melt in lava tube. The interpretation of electromagnetic data furnishes a lava tube geometry in agreement with volcanological evidences. The model proposed was performed on the base of a “calculated” magnetization. It presents a completely demagnetized body, about 9 m^2 in cross sectional area, located at 2 m depth. The body centre coincides with the VLF cross-over and is laterally marked by two GPR diffraction points located on the buried channel upper corners, between the melt and the host rock.
The experiment result suggests that electromagnetic surveys could be useful for monitoring the temporal evolution of lava tubes.

CONDUIT FLOW OF WATER IN VOLCANIC PSEUDOKARSTS

William R. Halliday

Hawaii Speleological Survey - 6530 Cornwall Court - Nashville, TN USA 37205

Abstract

The occurrence of steady state or flood pulse flow of groundwater in lava tube caves is widespread. The island of Hawaii is notable for several types of volcanic conduit caves. On Mauna Kea volcano, they are heavily eroded and extensively filled with mudflow and high velocity stream deposits. Others show much less modification. Unlike karstic conduits, these pseudokarstic conduits primarily function as leaky pipes; the presence or absence of adjacent aquacludes and porosity of adjacent volcanic materials largely determine their carrying capacity. In the presence of urbanization or intensive agriculture, they may be significant channels of pollution and contamination of groundwater and littoral springs.

Introduction

In recent decades, knowledge of lava tube caves and smaller lava tubes as conduits of flowing lava has become widespread. Much less known, however, is the function of these open tubes as conduits of flowing water: flood pulses, steady state flow, or both. The scientific literature is almost bare of recognition of this phenomenon. Yet scattered accounts and recent vulcanospeleological investigations clearly document its existance from Iceland to Tahiti, from Oregon to Madagascar. Their pseudokarstic flow differs fundamentally from that in karstic conduits. Yet in some basaltic regions, the public health implications of their flow volume and distribution must be considered much like those of their karstic analogues.

Differences between karstic and pseudokarstic conduit flow

Some of the difference between conduit flow in karsts and pseudokarsts reflects fundamental differences in their bedrocks. Because of the enormous porosity of many basalts, lava tubes are much leakier pipes than are karstic conduits. Thus they gather, contain, and transmit significant amounts of groundwater only under somewhat unusual conditions: clay fills in the tube and surrounding matrix, aquacludes (such as volcanic ash) immediately underlying the basalt flow, or the presence of an unusually dense lava containing the tube. Lava tube conduits can capture surface streams as do karstic conduits, but in the absence of such special factors, their water tends to leak away quickly. Conversely, groundwater leaks into lava tube conduits more readily than into similar conduits in consolidated limestones. And everything else being equal, water is less common in lava tubes than in limestone conduits because they form as readily in arid locations as in humid regions.

Types of flow in lava tube conduits

Both steady state flow and flood pulses occur in lava tube caves. A lava tube cave with seasonal or perennial steady state flow of glacial runoff is well known in Iceland, near the famous Surtshellir system. In Furna do Agua, Terceira, Azores, municipal waterworks capture and divert a perennial stream to supply a small town. In Oregon (USA), one of the headwaters of the Rogue River has been captured by a 100m segment of lava tube. In Utah (USA), water trickles into Duck Creek Lava Tube at several points, forming a stream which a rancher has dammed for domestic use.

In Hawaii (USA), during the last century a lava tube named Pukamaui captured the entire Wailuku River above the Hilo municipal water intake, and the cave had to be walled up.
In a populous suburb of the city of Hilo, flood pulses of much-visited Kaumana Cave are especially notable. These are of two types. After moderate rainfall (e.g., ca. 30 cm in 3 days), waterfalls spout at various heights along the corridor upslope from the main entrance. The resulting stream can be followed for several hundred meters before it sinks into a succession of crevices. Heavier rainfall floods lengthy sections of the cave to a maximum height of three to four meters and extensively redistributes sewage and trash which includes toxic and hazardous waste. Part of such floods emerges from an artificial lower entrance, whence it is diverted into a municipal floodwater drain; the remainder leaks into the peritubal groundwater. Especially heavy rainfall causes the cave stream to overflow these works and flood part of the subdivision.
Although of less public healh concern, bilevel Turtle Cave in the arid Kau District perhaps is more interesting hydrologically. An intermittent surface stream has cut a small gorge diagonally across and through the upper level at a point about 100 m downslope from the main entrance. Through an impenetrable orifice, extensive high velocity deposits including rounded boulders more than 10 cm in diameter have entered the lower level below the surface streambed. These flood deposits are well sorted. The lower end of the cave is obstructed by clay and mud.
On the windward (eastern) side of Mauna Kea volcano, several lava tube caves on moderate slopes have been heavily eroded by torrential stream flow and/or mudflows. In much of their courses, small scale features of lava tube caves have been obliterated. Large and small boulders and lesser stream deposits characteristically obstruct much of their courses. Where cave roofs have been destroyed, their trenches cannot be distinguished from other stream gullies and a fluvial pseudokarst is present. Most of these caves are in sparsely populated ranch country, but at least two are trash and sewage receptacles in populous Honokaa town.

Public health concerns

Although no serious public health problem has yet been traced to any such conduit in Hawaii, the presence of sewage and/or toxic and hazardous substances is worrisome. To date, none of their resurgences has been traced; presumably the ultimate resurgences are among the numerous beachline springs characteristic of tropical islands. Below Kaumana Cave, Hilo Bay is too contaminated for swimming. Here, fishing is permitted but I would not care to eat anyone's catch and the island's commercial fisheries have been decimated by undetermined factors.
At least for the city of Hilo, water tracing is needed as badly as in the infamous "natural sewers" of Bowling Green, Kentucky 50-odd years ago. A much higher level of public awareness is equally needed. An initial conference on this problem is scheduled in Hilo during the summer of 2000.

INVESTIGATION ON HYDRODYNAMIC INTERACTION BETWEEN TREE AND LAVA FLOW AND RESULTING STRUCTURE OF TREE MOLD

Tsutomu Honda

Mt.Fuji Volcano-Speleological Society, 3-6-1 Otsuka, Bunkyo-ku,Tokyo,112-0012 Japan

Abstract

On the northern flank of Mt.Fuji, a lot of groups of lava tree molds have been found and investigated by Ogawa and Tachihara (1997,1998). Tree molds are results and registered traces of interaction between tree and lava flow.

Tree molds are resulting from hydrodynamic interaction between living standing tree and lava flow (Honda,1999) as shown in Fig. l. This phenomena are strongly depending on lava viscosity, lava flow speed, diameter of living tree and its resistive strength against lava flow.

Broken tree inside of lava flow is also suffering the hydrodynamic force of lava flow its self. As lava flow has vertical velocity gradient to main flow direction, lifting force will be acting on broken tree inside of lava flow. However it depends on its mean density including crust around the broken tree and its rotating speed as shown in Fig. 2 and Fig. 3.

The author has investigated: l) Internal and external feature of tree mold depending on Re Number of lava flow, 2) the maximum diameter of standing tree resistive against lava flow by using flow resistive coefficient around the flow of vertical column and maximum bending stress of living tree, 3) Resistivity (against lava flow) of crust around the tree which has been burned out later, and finally 4) Magnus effect of broken tree with crust located inside of lava flow, which lifts up the tree mold to the surface of lava flow.

These analysis and effects were compared with the results of observations performed by Ogawa and Tachihara (1997) and these observations were found to be well explained by this interpretation and analysis of hydrodynamic interaction between lava flow and tree.

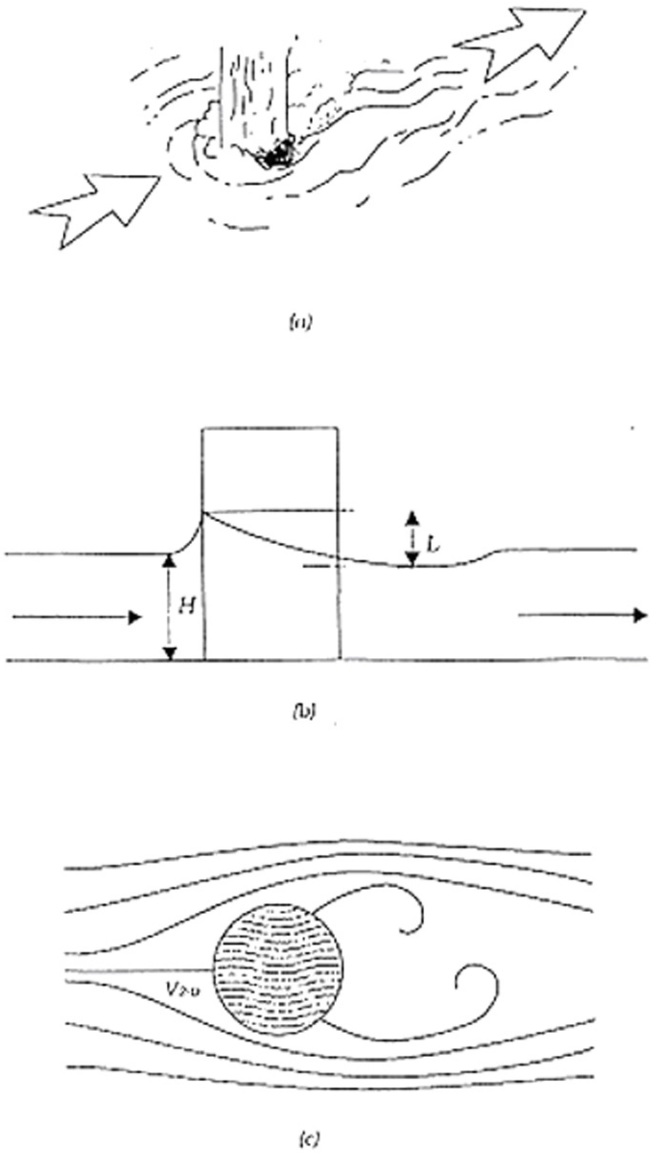


Fig. 1 – Flow around the standing living tree.

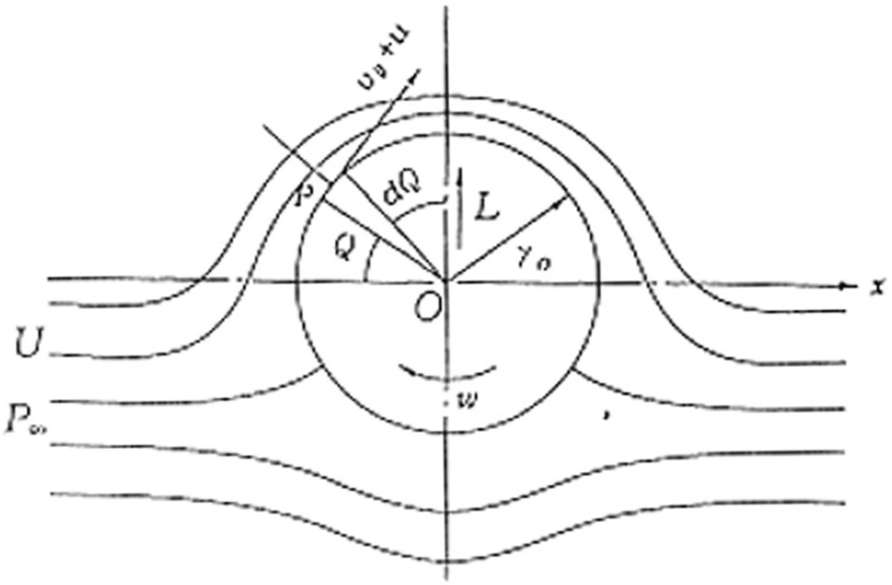


Fig. 2 – Lifting force acting on the rotating cylinder.

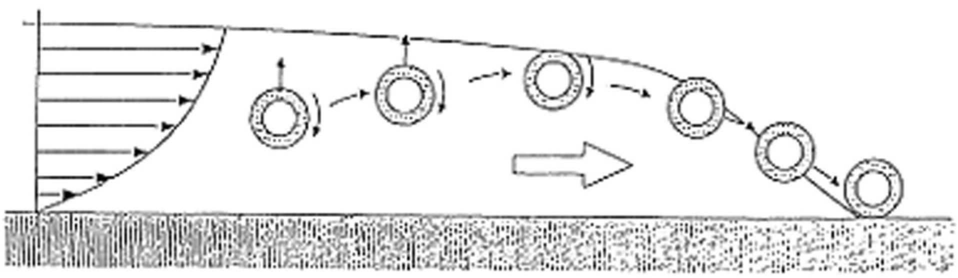


Fig. 3 – Lifting movement of tree mold located inside of the lava flow.

MAPPING LAVA FLOWS BY SURVEYING LAVA TUBES EXAMPLE: AILA'AU/KEAUHOU FLOWS, KILAUEA / HAWAII

Stephan Kempe

Geol.-Paleontol. Inst., TU-Darmstadt, Schnittspahnstr. 9, D-64287 Darmstadt, Germany

Abstract

The 500 to 350 years old Aila'au and Keauhou lava flow field of the Kilauea contains several of the longest lava caves yet explored. These are - among others - : Kazumura Cave, Pahoa Cave System, Keala Cave, Ainahou Cave System, J. Martin/Pukalani Cave System, Keauhou Trail System, Epperson's Cave (approximate ordered according to length). Of these Keala Cave (8.60 km) and the Keauhou Trail System (3.066 km in 5 caves excluding Jens' Puka which measures 0.401 km) were mapped by my students. The tubes offer a prime possibility to differentiate the lava flow fields into individual lava flows. This is an improvement compared to the first such attempt published by Holcomb, 1987, which relied entirely on aerial pictures. Much of the two flow fields are covered by intense vegetation or by grass, hiding flow boundaries from view. The trace of the tubes on the topographic maps in most parts follows a noticeable flow ridge, but not everywhere, making morphological mapping difficult. The mapping shows that clumps of trees are not only associated with the cave's pukas (collapse holes of tube roof) but also occur on top of the cave where the roots can penetrate the roof and tap the moist air below.

The geological map of the middle Aila'au Flow shows that the Keala Tube is an older branch of the flow which has been superceded by the Kazumura flow. Kazumura lava invades both the upper and the lower ends of Keala. In between of the two flows is an older kipuka (area surrounded by younger lava).

In case of the Keauhou Trail area, we were able to differentiate between three flows, one containing the Ainahou Ranch System to the west and one containing the Keauhou Trail System to the east. In between is a younger flow, superceding both Ainahou and Keauhou. It also invades the upper end of Keauhou, covering its upslope section. It is not clear which of the flows, Ainahou or Keauhou, is older. Keauhou may in fact be a discontinued branch of Ainahou. Ainahou certainly was active a longer time than Keauhou, featuring much deeper erosion and advanced development of secondary ceilings. Because the upslope area of the Keauhou flow field has been covered by later lava and by ash of the Mauna Ulu eruption, 1969, there is no chance of finding the upslope continuation of the Keauhou tube. Both Ainahou and Keauhou tubes end at the Poliokeawe Pali, a face of the lystric fault system displacing the southern shoulder of the Kilauea seaward. Ainahou ends in a portal, where the lava once issued to the open air, while the Keauhou tube is closed by collapse at the fault.

THE GENESIS OF ISOLATED LAVA CAVES ON HAWAII

Stephan Kempe

Geol.-Paleontol. Inst., TU-Darmstadt, Schnittspahnstr. 9, D-64287 Darmstadt, Germany

Abstract

The recent exploration of very long lava tubes on Hawaii has somewhat left isolated, smaller caves in the leeway of interest. Nevertheless there is much to learn from these as well. Here I present four lava caves which we have mapped on Hawaii over the past few years (Kempe, Halliday, Werner, Oberwinder). They occur somewhat isolated from others and are closed at both ends by lava seals. These are: Shield Cave, Big Room Cave, Giant Room Cave, and Kahiko Pele Cave.

Shield Cave is located in the Hawaii Volcanoes National Park (access only by permission). It is accessed through one of the right-lateral fault cracks dissecting a small, about 10 m high shield volcano belonging to the SW-Rift of Kilauea. The roof consists of a single 4 to 6 m thick lava sheet, much thicker than the lava sheets comprising normal lava tube roofs. To the east a 12*20 m wide and up to 4 m high chamber is entered. It has a solid floor with a concentric upwelling structure. Apparently this is a chamber developed above the once active vent for the shield volcano itself. To the west a semicircular, later gothic passage leaves the chamber, curving gently to the SW. At about 35 m the solid, flat floor is reached, which extends all the way to the very end of the cave where the descending ceiling touches the floor. The total length amounts to 112 m. This apparently was the lava conduit, which was fed by the vent and which was closed by ponding towards the end of the eruption.

Big Room Cave is situated at the south eastern coast of Hawaii in Kilauea E-Rift flows. Genetically the cave appears to be quite an enigma. It is entered through a central breakdown hole and essentially consists of one chamber 16 m wide, 20 m long and originally 5 m high. Upslope the cave's ceiling meets the floor, while downslope the passage becomes narrow and is blocked by breakdown. At high surf some water apparently can enter the cave, carrying fragments of marine shells into the cave. The walls are covered with a lining and where the central breakdown cone is situated the structure of the roof is exposed. The lower part is composed of lava laminae and the upper part is composed of small surface Pele's Toe type flows, apparently a later flow not directly associated with the formation of the cave. At best one can interpret this cave as a breakup cupola over a much larger tube, which at a time late in the eruption filled entirely with lava (hence the lining) which then subsided only partially, so that the original upslope continuation of the tube is blocked.

Giant Room Cave is even larger. It is situated in the lava delta of the Hualalai Puhia Pele Flow north of the Kona Airport. The cave has a length of 145 m, a width of up to 25 m and a height of up to 8 m. It is also entered through a central hole in its ceiling by rope or ladder. The floor is 11 m below the entrance and is composed of large slabs of lava, suggesting, that lava ponded to a great depth and then shrunk while cooling. At the upslope end, one can see spatter on the wall, as if lava had risen from below, bubbling up gas and throwing up spatter. Again the only explanation is, that the cave is not representing the lava conduit itself, but rather an early breakout cupola, albeit of enormous size, over the original tube, which now is inaccessibly by ponded lava. In case of Giant Room Cave other segments of the original tube-system are accessible as trenches above (Lava Curtain Trench) and below (Centashaft Trench and Cave) the cave.

Kahiko Pele Cave is another isolated section of cave. In this case no section of the same conduit is known either above or below of the cave. It is situated in the Aila'au Flow Field of the Kilauea west of the Pahoa Road. It also is entered through a central puka. It is 80 m long, forming one long hall, up to 12 m wide and 6 m high, petering out at both ends where the ceiling touches the floor.

The original floor appears at both ends below breakdown and seems to be completely level, at least we could not measure a slope over the length of the cave with the handheld inclinometer. Again, the best explanation we can give for the genesis of this cave is that it is a breakdown cupola over a much deeper rooted conduit, which ponded in the final phase of the activity. Alternatively, the floor could also be a secondary ceiling, consolidated above the lava conduit because of the opening up of the puka. However, the puka does not seem to be a hot puka, since much of the central part of the cave is covered by breakdown. Furthermore, there is a spectacular column of lava from a later flow, which invaded the cave forming a 15 m wide lava base around the 3 m wide stalagmitic column. It is conceivable, that the transgressing lava loaded the roof to a point causing the collapse of the puka. In view of this, the formation of a hot puka and the consolidation of a secondary ceiling seems unlikely.

It appears, that still much needs to be learnt about lava caves and that the wealth of processes which can form and shape caves in lava is by no means limited.

EMPLACEMENT AND TUBE DEVELOPMENT IN LONG TUBE-FED LAVAS IN N QUEENSLAND. AUSTRALIA

Jon Stephenson

Hon. Research Associate, James Cook University, Townsville, Australia 4811. jon.stephenson@jcu.edu.au

Abstract

Long tube-fed lavas that erupted in north Queensland flowed for distances of up to 160 km. They are basalts and erupted at temperatures around 1150° C, with normal basalt viscosity. There is no evidence of significant cooling down the flows, nor of much progressive crystallisation. Emplacement is held to have involved melt transportation in lava tubes, and some flows display extensive tube systems with lava caves. In some of the flows, the tubes appear to have remained filled. Most tubes appear to have been generated as subcrustal preferred pathways. Accessibility hinders fuller tube mapping, but geophysical methods hold great promise, including gravity and magnetic measurements. Seismic and ground-penetrating radar may also prove effective methods. Aeromagnetic surveys may provide new information about filled tubes in old lavas. Recently raised problems regarding flood basalt emplacement (such as for the Columbia River basalts) may also apply to the north Queensland long flows.

Introduction

A 4000 km-long belt of Cainozoic volcanic activity extends the full length of Eastern Australia (Figure 1). It is known as the Eastern Australian Volcanic Zone (EAVZ) and is reviewed by JOHNSON (1989). The EAVZ ranges in age from 70 Ma (late Cretaceous) to 4.3 ka (Holocene). In different parts of the EAVZ, especially in areas of young volcanism, lava caves are preserved. The nature and distribution of a number of the caves were described by WEBB et al. (1982).

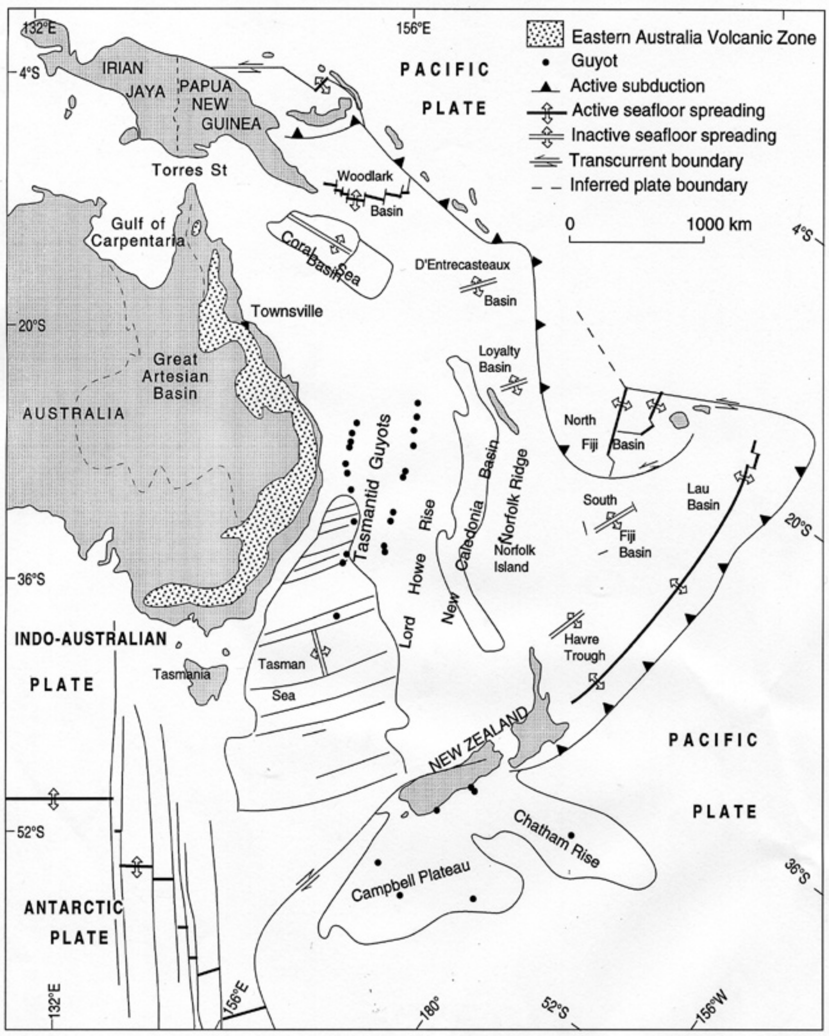


Fig. 1 - Cainozoic volcanic areas in Eastern Australia. The Eastern Australian Volcanic Zone (EAVZ) is dotted and extends for 4000 km. It is distant from plate boundaries (from STEPHENSON ET AL., 1998)

Most of the Cainozoic volcanic areas in north Queensland (Figure 2) range in age from 8 Ma to Holocene, but there was some earlier Cainozoic volcanic activity (from 44 Ma). Some of the younger lava fields contain extensive lava caves and it is likely lava tubes were very important in the emplacement of all the more extensive lava flows. Some tubes partially drained to form caves, but others which were more extensive remained filled.
This paper describes the style of basaltic activity in the north Queensland region, documents the occurrences of known lava caves and discusses the importance of lava tubes in lava flow emplacement.

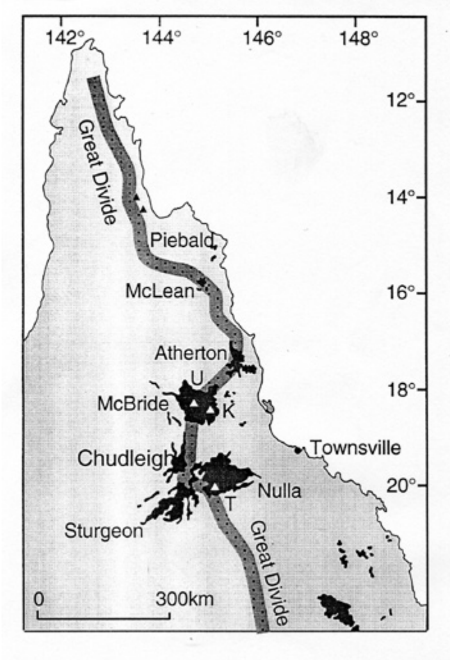


Fig. 2 - Cainozoic volcanic areas in north Queensland. The discrete areas are recognised as provinces and are all basaltic.

North Queensland Cainozoic Volcanism

The region contains a number of geographic areas containing Cainozoic volcanic rocks, referred to as volcanic provinces. Altogether 11 provinces occur north and inland from Townsville (Figure 2) and are all basaltic. Cainozoic volcanism in the region was reviewed by STEPHENSON et al. (1980) and STEPHENSON (1989). There are numerous volcanic centres in each province and age determinations indicate that sporadic activity has occurred, over periods of up to 5 million years. There have been no historic eruptions, but several provinces (Figure 2: Atherton, McBride, Chudleigh, Sturgeon and Nulla) are unlikely to be extinct. They show intermittent activity up until less than a million years ago. Age determinations indicate that although there have been concentrated periods of activity, the eruption centres were individual monogenetic volcanoes of relatively short eruption. There were long dormant periods (up to half a million years, or longer), before a new volcano erupted in the same province.
The volcanic regions have mild topography. Some provinces have radial drainage patterns and relationships suggest that very broad uplifts occurred shortly before the volcanism commenced. These uplifts are around 100 km across and rising up to 600 m. The central regions contain the volcanic centres, within oval-shaped areas 60 to 80 km long and 35 to 45 km across. The volcanic provinces do not appear to have been focused by exposed structural boundaries and they are not evidently controlled by bedrock geology. It is conjectured that lower crust or upper mantle structures determined their location, perhaps above small "plumes" in the mantle (STEPHENSON, 1989).
This paper will discuss those provinces which have known lava tubes (from the evidence of caves or of surface depressions interpreted to have been collapses). The essential characteristics of these provinces, (McBride, Chudleigh and Nulla) are summarised in Table 1. Lava caves may well come to be discovered in some of the other provinces of similar age. It is suggested that many lava fields in north Queensland are likely to contain numerous lava tubes which did not drain to form caves. Confirmation of these

Table 1. Summary details of three basaltic provinces in north Queensland which contain long lava flows and lava tubes.

	Area. km^2	Volume* km^3	Centres	Ages
McBride	5500	137	165	3 Ma-20 ka
Chudleigh	2000	50	46	8-0.2 Ma
Nulla	7500	187	46	5.2 Ma-13 ka

* Average thickness of 25 m assumed

filled tubes and further details of the recognised drained tubes will require indirect geophysical techniques for discovery.

Three volcanic provinces (McBride. Chudleigh. Nulla: Figure 2) These areas contain predominantly alkaline basalts. Most are hawaiites with less abundant alkali basalts and basanites, minor olivine tholeiites and rare mafic phonolite (as defined on the basis of their chemical compositions, using normative parameters; Johnson, 1989). A number of workers (eg. in JOHNSON, 1989; O'REILLY and ZHANG, 1995; and ZHANG et al., 1996) discussed the geochemistry and likely origin of the melts.

The provinces are broad constructional plateaus containing relatively thin lavas, usually from 5 to 30 m thick which flowed down low gradients in the landscape, commonly less than 2°. The lavas were typically captured by the natural drainage, flowing down depressions to reach and follow the drainage lines of dry stream courses and in some cases, sandy river beds. The evidence available suggests most were erupted during the long dry season. Water-interaction structures such as pillow lavas or hyaloclastites are generally absent.

The common volcanoes are broad lava shields with general similarity to Icelandic volcanoes. Some shields have summit craters. In a few instances, there is evidence of local fissure effusion. Some of the other volcanoes have steeper cones of pyroclastic or composite materials.

The surface structures of the lava flows has been examined to determine their pahoehoe or aa nature. This is difficult for older lava fields because weathering and erosion has lowered their surfaces and completely removed the original flow details. In some places, the nature of the lava can be seen where cave collapses permit examination of earlier flow units, as in the Undara lava flow (McBride Province). In the case of young lavas (such as Kinrara, McBride Province; and Toomba, Nulla Province), the original surfaces are very well preserved. Kinrara lavas are mainly pahoehoe, but extensive aa fields occur, especially near the volcano. Toomba lavas are almost entirely pahoehoe, with local aa areas and some more extensive aa fields near the volcano. Evidence in other lava fields in North Queensland indicates that pahoehoe was the dominant lava type.

Most of the lava fields have structures and morphology formed by inflation (melt injection beneath surface crust; WALKER 1991; HON et al, 1994). These structures include tumuli, broader lava rises, and lava rise ridges. Some of the lava rise ridges are up to 40 km long, 20 m high and 500 m wide, and are interpreted to have formed above river and stream channels (WHITEHEAD and STEPHENSON, 1998; STEPHENSON et al., 1998) Younger flows have crevasse-like clefts, some over 8 m deep. Although older lava fields have been affected by weathering and erosion, such that their surfaces have been lowered by more than a metre, lava rise topography formed by inflation can still be recognised in many cases. Many of the lava forms can be termed pahoehoe sheet flows and hummocky pahoehoe (compare HON et al., 1994).

The lengths of many of the lava flows are noteworthy, taking account of their estimated volumes and the very gentle topographic gradients down which they flowed. A "long" flow is nominally regarded here as more than 50 km and some examples are illustrated in Figure 3. Twenty long flows are known in the McBride, Chudleigh, Sturgeon and Nulla provinces. Three of these long flows were described by STEPHENSON et al. (1998), especially in relation to their likely emplacement. This study concluded the lavas had normal viscosity (12-105 Pas), erupted at typical basaltic temperatures (around 1150°C) and do not show evidence of unusually high eruption rates. Lava channels occur in only a few of the volcanoes, like Kinrara. The lava outpourings must have been continuous to sustain the progressive advance of the flows. It was probably important that there were no impediments to flow advance through the open savannah vegetation, that eruption was in the dry season and that there were natural pathways for the lavas down gentle drainage lines. The importance of lava tubes in the emplacement of extensive lava fields has been emphasised by many researchers, being seen as necessary to insulate the flows. The recent paper (STEPHENSON et al., 1998) referred to the modelling of temperatures of lava flowing in lava tubes by KESZTHELYI (1995) and by SAKIMOTO and ZUBER (1998) which concluded

that very long lava flows can be produced with effusion rates of the order of 20-100 m^3 s^{-1}. These models can account for the very small differences in apparent lava temperatures which have been measured in specimens from near the flow source down the very long Gingko basalt flow in the Columbia River Basalt Province (USA), using geothermometry (HO and CASHMAN, 1997). A noteworthy feature of the long flows in north Queensland is that the basalt textures show little change from near the volcano to the flow terminus. Glass compositions have been analysed from the Toomba flow to estimate flow temperatures from various places from the volcano to near the flow terminus, and the results ranged from 1130° to 1155° and their scatter does not appear to confirm higher temperatures closer to the volcano (STEPHENSON et al., 1998).

Evidence for the presence of Lava tubes

A number of lava cave localities are known in north Queensland and are referred to below. Four of these were referred to by WEBB et al (1982) and it is to be expected that further caves will be discovered in other volcanoes in north Queensland.:

McBride Province

Undara (Figure 3 a) has been most thoroughly investigated. Its age has been measured by K-Ar as close to 189 ka (GRIFFIN and MCDOUGALL, 1975). There are three extensive lava tube systems: north, north west and west. Aspects of the caves were described by ATKINSON et al.(1975) and are very well illustrated by ATKINSON AND ATKINSON (1995). They were further discussed by STEPHENSON et al. (1998).

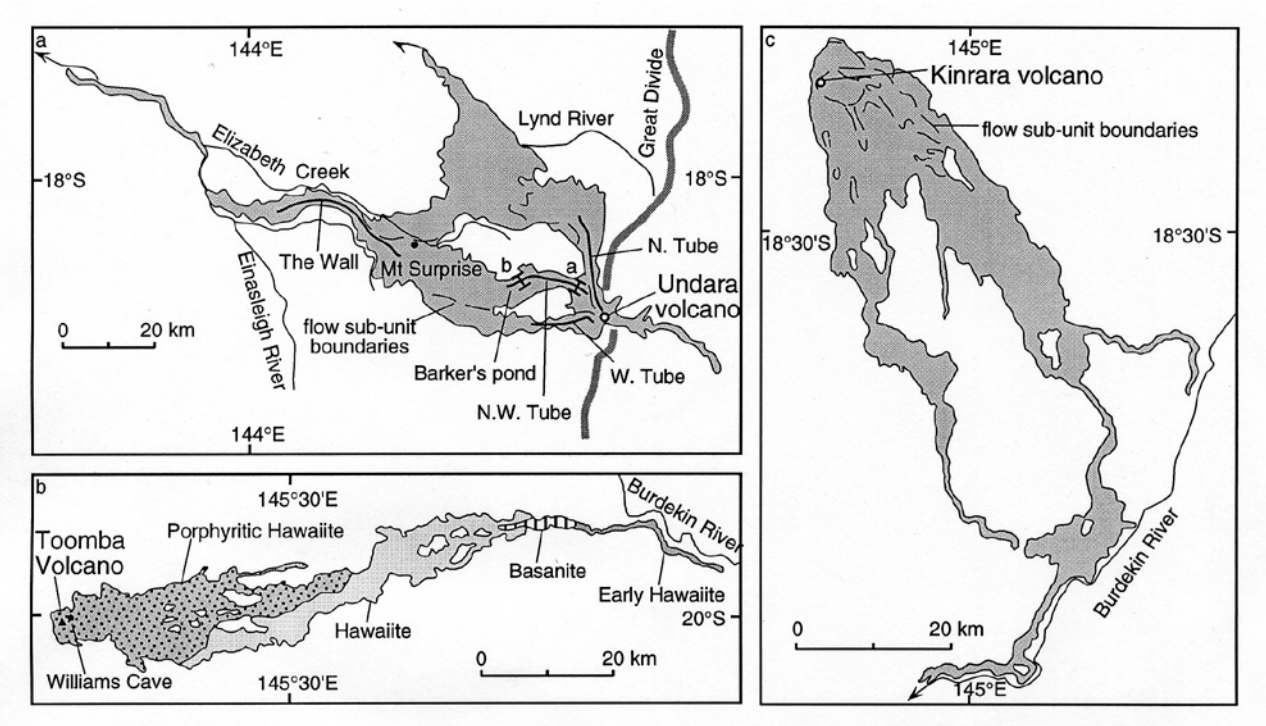


Fig. 3 - Maps showing the outlines of three long flow lava fields in the McBride Province. (From STEPHENSON ET AL., 1998).

a. Map showing the outline of the Undara lava field. Three lava tube lines are shown (N. Tube, N.W. Tube and W.Tube). The 40 km-long Wall is marked, west of Mt. Surprise. Some possible lava field boundaries are marked.

b. Map showing the Toomba lava field. This flow is composite, and four successive units are shown which can be distinguished on the basis of their phenocryst associations and chemical composition The distal part of the flow reached the ancestral Burdekin River and flowed down it.

c. Kinrara volcano and its lava field. The flows reached and flowed down the Burdekin River. Lava tubes occur south east of the volcano, within 6 km. Some likely lava field boundaries are indicated.

In 1988 Operation Raleigh, a young exploration group from the United Kingdom continued earlier exploration in the Undara lava field discovering a number of new caves, and a total of more than 60 are now known. The majority occur along the 30 km-long north west lava tube, and include the longest known caves, Bayliss (1.3 km) and Barkers (800 m).

The north lava tube appears to have formed after the north west tube. For much of their length the presence of the lava tubes is indicated by oval shaped depressions which have been referred to as "ponds', by analogy with lava ponds which occur on some of the Kilauea flows on Hawaii. These 'ponds' are conspicuous on aerial photographs, usually supporting dark vine scrub. The way in which these features were formed is uncertain - whether lava ponds (ATKINSON et al., 1975); lava-rise pits (WALKER, 1991; STEPHENSON, 1996); or generated in some other way (such as the rock rings described by KAUAHIKAUA et al, 1998). Their occurrence at Undara is along the lava tube lines, but they are found beyond the last known caves, suggesting undrained tube continuations. The relationship of some of the 'ponds' to the lava caves suggests they acted as a constraint to the later activity of the tubes which formed caves, which branch around or bypass the 'ponds'. The ponds themselves do not give access to caves. Cave entrances are usually found at the ends of narrower depressions which are probably cave collapses.

The Undara caves are usually of generous size, typical dimensions being 20m across and up to 16 m high. Most of the caves have a semi-circular roman - arch profile, with a lava-filled floor, but many are covered with later sediment which has caused the termination of some caves. Barkers Cave has profiles near its entrance which have elegant 'gothic-arch' shape, which may have been influenced in some way by the locally steeper gradient of up to 7°.

The caves carry typical ornaments, with well-formed linings concealing the near-horizontal layered lava behind. Level lines are common, from near the roof of many caves to the floor level, and seem likely to confirm progressive downward lava erosion (KAUAHIKAUA et al., 1998; GREELEY et al., 1998; STEPHENSON et al., 1998) rather than fluctuating levels in a lava stream. The thickness of cave roofs vary and in Barkers Cave it increases from 3 m near the entrance to 30 m, and the cave gets progressively deeper down its known 800 m, flooded by mud sediment at its apparent terminus (STEPHENSON AND WHITEHEAD, 1996).

The Undara lava field continues to the north and much further west, well beyond the last known caves. There are ridges interpreted as lava rise ridges formed by inflation above stream channels followed by the lava flows (STEPHENSON et al., 1998). The most impressive is "the Wall" which extends for 40 km and is 20 m high and up to 500 m wide.

Racecourse Mountain is 10 km west of Undara. It has a broad shield which contains several small caves and the larger Trimble Cave. Silent Hill. 13 km north west of Undara, has one inconspicuous vertical shaft and is a multiple-level cave system. Both these volcanoes are older than Undara.

Kinrara (Figure 3 c) is a volcano 30 km south east of Undara. It is a much younger volcano (~20 ka) and has well-preserved lava fields with pahoehoe and aa surfaces. It contains several tube systems south east of the volcano and a number of its caves were discovered and investigated by STANTON (1993). Brief descriptions are given in STEPHENSON et al. (1998), as a complex system of drained tubes up to 6 km from the volcano. These caves have a height of 8 m and have very well preserved flow features.

Mt. Joy and Murronga are volcanoes 8 and 13 km south of Undara. They are younger than Undara but over 100 ka. They are known to contain cave systems.

Chudleigh Province

Barkers Crater has a 5 known lava caves, with a total length of 250 m and a maximum height of 10 m and width of 15 m (SHANNON, 1974). There is also an impressive lava rise pit north west of the volcano's crater, with no tube caves leading from it.

Black Braes is 25 km to the west, where there are two craters. The western crater has 7 caves near it (GRIMES, 1978) ranging in size from a large cave 300 m long, 20 m wide and 7 m high. Grimes

described a number of shallow, irregular depressions which he suggested may represent lava ponds.

Nulla Province

Toomba (Figure 3b) is a well-preserved young volcano (13 ka) with lava fields extending 120 km to the east in a relatively narrow flow field. There are numerous small caves on the slopes of the volcano. Williams Cave is situated 4 km north east of the volcano. It is not much more than 100 m long but is interesting in having developed 3 levels. A new cave, Kelly Cave, has been recently discovered 15 km east of the volcano from a helicopter but awaits full exploration and mapping.
HATHEWAY AND HERRING (1970) suggested that a flow gradient of 0.5° is required for lava tubes to drain and form caves. This limit seems to account reasonably well for the occurrence of lava tube caves down the tube lines at Undara (STEPHENSON et al. 1998) and also at Toomba, where no caves have been found in the main part of the flow (gradients 0.4° decreasing to 0.1°).
Although no lava tube caves have been confirmed in the main parts of the Toomba flow, evidence indicates that subcrustal conduits must have been active. Inflationary lava rises over much of the flow suggest this (STEPHENSON et al., 1998 Figure 6), as do numerous pits, some over 60 m across and close to 20 m deep (STEPHENSON AND WHITEHEAD, 1996). Long, very wide lava rise ridges were formed in the last 15 km of the flow, where it reached and flowed down the Burdekin River (WHITEHEAD AND STEPHENSON, 1998).

Formation of Lava Tubes

The different ways in which lava tubes form have been well documented in active lava flows in Hawaii by different workers (referenced by KAUAHIKAUA et al., 1998). Many of the earlier observations on Mauna Ulu tubes were made near the vents on a moderately sloping surface and confirmed details of roofing-over of lava channels by crust growth, levee accretion and crustal raft aggregation.
OLLIER AND BROWN (1965) postulated that some lava tubes developed as subcrustal features within layered lava (multiple flow units) with diameters many time greater than the thickness of the layers. OLLIER (1988) quoted the following statement from Hatheway and Herring (1970): The lava tubes .. appear to have been formed by the development of mobile cylinders of lava in a cooler, more viscous host rock. These cylinders transported fluid lavas, to the toe of the flow as long as the source provided a continuous supply. When this ceased, the tube probably drained rapidly.' A similar subcrustal formation was deduced for some of the active tubes in Hawaiian pahoehoe sheet flows (HON et al, 1994) and detailed by KAUAHIKAUA et al. (1998).
CALVARI and PINKERTON (1998) confirmed that lava tubes on Mount Etna play a more important role in the formation of extensive aa flow fields than had been previously recognized. These tubes, which have been further described by CALVARI (1999), formed initially on distal parts of arterial flows where they encountered a reduced ground slope. Some tubes developed Systems more than 7 km long.
It is difficult to interpret how the tube systems originated at Undara from their final configurations which developed under progressive change. Cave details are certainly dominated by late-stage lava accretion, after an active history involving downward erosion (GREELEY et al. 1998; KAUAHIKAUA, 1998; STEPHENSON et al., 1998). Originally, the details in lava cave entrances at Undara were studied and interpreted (in Atkinson et al. 1975) as evidence for roofing of lava stream channels but re-evaluation confirms this evidence is uncertain. Cave entrance details could equally be seen to show that the tubes began as subcrustal, 'mobile zones' which appear to have increased in diameter and eroded across the 'layered lava' host basalts seen beyond the cave lava linings. On balance, this is the tube formation preferred for Undara. All the evidence suggests the Undara lava tubes developed in pahoehoe lavas, and this was also the case at Toomba.

The relationships of the tube lines at Undara suggest that they may have been active in the last stages of flow activity. They occur in proximity to the highest central line of the lava fields, and they appear to have been active later than the lava processes originating the "ponds" (STEPHENSON et al., 1998). There are some shorter lava tubes (evidenced by caves) near the southern edge of the Undara lava field. These tubes would appear to have been active much earlier than the main lava tubes. It is possible that older tube systems exist in all the lava fields, buried by the latest lavas.
Evidence was given from studies of the three long flow examples (Undara, Toomba, Kinrara; STEPHENSON et al. 1998) that each of their lava fields is composite. This is most easily seen in Toomba, where at least 4 lava units are apparent from differences in the sizes, abundance and association of different phenocrysts. The later Toomba lavas completely bury earlier ones, but did not flow as far as them, so that some units have only been recognised in their distal regions. Flow emplacement may well have involved successive tube systems which are concealed beneath the later units.

Detection of Lava Tubes

Lava tubes were first recognised on Hawaii through the occurrence of skylights above lava caves containing running lava. The existence of lava caves confirms the presence and course of drained lava tubes. At places like Undara the accessible lava caves confirm the dimensions of the active tubes, but raise numerous unanswered questions. Why do some relatively large caves attenuate or terminate unexpectedly? In particular, did known accessible caves really connect as parts of the same tube system? The recurrence of large caves down the northwest tube line at Undara strongly suggests this, but there are many sections several km long between some caves, in which no accessible caves have been discovered.
How can the presence of inaccessible caves be confirmed? Several methods may be applicable in detecting large cavities beneath the surface, apart from drilling, such as the following surface geophysical methods: seismic; magnetic; conductivity; gravity; and ground-penetrating radar.
Magnetic investigations have been made across several known Undara caves. Some of the results hold promise, but measurements indicated considerable fluctuation in measured intensities (Figure 4). It has not been fully confirmed why some segments have smooth variation, interrupted by more variable intervals, some of which may be associated with lava tubes. Some lava caves have a lava lining (tens of cm thick, and in places much thicker) and in places these basalts contain strongly oxidised olivines (eg. ATKINSON et al., 1975). Perhaps subcrustal parts of the flow contain other varied magnetic zones (such as vesicular crusts), as well as larger cavities.

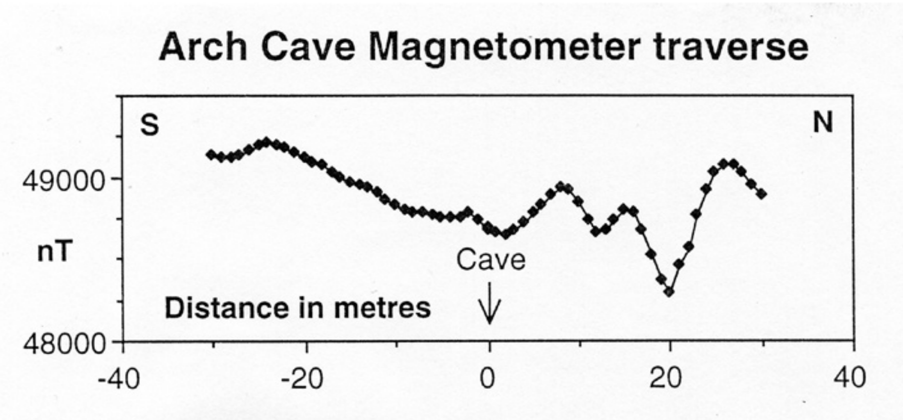


Fig. 4 - A magnetic profile across Arch Cave, Undara lava field. The known position of the 30 m-wide cave under the surface is shown.

Conductivity measurements were undertaken at Undara by SAM et al. (1996), using electromagnetic induction (EMI) technology. A transect over Road Cave showed a significant reduction in conductivity over the cave. Transects over Barkers Cave, which is smaller in diameter showed inconsistent, anomalous readings, but the general ground conductivity was very low around this cave in 1996 which was a very dry year. Although the EMI method was apparently able to detect some tubes, other surface targets also gave low apparent conductivity readings. These targets were presumably unweathered bedrock which often has very low conductivity. The lack of conductivity contrast between the cave and the surrounding rock thus places a major limitation on the use of the EMI technology. When ground conditions are wetter the situation would be improved. Further, water and moist sediment-filled caves would represent a very high conductivity target and may be easier to detect. The EMI instrument was also used to measure the thickness of high conductivity moist sediment inside Road Cave. The sediment thickness varied between 3 and 4 m in the first 50 m from the entrance and increased to 8 m at the rear approximately 90 m from the entrance. The conductivity of the top layer increased from 40 mS/m to 50 mS/m in the first 50 m and then decreased to about 30 mS/m at the rear. The bottom layer, presumably basalt, had a conductivity of less than 2 mS/m.
Gravity measurements were carried out at Undara in August 1999. The researchers (M.A. Sexton and R.G Hill, personal communication) used a gravimeter with a sensitivity of 0.02 mGal at stations 10 metre apart along three linear traverses. Elevations were accurately measured with an EDM theodolite. Corrections were made for time and altitude to obtain residual Bouguer anomaly profiles. Two of these were made above known caves:
Arch Cave, and Road Cave 90 m from its entrance (where the conductivity studies referred to earlier indicated thick cave sediments). Each profile was measured 150 m each way from a point near the cave axis. The results (eg., Figure 5) clearly indicated the presence of the caves, with local Bouguer anomalies of 0.6 and 0.25 mGal respectively. A third traverse was made across ground 100 m further up the flow from the collapse depression at Road Cave, suspected to conceal an inaccessible continuation of the cave.

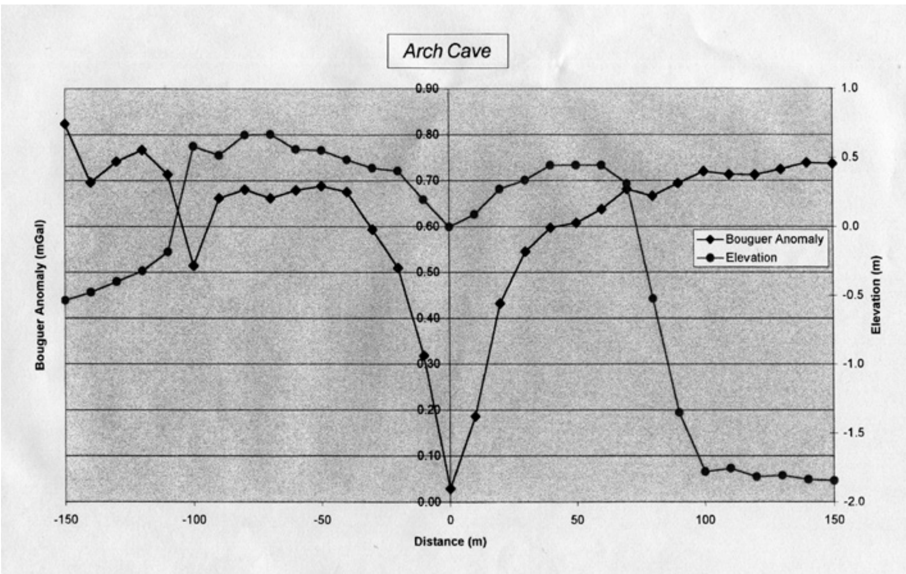


Fig. 5 - A gravity profile measured across Arch Cave, Undara lava field.
The minimum accurately indicates the cave position.

The measurements along a 250 m traverse also clearly demonstrated the presence of a cave, with a 0.17 mGal anomaly. Thus gravity measurements hold strong promise for revealing a variety of hidden details of lava tube cave systems.

The other surface methods suggested, seismic and ground-penetrating radar, have not yet been undertaken at Undara. Similar geophysical experiments could be undertaken at Toomba, but over somewhat rougher, more thickly-vegetated country with more remote lava caves.

Certain airborne geophysical methods may be capable of detecting lava tubes, drained and undrained. Thermal techniques are well established for tracing active lava tubes. Airborne magnetometer methods may be capable of delineating ancient tube systems. No results are known over lava caves, but several districts including Undara and Toomba have produced magnetic anomaly patterns over lava fields believed to contain undrained tubes. An example (provided by Normandy Exploration, Townsville) is shown in Figure 6, showing part of the Toomba lava field 20 km from the volcano where there are no known caves and the generally low lava gradient (0.3) may not have resulted in drained tubes. The anomaly patterns shows several narrow tube-like ribbons up to 15 km long which have configurations resembling lava tubes, though the anomalies are wider (100 to 300 m). Less distinct anomalies can been recognised in aeromagnetic surveys of some areas of Undara basalt, in the Mt. Garling survey (Normandy Exploration, Townsville).

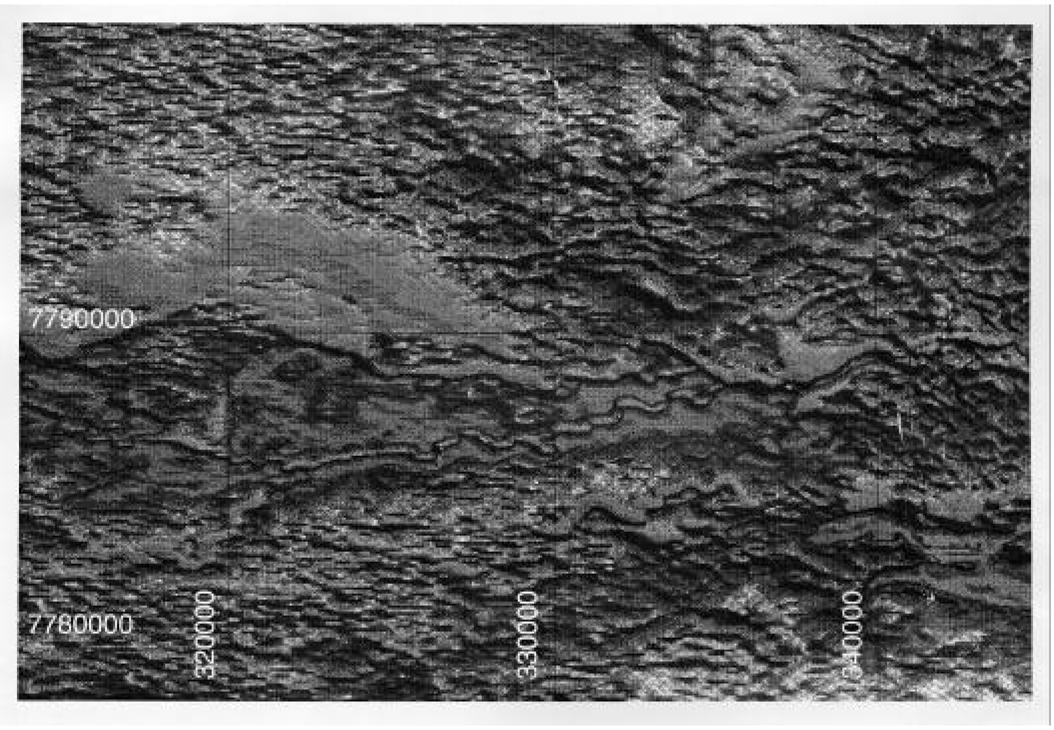


Fig. 6 - Airborne magnetic map of part of the Toomba lava field, 20 km east of the volcano. The high magnetic anomalies have geometries suggesting lava tubes. Lava caves are known closer to the volcano. The grid shown has a spacing of 10 km (Australian Map Grid).

Conclusions

Long lava flows extend for distances over 50 km and up to 160 km in north Queensland and some are known to contain lava tube systems. Individual tubes can be traced for up to 30 km from caves. They are believed to extend much further beyond the last known caves as undrained tubes. It is suggested that lava tubes provided the essential mechanism for transporting the lava in flow emplacement. Lava crust inflation was developed in most parts of the lava fields, forming an array of tumuli, lava rises and lava rise ridges, fed by a complex tube system.

To confirm the existence of such a complex of tubes, more information is needed to delineate systems in better detail than from known, accessible caves. Surface and airborne geophysical methods may prove successful in this exploration.

For longer flows, if tubes really do provide the essential lava transportation, a fuller knowledge of complete tube systems may help address some major questions. For example, how is a major, artery-like tube network sustained during the progressive emplacement of a long lava flow? This seems paradoxical, when only relatively short, disconnected cave sections are now accessible in extinct flows like Undara or Toomba. Likewise, the actual temperatures of the north Queensland long lava flows call for more careful study, especially in relation to the apparently slow cooling and minor crystal growth which seems to have occurred down the flows. Such details are closely relevant to the major problems raised by ANDERSON et al. (1999) about models for the emplacement of major lava floods like Columbia River Basalts on Hawaiian-style inflated flow mechanisms. The north Queensland flows are closely similar to those in Hawaii, and the severe difficulties raised by ANDERSON et al. (1999) for CRBs may also be seen to apply to them.

Acknowledgements

The work examining north Queensland volcanoes and lava flows has been undertaken over several decades, and involved many students, colleagues and associates. Encouragement and assistance was given by Undara Experience and its Savannah guides. National Parks and Wildlife Service, Queensland gave permits for the work at Undara and Toomba. A long list of grazing property owners gave access and information to visit lava flows on their properties. James Cook University hosted the work and awarded research grants for different phases of it. A special grant for Undara studies was provided by the National Geographic Society and by the Royal Geographic Society of Queensland.

The gravity experiments were achieved by Mike Sexton and Roland Hill, and the magnetometer readings at Undara were recorded by John McKinstry. Mick Godwin freely provided his special knowledge of Undara and reference to his careful library of mapped caves. I enjoyed stimulating discussions with Geoff Broadbent who challenged some of my tube ideas and raised nice analogies with circulation of the blood.

Karl Kizur provided computer assistance in preparing some of the diagrams. Alan Orpin rescued me on many occasions in handling computer problems.

This paper was critically reviewed by Sonia Calvari and by Peter Whitehead, and I am very grateful for their comments and suggestions.

References

- ANDERSON S.W., STOFAN E.R., SMREKAR S.E., GUEST J.E., WOOD B., 1999: *Pulsed inflation of pahoehoe lava flows: implications for flood basalt emplacement.* Earth and Planetary Science Letters, 168, 7-18.
- ATKINSON A., ATKINSON V.G., 1995: *Undara Volcano and its lava tubes.* V. and A. Atkinson, Brisbane, 85 pp.
- ATKINSON A., GRIFFIN T.J., STEPHENSON P.J., 1975: *A major la va tube system from Undara volcano. North Queensland*, Bulletin Volcanol., 39, 1-28.
- CALVARI S., 1999: *Lava tube morphology on Etna and evidence for lava flow emplacement mechanisms.* Journal for Volcanic and Geothermal Research, 90, 262-380.
- CALVARI S., PINKERTON H., 1998: *Formation of lava tubes and extensive flow field during the 1991-1993 eruption of Mount Etna*, Journal of Geophysical Research, 103, 27291-27301.
- GREELEY R., FAGENTS S.A., HARRIS R.S., KADEL S.D., WILLIAMS D.A., 1998: *Erosion by flowing lava: field evidence.* Journal of Geophysical Research, 103, 27325-27345.

- GRIFFIN T.J., MCDOUGALL I., 1975: *Geochronology of the Cainozoic McBride volcanic province. northern Queensland.* Journal of the Geological Society of Australia, 22, 387-397.
- GRIMES K.G., 1978: *The Black Braes Lava Tunnels. North Queensland*, Down Under, 17, 7-16.
- HATHEWAY A.W., HERRING A.K., 1970: *Bandera lava tubes of New Mexico and lunar implications.* Lunar and Planetary Communications, University of Arizona, Tucson, 8, 298-327.
- HO A.M., CASHMAN K.V., 1997: *Temperature constraints on the Ginkgo flow of the Columbia RiverBasalt Group.* Geology, 25, 403-406.
- HON K.J., KAUAHIKAUA J., DENLINGER R., MCKAY K., 1994: *Emplacement and inflation of pahoehoesheet flows: Observations and measurements of active Hawaiian lava flows.* Geological Society of America, Bulletin, 106, 351-370.
- JOHNSON R.W. (Ed.), 1989: *Intraplate volcanism in Eastern Australia and New Zealand.* Cambridge University Press, Melbourne, 408 pp.
- KAUAHIKAUA J., CASHMAN K.V., MATTOX T.N., HELIKER C.C., HON K.A., MANGAN M.T., THORNBER C.R., 1998: *Observations on basaltic lava streams in tubes from Kilauea Volcano, island of Hawai'i.* Journal of geophysical Research, 103, 27303-27323.
- KESZTHELYI L, 1995: *A preliminary thermal budget for lava tubes on the earth and planets.* Journal of Geophysical Research, 103, 20411-20420.
- OLLIER C., 1988: *Volcanoes.* Blackwell, Oxford,.228 pp.
- OLLIER C.D., BROWN M.C., 1965: *Lava caves of Victoria.* Bulletin Volcanol, 28, 215-230.
- O'REILLY S.Y., ZHANG M., 1985: *Geochemical characteristics of lava-field basalts from eastern Australia and inferred sources: Connections with the subcontinental mantle.* Contributions to Mineralogy and Petrology, 121, 148-170.
- SAKIMOTO S.E.H., ZUBER M.T., 1998: *Flow and convective cooling in lava tubes.* Journal of Geophysical Research, 103, 27465-27487.
- SAM R., RIDD P., STEPHENSON J., 1996: *Detection of inactive lava tubes with electromagnetic induction technology,* In Whitehead, P.W. ed., Chapman Conference on Long Lava Flows: Conference Abstracts, Economic Geology Research Unit Contribution 56, Department of Earth Sciences, James Cook University of North Queensland, Townsville, Australia, 69.
- SHANNON C.H.C., 1974: *Black Braes Area.* Down Under, 13, 141-43.
- STANTON D., 1993: *Morphology and geochemistry of the Kinrara volcano and lava field: An examination of a Holocene volcanic feature in the McBride lava province, North Queensland.* B.Sc honours thesis, James Cook University of North Queensland, Townsville, Australia.
- STEPHENSON P.J., 1989: *Northern Queensland*, In *Intraplate volcanism in Eastern Australia and New Zealand*, edited by R.W. Johnson, Cambridge University Press, Melbourne, 89-97.
- STEPHENSON P.J., GRIFFIN T.J., SUTHERLAND F.L, 1980: *Cainozoic volcanism in northeastern Australia.* In HENDERSON, R.A. AND STEPHENSON, P.J. (Eds.). *The Geology and Geophysics of Northeastern Australia.* Geological Society of Australia, Queensland Division, Brisbane, 349-374.
- STEPHENSON P.J., BURCH-JOHNSTON A.T., STANTON D., WHITEHEAD P.W., 1998: *Three long lava flows in north Queensland.* Journal of Geophysical Research, 103, 27359-27370.

- WALKER G.P.L, 1991, *Structure, and origin by injection under surface crust, of tumuli, "lava rises"."lava inflation clefts" in Hawaii.* Bulletin Volcanol.. 53, 546-558.
- STEPHENSON P.J., WHITEHEAD P.W., 1996: *Fied excursion guide. Long Lava Flows.* Economic Geology Research Unit Contribution 57, James Cook University of North Queensland, Australia.
- WEBB J.A., JOYCE E.B., STEVENS N.C., 1982: *Lava Caves of Australia.* Proceedings of the Third Int. Symp. on Vulcanospeleology, Bend, OR 1972, AB Publishing, Vancouver, WA; pp. 209-222.
- WHITEHEAD P.W., STEPHENSON P.J., 1998: *Lava rise ridges of the Toomba basalt flow, north Queensland. Australia, .Journal* of Geophysical Research, 103, 27371-27382.
- ZHANG M., STEPHENSON P.J., O'REILLY S.Y., NORMAN M., MCCULLOCH M.T., 1996: *Trace element and Sr-Nd-Pb isotopic systematics of North Queensland basalts: A preliminary study.* In, P.W. Whitehead, editor, Conference on Long Lava Flows: Conference Abstracts, Long Lava Flows, Economic Geology Research Unit Contribution, 56, Department of Earth Sciences, James Cook University of North Queensland, Australia, 98-99.

History
Archaeology
Artificial caves

ON THE ANCIENT CHURCH OF MOMPILIERI

Andrea Patti, Franco Politano and Fabio Santonocito

Centro Speleologico Etneo, Via Cagliari 15 - 95127 Catania

Abstract

Aim of the present paper is to get a better historical knowledge about the Church of “Annunziata” in Mascalucia.

According to researches and our studies “in situ”, this work try an historical description od the church with a hypothesis of three-dimensional graphic reconstruction of the building and a cartographic localization of the main artificial hollow strictly connected to the church.

The site is the main church of Mompileri, dedicated to “Maria SS. Annunziata”, that has very ancient origins: there are historical news about it since the half of the XV century.

Its history is tightly linked to the eruptions of the vulcano Etna: the sacred building has been licked up by the lava casting of 1537 and subsequently covered with the country of Mompileri from the eruption of 1669.

Since the beginnings of XVIII century, were builded artificial galleries (Eremita’s Cave) in order to reach the rests of the ancient church and subsequentely the famous simulacros.

Worthy of mention is the recovery of the cult statue dedicated to the “Madonna delle Grazie” that was discovered, in good condition, under a deep lava layer.

Purpose and location

By the critical analysis of the historical signs, this work wishes contribute to a deepest knowledge of the Church of SS. Maria Annunziata, covered by the Etnean eruption of 1669, and placed in the territory of Mascalucia, in Catania.

The building, which is the main cult site, was located in Mompilieri Village. The origin of the name "Mompilieri", which can be written in different fashions, comes from the homonymous mount located in the north side of the village.

The Mompilieri Mount rose in 693 B.C. during an ancient eruption (Romano and Sturiale, 1982), which started at an altitude of 650 m, just 1 Km SW from Nicolosi, and went on South.

We have proceeded to a hypothetical reconstruction of the church; in particular of its plan and elevation, and of the location of the holy statues, through an accurate detection of the existing signs, keeping in mind all the historical witnessess.

The site we are concerned with consists of a set of tunnels, for the most part artificial, at height of 610 m above sea level. It is an amount of artificial galleries which were built in order to find the holy statues, beginning from 1689 by Duke Giovan Andrea Massa, then in 1704, when the statue of the "Vergine delle Grazie" was found by local people, and recently in 1955 when some sculptured heads from the marble-made group of the "Annunziata" were found.

In this site there are also natural galleries, created by the lava flow above mentioned.

The Church is quite similar to the Mother Church of the old Misterbianco, which was also covered by the lava in 1669, in an area referred to as "Campanarazzu".

Table 1 Chronology of Mompilieri historical events

Date	historical event
1446	First confirmed news: Eugenio IV, designating the Church of "Maria SS. dell'elemosina" as a collegiate one, mantioned the Church of "Nunziata in Mompilieri".
1524-25	The marble–made group of the "Vergine con l'angelo", from the Gagini school, was placed on the main altar.
1537-1582	Etnean eruptions: there are some informations on the old church from historical writers. The church was partially damaged.
1669	The building was completely covered by Etna's terrible eruption.
1689-1704	After many attempts, the undamaged statue of "Madonna delle Grazie" was found and carried out: in fact, the lava river had created such as a bubble around the statue.
1704	A little church was built in 50 days over the place of discovery.
1898	Full description of the history of the Church, written by Rev. G. Lombardo.
1923	The Church was designated as Diocesan Sanctuary by Card. G. Francica Nava.
1954	The hypogeum was in part allowed to the pilgrims by the reconstruction of the entrance.
1955	Discovery of a part of the sculptured group attributed to A. Gagini.
1999	Restoration works of the sanctuary framework: new cult chapels and meeting points for pilgrims.

Historical overview

The old church, consecreted to Maria SS. Annunziata, was the "matrice" of Mompilieri Village, which rose at the foot of Etna Volcano, just under the homonymous mount.
The exact building date of the church is almost unknown and its origin is lost in the mists of the past. There are certain informations in 1446 when Pope Eugenio IV enriched the Church of Maria SS. dell'elemosina in Catania by designating it as collegiate church ang giving it some benefits such as the Beata Annunziata in Mompilieri.
This Church, which was already a prestigious cult centre, was further embellished between 1524 and 1525 when a marble sculpture from Gaginian school, dedicated to the "Annunziata con Arcangelo Gabriele", was placed on the major altar.
In fact, the sanctuary was very famous, but the holy pictures of the Arcangelo Gabriele, the Annunziata (attributed to Antonello Gagini) and the "Vergine delle Grazie" which were inside, were much more appreciated, as Massa wrote in his work "Etna in prospettiva"; he says: "Tra i più venerati Santuari della Sicilia accontavasi la Chiesa Maggiore di Mompilieri, che sorgeva sul rialto di un Colle, pertinenza del Monte Etna; quivi esposte all'adorazione dei popoli, tre grandi statue di finissimo marmo…" and then "erano sì belle che, non vi ha forse storico delle cose Siciliane, il quale ragionando di questo monte e di Catania, non ne faccia memoria…".
("Among the most venerated sanctuary of Sicily, there was the Major Church of Mompilieri, which rose on the top of a hill, close to the Mount Etna; here there were three big statues made of very pure marble, exposed to the adoration of the people…" and then " these were so beautiful that every historical writer on Sicilian things keeps them in mind while talking about this mount and Catania…").
In May 1537 between an altitude of 1800 and 1500 m, some fractures opened and from these ones a particularlly fluid magma outcame; this reached Nicolosi just in 4 days running for 10 Km and then going on.

Different autors talked about the eruption of 1537 which touched the church of Annunziata: autors as Carrera, Fazzello, Filoteo, Selvaggi and others.
In particular, there is a clear vision of all what happened thanks to a report written by Gaetano Motta in 1582 in Mompilieri (from "Ricordi storico-religiosi di Mompilieri e dell'omonimo Santuario", G. Lombardo, 1898): "Nello anno del Signore 1537 e nel mese di Maggio,… la Montagna scassò come haveva scassato lo hanno avanti 1536; lo foco che calava camminava pello nostro paese. Fu granni lo timore che si haveva, spingennosi a la aria le fiamme più di 40 palmi. Camminò tanti giorni lo foco e la xara arrivò alla detta Chiesa… Lo nostro Vicario D. Bartolomeo Macrì, presenti gli habitanti dello nostro paese, prese lo Velo miracoloso della Annunziata Maria e lo mise dinnanzi la porta della Chiesa, … Hallora lo foco si appoggiò allo muro di tramontana di detta chiesa, e non passò havanti…".
("In A.D. 1537, in May, the Mountain erupted in the same way it did the year before, 1536; the lava river flew through the village. Everyone was really worried because the fire was 40 roughly "hands" high. The lava river kept on flowing for many days, coming very close to our major church in Mompilieri. It burnt few houses and fields and then grazed the Church. So our Vicario Bartolomeo Macrì, at the presence of the local people, took the Holy Veil of Annunziata Maria and placed it just before the entrance of the church. The lava river stopped its run, after having touched the west side wall and did not go on.")

The greatest eruption was on March 11th 1669: it touched the southern side of Etna. From a fracture located at N of Nicolosi the lava river came down and covered many etnean villages and swept down to Catania.
Among the injured villages, Mompilieri and Misterbianco were completely destroyed by lava which covered them with a 10 m thick layer in some points.
Step by step an handwritten text of the chaplain of Mompilieri, Rev. Antonino di Urso, written in 1688 (from "Ricordi…"), deals with the development of the eruption. In particular he focused his attention on the fact that the inhabitants of Mompilieri considered themselves safe for the presence of Mount Mompilieri that could have saved the village but actually nothing could have saved them: "Copertò la strada che portava alli Nicolosi e poi lo foco camminando forte e senza risparmiare quello che incontrava, pervenne nella Chiesa maggiore e cominciò a copertarla e a diroccare il tetto, ch'era forte e solido… La lava dopo di havere covertato la Chiesa della Annunziata in poche ore covertò ancora tutte le case, …"
(" The lava river covered the way to Nicolosi and then, running and destroying everything it met, reached the main church. It demolished the strong roof and covered it all. After having buried the Church of Annunziata, the burning river covered all houses in few hours.")
Besides Lombardo reported an accurate description of the church: "A Nord-Ovest di Mompilieri sorgeva la Chiesa Maggiore, sacra alla Vergine Annunziata. Aveva la forma di una Basilica a tre Navate, con colonne e pilastri di lava che ne sorreggevano la volta. La porta maggiore, prospicente a Est, era contigua alla strada che conduceva in Nicolosi e Pedara. Un'altra porta più piccola della precedente trovavasi nella Nave di mezzogiorno, dirimpetto alla strada che conduceva a Malpasso ed a San Pietro Clarenza. Secondo il costume dell'epoca, il Cimitero era dietro il coro a ponente, osservandosene sino al presente le vestigia; a Nord del Tempio sorgeva il Campanile su cui tra le altre, trovavasi una campana denominata dell'Annunziata, che dopo tredici anni dall'eruzione etnea del 1669, fu rinvenuta sopra la lava, lungi alquanti metri dal sito dove ergevasi il Campanile. A desrta di chi entrava nel tempio, su d'un Altare posava la bellissima marmorea Immagine della Vergine SS. delle Grazie, e dietro l'Altare maggiore trovavasi l'edicola dove conservavasi le due divine Statue di Alabastro della Vergine SS. Annunziata e dell'Arcangelo Gabriele, in un unico gruppo. A Sinistra dell'Altare maggiore, trovavasi l'Altare del SS. Sacramento…".
("The Major Church, dedicated to the Vergine Annunziata, rose in NW side of Mompilieri. It had the plan of a twuin aisled Basilica, with columns and pillars, both made of lava, which supported the vault. The major gate, East oriented, was near the way to Nicolosi and Pedara. Another gate, smaller then the main one, was in the southern nave, in front of the way leading to Malpasso and

San Pietro Clarenza. According to the usage of that period, the Cemetery was placed behind the West side choir and we can still observe its ruins. The Bell Tower was located in the N side of the Temple, where,among others, there was a bell referred to as Annunziata Bell; this one was found over the lava just 13 year after the eruption of 1669, right some metres far from the place where rose the Bell Tower. On the right side with respect to one who entered the Temple, on an altar there was the beautiful marble sculpture of the "Vergine SS. delle Grazie" and behind the major altar there was the aedicule where the two holy alabaster statues of Vergine SS. Annunziata and of Arcangelo Gabriele were kept together. On the left hand of the major altar there was the SS. Sacramento Altar…".)

In 1689 Duke Massa began to search the three famous statues, but with poor outcomes: just some fragments were found, so he thought that the statues had been destroyed by lava.

At last, in 1704, after numerous attempts, the beautiful statue of Vergine SS. delle Grazie was found undamaged by a miracle. The statue was found right where it had been originally placed: entering the main gate on the right side on the altar.

After different attempts at carrying it out, the statue was placed on the major altar of a little church built in 50 days beside the place of the discovery.

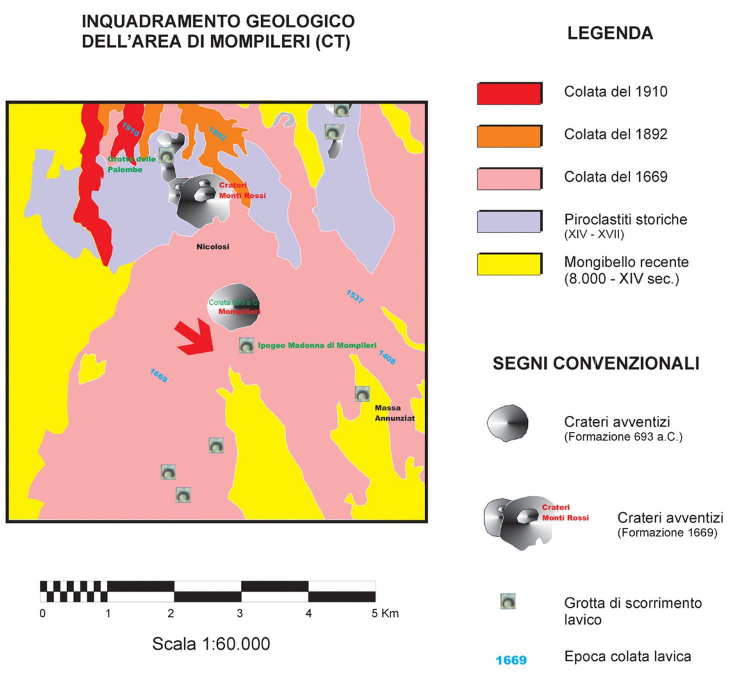
In 1898, Rev. Giuseppe Lombardo decided to publish a volume about the history of the Sanctuary entilted "Ricordi storico-religiosi di Mompilieri e dell'omonimo Santuario": this book, as known, is the first and most complete one still published.

According to Card. Francica Nava's will, in 1923 the ecclesiastic building was referred to as "Sanctuary".

Later, in 1954, the hypogeum was allowed to visitors by building stairs to the cave of discovery, accessible by an old gate built on that occasion; during the excavations inside the underground site, two marble heads of the Madonna and the Arcangelo Gabriele were found in 1955. These belong to the marble group referred to as "dell'annunciazione".

In 1999, during the rectorate of Rev. Incognito, some restoration works of the whole sanctuary were done on the occasion of Jubelee: the building of a room for cult purpose under the present church and different restoration works of the church itself are now under way.

Research contribute



The "Mompilieri Cave" took its origin from the lava flow of 1669 (fig. 1), on March 12^th (D'Urso). This eruption, which completely destroyed the villages of Mompilieri and Misterbianco, touched, among others, also the city of Catania.

Therefore the Mompilieri Village, which numbered almost 600 inhabitants, was completely covered by the lava river: the major church, dedicated to "Nunziata" was covered too.

Based on the historical knowledge, a systematic exploration of the hypogeum, which includes the ruins of the church has been developed.

Fig. 1 – Geological map of the area

At the present time the entrance (fig. 2) to the tunnels is allowed by a gate in the main area, recently built, beside the ecclesiastical temple. Here there are two flights of stairs going down for about 8 m. The entrance, as it is today, was built in 1954 in order to partially allow the view of the hypogeum.
Going down, we are in a narrow room just in front of the ruins of an half-destroyed pilllar, made of lava, and on the right side (towards NE direction) we can see the "miracle-altar", right where the statue of *SS. Maria delle Grazie* was found: this one is now kept in the upper part of the sanctuary.
On the left side of the stairs, we can see the length of the fence, high up to the vault, placed there to protect the following rooms.
According to our recreation (fig. 3), this "lavic room" was supposed to be in the north Nave.
A set of galleries starts from this point; they are in part digged in the lava stone and the other ones are natural.
Going on West, through an entrance on the N side, we get into a narrow tunnel that surrounds the NW corner of the church, near the hypothetical apsidal area. Bones were found among the ruins in the gallery that surrounds the West side; so it is easy to believe that there was the cemetery of the church in this area, according to the historical sources.
Inside the Church, on the N edge wall, there are the remains of a wall painting in bad conditions, not easy to identify; they let us suppose that the picture represents the "Madonna".

Fig. 2 – The entrance

Proceeding on West, we get to the NW outside corner of the building, where a great amount of reddish lava touchs the N side wall.
By the Rev. G. Motta's witness, we had believed to find the lava of 1537 inside the hypogeum, but a deepest analysis has made us think different.
The sample, referred to as H (taken from NW outside corner), has been submitted to a petrographical analysis, through a thin section, which has showed the main features.
The petrographical features have revealed that the sample belongs neither to the eruption of 1537 nor to the one of 1669 (Corsaro R.A., Cristofolini R., 1993); it has an older origin.
In the sample we are concerned with there are almost only tabular-shaped *plagioclase* phenocrysts, which are uncoloured, generally idiomorphic (limited by well-formed crystal faces) and can be 5-6 mm long and clearly shows compositional zones.

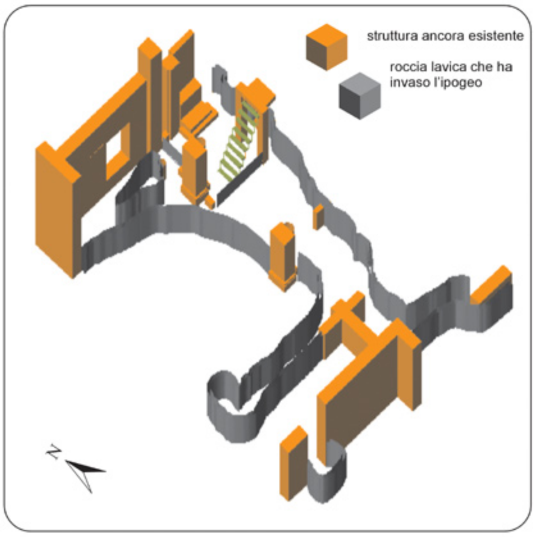


Fig. 3 - A complete survey of the "actual state of things".

The difference between this sample and the one analysed before, from now on named sample A, selected from the lava of 1669, close to the only altar still existing, comes out from the content of phenocrysts, given by the value of Porphyrytic Index, which has been assessed in about 20-25% in volume for the sample A, and in 15% for the sample H. In particular the two samples are different by the nature of their own phenocrysts.
Besides *plagioclase*, the most abundant mineral, whose size is seldom longer than a millimetre, there is also *clinopiroxene* in the sample A. This one, green-yellow coloured, generally appears as idiomorphic prismatic-shaped samples, whose length is up 4 mm; this mineral often includes oxides and forms an aggregate together with other piroxen crystals. *Olivine* crystals are more uncommon; they appear uncoloured, stronghly prominent, without any sign of cleavage, sub-rounded shaped and from 0.5 mm up to 1 mm long.

There are also some *matte oxides* which appear dark to an observation by the white-polarized-ligth microscope. They are less than 0.5 mm in length and they are sub-rounded shaped.
Going back to the altar zone and proceeding on S direction for about 15 m, right where the vault of the lava cave is gradually lower, there is a column, the same as the one mentioned before, almost covered by lava (fig. 4). This bounds the nave by partially coming out.
Going on, we get to the S wall; the gallery forks nearby a pillar and proceeds on W direction, ascending for about 10 m, ending with a round excavation which is about 1 m deep.

Fig. 4 – A column covered by lava

Near the pillar, found by the S wall, a little door to the church covered by lava was supposed to be (A. D'urso in "Mompilieri", pag 57, of Rev. Padalino). This entrance was also supposed to lead to the room in front of the southern side of the church, perhaps the sacristy. From the S wall, through a hole, the gallery keeps on going southward, and finally enters in a rectangular room through a breach in the W side wall. On the lavic "floor", which partially reveals an earthen floor (certainly the old floor of the church), a very regular rectangular excavation (maybe a tomb) was found, with traces of bones, on the bottom of the "lavic room" at the foot of the E side wall.
A complete survey of the "actual state of things" has been carried out both of the plan and of the elevation (fig. 3). A hypothesis of recreation of the building has been proposed too (fig. 5).
By the observations and by the detailed plan-altimetrical survey, we have obtained a set of useful information on the recreation of the church; we have noticed that the church had really three naves, it was about 15 m long and the pilasters were 4 m high.
The ceiling of the church presents "false vaults" made of canes and gypsum plaster – this hypothesis has been confirmed by the traces of this material in the hypogeum –; probably the highest part of the ceiling was built by wooden trusses, burnt by the lava flow.

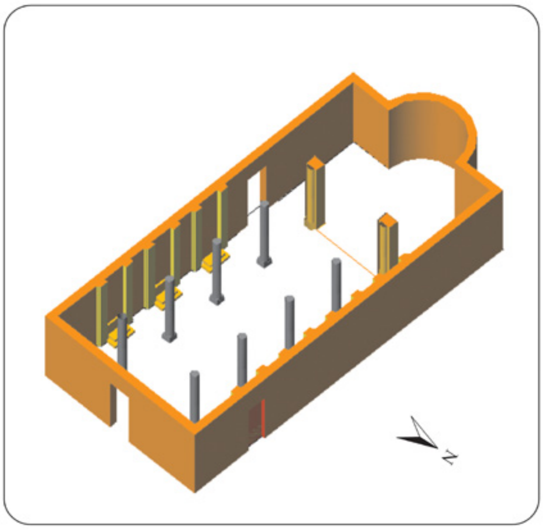


Fig. 5 - A hypothesis of recreation of the building.

By the numerous remains of roof tiles, we deduce that the top of the roof was supposed to be made of earthen tiles, maybe a double-pitch roof, while the inner part was supposed to be plastered, as we can see by the great amount of plaster still present, and the floor of the church consisted of 30 x 30 earthen-squared tiles.
The border walls are made of lava stones of different sizes, kept together by mortar, while columns and pilasters consists of well-squared and smoothed lava stones. Inside the building we have found traces of such as a hole in the N side wall, but historical sources do not confirm this.

Wishes

We hope for an exavation in order to a sistematical analysis of this hypogeum (and others like this one) which makes it possible to acquire a deepest knowledge of those underground "treasures" and then enables more visitors to view it, not only urban speleologists.

Besides it should be interesting to develop a deepest study about the overall area of Mompilieri Village; this could give us an historical profile of the Etnean village before the fatal eruption of 1669.

Special thanks

We would like to thank all the people who have collaborated to write this paper. In particular we thank the previous rector of the Sanctuary Rev. G. Padalino for his help in the historical part and the present rector of the Sanctuary Rev. S. Incognito for his kindness in having opened to us the cave of Mompilieri at any hour. We wish to thank Prof. Renato Cristofolini of the University of Catania because he has allowed us to use facilities to find the data relating to the petrographical exam of the lava-stone samples.
We thank also Dr. Rosanna Corsaro, geologist and researcher by the International Institute of Volcanology of Catania who gave her contribute to the scientific part of this work by writing much of the paragraph entitled " Research contribute"; right where we have talked about the outcomes of the analysis executed on the lava samples. Besides we thank Dr. Rosanna Corsaro for having helped us by analysing the lava-stone samples.

References

- AA.VV., 1989: *Santuari Mariani dell'Etna*, Luciano Tringale, Catania, pp.97-104.
- AA.VV., 1993: *Guida ai Beni culturali dei comuni di Mascalucia Tremestieri etneo, S.Pietro Clarenza e Camporotondo etneo*; tip. Lombardo & Licciardello, pp. 11-22 e 80-81.
- CONDARELLI D., 1981: *Momipileri*, “Speleoetna”, Gruppo Grotte Catania, Catania, pag. 25.
- CORSARO R.A., CRISTOFOLINI R., 1993: *Nuovi dati petrochimici ed isotopici sulla successione del Mongibello Recente (M.te Etna)*. Boll. Acc. Gioenia Sci. Nat., 26, 341, 185-225.
- LOMBARDO G., 1898: *Ricordi storico-religiosi di Mompileri e dell’omonimo santuario*; Tip. Bellia A., Belpasso.
- PADALINO G., 1980: *Mompileri*; Tip. A. Sarica, Catania.
- SANTI G., 1999: *Miti e leggende delle grotte dell’Etna*, “Dentro il vulcano, Le grotte dell’Etna”; Centro Speleologico Etneo, Ente Parco dell’Etna, Catania, pp. 128-135

RUINS OF ANCIENT "CAMPANARAZZU" BURIED BY 1669 ERUPTION

Franco Politano and Fabio Santonocito

Centro Speleologico Etneo, Via Cagliari, 15 - 95127 Catania, Italy

Abstract

The work intends to describe a site of speleological interest, denominated "Campanarazzu" by Misterbianco inhabitants. This site is situated in Catania's province and, granted that a church, It's very probable that the term "Campanazzu" ("Big and Ugly Bell Tower") refers to the imposing dimensions of the bell tower.

These ruins help in knowledge of structures built by man, part destroyed owing to lavic invasions, that preserve some intact subterranean environments with connections to the surface that allow the access and the following research of urban speleology.

Editing this work we didn't limit to the description of that speleogical site, but we did a photographic relief of little-know parts (such as valuable column).

We rebuilt graphically a tridimensional model of the antique church by C.A.D. - processing, assigning explanatory altitudes (to the bell tower, too), that could show up the building parts still existing against the already destroyed ones.

Nowadays, in Etna's territory, we know few examples with these peculiarities , and, for their singular location and composition, they have not only national, but even international importance.

Introduction

In this work we examine the vulcanospeleological site denominated "Campanarazzu", consisting of partially subterranean ruins of ancient main church of Misterbianco, a town in the north-west of Catania.

We analyzed the environments existing now and destroyed ones, by an analytical description and a reconstruction in tridimensional graphics, realized according to C.A.D. procedures, that showed how the advancement of flow of lava, after having come across the antique church, avoided it and infiltrated into some weaker environments destroying them and burying other ones.

We catalogued these environments in a table that show up parts existing now and already destroyed ones.

After repetitive explorations, we noticed how the only structure to resist the force of lava was the bell tower, both because of "natural" lavic way and of building tipology of period (very thick walls, cornices, reinforced, utilization of basaltic lavic rocks which have high mechanical resitance).

In planimetry in scale 1:10.000, in Regional Techinical Map published by the Councillor's Office of Sicilian Region Territory and Habitat, we localized the hypogeum, placed in the north-east of existing Misterbianco.

The towns hit by 1669 eruption

The story of vulcanospeleological site of "Campanarazzu" is connected with the imposing 1669 eruption, that hit most of Catania's province, such as Misterbianco, Mascalucia, Belpasso, Nicolosi, San Giovanni Galermo, Mompileri, san Pietro clarenza, Camporotondo Etneo and part of Catania's city.

Lava came out from "Monti Rossi" craters, so denominated owing to a dialectic term "M. Rossi" for "Big Mountains", which developed in Nicolosi's territory, in Catania's province at 900 metres above sea-level.
In XIX century it was colonized by a pine wood.
Lava flow allowed the population to save themselves and to move furniture and fittings and church ornaments and vestments to a safe place.
We haven't reliable news and sources about this vulcanospeleological site, particularly about the origin of Main Church of ancient Misterbianco, placed in country *"Chiesa di Santa Maria De Monasterio Albo"*.
First certain news date back to 1353 and we found them in two parchments: 24th January 1353 one and 22nd august 1358 one.
Ancient town, Misterbianco, rose on promontory limited by surrounding walls. In the south of it flowed "Amenano" river, which still has great importance because of numerous legends.
According to some scholars, Amenano has its source in Etna slopes, flows underground several kilometers and reaches Jonio Sea in the south of Catania.

Description of the famous eruption

As Tedeschi describes in a masterly manner on 11th March 1669, tow craters denominated "Monti Rossi" developed localized in Nicolosi and very soon Catania's province suffered destruction and terror.
Nowadays the 1669 is considered "Eruption Year", because its was the eruption per excellence, the most imposing, the most ravaging of recent Mongibello (other name for Etna).
An historical report of frightful 1669 eruption, is described in famous Tommaso Tedeschi's publication *"Breve ragguaglio degli incendi di Mongibello" (Short report about Mongibello's fires) Longo edition, napoli 1669*, because he was also eyewitness of that natural calamity.
He wrote: *"So on 8th March of this year 1669, first Friday of Lent, our Mongibello, with horrible and frightful lows (probably he didin't refer only to Etna roars, but even to seismic swarm of volcanic origin, that proceded the eruption) began to shake the earth so often and so fiercely, that the people were full of fear, particularly the inhabitans of its towns…"*
Then the descendants, sentimentally bound with their forefathers places tried to know as much as possible about ancient ruins.
In particular, they dug and llok for "finds" of historical past, where part destroyed structures, that probably represented interesting buildings, appeared on the surface.

Guide to hypogeum access and its description

We arrive to the ancient Churh after having gone the way from Catania to Misterbianco and then followed road markings to the ancient town, denominated on signs as "Campanarazzu, ancient Misterbianco".
We reach by auto the end of Campanarazzu street, and then we distinguish a barrier made by steel cable, so we have to continue on foot, descending a couple of metres in difference in level.
After a short way, a downhill path begins on lava found, where a small votive chapel (of bricks full and tanned of lava stone) is placed on little clearing to remember ancient Misterbianco and in particular its *"Matrice" (Main Church)*, evidence of "religious feelings" and sentimental bonds to the place, of Misterbianco's inhabitants.
The site hasn't any visible sign of realization of tourist / receptive structure, even if there is a legitimate proposal for found a suburban park.

As time went by "Campanarazzu" became so interesting, particularly for young generation, that dilettante-level explorations were organized to recover the ancient church decorative object or fragments, causing sometimes irreparable damage to those ones spared by lava flow.
"What lava spared, man damaged . . ."
Neither gates nor barriers are, to enter the partly integral environments. Those environments are narrow in some parts, partially destroyed and with difficulty accessible.
Surrounding landscape is suitable for tourist reception, because it is hilly location, that allows an almost global view of Jonio coast south and of south-east Etna, as if it remembers and warns against its powerful devastating action.
Unfortunately, in these last decades in south-east of site, unauthorized housebuilding and savage cementification developed excessively, without any respect for the "place".

Guide to hypogeum access

Fig. 1 – The Church ruins

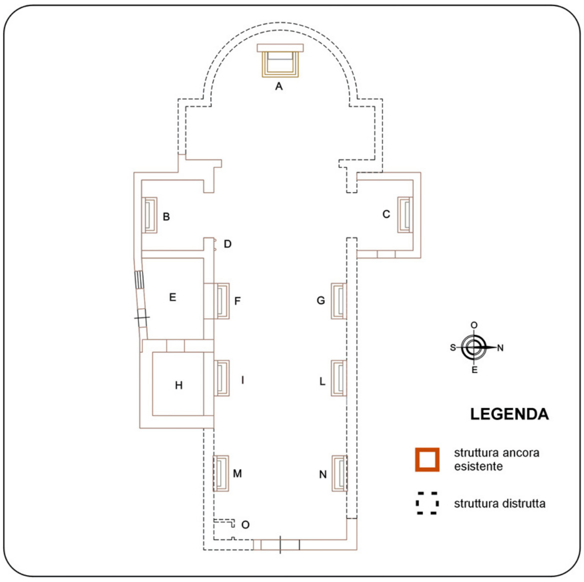
From Catania we reach San Giovanni Galermo, outlying ward in the north of Catania, and we go trough the provincial road to Misterbianco, for about 1,5 Km; then we enter Serra Belvedere street and we can see on road markings *"Campanarazzu - Ruins of ancient Misterbianco"* and *"Santuario Madonna degli Ammalati" (Madonna of the Sicks Santuary).*
The way goes on 1669 lavas, crossing an intensely built area. To the crossroads for *"Madonna of the Sicks Santuary"*, we enter Campanarazzu street. Once in the street, we can catch sight of squat bell tower ruins among lavas and houses.
Campanarazzu street ends close to Church ruins (Fig. 1). 100 metres before, on southern part, we can see the entrances of tow totally spared by lava cisterns. The cisterns aren't accessible owing to their state of preservation, they have about 3 metres diameter and are a couple of metres deep.

Description of cavity

The spared by lava, nowadays known and visitable environments are two: the ruins of Madonna of Graces Chapel and Crucified, and we can enter it from a hidden hole among lavas and excavation materials, that in environment of about 6,30 metres high, with east wall about 4,50 metres and north wall about 5 metres wide, trough an antique window placed o high part of east wall; remaining south-west parts is cluttered with lava.
We can see a little well entrance on north wall: in the past it was the preservation and today guarded in the main church of existing Misterbianco.
That environment is about 2,60 metres deep and about 1,20 metres wide. Lava came in from south to north, after having invaded nearly the whole chapel; it stopped few centimetres before the niche, that preserved the marble statue.
The Crucified Chapel lies on southern part of Main Church, and we enter it from an underground passage that begins from a room *(maybe "sacristy")* without roof and next to bell tower.

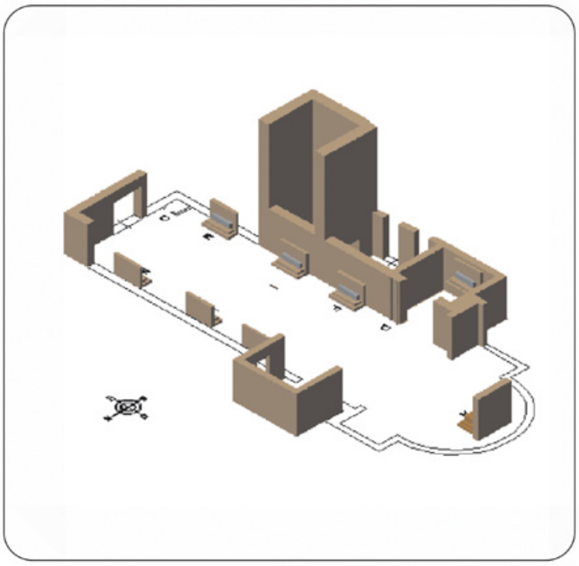
Fig. 2 – A column of the ancient Main Church of Misterbianco

Subsequently his room was artificially widened with some environments. Two semicircular columns (pilaster strips), of calcareous stone, finely historiated with bas-reliefs representing puttos, dragon and flowers interlaced with acanthus leaves, lean on the wall.
Those columns rise from the lava crushed stone floor and penetrate the lavic rocks (Fig. 2). Between the two columns there is a niche with a stucco statue (1,40 metres high), with the head set in rock.



Legend of accessible and not environments

A	*High Altar*
B	*Crucified Chapel*
C	*Madonna of Graces Chapel*
D	*Columns and niche*
E	*Environments annexed to the Church*
F	*St. Antonio Abate Altar*
G	*St. Francesco Altar*
H	*Bell Tower*
I	*St. Erasmo Altar*
L	*Carmelo's Madonna Altar*
M	*St. Annunziata Altar*
N	*St. Purgatorio Altar*
O	*Baptistery*



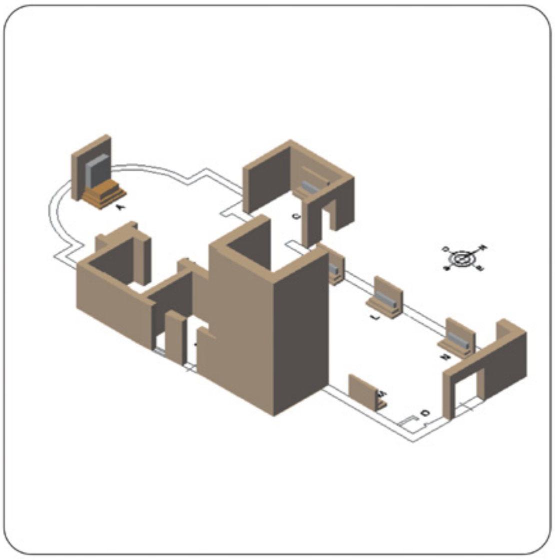


Fig. 3 - Plan and tridimensional modelling of ancient Main Church of Misterbianco

Conclusions

Not corroborated rumours inform of others environments existence; of these one keeps a wall with Madonna fresco, but its hypothetical entrance are unknown.
The authors hope that in the near future people have more *"respect"* for described before hypogean environments.
They also hope that country "Campanarazzu" may become one day an *Archaeological Reserve* or a sort of sub-urban park at the gates of Misterbianco.

Thanks

We thank so much for kind collaboration the whole Centro Speleologico Etneo. Photos published in this work were realized by partner Dr. Antonio Marino, and we thank him for his differing availability.
We thank the Councillor's Office of Sicilian Region Territory and Habitat for concession of Regional Techinical Map of Misterbianco.

Bibliography

- SANTONOCITO M., 1988: *Misterbianco ieri*, Edizioni Grafiche Artigianelli, Trento
- TEDESCHI T., 1669: *Breve ragguaglio degli incendi di Mongibello avvenuti nell'anno 1669*, Longo Editore, Napoli
- TOMASELLO O., 1987: *Catania e la sua montagna*, Greco Edizioni, Catania
- TOURING CLUB ITALIANO, 1989: *Guida d'Italia - Sicilia*, Palermo

ARCHAEOLOGICAL FINDINGS IN THE CAVES OF MT. ETNA

Francesco Privitera

Soprintendenza BB.CC.AA., Sezione beni archeologici, Catania, Italy

Abstract

After a short introduction about the importance of caves in studying prehistory, the paper discusses the volcanic caves on Mt. Etna. Their discovering is reported and the course of the different prehistoric cultures in Sicily and in the area of Mt. Etna is examined, studying the evidences inside the caves. So it comes out the great number of peoples who lived in many caves during the Late Copper Age and the Ancient Bronze Age.
Moreover, the paper talks about the different use of the caves for the prehistoric man (i.e. houses, graves, or religion places). On Mt. Etna the caves were chiefly used as graves, but in recent studies it seems that they could be also used as religion places, as in "Petralia cave" which has been explored recently.
At last, a short description of eight caves is reported. These caves are very important for the information they provide about their use during the prehistoric period.

STUDIES ON LAVA CAVES DURING THE PAST CENTURIES

G. Puglisi[*] and G. Santi[**]

* Istituto Internazionale di Vulcanologia - C.N.R., Catania, Italy
** Centro Speleologico Etneo, Via Cagliari 15 - 95127 Catania, Italy

Summary

This paper scours the evolution of the scientific thought dealing with volcanic caves. This aim will be achieved taking into account studies carried out mainly on Etna caves in the past centuries by several scholars. The main result is that, thanks to Hamilton's and Dolomieu's studies, the watershed between two different approach methods to the study on volcanic caves, and to their role in the general framework of volcanic phenomena, is to be placed at the end of the XVIII century.

ANCIENT FOREIGN VISITORS ON MT. ETNA

Giancarlo Santi

Centro Speleologico Etneo - Via Cagliari 15 - 95127 Catania, Italy

Abstract

This contribution reports and comments witness by some significant XVIII and XIX century travellers who wished to complete their *Grand Tour* of Italy by an adventurous ascension to Mt. Etna. Their experience was often preceded or followed by a gloomy descent *ad inferos* (to Hell), by visiting some volcanic cave (all visitors' teams usually made a stop at *Grotta delle Capre* [Goats Cave], for a brief night rest before the final climb for observing the dawn from top of Etna. Almost every visitor described this cave, though very often the various descriptions largely differ from one another). Besides this mandatory stop, the cave visits were generally unimportant fantasy trips, suggested by the unending cycle of tales related to Etna caves, rather than actual explorations

Only few travellers, induced by a great recklessness and an actual scientific concern, like Hamilton and Dolomieu, ventured inside lava caves and made scientific observations and measurements. Hamilton's annotations were still inadequate and cluttered, whereas Dolomieu's ones were accurate and skilful. Dolomieu also succeeded, during his tour, to recognize and describe some mechanisms of cave formation.

The final part of the lecture reports some original passages by some travellers, describing the preservation and commerce of Etna snow: the historical significance of these reports is evident, as snow was a very important good for the population at that times. Houel carefully described the operation of a snow-cave, the *Grotte à la Neige* (today's *Grotta dei Ladri*, Thieves' Cave), though his passage was never translated into Italian.

ARTIFICIAL CAVITIES IN LAVA FLOWS: GRAVEL QUARRIES

Franco Politano and Giuseppe M. Licitra

Centro Speleologico Etneo, Via Cagliari 15 - 95127 Catania, Italia

Summary

The Authors describe hereby the main characters of the gravel quarries buried under the modern Catania, as well as under its lava-formed surroundings, based on their observational and research studies of this kind of artificial cavities. Their attention is mainly focused on gravel quarries themselves, though some note does also concern ruins of artefacts existing prior to the covering lava expansions.

Foreword

Men dug wide underground cavities in past times, for quarrying a specific material, with tiny granulometry, generated by the action of lava flows on the pre-existing paleo-soil. These hollows are usually named *quarries of "agghiara"* (gravel), a stuff mixed with lime for production of mortar, in the building trade. Quarrymen named gravel according to its quality and different colours: *terra rossa* (red soil), for its reddish colour and its *pozzuolana* behaviour, and *azzolo*, the greyish variety of this building material.

The essential structure of a lava flow should be borne in mind: the flanks, made by sharp loose material, are named *lateral moraines*; the central part can host a *flow channel*; the cross section of a chilled lava flow has usually a lenticular shape, with central thickening of the roof, and of the bottom as well, when the flow occurred along a depression. The following characters can be observed from top to bottom: the upper scum, named *sciara* by quarrymen; the massive middle body, named *afficilàto*, constituted by the chilled flow; the bottom scum, that quarrymen name ***rifùsa*** (re-molten), as it is generated by the "*track motion*" of the flow front, buried and re-molten by the advancing flow. *Azzolo* results from an adequate riddling of the *rifùsa*; *terra rossa* is the reddish metamorphosed paleo-soil supporting the flow bottom.

Fig. 1 - Quarry front displaying the cross flow section. The sequence of various layers and their different features can be noted: the upper dark-greyish layer is formed by scoriae. The intermediate layer is much more thick and light-greyish coloured and is formed by basaltic rock («*afficilàto*»); it is currently exploited for hew lava stones production. The lower layer, of variable thickness, is made by «*rifùsa*» (re-molten), and down below the reddish «*agghiàra*» (gravel) layer can be detected (pict. by E. Lo Giudice)

Gravel utilisation techniques [1]

- The *terra rossa* gravel is mixed with slaked lime for kneading ordinary mortars, for wall manufacturing, at a mixing ratio of two volumes to one, whereas the ratio involves seven red gravel volumes and four ones of lime, for producing hydraulic mortars for exterior plastering.
- The mortars kneaded by mixing seven volumes of ***azzolo*** gravel with three ones of slaked lime, are employed in thwacked floor production, named ***làstrici*** (pavements), that harden like solid lava stone, whereas one volume of slaked lime and two volumes of ***azzolo*** are mixed for kneading ordinary mortars.

The quality of the resulting mortars is largely related to their manipulation: the minimum necessary quantity of water has to be used, and the longer the components are kneaded, the better the mortar results.

Some notes on origins and evolution of the use of (volcanic) gravel-lime mortars

Sumerian people already knew and used slaked lime, named *kalga*, to lock one stone block to another for wall manufacturing. Nevertheless Romans first kneaded slaked lime with Pozzuoli gravel, named *puteolana* (the trachytic tuff, nowadays known as *pozzuolana*), for producing a mixture capable of underwater hardening. Pozzuolana products are characterised by their content of amorphous silica, that is formed when silica reaches temperatures ranging between 500 and 900°C. Amorphous silica interacts with lime by producing calcium silicate, insoluble in water and even aggressive waters resistant. It was surely ascertained during Roman rule that the reddish soil of Etna, kneaded with lime, presented similar hydraulic characters, as those obtained from the *pozzuolana* of Pozzuoli.

The pozzuolana gravel of Etna, named *terra rossa* (reddish soil), is produced by thermal metamorphosis: the phenomenon occurs when the mass of the flowing lava is sufficiently thick for a durable preservation of its thermal energy as well as of its high bottom temperature, while flowing on gravelly soils without humus. Our pozzuolana gravel is perhaps the sole formation, with hydraulic features, generated by metamorphosis rather than by the chilling of pyroclastic products; furthermore it is “ready-to-use”, no previous crumbling is needed.

In former times gravel and stony materials were hauled together from the same quarries. The exploitation of specific underground gravel quarries spread around, especially from the eighteenth century to the first half of the twentieth one, when the request for *agghiàra* (gravel) largely exceeded the one for lava stone, because its tiny sands were massively utilised (after adequate riddling) for preparing external plasters which characterise, by their reddish colours, many facades in Etna villages. Unfortunately gravel mortars were entirely replaced by cement mortars, after the end of World War second, due to the increasing digging difficulties and high hauling costs. The quarries became rapidly misused and forgotten, many of their adits were destroyed and buried by the tumultuous expansion of urban centres, and entire boroughs, intensely populated, hid today a broad underlying network of artificial galleries.

Location of the main quarries

The main quarries known and reported by last century authors are:

- Ancient *Botte dell’Acqua* (water barrel) quarry [1], lava of the 1669 eruption that produced excellent gravel. Its entrance was probably located near the homonymous street, close to the ancient city walls, today almost entirely destroyed. A street named Via Petriera (Stone Quarry Street), in the nearby area, still shows cliff remnants of the Danieli quarry, formerly exploited for construction stones.

- *Ognina* quarry [(1)], produced second-rate material, due to the vicinity of the sea and the relevant marine salt contamination.
- Via di *Cave Villarà* quarry, 1669 eruption, is located inside an agricultural estate and its galleries wind around below an intensely populated area, in the outskirts of Catania.
- Via *Masaniello* quarry, lava-field *"Curia"* of the 1669 eruption, is located inside a former stone quarry that is used today as a dump for waste building material; its passages wind below intensely inhabited areas.
- Via *Condorelli* quarry, probably formerly exploited even for hauling pumice stone, used as ceiling-making material for its lightness. The quarry is located inside the Spina estates, includes remarkably ample rooms, and extends up to Due Obelischi (Two Obelisks) Street.
- Quarries of "*Prache*" (Gravina), 1669 eruption, providing first quality material; their venue is located in the territory of Gravina di Catania.

Terra rossa and *azzolo* were often hauled from quarries inside the city boundaries, to the extent of reducing problems and costs of transportation. Ancient quarries were exploited in the historic centre of Catania, in the lava expansion of Fratelli Pii (Merciful Brothers) covering the Santa Maria (Holy Mary) hill. They were probably used in the Roman period for building public edifices as the Amphitheatre, the Theatre, the Spas, and further ones. Maybe these quarries are the same underground cavities mentioned by F. Ferrara [(2)], who reports repeated visits to "*immense pozzuolana quarries*" close to the Buglio Mansion and to the St. Julian's Monastery, Via Crociferi (Crucifers Street); in Ferrara's times they were considered catacombs, rather than quarries. Sometimes the supplying quarry was directly dug inside the relevant building yard: the dungeons of the Capuchins Monastery host the entrance of a small gravel quarry.

The gravel quarrying was certainly widespread, and a large deal of minor quarries is still unknown. Sometimes ruins of loose-laid walls or gallery adits, observed in the trenches dug for new building groundwork, witness the pre-existence of probable hauling galleries. The hauling activity was very rough; no supporting structures were added to loose-laid walls, and very simple tools, mattocks and hoes, were used digging. The hauled stuff was placed into wicker baskets named *cufini*, back-carried outside the quarry by donkeys or children. A preliminary rough hand selection was performed inside the quarry, prior to arranging the stuff in the baskets, whereas a subsequent riddling was performed by hand sieves, named *crivi*, with wooden frames and metallic riddling plates. The diameter of the riddling holes varied according to the specific utilisation of the final stuff.

Fig. 2 - Villarà Quarry; typical entrance at the lava flow margin (pict. by A. Marino).

Description of typical quarries

The entrances of quarry adits are usually located at the margins of lava flows (Fig. 2), where the rock texture is not too dense, or inside construction stone quarries (Fig. 3). Frequent lighting shafts, harnessed with wooden ladders, ensure ventilation and rapid access to the underlying galleries. The adit normally slopes downward until the base of the flow, wherefrom horizontal trenches start, forming the quarry passages; the height of their vertical section continuously varies between one and two meters, as it was probably governed by the thickness of the exploitable deposit. Stony steps connect the steeper differences in height of the quarry passages (Fig. 4) winding here and there through the paleo-soil, according to

the pre-existent orography. The galleries are roofed by the lava flow bottom, which includes various stony materials carried by the flow. Sometimes a glimpse can be caught on fragments of brick-made walls (Fig. 5), and of an ancient – probably Roman – wheat crusher (Fig. 6) (Capuchins Quarry [(3)]). The digging activity proceeds towards every direction, often leaving wide hollow spaces (Fig. 7) behind, where supporting pillars (Fig. 8) are left (a hall some 30m wide was found inside a quarry, near Via Nuovalucello). The hollow spaces are subsequently filled by waste digging material – even huge stony blocks – and

Fig. 3 - Curia Quarry; typical entrance inside a stone quarry (pict. by N. Scalia).

Fig. 4 - Curia Quarry; steps connecting two different levels (pict. by N. Scalia).

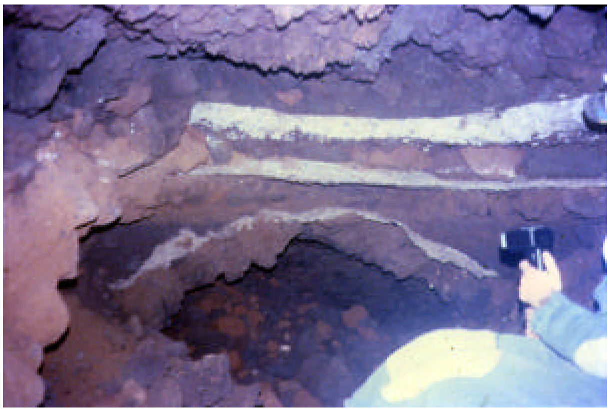


Fig. 5 - Capuchins Quarry; remnants of an edifice engulfed by the molten lava (pict. by F. Politano).

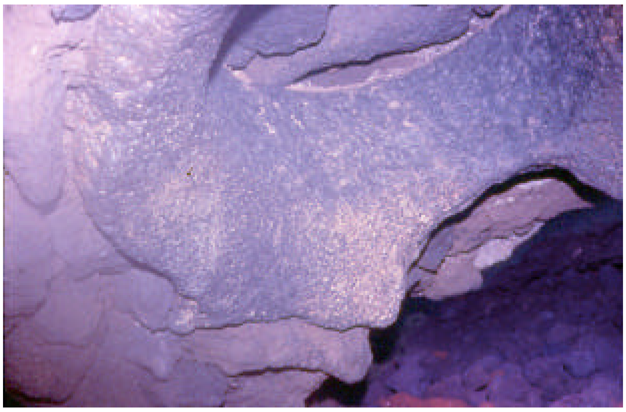


Fig. 6 - Capuchins Quarry; remnants of a lava-stone mill welded in the vault of a narrow passage (pict. by F. Politano).

eventually closed by loose-laid walls (the lateral walls marking many passages) (Fig. 9). Ceilings and walls are very crumbly, when supports are missing; in addition large flooded zones can be found in quarries underlying urbanised areas, due to the intense dripping of rainwaters or to the leaking of sinkhole sewage.

Fig. 7 - Curia Quarry; a large hall can be observed to the right, close to the quarry entrance (pict. by N. Scalia).

Fig. 8 - Botte dell'Acqua (water barrel) Quarry; residual «*agghiàra*» pillar close to material partially collapsed from walls and vault (pict. by A. Marino).

Fig. 9 - Botte dell'Acqua (water barrel) Quarry; passage flanked by loose-laid walls (pict. by A. Marino).

Archaeological potential of gravel quarries

Ruins of edifices, and traces of the ancient urban frame, can be eventually found in hauling passages, when the parent lava flow invaded and buried inhabited areas in historic times. Furthermore, as previously mentioned, the passage allure follows the pre-existing orography, and runways and staircases can be found, in connection with ancient subsidences and small relieves, whereas the present orography has quite changed.

The study of the late-medieval archaeology could take advantage from the topographic survey of the quarries underlying the 1669 lava flow (that reached the town of Catania). The upper parts of the artefacts were molten or engulfed by the fluid lava mass, whereas their lower parts – eventually survived to the lava destruction – were engulfed (and protected) by the ***rifùsa***. House walls, with openings introducing into close spaces defined by bricked-up walls and man-made ceilings – with eventual pavements and various debris – can be observed in the narrow galleries branching throughout the ancient buried village, from the cavity engulfing the transept of the ancient Church of the Annunciation, at Mompilieri. Local elders' *tales* report the alleged existence of galleries dug behind the ancient city walls (Botte dell'Acqua, Naumachia or Roman Gymnasium, buried by the 1669 eruption). If their entrance adits could be traced, probable ruins could be observed of skirting boards and ground structures of Roman and medieval artefacts, invaded rather than destroyed by the *rifùsa*.

Conclusions

The presence of wide networks of hauling passages, often unknown or forgotten, nowadays involves objective risks for the surface artefacts and activities, mainly in urbanised areas. The partial speleological exploration of some underground quarries revealed very insecure standing conditions both for the rough exploitation techniques, and for the progressive natural degradation of the underground artefacts. Limited collapse phenomena affect some passages (Capuchins Monastery, Via di Cave Villarà and Curia lava field quarries [3]), and huge collapsed blocks eventually obstruct the main passage (Fig. 10). These phenomena could result in turn in progressive surface collapses, chasm formation and more or less severe cracks. The sharp surface overlying Villarà quarries, still unfarmed and bare, is affected by several funnel-shaped depressions, of two and even more meters in diameter. House proprietors and masons of Gravina di Catania reported that the Prache quarry underlying Via Gramsci caused several dislodgments to the foundation ground of some edifices built up in the very last decades. The complex phenomena of structural instability, and of the various factors interacting with the urban framework, involve binding investigations and interventions in such cases, with heavy financial disbursements.

Fig. 10 - Botte dell'Acqua (water barrel) Quarry; example of vault collapse: this phenomenon is widespread throughout the quarry and often stops up the passage. A lava-stone slab in contact with the «*agghiàra*» and traces of water dripping through the vault cracks can be observed (pict. by R. Bonaccorso).

Obviously the whole resulting problem demands the Public Authorities' attendance and coordination, due to the remarkable financial commitment and to the involvement of institutional bodies with their interconnected specific competences. The preliminary localisation of all existent quarries should be therefore carried out, including the ones with buried entrance adits, with relevant exploration and topographic survey of their galleries, and, if and where possible, measurement of the thickness between the gallery roofs and the foundations of the overlying buildings. This operation should make possible a quantitative evaluation of the involved risks, and enable the observers to rationalise the technical and financial commitments for more detailed investigations, more accurate evaluations of risks and intervention demands, and determination of the most appropriate strengthening actions.

The present period is still particularly favourable for an organic and exhaustive research, since the last *agghiàra* quarries were abandoned at the beginning of the Sixties, and many ***ghiaiòti*** (gravel quarry labourers) are still alive. Their cultural heritage of sentences, tales, engravings, pictures, digging tools, knowledge of hauling and exploitation techniques, etc., represents an actual living memory of the world of quarries, exploited for materials destined to lime kneading, and uninterruptedly lasted from the Romans up to present times. This heritage should be assembled and published, in order to hand down to posterity the hard job reported by the writer Giovanni Verga in his novel «*Rosso Malpelo*» (Red-haired Mischief).

References

- SCIUTO PATTI C. (1), *Sui materiali da costruzioni più usati in Catania*, Estratto dagli atti del Collegio d'Ingegneri ed Architetti in Catania - Anni XVII e XVIII - fasc. unico
- FERRARA F. (2), 1870, *Catania Antica*, Riedizione anastatica, Atesa Ed, Bologna, 1984, 573 pp.
- POLITANO F. (3), 1994, *Primi risultati e prospettive della speleologia urbana a Catania*, Atti Acc. Gioenia di Sc. Nat., Vol. 27, n° 348, pp. 93-103, Catania

MYTHS AND LEGENDS ON ETNA CAVES

Giancarlo Santi

Centro Speleologico Etneo - Via Cagliari 15 - 95127 Catania, Italy

Abstract

The Author selected and reports hereby some most significant legends and tales related to Etna caves, in order to sketch an ideal underground itinerary through fantasy and wonder around Mt. Etna. The particular subject of the lecture prevented the Author from any kind of manipulation of the original texts or translation of it into a language other than Italian.

Two classic tales start this selection: both of them refer to caves presently existing only in people's memory, as they've unfortunately been destroyed or became inaccessible. The first tale concerns the Grotta delle Palombe (Doves' Cave) at Santa Maria La Scala, destroyed by a sea storm: popular belief placed here the scenic background of Aci's and Galatea's love story. The second one refers to St. Sophia's Cave on the hill of Cibali (northwest borough of Catania), buried by the expanding town: poets praised this cave as Hades Gate, wherefrom Pluto sorted out for Persephone's rape. Three legends are reported, among numberless tales very similar to one another, concerning enchanted hidden treasures, popularly said *truvature* (findings), often watched by demoniac beings. Also caves sanctified by hermits' presence are hereby reminded.

Though, the main part of the lecture reports the fascinating underground legends with a religious background, whose heroine is the Holy Virgin Mary, as they still feed Etna people's devotion. Four legends are reminded, concerning Our Lady of the *Pileri* at Randazzo, Our Lady of Valverde, Our Lady of the *Sciara* (lava flow) of Mompilieri, and Our Lady in the crypt of the church of St. Gaetano alla Grotta in Catania. A fifth tale, the *missed legend* of the Holy Virgin of Vadalato, concerns an unusual event that can be considered as a commentary of the subject dealt with.

Last but not least, an atypical polyedric tale brings the lecture to its end, a tale pregnant with epic and chivalrous atmosphere whose legendary world breaks into the sharp and rustic Etna caves, by hosting here a great northern king. This improbable legend, rides such different cultures and natural sceneries as Mt. Etna and the Round Table, that both topics get excited each other in turn: the legend of King Arthur on Mt. Etna.

A SHORT HISTORY OF VULCANOSPELEOLOGY

William R. Halliday

Honorary President, UIS Commission on Volcanic Caves

Introduction

As a subscience, vulcanospeleology began in 1972 and 1975, with the first and second international symposia on this specific subject. Millennia of field observations, and twenty centuries of written documentation - some of it truly illustrious - proceeded its formal beginning, however. Prehistoric man investigated and used lava tube caves just as he did those in limestone. We do not know if the walls of presently inaccessible lava tube caves in southern Syria or eastern Turkey carry age-old inscriptions like those of central Turkey's karstic Iskender-i-Birkilin Cave. Otherwise, documentation of lava tube caves of Monte Etna uniquely forms one of two mainstreams of vulcanospeleology, from the dawn years of protohistory.

Today, at the threshold of the 3rd Millennium, vulcanospeleology is the fastest growing branch of all speleology with constant new discoveries crying out for ever-expanding definitive studies. And ever since its dual beginning in 1972 and 1975, the international symposia have served as its forefront.

The development of vulcanospeleology

Like calcareospeleology, vulcanospeleology arose out of an unsystematic array of disparate observations, isolated cave descriptions, and scattered, more or less scientific reports. As in the case of calcareospeleology, its development was strongly influenced by the overall progress of civilization, especially that of European civilization and its American extension. For several reasons, however, the two branches of speleology did not develop precisely in parallel. Early man used caves without consideration of their bedrock. But during most of our literate centuries, limestone dissolution caves have been the type located closest to centers of population, learning, and travel. Further, the characteristics of karstic caves and karstic hydrology long rendered them of disproportionate importance in the lives of individuals, nations, and cultures. Unlike limestone caves, few lava tube caves serve as natural conduits for municipal water supplies, for example. Still further, the origin of lava tube caves long appeared so simple that no special studies seemed needed to determine their origin and development. Today, the paucity of pre-1960 vulcanospeleological literature reflects the distance of world centers of speleological thought from major lava tube cave areas. Even Trevor Shaw's monumental History of Cave Science (Shaw, 1992), is strictly limited to karstic caves.

Early Vulcanospeleology in Italy

Only in Italy do we know of lava caves in early areas of literate civilization and learning. Here, Titus Lucretius Carus wrote about "siliceous caves...full of air and wind” which he apparently had observed first-hand, virtually from base to summit of Monte Etna, early in the First Century BC (Cigna, 1993). Albeit rather fancifully, Carus began the Italian mainstream of vulcanospeleology. It continued without parallel for centuries. Many other citations on Monte Etna caves exist in the next 1600 years. In 1591, Filoteo's book Topographia mentioned the author's visits to many of them. In 1628, Kircher reported visiting another cave that could shelter 30,000 persons (Licitra, 1993).

Vulcanospeleology and Early European Voyages

Participants in early European voyages encountered Iceland, then other cavernous volcanic island terrains in the Atlantic Ocean. Surtshellir is mentioned in Icelandic sagas perhaps a thousand years old (Hroarsson and Jonsson, 1992). By 1757 it was the site of the first published map of a lava tube cave (van der Pas, 1998); one of the first published maps of caves of any type. (In contrast, the first map known of a lava tube cave in Italy was of Grotta delle Palombe, by Wolfgang Sartorius von Waltershausen, in 1880 [Licitra, 1993]).
During and after the conquest of the Canary Islands in the 1400's, Spanish soldiers, priests and colonizers encountered major lava tube caves on several islands. The original settlers had used many. In 1774 and 1776, major explorations were documented in Cueva de Viento and Cueva de San Marcos, respectively (Lainez Concepcion, 1996; Rosales Martin 1996). In 1896, Puig y Larraz was able to list many caves here. Reports on caves in the Azores and on Madeira began much later, perhaps with Webster in 1821 and Fouque in 1873 for the former (Borges et al, 1992).

Other Voyages and Vulcanospeleology

Early Spanish explorations in the Americas and the Pacific Ocean are not known to have recorded any lava tube caves. In the Indian Ocean, English and French military expeditions and settlements resulted in documentation of lava tube caves in Mauritius in 1773 and 1801, 1812, and 1814 - the last being by Mathew Flinders, first circumnavigator of Australia. Additional accounts appeared in 1859 and 1873, the latter by Nicholas Pike, U.S. consul and an enthusiastic caver. In 1895 and 1898 Haig added a notable scientific account followed by a not-so-notable bit of cave fiction (Middleton, 1997). On Reunion, at least one volcanic cave was reported (by letter) in 1769, with a more detailed consideration by Bory de St. Vincent in 1801 and studies by LaCroix in 1936. In the 1930's and 1940's, the existence of lava tubes on Madagascar and Grand Comoros Islands also became known. (DeCary, 1949). Reunion reports by Velain in 1878 and 1880 dealt with two cavernous hornitos.
In many parts of Oceania, English and American explorers recorded numerous lava tube caves. Charles Darwin was among the first, recording lava tube caves in the Galapagos Islands in 1845. Until 1962, however, there was little follow-up of his work here (Hernandez et al, 1992). At least by 1823 (Ellis, 1823) religious missionaries began to describe and discuss lava tube caves in Hawaii. Later famous for his system of mineralogy, James Dana (1849) was the first American scientist to study them in some detail. His work, however, was somewhat overshadowed by the prolific, precise reports of such missionaries as William Ellis and Titus Coan. Early in the 20^th Century, Thomas A. Jaggar (founder of the Hawaiian Volcano Observatory) built on their observations and added new input resulting from his linkage to the mainstream of American geology (Halliday, 1998). With Lorrin Thurston and others, he created the first wave of Hawaii spelology prior to World War I.
Systematic accounts of caves on Easter Island were in 1889, 1919, 1935, 1937 and 1948, followed by Thor Heyerdahl's prolonged investigation in the 1950's (Kiernan, 1993). In New Zealand, lava tube caves at the site of Auckland were visited early. Scientific accounts and maps date to 1869 (Stewart, 1869). In eastern Australia, most of the lava tube caves are so remote that their exploration and study have been 20^th Century phenomena. Some of those in Victoria have been known since the mid-1800, however, with especially important reports in 1866 and 1895 (Webb et al, 1993). Elsewhere in the southwest Pacific, lava tube caves in Samoa and other volcanic islands were reported at least as early as 1911, but with little follow-up.

Vulcanospeleology in the United States

The second mainstream of vulcanospeleology arose in the United States, but its onset was slow and fragmented. Most American lava tube caves were remote from centers of population and of academia, and - ultimately - from the burgeoning centers of early American speleology. However, the great American westward expansion brought pioneer explorers and government geologists to remote areas, and the National Geographic Society later funded expeditions into other volcanic regions. Many lava tube caves thus were reported between 1850 and 1915 but few were studied in detail. Local newspapers and various magazines recounted exciting underground ventures, especially where the caves were of special military or economic importance - the latter especially those which contained ice, a precious commodity in hot western summers. Others quickly became popular recreation sites. Henderson (1932) compiled a detailed annotated listing of lava tube caves of the U.S.A., including varied opinions about their origin. Through the mid-1940's, however, the American literature on lava tube caves remained scant and fragmented.

The Flowering of Vulcanospeleology

In many parts of the world, a sudden quickening of vulcanospeleology began independently in the 1960's and 1970's. In the American mainstream, my "*Caves of Washington*" (Halliday, 1963) has been given credit for beginning descriptions of lava tube caves "in earnest" and for introducing a widely used groundwork of terminology (Larson, 1993). However, the roots of this American flowering clearly were several years older. "*Caves of California*" (Halliday, 1992) contained much relevant information, and numerous important reports and articles appeared in newsletters of N.S.S. and Western Speleological Survey units in the 1950's. My "*Adventure Is Underground*" (Halliday, 1959) contained a full chapter on the subject, and Erwin Bishchoff published several important reports in he 1940's which included important examples. Rhodenbaugh also wrote extensively about examples in Idaho (Rhodenbaugh, 1947).

Somewhat similar growth occurred independently in so many other parts of the world that it is not possible to refer to them all here. Ultimately a specific vulcanospeleological society was formed in Japan, with Takanori Ogawa as leader. It has contributed greatly to world vulcanospeleology. Planetary geologists soon discovered the extraterrestrial implications of terrestrial lava tube caves, with still further expansion of the field work led by Ronald Greeley, Don Peterson, Don Swanson and other noted volcanologists. A UIS Commission on Volcanic Caves was chartered in 1993, and a world database on lava tube caves (at Arizona State University) soon followed.

Role of the International Symposia

To date, international symposia of vulcanospeleology have been held in the U.S.A. (Washington state, Oregon, and Hawaii), Italy (twice in Catania), Japan, Spain (Canary Islands) and Kenya. In 1972 and 1975, the first two symposia began to bring together the Italian and the American mainstreams of the field, with the English language spelling of the name itself reflecting the notable Italian contributions. The symposia continue to serve as the cutting edge of this expanding field, deliberately soliciting comprehensive reports designed to fill gaps in world knowledge. As we approach the 9th International Symposium on Vulcanospeleology, again in Catania, this 1999 meeting gives promise of being the most productive of all. So be it!

VULCANOLOGICAL SYMPOSIA CHRONOLOGY

1° **WHITE SALMON, WA USA**, August 1972. Organized by: Western Speleological Survey (William R. Halliday). Proceedings published (in English) by the organizers in 1976;

2° **CATANIA, ITALY**, August 1975. Organized by: Gruppo Grotte Catania of CAI (Giuseppe M. Licitra et al.). Proceedings published (in Italian & English) by the organizers in 1977;

3° **BEND, OR USA**, Jun/Jul 1982. Organized by: National Speleological Society (William R. Halliday). Proceedings published (in English) by ABC Publishing Inc, Vancouver WA, in 1993;

4° **CATANIA, ITALY,** September 1983. Organized by: Gruppo Grotte Catania of CAI (Orazio Mirabella, Giuseppe M. Licitra et al.) (UIS). Proceedings published (in Italian) by Centro Speleologico Etneo in 1987;

5° **IZU-NAGAOKA, JAPAN**, November 1986. Organized by: Japanese Vulcanospeleological Society (Takanori Ogawa). No news about proceedings;

6° **HILO, HW USA**, August 1991. Organized by: Hawaiian Speleological Survey (William R. Halliday) (UIS). Proceedings published (in English) by National Speleological Society in 1992;

7° **S.TA CRUZ DE LA PALMA, CANARY ISLANDS, SPAIN**, November 1994. Organized by: Fed. Canar. de Espeleologia (Conny Spelbrink, Pedro Oromì) (UIS). Proceedings published (in the official languages of the UIS) by Federacion Española de Espeleologia in 1996;

8° **NAIROBI, KENYA**, February 1998. Organized by: Caving & Exploration Group of East Africa (Jim Simons) (UIS). Proceedings published (in English) by Società Speleologica Italiana in International Journal of Speleology (U.I.S.) in 1999.

9° **CATANIA, ITALY**, September 1999. Organized by: Centro Speleologico Etneo (Nicola Barone, Giuseppe M. Licitra et al.) (UIS). Proceedings will be published (in English) by the division of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Catania.

References

- BORGES P.A.V., A. SILVA, AND F. PEREIRA, 1992: *Caves and Pits From the Azores* with Some Comments on Their Geological Origin, Distribution, and Fauna. pp. l2l-l5l in Proceedings of the 6th International Symposium on Vulcanospeleology, August l99l. G. Thomas Rea, editor. Huntsville, AL, National Speleological Society.
- CIGNA A.A., 1993: *Speleology by Titus Lucretius Carus*. pp. l7-28 in Proceedings of the International Symposium on the Proto-History of Speleology. Marco Bani, curator. Città di Castello (Italy), Edizione Nuova Prhomas.
- DANA J. D., 1849: *Geology*. Volume X, U.S. Exploring Expedition During the Years l838, l839, l840, l84l and l842 Under the Command of Charles Wilkes, USN. Philadelphia printed by C. Sherman.
- DECARY A., 1949: *Les Galleries Basaltiques de l''Ile de la Reunion et de Madagascar*. Soc. Geol. de France Compt. Rendu Sommaire 9 May l949, p. l66-l67.
- DE ST. VINCENT B., 1804: *Voyage dans les quatre principales isles des mers d'Afrique*. Tome 3.
- ELLIS W., 1823: *Journal of William Ellis*. Many editions, many publishers.
- HALLIDAY W. R., 1959: *Adventure is Underground*. New York, Harper and Brothers. 206 p. Russian edition l963, Geographic Press, Moscow, 238 p.
- HALLIDAY W. R., 1962: *Caves of California*. Seattle, Western Speleological Survey, l94 p.
- HALLIDAY W.R., 1963: *Caves of Washington*. Info. Circ. # 40, Washington State Division of Mines and Geology. 132 p.
- HARTUNG G., n.d.: *Die Geologischen Verhaltnisse der Inseln Lanzarote und Fuerteventura*. n.p., l64 p. 9 plates.
- HENDERSON J., 1932: *Caverns, ice caves, sinkholes, and natural bridges*. Univ. of Colorado Studies, vol. l0, no. 4, October, p. 359-405. Continued Vol. 20 no. 2-3 (l933), p. ll5-l58.
- HERNANDEZ J.J, I. IZQUIERDO & P. OROMÌ, 1992: *Contribution to the Vulcanospeleology of the Galapagos Islands*. p. 204-222 in Proceedings of the 6th Internat. Symposium on Vulcanospeleology August. 1991. G. Thomas Rea, Editor. Huntsville, AL, USA, National Speleological Society.
- HROARSSON B. & S. S. JONSSON, 1992*: Lava caves in the Hallmundahrhraun Lava Flow, western Iceland*. pp. 85-88 in Proceedings of the 6^th International Symposium on Vulcanospeleology, August 1991. G. Thomas Rea, editor. Huntsville, AL., USA, National Spelological Society.
- KIERNAN K., 1993: *Volcanokarst in the culture and landscape of Easter Island*. pp. 86-92 in Proceedings of the 3rd International Symposium on Vulcanospeleology, June-July 1982. William R. Halliday, Editor. Vancouver, WA, USA, ABC Printing.
- LACROIX A., 1936 : *Le volcan actif de l''Ile de la Reunion et ses produits*. Paris, Gauthier-Villars, Editor. Librairie du Bureau des Longitudes de l'Ecole Polytechnique.
- LAINEZ CONCEPTION A., 1996 : *Galleria "Hernandez Pacheco", un nuevo discubrimiento en el complejo de la Cueva del Viento-Sobrado (Icod de los Vinos, Tenerife)*. p. 69-76 in Proceedings of the 7th International Symposium on Vulcanospeleology, November 1994. Editor Pedro Oromi. Sant Climent de Llobregat (Spain), Forimpres. 1994.

- LARSON CHARLES, 1993: *An illustrated glossary of lava tube features*. Western Speleological Survey Bull. 87, 56 p.
- LICITRA G.M., 1993: *Volcanism and caves of Mt. Etna: a brief report*. pp. 93-l00 in Proceedings of the 3rd International Symposium on Vulcanospeleology, June-July 1982. William R. Halliday, Editor. Vancouver, WA, USA, ABC Printing.
- MIDDLETON G., 1997: *Early accounts of caves in Mauritius*. pp. 5-l8 in Proceedings of the 2nd Australian Spelean History Symposium, Sydney, July l994.
- RHODENBAUGH E. F., l947: *Sketches of Idaho Geology*. Caldwell (Idaho), Caxton Press.
- ROSALES MARTIN M., l996: *Historia de la espeleologia en Canarias*. pp. l0l-l08 in Proceedings of the 7th International Symposium on Vulcanospeleology, November l994. Editor Pedro Oromì. Sant Climent de Llobregat (Spain), Forimpres.
- SHAW T. R., l992: *History of cave science*, 2nd edition. Sydney, Sydney Speleological Society, 338 p.
- STEWART J., L869: *Descripton of lava caves at the "Three Kings", near Auckland*. Proc. NZ Institute, vol. 2, p, l62-l63. Reprinted in UIS Gr. de Trav.: Grottes Volcan. Newsl. no. 2, March 22, p. 4.
- VAN DER PAS J. P., l998: *Is this the oldest map of a lava cave?* UIS Comm. on Volc. Caves Newsl. # 2l, p. 5, Nov.
- WEBB J. A., E. B. JOYCE & N. C. STEVENS, l993: *Lava caves of Australia*. pp. 74-85 in Proceedings of the 3rd International Symposium on Vulcanospeleology, June-July l982. William R. Halliday, editor. Vancouver, WA, USA, ABC Printing.

Biology

ETNA'S CAVES FAUNA - DESCRIPTION AND CONSIDERATIONS

Domenico Caruso

Professore Ordinario di Zoologia presso il Dipartimento di Biologia Animale dell'Università di Catania

Abstract

The author briefly illustrates the characteristics of the volcanic caves and the cavern dwelling animals living in them; the fauna of the caves of Mt Etna are then discussed.
From this investigation it emerges that in the caves that have been so far explored the fauna present are the following: 59 species of animals of which only two have so far been found exclusively in volcanic caves; these are, however, of little speleological interest, in fact, one, *Araeoncus sicanus*, from the "Marrano" cave is almost certainly a trogloxen; the other, the dipteran *Limosina ventruosella* (Fig. 1), seems to be more interesting as it is a troglophil. In fact, to date the presence of paleoendemisms or neoendemisms have not been noted, though their existence cannot be ruled out as of the hundreds of known caves only a few have been studied for their fauna. The species that have been found are distributed in the following animal groups: 2 species of Oligochaeta, 7 Gasteropoda, 12 Isopoda Oniscidea, 1 Diplopoda, 3 Chilopoda, 1 Pseudoscorpiones, 10 Araneae, 2 Opiliones, 10 Collembola, 1 Orthoptera, 2 Coleoptera, 2 Diptera, and 6 Chiroptera.

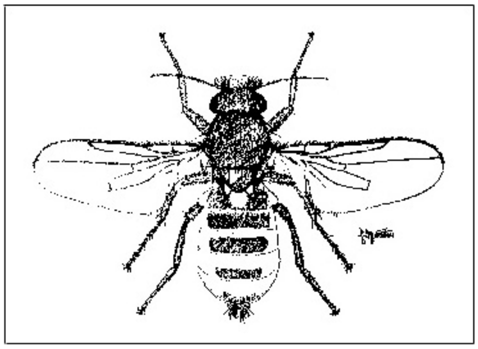


Fig. 1 - Limosina ventruosella

None of the above is troglobites while many are troglophiles. Among the Isopoda Oniscidea the following are of particular interest: *Trichoniscus matulicii* (Verh.), which is notable for its geographic distribution, that is of the transadriatic type; this species is known in southern-central Italy, southern Dalmazia and the island of Corfù; its passage to Sicily could be linked to one of the Calabrian-Sicilian connections of the Quaternary; *Haplophthalmus avolensis* (Vandel), a species that to date has been found only in the Iblean region; *Buddelundiella cataractae* (Verh.) (Fig. 2), this species is interesting as in Sicily it is known only in the "Nuovalucello I" cave, where it is abundant while it has never been found in or outside any other karsic cave; Sicily is the southern border of the area for this species, its distribution is of the south-European type with a paleo-European origin. The common troglophiles are *Chaetophiloscia cellaria* (Doll.) and *Porcellio dilatatus* (Brandt).

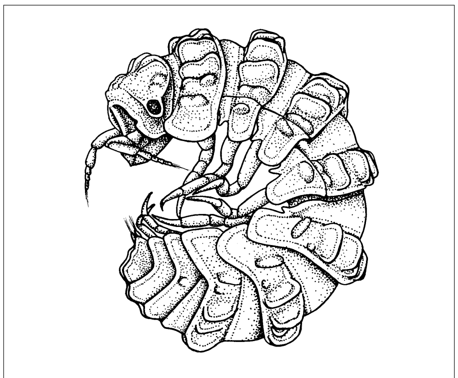


Fig. 2 - Buddelundiella cataractae (Verh.)

Only one species of Pseudoscorpiones is known for these caves, *Chthonius ischnocheles ruffoi* (Cap.), that is perhaps a troglophil. Spiders are well represented with 10 species: *Paraleptoneta spinimana* (Simon) appears interesting as it is the only Leptonetidae known in Sicily; *Porrhomma egeria* (Simon), genus and species that is known in Sicily only in volcanic caves ; *Lepthyphantes carusoi* (Brignoli) and *Araeoncus sicanus* (Brignoli) both endemic in Sicily; the latter species is only known in volcanic caves. The Opiliones are only represented by one troglophilic species, *Dicranolasma soerenseni* (Thorell). The Coleoptera are present with two troglophiles species, the Carabidae *Laemostenus* (*Pristonycus*) *algerinus* (Gory), and the Stafilinidae *Quedius ragusai* (Gory). There are two species of Diptera present, both are troglophiles: *Limosina ventruosella* (Venturi) that has not been found in other caves, and *Psicoda minuta* (Banks), this species is

known in Italy only in one lava cave in Sicily. There are various bats present in these caves with six troglophilic species, one of which, *Myotis myotis* (Borkhausen), forms large colonies in the "Immacolatella" cave (Fig. 3) where large quantities of guano have accumulated; this species often lives together with other species.

In one lava cave, called "Grotta dei Ladri", of which little is known including its exact location, a Coleoptera of the interesting troglophilic genus *Duvalius* is said to have been found, though this needs to be confirmed.

Fig. 3 – A colony of bats in the "Immacolatella" cave.

As can be seen from the above mentioned data there is no species of these volcanic caves of Mt Etna that is really troglobitic, it is neither possible to affirm that the fauna of these caves is original, though, as stated, there are still many caves to be explored, above all the oldest ones, where more specialised fauna could be present as in the lava-flow caves on the Hawaiian islands where interesting troglobitic species have been found (Howarth,1972).

Moreover, troglobitic species have been found in volcanic caves in the USA and Japan. As studies on Etnean volcanospeleology are still few, the only existing works are by Caruso, 1974 and Caruso et al. 1978 who take into consideration only a small number of caves, a more extensive study can only be wished for.

Conservation

MONITORING OF GROTTA DEL GELO

Salvatore Caffo and Antonio Marino***

* Volcanist, Etna Park Manager
** Geologist, Centro Speleologico Etneo

Abstract

What follow is a brief report of the first and only experiment in environmental monitoring, by means of automatic digital micro data loggers to collect data concerning temperature and humidity. It was carried out by speleologists of Catania Centro Speleologico Etneo, in collaboration with the Etna Park Organisation represented by the Volcanist. The data refers to July 1997- July 1998 biennium. Ten speleologists participated in this experiment in different roles. They voluntarily carried out the climatic survey and the data processing. This experiment cleared the general reasons for the reduction of ice volume inside the cavity and, above all, it let us verify that a wholesome and correct use of Grotta del Gelo does not modify meaningfully, hypogeous environment.

Introduction

Grotta del Gelo is probably the most well-known Etna volcanic cavity both locally and internationally. Its fame is consequence of the ice formation phenomenon, which started over three centuries ago and still lasts. In the past *Grotta del Gelo* was known by shepherds who drove their flocks of sheep to water; from the 1970s it became an obliged destination for many excursionists, who saw in it a goal to achieve at least once during their life.

The cave is located in the "A" [1] zone of Etna Park, which is integral reserve (Fig. 1), in the territory of Randazzo. Its access is located at an altitude of 2030 metres above sea level on the north-west face of *Etna*, in the area called *Sciara del Follone*. This is the result of *Dammusi* lava flow cooling, which is the product of the ten year eruption (1614-1624), on Etna north face, which started at an altitude of 2550 metres and reached *Collabasso* Mount, at about 1200

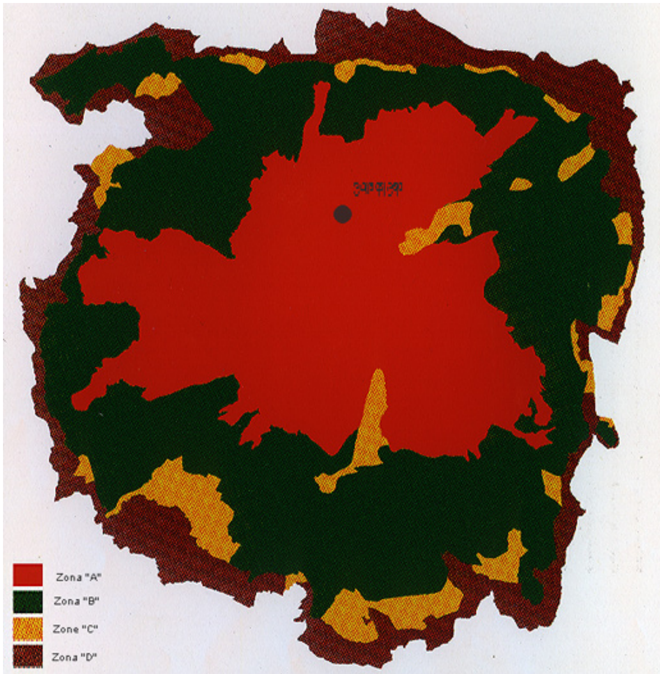


Fig. 1 – Map of Park zones

[1] The creation of the "A" zone has the purpose of integrally guaranteeing the preservation of volcano ecosystem difference, both to defend the general biological balance and to take care of natural environment of very high relevance both cultural and scientific. The intangibility of the "A" zone, whose size overcome the 19.000 ha, is fixed by the Law (art. 8, clauses I, II, III of the co-ordinated text of the law 98/81 and 14/88). It is an area where the naturalistic interest is prevalent and prior.

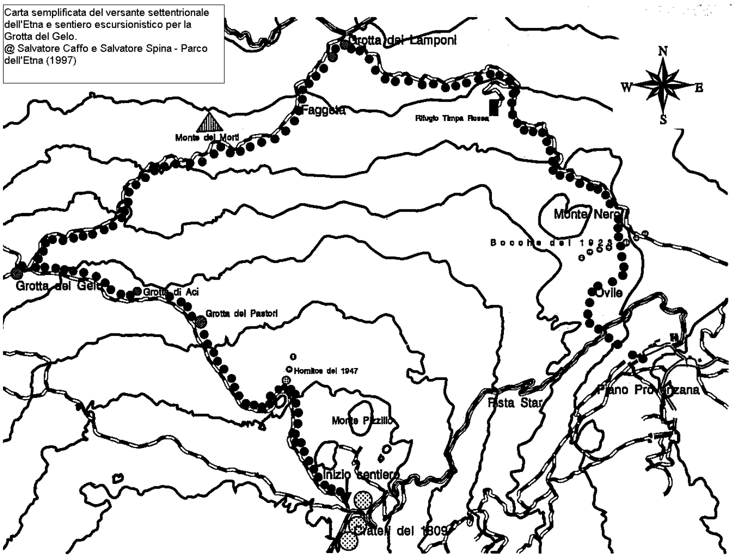


Fig.2 – Simplified map of Etna north side and excursion track to reach Grotta del Gelo. © Salvatore Caffo and Salvatore Spina – Etna Park (1997)

metres above sea level (Fig. 2). According to volcanospeleology, the cave is particularly important as an example of volcanic cavity of large dimension and for the presence of ice, which stuffs about the 40% of its volume, at a modest altitude if compared with the latitude.

Geological Framework

The radial eruption (Romano and Sturiale, 1982), which took place from 1614 to 1624 and was the longest among the Etna historical eruptions, during its activity, emitted an enormous quantity of lava, quantifiable in about 1050 x 10^6 m^3 (Romano and Sturiale, 1982), which flooded a considerable area of the volcanic edifice flowing from an altitude of 2550 metres for over 1400 metres of difference in height and enlarging for 21 km^2.

The complexity of the phenomenon that produced *pahoehoe* lava (Fig. 3), which are not frequent on our volcano, usually emitting *aa* lava, created a series of important morphologies as domes and mega-domes. They are located all over the surface of the immense lava flow. Furthermore, the streams of lava flow, during their evolution, were superimposed overlapping and obstructing one each other in their flowing towards lower altitudes. They produced cavities different in size and shape: superficial, deep or laminar, which were surmounted by rock slobs, few centimetres high resounding when somebody walks over them. This is why they were called *Dammuso*, in Arabic, which means ceiling, covering.

The main streams created deeper canals, which were covered by crusts of different thickness and became the well-known cavities of this area. From the highest altitude we distinguish: Grotta del Diavolo (Devil Cave) at an altitude of 2400 m, Grotta del Lago (Lake Cave) at an altitude of 2200 m, Grotta di Aci (Aci Cave) and Grotta del Gelo (Ice Cave) at an altitude of 2000 m, Grotta dei Lamponi (Raspberry Cave) at an altitude of 1700 m. The secondary streams, which were more superficial, created, in natural lava flow terraces, other small cavities, which are not less interesting than the main ones. Some of them are well-known, thanks to their morphology, such as Grotta del Labirinto (Labyrinth Cave) at about an altitude of 1800 m and Grotta degli Inglesi (English People Cave), which, with other fifteen cavities constitutes a speleovolcanic complex of great importance.

Fig. 3 – Pahoehoe lava field in "Dammusi" area inside "Sciara del Follone" (1614-24). Picture by Salvatore Caffo © 1997

The situation of the glacial phenomenon

Fig. 4 – Grotta del Gelo. detail of the canal which was formed by the decrease of ice thickness. Picture by Roberto Maugeri © 1998

The peculiarity of the glacial phenomenon inside Grotta del Gelo has drawn, during the time, the interest of naturalists and geologists who tried to explain the phenomenon and to describe its evolution. According to a series of observations, during the last thirty years, it was noticed that, from the 1980s, the glacial mass has transformed itself (Fig. 4), probably because of the 1981 eruption, which took place near the cave, or because of the frequent presence of excursionists. The difficult situation of the glacial mass induced some naturalistic associations to ask the competent organisations to help them start a campaign of research to define the size of the phenomenon better and to avoid a lost in the environmental resources.

Monitoring

Thanks to its peculiarity, *Grotta del Gelo* has a great environmental and scientific value. This is why naturalistic and speleological associations called the attention of Etna Park Service to a potential environmental alteration of the Cave, also because of uncontrolled presence of excursionists. On 12 January 1996, Etna Park organised, at the administrative office of Etna Park Service, the first technical meeting to discuss about *Grotta del Gelo.* At the meeting there were: Technical Managers of Catania Forest Inspectorate, competent for the territory, the Manager and speleologists of Cave Group of Club Alpino Italiano, Etna section, , the President and speleologists of Centro Speleologico Etneo, Head Manager and Managers of Etna Park Service.
During the meeting two goals to achieve were planned:
To regulate the fruition of the Cave to safeguard the hypogeous environment from potential situation of degradation.
To monitor the environment recording temperature and humidity by means of automatic micro data loggers.
The first goal, that is the regulation of the Cave fruition to safeguard the hypogeous environment from potential situation of degradation, was achieved thanks to the Presidential Measure n. 01/97 emitted on 10 January 1997. This action aims to regulate the fruition of the hypogeous cavity;
The second goal was achieved by means of the environmental monitoring of *Grotta del Gelo* from 9 July 1997 to 9 July 1999; that is one year longer than the term that was foreseen for the test: 9 July 1998.
Never before any institute of research, either Italian or foreigner, had constantly surveyed climatic-environmental data of the inside area of *Grotta del Gelo*, which could strengthen or deny the various hypotheses formulated by specialist and non specialist about the decrease of ice deposits thickness. So the administration of Etna Park Service decided to entrust the Volcanist , Co-ordinator Manager of “Nature Conservation” office, with the co-ordination of the scientific experiment.
On 22/4/97 the President empowered the Volcanist to start the necessary technical-administrative steps to carry out the experiment;

In order to cause the least environmental impact to the hypogeous ecosystem of *Grotta del Gelo,* even obtaining significant scientific data concerning the experiment, it was decided, after hearing the Technical-scientific Committee and the Executive Committee, to acquire the instruments: digital micro data loggers and software with relative licence whose total cost should not exceed £ 1.500.000;

On 26 June 1997 the President of Etna Park and the President of Centro Speleologico Etneo signed a specific agreement giving the micro data loggers, which had previously been bought, to the speleologists who would have recorded the measures inside the rheogenetic cavity;

On 9 July 1997 the Volcanist of Etna Park Service, Salvatore Caffo, in collaboration with an alpine guide of Park Service, Sebastiano Russo, and the speleologists of Centro Speleologico Etneo: Antonio Marino and Roberto Maugeri, installed the instruments, according to the technical project, which was planned by Roberto Maugeri with Park Service's approval (Fig. 5). The temperature and humidity loggers were programmed to acquire, automatically, data every hour for two months. Then, data was transferred to Personal Computer and processed by means of the proper software. Later the instruments were reprogrammed to record next data;

Fig. 5 - Installation of the automatic micro data loggers on the bottom of the hypogeous cavity. Picture by Roberto Maugeri © 1997

Temperature and humidity data concerning the first quarter, that is 9 July 1997 – 07 September 1997, regularly reached the Park Service on 24 September 1997;

The second group of data concerning the period 8 September 1997 – 9 November 1997 regularly reached the Park Service on 9 December 1997;

On 20 November 1997 the Italian *Glaciological Committee*, which is located in Turin, was informed about the kind of research which was taking place inside *Grotta del Gelo*;

The third group of data concerning the quarter from 9 November 1997 to 9 April 1998 regularly reached the Park Service on 24 April 1998;

On 9 April 1998, in collaboration with the International Institute of Volcanology of Catania *CNR*, an automatic temperature micro data logger, placed on anemoscope, was placed at *Timpa Rossa*, on the north side of Etna, at an altitude of about 2000 m above sea level using as backing a present station of the institute. This data will be useful for a better reading and interpretation of surveyed data;

The fourth and fifth groups of data concerning, respectively, the period 9 April 1998 – 23 December 1998 and 18 January 1999 – 18 April 1999 were given, by the President of Centro Speleologico Etneo, the Volcanist who agreed with him on the extension of the experiment until 9 July 1999, so that to survey temperature and humidity concerning two seasons was possible. The sixth and last group of data was given the Park Service on August 1999. There is no need to highlight the high appreciation and esteem by Etna Park Service for the praiseworthy and free work, which so many geologists and speleologists of C.S.E. carried out.

All data concerning temperature and humidity were processed by qualified engineers of the Centro Speleologico Etneo using the proper software which Etna Park Service had supplied them. In order to interpret the surveyed data, the same were compared with the information relative to the number of people that were accompanied by the alpine guides of Etna Park during the follow excursions: 31/08/97; 14/09/97; 5/10/97; 02/11/97; 30/08/98; 27/09/98; 18/10/98; 08/11/98 which practically correspond to eight load tests. Furthermore a load test with 20 people inside *Grotta del Gelo* was made on 9 May 1998 by C.S.E.

Conclusive Results and Considerations

The survey conducted by the speleologists of Centro Speleologico Etneo under the technical-scientific co-ordination of the Volcanist let us get some conclusions:
Data concerning relative humidity has not shown any particular characteristic because the aria inside *Grotta del Gelo* is everlastingly saturated (Fig. 6).

Humidity variation are attributable to percolation water which, by chance, wetted the sensors (Fig. 7); As regards temperature inside *Grotta del Gelo*, there was a different situation in the middle area compared with the bottom one.

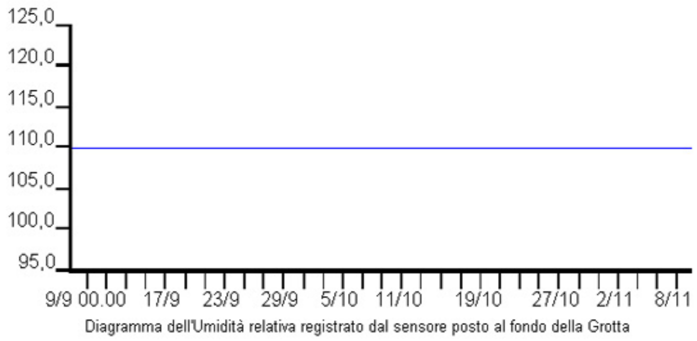


Fig. 6 – Diagram showing the relative humidity recorded by the sensor placed on the bottom of the Cave.

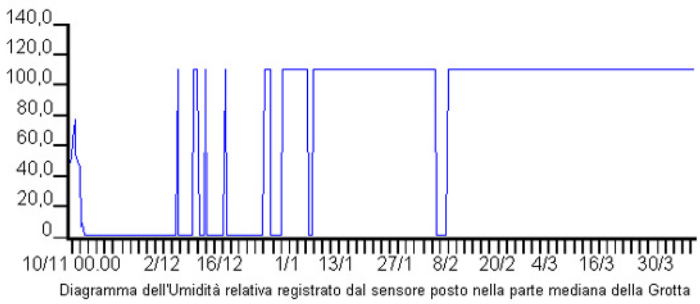


Fig. 7 – Diagram showing the relative humidity recorded by the sensor placed in the middle area of the Cave.

In fact the sensor located in the bottom area recorded temperature variations of few tenths of degree; on the contrary, the one in the middle showed variations of 0.5° C. However the most significant variations are attributable to atmospheric events such as long, abundant rains, quick decrease of temperature etc…(Fig. 8 and 9).

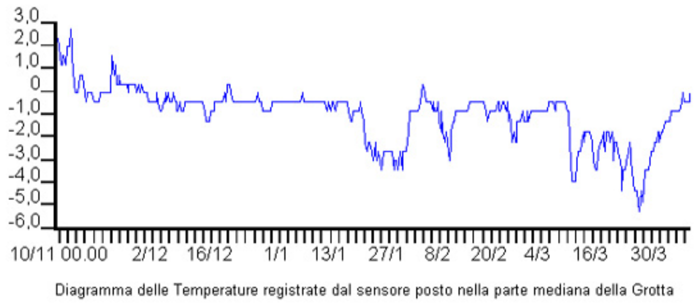


Fig. 8 - Diagram showing the temperature recorded by the sensor placed in the middle area of the Cave.

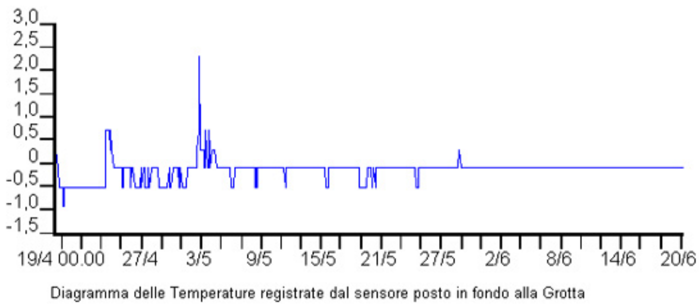


Fig. 9 - Diagram showing the temperature recorded by the sensor placed on the bottom of the Cave

It was noticed that human presence would appreciably not modify the internal environment (load test which took place on 09/05/98 (Fig.10) as well as the excursions of: 31/08/97; 14/09/97; 05/10/97; 02/11/97; 30/08/98; 18/10/98; 08/11/98 which practically correspond to eight load tests) as long as people do not stop there for a long time.
The temperature micro data logger, which was located at *Timpa Rossa*, on the north side of Etna, at an altitude of about 2000 m above sea level from 09/04/1998, allowed to verify that the sudden

Fig. 10 - Load test. Terminal area of lava duct inside Grotta del Gelo. Picture by Roberto Maugeri © 1998

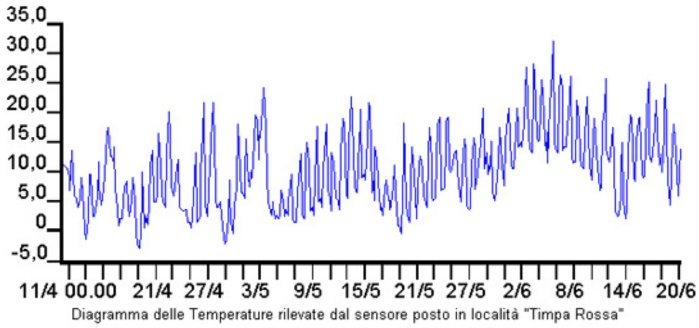


Fig. 11 - Diagram showing the temperature recorded by the sensor placed at “Timpa Rossa”

variations of temperature inside *Grotta del Gelo* correspond to external maximum values, according to the experiment (Fig. 11).
Not only does we consider valuable to highlight the importance of this project about the environmental monitoring of *Grotta del Gelo* for its intrinsic scientific value, but because it was also an excellent example of synergism between public institutions and associations of voluntary service demonstrating that what is required to act is only good will and professionalism.

Bibliography

- AA. VV., 1979: *Carta Geologica del Monte Etna*, Scala 1:50.000, C.N.R., Prog.Fin. Geodin., I.I.V., Alleg. a Mem. Soc. Geol. It., 23, Roma.
- AA. VV., 1982: *Mount Etna volcano.* Mem. Soc. Geol. It.,23, Roma; pp.205
- MARINO A., 1982: *Nota preliminare sul fenomeno glaciologico della Grotta del Gelo (Monte Etna)*. Geogr. Fis. Dinam Quat. 15; pp. 127-132
- ROMANO R ., STURIALE C., 1982: *The Historical eruptions of M. Etna (Volcanological-data).* Mem. Soc. Geol. It. 23, Roma; pp. 75-97
- RITTMANN A., 1973: *Structure and evolution of Mount Etna,* Phil. Trans. R. Soc. Lond:, 274 A; pp. 5-16

THE ICE CAVE AND ITS GLACIOLOGICAL PHENOMENON

Antonio Marino

Centro Speleologico Etneo - Via Cagliari, 15 - 95127 Catania, Italy

Abstract

The Ice Cave (La Grotta del Gelo) is well known among Mt Etna's volcanic caves for its main feature: the largest part of the hollow is occupied by a massive stack of ice, the formation of which is governed by the geographic position, the altitude (2,030 m) and the cave's morphology.

Geographic profile

The Ice Cave (Grotta del Gelo) is one of Mt. Etna's most well known volcanic caves due to the year round presence of a stack of ice which occupies 30% of the cave's volume. The cave is located on the north side of the volcanic structure at about 2,030 m in the area of "Sciara del Follone" (Randazzo's municipality) (fig. 1). It can be reached from the Linguaglossa side by a dirt road which starts at the Pitarrone Forestry station and continues, beyond the "Raspberry Cave" (La Grotta dei Lamponi), on a footpath. From the Randazzo side the footpath begins at the Pirao Forestry station. From the Maletto side there are the "Monte La Nave" and "Dagala dell'Orso" footpaths. From Piano Provenzana there are the "Monte Nero and Monte Timpa Rossa" footpaths. From 2,400 m there is a footpath which begins at Monte Pizzillo.
The large entrance faces uphill and in front of it there is a big gully which is sometimes full of snow into the summer months.

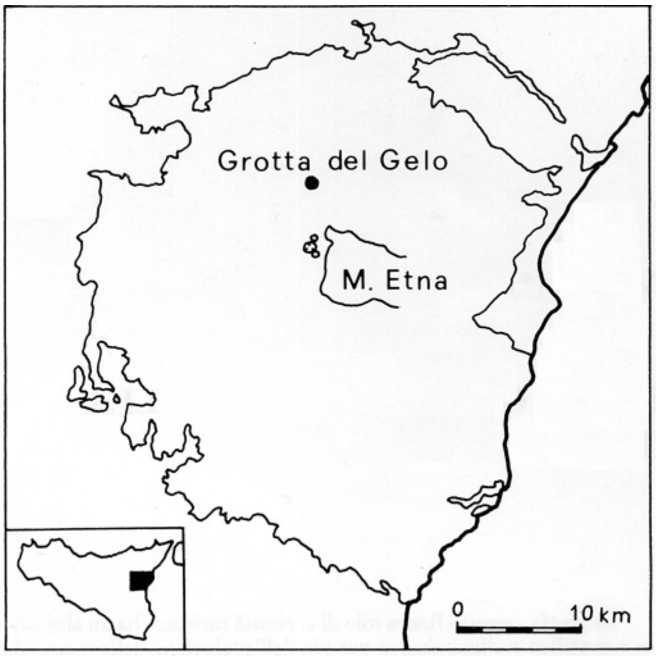


Fig. 1 - Location of the Ice Cave

Tourist profile

For more than 70 years, and in especially the last 20, The Ice Cave has been a favorite destination of hikers on Etna's tourist excursions. Even though it is not that easily reached (it is, on the average, a 3 hour hike with a 400 m difference in level) more and more people are visiting it. Only just recently the visitors have been accompanied by the Etna Park guides who lead and regulate the visitations. In the past, especially in the summer months, more than 30 people at a time, with consequential impact on the stack of ice, in spite of its remarkable size, continuously passed through and were disrespectful leaving behind, in the entrance, graffiti with names and dates. Presently the limit is set at 20 per visit, hoping to slow down man's impact on this peculiar cave.

Previous observations

Even though this cave has been mentioned since the late 1800s, bibliographical references are not that many. Sartorius (1880) called it “Bocche del Gelo”. At last, after nearly a century, other reports have been published: Brunelli & Scammacca (1975) include it in their list of Etna’s caves. Biffo & Cucuzza Silvestri (1977) call attention to the cave’s possible deterioration due to the high number of visitors and hope that the cave will be visited only on scientific terms. Bella et al. (1982) give the land office’s data, the access itinerary and morphology. He made note, for the first time, of the decreasing volume in the ice which was perhaps tied to the eruption and events in 1981 which occurred just a few meters west of the cave’s entrance It has been mentioned in other magazines such as “Lo Scarpone (C.A.I.’s magazine), “Etna Territorio”, (an ecological and environmental magazine printed in Catania) and in the daily newspaper “La Sicilia” where Licitra (1991) made note of the cave’s deterioration caused by an excessive number of visitors. Marino (1992) describes the glacial phenomenon and urges scientific institutions to monitor and protect the cave. Starting in 1997, the cave’s atmospheric humidity and temperature were, and still are, being measured. In 1998 Marino (1998) reports on the data collected in the first year.

Geological aspects

The Ice Cave’s hollow was formed by the lava flows called the “Lave dei *Dammusi*” [1] which lasted about ten years, from 1614 to 1624. This was Etna’s longest eruption ever in historical times. The lava flowed on the north side from 2,500 m to 1,200 m, (Monte Collabasso’s altitude), branching off to 975 m; covering an area of 21 square km (Romano & Sturiale, 1982). The series of flows which followed overlapped during the different eruptive stages and formed many tubes which helped the lava reach lower altitudes. Often, large main heaps, upon surface solidification, formed thick lava crusts under which lava continued to flow as in a tube. At the end of the eruption the feed ran out, reducing the lava flow, and the tubes were left almost completely empty. That is how the numerous existent hollows were formed in the *“Dammusi”;* roofs centimeters thin on the surface levels and meters thick at deeper levels.

The formation of the stack of ice

Fig. 2 - Entry of the Ice Cave.

The Ice Cave has only one aperture which is the large funnel shaped entrance facing uphill (fig. 2). As mentioned above, the gully in front of the entrance is full of snow for many months. A fair amount of snowfall enters the first part of the cave due to its conformation. The cave is about 120 m long and it is mainly flat with a slight downhill slope. Lava’s non-conductivity doesn’t favor external temperature exchange, even if the lava walls are quite thin. This type of morphology allows atmospheric circulation to keep the colder air masses inside and release the warmer ones (fig. 3). The cave’s temperature is lower than the outside’s. Since the cave is on the shady side of Mt. Etna and at a high altitude its

[1] The word “Dammusu” in Sicilian dialect means the floor or covering. This lava flow has this name because the surface is formed by a thin crust, which is the roof or covering of smaller caves underneath. Walking on this crust sounds like someone walking on an attic floor.

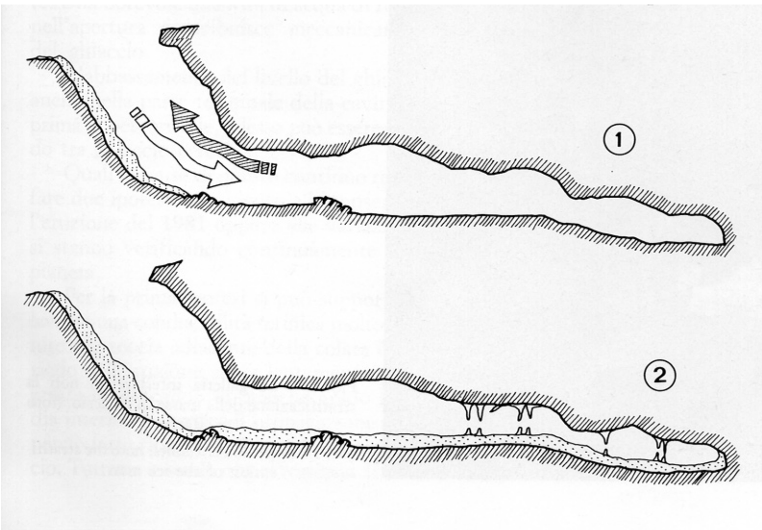


Fig. 3 - Probable evolution of the glacial mass inside the Ice Cave: the cold air tends to enter while the warm air goes out from the tunnel. So we have a lower temperature in the tunnel and the snow remains the same, some of it melting and becoming ice.

average annual temperature is never above 5° C. The snow doesn't disappear totally as in other near-by caves with numerous apertures and different morphologies. The snow stays inside of them only in the winter months. In The Ice Cave during the warmer months, at the very beginning, in a flat area of the entrance, you can watch the snow melt, forming a 10 m in diameter lake.

It is likely that the formation of the stack of ice began in the second half of the 17th century; ten years after the end of the eruption. It has been as ascertained (Bullard,1978) that a lava flow of such a vast size as this (50 m average thickness) would take more than ten years to cool down completely. Year after year snow and ice layered inside the hollow, reaching a thickness of over 2 m. The stack of ice covers the total length of the cave. It ends in a final shaft which is accessible, only on certain occasions, by sliding between the ice and the ceiling of the cave. The upper part (fig. 4) has always been empty except in the colder years when it is partially filled by abundant stalactites and ice columns which regularly disappear in the warm season. On the right side, in the lower part, there is a smaller hollow between the lava and the stack of ice (fig. 5).

Fig. 4 - Ice stalactites in the main cave.

Fig. 5 - The hole in the ice between the main cave and the lower one in July 1993.

In the final part of the cave the roof slopes down towards to the floor and the ice almost reaches the ceiling; leaving only a few centimeters of space between them. On the left wall of the smaller hollow the continuous layering can be easily observed in the ice. There are different types of waste materials (lava scoriae, plant residuals) frozen in the ice layers (fig. 6).

Fig. 6 - The numerous vegetable and rocky debris included in the ice.

The evolution of the stack of ice

There is no precise information on the evolution of the stack of ice as only in the last few centuries there have been sporadic observations of the phenomenon and for the most part without details. However, in the last decades, up to 1981, the periodical visitors of the cave had noticed a progressive increase in the ice's thickness. It increased by several centimeters a year and due to insufficient space, the final shaft was not accessible (verbal communications and personal observations). In that year, at a few meters distance from the cave, an eruptive fracture opened on Etna's north flank. As the river of lava flowed from the lower part, destroying numerous cultivated fields and even threatening the inhabitants of Randazzo, in the upper part of the fracture, very close to The Ice Cave, a huge cavity came to light and massive quantities of lava scoriae, ashes and lapilli tumbled out; covering the fields and even entering the cave itself. The sudden rise in temperature, even though short, caused the stack of ice in the entrance to retreat. In the entire cave a small decrease in the ice's thickness was noticed; new fractures were formed inside the hollow (Bella et al., 1982). Luckily the eruption lasted only a few days and in a short while the situation appeared normal. In the following winters the ice's thickness increased slightly. However since the late 80s, probably due to an increase in the average internal temperature (fig. 7), a slow but constant decrease in the thickness has been noted. A hole has formed in the thinner part; exactly between the upper hollow and the smaller one underneath.

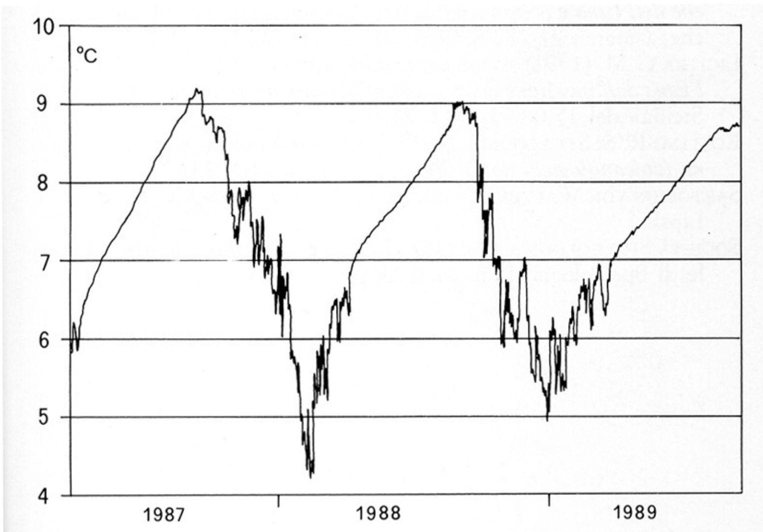


Fig. 7 - Temperature recorded from April 1987 to October 1989 in the clinometer station installed inside the Grotta del Cernaro by I.P.G.P. (France). Note that the minimum temperature since 1989 is about one degree higher than, that of the previous year.

The present situation

Between 1988 and 1996 the hole deepened by over five meters and a third small hollow was found. Large amounts of melt water, flowing into the entrance, have mechanically contributed to the ice's erosion.
The decrease in the ice's thickness was noticed in the final part of the cave too. The space between the floor and the ceiling increased, making it possible to slide between lava and ice so as to reach the final shaft.
In the last two years the ice has decreased in the upper part and increased in the final part and in the trench of the former smaller hollow because of a sort of transfer of the stack of ice due to a more favorable temperature in the lower part. The thickness has once again increased making it impossible to reach the final shaft.
What are the causes of all these changes? Two hypotheses can be formulated: the first is that these are late consequences of the 1981 eruption and the second is that the whole planet is experiencing climatic differences.
As regards the first hypothesis, we can suppose that since lava has such a low conductivity level; the heat gathered by the lava rocks near the flow, in the brief time of the eruption, slowly spread to the cave itself: changing the inside temperature by a few degrees. The beginning of the melting of the ice occurred later because of the slow diffusion of the heat. However it has been 18 years since the eruption and the lava rock should have its normal temperature by now; therefore the stack of ice should not still be melting. The second hypothesis, is supported by the slight decrease in rainfall in the last decade. Snowfall, on the other hand , has been heavier.
Up until 1997 the only control of the evolution of the phenomenon was through sporadic observations of the stack of ice. There weren't instruments available to conduct appropriate tests. The only data, on the differences in temperature in Etna's caves, was courtesy of The International Institute of CNR Volcanology. The data was provided by the *"Institute de Physique du Globe"* of Paris. In its study, on the slow deformation of Etna, temperatures of cave environments, over several years, were also measured. It gave temperatures of the "Grotta del Cernaro", which is near The Ice Cave at a lower altitude (1400 m). It can be seen from the temperature graphs that in 1989 the minimum inside temperature is one degree higher than the previous year's. The measurements ceased in 1990 and there was no more official data until July 1997 when The "Ente Parco dell'Etna" provided funds to buy instruments (two thermometers and two hygrometers). They were set up on the bottom and in the center of The Ice Cave to get direct readings on climatic differences inside the cave. A third thermometer was set up, outside, at "Timpa Rossa" in order to compare the internal and external differences. After one year of measurements it was found that the humidity is constantly elevated: therefore the hygrometer data is of little interest. On the other hand the temperature data showed that the temperatures in the central part of the cave varied a lot more than in the final part. This could explain the transfer of the stack of ice to the lower parts. Furthermore it was found that external temperature changes only slightly influence the cave's internal conditions (CAFFO S. & MARINO A., 1999).
Presently we are not sure whether we will be able to continue our climatic research due to bureaucratic will to remove our instruments from inside the cave. It would be a good idea to continue the research project in view of the new and quite evident changes that are occurring in the stack of ice. Once again, perhaps they are due to excessive visits and/or the lighting used when televising inside the cave. The fast rise in temperature may have cracked the surface of the ice. It would also be helpful to increase the number of instruments so as to further the research and obtain more details and truths as to the causes of the continuous changes in the stack of ice.

Conclusion

It would be good idea to continue the research and measurements of the phenomenon. It is well known that in the cave, due to the difficulty in exchanging temperature with the outside, the inside temperature is the average of the annual outside temperature at the entrance. Since the outside temperatures are changing there will certainly be repercussions on the cave's micro climate. The climatic research on caves could help us better understand environmental changes in the area. The Ice cave, because of its peculiarity, is of considerable scientific value and should not be underestimated especially since, still today, the stack of ice is undergoing persistent changes.

References

- BELLA V., BRUNELLI F., CARIOLA A., & SCAMMACCA B., 1982: *Grotte Vulcaniche di Sicilia, notizie catastali: secondo contributo (da Si CT 26 a Si CT 50).* Boll. Acc. Gioenia Sc. Nat., 15 (320), Catania; pp. 229-292.
- BRUNELLI F. & SCAMMACCA B., 1975: *Grotte Vulcaniche di Sicilia, notizie catastali: primo contributo*. Gruppo Grotte Catania del CAI, Catania; pp. 61
- BULLARD F.M., 1978: *I vulcani della Terra.* Paperbacks ricerca, Newton Compton, Roma; pp. 86-88.
- BIFFO L. & CUCUZZA-SILVESTRI S., 1977: *Relazione preliminare alla Direzione dell'Istituto di Vulcanologia dell'Università di Catania sull'importanza scientifica della Grotta del Gelo (Etna).* Appendice alla comunicazione: CUCUZZA-SILVESTRI S. (1977) – *Le Grotte Vulcaniche dell'Etna e il loro studio,* Atti del IV Simposio Internazionale di Vulcanospeleologia e Seminario sulle Grotte Laviche, Catania 1975; pp. 215-229
- CAFFO S. & MARINO A., 1999: *Il monitoraggio della Grotta del Gelo.* Atti del IX Simposio Internazionale di Vulcanospeleologia, Catania 10-19/09/1999, in stampa.
- LICITRA G.M., 1991: *Seriamente minacciata la "Grotta del Gelo" sull'Etna dall'invasione continua e indiscriminata di "allegri" turisti.* La Sicilia del 15.08.91, 202, Catania; p. 25
- MARINO A., 1992: *Nota preliminare sul fenomeno glaciologico della Grotta del Gelo (Monte Etna).* Geog. Fis. Dinam. Quat. 15; pp. 127-132.
- MARINO A., 1998: *Indagine sul fenomeno glaciale della Grotta del Gelo (prime conclusioni dopo la campagna di raccolta dati climatologici 1997/98).* Lavoro inedito consegnato all'Ente Parco dell'Etna nel Dicembre 1998 e reperibile presso il Centro Speleologico Etneo, Via Cagliari 15, Catania; pp. 10.
- ROMANO R. & STURIALE C., 1982: *The historical eruptions of Mt. Etna (volcanological data).* Mem. Soc. Geol. It., 23, Roma; pp. 75-97.
- SARTORIUS VON WALTERHAUSEN W., 1880: *Der Aetna*, v. II, Lipsia; pp. 373-374
- SOCIETÀ SPELEOLOGICA ITALIANA, 1978: *Meteorologia ipogea.* Manuale di Speleologia, Longanesi, Milano; pp. 341-367.

VOLCANIC SHOW CAVES

William R. Halliday

Honorary President, IUS Commission on Volcanic Caves
6530 Cornwall Court Nashville, TN, USA

Abstract

More than 100 show caves of volcanic origin are currently identified throughout the world, in Iceland, Azores (Graciosa, Pico, Terceira and São Miguel islands), Madeira, Canary Islands (Fuerteventura, Lanzarote, La Palma and Tenerife islands), Galapagos, Samoa (Savaii and Upolu islands). New Zealand, Hawaii (Kauai, Maui and Hawaii islands), Mauritius, Reunion, Kenya, Rwanda, Uganda, Zaire, Mexico, U.S.A. (California, Idaho, New Mexico, Oregon and Washington states), Korea, Japan, Australia, and Italy. The present list undoubtedly is incomplete.
To qualify, a volcanic cave must be sufficiently celebrated that more than a few persons seek it out. Littoral and other erosional or solutional caves in volcanic rocks (Fingal's Cave, Kitum Cave, etc.) are not included. Three categories are identifiable: developed, semi-developed, and self-guided. More than half the known examples are essentially undeveloped caves in national forests and national monuments in the western United States.

Introduction

Not including caves of littoral or other erosional or solutional origin like Fingal's Cave and Kitum Cave, more than 100 show caves are currently known in volcanic rocks throughout the world. The present list undoubtedly is incomplete, and additions and corrections will be welcomed. To qualify, a volcanic cave must be sufficiently celebrated as an attraction that more than a few persons seek it out. Because of presistent gaps in world knowledge of volcanic caves, postcards and advertising leaflets provide the only current information on some caves.

List of volcanic show caves

OCEANIC ISLANDS - ATLANTIC

***Iceland**:* Surtshellir, Raufarholshellir, Blafjoll Cave, Amarker Cave, Grotagja

***Azores**:* *Graciosa*: Furna do Enofre
Pico: Furna dos Montanheiros, Furna das Torres caves, Furna Frei Matias.
Terceira: Algar do Carvão, Gruta do Natal, Gruta das Agulhas, Furna Agua
São Miguel: Gruta do Carvão (in preparation)

***Madeira**:* Ribeira Grande Cave (São Vicente Cave)

***Canary Islands**:* *Fuerteventura*: Cueva del Llano (in preparation)
Lanzarote: Cueva de Los Verdes, Jameo del Agua.
La Palma: Cueva de Todoque (in preparation)
Tenerife: Cueva del Sobrado (in preparation)

OCEANIC ISLANDS - PACIFIC

***Galapagos**:* Bella Vista Cave

***Samoa**:* *Savaii Island*: Peapea Cave, possibly Aopo Cave.

Upolu Island: possibly Peapea Cave, Senoa Cave, Falemauga Cave.

New Zealand: Ruatapu Cave, Orakei Korako

***Hawaii**:* *Kauai Island*: Blind Eye Spider Cave, Wet and Dry Caves near Haena.

Maui Island: KaEleku Cavern, Hana.

Hawaii Island: Thurston Lava Tube, Kula Kai Caverns,Kaumana Cave, Kazumura Cave (short section), "Lava Tube" (south of Captain Cook), Cocks-comb Cave (Puapoo Cave, Fence Cave).

Molokai Island: Old Ladies Cave.

OCEANIC ISLANDS - INDIAN OCEAN

***Mauritius**:* Pont Bondieu Cave

***Reunion**:* (show cave in preparation)

CONTINENTAL

***Africa**:* *Kenya*: Shetani Cave. Mathioni Cave now closed.

Rwanda: Ubuvomo bwa Musanze (status uncertain)

Uganda: Garama Cave (status uncertain)

Zaire: unnamed cave, Virunga (status uncertain)

***Americas**:* *Mexico*: Cueva del Baile, S.L.P., La Gruta and other Teotihuacan caves (may be artificial)

Mainland U.S.A.: Arizona: Lava River Cave (Government Cave), Slate Lakes Cave. Sunset Crater Ice Cave now closed.

California: Balcony Cave, Barnum Cave (Shastina Cave), Big Painted Cave, Blue Grotto, Boulevard Cave, Captain Jack's Cave, Catacombs, Golden Dome Cave, Harris Mtn. Cave, Hercules Leg Cave, Hopkins Chocolate Cave, Indian Well, Inskip Caves, Jot Dean Ice Caves, Juniper Cave, Labyrinth, Lava Brook Cave, Mammoth Cave, Mayfield Ice Cave, Merrill Ice Cave, Mushpot Cave, Ovis Bridge, Pluto's Cave, Sentinel Ice Cave, Skull Cave, Subway Cave, Sunshine Cave, Thunderbolt Cave, Valentine Cave.

Idaho: Beauty Cave, Boy Scout Cave, Crystal Falls Cave, Dead Horse Cave, Dewdrop Cave, Higby Cave, Indian Tunnel, Kuna Cave, Mammoth Cave of Idaho, Shoshone Indian Ice Cave, Surprise Cave, Teakettle Cave. Crystal Ice Cave now closed.

New Mexico: Bat Cave (status uncertain), Big Skylight Cave, Braided Cave, Classic Cave, Four Windows Cave, Ice Cave, (Perpetual Ice Cave), Junction Cave.

Oregon: Arnold Ice Cave System, Lavacicle Cave, Lava River Cave, Malheur Cave, Skeleton Cave, South Ice Cave.

Washington: Ape Cave, Falls Creek Cave, Ice Cave (Trout Lake)

***Asia**:* *Korea*: Manjang Cave, Hallim Park Caves.

Japan: Mt. Fuji (Yamanashi Pref.): Fuji Ice Cave, Narusawa Ice Cave, Narusawa Bat Cave (Narusawa Koumori ana #1), Narusawa Koumori ana # 2-4, Fugaku Wind Cave, Saiko Bat Cave.

Mt. Fuji (Shizuoka Pref.): Hita Ana, Sekotsuji Wind Cave.

Daikon-Jima (Shimane Pref.): Yuki dou.

Fukue-Jima (Nagasaki Pref.): Sakishimazunoi ana, Torinukei ana, Toshi ana.

Mt. Aso (Kumamoto Pref.): Konezuka Wind Cave.

Hyate town (Kagoshima Pref.): Kumaso ana.

Takarabe town (Kagoshima Pref.): Mizonokuchi ana.

Australia: Bya duk Caves, Mt. Eccles Caves, Undara Caves.

Europe: *Italy*: Alum Cave (Vulcano Island), Grotta del Gelo (Mt. Etna).

Categories

Three categories are reasonably well demarcated among these show caves:
1) *developed*, with touristic modifications such as electric lighting, walkways and stairs, advertising and souvenirs. Guides usually are required and fees usually charged. Cueva de Los Verdes in Lanzarote, and Thurston Lava Tube in Hawaii are notable examples. The latter is the most visited volcanic cave of the world.
2) *semi-developed*, with controlled access, guides, and minimal modifications such as trails and occasional handrails. Peapea Cave, Savaii Island, Samoa is an example. KaEleku Cavern, Hawaii, and possibly other ecotourism caves are in an interface between this category and Category 1.
3) *self-guided*, with few if any modifications of the cave. Rua-tapu Cave, New Zealand and Trout Lake Ice Cave, WA, USA are examples.

Discussion

The majority of volcanic show caves are Category 3. Most of these are in national monuments and national forests in the western United States.

Acknowledgments

My sincere thanks to Paolo Borges, Elery Hamilton-Smith, Naruhiko Kashima, Greg Middleton, Takanori Ogawa, Pedro Oromi and Sigurdur Sveinn Jonsson who provided current information, to Jack Lockwood for information and photos of caves in western Samoa, and to Giuseppe Licitra who encouraged the preparation of this report.

CONSERVING THE LAVA CAVES OF MAURITIUS: THE CAVES OF MAURITIUS PROJECT 1998

Gregory J. Middleton

Member, IUS Commission on Volcanic Caves, Sydney Speleological Society, Southern Tasmanian Caverneers. Address: PO Box 269, Sandy Bay, Tasmania 7006, Australia. e-mail: regmi@dpiwe.tas.gov.au

Abstract

The Caves of Mauritius Project 1998 was conducted by the author and Jörg Hauchler for the Mauritian Department of Environment. It raised the number of lava caves documented on the Indian Ocean island to 114, with a total 12.8 km of surveyed passage. Information collected was placed into a computer database, including maps of most of the caves. The project highlighted the values of the caves and the threats to them and their fauna. It assessed the particular values of the more significant caves and recommended measures for their protection, particularly a "Plaine des Roches National Park" for the largest assemblage. Management agreements were suggested for privately-owned caves.

The Project

At the 8th Symposium on Vulcanospeleology in Nairobi in February 1998 I presented a summary of the current knowledge of the lava caves of the Indian Ocean island of Mauritius, what was known of their fauna and the threats to them (Middleton 1998). In concluding that paper I expressed the view that "Appreciation of the country's cave resources is coming only slowly and belatedly to Mauritius" and added, with more hope than confidence, "It now seems likely that a project to fully document, assess and conserve at least a representative sample of Mauritian caves will be undertaken." That prediction was based on the belief that two years of negotiations with the Mauritian authorities was about to come to fruition. And so it was. On 28 May 1998 I received an offer of a contract to undertake a project entitled "Planning the Conservation and Management of the Caves of Mauritius and Rodrigues" – soon abbreviated to the "Caves of Mauritius Project 1998".

The project was conceived as comprising three stages:

1. Undertake a comprehensive study of as many as possible of the caves, pipes and lava tunnels of Mauritius and Rodrigues and prepare or obtain surveys of each and compile an inventory of their significant features including location, ownership, current land use and biological content. Make a photographic record of notable features.
2. Prepare an assessment of each cave in terms of its specific values and its potential uses (such as for conservation, recreation, science, education, tourism, water supply, etc.) and determine the optimum use for each cave.
3. Prepare recommendations on the future use and management of each cave, including reservation, as appropriate. Report also on the need for a specific Act for the protection of caves and their contents, and for the conduct of education and publicity campaigns in relation to caves and their conservation.

A period of four months was initially set aside for this work; this was subsequently extended to five (and would have benefited from another). The project report, including the caves database, was presented to the Director of Environment and his staff (and the press) on 22 December 1998.

The author was assisted throughout the project by a German-born resident of Mauritius, Jörg Hauchler, with whom I had been exploring the caves since 1993. We were assisted for the first few weeks by volunteer Imran Vencapah and at other times by Vikash Tatayah and Mario Allet.

For a few days, on Rodrigues, we were joined by Swiss biospeleologist, Pierre Strinati, who added to his collections of Mauritian cave fauna.

Documentation of the resource

The documentation phase went much better than had been expected. While we were initially concerned as to how we might locate more caves, eventually we had to stop looking, although we were still receiving reports of other caves.
Table 1 shows the lava caves documented before and those added during the project.

Table 1 - Documented caves by Region and Area – before and after the 1998 Project

		Prior to July 1998			By December 1998		
Region	Area	No. of entrances	No. of caves	Total length (m)	No. of entrances	No. of caves	Total length (m)
North-West	Goodlands	1	1	225	3	2	355
North-East	Plaine des Roches	28	16	2,500	46	22	3,520
Central West	Moka Range	-	-	-	1	1	4.2
	Plaine St Pierre	8	6	920	11	9	1,115
	Plaine Wilhems	18	9	889	22	12	1,160
Central East	Beau Champ	-	-	-	2	2	14
	Nouvelle Decouverte	11	8	1,406	39	26	3,509
	Quartier Militaire	3	3	129	7	7	749
	Trou d'Eau Douce	3	2	35	3	2	63
South-West	Bassin Blanc	-	-	-	1	1	80
	Chamarel Falls	6	6	109	6	6	109
	Kanaka	-	-	-	13	10	725
	Mont Blanc	8	6	754	9	7	754
South-East	Plaine Magnien	1	1	85	1	1	85
	Rose Belle	-	-	-	2	2	68
	Savannah	3	3	205	4	4	500
	TOTAL	88	61	8,120	170	114	12,810

An additonal 3,691 m of passage was documented in karst caves, mainly on the island of Rodrigues.

As this indicates, a further 53 caves were documented during the project; these ranged from a 4.2 m isolated lava tube high in the Moka Range, to an 810 m cave at Roches Noires; in addition, some significant extensions were made to known caves.
These caves and a range of data associated with each are recorded in the Mauritius Cave Database, a copy of which was provided to the Ministry of Local Government & Environment. A total of 93 cave maps accompanied the report, depicting 133 caves (109 of them lava caves).

Fig. 1 – The Mascarene cave swiftlet is the most obvious of Mauritian cave fauna. For its value to agriculture alone it deserves to have its main breeding caves protected.

Values

The caves were shown to posses a range of values, most particularly as essential nesting and roost sites for the Mascarene cave swiftlet, *Collacalia francica,* (see Fig. 1) and the free-tailed bat, *Tadarida acetabulosus.* No less than

35 caves have been reported to house swiftlet populations; two are known to have been destroyed and in three the population sizes are unknown but the remainder have been estimated as indicated in Table 2.

Table 2 – Cave swiftlet population estimates

Estimated population	*No. of caves with population within range*
>500	1
200–500	2
100-200	3
50-100	3
20-50	7
10-20	10
<10	4

At least 8 caves shelter populations of *Tadarida*, in three cases numbering many thousands. Both the insectivorous bats and swiftlets are insectivorous and consume large quantities of insects, many of which are harmful to agriculture.

The caves also provide habitats for invertebrate fauna which is largely yet to be documented. Pierre Strinati had earlier collected the first endemic Mauritian silverfish (Mendes 1996) and an amphipod which had not previously been recorded in the Indian Ocean region (Stock 1997). During the project the author collected a scutigerid, eyeless opilionids, spiders, thysanuras, slaters and isopods, a wingless fly, symphyla, beetles, earwigs, flies and millipedes (Humphreys, pers. Comm.); none of these has yet been identified to species level.

Some of the caves provide reliable access to water (particularly at Roches Noires in the NE - at least 3 caves, Goodlands in the north and Chemin Grenier in the south) which is still used by local people at times.

Many of the caves exhibit interesting geological features indicative of their volcanic origins and are of considerable scientific and educational interest (Fig. 2).

Some of the caves are of historic interest (Middleton 1996, 1997): one was surveyed before 1769, another housed escaped slaves in the 1770s and was visited by Matthew Flinders, in another the owner gave parties and was later entombed, another, containing water, was of such regular shape as to inspire the name “Puits des Hollandais” (“Dutch Well”) by early French settlers.

At least two caves have religious significance: at Palma a Hindu temple has been built in the mouth of a lava tube; at Trois Bras a cave was for many years the site of a Hindu shrine or *kalimye.* Altars in at least two other caves attest to their use as black magic sites.

Very many of the caves have high scenic and recreational values and, in the case of Pont Bondieu, stairways have been installed to facilitate tourist and local community access. Unfortunately this has not been accompanied by information or interpretation so it has done little to raise public appreciation of caves. Promoting the recreational and scenic values of the caves in the absence of a responsible management authority and enforcable statutory protection would pose significant risk of irreparable damage to the caves and threats to public safety.

Fig. 2 – Lava caves contain unusual geological and mineral deposits worthy of protection.

Threats

The lava caves of Mauritius are vulnerable to a wide range of threats. These include:

Entrance closure

The clearest cases of this were the total filling of Providence Cremation Ground Cave (QM2) by FUEL Sugar Eastate and the filling of entrance MB4 (Trou Hirondelle #2) – both of which occurred after we mapped the caves. However, we also had earlier reports of entrances being filled at Petite Rivière, La Louise, Henrietta, Palma, La Martiniere (4), Trou D'Eau Douce, Nouvelle Decouverte, Kanaka, Gros Bois, Savanne and Trois Caverne.

Internal closure

At Palma, Beau Songes and Anna caves have been sealed or cut short; and this has virtually happened at Roches Noires because of dumping of huge quantities of rubbish into a daylight hole.

Rubbish dumping

The dumping of rubbish into caves is extremely widespread. Alhough, fortunately, in most cases it does not physically seal the cave but it can make entering the cave most unpleasant. The worst cases are industrial rubbish dumped at Pont Bondieu and Plaine des Roches Cremation Ground Cave (Fig. 3) and animal waste at Roches Noires (cows), Bergerie Lava Tube (sheep) and at Mont Blanc (chicken manure etc). We noted significant quantities of garbage in at least 13 other caves.

Vandalism

As occurs elsewhere, the breaking of speleothems is not an uncommon event. This may be accidental but from the fact that the broken pieces are rarely seen, one can assume that "souveniring" is farely common. Burning of old tyres has had a major impact on some caves, particularly Caverne Trois Bras where every surface in the larger part of the cave is covered in carbon. It is hard to see this activity as other than vandalism, though in some places it seems to occur in conjunction with black magic.

Fig. 3 – Cremation Ground Cave, Plaine des Roches, is almost filled with industrial waste.

Cave Swiftlet nest removal

George Clarke (1859) observed that attempts had been made to commercially exploit the nests of cave swiftlets 'many years'; before, but apparently without success. Nevertheless, the taking of swiftlet nests is a common occurrence and is presumed to pose a threat to this species which no longer exists in the 'vast numbers' noted by Clarke. Despite the erection of a grille to try to protect swiftlets in Petete Rivière Cave and a fence at Palma Lava Cave, no nesting site is currently protected.

Pollution

Unfortunately the island's largest lava cave, Camp Thorel (Fig. 4) with just over a kilometre of passage, lies entirely under the village of Camp Thorel which is not sewered. The result is that the cave receives large amounts of waster water and only partly-treated sewage from the overlying dwellings. Analysis of samples indicated very high levels of fecal contamination. At least ten other caves receive water of questionable quality.

Siltation

Siltation is a problem wherever sheet flow causes erosion and the products wash into a cave. Mangapoule Lava Cave QM4, Trois Caverne #1 PP2, L'Esperance Lava Cave ND22 and Double Cave ND29 which have all been completely blocked by silt are the worst known examples. All are in sugar cane fields. Many other caves suffer siltation to lesser degrees.

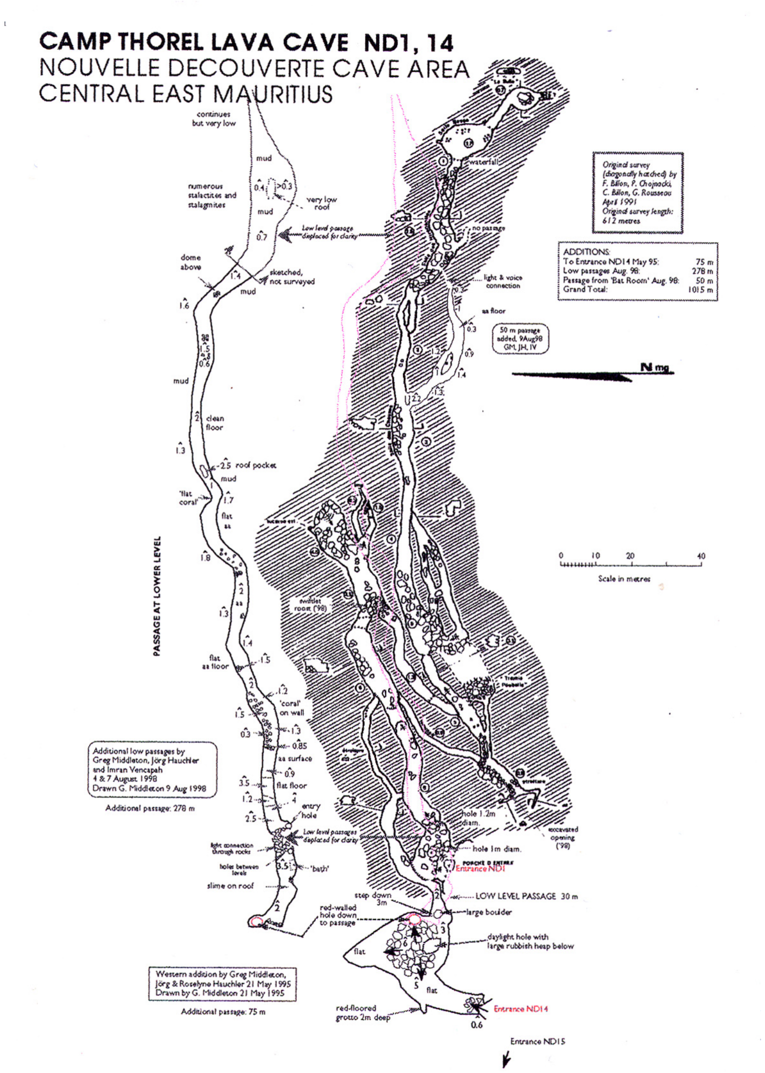


Fig. 4 – The most extensive lava cave in Mauritius, Camp Thorel Lava Cave, is unfortunately also its most polluted.

Protective measures already taken

The first official attempt to protect a Mauritian lava cave from the dumping of rubbish was undertaken by the Department of Environment in late 1993 at Pont Bondieu. A wall and chain wire fence were erected beside the road which passes over the cave and provided extremely easy access for trucks dumping rubbish. Stone steps and a handrail were installed to provide safe access into the large pit. As a result all ferns within easy reach have been remove and access for nest bobbers has been facilitated. Unfortunately no effort has been made to provide interpretation so visitors gain no understanding of the geological structures or processes involved in the formation of the caves and the pit , nor of the fauna which lives there.

Late in 1994 a private effort was made to protect the important swiftlet nesting cave at Petite Rivière, PP1. At the urging of Roger Safford, an English ornithologist who studied the swiftlet (Safford 1993) and the Mauritian Wildlife Foundation, the owners of the land, Medine Sugar Estate, agreed to gate the cave. By January 1995 the hinges had been broken and the gate removed. When questioned, some local people who visited the cave admitted that in the past they had taken swiftlet nests, but said they no longer did so. They thought the gate may have been broken by people thinking it must be protecting something of monetary value. Subsequently the owners repaired the gate but in May 1996 it was blown open using a high explosive (Hauchler, pers. comm.). It has not been repaired since. As the swiftlet population seems to have been growing it does not seem likely that nest removal was the motive for the repeated breaking of the gate. Hauchler has also noted that a second "altar" has recently been constructed closer to the entrance and it may be that practices associated with this are the major motive for keeping free access to the cave.

In May 1994 the owner started actively filling the entrance pit to the Palma Caves with rubble. Because of the importance of this cave for swiftlet nesting this activity was stopped by the Department of Environment and an agreement was subsequently reached with the owner to the

effect that the Department could carry out protective works and no further filling would occur. A chain-wire fence with a locked gate was subsequently constructed around the pit but this has not been maintained. The lock has been broken and access is unrestricted. Although dumping into the pit has been stopped, rubbish is still being dumped adjacent to the fence, weeds are overgrowing the fence and the area is an eyesore. This demonstrates the need for active maintenance and on-the-ground management in any program to provide long-term protection to the caves.

Recommendations on future use and management

The major recommendations which arose from the study were:

1. The creation of a "Plaine des Roches Lava Caves National Park" encompassing a series of significant caves in the Plaine des Roches area.
4. The other significant caves should either be reserved for conservation and low-key recreation purposes, or made the subject of a management agreement between the appropriate agency of Government and the landowner.

[Recommendations 2 and 3 concerned a karst national park on Rodrigues and priority funding for the cleaning and rehabilitation of Caverne Patate and its eventual lighting with electricity.]

Plaine des Roches Lava Caves National Park

It was proposed that this park be established under the *Wildlife and National Parks Act 1993* and be managed by the National Parks and Conservation Service of the Ministry of Agriculture. Where the land was not State-owned, except where occupied by dwellings, it was proposed for purchase to enable its reservation. Most of the land is extremely poor for agricultural purposes, has very thin soils and supports only exotic weeds and Eucalypts, grown for scaffolding.

Important elements of the project would be:

- The inclusion of as much of the area underlain by caves as possible, extending from the Roches Noires Rising on the coast inland at least as far as the Cremation Ground Caves west of the village of Plaine des Roches, south to the Roches Noires-Plaine des Roches road and north as far as the caves west of Roches Noires football ground. It may be that the park would not be able to be contiguous (at least on the surface) but it should be based on an ecological view of the area, recognising the geological processes that formed the region and the hydrological connections which unify many of the caves at the present time.
- Investigation of the feasibility of opening "Twilight Caverne" (PR18-30-31) (Fig. 5) as a tourist/show cave and offering guided tours through it on a regular basis, eventually with electric lighting. A study should also be undertaken of the feasibility of opening a second entrance to the cave at the terminal rockfall (Fig. 6) and of opening up further lava tunnel presumed to exist beyond that rockfall. This would facilitate trips through the cave and perhaps reveal further pristine lava tube for study and/or opening to visitors.
- Involvement of the local community through a Community Advisory Group to ensure that there was local input to planning decisions, local understanding of the objectives of the park and that opportunities for employment of local people, directly and indirectly, were maximised.

Fig. 5 – Twilight Cavern would be the major focus of a Plaine des Roches Lava Caves National Park.

- Investigation of the feasibility of restoring significant tracts of land with its original native vegetation, particularly around caves were public facilities are to be provided.

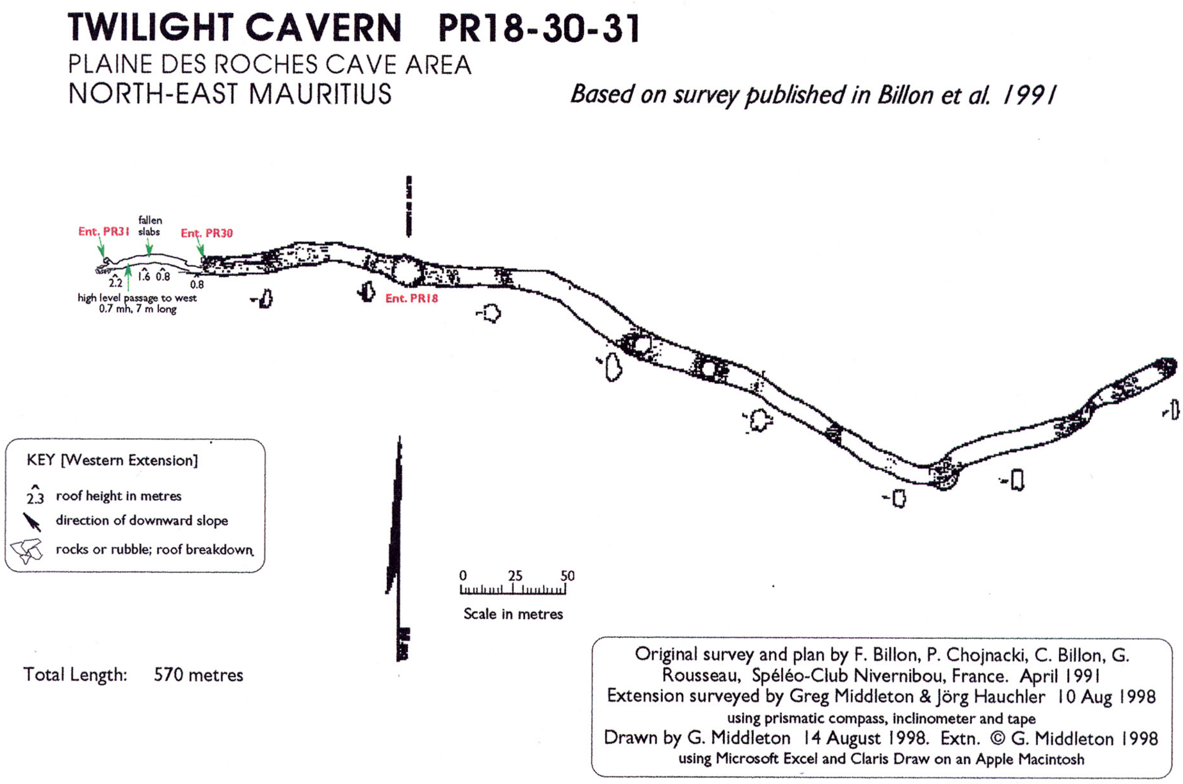


Fig. 6 – Twilight Cavern consists of a simple tube averaging about 12 metres in diameter, with a number of daylight holes. It appears to offer the best prospects for show cave development, especially if the rockfall at the eastern end could be penetrated.

A major cause for concern in relation to this project is the proposal to construct a second international airport in this region. It is not known exactly what site is contemplated but it is hoped that any such proposal would not impact directly on the area proposed as a National Park. This will need to be clarified before the project could proceed.

Management agreements for privately-owned caves

While it is preferable for nationally-important natural and scenic features such as caves to be protected and managed by the official conservation agency wherever possible, it is recognised that this will not be feasible in many cases and the best that can be expected is that the owner will agree to protect any caves on his property - or at the very least agree not to destroy them.

Management agreements can constitute a legally-binding contract between the owner and the Government to ensure that caves are protected or at least not adversely impacted upon, to specify the terms and conditions for access and to give the Government the right to carry out protective works and to maintain the site.

An existing agreement, entered into between the owner of Palma Lava Caves and the Minister in 1995 has not been entirely effective, probably due to lack of action on the part of the Department. It is probably not reasonable to expect a landowner to play a particularly active role under such an agreement (unless there is some way that he can derive some financial benefit). Most of the management action, construction, maintenance works, policing and interpretation is going to have to be carried out by the Government. This needs to be adequately funded and staffed to ensure the most is made of management agreements and that the Government can keep to its side of the bargain.

An improved pro forma management agreement needs to be developed and trial-run in some real situations before the appropriate content and wording can be finalised. Presumably there will always need to be some flexibility and the capacity to insert special clauses to cope with local situations but a pro-forma document should be able to be drafted which covers most situations.

Postscript

The project report and recommendations were submitted to the Department of Environment on 22 December 1998. No advice has been received in the 8 months since as to any action proposed to be taken by the Department or the Government.

References

- BILLON FRANÇOIS, CHOJNACKI PHILIPPE, BILLON CATHERINE & ROUSSEAU GHISLAINE, 1991: *Explorations Souterraines à L'Île Maurice: Compte rendu expédition Avril 1991*. Spéléo-Club Nivernibou: Decize (France) 46pp.
- CLARK G., 1859: *A ramble round Mauritius with some excursions to the interior of that island* ... [in] Palmer & Bradshaw (compilers) The Mauritius Register: historical, official and commercial pp. i-cxxxii. L. Channell: Port Louis. Reprinted in La Revue Agricole, 24(1):34-51; (2):96-114.
- MENDES L.F., 1996: *Further data on the Nicolettidae (Zygentoma), with description of a new species from Mauritius*. Revue Suisse de Zoologie, 103(3):749-756
- MIDDLETON G., 1996: *Early accounts of caves in Mauritius*., Proc. Roy. Soc. Arts & Sci. Mauritius, VI:49-87
- MIDDLETON G., 1997: *Historical accounts of caves in Mauritius*., J. Spelean History, 31(2):27-46.
- MIDDLETON GREGORY J., 1998: *Lava caves of the Republic of Mauritius, Indian Ocean*., Int. J. Speleol., 27B(1/4):87-93
- SAFFORD ROGER J., 1993: *Conservation of the Mascarene swiftlet* Collocalia francica *on Mauritius, by protection of a nesting cave*. A report to the Fauna and Flora Preservation Society (project No. 91/17)
- STOCK J.H., 1997: *A new species of* Brevitalitrus *(Crustacea, Amphipoda, Talitridae) from Mauritius - first record of the genus from the Indian Ocean*. Revue Suisse de Zoologiyñ 104(1):3-11

A RATIONALE FOR THE PROTECTION OF VOLCANIC CAVES

Christopher Wood

School of Conservation Sciences, Bournemouth University, U K
e-mail: cwood~bournemouth.ac.uk

Abstract

On an international scale, the protection of volcanic caves is extremely limited. Whilst it is true that some of the world's most important caves lie within internationally-recognised protected areas, many others do not, and even in the protected areas there is scant evidence of any specifically-directed conservation management policies. One important handicap to the protection of these features is the lower priority generally applied to geological conservation. Another is poor perception, there being a common view among conservation managers and their geological advisors that volcanic caves are inconsequential landforms, ranking of minor importance or merely as curiosities.

This paper lays out the case that volcanic caves have important scientific, economic, cultural and aesthetic values and are important, both as landforms in their own right, and as a part of a wider assemblage of volcanic landforms. Existing protective designations will be reviewed and justifications for protection of these remarkable features laid out. A point of debate will be the extent to which the world's volcanic cave estate is under threat and whether or not this justifies the development of protective guidelines. Such guidelines might follow the model of the IUCN's Guidelines for Cave and Karst Protection, and could be approached either by including volcanic caves within the remit of that document (speleological approach), or by considering them as a member of the wider assemblage of landforms that consitute particular volcanic terrains (volcanological approach).

GUIDED TOURISM AT UNDARA CAVES. NORTH QUEENSLAND

Jon Stephenson

Hon. Research Associate, James Cook University, Townsville, Australia, 4811.
e-mail: jon.stephenson @jcu.edu.au

Abstract

Numerous outstanding lava caves occur within the Undara Volcanic National Park in Queensland and are visited by numerous tourists. This commercial tourism is managed through a Commercial Activity Permit to "Undara Experience", supervised by the Queensland National Parks and Wildlife Service. The company provides accomodation facilities at Undara Lodge on a special lease area outside the National Park, and guided tours to selected caves operate from the Lodge. This scheme has been operating for 10 years, and the environment is being well sustained even with many tens of thousands of visitors each year.

Introduction

Lavas were erupted from Undara Volcano in north Queensland 190, 000 years ago. They contain extensive lava tubes and caves most of which are included in the Undara Volcanic National Park. This National Park was gazetted by the Queensland Government over several years, from 1989 to 1993.

This paper describes how public access to some of the caves in the National Park is managed. A commercial tourism enterprise, Undara Experience, provides accommodation at Undara Lodge for visitors on a special lease area adjacent to the National Park. Under the terms of a Deed of Agreement and a Commercial Activity Permit supervised by the Queensland National Parks and Wildlife Service, Undara Experience conducts guided tours to visit some of the nearby caves inside the National Park. This interesting and successful operation has been conducted over the last ten years, and has ensured controlled, ecologically sustainable use of the caves by visitors.

The Undara Caves

The volcanism at Undara volcano was active close to 189 thousand years ago, as indicated by potassium-argon age determinations of its lavas (Griffin and McDougall, 1975). There are three principal lava tube systems associated with lava flows from this crater, and more than 50 lava caves are known in the Undara Volcanic National Park. The north-west tube extended a considerable distance, perhaps for over 100 km. Intermittent lava caves occur along it, but the last known cave is 30 km from the crater. Further along, the tube may not have drained to develop caves.

The caves vary in length, up to more than a kilometre. They are noteworthy for their very good preservation, easy access and generally spacious character. They are up to 20 m wide and have ceilings 10 to 20 m above the floor. The floors are typically smooth and most are covered by cave sediment except where rock falls from the roof have occurred. They are classic lava caves, with well-preserved lava structures of various kinds, nicely described and illustrated in the book by Atkinson and Atkinson (1995). Aspects of the very long lava Undara flows and the lava tube systems are discussed by Stephenson et al. (1998) and Stephenson (this volume).

Location and access

The Undara Volcanic National Park is 160 km from the coast, adjacent to the Main Divide between east coast drainage and drainage to the Gulf of Carpentaria in the north-west. This is a

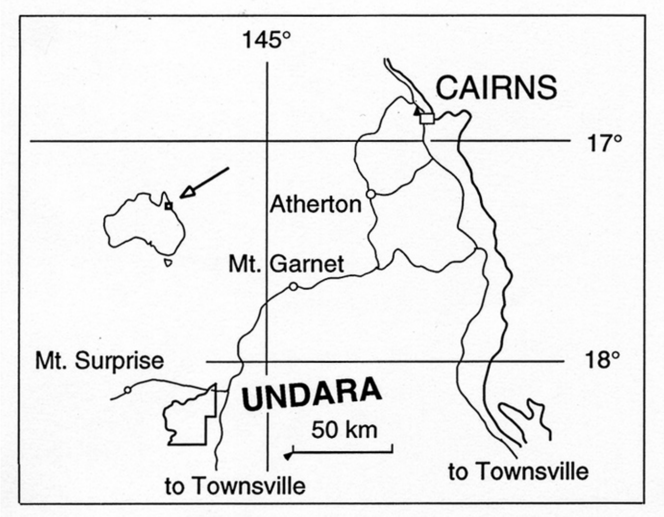


Fig. 1 – The location of Undara Volcanic National Park and highway access from Cairns and Townsville.

broad divide, and there are numerous small volcanoes in the Undara district. Open eucalypt woodlands are a feature of the district but some local vine thickets occur in areas which are naturally protected from fire. In the local region there are no major streams, but perennial springs associated with the basalt lava flows are present along some small watercourses.

Undara Lodge is the best access point for the lava caves. It can be easily reached along the sealed highways (Fig. 1) from Cairns (275 km) and Townsville (430 km). The closest townships are Mount Surprise (55 km) and Mt. Garnet (100 km).

History and development

This region was first settled for grazing in the mid-nineteenth century and is currently involved mainly in raising beef cattle, with some mining. The cattle grazing industry is managed from widely-spaced homesteads in the region.

Lava caves in the region were first referred to in geological reports late last century, and their existence was certainly known to the graziers involved in the district. The original road to Mt.Surprise from the coast actually passed one of the caves and its presence was well recognised as a rest-point because of its cool shade and a spring inside the entrance.

A number of the caves were known to the Collins family which held grazing leases over parts of the Undara country. A regional geological survey in 1960 demarcated the locations of many of the volcanoes in the local region, and recorded the conspicuous darker vine-scrub patterns which are associated with the lines of lava tube collapses and caves, and are prominent on aerial photographs.

Interest in the Undara lavas and its caves was stimulated by pioneer exploration work searching for more lava caves by Anne Atkinson and her family in the seventies and the cave system was first described by Atkinson et al. (1975) who emphasised that with a flow length of 160 km Undara contained some of the longest young lava flows in the world (Stephenson and Griffin, 1976).

From 1967, proposals were made that an area including Undara and its caves be declared a National Park, and most of the present Undara Volcanic National Park was declared between 1989 and 1993. The main Queensland legislation involved is the Nature Conservation Act 1992.

The Tourism Enterprise

The manager of a cattle grazing property in the Undara region, Gerry Collins, promoted ideas for a commercial tourism project for the Undara Caves. Collins had grown up in the district and recognised that its unique features could be appropriate for promoting tourist visits to include guided tours of some of the caves. His company was granted a Commercial Activity Permit (CAP) to operate in the Undara Volcanic National Park, and was granted a special Business Lease of a small area nearby, but external to the Park. The Undara Lodge was constructed in this area, to provide accommodation for visitors and to house facilities for conducting guided tours and providing tourist information.

The Undara Lodge has accommodation for up to 200 visitors. Several levels of accommodation are available including: fully serviced residential accommodation; camping areas; and a youth hostel association "swags tent village" comprising permanent A-type structures. Caravan visitors are also provided for. There are full facilities for all levels, and a restaurant provides meals.

The Lodge has operated since June 1990. The numbers of annual tourist visitors has increased from 20, 000 in 1993 to 32, 500 during the year ended mid-1999. Undara has generated strong international and national interest. Approximately 20, 000 questionnaires are completed each year by visitors and of 2000 collated and analysed from the second half of 1996 and the first half of 1997, 35% were from overseas, with similar numbers from Queensland and from other Australian states.

Guided tours and activities

The Queensland Environment Protection Agency is responsible for managing the National Park through its Queensland Park and Wildlife Service (QPWS). There is a Ranger station located 12 km from the Lodge. The responsibilities of the Ranger and his staff are the upkeep of the whole National Park, involving maintenance of fences, management of fire (an important consideration without grazing), the improvement of certain access details and the provision of cave infrastructure.

Subject to the commercial agreement with the Queensland Government, guided tours inside the National Park are organised by Undara Enterprise, and administered by the staff of the Savannah Guides Organisation who operate from the Lodge.

Different Guided Cave Tours

A range of tours is available, which vary in duration and distance from the Lodge. There are four outstanding cave systems which are visited by tours, ranging from shorter visits of around two hours to full-day tours. The tours move visitors in buses, distances of from 3 to 10 km from the Lodge. At this stage, no self-guiding tours are allowed for safety and environmental protection reasons. There are local granite tors outside the Park which are adjacent to Undara Lodge and these have paths to lookouts which visitors are free to enjoy at any time, as has Kalkani (a nearby volcanic cone). These viewpoints provide excellent vistas across the lava country in the National Park where the caves occur.

The tours involve walking on paths and walkways into the caves. QPWS has constructed special timber walkways for easy, safe access. The longest walking distances are less than 1 km.

The size of each tour group is restricted to a maximum of 22 people, with 2 guides. Each group is given a verbal introduction to aspects of the district's history, fauna and flora. In addition, geological aspects of the region are explained including the formation of the caves, using maps and displays on the site.

Park Management and environmental questions

All the commercial tourism activities which involve use of the National Park are sanctioned under the Commercial Activity Permit controlled by QPWS. An advisory Planning Committee was established in 1992 to assist in the development of a draft management plan for the Undara Volcanic National park. The Planning Committee consists of QPWS officers and their consultant geologist, and wide representation from other Queensland Government departments and bodies (Primary Industries, Tourist and Travel Corporation, Fire Services), the adjacent local Shire Council, James Cook University, the Chillagoe Caving Club, a spokesperson for landholders adjoining the National Park, and the Queensland Conservation Council (an independent

organisation) - in addition to the representative for the Undara Lava Lodge. This planning committee met over the course of several years to advise QPWS on management planning.
Historically, the Undara region has been very well preserved environmentally. It has had no problems induced by urbanisation because there has been no such development. The original Australian bush landscape has remained virtually unchanged by grazing, and the draft management plan has set out to maintain this situation in what is now a National Park.
There is potential risk of wear of certain caves and the access to them, through visits by numerous tourists. However, the commercially guided tour system minimises possible damage with defined tracks which are maintained. There are timber stairs and walkways which protect the access. A network of vehicle access tracks to the cave has been established, with designated parking areas strategically located with respect to the entrances.
Many of the smaller caves are used by bats, mainly for roosting or possibly assembly. There are six species of cave-dwelling bat, and one cave is a major nursery site for some of these, the total colony consisting of about 40, 000 bats during the maternity period. Guided visits are restricted to outside this period. The caves contain arthropods and troglobite cave-adapted animals. Several caves known to be biologically diverse are not available for visits by guided parties. The areas surrounding the caves host nine species of macropod fauna (such as wallabies and kangaroos). The area supports a natural diversity of vegetation habitats and species, with about 400 native plant species.
The climate is seasonal, with around 70% of the annual rainfall falling in the wet season (November - April). A heavy wet season modifies the sediment floors of some of the caves (in certain years actual flooding affected some caves), and heavy foot traffic might have modified them. This possibility of damage has been minimised by construction of wooden walkways. Possible damage by repeated visits has also been minimised inside the caves by marked ways on the cave floors. The supervised, guided tour system also strictly minimises possible vandalism because other visitors cannot gain access to the caves. Most of the vehicle access tracks pass Undara Lodge and private vehicles do not have access inside the park.

The Guides

The tour parties are supervised by guides who are either fully-accredited Savannah Guides or are training to achieve this recognition. Savannah Guides receive advanced accreditation under the National Government Eco Tourism Accreditation Program. Savannah Guides is a non-profit company managed by a six-member board of management. It organises similar guiding work at a number of other districts of tourist interest in north Queensland. The guides train at Guide schools conducted several times each year, and work as assistants at Undara before achieving their accreditation. To become accredited requires the demonstration of good guiding and group-leading ability, a good understanding of the natural history and geological features at Undara, and the ability to explain features to visitors.
The period over which different guides undertake their professional work at Undara varies. Their previous background before they apply for training at Undara (or elsewhere) covers a very broad spectrum. But those who successfully become accredited guides all have a natural affection and respect for the Australian bush. They typically work at Undara for several years, and in some cases for much longer. After their service, many move to other guiding locations to widen their knowledge and experience.
Good guiding calls for a range of abilities and skills, in addition to a proper understanding of the cave environment. Good, fluent presentation is required and an easy communication style - but the ways in which different guides achieve this successfully vary considerably. Guides find themselves called on to repeat several tours a day, and to maintain effective presentation and enthusiasm can be especially demanding. A relaxed ability to respond to questions, and make the best of the special opportunities they provide, is vital.

The nature of the Undara lava caves is highly suited for guide explanation. Tourists are generally astonished by the lava cave spectacle. The experience is accentuated at Undara, because of the absence of cave indications in the gently undulating surroundings, remote from the volcano. The surface of the 190,000 year old lavas has become subdued by time, with no original lava surfaces remaining and only well-grassed and open forest country apparent. The sudden entry into depressions and the abrupt caves can be very surprising.

Reaching the caves, visitors are interested to learn as much as they can about how the caves formed geologically, and how the natural environment (fauna and flora) has responded. An essential guide presentation of what is known about the natural environment, including all these aspects, mainly relies on accumulated knowledge including the results of scientific observation and research. It can be argued that the vitality of continuing research contributes to both guide interest and that of their visitors. Research work has focused not only on the caves themselves, but also on the district flora and fauna (including the remarkable cave microfauna). Scientific interest is active, and many questions remain to be satisfactorily accounted for. Explanations in an illustrated written form which is easily accessible to the public can provide an important parallel to guide presentation. The book by the Atkinsons (1995) serves well in this regard, but further booklets accounting for the natural phenomena should be encouraged.

Tourism assessment

Promotion and advertisement of tourism facilities and services are vital for the economic health of any such enterprise. Another essential aspect involves a good response from the participating tourists, in relation to their visit. Undara monitors this response by inviting visitors to respond to written questionnaires, summarising their assessments.

An analysis of 2000 tourists reports has been recently undertaken for a 12 month period in 1986-87. This independent investigation was undertaken by a Dr. N. Black of the Tourism Department at James Cook University in Townsville.

The results provide evidence of very positive tourist assessment. Questions sought the visitor grading of various aspects of the Undara Lodge operation, including its accommodation, meals and facilities. The survey by Black also assessed visitor opinions in relation to the guided cave tours. The tours and their guides achieved very high ratings, For the tours, over 95% of the responses were "good" to "excellent" in a 5-level scale and all the ten guides assessed were recognised for exceptional service.

Conclusions

In the ten years of commercial operation visible damage to the caves and their access has been negligible. The style of management of guided tourism at Undara Caves can be judged to be highly successful and Undara Experience itself has won a number of Tourism awards.

The commercial tour operation has been effective in stimulating wide appreciation and information among the public visiting this remote part of North Queensland. It has provided safe visits and has been effective in helping to preserve the special cave environment.

Although this management plan was developed for a region distant from urban centres, perhaps related structures could be designed for more easily accessible cave systems which are endangered environmentally.

Acknowledgements

This paper was critically reviewed by Bram Collins and by an anonymous reviewer. I acknowledge their careful comments and suggestions.

I am grateful to Dr. Neil Black, James Cook University, for giving me permission to refer to his visitor survey results.

References

- ATKINSON F.A., ATKINSON V.G., 1995: *Undara Volcano and its lava tubes.* V.and A. Atkinson, Brisbane, 83 pp.
- ATKINSON F.A., GRIFFIN T.J., STEPHENSON P.J., 1975: *A major lava tube system from Undara volcano, north Queensland*, Bulletin Volcanol,, 39, pp. 1-28.
- GRIFFIN T.J., MCDOUGALL I., 1975: *Geochronology of the Cainozoic McBride volcanic province, northern Queensland*, Journal of the Geological Society of Australia, 22, pp. 387-397.
- STEPHENSON JON, 2000: *Emplacement and tube development in long tube-fed lavas in N. Queensland. Australia.* This volume.
- STEPHENSON P.J., GRIFFIN T.J., 1976: Some *long basaltic lava flows in north Queensland.* In Johnson R.W.(Ed.), Volcanism in Australasia, Elsevier, Amsterdam, pp. 41-51.
- STEPHENSON P.J., BURCH-JOHNSON A.T., STANTON D., WHITEHEAD P.W., 1998: *Three* tono *lava flows in north Queensland*, Journal of Geophysical Research, 103, pp. 27359-27370.

SPELEOLOGY IN VOLCANIC PARKS

William R. Halliday

Honorary President, IUS Commission on Volcanic Caves
6530 Cornwall Court Nashville, TN, USA

Abstract

Inevitably, speleology and the progress of vulcanospeleology differ considerably in different volcanic parks. But the parks and the progress of vulcanospeleology clearly are intertwined irrevocably.

Until recent years, speleology was a karstic subscience and no one even fantasized that volcanic parks were a tremendous worldwide speleological resource. Today, vulcanospeleology suddenly has become the fastest growing subdivision of speleology. And much of this impetus has been because of speleology in these volcanic parks.

Although fundamental studies like mapping still are incomplete, investigations in Hawaii Volcanoes National Park have been especially productive. Even preliminary studies in its Kilauea Caldera, for example, have revealed a wide spectrum of subterranean rheogenic features in conduit tubes, hollow tumuli, boundary ridge caves of lava rises, and flow lobe and other drainage caves. These are highly relevant in determining emplacement mechanisms of pahoehoe flow fields.

In the U.S.A., this sudden progress in vulcanospeleology paralleled and assisted creation of at least one of its new volcanic parks. The boundary of Mount St. Helens National Volcanic Monument was specifically drawn to include the Cave Basalt Lava Flow. The future should bring even closer teamwork.

Introduction

Volcanic parks and their potential for speleology inevitably differ widely amongst themselves. Kenya's Mt.Elgon National Park apparently lacks lava tube caves but its huge Kitum, Makningen and other solutional and/or piping caves in tuff are of world-class geological importance. America's famous Mount Rainier National Park contains no pahoehoe lava but has wonderful geothermal and transient glacier caves. Perhaps the two extremes of volcanic parks are the pretty little city park in Ponta Delgada (Azores) and Hawaii Volcanoes National Park. The attractive grotto-like caves in the former may be artificial; the latter is the site of dozens of major lava tube and other volcanic caves only partly known even today.

The flowering of vulcanospeleology

Almost universally, speleology was considered a karstic subscience until recent years. The past three or four decades, however, have seen a well-recognized sudden flowering of vulcanospeleology worldwide. Its wave has accelerated so rapidly that vulcanospeleology now is the fastest-growing subdivision of all speleology, with no outer limits yet evident. The nine international symposia of vulcanospeleology have served as its cutting edge, and field data from volcanic parks have contributed markedly to its continuing impetus.

Investigations in Hawaii Volcanoes National Park

Although fundamental studies like mapping still are very incomplete, investigations in Hawaii Volcanoes National Park have been especially productive. This huge volcanic park includes the western and southern sides of Kilauea volcano and its caldera (although only the head of its Ailaaa flow field, locus of Kazumura and some other world-class lava tube caves). It also includes the summit caldera and a wide speleoliferous strip of Mauna Loa Volcano. As I write, some of the park's lava tube caves still are too hot to enter, while some of its high elevation caves have been located only from the air. Lifetimes of study exist here, in volcanology, in applied and descriptive speleology,in biospeleology, in archeology and in other fields. Even the preliminary studies in its Kilauea Caldera have revealed spelean rheogenic features highly relevant in determinations of emplacement mechanisms of pahoehoe flow fields. In addition to "ordinary" lava tube conduit caves, we and others have found hollow tumuli of at least two types (some of them interconnected), boundary ridge caves of lava rises with complex internal structures, and flow lobe and other drainage caves with complex patterns including three-dimensional nests of drained chambers.

At this time of keen interest in extraterrestrial volcanology, another Kilauea cave - outside the caldera - also may be of special interest. It originates at the bottom of a punched-out crater much like a true pitcrater. Its only surface traces are small skylights several hundred m downflow - seemingly a common pattern in photos of the surface of Mars and the Moon, but not on Earth.

Creation of new volcanic parks

At least in the U.S.A. and in Kenya, this half-century's sudden progress in vulcanospeleology accompanied and assisted creation of new volcanic parks. Kenya's new Chyulu National Park was created almost entirely because of Leviathan Cave and its world-class neightbors. In the U.S.A., the new El Malpais National Monument has featured giant lava tubes since its creation. After a battle in committees of the U.S. Congress, the boundary of the new Mount St. Helens National Volcanic Monument was specifically drawn to include the Cave Basalt Lava Flow. And when U.S. Forest Service surveyors drew a boundary line. to exclude a fine stand of virgin timber atop this flow (and part of one of its caves) a specific mandate by the U.S. Congress forced relocation of the faulty survey line.

Contributions to volcanic parks by vulcanospeleologists

Just as volcanic parks can contribute greatly to the advancement of vulcanospeleology, speleologists can and do contribute to administration of volcanic parks. In the American state of Idaho, administrators of Craters of the Moon National Monument long ago developed several caves as interpretive sites. Recent exploration and cave inventory revealed: many additional caves, most of them not needed nor suitable for additional show caves. During the process, local speleologists and park administrators developed a close working relationship that led to an appropriate management plan for each cave.

Such teamwork is not always easy. On Hawaii's island of Maui, Haleakala National Park is basically administered as a biological preserve, with all else - including basic descriptive speleology - subordinated. Yet, throughout the world, volcanic parks are truly notable storehouses of speleological values - geologically, biologically, culturally, and in many other ways. My firm belief is that teamwork between park administrators and vulcanospeleologists can and will enrich the world in years to come. Let it be so.

In absentia
Posters

VOLCANIC CAVES IN ARGENTINA

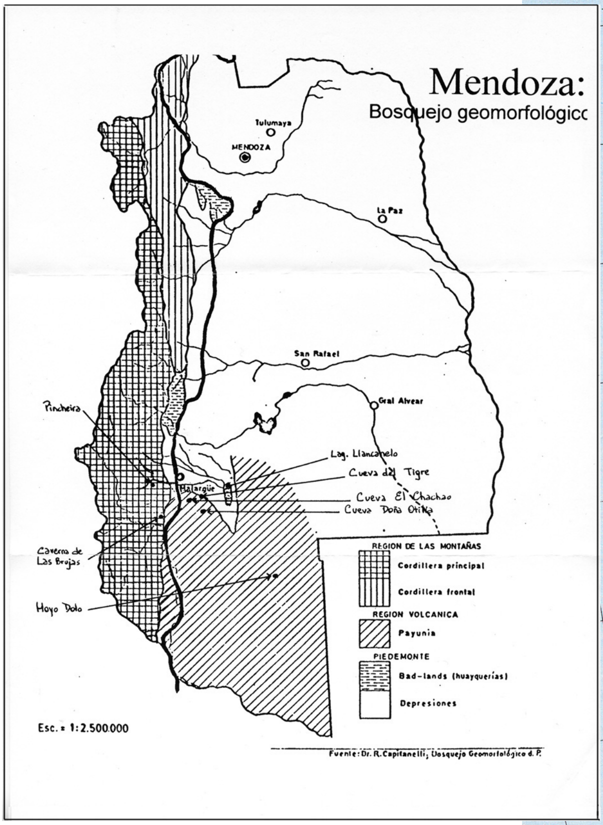
Carlos Benedetto

Instituto Argentino de Investigaciones Espeleológicas (IN.A.E.)
M.T. de San Martin 752 - Barrio Parque, 5613 MALARGÜE, Mendoza, Republica Argentina

Abstract

The SE part of the province of Mendoze, Argentina, consists of a basaltic area known as "Payunia", after the name of Payun Matru, its main volcano. A very active volcanism affected this area during Pleistocene, and its surface features retain evidence ot this activity. Such features are also reckoned underground, where several lava caves were located. The most important among them is Cueva Dona Otilia, with 838 m development. The cave environment is featured by a high humidity percentage and by a remarkable organic inflow, which could infer to an eventual biospeleological importance. Further lava caves were also found in two more provinces of Argentina, La Pampa and Neuquén, with an average development of 300 m.

Foreword



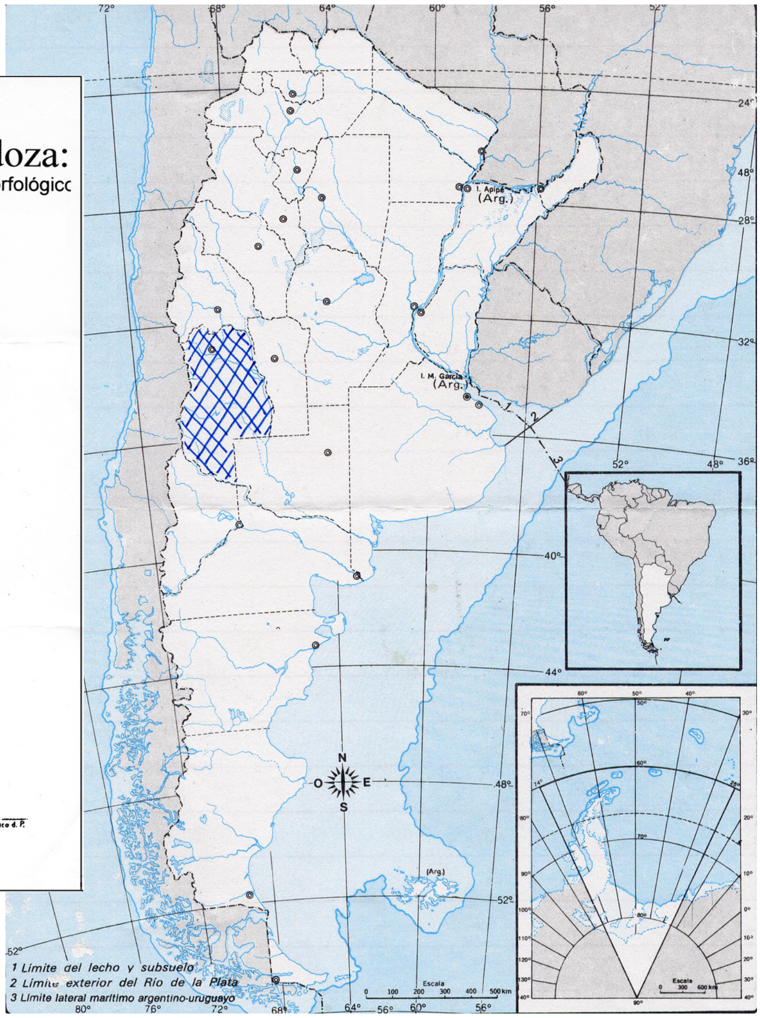


Fig. 1 – The morphological map of Mendoza's province and its location map.

Speleology in Argentina is rather young, though it is rapidly evolving, mainly in the provinces of Mendoza and Neuquén, on the Cordillera of the Andes. In fact Argentina's Andes provide the most favorable grounds for speleogenesis: Jurassic limestone and gypsum, and Pleistocene basalt, though this latter is rather approximately dated.

Malargüe, a department of Mendoza, is placed in the southernmost area of the province, at the boundary with the province of Neuqüen; the western side of Malargüe is occupied by the Cordillera of Andes, whereas its eastern side hosts a broad volcanic area, with several extinct volcanoes that give the landscape a singular aspect. The basaltic sub-region, identified on the morphological map by the transverse sketch (Fig. 1), is known as "*Payunia*", just after the name of the Payun Matro, the main volcanic presence.
The map reports also the towns in the province of Mendoza, and Malargüe among them, and the most important studied caves up to date. Prospective and survey studies are actually in progress, and this communication will be soon outdated, though our foreign colleagues can use it as an approach to Argentina's speleological reality.

Volcanic caves of Malargüe, Mendoza

The Centro Argentino de Espeleologia (C.A.E.) produced in the Seventies the first researches on Argentina lava caves, and published *Cueva Doña Otilia*'s survey (Fig. 2). Their researches were successively abandoned, and resumed again between 1995 and 1996, by the IN.A.E.
This communication does not concern shelters and holes, because of their negligible size, though they were surveyed and studied as well. "*El Manzano*", among them, was considered in a joint study performed in collaboration with Prof. Paolo Forti (University of Bologna, Italy) in 1997. The study was stimulated by the high concentration of phosphate minerals in the cave.

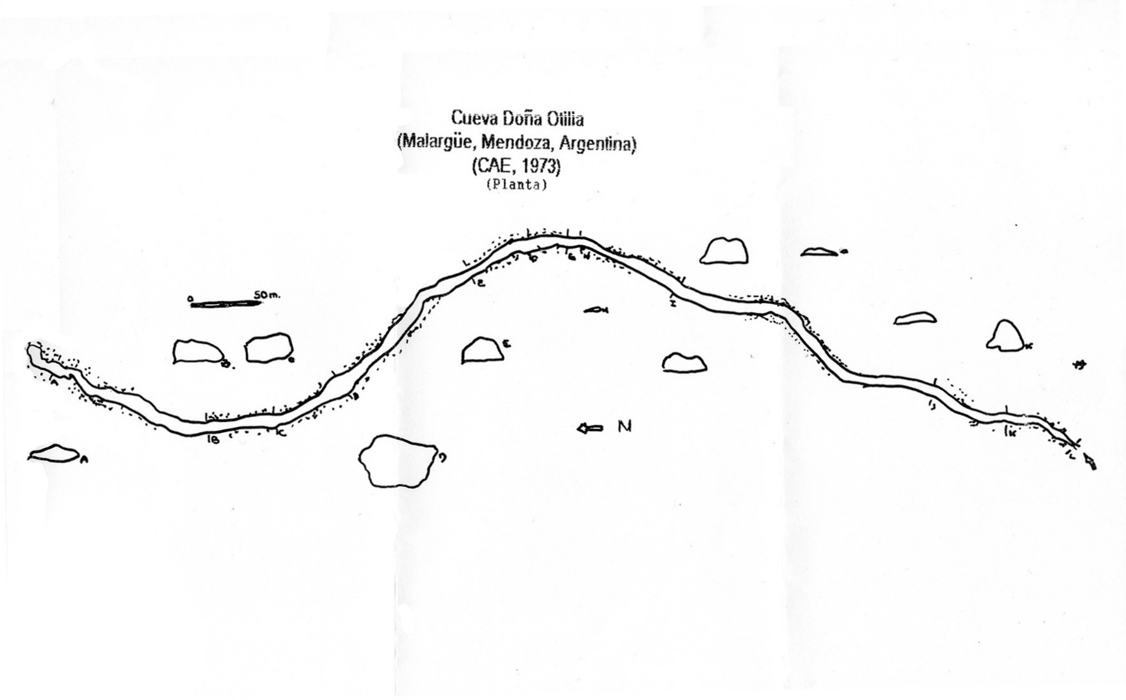


Fig. 2 – The *Cueva Doña Otilia*'s survey

Only the three major basaltic caves of Malargüe department will be considered, and summarily reported here.

Hoyo Dolo

Surveyed by C.A.E. Its total length is 350m, though the original tunnel should have been approximately 2500m long, according to the aerophotogrammetric surveys. This cave did not arouse speleologists' interest, due to the massive presence of collapses.

Cueva del Tigre

This cave is located something less than 70 km SE of Malargüe, and was surveyed by the IN.A.E. in 1996. Dr. Eleonora Trajano (U.S.P., Brazil) already biologically surveyed it in 1991; Dr. José Palacios Vargas (UNAM, Mexico) carried out an additional biological study in 1996. Neither research, however, gave positive results, due to the high dryness of the cave. In 1997 the cave was visited by Prof. Paolo Forti (University of Bologna, Italy), who carried here mineralogical researches. This cave is subject to uncontrolled tourist visits, notwithstanding speleological Organizations' complaints and oppositions.

Cueva Doña Otilia

This cave too is situated at about 70 km SE of Malagüe. It is the longest known lava cave in this area, and the most picturesque too, thanks to the quantity of roots penetrating through ceiling cracks, and to its gypsum and calcite speleothems, very rare in this kind of caves. The hollow is highly humid and encumbered with abundant organic debris. The presence of depigmented micro-arthropods was recently ascertained, therefore a program of systematic biological researches will be started within brief times.

The following peculiar features can be observed:
Stalactites made by Calcium carbonate, carried as a solution by abundant drainage waters;
Roots penetrating from the overlaying surface, to the aim of drawing water from the sandy bottom; the previously cited fauna was hosted on these roots, and this phenomenon was photographically witnessed;
Roots penetrating through the ceiling and descending along the walls until the floor;
Roots on which the deposition of a translucent gypsum lining is in progress; this phenomenon is singularly attractive, since the roots are becoming the "*live*" core of extremely fragile speleothems.
Cueva Doña Otilia lies in a flattish basaltic area, with an almost unidentifiable entrance; notwithstanding this some tourist operators proposed to use this cave for commercial purposes. This could heavily endanger the inner environment for the following reasons:
These operators are already undisturbedly destroying the *Caverna de Las Brujas*, despite it is a natural reserve shielded by law, and notwithstanding unattended speleologists' claims;
Cueva Doña Otilia is an extremely vulnerable cave: its speleothems can be shattered into fragments by simple visitors' hand-touch, and its fauna wasn't yet exhaustively studied.

A further developing research

If we consider the broad extension of basaltic areas in Malargüe, there could be a large presence of volcanic caves: Malargüe's surface is 21,000 square km, almost half of which is represented by *Payunia*. We rely that many lava caves can be discovered in the concerned area during the

investigations in progress, as it already happens with gypsum caves (continuous discovery of further caves in Cordillera Principal).
Argentina's speleologists will submit the attained results to their compatriots, and foreign colleagues, during the I Congreso Nacional Argentino de Espeleologia, to be held in Malargüe in February 2000.

Translated into English by Giuseppe M. Licitra

POZZO DEL DIAVOLO OF MOUNT VENERE (CAPRAROLA, VITERBO) DESCRIPTION OF THE ONLY VOLCANIC CAVE IN LATIUM (ITALY)

Maria Luisa Battiato, Giulio Cappa, Alberta Felici, Lorenzo Grassi, Gianni Mecchia and Maria Piro

Federazione Speleologica del Lazio

Abstract

This report show information about “Pozzo del Diavolo”, that is the only volcanic cave in Latium (Italy). This little cave - near the top of the cone of Monte Venere in the natural reserve of Lago di Vico (Caprarola, Viterbo) - is very interesting also for archeological discovery.
The volcanic history of Vico spans the period from 0.8 Ma until about 85-90 ka ago. The final phase of volcanism was strongly influenced by the presence of a lake filling the newly formed caldera, and thus was violently hydromagmatic. Only in its very final stage the character of the eruptions became magmatic again, building the cone of Monte Venere that lies eccentrically in the N part of the caldera basin. The activity of this fourth period lasted from 140 to about 90 ka ago.

RADON MONITORING IN A GEOTHERMAL ICE CAVE OF MT EREBUS, ANTARCTICA

*J.C. Sabroux * , P. Richon * and R.X. Faivre-Pierret ***

* Institut de Protection et de Sûreté Nucléaire - BP 6, 92265 Fontenay-aux-Roses cedex, France
** Commissariat à l'Energie Atomique - 17, rue des Martyrs, 38054 Grenoble cedex 9, France

Summary

Uranium (^{238}U) is ubiquitous, though at highly variable concentrations, in every rock making up the earth crust. Through radioactive decay, it yields radium (^{226}Ra) which, similarly, produces an inert but radioactive gas, namely radon (^{222}Rn). Rocks, soil, endogenous fluids, ground water and even building material are an inexhaustible source of radon.

Radon ends up in the atmosphere where, due to a radioactive half life of 3.82 days, its residence time is less than one week, and its concentration is low. On the other hand, in enclosed environments (mines, underground natural or man-made cavities, and buildings), radon and its decay products may reach levels potentially dangerous for health.

In underground cavities, radon volumic activity is a function of the radium content of the wall rock, but it depends also on the ventilation, either naturally or mechanically driven. Speleologists are accustomed to the air streams that flow along the passageways, and often reverse in spring and autumn, when the outdoor temperature equals the average local temperature (*ca.* the cave temperature). Despite their natural ventilation, caves are always much more radon-rich than the outdoor atmosphere, rocketing, for example, up to an unprecedented 155 000 Bq/m^3 during the summer in the limestone Giant's Hole in Derbyshire, UK (Bown, 1992).

Due to the high permeability of volcanic piles, caves (mainly, lava tubes or collapse cavities) in volcanoes are energetically ventilated. This thermally and wind driven ventilation generally conceal the geothermal gas seeping through the ground from the volcano interior —a convective gas flow of potential use for volcano monitoring and eruption forecasting. Gases making up this volcanic emanation are, among others, CO_2, He and Rn, the latter being by far the most easily amenable to continuous monitoring (Baubron *et al.*, 1991). Any attempt to monitor this flow in a volcanic cave would, in most cases, be hindered by the ventilation of the cave and the meteorological disturbances.

At high latitudes, however, a volcano may present underground cavities with a steady ventilation, driven by a strong heat flow sustaining, throughout the year in the cavity, a temperature above the outdoor temperature. Such is the case of Mt Erebus (77°34' S), Antarctica, the summit area of which accommodates numerous sub-glacial caves, unveiled by conspicuous ice towers, up to ten meters high. These towers are no more than genuine chimneys, made up of congealed steam originating from the melting of glacier ice in contact with the warm volcanic soil.

One of these caves (3700 m a.s.l.) was discovered in 1972 by New Zealander volcanologists (Lyon and Giggenbach, 1974), and mapped two years later (Giggenbach, 1976; see Fig. 1).

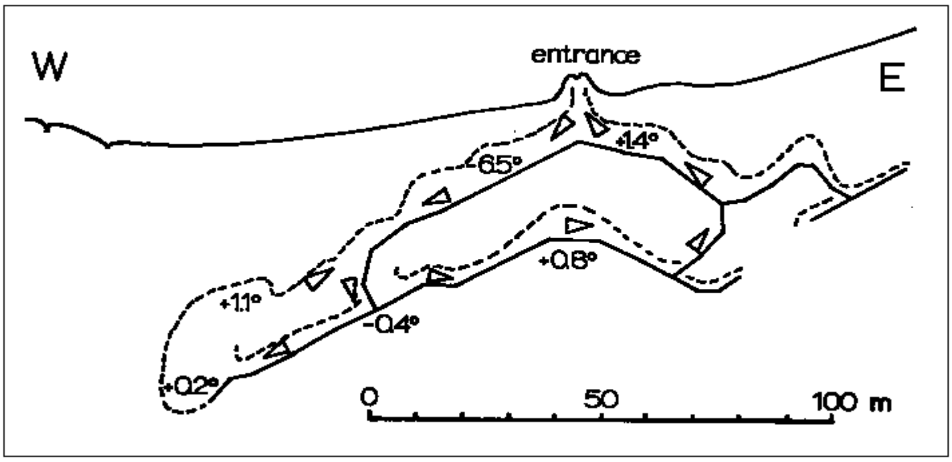


Fig. 1 - Side view of cave from south, with the air flow pattern (arrows). After Giggenbach (1976).

It consists of a 400-meter-long system of branching passages, connecting larger caverns (Fig. 2), with glacier or firn ice at the ceiling, and volcanic ash or lava making up the floor. Cave air temperature, regulated by ice melting, is consistently around the freezing point of water (up to 1.4°C).

Fig. 2 - The large ice cavern below the cave entrance (*Photo*: J.C. Sabroux).

The cave atmospheric radon was sampled for the first time in December 1974, during an international (France, New Zealand and the USA) expedition, leaded by the late H. Tazieff. Scintillating gas flasks, internally coated with zinc sulphide (Pradel and Billard, 1959), were used for both sampling and measurement. Table I displays the mean radon volumic activity of each sample. The values are the expression of the uranium content of the Mt Erebus lava (phonolytic trachyte), of the cave ventilation and, last but not least, of the volcanic heat flow: 11.3 W/m^2, according to Giggenbach (1976), two hundred times the mean geothermal heat flow on the continents.

TABLE I.

SAMPLE	Radon (Bq/m^3)
D107	16 300 ± 960
B81	11 600 ± 780
H81	12 200 ± 810

Table I - Radon volumic activity (in becquerels per cubic meter of filtered air at the sampling altitude), as sampled in a Mt Erebus ice cave on December 15th, 1974. The values (pressure corrected) are the result of several 6 minute-counts of the scintillating flasks by a photomultiplier.

Twenty years later, on the occasion of the 1994-95 cruise of the polar vessel *Antarctica*, commanded by Dr J.L. Etienne, the Mt Erebus ice cave was again visited, and its atmospheric

radon monitored for a few days by means of two automatic probes BARASOL (*Algade*, France), incorporating a silicon detector, a counting unit, and a data storage capability. Such probes are widely used as radon monitors in soil gases, in dwelling basements, or in underground cavities (Trique *et al.*, 1999), all settings in which the radon volumic activity is well above the "normal" outdoor atmospheric radon level (typically, between 5 and 50 Bq/m^3).
The mean radon volumic activity in the Mt Erebus ice cave (see Figure 3) is significantly lower than the level measured twenty years earlier, but at a different location in the cave.

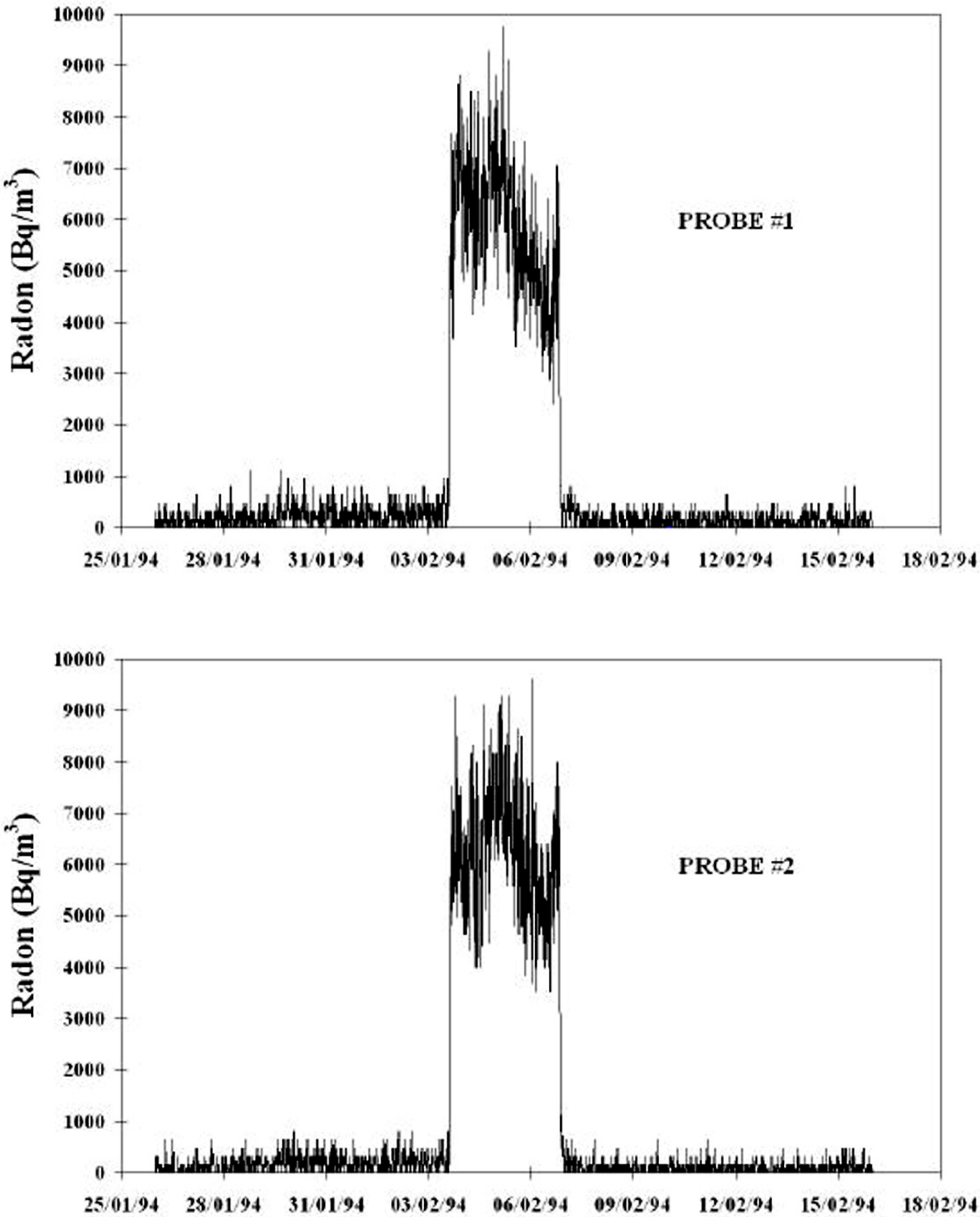


Fig. 3 - Radon measurement in the ice cave of Mt Erebus, Ross Island, Antarctica. The continuously operating probes were installed on February 3rd 1994, and withdrawn three days later. Outside this interval, the probes output is clipped at its background noise (outdoor atmosphere).

The 1994 experiment was too short to allow any correlation between the observed radon level fluctuation and the geophysical activity (not to mention the always possible influence of meteorological variations); yet, it paves the way towards a continuous radon monitoring of the Mt Erebus ice cave atmosphere. The monitoring station would, at least, incorporate several BARASOL probes and an ARGOS radio link. Taking advantage of the high rate of passes of polar orbiting satellites at high latitudes, a battery powered station would be autonomous for the compulsory ten-month or so time interval due to the remoteness of the southernmost active volcano of the world, visited only once during each Antarctic summer.

References

- BAUBRON J.C., ALLARD P., SABROUX J.C., TEDESCO D. AND TOUTAIN J.P., 1991: *Soil gas emanations as precursory indicators of volcanic eruptions.* J. Geol. Soc., London, 148: 571-576.
- BOWN W., 1992: *Cavers risk cancer from underground radon.* New Scientist, 135(1838): 4.
- GIGGENBACH W.F., 1976: *Geothermal ice caves on Mt Erebus, Ross Island, Antarctica.* N.Z. J. Geol. Geophys., 19(3): 365-372.
- LYON G.L. AND GIGGENBACH W.F., 1974: *Geothermal activity in Victoria Land, Antarctica*. N.Z. J. Geol. Geophys., 17(3): 511-521.
- PRADEL J. AND BILLARD F., 1959: *Le thoron et les risques associés dans la manipulation des composés du thorium*. Rapport CEA, R-1165: 44 pp.
- TRIQUE M., RICHON P., PERRIER F., AVOUAC J.P. AND SABROUX J.C., 1999: *Radon emanation and electric potential variations associated with transient deformation near reservoir lakes.* Nature, 399: 137-141.

VULCANOKARST: A ROMANIAN CONTRIBUTION TO SPELEOLOGY

Alexandru Szakacs

Institutul Geologic al Romaniei, str. Caransebes 1, 78344 Bucaresti, Romania
e-mail: szakacs@ns.igr.ro

Abstract

The term vulcanokarst has been introduced in the scientific literature by Naum and coworkers (1962) in a pioneering article published in Romanian entitled “The vulcanokarst in the Calimani Massif (East Carpathians)”. The sense of the term “karst” has been broadened towards the domain of volcanic rocks by this conceptual contribution. The authors describe geomorphologic features observed on volcanic rocks (lava flows and pyroclastics) which they identify with karst. Features belonging to both exokarst (“surface karst” in author’s terminology) and endokarst (“deep karst”) have been recorded. The “surface karst” develops on ancient (ca. 7 Ma old) weathered pyroxene andesite lava flow surfaces and along platy cooling joints by enlargement of fissures and other mechanical discontinuities. Alveolar voids lending a cellular appearance to the rocks - actually gas-escape vesicles of the lava - are mistakenly interpreted as a result of alteration and removal of feldspar crystal. It is disputable to what extent gas-vesicles in lava are enlarged by dissolving action of water. Other surface karst features include “dolinas” 5-7 m across, 2-3 m deep, developed on pyroclastic rocks affected by strong silicic and argillic hydrothermal alteration processes as a result of collapse of the roofs of subsurface voids. "Deep karst" consists of caves encountered in pyroclastic rocks strongly affected by hydrothermal alteration processes. Three main caves - Chaos Cave (48 + 77 m long, up to 6 m high), Chocolate Cave (33 m long, up to 2.5 m high) and Ruins Cave (>60 m long, 3-30 m wide, 2-2 m high) - and their formations have been described in great detail. Spectacular constructional features such as limonite crusts, stalactites, stalactites and draperies, were present in the Chocolate Cave. The origin of the limonite formations is explained by leaching of Fe-rich minerals of the andesite by CO_2-charged infiltration waters, oxidation of Fe^{2+} and its dissolution in the bicarbonate waters, and subsequent deposition of Fe-hydroxide gel by oversaturation and evaporation.

Although more descriptive than explanatory, the paper by Naum et al. (1962) correctly identifies the possibility of karst process development in volcanic rocks. At our present-day knowledge one can explain more accurately the formation of voids by dissolution of volcanic rocks, either lava or pyroclastic in origin, by hydrothermal solutions through acid leaching, using original rock permeability.

Unfortunately, the caves, as the most important testimony of the vulcanokarst at its type locality, described by Naum et al. (1962), have been destroyed during sulfur exploration work in the Calimani Mts. during the 70' s.

Reference

- NAUM T., BUTNARU E., GIURESCU M., 1962: *Vulcanokarstul din masivul Calimanului (Carpatii Orientali)*. An. Univ. Bucuresti, Ser. St. Nat., Geologie-Geografie, 32, p. 143-179

MAIN MORPHOLOGIC FEATURES OF ETNA LAVA TUBES
PRINCIPALI CARATTERI MORFOLOGICI DI TUNNEL LAVICI ETNEI

Sonia Calvari and Alfio Amantia

Istituto Internazionale di Vulcanologia - Consiglio Nazionale delle Ricerche
Piazza Roma 2 - 95123 Catania (Italy)

Several features can be recognised inside lava tubes of Mt. Etna, due to the recent age of the tubes and to the low degree of erosion. Here we present a selection of the best structures, which can have important genetic implications on the mechanisms of emplacement of lava flows and growth of lava tubes (see Calvari and Pinkerton, 1999).

All'interno dei tunnel lavici dell'Etna si riconoscono diverse strutture, spesso peculiari. La copiosità di queste strutture deriva dal fatto che molte grotte sono recenti, e quindi anche poco erose. Presentiamo qui una selezione delle strutture migliori, che diventano molto importanti per le loro implicazioni nella ricostruzione dei meccanismi di messa in posto dei flussi lavici e di formazione dei tunnel lavici (vedi Calvari e Pinkerton, 1999).

Lava stalactites - Stalattiti di lava


Foto 1


Foto 2


Foto 3

Calvari and Pinkerton (1999) have identified four kinds of lava stalactites into Etna lava tubes. Smooth stalactites form by melting of the roof [Photo 1, entrance of the Cassone Cave, 1792-1793 flow field]. Rough and spiky stalactites form by dribbling of lava that filled the tube and then drained, remaining partially attached to the roof [Photo 2, Cassone Cave, 1792-1793 flow field]. Rough, "pull-apart" stalactites form when part of the inner lining drops or rolls off [Photo 3, KTM Cave, 1792-1793 flow field].

Calvari e Pinkerton (1999) hanno distinto quattro tipi di stalattiti di lava nei tunnel lavici etnei. Le stalattiti a superficie liscia si formano per rifusione del tetto del tunnel [Foto 1, entrata della Grotta Cassone, campo lavico del 1792-1793]. Le stalattiti a superficie ruvida e spinosa si formano per gocciolamento della lava dal soffitto quando il tunnel, una volta pieno, viene drenato [Foto 2, campo lavico del 1792-1793]. Le stalattiti "sfilacciate" si formano quando il rivestimento interno dei tunnel si stacca parzialmente [Foto 3, Grotta KTM, campo lavico del 1792-1793].

Lateral benches - Balconate laterali


Foto 4


Foto 5

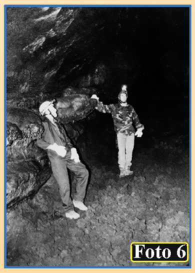


Foto 6

Lateral benches are very common in many caves. They represent a stable lava level, which remained for long enough to allow cooling and lateral solidification. Photo 4 shows asymmetric benches into the Lamponi Cave, 1614-1624 flow field. Photo 5 is taken in the same cave, and Photo 6 shows discontinuous benches thickened by lava splashes, highest part of the Tre Livelli Tube, 1792-1793 flow field.

Le balconate laterali sono strutture comuni in molte grotte. Esse si formano quando il livello della lava nel tunnel rimane alla stessa altezza per un tempo abbastanza lungo da consentirne il raffreddamento e la solidificazione sulle pareti. La Foto 4 mostra balconate asimmetriche nella Grotta dei Lamponi, nel campo lavico del 1614-1624. La foto 5 è stata fatta nella stessa grotta, e la Foto 6 mostra balconate discontinue inspessite da spruzzi di lava, nella parte alta della Grotta Tre Livelli, campo lavico del 1792-1793.

Peeling-off and rolling-over strucutres - Rotoli laterali


Foto 7


Foto 8


Foto 9

The detachment of the inner linings from the walls and roof of lava tubes often forms these cilindrical structures at the margins of the floor. Photos 7 and 8 have been taken in the Cassone Cave, 1792-1793 flow field. Photo 9 is from La Montagnola Cave, 1763 eruption.

Il distacco del rivestimento interno dalle pareti e dal soffitto dei tunnel lavici produce spesso queste strutture cilindriche che si rinvengono ai lati del pavimento. Le Foto 7 e 8 sono state scattate nella Grotta Cassone, nel campo lavico 1792-1793. La Foto 9 proviene dalla Grotta La Montagnola, eruzione del 1763.

Buldges - Protrusioni


Foto 10

Downward directed buldges form at the plastic roof of wide tubes by loading. They are often accompanied by longitudinal cracks (Calvari and Pinkerton, 1999). Photo 10 has been taken into the Cassone Tube, 1792-1793 eruption.

Protrusioni dirette verso il basso sono tipiche di tunnel larghi e sono causate dal carico su un tetto ancora plastico. Esse sono spesso accompagnate da fratture longitudinali (Calvari e Pinkerton, 1999). La Foto 10 è stata scattata nella Grotta Cassone, eruzione del 1792-1793.

Tube coalescence - Coalescenza di tunnel


Foto 11


Foto 12

Vertical tube coalescence is a typical mechanism of reactivation of deeper-level tubes. It is often marked by a key-hole shape of transversal section, such as the example of the Cassone Tube, 1792-1793 eruption [Photo 11]. Horizontal coalescence is rarer, and an example is the Micio Conti Tube into prehistoric, pahoehoe lava flows [Photo 12].

La coalescenza verticale di tunnel lavici è il meccanismo più tipico di riattivazione di tunnel lavici profondi. Spesso viene evidenziata da una sezione trasversale a buco di serratura, come nella Grotta Cassone, eruzione del 1792-1793 [Foto 11]. La coalescenza orizzontale è più rara, ed un bell'esempio è dato dalla Grotta Micio Conti, che si è formata in colate preistoriche a superficie pahoehoe [Foto 12].

Edito e stampato presso il CNR - Area della Ricerca di Catania

IX international Symposium on Vulcanospeleology

"INSIDE VOLCANOES"

CATANIA, SEPTEMBER 11 - 19, 1999

Cultural Center "Le Ciminiere"

SESSION : HISTORY, ARCHEOLOGY, ARTIFICIAL CAVES

" Mompileri " M. Etna, Italy

Regione Siciliana - Assessorato al Territorio e Ambiente
NICOLOSI - Carta Tecnica 1:10.000
Sezione n° 625, Quadro 130 Edizione 1988

Visione del "Santuario di Mompileri ". Sulla sinistra si accede all'ipogeo.

Particolare di colonna all'interno dell'ipogeo con inferriate

ABOUT THE ANCIENT MAIN CHURCH OF MOMPILERI

ANDREA PATTI, FRANCO POLITANO, FABIO SANTONOCITO

Centro Speleologico Etneo, Via Cagliari 15 95127 Catania

ABSTRACT

Aim of the present paper is to get a better historical knowledge about the Church of "Annunziata" in Mascalucia.

According to researches and our studies "in situ", this work try an historical description of the church with a hypothesis of three-dimensional graphic reconstruction of the building and a cartographic localization of the main artificial hollow strictly connected to the church.

The site is the main church of Mompileri, dedicated to "Maria SS. Annunziata", that has very ancient origins: there are historical news about it since the half of the XV century. Its history is tightly linked to the eruptions of the vulcano Etna: the sacred building has been licked up by the lava casting of 1537 and subsequently covered with the country of Mompileri from the eruption of 1669.

Since the beginnings of XVIII century, were builded artificial galleries (Eremita's Cave) in order to reach the rests of the ancient church and subsequentely the famous simulacros.

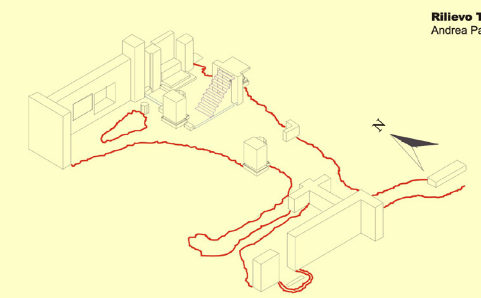
Worthy of mention is the recovery of the cult statue dedicated to the "Madonna delle Grazie" that was discovered, in good condition, under a deep lava layer.

Words key: urban speleology, church, undergrounds, lava eruptions, Mompileri.

PARTICOLARI DI COLONNE (A) E PILASTRI (B) DI ROCCIA LAVICA ALL'INTERNO DEL SITO VULCANOSPELEOLOGICO " Mompileri "

ELABORAZIONE TRIDIMENSIONALE IN CAD DEL SITO VULCANOSPELEOLOGICO " Mompileri "

Rilievo Topografico
Andrea Pati, Fabio Santonocito

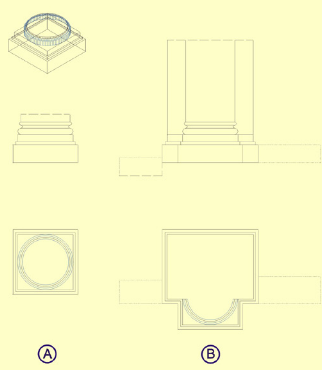


LEGENDA

- Parti strutturali integre
- Parti strutturalidistrutte o inesistenti

Scala 1:100

DISEGNO CAD di Fabio Santonocito 1999



DISEGNO CAD di Fabio Santonocito 1999

[Il Presente Lavoro è stato realizzato a totale carico degli autori]

Grafica & Impaginazione : Fabio Santonocito 1999
Foto : Andrea Patti • Disegni : Fabio Santonocito

IX International Symposium on Vulcanospeleology

"INSIDE VOLCANOES"

CATANIA, SEPTEMBER 11 - 19, 1999

Cultural Center "Le Ciminiere"

SESSION : HISTORY, ARCHEOLOGY, ARTIFICIAL CAVES

" Campanarazzu " M. Etna, Italy

Base cartografica dei tipi della Carta Tecnica Regionale 1:10.000 prodotta dall'Assessorato Regionale Territorio ed Ambiente - Sicilia n. 625130 Gruppo XXIV Prot.10757 del 26 ottobre 1999

Particolare delle colonne calcaree inglobate dalla lava

RESTS OF THE ANCIENT BURIED "CAMPANARAZZU" FROM THE ERUPTION OF 1669

FRANCO POLITANO, FABIO SANTONOCITO

Centro Speleologico Etneo Via Cagliari 15 95127 Catania

ABSTRACT

The paper try to describe a speleological site, called by the inhabitants of Misterbianco: "Campanarazzu". Such site, in the neighbourhood of Catania, was probably so called becouse the big dimensions of the bell tower campanarazzu higher in comparison to the rest of the buildings of the ancient country.

This paper is a contribution to the knowledge of structures that subsequently to lava invasions have been partly destroyed and have preserved some complete undergraund environments.

Some of these enviroments are connected to the surface and hollows the access and the following study within the urban speleology.

In compiling such paper there we are not limited to a description of the speleological site, on the contrary we have performed a photographic relief of a little known parts (like one appreciated column).

We have builded a three-dimensional (3D) model of the ancient church graphically through elaboration CAD (Computer Aidid Design), assigning some explanatory heights (also to the bell tower) in order to have the existing constructive parts jumped from those by now destroyed goings.

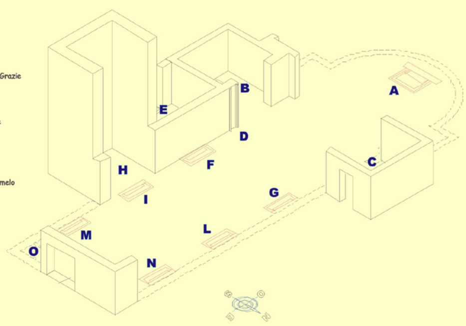
Today, in the Etneos territory are known a few examples with such peculiarities that for their unusual location and constitution they not only reach a national importance, but also are of the international interest.

Words key: urban speleology, archaeology vulcanospeleologica, eruption 1669, lava invasion, underground environments, mother church, Misterbianco.

VISTA TRIDIMENSIONALE DEL SITO VULCANOSPELEOLOGICO " Campanarazzu "

LEGENDA

- A Altare Maggiore
- B Cappella del Crocifisso
- C Cappella della Madonna delle Grazie
- D Colonne e nicchia
- E Locali annessi alla Chiesa
- F Altare di Sant'Antonio Abate
- G Altare di San Francesco
- H Campanile
- I Altare di Sant'Erasmo
- L Altare della Madonna del Carmelo
- M Altare di S. Annunziata
- N Altare di S. Purgatorio
- O Battistero



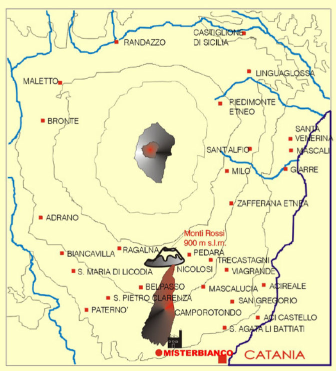
DISEGNO CAD di Fabio Santonocito 1999

LEGENDA

- Parti strutturali integre
- Parti strutturalidistrutte o inesistenti

E' possibile notare tracciati in rosso gli altari, sia secondari, che principali. Sono visibili le strutture ancora esistenti e quelle ormai distrutte dalla lava, durante la grande eruzione del 1669.

LOCALIZZAZIONE DEL SITO VULCANOSPELEOLOGICO " Campanarazzu " , Misterbianco



DISEGNO di Fabio Santonocito, 1999

Grafica & impaginazione : Fabio Santonocito 1999
Disegni : Fabio Santonocito

[Il Presente Lavoro è stato realizzato a totale carico degli autori]

Collateral events

Excursions: some pictures

Excursion B - Caves of Piano Immacolatella, in the territory of San Gregorio di Catania
September 12 1999

General Excursion to the northern flank of Etna and to the crater area
September 15 1999

Excursion C - ÆOLIAN ISLANDS (LIPARI and VULCANO)
September 17-19 1999

INSIDE THE VOLCANO: THE EXHIBITION
(The Caves of Etna)

Vulcanospeleology, i.e. the study of volcanic caves, has an ideal investigational field on Mt. Etna. This mountain, in fact, is an actual crucible of fire and caves, due to its recurrent and mainly effusive activity, with mainly fluid lavas on rather step slopes. The cave formation is therefore recurrent, and hundreds of caves characterise the flanks of the volcano. Every other eruption supplies new caves, often burying the older ones. Tommaso Fazello, a XVI century scholar, defined «*Ætna cavernosa*» the huge, thumping body that generates lava and caves, viz the deep labyrinthic bowels acting as breathing conduits of the volcano, that inhaled «*ventos extraneos*» and exhaled «*exhalationes*».

The exhibition «INSIDE THE VOLCANO» is an excellent introduction to the various faces (vulcanological, archaeological, legendary) of the caves on our volcano. These faces are often fascinating, though rather unknown. Yet their reality is very close to those living in the volcano's shadow, because men's fantasy always gambled with underground mysteries. Furthermore the lava tube formation is also the relentless mechanism by which Mother Nature governs the lava effusions and makes them flow.

The exhibition is segmented into six sections:

- *The Caves of Etna* – an itinerary around the volcano, through a selection of eruption and cave pictures from the archives of Centro Speleologico Etneo.
- *The Prehistory* – a survey organised and arranged by the Superintendence of the Cultural and Environmental Estates (Archaeological Department) of the Province of Catania. The section deals with the exploitation of caves by prehistoric men, from the Neolithic period onwards, for residential, worship and, mainly, burial purposes. The topic is introduced by a scheme of the subsequent prehistoric cultures in the caves of Sicily and of Etna, then a chronicle of the various discoveries is presented, split into phases and areas, as well as an excursus through the most archaeologically significant caves. Special attention is given to «*Grotta Petralia*», discovered a few years ago and holding remarkable traces of its worship and burial exploitation.
- *The Cave of Fingal* – a collection of about forty ancient prints and engravings (kindly lent by the proprietor Società Speleologica Italiana) illustrating a marine volcanic cave in the Scottish island of Staffa, celebrated by writers and musicians. "*The eternal human imaginifique transformed this place into one of the most famous places on Earth*".
- *Travellers* – a trip through memories, supported by the «Riccobono collection» of ancient prints and volumes. The romantic travellers of the XVIII century witnessed, by drawings and reports, their adventurous rove to the top of Etna.
- *Myths and legends* – The section illustrates the fantastic world of local underground myths and legends.
- *The Grotta del Gelo (Cave of Frost) and the Park of Etna* – the last section illustrates the environmental monitoring jointly performed by the Park of Etna and Centro Speleologico Etneo inside the Grotta del Gelo, the outstanding "sick cave" that lost a huge percentage of its ice content in the last decade, for climatic reasons; then an exhaustive portrait of the Park (purposes, boundaries, organisation and activity) is given. In addition some significant crystalline minerals are exhibited, derived from fractioned crystallisation processes inside still hot caves, and some examples of secondary mineralisations (geodes) formed inside small lava hollows.

(*English text elaborated by Giuseppe M. Licitra*)

INSIDE THE VOLCANO: THE BOOK
The Caves of Etna

Centro Speleologico Etneo - Parco dell'Etna - Catania, 1999 - pp. 320 + XXI

Book review by Paolo Forti

The book «*The Caves of Etna*» was presented during the IX international Symposium on Vulcanospeleology (Catania, September 1999). It is a complete monography on the caves of the largest volcano in Europe, and was assembled and coordinated by Centro Speleologico Etneo, that took full care of its writing down and editing, and largely collaborated to its graphic fulfilment, whereas the publication was financed and performed by Parco dell'Etna.

The most skilled, both Italian and foreign, specialists contributed with specific related topics: the book therefore exhaustive deals with the local environment, though it also considers such general arguments, as the volcanic caves in the world and a sketch of the history of worldwide vulcanospeleological explorations. Useless to say that Etna caves are considered in detail, with papers dealing with their genesis, fauna, mineralisations, and hosted prehistoric and historical witnesses. Very interesting sections also deal with the flourishing of legends and with the reports made by ancient travellers, who hazardously roved the volcano slopes for having a look not only at *hell's mouth*, yet even to some small volcanic caves. The main known caves of the volcano have been arranged per their relevant municipal distribution, and exhaustively described, and the actual cadastral files of the area are also reported.

A special emphasis must be focused on the excellent coloured iconography illustrating almost all sections of the volume. Masses of splendid pictures make this volume interesting even for people not concerned with Vulcanospeleology. In other words, this can be surely considered the best popular manual ever published worldwide on volcanic caves. The difficulty of tracing this volume in the usual circuits is its only deficiency, as we argue that the book will not be available via the regular distribution channels. Interested people should therefore apply the publisher Parco dell'Etna (Via Etnea 107/a, I-95030 Nicolosi CT, Italy) for commercial copies, or the author Centro Speleologico Etneo (Via Cagliari 15, I-95127 CATANIA, Italy) for publication exchange.

One copy of the book is also available, for consultation, at the library of Centro di Documentazione Speleologica (Speleological Documentation Centre) «Franco Anelli» of the Italian Speleological Society (Via Zamboni 67, 40100 BOLOGNA, Italy).

(*Originally published in Italian by «SPELEOLOGIA», half-yearly magazine of Società Speleologica Italiana - # 41 year XX, December 1999)*

(English translation by Giuseppe M. Licitra)

Centro Speleologico Etneo

via Cagliari 15 - 95127 Catania

telefax 0039 095 437018

e-mail: cse.mail@tin.it