PROCEEDINGS
of the
19TH INTERNATIONAL SYMPOSIUM ON VULCANOSPELEOLOGY

CATANIA **28**th **AUGUST - 3**rd **SEPTEMBER** 2021

19TH INTERNATIONAL SYMPOSIUM ON VULCANOSPELEOLOGY

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of the

19th International Symposium on Vulcanospeleology

28 August - 3 September 2021

Edited by: Dr Giuseppe Priolo, Dr Roberto Conti, John Brush and Olga Lucherini

Proceedings

of the

19th International Symposium on Vulcanospeleology

Catania, Sicily, Italy

28 August – 3 September 2021

Published by the Organising Committee, 19th International Symposium on Vulcanospeleology for the Commission on Volcanic Caves, International Union of Speleology

The International Symposiums on Vulcanospeleology (ISVs) are held under the auspices of the International Union of Speleology's Commission on Volcanic Caves.

Information about the Commission and past ISVs can be obtained from: www.vulcanospeleology.org

Published February 2023

DEDICATION

This volume is dedicated to the memory of
Roberto Conti who passed away on 23 July 2022.

Roberto lived in Milan in northern Italy and was an active speleo for the whole of his adult life. He joined the Gruppo Grotte Milano while studying at the University of Milan. Some years later, in the late 1970s, Roberto and a few friends founded the Gruppo Grotte CAI Busto Arsizio in the nearby city of Busto Arsizio and he remained a member of the group until his passing.

Roberto was a passionate and enthusiastic member of the UIS Commission on Volcanic Caves and was a strong supporter of the International Symposiums on Vulcanospeleology. He first attended one in 1983. It was the 4th ISV and it was, coincidentally, also held in Catania. For several years up until the time of his death, Roberto was the Commission's Membership Officer.

Behind the scenes, Roberto quietly assisted the Catania-based organisers of the 19th International Symposium on Vulcanospeleology by doing a considerable amount of work over a period of several years. Roberto also laid the groundwork for this Proceedings volume, but passed away before a consolidated draft could be completed.

Roberto will be fondly remembered but sadly missed by all who knew him.

John Brush Giuseppe Priolo

CONTENTS

WELCOME TO CATANIA

Dear friends,

I wish you all a very warm welcome to Sicily, to Catania and to the 19th International Symposium on Vulcanospeleology (ISV).

It has been more than 20 years since an ISV was convened in this historic and dynamic city but over the years, Catania has hosted more ISVs than anywhere else. This is no coincidence.

Catania is draped around the base of Mt Etna, the highest and most active - and also one of the most famous - volcanoes in Europe. The city's culture and history, its geography, its food and wine traditions, and the recreational pursuits of its residents have all been indelibly linked to the vagaries of the omnipotent 'Mungibeddu', as the locals call the mountain. With its dramatic volcanic setting and the welcoming attitude of its residents, it is little wonder that Catania has been such a popular location for ISVs.

Mungibeddu has forged a tenacious resilience into Catanese culture. This determination to bounce back from disappointments and challenges also pervades the Gruppo Grotte Catania (GGC), the organisers and key hosts of this ISV. In the early months of 2020, a series of minor eruptions near the Mungibeddu summit simultaneously excited and worried intending participants and GGC members alike. If the eruptions continued, there was a chance of a spectacular show for visitors but there was also the possibility of impacting on planned excursion activities. The eruptions continued into March, but as the month progressed, members of the GGC and the Commission on Volcanic Caves became more concerned about a different type of eruption; the Corona virus pandemic.

In early April last year with the pandemic rapidly spreading around the world, GGC in consultation with the Commission, bravely decided to postpone the ISV for 12 months. This early decision greatly assisted many intending participants in revising their travel plans. As it happened, staging the ISV in August-September last year would have been impossible. Throughout the remainder of 2020 and into 2021, GGC continued to refine the ISV program and also make modifications in the light of the ever-changing Covid situation and government responses to the pandemic.

On behalf of all ISV participants, I wish to acknowledge the sustained efforts of GGC members to make this 19th ISV a reality. In particular, I thank the key members of organising committee Dr Andrea Belfiore, the GGC Chairman, Dr Carmelo (Mel) Bucolo, the immediate past Chairman of GGC, Dr Giuseppe Priolo and Dr Roberto Conti for their ongoing commitment as events have unfolded over the last three years. Without them, and the wider GGC membership, this ISV would not have been possible.

I sincerely hope that everyone attending the 19th ISV in Catania has an interesting and rewarding time, is able to fully experience the local volcanic terrain and its caves, meets up with old friends, makes many new friends and makes the most of the opportunity to enjoy the local food and wine. On behalf of all Commission members who, because of Covid, are unable to attend in person, I thank GGC for their recent efforts to enable online participation in the symposium program. As I am among the members who would dearly like to be physically present in Catania, but simply cannot because of travel restrictions and vaccine and other Covid-related complications, I will be watching on with interest.

John Brush, Chairman, Commission on Volcanic Caves, International Union of Speleology

Dear caving friends,

As Chairman of the Gruppo Grotte Cai Catania I am pleased to join in the organization of the 19th International Symposium on Vulcanospeleology which will take place in Catania from Saturday 28 August to Friday 3 September 2021.

Sicily is the largest island in Italy and in the Mediterranean; it is a surprising land, rich in history and traditions, in which art and culture are intertwined with a spectacular natural environment. There are many reasons to visit Sicily: a beautiful coast, picturesque fishermen villages, a green and flourishing countryside, high mountains, and impressive volcanoes.

On the eastern side of the island, not far from the strait of Messina, is Mt. Etna, the highest active volcano in Europe. Over the centuries its eruptions have modified the slopes of the mountain, drawing spectacular views of lava and ice, now protected by a vast natural park, open to visitors thanks to countless nature trails.

Mt. Etna is rich both in fracture caves and lava tunnels which were formed during the periods of eruptive activity because of the cooling of the outermost layer of the eruptive flow. The length of the caves varies greatly, from a few metres to over a kilometre. Many of the horizontal caves can be visited easily. When you visit a cave, besides the excitement of descending into the "underworld" of the volcano, you can also understand some of its dynamics and some of its interesting features. Mt. Etna and its caves are waiting for you to surprise you with the wonders of our island. The coronavirus (SARS -CoV-2) has changed our daily habits, like a hug or a handshake. I hope that this Symposium, in addition to being an international event, can also be the dawn of a new period of normality in which warm human relations are re-established.

Our caving group is doing its best to make this happen and we are confident that the bad times will be over soon.

Belfiore Andrea

Dr Andrea Belfiore
Chairman, Gruppo Grotte Catania

UNIVERSITÀ degli STUDI di CATANIA

Ladies and gentlemen, dear participants,

It is with great pleasure that, on behalf of the Rector of the University of Catania, we welcome all of you to the XIX Symposium on Volcano-Speleology.

A special thank goes to Dr Giuseppe Priolo for inviting us and for all efforts made for organizing this important international meeting whose success is also testified by the great number of participants.

We are really honoured that Catania, which hosts the oldest Sicilian university and is located at the foot of the highest active volcano in Europe, was enthusiastically chosen as the organization committee.

This conference is an important opportunity for many researchers from all over the world for comparing and sharing their knowledge on several topics, particularly interesting for the volcanological and speleological scientific community.

Finally, Mt. Etna and the old city of Catania are waiting on you for a visit. We hope that your stay in Sicily will be great, and we are sure that the meeting will be fruitful.

Thank you-all for your participation and enjoy the meeting and the city as well.

Rosolino Cirrincione

Carmelo Ferlito

Gian Pietro Giusso del Galdo

Carmelo Monaco

SYMPOSIUM PROGRAM – SUMMARY

SATURDAY AUGUST 28TH

Afternoon Opening of the exhibition:
“The Fingal cave, between history and legend”

SUNDAY AUGUST 29TH

All day **PRE-SYMPOSIUM EXCURSION**: MT. ETNA GEOLOGY an overview of the volcano guided by a geologist, with stops at the most significant points (all day).

Evening **Welcome party** (Scammacca’s Farm)

MONDAY AUGUST 30TH

Morning **Symposium opening and institutional work sessions**
(University of Catania – Geological Faculty)

Afternoon **Catania’s natural and cultural heritage**
Katane: the Greek and Roman city (guided trip)

Evening **Recent discoveries** video presentations (GGC Arena)

TUESDAY AUGUST 31ST

Morning **Symposium lectures & work sessions**
(University of Catania – Geological Faculty)

Afternoon **Catania’s natural and cultural heritage**
The City revives after the 1693 earthquake & the “Catanese” Baroque

Evening **Participants’ video or slide** contributes (GGC Arena)

All day **Taormina and Alcantara Gorges** Guided tour

WEDNESDAY SEPTEMBER 1ST

Morning **Lectures and conclusion of work sessions**

Meeting of the UIS Commission
(University of Catania – Geological Faculty)

Afternoon **Catania’s natural and cultural heritage**
Historical Museum of the Landing in Sicily 1943 and Cinema Museum, or
Guided tour of the Botanical Garden.

Evening **Gala Banquet** in a typical Sicilian restaurant

All day **Syracuse and Noto** Guided tour

THURSDAY SEPTEMBER 2ND

All day **GENERAL EXCURSION** – Visit of the “**Valle del Bove**” (for all participants).

Evening **Sicilian “granita” time (**GGC Terraces)

FRIDAY SEPTEMBER 3RD

All day **CAVES OF MT. ETNA** – **Visit to some of Etna’s caves.**

“The Fingal cave, between history and legend”

Evening **Closing ceremony and Farewell party** (GGC Terraces).

ORGANISING COMMITTEE

Prof. Gianpietro Giusso del Galdo[1]

Prof. Rosolino Cirrincione[1]

Prof. Carmelo Monaco[1]

Dr Roberto Conti[2]

Mr. Umberto Marino[3] (Chairman CAI Catania)

Dr Giuseppe Priolo[4] (Chairman CAI CCST)

Dr Andrea Belfiore[5] (Chairman GGC)

SCIENTIFIC COMMITTEE

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Prof. Rosario Grasso

Prof.ssa Emilia Poli Marchese

Prof. Blasco Scammacca

Dr PhD Salvatore Caffo[6]

EXECUTIVE COMMITTEE

Dr Carmelo Bucolo

Dr Roberto Conti

Prof. Carmelo Ferlito

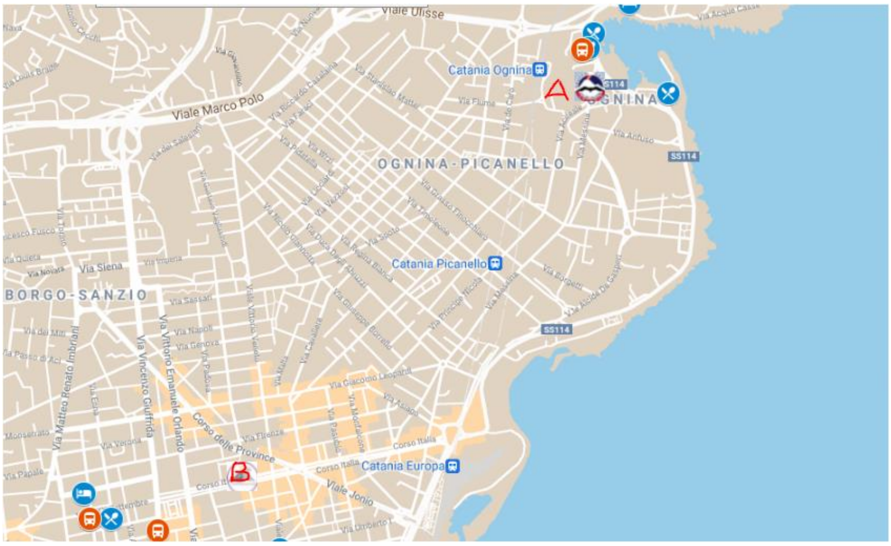
Dr Giuseppe Priolo

[1] Università degli Studi di Catania (UNICT)
[2] Commission on Volcanic Caves, International Union of Speleology (CVC UIS)
[3] Club Alpino Italiano – Sezione dell'Etna (CAI Catania)
[4] Club Alpino Italiano – Commissione Centrale Speleologia e Torrentismo (CAI CCST)
[5] Gruppo Grotte Catania CAI Sezione dell'Etna (GGC)
[6] Parco dell'Etna – Volcanologist Manager.

LOCAL INFORMATION

Catania was founded in the 8th century BC by Chalcidians, a Greek population coming from Thrace. In 1434, the first university in Sicily was founded in the city. In the 14th century and into the Renaissance period, Catania was one of Italy's most important cultural, artistic and political centres.

The city is well known for its history, culture, architecture and gastronomy. Its old town, on account of its spectacular baroque architecture, is a World Heritage Site, protected by UNESCO.



City of Catania (Ognina department).

On this page you can find city maps showing the places connected with the Symposium.

A GGC HEADQUARTERS

CLUB ALPINO ITALIA – Sez. ETNA / GRUPPO GROTTE CAI CATANIA

Via Messina 593 a - Ognina - Catania CT

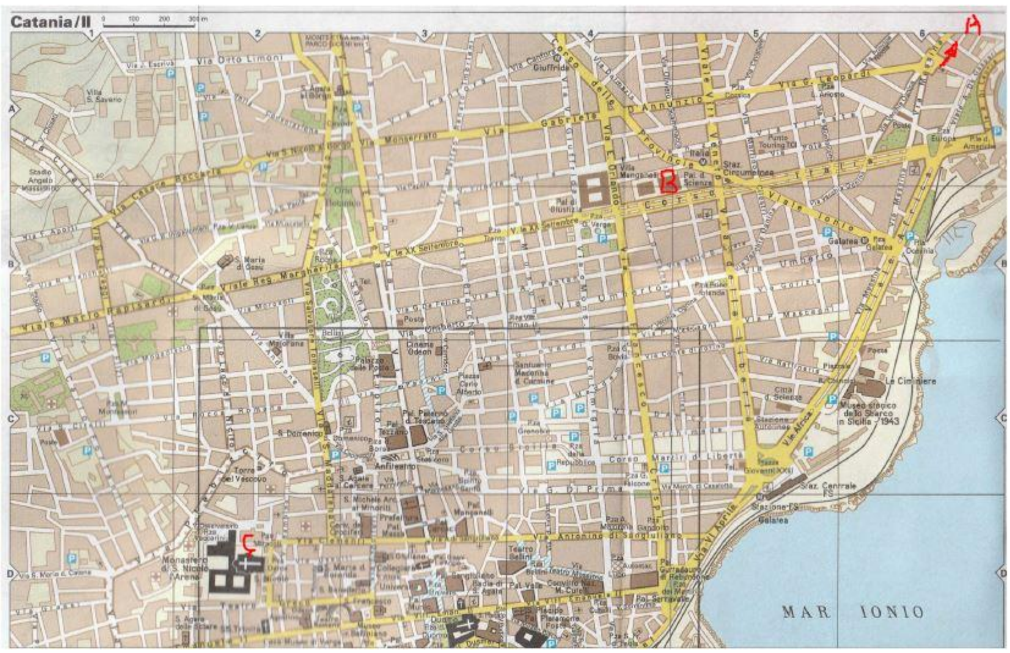
B SYMPOSIUM VENUE (CATANIA UNIVERSITY)

Università di Catania – ex Department of. Science, Corso Italia, 55 - Catania CT

C EXHIBITIONS (SAN NICOLO' L'ARENA)

Chiesa di San Nicolò l'Arena

Piazza Dante Alighieri, 12 - Catania CT



Town centre map.

EXHIBITIONS

EXHIBITION 1

Fingal's Cave, between history and legend

During the annual meeting of the Italian Speleological Society held on November 27th 2020, Michele Sivelli, trustee of the Franco Anelli Italian Speleological Documentation Center at the University of Bologna (in short, the Center), announced the acquisition of a very rare volume, dating from 1831, dedicated to the cave of Fingal.

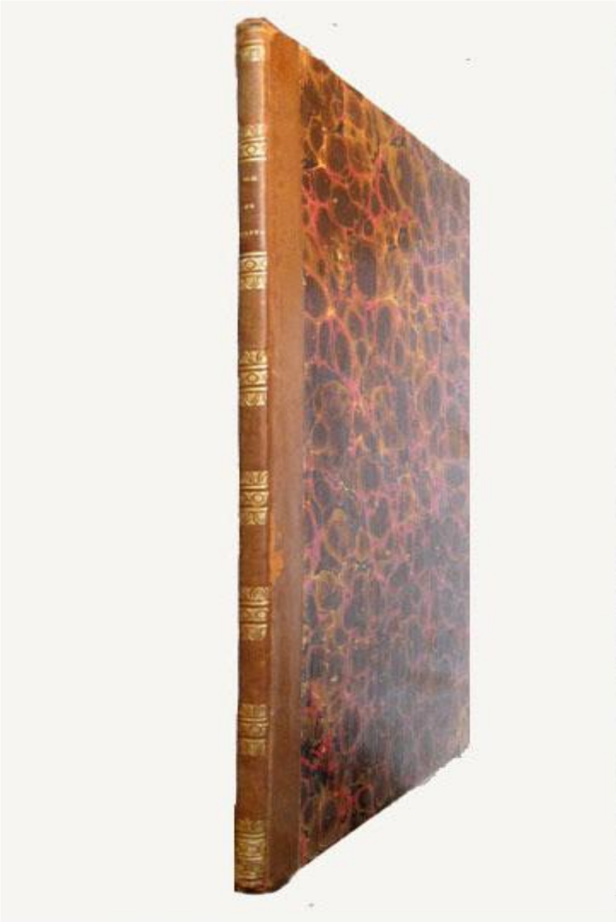
The title of the book is *L'Ile de Staffa et sa grotte basaltique by Panckoucke CLF, Paris 1831*; it is a book completely dedicated to the cave, illustrated by large engravings (see Figure 1), that was published in Paris in the same year in which the great English painter William Turner completed the famous painting that made this cave famous all over the world.

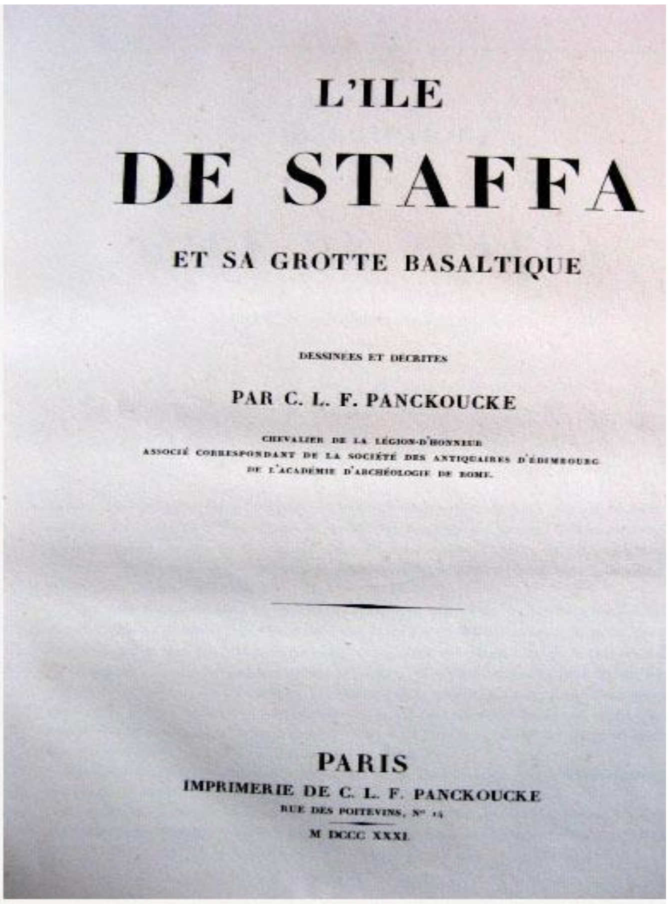
Due to its resemblance to the "Grotta delle Colombe" near Aci Trezza, today destroyed by storm surges, the Fingal cave had already been mentioned in 1999 during the 9th International Congress on Volcanospeleology, in Catania, in two presentations by Giuliano Perna and Giancarlo Santi. For the next edition of the Symposium, the Center is planning to prepare an iconographic exhibition on this cave, the most represented in the world, on which the Library in Bologna has several publications and a vast collection of splendid antique prints, and now also the very rare book that more than any other describes it from a historical and iconographic point of view. The inauguration will be attended by Professor Paolo Forti, former director of the Center, who has worked hard to reach the acquisition of the very rare volume.

As many of you will remember, Fingal's Cave is located on the Isle of Staffa off the coast of Scotland. The main feature of this cave is that it has been completely excavated in the columnar basalt by the incessant action of the sea that developed a sub-horizontal floor, consisting of the bases of the truncated and removed columns, just above the current high tide level. It is therefore a small coastal cavity, like many others all over the world, yet, as Professor Forti wrote in an article of the year 2000 in the magazine "*Speleologia*" the eternal human imagination has transformed it into one of the most famous and well-known in the world ". The first description of the island of Staffa and the Cave of Fingal was made by the naturalist Joseph Banks, who became famous for following Captain Cook on his first tour around the world between 1768 and 1771. Not only explorers or scientists visited Staffa and its caves, but also great writers and poets like the writer Sir Walter Scott who went to Staffa in 1810 and 1814 and dedicated a poem to the island and the cave of Fingal. Also, Queen Victoria entered the Fingal Cave in 1847, with the royal family and all the retinue, and left a passionate description of the cave in her diary. Giulio Verne visited Staffa in 1859 and, a few years later, set one of his novels (The green ray) there. Although it was probably the most famous and well-known cave of the time, very few visitors had the opportunity to see it directly on account of the difficulties of docking: as a matter of fact, the stormy sea prevents visitors from reaching the island of Staffa for many months a year. This is probably the reason why this cave has become the most represented through prints and paintings; the very famous one by the great English painter William Turner, dated 1831, was completed in the same year of the publication of the ancient volume just purchased by the Center.

Together with this rare book, many other rare "pieces" that are in the availability of the Franco Anelli Italian Speleological Documentation Center were on show in the exhibition set up for IVS19. The visit was free for all participants of the Symposium.

Roberto Conti





L'ILE

DE STAFFA

ET SA GROTTE BASALTIQUE

DESSINÉES ET DÉCRITES

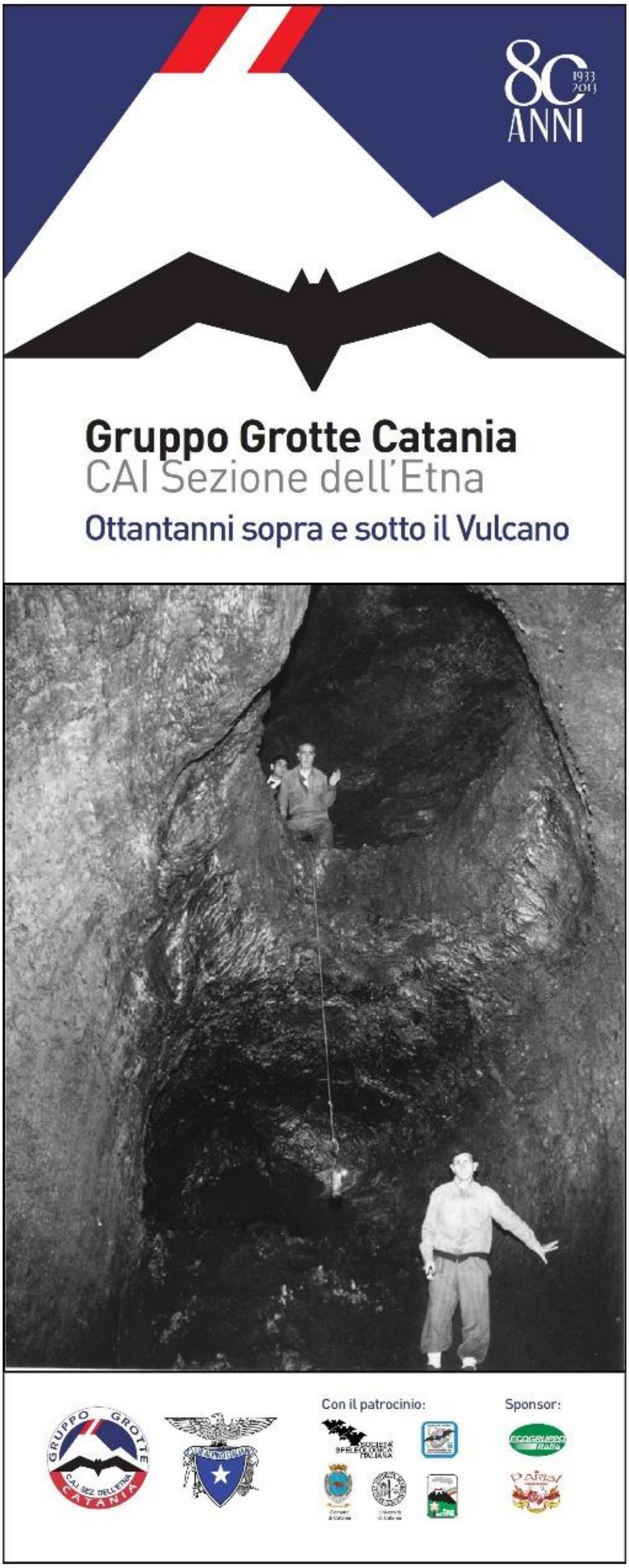
PAR C. L. F. PANCKOUCKE

CHEVALIER DE LA LÉGION-D'HONNEUR
ASSOCIÉ CORRESPONDANT DE LA SOCIÉTÉ DES ANTIQUAIRES D'ÉDIMBOURG
DE L'ACADÉMIE D'ARCHÉOLOGIE DE ROME.

PARIS
IMPRIMERIE DE C. L. F. PANCKOUCKE
RUE DES POITEVINS, N° 14.
M DCCC XXXI

EXHIBITION 2

Gruppo Grotte Catania, 80 years of Speleology



Speleology in Catania was born in the last year of the 19th Century.

The historical archive of the Catania CAI section preserves some documents of its origin.

But the history of the Grotte Group begins with the work of Francesco Miceli: the first document is dated 1933.

The exhibition told this story with a collection of images and documents, from 1933 to this day.

EXHIBITION 3

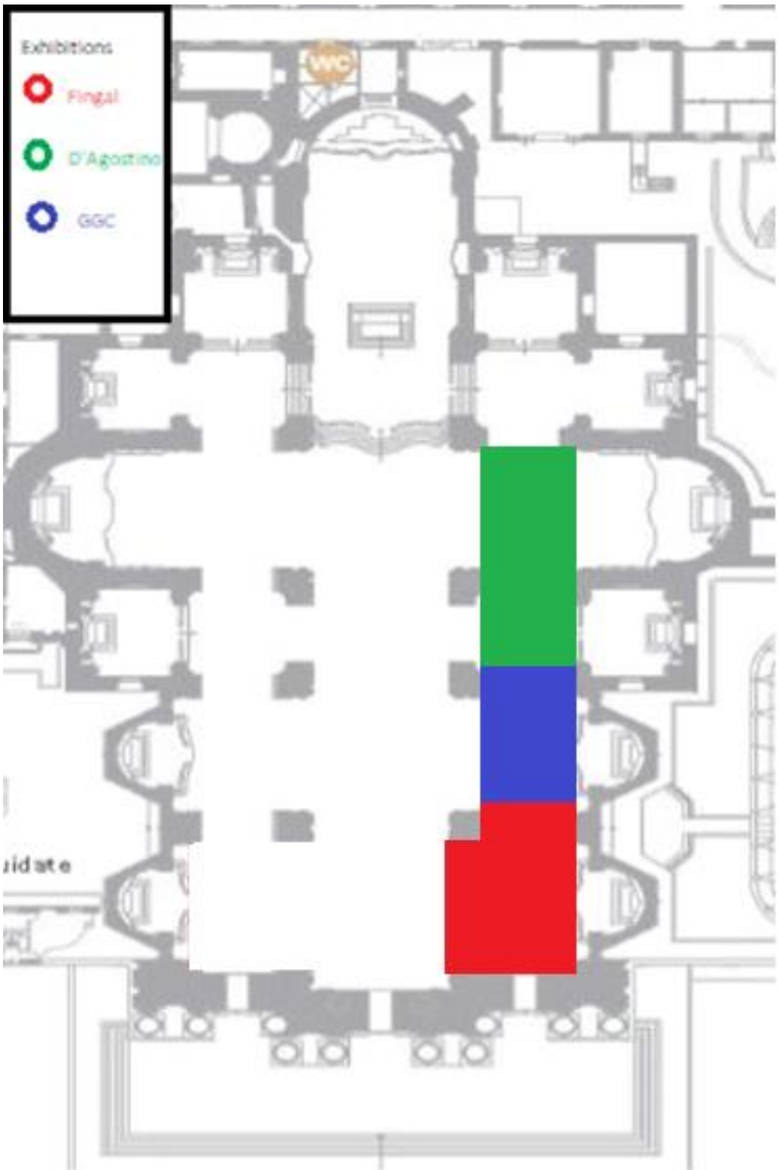
Personal exhibition of Prof. Carlos D'Agostino.

Carlos D'Agostino was born in Argentina and in that part of the world he learned about Speleology.

His paintings, made with different techniques, are full of his love for nature. Etna is one of the nymphs that inspired him.

During the period of the exhibition the author made some portraits of the visitors.

Exhibitions Map



PRE-SYMPOSIUM EXCURSIONS

SUNDAY AUGUST 29TH

PRE-SYMPOSIUM EXCURSION: MT. ETNA GEOLOGY an overview of the volcano guided by a geologist, with stops at the most significant points

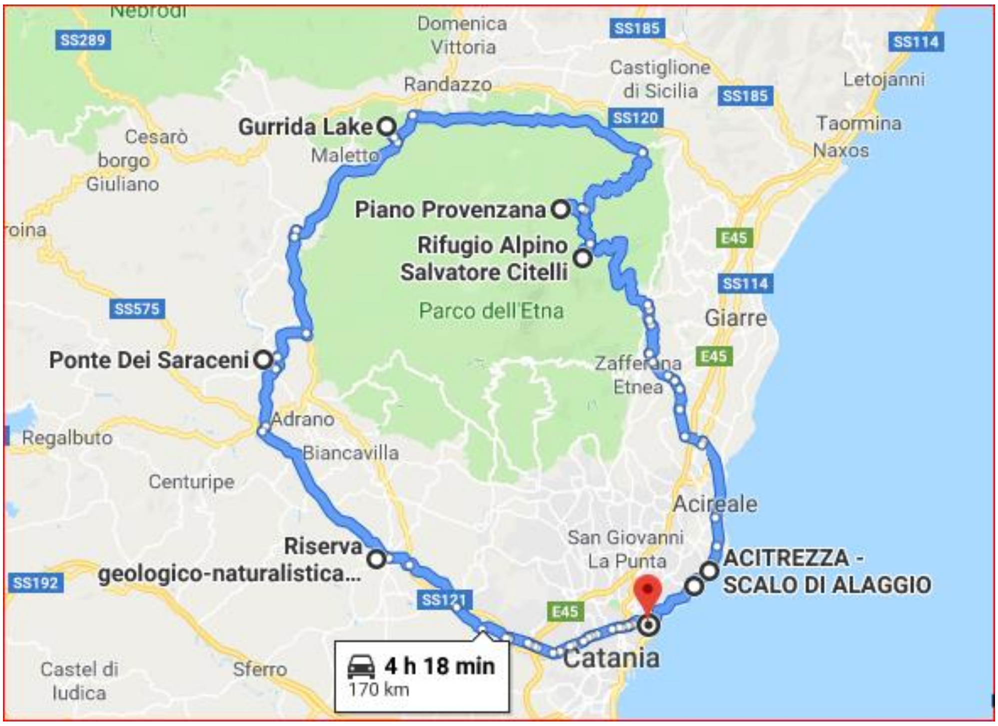
WELCOME PARTY (Scammacca's Farm)

EXCURSION
GEOLOGICAL TOUR OF MT. ETNA

The purpose of this excursion was to provide participants with a first-hand geographical and geological overview of the Etna volcano. The excursion was led by the senior geologist Dr Giuseppe Priolo and lasted a whole day.

It comprised a circular minibus tour on the mountain slopes (see following map), that stopped at the most significant points in the history of volcano eruptions.

Lunch was included in a typical mountain lodge; and the group returned in time to attend the welcome party.



Geological Tour of Mt. Etna, route.

EXCURSION OUTLINE

1st geological stop

Acicastello and Acitrezza: the first time of Etna, submarine eruptions and oldest Etna's activities.

1st gastronomic stop

Zafferana Etnea: a typical Etna's snack.

2nd geological stop

Piano Provenzana, Linguaglossa: Etna, the 2002 eruptive theatre, lava flow and secondary cones.

2nd gastronomic stop

Rifugio Citelli, Sant'Alfio (www.rifugiocitelli.it): lunch on the edge of a crater rim.

3rd geological stop

Gurrida lake, Randazzo: it was created when an eruption of Etna in 1536 blocked part of the course of the Flascio river.

4th geological stop

Simeto lava gorges and Saracen's bridge, Adrano: an ancient bridge climb over the lava riverbed of Simeto river.

5th geological stop

Salinelle dei Cappuccini, Paternò: the Etna secondary volcanic activity: small mud volcanoes on the slopes of Mt. Etna.

STOPS DETAILS

1st geological stop: We went to the City Hall square and visited the Castle area. We saw the primary Etna's activity: submarine eruptions, pillow lava, hyaloclastite and the filonian intrusion born of the submarine eruption.

Acicastello, the castle on the volcanic rock (ph. R. Conti, 2021).

With the minibus from Acicastello to Acitrezza (10') for observing the Ciclopi (Cyclops) Islands with the very interesting columnar basalt and the white clay cap on the Lachea Island.

The volcanic rocks are dated 600.000 years ago, the clays called "Argille azzurre" are dated to the Plio-Pleistocene, they were "cooked" by the lava and remodelled by the tectonic activity of the area.

1st gastronomic stop: On the minibus, from Acitrezza to Zafferana Etnea (30-40 minutes), we made a short stop for taste a typical fried pizza: the "Siciliana" (wheat flour, sheep cheese, salted anchovies, olives).

2nd geological stop: On the minibus, from Zafferana Etnea to Piano Provenzana. We visited the eruptive scenario of 2002: we will observe the eruptive fracture and the lava flow that destroyed the tourist station. The 2002 eruption was famous for the biradial eruptive activity: the South and North side of Mt. Etna were simultaneously involved from the crater's activity and several precursory phenomena (earthquakes, soil fractures).

2nd gastronomic stop: On the minibus, from Piano Provenzana to Rifugio Citelli. We had lunch with a typical dish of the Sicilian mountain. The Rifugio Citelli is one of 774 refuges and huts that the CAI (Club Alpino Italiano) have in Italy.

Piano Provenzana, 2022 lava flow (ph. G. Priolo, 2021).

3rd geological stop: On minibus, from Rifugio Citelli to Gurrida Lake. The Gurrida Lake is a unique element inside Etna Park. It is the only wet area near the volcano. Here visitors can admire many migrating birds, especially during winter and spring. The lake is seasonally fed by the Flascio stream, a small river that throughout the centuries has been a tributary of alternately, the Simeto or Alcantara rivers, until the 1536 eruption blocked its flow. This caused the formation of the Gurrida Lake.

4th geological stop: This stop was to see the old bridge made by the Arabic people during the occupation of Sicily. The bridge crosses the Simeto river that in this area runs in the andesitic rocks of Etna's oldest lava flow.

Salinelle dei Cappuccini (ph. G. Priolo, 2014).

5th geological stop: in the Est area of Paternò, an important town in the Catania Metropolitan District, we observed two important morphologies: the Paterno's Nec, born by old and peripheral activity of Mt. Etna and the volcanic mud fields called "Salinelle dei Cappuccini". The Paternò's Nec is an andesitic intrusion exposed from erosion and landslides. The "Salinelle dei Cappuccini" are a secondary episode linked to the H_2O and CO_2 ascent reheated to the Etna's magma. The fluids acquire the clay to the sedimentary basement of Etna's area. When the fluids are exposed deposit the clay and the hot H_2O, boiling made the typical morphologies.

End: the tour ended at the GGC Headquarters.

Arabian bridge on Simeto river (ph. R. Conti, 2021).

SCAMMACCA’S FARM

The Scammacca's Farm is a typical example of Catania farm. The old building (A.D. 1710) dominates the citrus plots and other crops.

Blasco Scammacca (www.blasco.scammacca.name): speleologist, diver, professor at Catania University, was very happy to host the welcome party of the Symposium.

The menu of the party was based on typical Sicilian dishes, cooked by Fratelli Vescera srl (www.francescovescera.it) accompanied by the wines of Mandrarossa (www.mandrarossa.it), that successfully aimed to make participants fall in love with Sicilian aromas and flavours.

Menù

Powered by Fratelli Vescera srl, sponsor of Symposium:

- Cous with vegetables
- Cudduruni (stuffed pizza with vegetables and other ingredients)
- Pizza

Wine

Mandrarossa wine by sponsor Cantine Settesoli:

- Chardonnay
- Zibibbo
- Perricone
- Syrah
- Nero d’Avola

MANDRAROSSA
LA SICILIA CHE NON TI ASPETTI

Welcome party at Scammacca’s farm (ph. R. Conti, 2021).

THE SYMPOSIUM

INTRODUCTION

The 19th ISV took place in the prestigious setting of the University of Catania, in the middle of the city.

The lectures were held in the building of the geological Faculty starting at 9 O'clock from Monday August 31 to Wednesday September 2.

On Wednesday, at the end of the lectures, in the same room there was the annual meeting of the UIS Commission on Volcanic Caves.

All the work sessions and the commission meeting have been placed via web link with all those who have registered as online members.

The official language of the Symposium was English.

A symposium work session at Catania University (ph. G. Priolo, 2021).

SYMPOSIUM DAY 1, MONDAY 30 AUGUST

OPENING SESSION OF THE SYMPOSIUM

PROGRAM

Opening of the Symposium (George Veni, Roberto Conti and John Brush).

Evolution of Lava tubes (S Kempe).

Geology of the Etna Volcano (C. Ferlito).

OPENING ADDRESS

JOHN BRUSH

President, UIS Commission on Volcanic Caves

Distinguished guests, Commission members, ladies and gentlemen. Good morning to you all and especially to our guests Professor Del Gaddo, Signora Mirabella and Dr Lo Cascio.

Welcome to the 19th International Symposium on Vulcanospeleology – or more simply, ISV19. I understand Mt Etna has already welcomed the ISV participants to Sicily. It gives me great pleasure to speak to you today, no matter where you are.

I dearly wish that I was able to be with you in Catania to mark this important occasion. Speaking to you now, indeed participating in the whole symposium in this manner, is a very poor substitute for being physically present in Sicily. Unfortunately, for many of us this is our only option. In Catania today there are participants from Italy, the Netherlands, Germany and the United States. We also have online participants from those 4 countries, as well as from Iceland, the United Kingdom, Ecuador, Japan, Vietnam, New Zealand and of course, from here in Australia.

I extend a very warm welcome to you all. In doing so, I wish to make special mention of our friends in Vietnam as this is the first time anyone from that country has participated in an ISV.

ISV19 has been organised by the Gruppo Grotte Catania (GGC) under the auspices of the Commission on Volcanic Caves. The Commission started as a small international group of people who shared a common interest in volcanic caves. That was in 1972.

In 1993, the group achieved full commission status within the International Union of Speleology and since then, ISVs have been held every two years - approximately! The ISVs are the Commission's most important activity.

This is not the first ISV in Catania. In fact, more ISVs have been held in Catania than anywhere else. This is not surprising. The Catanese people are warm and welcoming and Catania sits at the foot of one of the most active volcanoes in Europe. Mt Etna is also the highest volcano in Europe and there are many cave entrances on its slopes.

Catania's long history, its culture, its local produce and the interests of many of its residents are indelibly linked to the vagaries of the volcano. Living so close to Mt Etna, the local people have a tenacious resilience. And that strength of character extends to GGC members and it has been essential for ISV19.

In 2018 when GGC took on the challenge of organising this ISV, little did it know - little did any of us know - how much the world would change because of a virus. In April last year, GGC wisely decided to postpone for 12 months. Covid-19 remains with us and GGC has faced many difficulties in making it possible for you to participate in the ISV in Catania or from your home.

I acknowledge GGC's sustained efforts on the symposium. In particular, I thank key members of the organising committee, Mel Bucolo, Andrea Belfiore and especially Giuseppe Priolo and Roberto Conti for their efforts over the last three years. These people and the wider GGC membership have made it all possible.

In concluding, let me say it is my sincere hope that everyone participating in ISV19 has an interesting and rewarding time.

In addition, for those of you in Catania, I trust that you are able to renew old friendships, make new friends, become more familiar with Mt Etna and its caves and fully embrace the local food and wines. That is your duty to all the online participants.

SYMPOSIUM DAY 1, MONDAY 30 AUGUST (continued)

PAPERS

Session 1: Rheology and Geomorphology of volcanic caves

The Grotta del Gelo (Etna): a volcanic cold trap ice cave (Gaetano Giudice, Francesco Leone, Luca Randazzo, Guido Raciti, Marianna Messina, Salvatore Petralia, Elvira Finocchiaro).

*Estimation of the formation temperature of lava stalactite inside the cavity of lava tree mould (*Tsutomu Honda).

Grotta del Gelo, Mt. Etna (Photo: Scammacca, 1971.

The Grotta del Gelo (Etna): a volcanic cold trap ice cave

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Abstract

The Grotta del Gelo is probably the best known volcanic cave of Mount Etna because of the fascination exercised on visitors by the perennial ice inside it, rather unusual at its latitude and in strong contrast with the arid environment of the large lava field in which it opens. A very popular destination for hikers, with the increase in visits has also grown the concern of environmentalists and scientists for the effects of human presence on the conservation of the glacial mass. The variability of the seasonal phenomena of glacial speleothems formation and fusion and the lack of systematic instrumental observations of the ice mass evolution have given rise, over time, to the belief that the ice mass end was forthcoming. In 1981 the cave was at risk to be covered by a lateral eruption and, being in the neighbours of the area where the eruptive fissures opened, it is plausible that the cave was interested by an increase in geothermal flow and that the qualitative observations, reporting the partial melting of the ice mass, were correct. Instrumental studies have begun since the 1990s and, through various phases, the number of measured parameters has increased, up to the monitoring carried out since the end of 2013, employing staff, equipment, and instruments of CSE and INGV. Thanks to the agreement signed between Ente Parco dell'Etna and Centro Speleologico Etneo in 2017, additional instrumentation requirements were met, and the monitoring activity is still carried on.

Since the end of 2013 temperatures inside the cave and externally near the entrance were monitored continuously, even with some limitations caused by faulty sensors. Each year from spring to autumn, the evolution of the glacial surface was monitored systematically, and a meteorological station was placed in the neighbourhood of the cave to collect rain, wind, and barometric data beyond the temperature. After seven years of monitoring a preliminary analysis of data allows to confirm the cold trap model for the dynamic of ice formation and the role of autumnal rainfalls as the main cause of ice melting. It results in an average loss of ice at a rate of about 6 m^3 per year with one exceptional build up event in the 2014 Winter and increasingly destructive events in the recent Autumns.

Even if the results suggest that the glacial deposit is mainly endangered by meteorological changes caused by global warming, the exhortation is that hikers approach the visit to the cave in the most respectful way to avoid contributing to acceleration of the ice melting.

Riassunto

La Grotta del Gelo è probabilmente la più nota grotta vulcanica dell'Etna per il fascino esercitato sui visitatori dalla presenza di ghiaccio perenne al suo interno, piuttosto insolito alla sua latitudine ed in forte contrasto con l'ambiente arido del vasto campo lavico in cui si apre. Meta molto ambita per gli escursionisti, con l'incremento delle visite è cresciuta anche la preoccupazione di ambientalisti e studiosi per gli effetti della presenza umana sulla conservazione della massa glaciale. La variabilità dei fenomeni stagionali di formazione e fusione degli speleotemi glaciali e la mancanza di osservazioni sistematiche strumentali sull'evoluzione della massa glaciale hanno contribuito a far sorgere, nel tempo, la credenza che la fine della massa di ghiaccio fosse imminente. Nel 1981 la grotta rischiò di essere coperta da un'eruzione laterale le cui fratture eruttive si aprirono nell'area circostante. In quella occasione può avere risentito di un incremento del flusso geotermico e quindi le osservazioni qualitative di un parziale scioglimento del ghiaccio potrebbero essere state fondate. Studi strumentali sono cominciati a partire dagli anni Novanta e, attraverso varie fasi, si è incrementato il numero di parametri misurati, fino al monitoraggio condotto a partire da fine 2013, impiegando personale, mezzi e

strumentazione di CSE e INGV. Grazie alla convenzione sottoscritta tra Ente Parco dell'Etna e Centro Speleologico Etneo nel 2017 si è fatto fronte a ulteriori esigenze di strumentazione e l'attività di monitoraggio continua ad essere condotta sino ad oggi.

Dalla fine del 2013 la temperatura all'interno della grotta ed esternamente nei pressi dell'ingresso è stata monitorata con continuità, seppure con qualche limitazione dovuta a guasti dei sensori. Inoltre, ogni anno, dalla primavera all'autunno, l'evoluzione della superficie glaciale è stata monitorata sistematicamente e una stazione meteorologica è stata posizionata nelle vicinanze della grotta per raccogliere i dati di piovosità, vento, umidità e pressione oltre alla temperatura.

Dopo sette anni di monitoraggio una analisi preliminare dei dati permette di confermare il modello a trappola fredda per la formazione del ghiaccio e il ruolo delle piogge autunnali come principale causa della fusione del ghiaccio. Risulta una perdita media di ghiaccio ad un tasso di circa 6 m^3 l'anno con un evento eccezionale di incremento della massa glaciale nell'inverno del 2014 e una serie di eventi sempre più distruttivi negli autunni recenti.

Anche se i risultati sembrano indicare che il deposito glaciale è prevalentemente messo a rischio dai cambiamenti meteorologici causati dal riscaldamento globale, l'esortazione agli escursionisti è che si accostino alla visita nella maniera più consapevole e rispettosa per evitare di contribuire ad accelerare la fusione del ghiaccio.

Key words: Grotta del Gelo, ice, freezing, melting, cooling, monitoring.

Introduction

The Grotta del Gelo is probably the most famous known volcanic cave of Mount Etna, visitors are attracted by the perennial ice inside it, rather unusual at its latitude and in strong contrast with the arid environment of the large lava field in which it opens and is currently a very popular destination for hikers. This publication illustrates the results of the five years monitoring from December 2013 to December 2018. Before describing the monitoring and its results we give a synthetic description of the *Grotta del Gelo* and its environmental framework, the minimal theoretical background to understand the ice cave and an account of the previous monitoring.

Environmental description

The *Grotta del* Gelo is a lava tunnel in the lava flow of the 1614-1624 eruption (see Figures 1 & 2), the one of greatest duration in the historical period, during which it is estimated that about 1Gm of effusive material poured over a surface of approximately 21km^2 between altitude 2550 m and 1400 m of the northern side of Etna (Romano and Sturiale, 1982). The long duration of the eruption has caused the lava flows to overlap in a complex way, moreover it has produced pahoehoe lavas, unusual for Etna's eruptions, which have created a series of peculiar morphologies both on a medium-large scale, with the formation of mounds and mega-mounds, and on a small scale with the typical rope-like morphologies and the formation of laminar cavities below the surface. The characteristic noise that is produced by walking on these surfaces, due to the reverberation of the sound in the voids below, analogous to that produced when walking on the roofs, is the origin of the name of lava of the "Dammusi" popularly given to this lava flow. Four more lava tunnels of large dimensions are known in this lava flow: the *Grotta del Diavolo* (at 2400 m of altitude asl), the *Grotta del Lago* (2200 m), the *Grotta di Aci* (2000 m) and the *Grotta dei Lamponi* (1700 m), and just over fifteen smaller caves at altitudes below 1800m The *Grotta del Gelo* opens at an altitude of 2045 m, in the integral reserve area of the Park (see Figure 1), it is accessible through a collapse of the roof and the tunnel extends approximately northwards for about one hundred metres. The entrance is a declivity of about 30 m consisting of the accumulation of collapsed material from the vault and subsequent pyroclastic deposits. In winter the snow can completely block the entrance and depending on the intensity of the snowfall and the weather conditions in the following months, it can take the whole spring and even part of the summer to melt completely. The cave continues with an almost horizontal course for about 50 m with a section of 10 m of width and 5 m of height on average. The initial part and the middle part are affected by the formation of a layer of ice on the floor that prevents the outflow of meteoric water and that from the melting of the snow that percolate into the cave from the roof, giving rise to two ponds, separated from each other by an irregular area occupied by large boulders.

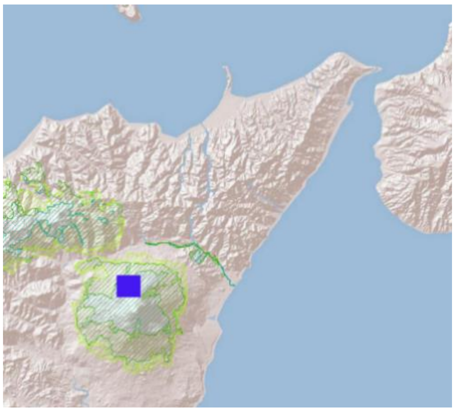

Figure 1: Geographical position of Grotta del Gelo.

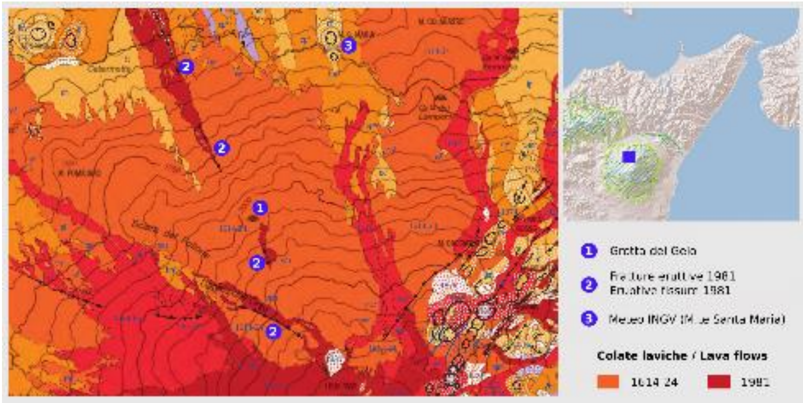

Figure 2: Geological map of the area around the Grotta del Gelo. Modified from (Branca et al., 2015).

The size, the amount of water and ice on the bottom and the freezing of the surface of the two ponds vary according to the season and from year to year. The first pond is often reduced to small puddles or totally dry, in the case of complete melting of the underlying ice, while the second pond has rarely been observed dried and free of ice. Over time the ice has displaced towards the final wall and some gaps and continuations have become filled or occluded (see Figure 3) The power of the caves to preserve the ice inside them throughout the year has been exploited by man for economic purposes, an example of the use of an Etnean cave as a *niviera*1 is the *Grotta della Neve*, also known as the Grotta dei Ladri (Bonaccorso and Maugeri, 1999). Similarly, to what happens in the tunnel of the *Grotta del Gelo*, in the *Grotta del Lago* (Bonaccorso and Maugeri, 1999) the freezing of the ground allows the formation of a large pond, which was used by shepherds to collect water for the sheep. In the case of the *Grotta del Gelo* there is no certain evidence of its use as a *niviera* (an hypogean depot for the snow), but the presence of terracotta fragments may be indicative of the collection of water by the shepherds.

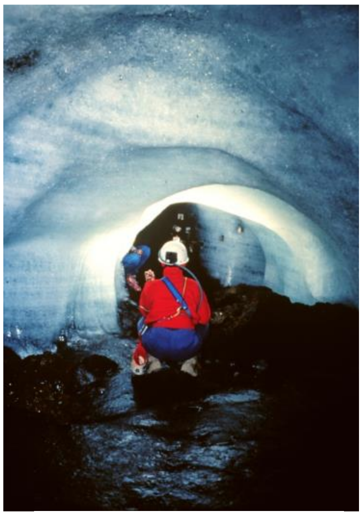

Figure 3: Tunnel under the ice.

Fundamental concepts on ice caves

Caves that open in environments whose average annual temperature is higher than 0 °C may have perennial ice masses if there are particular climatic conditions and morphologies (Persoiu, 2018). The mechanisms of air circulation that can create the right conditions are two: gravitational settling, or cold trap, and the chimney effect. The latter requires two entrances at different altitudes and does not concern the case of the *Grotta del Gelo*. The cold trap occurs in caves with only one entrance and downward trend, as in our case. In periods when the outside air is colder, and therefore denser, it enters the cave and expels the hotter and less dense air from the cave. When the outside air is warmer, the air masses are stable, and the heat is exchanged through air and rock thermal conduction. Under these conditions, the water that penetrates from the surface transports heat inside the cave and may contribute to the variation of the glacial mass. Three phases may be schematically identified (Ohata et al., 1994):

Cooling : Colder external air enters the cave, lowering its temperature.

Freezing: There is no air circulation, the water that penetrates freezes transferring heat to the hypogeal environment, but the internal temperature remains lower than the melting point of the ice. In these conditions glacial speleothems are formed and the glacial mass is increased. If *Tint* ' 0 it is possible that the latent heat released by the freezing water melts other parts of the ice mass.

Melting : The heat transferred from the water that enters the cave to the ice causes it to melt.

With good approximation the three phases dominate the winter, spring/summer and summer/autumn periods respectively, but depending on weather events the transition is not clean and unidirectional: for example, a return of cold temperatures in spring can reactivate the cooling mechanism after it had entered the freezing phase. Furthermore, in winter the cooling can be slowed down, or stopped by the obstruction of the entrance by snow, which prevents the air flow. In addition to the gravitational mechanism, due to the dependence of the air density on temperature, the cave atmosphere can be affected by the pressure variation of the external atmosphere and of the wind. These factors can compress or expand the air in the cave with consequent effect on the temperature, moreover they can transiently force the exchange of air between the outside and the cave.

Previous studies on Grotta del Gelo

The first known description of the *Grotta del Gelo* is in (Bella et al., 1982) but contains only a handmade sketch, the first instrumental topography was carried out by the *Centro Speleologico Etneo* in 1992 (Marino, 1992) and we reproduce it here (Figure 4) because it contains the survey of a tunnel inside the ice that has filled over the past 20 years and the terminal gut now occluded by the displacement of the glacial front forward. In (Marino, 1992) it is also highlighted, for the first time, that the morphology of the cave is that of a cold trap.

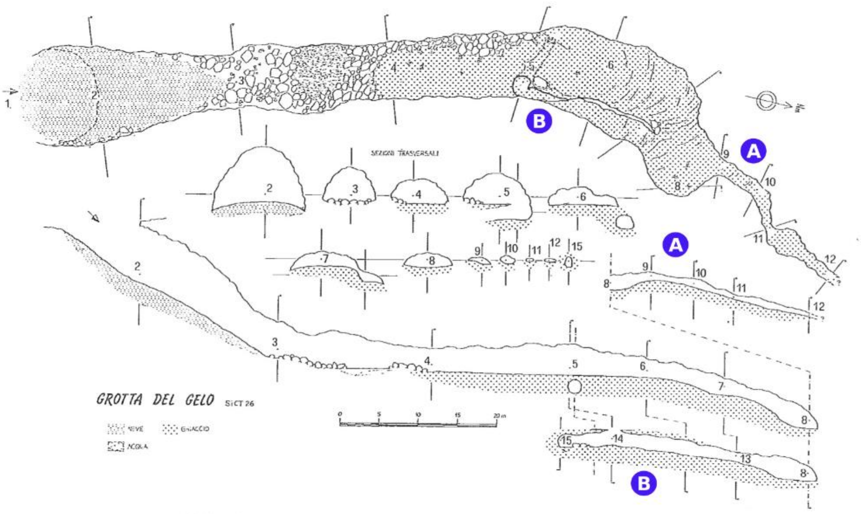

Figure 4: The continuation of the tube (A) and the tunnel under the ice (B) are signalled in the survey, both occluded today. Survey from the 90s edited by the CSE (Marino, 1992).

From 1997 to 1999, the first microclimatic monitoring was performed as part of a first collaboration between *Ente Parco dell'Etna* and *Centro Speleologico Etneo* (Caffo and Marino, 1999). Two sensors were placed, each measuring *T* and *RH%*, one at the end of the cave and one in the middle part. Humidity measurements were largely unusable due to condensation or percolation water that wet the sensor. The temperature measurements showed greater stability in the deep, and greater variability in the middle part, due to external climatic events, with trends compatible with the cold trap hypothesis. A probable translation of the glacial mass towards the bottom was evidenced, and a low sensibility to the human presence for short stays. The study highlighted the importance of monitoring the evolution of the glacial surface, of having an outdoor weather station near the cave and the need of greater resolution in the thermometric measurements (Caffo and Marino, 1999). In the spring of 2013, a new microclimatic monitoring was undertaken by a student in Geological Sciences of the University of Catania (Scoto, 2013) for his thesis work. We collaborated with him creating a new cave survey using a total station. Three sensors were installed, one of which was used to measure *T* outdoor and two inside the cave. The greater stability of the temperature at the bottom was confirmed and the bases were laid for the future work of monitoring the glacial surface. A first partial presentation relating to the early years of this monitoring was given in (Maggi et al., 2018).

Materials and methods

Starting from December 2013, based on previous experiences, the following were monitored:

- temperature in 4 internal sites and one external, during all the year;
- ice elevation of 14 sites on the ice surface and data from a weather station, from spring to autumn.

Temperature measurements

The arrangement of the sensors inside the cave is shown in Figure 5. A fifth sensor was placed a few tens of metres from the entrance. Sensors with resolution of 0.06 °C and 0.01 °C were employed, the most sensible ones were used for the depth of the cave where temperatures are more stable. Two sets of data loggers were used, alternating the field set with the one in the laboratory. By avoiding the download of data on site the time spent by the operators in the cave was reduced and it was also possible to perform periodic maintenance of the devices. All data loggers have been programmed to acquire a sample per hour. In some cases, there have been failures of the devices, if they were with good approximation due to offset or trend, corrections have been made, otherwise they have been discarded. The monthly averages of the 5 thermometers for each year and globally for the whole period have been calculated. The seasonal averages of the thermal measurements were used to build four maps of the temperature distribution inside the cave, one for each season.

Ice surface measurements

Measurement campaigns were conducted each year from the deploying of the weather station in the spring, to removal in the autumn, approximately every two months. In each measurement campaign we proceeded by surveying the altitude of 14 points of the glacial surface, referring to as many control points on the roof of the cave. The grid of points was defined in June 2013 when the new survey was made using the total station. In 2016 a Differential GPS and a total station were used to refer the roof control points in the cave to external points and orient the survey (Figure 5). By interpolating the points, a surface is reconstructed and integrating the altitude change with respect to the reference surface, on the domain defined by the perimeter of the cave portion considered, an estimate of the variation in volume of the glacial mass with respect to the reference is obtained. The area in plan of the part occupied by the glacial mass is equal to $137 m^2$. Elevation measurements are carried out using a Leica Disto Laser metre and a plumb line for vertical positioning, with an error of the order of the cm, so that overall, the error in volume measurements can be estimated in the order of $\pm 1.5 m^3$.

The stations measure temperature, pressure, humidity, precipitation, speed and wind direction. The one used since 2014 had a failure in 2017 and was replaced in 2018 by a more sophisticated one that allowed a higher angular resolution in the measurement of wind direction, which is 1° compared to 45° of the older, and a sampling frequency of one measure every 15 min instead of hourly.

To assess the consequences of rainfall, an estimate was made of the heat transferred from rainwater to ice, the volumes of rainwater corresponding to the rainfall recorded on an area of $137 m^2$, assuming that the water has the atmospheric temperature and all the heat released by the water to cool down to the temperature inside the cave is absorbed by the ice causing its melting (Messina, 2015). These are very rough approximations, but at present the only possible.

We compared the estimated losses (ΔVe) with the measured ice changes in volume (ΔVm) for each period in which the weather station recorded rainfalls. Rainfall data for 2017 have been discarded because they are fragmentary due to the weather station failure. Wind measurements were treated statistically in search of correlations with changes in internal temperature. With the installation of the new weather station, having 4 samples per hour, it was considered for each direction and on daily intervals, the correlation between the average over the previous hour of wind speed component in a given direction and the temperatures measured in the cave, making a statistic of the number of days in which the correlation is maximum for each direction.

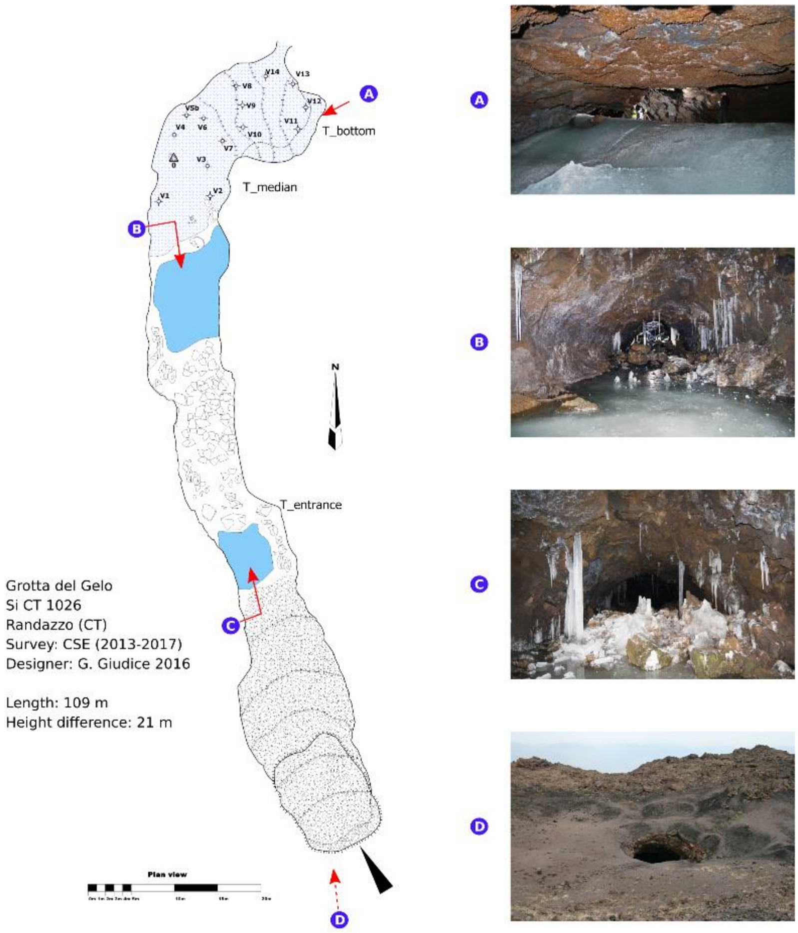

Figure 5: Topographical survey of Grotta del Gelo with some representative photos of the entrance, of the ice lakes and of the perennial ice mass

Results

The daily averages of all the data collected by the data loggers and by the weather station are shown in Figure 6 The variation of the glacial mass, compared to the reference of June 2013, is represented in the Figure 7. The great increase of ice volume in the 2013-2014 winter and the sharp decrease between November and December of 2018 are noticeable. Excluding these exceptional events, from the end of June 2014 the volumes fit very well with a linear trend (R^2 = 0.92) with a slope of $-6m^3$/year, around which they oscillate seasonally. The exceptional growth of 2014 was around 24 m^3 while the drastic drop between November and December 2018, equal to about $-10m^3$, brings the loss, compared to the reference volume of June 2013, to around $-17m^3$. The variation between maximum (2014) and minimum (2018) is equal to approximately $-39m^3$. The comparison between the

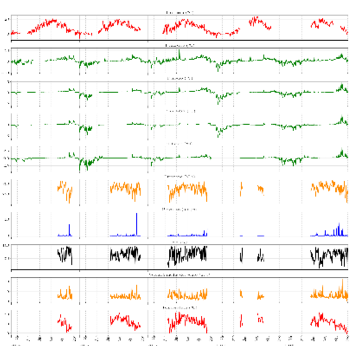

Figure 6: Daily averages of all the sampled quantities.

measured ice volume variations and those that would be expected due to rainfalls is presented in Figure 8. The annual cumulative variations adapt quite well to the hypothesis that 50% of the heat brought by rainwater over the area corresponding to the glacial mass determines the observed volume loss. We can suppose that on average the remaining 50% of the heat is transferred to the rock or escapes from the cave because part of the water flows away before being able to enter thermal equilibrium with the cave environment. The thermal maps in Figure 9 show that in winter the bottom is a little warmer than the rest of the cave, which cools down as a result of the entry of cold air from the outside.

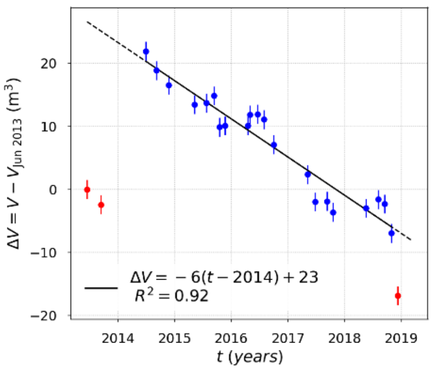

Figure 7: Ice volume variations compared to June 2013.

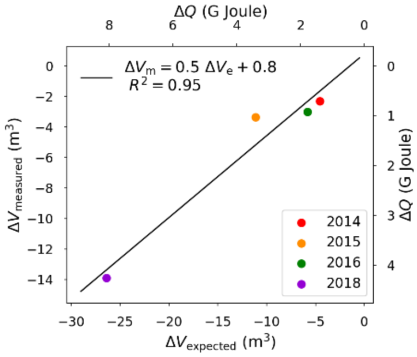

Figure 8: ΔV measured vs expected and relative latent heat.

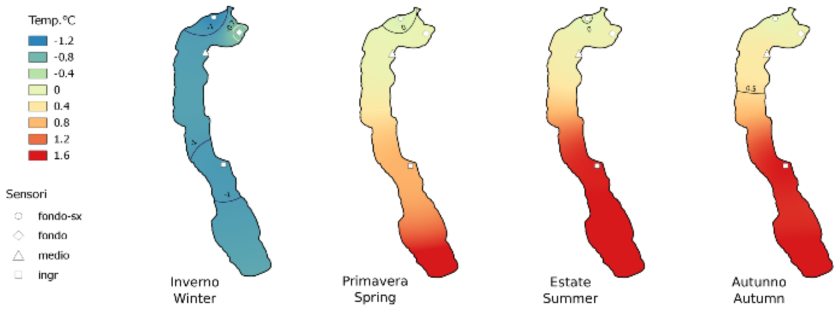

Figure 9: Thermal maps obtained from seasonal averages.

Starting from spring the temperature distribution is reversed, in fact the depth is colder than the initial part. In summer the cave gets warmer in the deeper parts until it reaches a fusion phase, with averages higher than 0°C detected by all the sensors, in autumn. Figure 10 shows the monthly averages of the temperatures for each year and for the overall period of 5 years.

Once again it highlights how the peak temperature in the cave occurs in the autumn, it should also be noted that in November 2018 there is an absolute maximum for *T*fondo (bottom temperature) corresponding to one of the rainiest autumns and most significant loss of volume recorded up to now.

Figure 11 shows the statistic of the daily correlation between wind direction and *T* in the cave for the 4 sensors. The histograms represent the number of days in which the correlation is maximum between temperature and hourly average of the wind component in a given direction. The distributions are all concentrated around 190°~200°, therefore in proximity to the direction from south (180°). A comparison between the histograms shows how the peak is more pronounced in depth than near the entrance, the initial parts of the cave are affected by wind coming from a wider range of directions, while at the bottom only those coming from a narrower range.

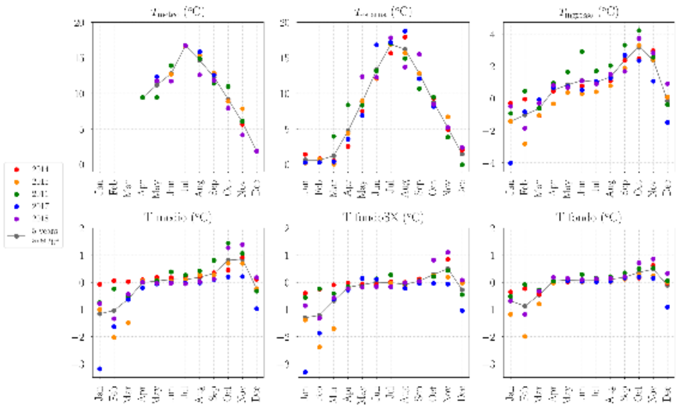

Figure 10: Monthly averages of temperatures, for each year and for the 5 years

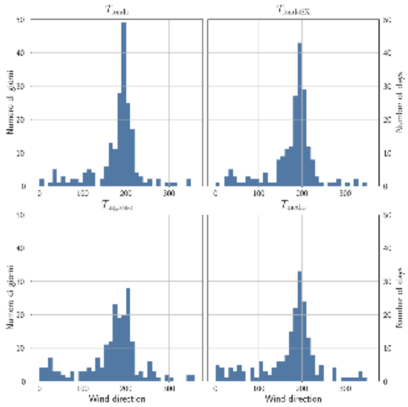

Figure 11: Number of days of max correlation between T in the cave and hourly average wind component in a given direction, 10° intervals. Wind direction: 0° = N, 90° = E, 180° = S, 270° = W

Concluding remarks

The current monitoring of the *Grotta del Gelo* is the longest in duration ever carried out for this cave. For the first time there is a measure of the evolution of the glacial mass, which confirms, on a quantitative basis, some of the wisest qualitative observations of the past, that is few major events cause both most of growth and most of the reduction of mass. The observation window remains of modest duration compared to the secular variations of the climatic phenomena, but the general trend from the beginning of the 20th century is the reduction of the glacial masses in caves (Kern and Persoiu, 2013), so if we extrapolate the net loss observed in these five years (see Figure 7) we could estimate a maximum life a few more decades of perennial ice in the *Grotta del Gelo*. The relative superficiality of the cave and the lack of soil and vegetation on the overlying surface expose the ice to considerable water flows, some effects of the passage of water on the ice during the last rainy autumn, are illustrated in Figure 12.

Figure 12: Ice on the cave floor showing the effects of flowing water after heavy autumn rains.

Overall assessments of the heat balance would require a systematic measurement of the evolution of the two ice lakes as well as the runoff of water on the ice and reliable measurements, during the winter, of external parameters including snowfall and the occlusion state of the entrance. The energies involved are greater than those that the human presence due to frequentation, all in all sporadic, even if it could be consistent on some occasions, can thermally transfer. A quantitative evaluation would require the systematic verification of people transit throughout the year, but in general is possible to give the following considerations:

- Water rain seems to be the main cause of ice loss.

- Visitor impact, not yet measured but just modelled (Simonazzi and Yaber, 2016), considering a mean permanence of 10 minutes on the terminal part of 1000 visitors per year, seems to affect the ice loss about 10% of the water rain.
- Estimated local ice loss trend looks similar to global cave ice loss, but it would be important to calculate the specific ice loss rate (i.e., m^3 lost referred to m^2/year, or % of ice lost by mass per year) comparing local and global cases.

In conclusion, it is possible to say that visiting the cave is recommended, for its fascination and uniqueness, but just in a real respectful way, limiting the human impact by minimising the permanence time and the alterations of the ice surface.

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Estimation of the formation temperature of lava stalactite inside the cavity of a lava tree mould

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Abstract

In order to understand the igneous activity of lava flow, it is essential to know the temperature at which the cavity and void of lava tree mould was formed. From the pitch of the lava stalactite which could be formed on the inner surface of the cavity associated with the void of lava tree mould, the lava surface tension, which is one of the lava physical properties, could be obtained. Then, the lava temperature could be estimated from the temperature dependent data of the surface tension of the lava. The research results regarding the lava tree mould for the old historical lava flow (erupted about 1000 years ago) of Mt. Fuji are mentioned.

Riassunto

Per comprendere l'attività ignea della colata lavica, è essenziale conoscere la temperatura alla quale si è formata la cavità e il vuoto dello stampo lavico dell'albero. Dall'inclinazione della stalattite lavica che potrebbe formarsi sulla superficie interna della cavità, si potrebbe ricavare la tensione superficiale della lava, che è una delle sue proprietà fisiche.

Quindi, la temperatura della lava potrebbe essere stimata basandosi sui valori, dipendenti dalla temperatura, della tensione superficiale della lava.

Vengono citati i risultati della ricerca sulle grotte di scorrimento contenute in una vecchia colata lavica (eruttata circa 1000 anni fa) del Monte Fuji.

Key words: Lava tree mould, Lava stalactite, Lava temperature

Introduction

Regarding the type of womb (Tainai) like lava tree mould of Mt. Fuji, after the tree is covered with lava flow, the tree and its containing water react with the lava to form a gas and cavity, then the burning gas will remelt the lava [1,2]. It is known that the remelted lava is formed on the ceiling and side walls in the cavity. Lava stalactites and ribbed walls formed on the side wall are often observed in this lava tree mould [3,4] as shown in Figures 1 & 2. This phenomenon relating to gravity and surface tension in which the droplets of lava fall from a ceiling and flow down the wall, then deposit on the floor. The surface tension of the lava can be estimated from the measured pitch of the lava stalactite and ribbed wall [3,4]. Here, we attempted to estimate the temperature (remelted temperature of lava) when lava stalactite and ribbed wall were formed by using the temperature-dependent curve of the surface tension of lava.

Figure 1: Lava tree mould void and front cavity of Ken-marubi lava flow.

Figure 2. Lava tree mould void and upper cavity of Ken-marubi lava flow.

Relationship between surface tension and pitch

The remaining molten lava layer adhering to the ceiling begins to swell downward due to gravity, while surface tension tends to prevent it (Figure 3 (a)). A linear equation is obtained by giving a small disturbance to the hydrodynamic equation and omitting the terms of quadratic or higher. From the stability-instability limit condition of the linear theory of Rayleigh-Taylor instability, the intrinsic pitch P of the wave is given by the following equation [3,4,5,6]:$P = 2\pi (\gamma / g\rho)^{1/2}$, where γ is the surface tension of the lava, g is the gravitational acceleration, and ρ is the density of the lava (2.5 g / cm^3). In other words, the surface tension γ of lava can be obtained from the equation $\gamma = P^2 g\rho / 4\pi^2$ by measuring the pitch P of the lava stalactite hanging from the ceiling and ribbed walls inside the lava tree mould cavity.

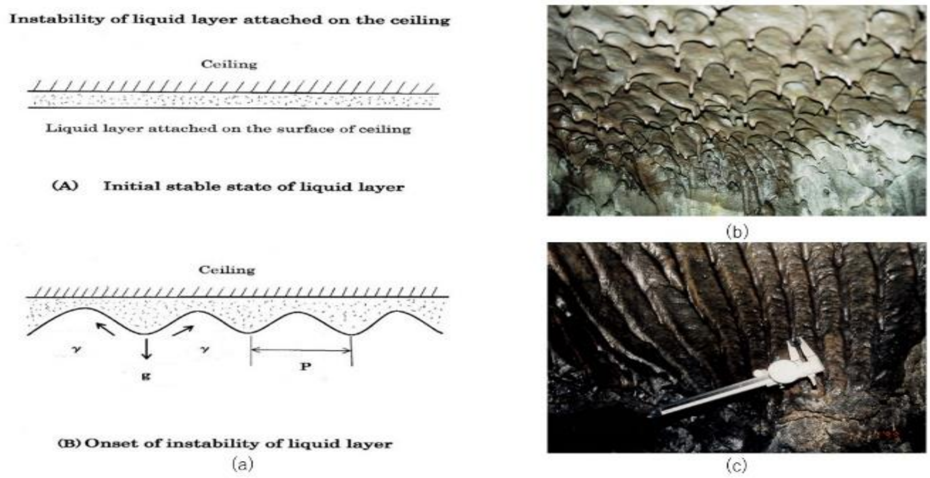

Figure 3: (a) Analysis model, (b) Lava stalactite on the ceiling of the cavity of lava tree mould, (c) Lava ribbed wall of the cavity of lava tree mould.

Temperature-dependent equation and estimated temperature

Regarding the temperature-dependent equation of surface tension, we have used the data of Mt. Mihata of Izu Oshima as we have no data for Mt. Fuji. I. Yokoyama and S. Iizuka [7] measured the temperature change of the surface tension of lava from the 1950/1951 eruption at Mt. Mihara of Isu-Oshima Island. Their measurement was performed in the range of 1200 ° C to 1500 ° C. Then, the estimated equation obtained by extrapolating these measurements up to 1000 ° C was given as $\gamma=2100-1.1\theta$. (shown in Figure 4). Consequently, by introducing $\gamma=2100-1.1\theta$ to $P = 2\pi (\gamma / g\rho)^{1/2}$, the lava stalactite pitch can be shown as $P = 2\pi ((2100-1.1\theta) / g\rho)^{1/2}$. The relationship between the pitch and temperature is shown in Figure 5. In the Mt. Fuji womb type (Tainai) tree mould, the pitch is about 4 cm (shown in Figure 3(b),(c)). So, the formation temperature of lava stalactite is estimated about 1000 ° C from Figure 5.

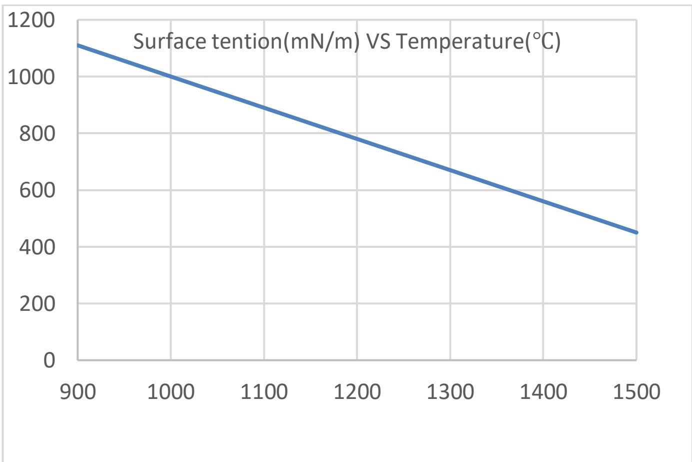

Figure 4: Relation between lava surface tension and temperature (Mt. Mihara lava of 1950/1951)

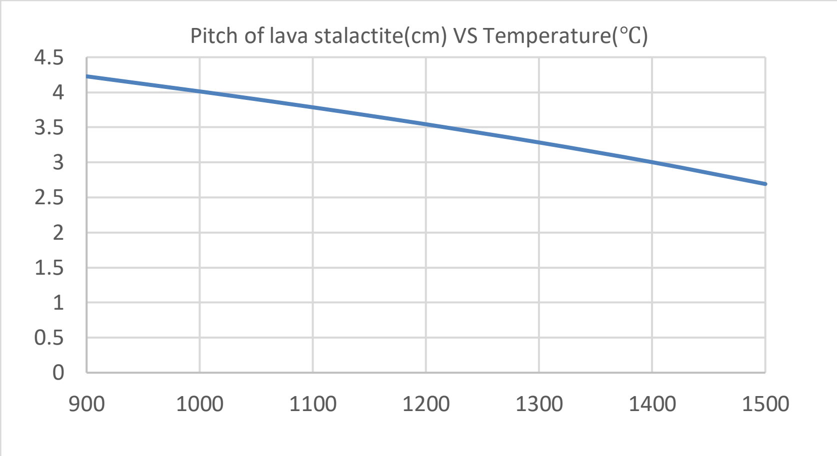

Figure 5: Relation between lava stalactite pitch and temperature (Mt. Mihara lava of 1950/1951)

Conclusion

The estimation of the formation temperature of lava stalactite inside the cavity of lava tree mould void was carried out. The experimental surface tension values of the lava of Mt. Mihara were used for temperature estimation. As the surface tensions of the rocks are insensitive to the content of SiO^2 in contrast with the case of viscosity [7], the use of the surface tension data of Mt. Mihara (SiO_2 52.45wt%) for Mt. Fuji (SiO_2 51.2wt%) seems to be reasonable. Though, it is desirable in future to use the values obtained by measuring the temperature change of the surface tension of the lava of Mt. Fuji for more accurate estimation. Also, as the observed pitch is not always strictly constant value through the cavity surface, it is necessary to consider the influence of the shape effect of the cavity for the measurement of the pitch or to use the statistical values of the pitch in the cavity.

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SYMPOSIUM DAY 2, TUESDAY 31 AUGUST

PAPERS

Session 2: Rheology and Geomorphology of volcanic caves

Descriptive note on some volcanic cases surveys in three Transcaucasian regions of the Republic of Armenia (R. Ruggieri, S.R. Davtyan, S. M. Shaihinyan, A. Ingallinera, R. Orsini, G. Agosta).

Geoheritage assessment of lava tube caves on Jeju Island, Korea – (Kyung Sik Woo, Lyoun Kim, Jonghee Lee).

Spatial distribution characteristics of the Nâm B'Lang Volcano lava tube system, Dak Nong UNESCO Global Geopark, Vietnam (Ton Thi Ngoc Hanh, Vu Van Tu, Bui Thanh Ha, Pham Duc Anh, Ho Tien Chung, Tran Tan Van).

Interesting morphologies in a small lava tube in the lava flow of "Piano Cannelli", Mt. Etna G. Priolo, S. Raciti, M. Ragusa).

DESCRIPTIVE NOTE ON SOME VOLCANIC CAVES SURVEYED IN THE TRANSCAUCASIAN REGION OF THE REPUBLIC OF ARMENIA

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Abstract

As part of an international research agreement, called "Armenia Karst Project", set up between the Armenian Speleological Center and the CIRS - Hyblean Center of Speleo-Hydrogeological Research of Ragusa, in the years 2016 to 2019, four research campaigns are carried out with the aim of studying both the surface and hypogean karst morphologies and the caves of volcanic origin present in different geographical contexts of the Republic of Armenia. In this regard, in the last three campaigns, thirteen caves of different volcanic genesis have been surveyed, of which: one in the District of Lori Marz in the north-eastern sector of the country; three in the volcanic district of the Sisian Region in the southern sector, and nine in the south-east of the country, in the region of Syunik. The latter located in a spectacular natural landscape with spiers and pinnacles, in the old Town of Goris, carved in the pyroclastic volcanic material, were used since the Stone Age, in medieval times and up to the last decades of the last century, both as dwellings and for the shelter of animals. With this report one describes the speleometric and morphogenetic features of the aforementioned caves, for some of which, due to the remarkable landscape and historical-anthropic context in which they are located, an enhancement and safeguarding action is proposed.

Riassunto

Nell'ambito di un accordo di ricerca internazionale, denominato "Progetto Armenia Karst", instaurato tra il Centro Speleologico Armeno e il CIRS - Centro Ibleo di Ricerche Speleo-Idrogeologiche di Ragusa, negli anni dal 2016 al 2019, vengono svolte quattro campagne di ricerca con lo scopo di studiare le morfologie carsiche superficiali e ipogee nonché le grotte di origine vulcanica presenti in diversi contesti geografici della Repubblica di Armenia. A tal proposito, nelle ultime tre campagne sono state censite tredici grotte di diversa genesi vulcanica, di cui: una nel Comune di Lori Marz nel settore nord-orientale del paese; tre nel distretto vulcanico della Regione di Sisian nel settore meridionale, e nove nel sud-est del Paese, nella regione di Syunik. Queste ultime situate in uno spettacolare paesaggio naturale di guglie e pinnacoli, site nel centro storico di Goris, scolpiti nel materiale vulcanico piroclastico, furono utilizzate fin dall'età della pietra, in epoca medievale e fino agli ultimi decenni del secolo scorso, come abitazioni e per il ricovero degli animali. Con questa relazione si descrivono le caratteristiche speleometriche e morfogenetiche delle suddette grotte, per alcune delle quali, per il notevole contesto paesaggistico e storico-antropico in cui si trovano, si propone un'azione di valorizzazione e salvaguardia.

Key words: *Armenia, Lori Marz, Goris, volcanic caves*.

Introduction

The Armenian Highland is an aerial plateau framed by high marginal mountains (*Figure 1*).

In the Neogene, the plateau system was broken by discharges onto a number of differently elevated blocks. Along the line of splits, volcanic processes were intensified and continued in the Quaternary period, with solid covers of Neogenic-anthropogenic effusions disseminated over vast areas of the Armenian Highland. In addition to the Armenian Highland, continuous covers and separate “cameo islands” of Neogene volcanic covers indicating the one-time existence of vast area of development of a powerful cover of effusions, which subsequently underwent an intensive process of denudation and erosion, exist in neighbouring Asia Minor and Iranian plateaus (BALYAN, 1969).

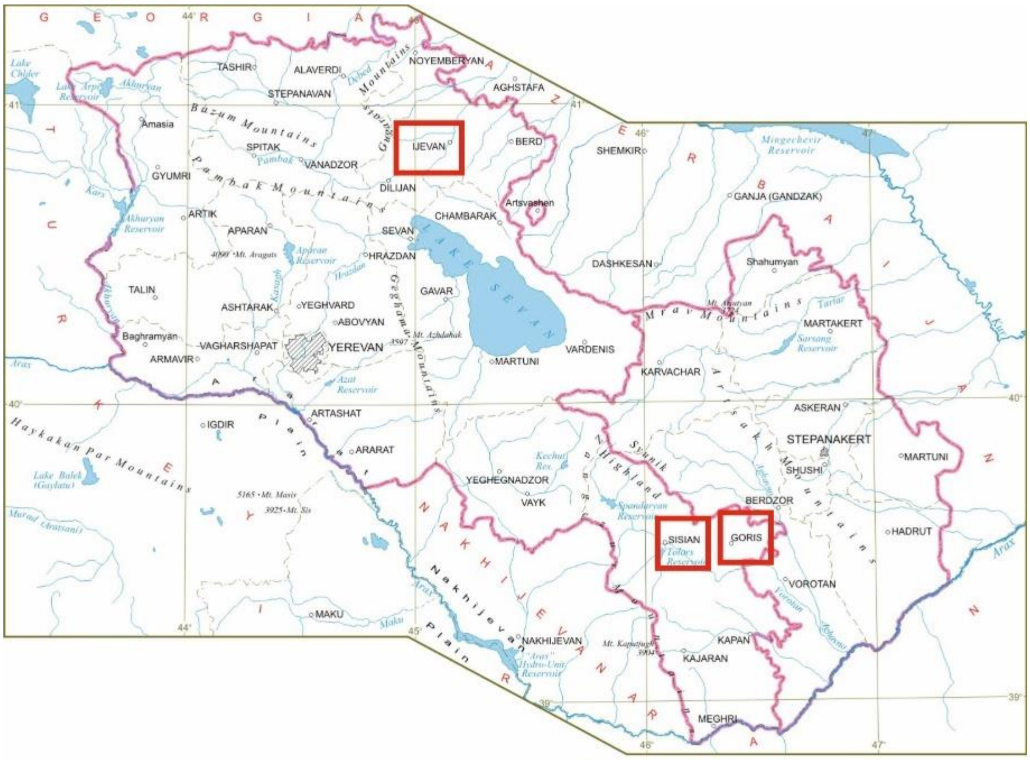


Figure 1: Map of Republic of Armenia with locations of area of investigation.

The volcanic cover of the Armenian Highland is represented by two formations: lower, pyroclastic, of Neogenic age, with thickness of 200m-300m and upper, actually effusive one (lava covers and flows), of quaternary period, having sharply variable thickness from 50 metres to 1 km.

Caves in the Quaternary effusive lava

Active volcanism in Armenia and the Armenian Highland (eastern Turkey and northwest of Iran) was directly linked to the Alpine geotectonic processes. The process that began 10 million years ago continued almost continuously until the anthropogenic and even after the formation of civilization. A huge amount of volcanic material has been ejected. Suffice it to say that the amount of material released in the Armenian Highland and in the Caucasus is extremely high. More than 27 percent of volcanic material emitted from Gibraltar to Pamir. The most common excretions are represented by high SIO content in rocks, in the form of basalt, diabase, liparits, ignimbrite. The volcanic caves and tunnels we studied had a different genesis. Most of the caves are just gas bubbles left in the magna stream to form round or spherical shapes. It can safely be stated that the active gas components in these gas “pockets” were extremely low, as the oxidation surfaces were absent. The same can be said for tunnels, the occurrence of which was probably due to differentiation of density in different parts of the flowing lava. For this reason, a slow-moving layer of lava created a steep flow path, the surrounding walls of which were frozen earlier as the heat disconnection was much greater.

Campaigns of research October 2017 - September 2018

As part of the 2017 and 2018 research campaigns on karst phenomena in the Republic of Armenia (RUGGIERI et al., 2019 a, b) n. 4 caves of volcanic origin, of which 1 located in the Lori area, in the north-eastern sector of the country, and 3 in the volcanic district of Sisian in the south-eastern sector, have been surveyed. The aforementioned caves of different volcanic origin are described below.

Sanahin cave, located in the district of Lori Marz, near the Sanahin village, on the right slope of the Debed river valley, at 834 m a.s.l., it is a volcanic cave developed in the basalt of Quaternary age (Q2-Q3). The cave consists of a main gallery and two short conduits for a total development of 78 m with a total difference in height of 3 m (*Figure 2*).

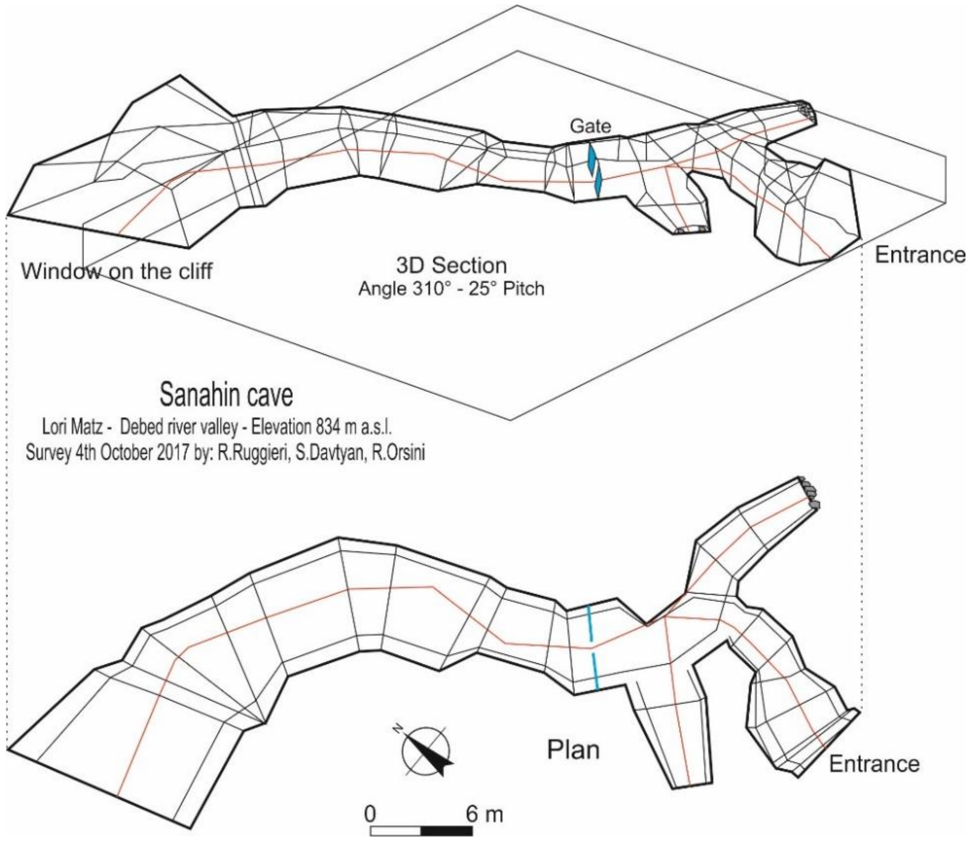


Figure 2: Map of Sanahin cave.

Figure 3: Main gallery of the cave (ph. R. Ruggieri).

The main gallery, after the first section of about 17 m, with an average North-South direction, has two branches: the conduit on the right after about 11 m is closed by boulders and cement, while the one on the left, after about 10 m is partially obstructed and overlooks the outside. After a few metres the main gallery is closed by a sheet of metal with a passage. Beyond the latter, the cave begins to widen and extends for about 31 m with an average direction NNW, then continuing for another 9 m, with a direction E-W, until it faces a spectacularly large opening suspended over the valley below (*Figure 3*). The morphologies found along the gallery show a massive lava structure along the section with a lower part, visible in stretches and particularly in the middle-terminal walls, consisting of a sequence of regular vacuolated centimetres layers, in a short section encompassing small rounded (fluvial) pebbles. From this evidence a genesis of the lava tube given by a first lava emptying phase is hypothesized, followed by a second brief filling phase of alluvial material, on which cyclical layers of lava overlapped, and a last phase of the partial dismantling of the filling sediments by the erosion. This last sequence filled an already existing void (from the cooling of the outermost layer of the lava flow to the emptying of the hottest layer below), highlighted by the clear passage between the massive wall lava on which the cyclic sequence of the previously mentioned layers laterally hinges. Entrances of other smaller caves are present along the cliff below this cave, these latter probably due to emptying of gas bubbles, as is even highlighted by a large degassing void-chimney on the vault of the main conduit. The presence of alluvial material and the morphology of a fluvial paleo-terrace within which the lava tube caves are located seems to support the hypothesis that the cave came to light as the above terrace was cut off from the deepening of the valley, with subsequent episodes of flooding inside the cave. As regards the geostructural context for safety purposes, the cave presents portions of the vault with large lava blocks in precarious geostatic condition, very likely close to a possible collapse.

Spring cave, located in the Sisian Region on the side facing the Sisian Agricultural Center at an altitude of 1,625 m a.s.l., develops in the Quaternary basalts (Q3), with a total length of 77 m, a maximum height of 4.5 m and a positive difference in level of 1.4 m. On the front of the cave there is a small spring emerging through cooling fractures of the lava complex. Along the cave are present large boulders collapsed from the vault (*Figures 4 and 5*).

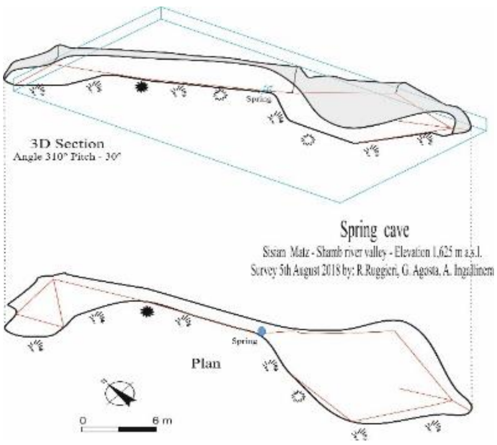


Figure 4: Map of Spring cave.

Figure 5: Chamber of Spring cave (ph. R. Ruggieri).

Bridge cave, located in the Sisian Region on the side facing the Sisian Agricultural Center at an altitude of 1,628 m a.s.l., develops in the Quaternary basalts (Q3), with a spread of 68 m, a maximum height of 4.6 m and a positive difference in height of 2.2 m. The cave compared to the previous one is a little more articulated, with a singular arch / bridge, originated by the widespread collapses of the lava layers of the vault, and overcome the latter, in the right sector, with a lower cave with conglomerate deposits made of pebbles rounded of fluvial origin. The cave is located on the same side of the Spring Cave which is about ten metres, with a spring flowing about halfway between the two caves (*Figures 6&7*).

Speleogenetic aspects

The morphostructural elements observed in both the neighbouring lava caves suggest a genesis of the same linked to the presence of original degassing voids contained in the lava complex, which came to light in a subsequent phase because of erosive fluvial processes, when the underlying river flowed to a higher level. This circumstance would be supported by the mentioned presence of conglomerate deposits with rounded river pebbles preserved in the innermost part of the Bridge cave. The subsequent collapses, which originated for the physical decompression processes of the fractured lava mass, have therefore over time modified the morphology of the two caves, enlarging the environments.

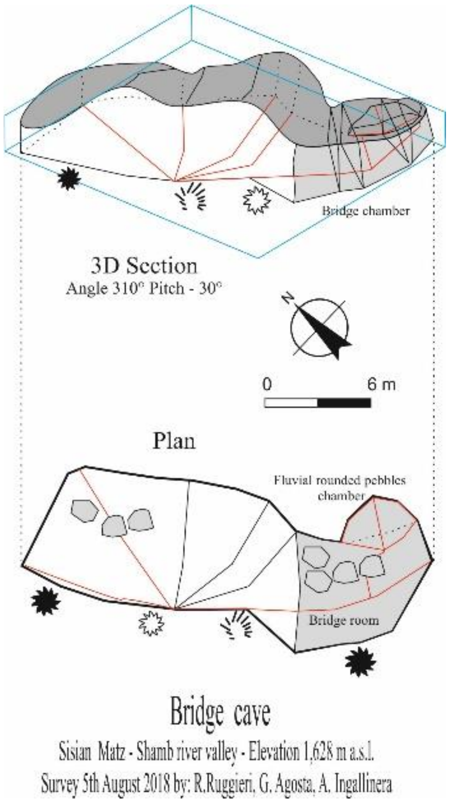


Figure 6: Map of Bridge cave

Figure 7: Bug chamber of the Bridge cave (ph. R. Ruggieri).

Shamb cave, located in the Sisian Region in the middle-upper part of the left side of the Shamb River, at an altitude of 1,912 m a.s.l., develops in the Quaternary basalts (Q3-4), with a length of 21.4 m with NNE-SSW direction, a maximum height of 3.4 m and a total difference in level of 1.2 m. From the detected morphologies, including a singular cluster of rounded globular shape in the final part of the cave, it is evident a genesis of the cave conduit due to a first phase of cooling of the upper part of the lava flow with a simultaneous emptying of the conduit by the underlying hotter portion of the lava. In a subsequent phase the generated lava tube was intercepted and truncated by the Shamb River following the deepening of the underlying valley (*Figure 8 & 9*).

Caves in the Neogene pyroclastic formation

A pyroclastic stratum is composed mainly of tuffs, tuff breccia, agglomerates, interspersed with sandstones, conglomerates and lava flows. Denudation of this stratum, named in the literature as the Voghjaberd (Geghard, Goderz) Stratum found in the territory of the modern Republic of Armenia (Voghjaberd, Geghard, Yelpin, Syunik Highland, etc.), in the Western Armenia (Byurakn, Basen, Kars, Ani, etc.), in the Southern Georgia (Vardzia), in the Eastern Anatolia (Cappadocia), and in the Northern Iran (Maragha).

The stratum, being almost in horizontal bedding in most cases, composes table-shaped uplands or as a result of dissection by deep ravines and gorges, appears in the form of outliers of bizarre forms of different sizes

(DAVTYAN, 2013). Intensive deep erosion occurs in the pyroclastic stratum, which is associated with the vertical fracturing of rocks as well as with agglomerate composition of large fragments, poorly cemented with pumice-ash material. As a result, the marginal parts of table-shaped plateaus composed of pyroclasts are divided into separate segments by numerous narrow and deep canyon-like valleys. Therefore, on the slopes of the plateau drainage funnels are formed, in which outliers of different sizes and forms are developed. The formation of pyramids is associated with sawing the marginal parts of plateaus with permanent and temporary streams, forming vertical gutters and potholes, with rocky outliers remaining in-between. As a result of further dissection, they turn into separate pyramids or stone mushrooms. (GEOLOGIA, 1962). Some outliers end with “stone caps”, represented by boulders that protect from erosion the part of the pyramids below them.

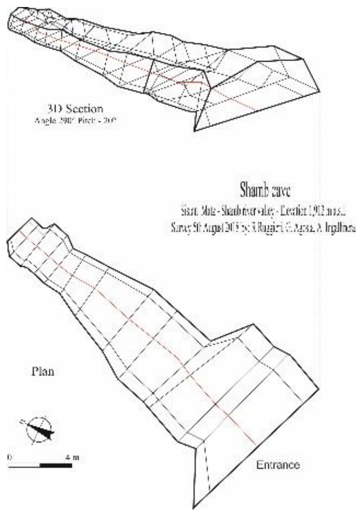


Figure 8: Map of Shamb cave (ph. R. Ruggieri.)

Figure 9: Gallery of Shamb cave (ph. R. Ruggieri).

Speleological peculiarities of pyroclastic stratum

The topographic and morphological conditions of the Neogene pyroclastic stratum and the degree of its dissection were very favourable for the formation or creation of underground structures. A characteristic feature of this stratum is the wide distribution of underground cavities of natural, semi-artificial and artificial genesis.

Most caves in pyroclasts have been created by man. The huge capacities of tuffs allowed the man to create a huge number of cave structures for different purposes. Underground dwellings were cut in the stratum comparatively pliable for processing rhyolite tuffs and lithoclastic pumices (perlites). In several cases, for the longevity of the structure (monasteries, tombs, etc.), caves were cut in dense tuffs (ignimbrites).

Natural, semi-artificial and artificial cavities of the Neogene pyroclastic stratum are widespread throughout Armenia, forming secular and cult complexes consisting of cavities, the number of which ranged from several to hundreds. Almost all secular complexes have cult caves, in which residential and industrial buildings also can be found.

Rock structures are cut in the Neogenic stratum also in Cappadocia, South Georgia and Iran. The data of archaeological research in Neogene pyroclasts have identified three main periods of creation of artificial caves: the Bronze Age, the Urartian Period and the Medieval period.

Campaign of research September 2019

Caves surveyed in the Old Town of Goris, Region of Syunik (South-east Armenia).

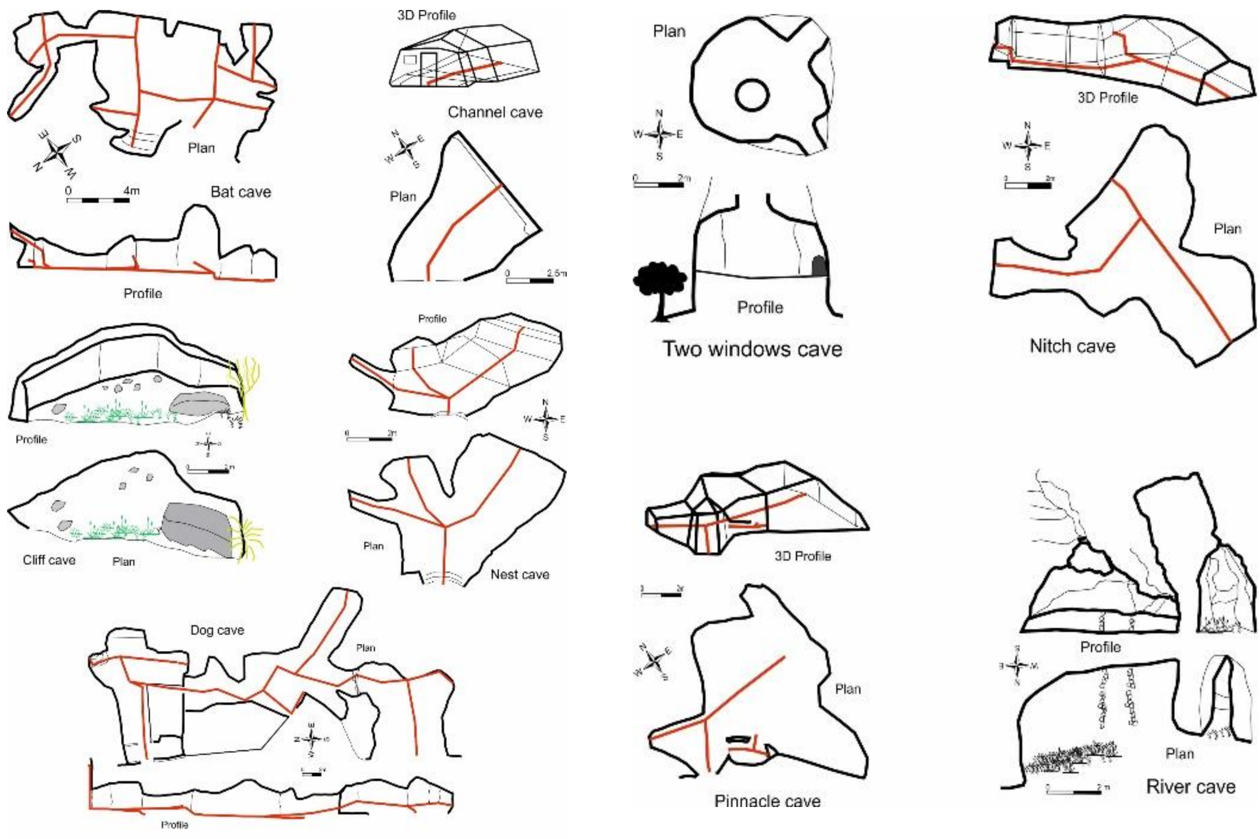
Nine caves, located in the spectacular natural landscape with spires and pinnacles, of the old Town of Goris, were surveyed (*Figure 10*).

These caves, carved in the pyroclastic volcanic, as previously described, were used since the Stone Age, in medieval times and up to the last decades of the last century, both as dwellings and for the shelter of animals (*Figures 11 and 12*).

Figure 10: Panoramic view of the new and old town of Goris. (ph. S. M. Shaihinyan).

Conclusion

As part of a more general research project aimed at the study of the karst phenomena present in the Republic of Armenia, 13 non-karstic caves have also been documented and surveyed, of which 4 caves originated in the Quaternary lavas, 9 caves, semi-artificial, in the Neogenic pyroclastic formation. Two cavities showed typical morphologies related to lava emptying processes (lava tubes), the other two showed morphologies originating from the formation of gas bubbles within the magmatic mass. The cavities surveyed in the pyroclastic formation are mostly made by man, some by digging initial natural voids, and used since the Stone Age until the last decades of the last century, as highlighted in the suggestive old town of Goris (*Figures 13 and 14*) and (*Figures 15 - 20*). For the latter context of great landscape appeal and remarkable archaeological and historical-anthropic value, enhancement and conservation projects are planned.



Figures 11 and 12: Maps of the caves surveyed in the Old Town of Goris.

Figure 13: Cluster of pinnacles with caves (ph. R. Ruggieri).

Figure 14: Sight of the pyroclastic ridge from inside one of the surveyed caves (ph. R. Ruggieri).

Figures 15 and 16: Singular morphologies with caves in the Neogene pyroclastic formation (ph. Mayr).

Figure 17: River cave: natural cave originating from the erosive action along fractures from the river waters *(ph. Mayr).*

Figure 18: Cave at the foot of a cluster of pinnacles (ph. Mayr).

Figure 19: Fences cave: cave dug by man and used as a shelter for animals (ph. Mayr).

Figure 20: Dog cave: System of multiple connected cavities used for different uses (ph. Mayr).

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GEOHERITAGE ASSESSMENT OF LAVA TUBE CAVES ON JEJU ISLAND, KOREA

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Abstract

Recognition of geoheritage values and conservation of their geodiversity elements are largely neglected in protected areas. Geoheritage comprises the elements of the Earth's geodiversity that are considered to have significant value for intrinsic, scientific, educational, cultural, aesthetic and ecological reasons and therefore deserving conservation for the benefit of future generations. Some geodiversity elements can be quite dynamic, representing ongoing Earth's surface processes to form long-term geological products. It is almost impossible to protect all the significant geological sites legally due to high development pressure. Also, unlike biodiversity and ecosystem, geodiversity constituents tend to be more durable, thus last much longer as outcrops but they are non-renewable. It is thus very important to assess and select geoheritage sites scientifically. Scientific investigation of caves has been seriously conducted in the past, however geoheritage assessment of caves has been largely neglected among the scientific community. The Korean Government has investigated geoheritage values of caves since 2001, but most investigation has been concentrated on limestone caves in the Korean Peninsula. Jeju Island has formed by volcanic activities on the continental shelf by fissure-type eruption during the Quaternary, and became an island due to sea-level rise during the Holocene. Basaltic lava mostly has formed volcanic rocks on Jeju Island and produced numerous lava tube caves. It is known that more than 150 lava tube caves are present.

This study provides the scientific basis for geoheritage assessment of lava tube caves in Jeju Island. Basic 6 criteria used here are (1) representativeness, (2) rarity, (3) distribution, size, and diversity of internal micro-topographic features and speleothems (lava and secondary speleothems), (4) presence of special environments (i.e., lakes) or special features (sediments, guano deposits with secondary minerals, etc.), (5) dimension of caves, and (6) integrity (preservation state, intactness). Based on assessment data, four categories are classified: (1) Type A = national monument, (2) Type B = provincial monument, (3) Type C = caves with potential geoheritage values, thus necessary for conservation, and (4) Type D = caves without geoheritage values, thus not necessary to be protected. Type A and B are evaluated subjectively by speleologists based on one or more criteria, whereas Type C and D are classified based on quantitative and cumulative assessment data of six criteria.

Riassunto

Il riconoscimento dei valori del geopatrimonio e la conservazione dei loro elementi di geodiversità sono ampiamente trascurati nelle aree protette. Il geopatrimonio comprende gli elementi della geodiversità terrestre ritenuti di rilevante valore per ragioni intrinseche, scientifiche, educative, culturali, estetiche ed ecologiche e quindi meritevoli di conservazione a beneficio delle generazioni future. È quasi impossibile proteggere legalmente tutti i siti geologici significativi a causa dell'elevato sviluppo. È quindi molto importante valutare e selezionare scientificamente i siti di geopatrimonio. Le indagini scientifiche sulle grotte sono state in passato valide; tuttavia, la loro importanza nel contesto del geopatrimonio è stata ampiamente trascurata dalla comunità scientifica. Il Governo coreano ha studiato i valori del geopatrimonio delle grotte dal 2001, ma la maggior parte delle indagini si è concentrata sulle grotte calcaree nella penisola coreana. L'isola di Jeju si è formata da attività vulcaniche sulla piattaforma continentale da eruzioni di tipo fissurale durante il Quaternario divenendo un'isola a causa dell'innalzamento del livello del mare durante l'Olocene. La lava basaltica costituisce le rocce dell'isola di Jeju e ha prodotto oltre 150 grotte di scorrimento lavico. È noto che sono presenti più di 150 grotte a tubi di lava.

Questo studio fornisce la base scientifica per la valutazione del geopatrimonio di grotte di scorrimento lavico nell'isola di Jeju. I 6 criteri di base utilizzati sono: (1) rappresentatività, (2) rarità, (3) distribuzione, dimensione e diversità delle caratteristiche microtopografiche interne e degli speleotemi (lave e speleotemi secondari), (4) presenza di ambienti speciali (cioè, laghi) o caratteristiche particolari (sedimenti, depositi di guano con minerali secondari, ecc.), (5) dimensione delle grotte e (6) integrità (stato di conservazione, integrità). Sulla base dei dati di valutazione, vengono classificate quattro categorie: (1) Tipo A = monumento nazionale, (2) Tipo B = monumento provinciale, (3) Tipo C = grotte con potenziali valori di geopatrimonio, quindi necessario per la conservazione, e (4) Tipo D = grotte prive di valori di geopatrimonio, quindi non necessariamente protette. I tipi A e B sono valutati soggettivamente dagli speleologi sulla base di uno o più criteri, mentre i tipi C e D sono classificati in base a dati di valutazione quantitativi e cumulativi di sei criteri.

Key words: lava tube, volcanic cave, Korea, geoheritage.

Introduction

Geoheritage comprises the elements of the Earth's geodiversity that are considered to have significant value for intrinsic, scientific, educational, cultural, aesthetic and ecological reasons and therefore deserving conservation for the benefit of future generations. Some geodiversity elements can be quite dynamic, representing ongoing Earth's surface processes to form long-term geological products. It is almost impossible to protect all the geological sites legally due to high development pressure, thus high quality representatives need to be selected for conservation. Also, unlike biodiversity and ecosystem, geodiversity constituents tend to be more durable, thus last much longer as outcrops but they are non-renewable. It is thus very important to assess and select geoheritage sites scientifically for conservation (Ju & Woo, 2018).

Heritage assessment for caves has been carried out by Cultural Heritage Administration (CHA) since 2003 for effective conservation and management of all the caves in Korea (Woo & Kim, 2018), most has been concentrated on limestone caves in the Korean Peninsula (CHA, 2003, 2004, 2006, 2008, 2009, 2010, 2011, 2014, 2015, 2016, 2017, 2018, 2019). Jeju Island is known to include more than 150 lava tube caves (CHA, 2003). Among them fourteen caves have been designated as a natural monument and one cave as a Jeju provincial monument (Table 1). It has been strongly suggested by speleologists that there are more caves with high geoheritage values to be legally protected in Jeju Island, but detailed data are lacking. In 2019, Jeju Special Self-Governing Province (JSSGP) decided to explore and evaluate all the lava tube caves in Jeju Island again for re-assessment because the investigation which was carried out in 2003 did not provide enough information on heritage values for proper protection (e.g., JSSGP, 2020). Also, due to high development pressure, lava tube caves can be regarded as very vulnerable sites because they are mostly distributed near the surface on Jeju Island. Even though scientific investigations of a few lava tube caves have been seriously conducted in the past (Woo et al., 2008a, 2008b; Ji et al., 2010, 2011; Hong et al., 2012; Woo et al., 2013a, 2013b; Woo et al., 2013a, 2013b; Ahn, 2017; Woo et al., 2018; Woo et al., 2019), geoheritage assessment of Jeju caves has been largely neglected among scientific community. Therefore, the objectives of this paper are to provide objective criteria for assessment of all the lava tube caves in Jeju Island, to classify these caves based on different levels of heritage values, and thus provide the Korean government scientific standard information for legal protection.

Lava tube caves in Jeju Island

Jeju Island is located about 100 km south of the Korean Peninsula (Figure 1), and has formed by volcanic activities on the continental shelf during the Quaternary (Sohn, 1996). It is well known that Jeju island was connected with the peninsula during the last glacial maximum, and became an island due to sea-level rise during the Holocene. This eruption can be distinctive from hot spot volcanism within an intraplate region which is considered to be a result of active upward-moving plumes (Depaolo and Manga, 2003). Basaltic lava on Jeju Island produced numerous lava tube caves (CHA, 2003). The large size and high number of some lava tube caves on Jeju Island are famous worldwide. The Geomunoreum Lava Tube System, which is composed of five lava tube caves, was inscribed as a UNESCO World Natural Heritage site for its outstanding geoheritage value in 2007, and three lava tube caves (Utsanjeongul, Bukoreumgul, and Daerimgul: '-gul' or '-donggul' at the end of some words means 'cave' in Korean herein) were recently added on the World Heritage List in 2018. Especially lime-decorated caves such as Yongcheondonggul and Dangcheomuldonggul played a critical role for the inscription. In addition to geoheritage values of some lava tube caves, Jeju Island is characterized by numerous and diverse volcanic landforms (Woo et al., 2013). As a result, the whole Jeju Island was endorsed as a UNESCO Global Geopark in 2010 based on international significance of geological values. Mangjanggul and Ssangnyonggul-Hyeopjaegul in Hallim Park are main geosites as tourist caves in the geopark. Because Jeju Island is surrounded by shallow seas (mostly about 100 m in water depth), it is expected that more submerged lava tube caves which formed during glacial periods, are expected to be distributed in the sea during lower sea level.

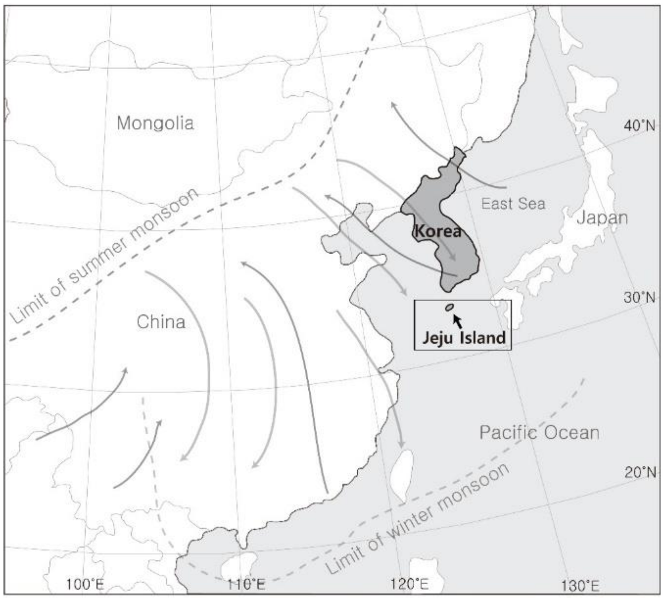

Figure 1: Location of Jeju Island.

Legal protection of natural caves in Korea

All natural caves as well as animals, plants and significant geological elements (fossils, minerals, rocks and other geological features) are protected by the Cultural Heritage Protection Act since 1983 (www.law.go.kr/main.html, accessed 2007.08.17) and by the Act on Protection and Inspection of Buried Cultural Heritage (elaw.klri.re.kr/kor_service/main.do, accessed 2007.08.17) since 2011. The Cultural Heritage Protection Act is the strongest protection measure among all the other laws for nature protection. Once an area is designated by the Cultural Heritage Protection Act, it can be very well protected because permission is required for any development activities, even in buffer zones of the designated properties. Caves with the highest scientific value are designated as a natural (national) monument, provincial monument or cultural property materials in order (Woo and Kim, 2018).

Caves that are not designated as above are protected by the Act on Protection and Inspection of Buried Cultural Heritage. Also, for adequate and effective conservation and management of natural caves (including tourist caves), the Cultural Heritage Administration published the Guideline for Conservation and Management of Natural Caves in Korea in 2000, which has been revised several times since. This includes how to investigate and manage legally protected natural caves (Woo and Kim, 2018). It is estimated that there are over 1,500 caves in Korea. At present, only 39 caves are protected as natural and provincial monuments and 13 caves in Jeju Island are legally protected (*Table 1*). No cave has been designated as a 'Cultural Property Material' in Jeju Island. All other caves which are not designated are protected under the Act on Protection and Inspection of Burial Cultural Heritage.

Table 1: The list of natural and provincial monuments of lava tube caves in Jeju Special Self-Governing Province, Korea. "-gul" or "-donggul" means "cave" in Korean.

Types of protection	Cave name	Monument no.	Date of designation
Natural monument	Gimnyeonggul and Manjanggul	98	7 December 1962
	Lava tube area in Hallim (Socheongul, Hwanggeumgul and Hyeopjaegul)	236	30 September 1971
	Billemotdonggul	342	14 August 1984
	Dangcheomuldonggul	384	30 December 1996
	Yongcheondonggul	466	7 February 2006
	Susandonggul	467	7 February 2006
	Bengdwigul	490	15 January 2008
	The Upper Geomunoreum Lava Tube System (Utsanjeongul, Bugoreumgul and Daerimgul)	552	4 January 2017
Provincial monument	Bugchondonggul	53	7 October 1999

Evaluation criteria

This study provides the scientific basis for geoheritage assessment of lava tube caves in Jeju Island. The criteria used for evaluation consist of (1) dimension (total length, the length of main passage, width and height of the passage, etc.) (2) shape of the passageway inside cave (the degree of multi-levels, the number of divided passages without merging downstream, labyrinth type and anastomosing patterns, etc.), (3) distribution, diversity, size and peculiar shape of internal micro-topographic features and lava speleothems, (4) distribution and diversity of secondary cave minerals which formed by seepage of groundwater into lava tube caves, (5) presence of special sites (lake, submerged passage, brackish water with halocline) as well as cave sediments which may be useful for paleoenvironmental or paleoclimatic reconstruction, (6) presence of cave system (a series of lava tube caves separated by later collapse of surface) which enable to understand the source of lava and the direction of the cave system development and (7) conservation status (intactness) of internal features to delineate the formation process of lava tube caves. These criteria for geoheritage evaluation are listed in *Table 2* and *Table 3*.

Table 2: Evaluation criteria and division standards for class A and B of lava tube caves in Jeju Island. Representativeness and rarity are applied for all the criteria except for intactness. The type of Class is determined based on the highest evaluated result among all the criteria. When a cave has more than two criteria for Class B, it can be considered to be eligible for Class A through discussion among evaluators. The evaluated result should be approved by the Heritage Committee of Cultural Heritage Administration and Jeju Special Self-Governing Province for the suggested result to be finally accepted.

Criteria	Class	Division					Remarks
Cave dimension	A	>3 km					
	B1	>1.5 km					
	B2	>0.5 km					
Micro-topographic features and lava and secondary speleothems		Distribution of lava speleothems and topographic features	Distribution of secondary speleothems	Density of lava and secondary speleothems	Presence of rare size	Presence of erratic shape	Rare size and erratic shapes should be analysed through comparative analysis.
	A	>300 m	>50 m	Common	Present	Present	
	B1	>200 m	>30 m	Rare			
	B2	>100 m	>10 m	Present			
Presence of special sites (lakes, halocline, sediments, authigenic minerals, guano deposits, etc.)		Presence of lake or submerged passage (length)	Presence of brackish water	Presence of cave sediments (thickness)	Presence of guano deposits	Presence of authigenic minerals in guano	After the presence of authigenic mineral is confirmed, the Class can be changed.
	A	>500 m	Present	>1.5 m	> 1m	Present	
	B1	>100 m		>1 m	> 0.5 m		
	B2	Present		>0.5 m			
Passageway pattern		Division of passages	Anastomosing Pattern	Multiple Levels			
	A	>15	>15	>5			
	B1	>10	>10	>4			
	B2	>5	>5	>3			
Integrity (wholeness); Evidence for a lava tube system		After the discovery of any evidence for the continued pattern of the lava tube system, all the lava tube caves follow the best Class evaluated within the system					
Integrity (intactness);		very good	good	moderate	poor	very poor	

the state of preservation	11~20	6~10	0~5	0~-10	-11~-20	The Class can be changed due to this item.

Table 3: Evaluation criteria and division standards for Class C and D of lava tube caves in Jeju Island.

Criteria	Total point		Points given		Remarks
Cave dimension	40		2 points/10 m		Total points cannot exceed 40 points.
Passageway pattern	10	No. of passage division	>4	3	Divided passage means that they do not merge downstream.
			3	2	
			2	1	
		No. of anastomosing pattern	>4	3	Anastomosing passage means that they merge downstream.
			3	2	
			2	1	
		No. of levels	4	3	Separate levels are accepted despite the presence of partial collapse.
			3	2	
			2	1	
Micro-topographic features and speleothems	20		Distribution/ Density/ Erratic size and shape	0~20	Grading is achieved by speleologists.
Presence of special sites (the same as in Table 2)	10		Present	1~10	Grading is achieved by speleologists.
			Absent	0	
Integrity (intactness); the state of preservation	-10 ~ 20		very good	11~20	
			good	6~10	
			moderate	1~5	
			poor	-5~0	
			very poor	-10~-5	

The first criterion is the dimension of caves, which is the total length of caves as well as the size of passages (width and height). Because most lava tube caves in Jeju Island are less than 0.5 km in length, any caves exceeding this length can be considered to be valuable. However, even though a cave is longer than 0.5 km, it may be reconsidered before final classification if it contains very little internal features (lava and secondary speleothems and/or internal micro-morphologic features). The second is the development pattern of a passageway within lava tube caves. Division of passages refers to divided passages without merging whereas anastomosing pattern includes dividing and merging of the same passages. By combination of both, the development of cave passages can be quite complex (*Figure 2*). It is common to have multi-levelled passages due the subsequent lava flows after cave formation. Even if the same level in the cave is not continuous and became separated due the collapse of the floor, they should be considered as the same level. To be treated as a separate level, the space between two levels should contain the size of at least 50 cm in height.

The third deals with lava speleothems and micro-topographic features. Micro-topographic features provide valuable information on the flow pattern and types of lava. The subsequent lava flows within the caves may not be the same lava responsible for the formation of the cave. Numerous lava speleothems and micro-topographic features are known (Woo, 2005). Their characteristics not only provide significant scientific information on cave formation processes but also display magnificent views in lava tube caves (*Figures 3 and 4*). Also, it is not uncommon to observe rare size or shape of lava speleothems (*Figures 5 and 6*)

Figure 2: *Bilemotdonggul with an anastomosing passage pattern (Natural Monument No. 342).*

Figure 3: *Pahoehoe lava on the floor in Bukchondonggul (Jeju Provincial Monument No. 53).*

Figure 4: *Lava helictites in Bukchondonggul (Jeju Provincial Monument No. 53).*

Figure 5: *Erratic-sized lava stalactite in Bilemotdongul (Natural Monument No. 342).*

Figure 6: *Erratic-shaped lava stalactites in Bilemotdongul (Natural Monument No. 342).*

Also, secondary mineralization is commonly observed in any lava tube cave in the world, which is the fourth criterion. Opaline silica is a very common mineral which can be found in any lava tube caves of the Jeju Island (*Figure 7*), however it is also common to observed carbonate speleothems in some lava tube caves (*Figures 8, 9 and 10*), due to carbonate sand dunes overlying the caves which formed by transportation and deposition of carbonate sediments from nearby carbonate beaches (Woo et al., 2008b).

Figure 7: *Secondary mineralization (cave coral) composed of opaline silica in Bilemotdongul (Natural Monument No. 342).*

Figure 8: *Cave pearls composed calcite in Geonjigul*

Figure 9: *The passage of the Handeulgul covered with numerous calcareous flowstones.*

Figure 10: *Carbonate speleothem on the wall and floor of the Handeulgul. Note flowstone and rimstone are growing.*

Other minerals such as gypsum were also reported (Jeju Special and Self-Governing Province, 2012), and the gypsum is co-occurring with calcite and opal. It is notable that calcite and gypsum could be replaced by opal through diagenesis, probably due to climate change (Woo et al., 2008a). These kinds of mineralization forming secondary speleothems in lava tube caves may be able to provide significant information on paleoclimate changes on the surface.

Figure 11: *Cave passage filled with a stream in Joronggul.*

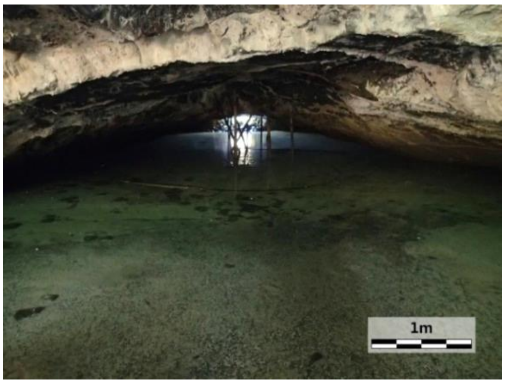

Figure 12: *Cave stream extended to the sea in Jaeamcheongul. Brackish water is present in the mixing zone between freshwater and seawater.*

The fifth criterion is the presence of special sites such as lake, stream (*Figure 11*), submerged passage brackish water with halocline (*Figure 12*), thick guano deposit (with an authigenic mineral), cave sediment, etc. Lakes and submerged passages contain water-dwelling cave fauna, but it may also contain submerged lava speleothems if the cave was formed during glacial periods when sea-level was lower than the present. In the submerged passage of the Yongcheondonggul, numerous lava stalagmites were observed, indicating that the cave formed during a glacial period. Because Jeju Island is surrounded by sea, some lava tube caves include freshwater, brackish water and seawater in the same cave, which may provide significant habitats for water-dwelling cave fauna as well as microbes. Lava tube caves in Jeju Island provide suitable habitats for bats, thus guano deposits are common. Even though mineralogical investigation has not been carried out, it is likely that new phosphatic minerals may be discovered in the future (Hill and Forti, 1976). In some lava tube caves, carbonate sediments are deposited on the cave floor which were originally transported from nearby carbonate beaches as mentioned above (*Figure 13*). Also, some lava tube caves include clastic sediments which were transported from overlying soils through cracks or skylights. It is observed that the sediment in Bilemotdonggul is as thick as 1.7 m (*Figure 14*).

Figure 13: *Carbonate sediments deposited on the floor in Geonjigul.*

Figure 14: *Cave sediments composed of muds derived from overlying soils in Bilemotdonggul (Natural Monument No. 342).*

The sixth criterion deals with geological wholeness of a lava tube system. Because lava tube caves are formed near the surface, it is very common that cave roofs collapse dividing them into separate caves. If the collapsed part is long enough, it is sometimes difficult to recognize the same cave system and this is the case for many lava tube caves in Jeju Island. It is geologically important to trace the origin of lava flows responsible for the cave formation to understand its formation process. Thus, if a series of caves is distributed in a linear pattern, lithologic and petrologic investigation may be necessary to understand the source of lava and lava flow pattern associated with the cave system. The last criterion is also an intactness which is the state of preservation. Some caves have been influenced by local development and vandalized. Also, local people used some caves for resting, economic or religious purposes. It is necessary to find out that those caves still retain scientific values to be properly classified and protected. Using the criteria above the basic concept for categorization is based on representativeness, rarity and integrity as commonly used for geoheritage assessment (Ju and Woo, 2018).

(1) Representativeness: Representativeness is defined as a geological phenomenon that indicates the best representative example of stratigraphy, palaeontology, geomorphology, etc., and contributes to further understanding of geological concepts, processes, and features (Ju and Woo, 2018). For the assessment of lava tube caves in Jeju Island, good representatives can be recognized if some caves display one of the best examples for the criteria mentioned above.

(2) Rarity: Rarity implies very peculiar features which are very rare compared to most other lava tube caves in Jeju Island.

(3) Integrity (intactness and wholeness): Integrity can be defined as a measure of the wholeness of the geological system or an intactness of a geoheritage conservation state in any geosites. Due to the fact that most lava tube caves are located very near the surface, the ceilings tend to be collapsed or rockfalls are very common from cave ceiling after cave formation and lava cooled down. Thus, intactness of a cave is very significant for continuous display of geoheritage values in any caves. The second one is the geological wholeness of the cave system. In Jeju Island, due to the collapse of the surface overlying lava tube caves, it is sometimes difficult to infer the source lava flows for their formation. Understanding the source area (commonly volcanic cones, *oreums* in Jeju dialect) can enable us to understand the volcanic activities responsible for cave formation.

Heritage assessment for ecosystem and biodiversity were also conducted but is not included in this paper. Biological criteria are: (1) diversity and population of cave organisms; (2) habitat suitability for cave organisms; (3) and the degree of adaptation of organisms in caves. Separate evaluation of the same cave will be carried out by cave biologists, and a compromise will be reached for the overall evaluation of a cave. Because most of the evaluation results can be subjective, the objectivity can be achieved by thorough discussion among investigators before final decision.

Class Category

Based on geological (and also separate biological) criteria, caves can be evaluated and classified as four classes for protection as follows:

Class A (national and natural monument): Natural monument has the highest scientific (geological and biological) significance. This cave includes features of national and international geoheritage value and is designated under Cultural Heritage Act by Cultural Heritage Administration after review by national heritage committee. Natural monuments (Class A) are protected under the Cultural Heritage Protection Act. Any environmental change within the buffer zone should be approved by the natural heritage committee of the Cultural Heritage Administration. Buffer zones are determined considering various threats to the property.

Class B (provincial monument and monument): Provincial monument (B-1) and 'Monument' (B-2, also called 'Cultural Property Material' by the Korean Government) have high scientific value of provincial and regional level for protection. Both of them are directly managed by the provincial government. Provincial monument (Class B) is protected under the Cultural Heritage Protection Act whereas Monument (Class C) is protected by ordinance of the provincial government. Any environmental change within the buffer zone should be approved by the Natural Heritage Committee of the provincial government. Buffer zones are determined considering various threats to the property but they are not usually as strict as those of natural monuments.

Class C: Caves with potential geoheritage values, thus necessary for conservation. This class is considered as a burial heritage. This class is protected under the Act on Protection and Inspection of Buried Cultural Heritage and also by the ordinance of local government. Cultural property material and buried monuments have relatively low scientific value and are not directly managed by local government, however permission for the entry to these caves or their utilization for private or public use should be obtained by provincial government via local county government.

Class D: Caves without geoheritage values, thus not necessary to be protected.

Even though it may be ideal to make the heritage assessment objectively, we found out that it is not possible to do so for Class A and B after thorough discussion. It was decided that the evaluation for Class A and B needs to be carried out subjectively based on the criteria given (*Table 2*). However, classification assessments for Class C and D are made by quantitative analysis in addition to compiled subjective evaluation by speleologists. Based on the individual criteria and associated rarity, representativeness and integrity (*Table 2*), Class A and B are evaluated. If one criterion has the highest evaluated heritage value among all the criteria assessed, the result of that criterion will be given for the Class. If more than two criteria are evaluated as B-1 and/or B-2, the class can be considered to be promoted to one higher level. Class C and D are based on five criteria: (1) dimension of a cave, (2) development of cave passageways, (3) distribution, size and diversity of lava and secondary speleothems, (4) presence of special sites and (5) degree of conservation (*Table 3*). The evaluated, quantitative data are added by the separately assessed qualitative result by speleologists. If the compiled points are less than 20 after assessment, those caves are classified into Class D. If the degree of conservation is not in good condition, Class C can be downgraded into Class D. If the cave system is recognized for the source and direction of lava flows to delineate the formation process of a series of lava tube caves, the cave classified as Class D should be upgraded to Class C.

Evaluation Result

Heritage evaluation was carried out for the northwestern part of Jeju Island from November 2019 to May 2020, and another is currently being conducted for northwestern part. This evaluation was only based on geoheritage values alone. As mentioned above, Class A and B were classified after subjective evaluation process whereas Class C and D were conducted by quantitative methods with minor input of subjectivity by evaluators (*Table 3*). Decision of assigned points for each criterion may be subjective, but it was decided after thorough discussion among experienced speleologists. Among the caves investigated in the study area, no cave was evaluated as Class A. Five caves for Class B-1, 7 for Class B-2, 9 for C Class and 5 for Class D were recognized (*Table 4*).

This investigation was carried out only in the northwestern part of Jeju Island. Continuous investigation for the rest of the island in the future would make these evaluation criteria more objective. Because lava tube caves in Jeju Island contain other heritage values, additional investigation should be necessary for biological, archaeological, historical and cultural heritage values independently. The final results for all the heritage values will provide the basis for legal protection by the Korean Government and effective management and utilization for geotourism in the future.

Table 4. Evaluation result of all the lava tube caves investigated in the northwestern part of the Jeju Island investigated in this study.

Class	Cave name	Total length (m)	Description		Remarks
B-1	Oksanigul	390	Well preserved speleothems and micro-topographic features		
	Gamnamdapgul	800	Well preserved micro-topographic features such as lava tongue, lava toe and bench		
	Jaeamcheongul	128	Presence of brackish water with halocline, carbonate sediments		Manmade infrastructure needs to be removed.
	Handeulgul	1,440	Well displayed lava and carbonate speleothems and micro-topographic features		This cave may belong to the same cave system with Socheongul upstream
	Guringul	325	Sinuous pattern of passageway, well preserved		
B-2	Seonggul	940	Good micro-topographic features		
	Chogiwatgul	1,290	Many divisions, labyrinth type		These three caves may belong to the same cave system.
	Geonjigul 1	230	Carbonate speleothems and sediments		
	Geonjigul 2	335	Carbonate speleothems		
	Paljagul	210	Well preserved, multiple divisions and levels		
	Joronggul	140	Submerged passage, two levels		
	Pyeonggul	285	Two levels, Lava tongue and bench, labyrinth type passage, lake		
Class	**Cave name**	**Total length (m)**	**Points from 5 criteria in Table 4**	**Total points**	**Remarks**
C	Gupeunoreumseogul	95	18+3+3+1+5	30	Two levels, 2 divisions
	Gunnambilemotgul	70	14+1+5+0+8	28	One division
	Saengjaengiwatgul	45	8+4+5+0+7	24	
	Jeonggusugul	80	16+2+2+3+0	23	Two levels
	Eoeumnigul	80	16+3+8+0+3	30	Two anastomosing passages, two levels
	Yeongchanggul	53	10+0+3+7+0	20	Sediments (<20 cm)
	Kutnangmotgul	33	6+1+7+0+12	26	One division
	Gosanidonggul	250	40+1+7+2+5	55	Two divisions, sediments
	Ggwangnangmotgul	45	8+0+3+5+6	22	Guano deposits (<30 cm)
D	Dongmulmokigul	25	4+0+1+0-5	0	
	Ggeulwatdidonggul	18	4+0+1+0+10	-6	
	Jagunaegeorigul	22	4+0+1+0+5	-1	
	Gaegumidonggul	18	4+0+1+0+0	5	Scoria bed

Summary

Lava tube caves in Jeju Island were evaluated based on geoheritage values. The criteria for assessment based on geoheritage values are developed considering the overall characteristics of the caves in Jeju Island. Four classes were classified based on eight individual criteria. This assessment will provide the basic information on legal protection of the lava tube caves by the Korean government and effective management in the future.

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SPATIAL DISTRIBUTION CHARACTERISTICS OF THE NÂM B'LANG VOLCANO LAVA TUBE SYSTEM, DAK NONG UNESCO GLOBAL GEOPARK, VIETNAM

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Abstract

News on the discovery of the volcanic lava tube system around the Nâm B'Lang (Chu B'luk) Volcano, Daknong Geopark has been reported recently by many domestic and international media. Several exploration expeditions have been conducted by international researchers such as Tsutomu Honda et al. (2013-2014), Michael Laumanns et al. (2014-2017).

During the inventory of geoheritage and preparation of the dossier of the Daknong Geopark to UNESCO in 2018, VIGMR carried out another extensive survey and paid attention to the spatial distribution characteristics of these lava tubes, their identification signs on the ground surface and their development and connectivity underground.

In total about 50 lava tubes have been mapped, but the findings of these studies show a considerable potential for searching and discovering more new lava tubes. Interestingly, other related research by Vietnamese archaeologists found lots of evidence of pre-historic human settlements inside these tubes, making them even more valuable for science and education. The discovery and research of the Nâm B'Lang Volcano lava tube system open great opportunities for other conservation and tourism promotion related activities of the Geopark.

Riassunto

Le notizie sulla scoperta del sistema di tubi di lava vulcanica intorno al vulcano Nâm B'Lang (Chu B'luk), Daknong Geopark, sono state riportate di recente da molti media nazionali e internazionali. Diverse spedizioni esplorative sono state condotte da ricercatori internazionali come Tsutomu Honda et al. (2013-2014), Michael Laumanns et al. (2014-2017).

Durante l'inventario del geopatrimonio e la preparazione del dossier del Daknong Geopark all'UNESCO nel 2018, VIGMR ha effettuato un'altra vasta indagine e ha prestato attenzione alle caratteristiche di distribuzione spaziale di questi tubi di lava, ai loro segni di identificazione sulla superficie del suolo e al loro sviluppo e connettività sotterraneo. In totale sono stati mappati circa 50 tubi di lava, ma i risultati di questi studi mostrano un notevole potenziale per la ricerca e la scoperta di nuove gallerie di scorrimento.

È interessante notare che altre ricerche correlate degli archeologi vietnamiti hanno trovato molte prove di insediamenti umani preistorici all'interno di questi tubi, rendendoli ancora più preziosi per la scienza e l'istruzione.

La scoperta e la ricerca del sistema di tubi lavici del vulcano Nâm B'Lang aprono grandi opportunità per altre attività legate alla conservazione e alla promozione turistica del Geoparco

Key words: lava tube, volcanic cave, Vietnam, geopark.

INTERESTING MORPHOLOGIES IN A SMALL LAVA TUBE IN THE LAVA FLOW OF "PIANO CANNELLI", MT. ETNA.

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Abstract

In the Pedara area of Mt Etna, in the location called *Passo Cannelli*, there are some volcanic caves. One of these, a small lava tube, named *Grotta dei Rovi a Piano Cannelli*, contains interesting morphology: some small, blind holes on the floor, on the walls and in the roof.

The observation of these peculiar morphologies has led to a hypothesis: they are small tubes generated by carbonisation of shrubby plants, probably broom (*Genista aetnensis)*.

The bushes were engulfed by the lava flow. They were consumed with an anoxic combustion of wood, leaving behind the small cavities. These are oriented due to the original geometry of the branches.

Inside the cave secondary crystallizations were sampled and the mineralogical classification is in progress.

Riassunto

Sull'Etna, nel territorio di Pedara, in località Piano Cannelli, alcuni anni fa ci è stata segnalata la presenza di alcune cavità: Le esplorazioni effettuate hanno consentito di identificare due cavità, una di queste, battezzata Grotta dei Rovi a Piano Cannelli, se pur di modeste dimensioni è risultata estremamente interessante a causa di alcune morfologie riscontrate sia sul pavimento che sulle pareti e sulla volta.

Si tratta di alcuni incavi, a fondo cieco che risultano isorientati a coppie. Lo studio geometrico delle forme e l'osservazione delle morfologie hanno portato all'ipotesi illustrata in questo lavoro. Gli oggetti osservati sarebbero il risultato della carbonizzazione di piante arbustive, probabilmente Ginestra dell'Etna (*Genista aetnensis*) che essendo coinvolte dal flusso lavico sono state carbonizzate lasciando l'impronta sulle parti della galleria di scorrimento. Al momento del ricoprimento, la volta, le pareti e il pavimento, presentavano condizioni di fluidità minori quindi una reologia inferiore rispetto alla parte centrale del flusso all'interno del tubo di lava.

All'interno della grotta sono state campionate cristallizzazioni secondarie le cui determinazioni mineralogiche sono in corso.

Key words: lava tube, volcanic cave, stone guns, Etna.

Introduction

The lava flows of Mt. Etna contain two-hundred and more volcanic caves that were generated in different ways and show different morphologies; during our exploration activity we concentrated on a small lava tube in an old lava flow: the *Grotta dei Rovi* at *Passo Cannelli*.

We were intrigued by some small holes in the floor and in the top of the gallery that matched in their orientation. In this paper we will describe the cave and this new morphotype and we will suggest a hypothesis as to the genesis of these holes.

Geography and Geology of the area

The *Grotta dei Rovi a Passo Cannelli* is located on the South side of Mt. Etna in the small plain which bears the same name and is characterized by a "blocks lava" ("a'a") flow.

The cave can be reached by driving on the *Salto del cane* road for about 8.5 km from Nicolosi. It is located in a private area and its entrance is closed by a gate, beyond which a short walk (600 m) northward will take you to the cave.

The GPS location of the cave is 37°40'18.04"N 15° 1'29.75"E (WGS84 datum), the altitude is 1313 m above sea level (Figure 1). The entrance is on the east side of a small pahoehoe lava flow (Figure 2).

Figure 1: Satellite image of the area (Google Earth).

Figure 2: Entrance to the cave (ph. G. Priolo).

The lava flow of the area is related to eruptive activity of *Tarderia Volcano* (about 100, 000 years ago) and is characterized by massive lava flows interbedded with epiclastic deposits composed of sandy matrix containing blocks, of variable size, of the associated lava flows. The lava composition ranges from havaiite to benmorite, and the texture is porphyritic with phenocrysts of plagioclase, pyroxene and olivine. The maximum thickness of the lava is over thirty metres.

The plant cover is characterized by genista plants, with the dominance of endemic *Genista aetnensis*. This species in very important for this study.

The cave and its morphologies

The *Grotta dei Rovi* at *Piano Cannelli* is a typical Etna lava tube. The exploration and the data collection have been carried out by a team of Gruppo Grotte Catania of Club Alpino Italiano on January 26, 2020. The tools that were used are a Suunto compass and inclinometer and Leica A3 Disto. The drawing was made by Giuseppe Priolo and Marco Ragusa using cSurvey software

The lava tube is only 63 m long, but it features some interesting morphologies. The gallery has a half-moon shape oriented towards the West.

Entrance to the gallery is through a side entrance where the lava carapace has not completely sealed the lava tube (Figure 3).

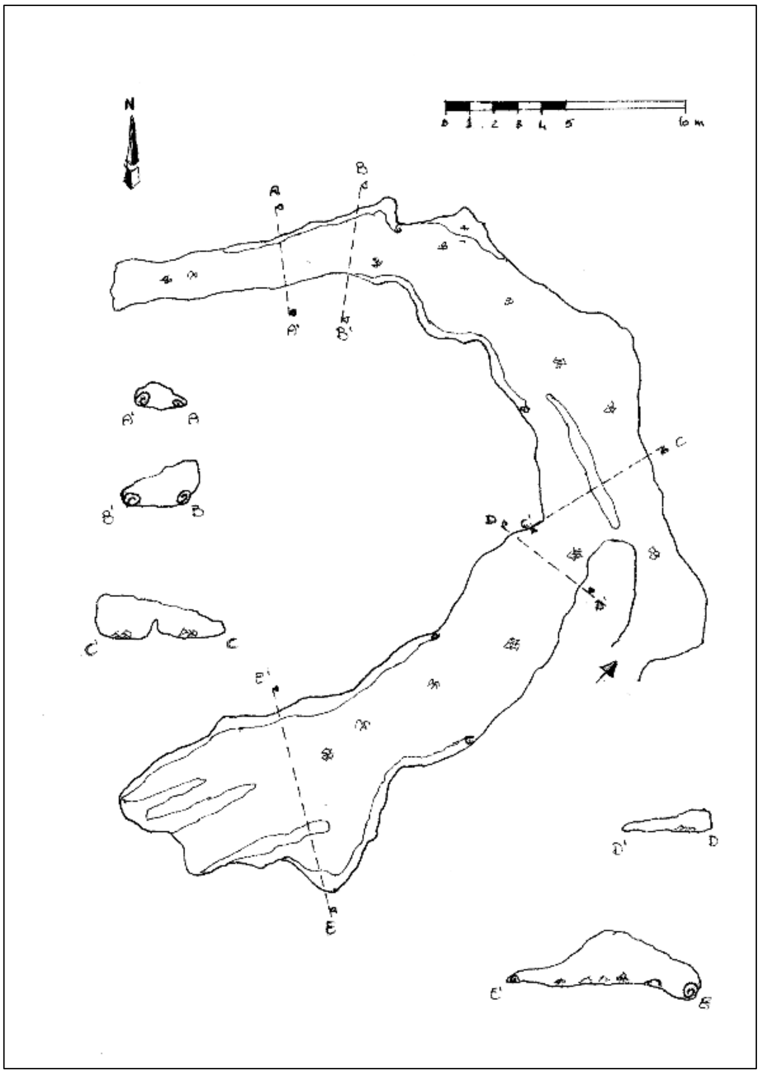

Figure 3: Planimetry and sections of the cave.
Data collection: Belfiore A., Bucolo C., Cotechini R., La Loggia F., Priolo G, Raciti S. and Ragusa M, 2020.
Drawing: Priolo G. and Ragusa M., 2021.

In the first section of the cave, the original flow is covered by some centimetres of pyroclastic products (sand and small lapilli); some lava blocks can be found in this part of the cave (Figure 4) where it is not possible to stand up due to its limited height.

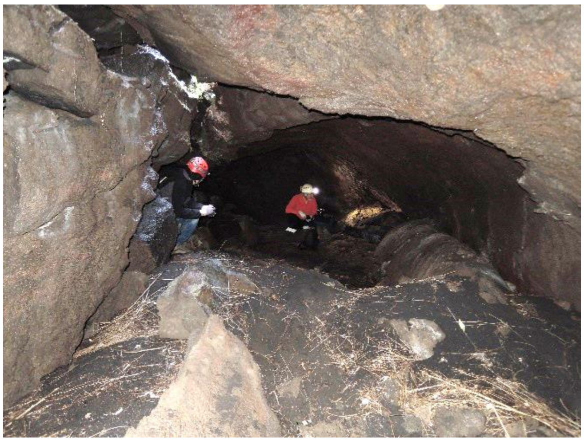

Figure 4: Sand and small lapilli in the lava tube (ph. S. Raciti, 2020).

The next part of the lava tube is characterized by some blocks of lava that collapsed from roof and sides (Figure 5).

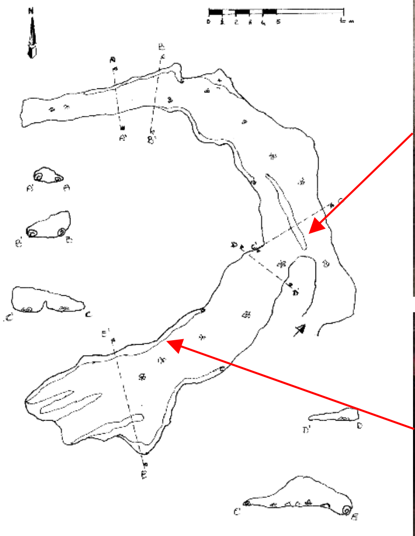

Figure 5: A detail of the lava tube with collapsed from the roof (ph. S. Raciti, 2020).

Figure 6: Lava rolls in the SW section (ph. S. Raciti, 2020).

In the other parts of the cave, it is possible to observe different morphologies: lava rolls (Figure 6), recasts, small blisters and some weird small holes.

The floor in this part of the cave is made up of smooth lava rock with some small pahoehoe morphologies.

During the exploration of the cave, we picked some samples of secondary mineralization. The analysis of these samples has identified *Gypsum* (Ca_2SO_4) and *Thénardite* (Na_2SO_4).

Exploring the cave, what intrigued us the most were some strange small blind holes in the floor and in the roof of this cave. These morphologies, located in the north part of the cave, are unusual in Mt. Etna's lava tubes (Figure 7).

Figure 7: The small blind holes in the lava tube (ph. S. Raciti, 2020).

The peculiarity of these blind holes is that each hole in the floor matches a blind hole in the roof. At first, we thought that for each hole in the floor we would find a corresponding through hole in the roof, but that was not the case: the corresponding holes in the roof were blind too. So, the question is: what is the origin of these matching holes? Why are they both in the floor and in the roof of the cave?

Hypothesis on the "blind holes" morphology

The morphology of the holes, their position and their size led us to make a comparison with the most famous holes in the lava flow: what local people call "the gun stones" (Figures 8 and 9).

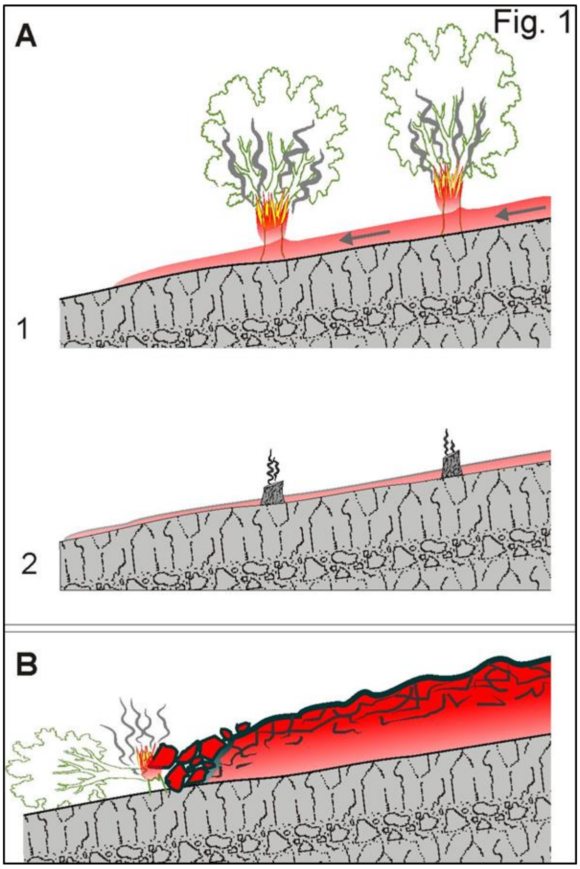

Figure 8: Etna's gun stone (ph. G. Priolo, 1998).

Figure 9: Genesis of stone gun (ph. Carveni et al, 2007).

If we apply this model to the small holes observed in the *Grotta dei Rovi* at *Piano Cannelli* we can get a hint as to the origin of this phenomenon. The geometry of the holes leads us to make the hypothesis that the plant carbonized by the lava flow is a typical shrub that grows on the slopes of Mt. Etna: the *Genista aetnensis.*

If we compare the primary branches of a Genista plant with the holes on the floor of the cave it is simple to match the two geometries (Figures 10 and 11).

This is the timetable (hypothesis) for the genesis of the blind holes:

1. The lava flow makes a lava tube.
2. The lava flow impacts the Genista.
3. The lava envelops the shrub (similitude with gun stones).
4. The low temperature and high viscosity of the outer part of the lava tube and the lack of oxygen activate the process of carbonization of the branches, so that they leave a circular imprint.
5. The high temperature and low viscosity of the inner part of the lava tube burns the central part of the branches without leaving any trace of them.

Figure 10: Genista aetnensis *(ph. G. Priolo, 2020).*

Figure 11: Holes on the floor and roof (ph. S. Raciti, 2020).

Conclusions

The *Grotta dei Rovi* at *Piano Cannelli* features unusual morphologies: some blind holes both in the floor and in the roof. The study of such unusual features allows us to better understand the rheology of lava flows.

The geometrical location of the holes, their dimensions and their depths led us to think that their origin most likely is due to the carbonization of primary branches of the plants of *Genista aetnensis.*

The genetic mechanism of the holes, for the authors, is comparable to the genesis of the gun stones. The lava envelops the branches of *Genista aetnensis*, it destroys the part which is in contact with the fluid phase in the lava tube and it retains an imprint of the lower part of the branches in the floor of the lava tube and of the upper part of the branches in the roof. The very viscous lava and the absence of oxygen carbonize the wood of the branches generating the circular imprint.

We hope, in coming months, to start sampling micro residues in the blind holes to search for organic residues and come up with the genetic determination of the species of shrub involved.

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SYMPOSIUM DAY 2, TUESDAY 31 AUGUST (continued)

PAPERS

Session 3: Botany and Biology in volcanic caves

Mico-Speleologic finds on Mt. Etna's volcanic caves (Gianrico Vasquez, Carmelo Bucolo, Elisa Musumeci).

Pahoehoe lava and endemic fauna of basaltic caves in Payunia, Malargüe, Mendoza, Argentina (Carlos Benedetto and Carlos D´Agostino).

Shedding light on long-eared bats (Plecotus spp.) from Sicily: more complex than we thought (L. Ancillotto, C. Bucolo, E. Musumeci, N. Tommasi).

Pleucotus spp. in a Mt. Etna cave. Author and year: *Priolo G., 2013*

MICO-SPELEOLOGIC FINDS ON MT. ETNA'S VOLCANIC CAVES

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Abstract

This study has the purpose to create a systematic framework of the fungal species found inside the lava flow caves of Etna. Afterwards, this study offers a detailed mapping of every single finding in the geographic and environmental context of the volcano Etna. The ecological role and modality of growth of the sporophores are important in this process to discover the ecological niche and the procurement capacity for every single species considering them into parasitism, symbiotic and saprotrophic relationship.

The peculiarity of some fungi is that they grow "head down" and they "instinctively" try to find an "erect" position, the easiest and the most logical way to put the cap in the best condition to disperse the spores, according to gravitropism.

Riassunto

Il seguente studio si pone come obiettivo l'inquadramento sistematico delle specie fungine individuate all'interno delle gallerie di scorrimento lavico (grotte vulcaniche) dell'Etna. Ne segue una mappatura dettagliata di ogni singolo ritrovamento nel contesto geografico e ambientale etneo. Particolare attenzione viene posta al ruolo ecologico e alle modalità di crescita dei singoli sporofori individuandone la nicchia ecologica e le capacità di approvvigionamento delle singole specie, delineandole all'interno del parassitismo, della simbiosi micorrizica o del saprotrofismo. La particolarità di alcuni funghi è che crescano a "testa in giù", cercando "istintivamente" di trovare una posizione "eretta", la via più semplice e logica per mettere il cappello nella migliore condizione per poter disperdere le spore, secondo le leggi del geotropismo gravitazionale.

Key words: Fungi, Etna, volcanic caves, gravitropism, depigmentation, environment.

Introduction

In terms of biodiversity, it is believed that there are 1.5 million species of fungi, but only about 75,000 species (5% of the total) have been described so far. For a simple comparison it is estimated that there are 4.9 million species of arthropods and about 420,000 plants.

Fungi were originally placed within the Plant Kingdom, even if they lacked chlorophyll, by virtue of some cellular characteristics and for the presence of cellulose in the cell walls and above all for their immobility and for the macroscopic external appearance. Subsequently, this position was overcome above all in the consideration that fungi are organisms incapable of chlorophyll photosynthesis, therefore forced to take nutrients directly from the growth substrate, with cell walls consisting largely of chitin, a substance present only in some phyla of the Animal Kingdom and equipped with other peculiar metabolic and cellular characteristics: these are the reasons why fungi could not be considered vegetables.

Current systematic trends regard these living organisms as belonging, independently of all other organisms, to the Fungi Kingdom.

Green plants (autotrophic organisms) using water, oxygen and mineral salts, thanks to chlorophyll photosynthesis, are able to independently synthesize the sugars and starches they need to live.

On the contrary, the fungal organism must find a nutrition already elaborated by other living beings as it is unable to implement this process. Mushrooms for this characteristic are therefore defined as "heterotrophic organisms" and to obtain the substances already processed they need, they use three different nutrition strategies: parasitism, saprophyticism and symbiosis.

Parasitic fungi feed at the payment of other living organisms: plants, animals, or even other fungi themselves. They can harm or even kill the guest, but even when they do not cause any obvious damage, they do not bring any benefit. In particular, the macromycetes, which are those that interest this research most, carry out their action mainly to the detriment of higher plants. Although these fungi perform a destructive action, they are useful for the environment as they perform a selective function towards those weak plants, already sick or forced to live in an unsuitable environment.

Saprophytic fungi, or rather saprotrophic, are those that feed on organic matter of the most varied origins: dead animals, wood residues, leaves, excrements, etc. They are formidable biodegraders and their contribution is essential to allow the subsequent attack by bacteria and the return to the ecosystem of the elementary substances of which the original organism was composed. The relative ease with which it is possible to reproduce their growth substrate has meant that some edible saprophytic fungi are widely cultivated.

In the end, symbiotic fungi are those that ultimately establish an intimate connection between the fungal mycelium and the root of the plant. Through this union, fungus receives already elaborated substances from the plant, while the plant uses the fungal mycelium to extend its root system through which it collects water and mineral salts. It has been shown that mycorrhized plants have a significant advantage in terms of growth and greater resistance to critical events such as drought or attack by parasites. Some of the most sought-after species for consumption, such as “porcini” and truffles, belong to this category. Mycorrhizae are symbiotic formations of a mutualistic type between fungi and roots of higher plants: the fungus absorbs water and mineral salts from the soil which it partially yields to the plant, which, in turn, makes organic carbon available to the heterotrophic symbiont (continuous and reciprocal exchange).

Purpose of the research

This work was carried out because there is very little information available in the literature showing the findings of fungi in underground environments (fruit bodies developed not on organic substances but perfectly integrated with the "cave" ecosystem), those of the volcanic caves of Etna.

The purpose of the survey is the systematic and taxonomic study of the hypogeal mycological flora of Etna concerning the class of *Basidiomycetes* and *Ascomycetes*, at a specific and intraspecific level. The scientific research activity was carried out primarily with macroscopic, microscopic and macrochemical analysis for the determination of the fungi found. In addition to these initial investigations, further molecular investigations are underway for the most interesting findings.

The aims of the research can be summarized as follows:

- Systematic and taxonomic study at a specific and intraspecific level of the hypogeal mycological flora of the Etna lava flow caves.
- Census and georeferenced mapping of the species found.
- Parallel studies on the flora of mushrooms in Sicilian karst caves and in other Italian caves and foreign regions caves.

Census and mapping of the cave mycological flora were carried out in situ for all the species, taking several samples from time to time to be studied and further analysed in the laboratory.

The research phases lasted about 2 years (from June 2019 to September 2021) and were divided into several missions inside the Etnean caves, each time preferring a different area, also depending on the current weather and environmental conditions of the moment. It was useful and valuable to simultaneously carry out parallel studies on the hypogeal mycological flora of the remaining Sicilian territory (Figure 17) and in other Italian and foreign regions, to be able to compare the Sicilian samples with those coming from other non-Sicilian growth stations.

The data obtained not only made it possible to formulate a complete list of the species found, with the respective slides and digital photographs taken in situ and in the laboratory, and the respective desiccated specimens preserved in special herbaria, but above all, they allowed an easy comparison of the critical samples of doubtful systematic placement with reference samples already known. These interesting findings are the basis of new further taxonomic studies that cannot ignore microscopic and especially biomolecular investigations.

Carrying out these studies, it has proved the indispensable and fundamental importance to always consider the relationships between the fungi studied and the host mycorrhizal plants that grow outside the hypogeal environment, and between the hypogeal environments of the various stations where the investigations were done. And then again, to relate the collections made with the other fungal species present at the same time and place of growth outside the cave environments (Figure 4, *Xerocomus subtomentosus*).

As soon as in possession of a complete and satisfactory checklist and an adequate geo-referenced mapping of the found mushrooms (including the smaller islands), the purely diagnostic discourse took over. The investigations resumed dated searches for fungal findings belonging to the particularly curious Boletaceae, carried out at the Grotta Immacolatelle-Micio Conti di San Gregorio in Catania (VASQUEZ, 2002, *Figures 1, 2 and 3*), and at the Cava Sture on Iblei's mountains (CHIARENZA, 2009, Figure 17); these studies were still fragmentary, for that it was decided to deepen them and complete them with the new data acquired.

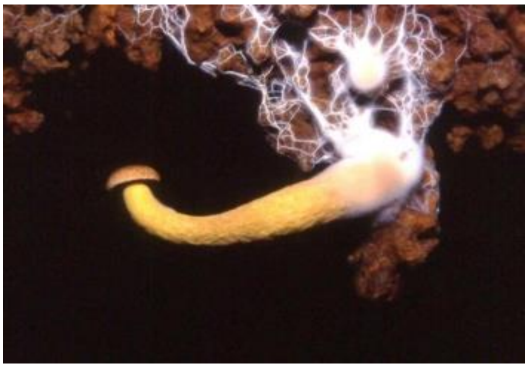


Figure 1: Xerocomus sp.

Figure 2: Xerocomus sp.

Figure 3: Xerocomus sp.

Figure 4: Xerocomus sp.

In order to achieve perfect positioning of their tubes in boleti for spore dispersal, fruiting bodies of higher fungi rely on the omnipresent force gravity. Only accurate negatively gravitropic orientation of the fruiting body cap will guarantee successful reproduction. Most likely every hypha in the transition zone between the stipe and the cap region is capable of sensing gravity. All photos by G. Vasquez, 2001.

Methods and materials

Census and sampling were carried out in various horizontal lava flow caves at the different slopes of Etna and at different altitudes. For the most part, caves were chosen that were located within woods or with a rich substrate. Caves in sterile lava fields were excluded.

After taking in situ, samples were stored in plastic jars with screw closure and temporarily preserved in the fridge at a temperature of about 4 ° C in order to maintain the morphological and organoleptic characteristics of the fruiting body and subsequently study the spores in the microscope to better determine the species. The recognition of taxa was also accomplished through a microscope or through photographs that were given to us by other different collectors.

The phases of the job search lasted about 2 years, and took place in the private homes of the authors, partly in the premises of the University of Catania (Botany Section) of the Botanical Garden in via Antonino Longo 19, and above all at the headquarters of the Bresadola Mycological Association of Catania, in via Macallè 18 (Catania), with the collaboration of the technical-organizational of the Scientific Committee of the Association itself, both local and national.

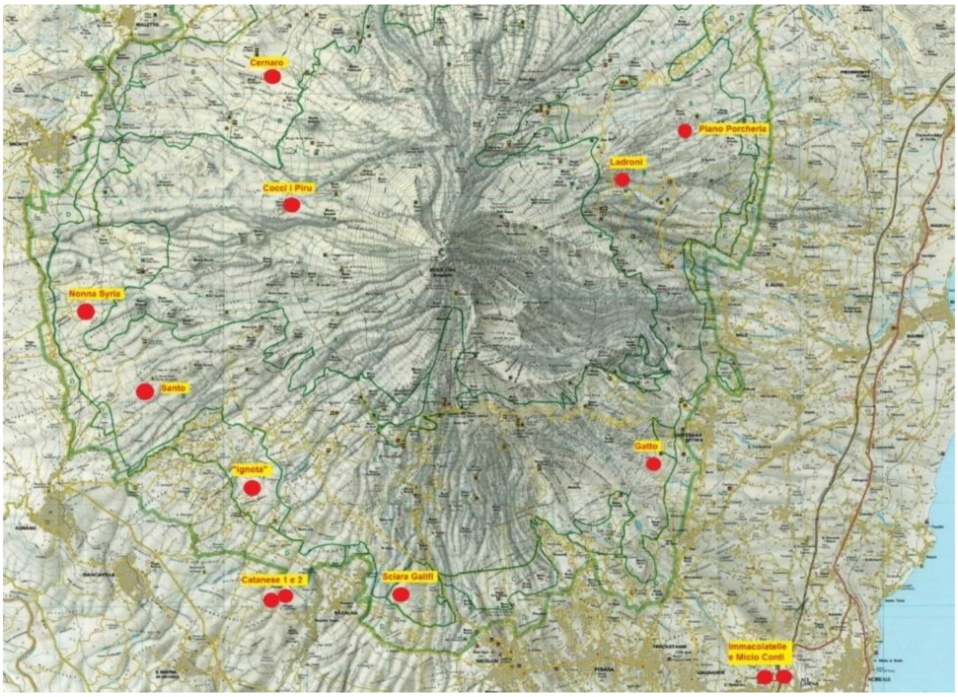
The research activity was carried out, for the correct determination of the fungi collected, through the following investigations:

- Bibliographic investigations;
- Field investigations;
- Macroscopic and microscopic investigations;
- Organoleptic investigations;
- Macrochemical and microchemical investigations;
- Edaphic-environmental and phytogeographic surveys;
- Molecular investigations (ongoing).

The obtained data made it possible to draw up a list of the species found and studied and an adequate georeferenced mapping of the collections. Almost all the findings have been documented in situ through digital photographs. The respective dried remains of the material in the photos were then preserved in the herbaria of the Bresadola Mycological Association of Catania and in the personal herbarium of the author Gianrico Vasquez.

The considered data to analyse the characteristics of the climate of the area in question in this research are obtained from the Ideological Annals of the National Hydrographic Service, referring to different rainfall stations of the Etna volcano. The years of pluviometric observation, the annual precipitation average, the annual temperature average, the monthly rainfall average and the monthly temperatures average of the Etna area, are all data reported and deducible from the thermodiagrams of Bagnouls and Gaussen (1952), built according to the specifications by Walter and Leith (1960). To determine the climatic bands of the studied areas, reference was made to the bioclimatic classification of Rivas Martinez (1993).

In order to highlight the obtained results, graphs and diagrams were created, relating to the families and genera of the species present, to the locality of origin of the samples (indicating the locality and municipality of belonging for each cave, see Map 1), to the substrate on which the specimen was found (soil, bark, other fungus, etc.), and specifying in which area or part of the cave from time to time samples were collected (on the floor, the walls or in the vault).



Map 1: Etna Park Map with the location of the 13 caves examined.

As regards macroscopic and microscopic investigations, the study observed mushrooms in fresh fragments or variously preserved and also, when deemed appropriate, desiccated mycological specimens kept in the herbaria of the Bresadola Mycological Association of Catania and in the Vasquez herbarium, at the private home of the author. Each time a sample to be analysed was acquired, the necessary observations of the collected material were made with an accurate description of the macroscopic characteristics of each fragment of fungus; various types of samples were divided the first of all by similarities of macroscopic characters, evaluating the presence or absence of hymenophore, the colour of the flesh, the colour of the cuticle of the cap and any other macroscopic characteristic that could be useful for the recognition of the species in question; for each type of sample found, was also carried out an additional fragment of the hymenophore (lamellae or tubules) or other fertile matrix, in order to fix a preparation for microscopic examination; in the case of fragments without a hymenophore, other microscopic elements were sought, such as the caulocystidia of the stem or the pileocystidia of the cap.

In doing this, great care has always been taken in clearly separating the specimens analysed, both belonging to the same taxa and to different taxa, to avoid possible contamination that would have distorted the results of the research; for this reason, the tools used (cutters, scalpels, slides, various blades and knives, object holders) were carefully sterilized and washed at the end of each working session.

In the research carried out, a Leica optical microscope with 10x, 100x and 1000x magnifications and integrated camera was used.

As regards macrochemical and microchemical investigations, the reagents used during this research are : Melzer's reagent, Cresile Blue, Ammonia, Cotton Blue, Congo Red, KOH, and simple distilled water reagents. These reagents were purchased, along with many others not used in research, by the company TITOLCHIMICA spa of Rovigo and are still kept at the headquarters of the Bresadola Mycological Association of Catania.

Discussion

Most of the samplings were carried out in an unfavourable season, in the period of June, with high external temperatures but nevertheless, in that period, several species were found thanks to the constant temperatures and humidity that are maintained inside the caves. Mushrooms have been found on the walls, roof or floors of natural cavities. It should be remembered that the thickness of the soil between the outside and the roof of the cave is only a few metres, so that fungi can penetrate through the micro-cracks present on the vaults of the caves themselves.

In Piano Porcheria cave, located within the forest property of Monte Crisimo, on the north side of Mt. Etna and at an altitude of 1110 m asl, samplings were carried out in a dense mature wood with chestnut trees (*Castanea sativa*), downy oak (*Quercus pubescens*) and other deciduous oaks of the group (*Quercus robur*) (POLI ET AL., 1981). This cave peculiarity is the presence of dense roots hanging from the vault and soil rich in debris and sand. The species found were some near the entrance and others in the larger room with hanging roots and dusty soil about 50 metres from the entrance, in particular on bat guano. The fungal species catalogued within this cave are part of the *Marasmiaceae*, *Omphalotaceae* and *Paxillaceae* families, and in particular the genus *Collybia* (Figure 11), *Collybiopsis* (*Collybiopsis peronata*) and *Melanogaster*: *Melanogaster ambiguus* (Figures 8, 9), a very interesting and rare find for Sicily, was collected in the most scoriaceous, darkest and deepest section of the tunnel about 100 metres from the entrance.

Also, at the Grotta del Santo a specimen of *Melanogaster ambiguus* (*Paxillaceae* family) was found on a fracture of the vault of one of the many parallel galleries present inside this cave, together with *Mycena pilosella* and other *Mycena* sp. (family *Mycenaceae*) not identified at a specific level, collected on pine cones and small pieces of wood (Figure 10). This time we are at 1043 m a.s.l. in the municipality of Adrano (CT), west side of Mount Etna.

Figure 5: Scleroderma sp.

Some Basidiomycetes fungi that have been found in natural volcanic caves of Mt. Etna ("Grotta Immacolatelle" R.N.I.), represent the first records of "mushroom caves" in Sicily. A. Reitano, 2001.

Figure 6: Xerocomus armeniacus *(G. Vasquez) 2015.*

Figure 7: Grotta Micio Conti (G. Vasquez) 2015.

Figure 8: Melanogaster ambiguus
(C. Bucolo) 2021.

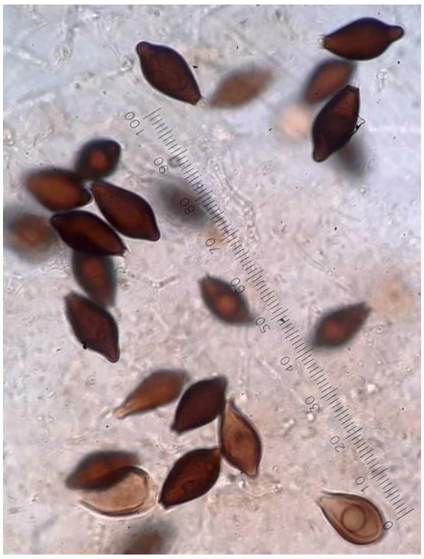


Figure 9: Spores of Melanogaster ambiguus
(G. Vasquez) 2021.

Figure 10: Collybia *on strobile of* Pinus
(C. Bucolo) 2021.

Figure 11: Collybia *on plant root residues*
(C. Bucolo) 2021.

Figure 12: Hymenopellis radicata *(C. Bucolo) 2011.*

Figure 13. Xerocomus armeniacus *(G. Vasquez) 2000.*

Figure 14: Xerocomus *(A. Reitano) 2001.*

Figure 15: Entoloma sp. *(C. Bucolo) 2018.*

Figure 16: Scleroderma verrucosum *(C. Bucolo) 2021.*

Figure 17: Xerocomus sp. *in karst cave of Sicily (G. Chiarenza, 2009).*

On the west side of Mount Etna at 940 m a.s.l. in Bronte municipality (CT), inside the Nonna Syria cave, several mushrooms were found in the deepest tunnel. On the roof, they found *Melanogaster ambiguus* (family *Paxillaceae*), while on the ground there were some dried fungi which, after a careful microscopic examination, they realized that they could belong to the genus *Laccaria* (family *Hydnangiaceae*). The environment outside the cave is characterized by a lava flow with some oaks and gorse.

In the Cave of the Thieves, or better known as the "Cave of the Thieves or of the Snow", a specimen of rooted *Hymenopellis* (family *Physalacriaceae*) was found on the ground in the room near the entrance (Figure 12). The cave is located in Sant'Alfio municipality (CT), east side of Mount Etna, at an altitude of 1547 m a.s.l. inside a dense birch forest (*Betula aetnensis*).

At an altitude of 910 m a.s.l. in Ragalna municipality (CT), on the southern side of Mount Etna, among ancient lavas dating back to the year 1000, stands the Sciara Galifi lava flow cave. The external environment is characterized by a classic lava "sciara" with the presence of some downy oaks, holm oaks, terebinths and hackberries. Inside the cave, in a secondary tunnel about 60 m away from the entrance, a *Scleroderma verrucosum* (family *Sclerodermataceae*) was found rooted on the floor in total darkness (Figure 16).

The Grotta del Cernaro is hidden among a dense forest of holm oaks (*Quercus ilex*), at an altitude of 1400 m a.s.l. in the municipality of Maletto (CT). Between the cracks in the vault and the side walls, several fungi of the genus *Collybia* (family *Omphalotaceae*) have been observed (Figure 11).

The Grotta del Gatto is a small lava flow cave immersed in an ancient chestnut wood (*Castanea sativa*) on the east side of Mount Etna at an altitude of 960 m a.s.l. in the municipality of Zafferana Etnea (CT). In the final section of the tunnel, about 25 metres from the entrance, various fungi of the genus *Gymnopus*, *Mycena* and *Tubaria* were found.

In the Immacolatelle and Micio Conti complex Nature Reserve, about 300 m a.s.l. , south side of Mount Etna, in San Gregorio municipality (CT), characterized by lava flows and virgilian oak woods (*Quercus virgiliana*), together with the *Quercus amplifolia* and *Celtis australis*, there are some caves where several species of fungi have been found during a long period. Among these, for example, in the Micio Conti cave, *Rheubarbariboletus armeniacus* (family *Boleataceae*) was found on the vault of the cavity (Figures 6 and 7), and on the floor (Figure 13) next to a lava roll and next to a little *Mycena* sp. (family *Mycenaceae*). In the largest cave of the whole complex, the Immacolatella 1 cave, splendid specimens of *Xerocomus subtomentonsus* (family *Boletaceae*, Figures 1, 2, 3 & 14) and *Scleroderma bovista* (family *Sclerodermataceae*, Figure 6) were found deep down and on the side walls. These last two findings took place inside the same cave and on the same site where they had already been photographed about twenty years earlier by Vasquez and Reitano (VASQUEZ, 2000).

The Cocci i Piru cave is a recently discovered lava flow cave located in the lava sciara near Mount Egypt in the municipality of Bronte, west side of Mount Etna at an altitude of 1600 m asl, inside which only certain fungi have been found through photographic finds (Photo Teri) such as *Scleroderma verrucosum* (family *Sclerodermataceae*).

At an altitude of 1220 m a.s.l. in the municipality of Biancavilla (CT), on the west side of Mount Etna, the presence of mushrooms is reported, through a photographic contribution, inside a still unknown cave.

Some other species can also be found inside the Catanese caves 1 and 2 in the municipality of Ragalna (CT), on the southern side of Mount Etna, at an altitude of 905 m a.s.l. The territory is characterized by a dense forest of holm oak, downy oak, terebinth and hackberry. Inside Grotta Catanese 1, the larger of the two, near the tunnel located in the largest room of the cave, a trunk with the aphilloforal *Stereum hirsutum* (*Stereaceae* family) was found. In the Catanese cave 2, about 10 metres from the entrance, a *Collybia* sp. (family *Omphalotaceae*) in a small tunnel buried by collapses, was found.

Results

Through the study of the collected and analysed fungi, it was possible to census 11 species of superior fungi (between *Basidiomycetes* and *Ascomycetes*) at a specific level; a further 11 species have been identified at a generic level. These species are included in the following 12 families: *Boletaceae* (genus *Xerocomus* in 2 caves), *Entolomataceae* (genus *Entoloma* in 1 cave), *Hydnangiaceae* (genus *Laccaria* in 1 cave), *Marasmiaceae* (genus *Collybiopsis* in 1 cave), *Mycenaceae* (genus *Mycena* in 2 caves), *Omphalotaceae* (genus *Collybia* in 4 caves), *Paxillaceae* (genus *Tapinella* in 1 cave), *Physalacriaceae* (genus *Hymenopellis* in 1 cave), *Polyporaceae* (genus *Fomes*, in 1 cave), *Sclerodermataceae* (genus *Scleroderma* in 3 caves), *Stereaceae* (genus *Stereum* in 1 cave), *Tubariaceae* (genus *Tubaria* in 1 cave). The aforementioned genera belong to the three trophic categories of saprotrophs (10 species on wood residues, roots, animal corpses and pine cones, as well as on bat guano), symbiotic species (3 species connected to the roots of higher plants) and parasite (on animals and organic remains).

Melanogaster ambiguus (Vittad.) Tul. & C. Tul., found in three different lava caves on Mount Etna, is considered a rare species in Sicily. Its semi-hypogeal growth in nature reflects the fact that this taxon has been able to find a profitable and ideal habitat, and no longer an occasional one, within the Etnean cavities. The evolutionary strategies and adaptations of this species will certainly be the subject of future observations and phylogenetic studies to highlight any differences with the specimens found on the surface.

Furthermore, has been created a database of the studied material, for the moment usable in stand-alone mode but which in the future will be available online, and a georeferenced mapping that allows to associate the findings made to the respective Etnean natural cavities.

Conclusions

All the organisms that live inside the caves require particular adaptations for the underground environment. Fungi grow almost everywhere, even inside volcanic caves, they grow on the walls, roofs and floors of Etna lava tunnels. Cave mushrooms are not cave-adapted mushrooms, but simply normal mushrooms, at least most of the species examined in this work, where caves are a general part of their habitat. The caves represent microenvironments similar to the natural habitat of the fungi in question, even if there is generally not enough food for them, they manage in any way to survive and perform all biological functions by exploiting the poor organic matter present or the roots of the plants that they live outside the cavity. Let us remember that the food chain inside the cave is very simple and that mushrooms represent the trophic basis for all other cave dwelling beings, starting with bacteria and detritivorous ones and ending with carnivores. The ecological role and the mode of growth of the sporophores are important to examine in this process to discover the ecological niche and the supply capacity for each individual species by considering them in relation to parasitism (parasites of plants and insects), symbiosis (symbiotic mycorrizes of higher plants) and saprotrophism (saprophytes of plants and animal remains). The adaptations of mushrooms grown in caves on Etna can be summarized as follows:

- Cap and stem depigmentation and of all micellar tissues;

- Fruiting bodies deformed and elongated for growth on a substratum that is often rocky and steeply inclined;
- Very slow biological cycle, facilitated by the constant conditions of the environment and the scarcity of predators;
- Gravitropism of fruiting bodies (gravitational geotropism).

Based on this last adaptation, examined fungi showed different peculiarities: the depigmentation of the fruiting bodies and the growth movement they have in response to gravity. This growth response to gravity is called gravitropism (also known as gravitational geotropism) and fungal gravitropism was little known until very recently (MOORE, 1991). Today, precisely due to the capacity of the fungal hyphae, in particular those placed between the stem and the cap of the fruiting bodies, fungi are even studied by NASA scientists. The peculiarity of these mushrooms is that they grow "upside down" and try "instinctively" to find an "upright" position, the simplest and most logical way to put the hat in the best conditions to disperse the spores, according to the rules of gravitropism . Finally, the lack of a real growth substrate and the almost total absence of litter, made it possible to examine and photograph, in the vast majority of cases, not only the fruiting bodies of the fungi, but also the intertwining of their mycelium and the beginnings fruiting bodies that derive from it.

Thanks

We wish to thank Eros Fichera and Salvatore Lo Iudice for participating in the sampling in the cave and Agatino Reitano and Gregorio Chiarenza for the photographic contributions. A heartfelt thanks also to the Bresadola Group Mycological Association of Catania and to all its members for making their scientific laboratory and mycological herbarium available, without whose contribution the work would not have been possible.

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Sitography

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Hypogeous fungi: www.sites.google.com/site/hongoshipogeos

International Code for Botanical Nomenclature: www.iapt-taxon.org

GROTTA	FAMIGLIA	SPECIE
Grotta Immacolatella 1	*Boletaceae, Sclerodermataceae*	*Xerocomus subtomentosus*, *Scleroderma bovista*
Grotta Micio Conti	*Boletaceae, Mycenaceae*	*Rheubarbariboletus armeniacus*, *Mycena* sp.
Grotta dei Ladri	*Physalacriaceae*	*Hymenopellis radicata*
Grotta di Piano Porcaria	*Entolomataceae*	*Entoloma* sp.
Grotta Cocci i Piru	*Sclerodermataceae*	*Scleroderma verrucosum*
Grotta dei Briganti	*Polyporaceae*	*Fomes fomentarius*
Grotta ignota	*Tubariaceae, Omphalotaceae*	*Tubaria* sp., *Collybia* sp.
Grotta di Sciara Galifi	*Sclerodermataceae*	*Scleroderma* sp.
Grotta Catanese 2	*Omphalotaceae*	*Collybia* sp.
Grotta Catanese 1	*Stereaceae*	*Stereum hirsutum*
Grotta del Santo	*Paxillaceae, Mycenaceae*	*Melanogaster ambiguus*, *Mycena* sp., *Mycena pilosella*
Grotta Nonna Syria	*Hdnangiaceae, Paxillaceae*	*Laccaria* sp., *Melanogaster ambiguus*
Grotta del Cernaro	*Omphalotaceae*	*Collybia* sp.
Grotta del Gatto	*Omphalotaceae*	*Collybia* sp.
Grotta di Piano Porcaria	*Marasmiaceae, Omphalotaceae, Paxillaceae*	*Collybiopsis peronata*, *Collybia* sp., *Melanogaster ambiguus*

Table 1: Species found in the caves.

CAVES	LOCALITY	ALTITUDE	COORDINATES	DATE
Grotta Immacolatella	San Gregorio	295 m a.s.l..	37.561046, 15.110229	ott- 00
Grotta Micio Conti	San Gregorio	300 m a.s.l.	37.572489, 15.115876	ott-15
Grotta dei Ladri	Sant'Alfio	1547 m a.s.l.	37.771604, 15.071868	ago-11
Grotta di Piano Porcaria	Linguaglossa	1110 m a.s.l..	37.797824, 15.108010	nov-18
Grotta Cocci i Piru	Bronte	1600 m a.s.l.	37.695284, 14.935423	apr-21
Grotta dei Briganti	Pantelleria	700 m a.s.l.	36.777611, 12.003394	giu-21
Grotta ignota	Biancavilla	1220 m a.s.l.	37.692867,14.918965	dic-20
Grotta di Sciara Galifi	Belpasso	910 m a.s.l.	37.633685, 14.971761	giu-21
Grotta Catanese 2	Ragalna	905 m a.s.l.	37.648262, 14.939667	giu-21
Grotta Catanese 1	Ragalna	905 m a.s.l.	37.648237, 14.939361	giu-21
Grotta del Santo	Adrano	1043 m a.s.l.	37.709164, 14.875873	giu-21
Grotta Nonna Syria	Bronte	940 m a.s.l.	37.728966, 14.849328	giu-21
Grotta del Cernaro	Maletto	1400 m a.s.l.	37.805909, 14.930775	giu-21
Grotta del Gatto	Zafferana Etnea	960 m a.s.l.	37.683066, 15.085756	nov-20
Grotta di Piano Porcaria	Linguaglossa	1110 m a.s.l.	37.797824, 15.108010	giu-21

Table 2: Data on the caves.

PAHOEHOE LAVA AND ENDEMIC FAUNA OF BASALTIC CAVES IN PAYUNIA, MALARGÜE, MENDOZA, ARGENTINA*

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Abstract

The importance of having discovered, in the volcanic district of Payunia, the most extensive flows of pahoehoe lavas on the planet is once again highlighted, which although they have not yet been explored stereologically, the bibliography was updated, and studies emerge that allow dating some from them.

Pahoehoe formations were studied from 3.8 million years to -10,000 years (Pliocene to Pleistocene). The recent discovery of a new family of troglobitic arachnids in a lava tube in the region is very relevant.

Chronology of the main scientific studies carried out in a basaltic area that includes three Argentine provinces.

Riassunto

Questo lavoro è il resoconto della ricerca svolta nel distretto vulcanico di Payunia, caratterizzato dai più estesi flussi di lave pahoehoe del pianeta. Le formazioni pahoehoe studiate sono datate da 3,8 milioni di anni a -10,000 anni (dal Pliocene al Pleistocene).

La recente scoperta di una nuova famiglia di aracnidi troglobi in un tubo di lava nella regione è molto rilevante.

Si riporta inoltre la cronologia dei principali studi scientifici condotti in un'area basaltica che comprende tre province Argentine.

Key words: troglobitic arachnids, biospeleology, volcanic cave, lava tube, Argentina

Fig 1. *Otilioleptes marcelae* gen. nov., sp. nov. Paratype male (FML-OPIL 00218), dorsal view. Photo: Abel Pérez-González.

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SHEDDING LIGHT ON LONG-EARED BATS (*PLECOTUS* SPP.) FROM SICILY: MORE COMPLEX THAN WE THOUGHT

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Abstract

Cryptic species represent a major challenge in biodiversity assessments, due to the difficulties in detecting and correctly identifying such taxa, particularly when species recognition is based solely on morphological characters. Bats have a long history of research efforts in Europe, and yet knowledge on the bat fauna of Sicily is scarce.

Palearctic long-eared bats from the genus Plecotus have traditionally represented a conspicuous challenge to bat specialists, due to their complex biogeographical and phylogenetic histories, paired by a marked phenotypic resemblance across most species. As such, molecular tools for species identification are a fundamental step to shed light on species identity, particularly when more than one species occur in sympatry.

Here we review the literature on the presence of three Plecotus bats from Sicily, reporting new records for two species (*P. austriacus, P. auritus*), revealing the importance of molecular identification when these species are found. Among these new findings, we report on the phenology and roost use by the first documented colony of brown long-eared bats (P*lecotus auritus*) from Sicily, occupying a crevice within a volcanic cave on Mount Etna.

Riassunto

Le specie criptiche rappresentano la più grande sfida nella valutazione della biodiversità a causa delle difficoltà nel riuscire a localizzare e identificare tali taxa, in particolar modo quando il riconoscimento delle specie si basa esclusivamente sui caratteri morfologici.

I pipistrelli sono da diversi anni protagonisti di una ingente mole di ricerche in Europa ma, ad oggi, è ancora scarsa la conoscenza della chirotterofauna in Sicilia.

La classificazione degli orecchioni del Paleartico, discendenti dal genere Plecotus, hanno da sempre rappresentato una dura prova per i chirotterologi, a causa della complessità della loro storia biogeografia, e filogenetica e per le marcate somiglianze fenotipiche tra la maggior parte delle specie.

Per questo motivo gli strumenti molecolari per identificare le specie sono un elemento fondamentale per far luce sull'identità delle stesse, in particolare quando più di una specie si presenta in simpatria.

In questo studio abbiamo esaminato la letteratura sulla presenza dei tre pipistrelli del genere Plecotus, provenienti dalla Sicilia, riportando nuove testimonianze per le due specie (*P. austriacus, P. auritus*), sottolineando l'importanza dell'identificazione da un punto di vista molecolare quando si rilevano le due specie. Tra queste nuove scoperte, forniamo dati sulla fenologia e sulla presenza del roost della prima colonia di orecchione bruno (Plecotus auritus), documentata in Sicilia, occupante una fessura all'interno di una grotta vulcanica, sull'Etna.

Key words: bats, molecular identification, volcanic caves, Etna, Catania.

Introduction

Cryptic species are distinct biological entities that are difficult or impossible to distinguish from one another due to extreme overlap in their appearance (Bickford et al., 2007). In turn, they are often overlooked, neglected to the difficulties to study them, or misclassified. Such species can only be revealed as genetically isolated entities using appropriate molecular tools (Chenuil et al., 2019). Cryptic species are one of the major challenges to biodiversity assessments (Bickford et al., 2007). Ignoring the existence of cryptic species may lead to a significant underestimation of species richness (Funk et al., 2012), so that despite some of such species may be threatened, they are excluded from conservation actions because they remain undescribed. Moreover, even after cryptic species are described and thus known to science, their presence may be overlooked in field surveys, leading to underestimation of local species richness, over-estimation of the abundance or distribution of the nominal species (Chenuil et al., 2019), and possibly insufficient conservation measures towards local populations. Molecular techniques are being increasingly in use (favoured by a continuous decrease in cost and time required for analyses) in identifying cryptic species (Galimberti et al., 2015). The parallel creation and growth of genetic reference datasets has further contributed to the routinary adoption of molecular tools in ecological studies.

Knowledge of bat species richness in Europe has improved significantly in the recent decades, thanks to the application of integrated taxonomy, including bioacoustics, molecular and morphometric techniques, which led to the identification of several cryptic species. Among these, the long-eared bats from the genus *Plecotus* represent a challenging study system. Palearctic long-eared bats have in fact a complex biogeographical and phylogenetic history, paired by a strong phenotypic convergence across species (Mayer et al. 2007). *Plecotus* species occur throughout Europe, along the belt of Mediterranean basin, as well as along the Nile River valley (Dietz et al. 2009). All Palearctic long-eared bats were classified as P*. auritus* until 1960, when *P. austriacus* was formally recognized. Soon after this first splitting event, further studies evidenced a far more complex pattern of diversification within the genus, leading to the description of new taxa from both the *auritus* and *austriacus* clades (Mayer et al. 2007).

Islands often comprise unique faunal assemblages, particularly when they lie at the boundaries of different bioregions (e.g., Afrotropical and Mediterranean, as in the case of the islands in the Sicily Channel). Sicily, as Southern Italy in general, has long been neglected as a study area in terms of bat-related studies, so that the knowledge of the bat fauna of the island is scarce, fragmentary or sometimes even confusing (Di Salvo et al. 2012). A relatively recent review on Sicilian bats by Agnelli et al. (2008) mentioned 20 species for the island, and at least three more were added by further investigations, namely *Myotis bechsteinii*, *Pipistrellus pygmaeus* and *Myotis punicus*. Moreover, an in-depth understanding of bats' ecology and distribution, on islands in particular, is key to grant their long term survival, e.g., by securing proper conservation actions and landscape management (Ancillotto et al. 2021) to foster their populations.

Here we aim at reviewing the current knowledge on long-eared bats of the genus *Plecotus* from Sicily from the available literature and novel field findings from the Etna National Park, supported by the use of molecular tools and by year-round surveillance of newly discovered sites.

Materials and Methods

Old and new records

Historical and recent records were screened by searching on scientific search-engines (Web of Science, Google Scholar), alternatively using the keywords *"Plecotus", "long-eared bat"* and *"Sicily",* in both English and Italian. Additionally, original records were obtained by online biodiversity repositories (iNaturalist.org) and by field observations by the authors (CB, EM); in the latter case, since Plecotus bats show extremely overlapping morphological characters that may hamper their identification in the field by non-specialists, we employed molecular tools (namely, barcoding identification pipelines: see Galimberti et al. 2015) to properly identified bats found in the field. Namely, molecular identification was conducted for one specimen found dead at a roost (see further), from which a wing membrane sample was used for DNA extraction and sequencing, following published protocols (Galimberti et al. 2015).

Field monitoring

When a roost of long-eared bats was retrieved, we conducted monthly surveillance visits to assess the use of the site by bats, i.e., whether a site was used as a hibernaculum, nursery, swarming site or a mix of these. Bat presence was visually assessed, with the aid of torch-lamps, and photographs were rapidly taken in order to reduce disturbance.

Results & Discussion

Overall, we retrieved evidence of Plecotus bats from Sicily in very limited numbers, highlighting that knowledge on the species' distribution on the island is scarce and highly fragmentary. One specie, the grey long-eared bat (*P. austriacus*) is known from Sicily by 4 only historical records, all retrieved between 1880 (Galvagni 1837) and 1990 (Caruso & Costa 1978; Zava et al. 1986), with no coordinates and exact toponyms provided. More recently (2015-2019), two species were discovered to occur on the Sicilian territory, namely *P. gaisleri* (on Pantelleria island; Ancillotto et al. 2020), and *P. auritus* (one record from Nebrodi mountains; Fulco et al. 2015). Additional records of *Plecotus* bats were recently published by Fichera et al. (2021), with one record of *P. austriacus* from Adrano, and one *P. auritus* from Grotta di Monte Corruccio (Linguaglossa). One additional record of *P. austriacus* was retrieved from iNaturalist, from the Palermo province. In all these cases, records are represented by single individuals observed inside caves, tunnels or abandoned buildings, with no additional evidence of colonies or reproduction by either *P. austriacus* or *P. auritus*.

In 2012, a large group of unidentified *Plecotus* bats was found by the authors in a site named Grotta del Brigante, a lava tunnel in the Catania province, within the Etna National Park. A first morphological assessment conducted on a dead specimen found on the ground of the tunnel led to the identification of these bats as *P. austriacus* (Bucolo & Musumeci 2013), yet several characters were highly overlapping (e.g., thumb length and tragus appearance). In fact, molecular identification provided 100% match with *P. auritus*, identifying the site as the first ever reported colony roost for the species on the island.

Grotta del Brigante cave is located a ca. 1,560 m a.s.l., and is a typical lava tube, only recently described (2012). The tube stretches ca. 130 metres long, with a maximum width of 4 m and 3 m height. Two accesses are present at the opposite sides of the tunnel. Within the structure, *P. auritus* are usually found in a large roof crevice located ca. at the centre of the tunnel, as well as in several lateral roof niches (Figure 1a-b)

Figure 1: Brown long-eared bats (Plecotus auritus) *in Grotta del Brigante cave; a) central roof crevice, the main roost used by bats in this cave; b) lateral roof cavities. Photo by C. Bucolo & E. Musumeci (2013).*

During a full year of monthly monitoring (between 2013 and 2014) and subsequent scattered visits in the following years (2015-2021), bats were present in all seasons but winter, when cave entrances were obstructed by snow. Peak numbers (up to 50 adult bats) were recorded in May-June, highlighting that the site is presumably used by bats as nursery site, at least by some of the resident adult females. In early summer, pregnant and lactating females were discernible from photographs and video recorded onsite, e.g., by the observation of enlarged nipples surrounded by bare skin. Numbers of individuals at the site decrease in autumn, and no bat is found during winter months. It is thus likely that *P. auritus* select different caves for hibernation, e.g., choosing sites that provide more insulation and stable microclimatic conditions. In late summer 2021, an extensive wildfire occurred at the focal site, with huge amounts of smoke and cinders invading the cavity; at the same time, a quick check of the tunnel resulted in the finding of several freshly dead *P. auritus* (n=3; Figure 2) found on the floor of the lava tunnel.

*Figure 2: Two of the three brown long-eared bats (*Plecotus auritus*) found dead ca. three days after a massive wildfire occurring around the roost at Grotta del Brigante (July 2021). Photo by C. Bucolo & E. Musumeci 2021.*

We thus provide a timely perspective on current knowledge about occurrence and distribution of long-eared bats in Sicily, also reporting about the first ever identified roost for *P. auritus* on the island, which is also the first documented record of reproduction for the species in Sicily. Moreover, we highlight that identifying *Plecotus* bats using morphological keys only may lead to misidentifications, particularly in the case of non-expert operators, so that in this case an integrative approach including also molecular tools may prove essential. Long-eared bats are presumably rare in Sicily, as suggested by the very limited numbers of records, which are largely represented by the report of single individuals observed at temporary roosts. Consequently, the observation of a huge colony of *P. auritus* in the Etna area warrants further monitoring and conservation actions to secure this important site. *Plecotus auritus* usually forms rather small colonies numbering, on average, 10-20 bats (Dietz et al. 2009); as such, Grotta del Brigante cave represents a key site for the conservation of the species on the island, presumably attracting individuals from a wide surrounding area.

Islands are particularly fragile areas (Vernicos 1987), and so are the wildlife populations living therein, as these are highly susceptible to environmental anthropogenic pressures such as land use change and climate change. The latter in particular represents a major threat to island ecosystems, and to bats in particular (Sherwin et al. 2013): increasing occurrence and intensity of climate-change related events such as temperature extremes (heatwaves), droughts, and wildfire all contribute to hampering the long-term conservation of insular populations of bats (e.g., Ancillotto et al. 2021). As such, further efforts are needed to ascertain the status and distribution of cryptic species in poorly investigated areas such as Mediterranean islands, including Sicily, in order to properly assess extinction risk at a local scale and thus plan and implement timely conservation actions.

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SYMPOSIUM DAY 3, WEDNESDAY 1 SEPTEMBER

PAPERS

Session 4: Exploration and Topography

Al-Fahda Flow, Pyroduct and Archaeology, Jordan (Stephan Kempe & Ahmad Al-Malabeh).

The Key Geoheritage Area: A potential new IUCN program on geoheritage conservation (Kyung Sik Woo).

*The Grotta Di Salvo, an ancient lava tube on the South side of Mt. Etna: notes on morphology and archaeological aspects (*C Bucolo, D Guzzetta, E Musumeci, O Palio, G Priolo, M Turco).

The first census of volcanic caves in Pantelleria (C Bucolo, E Musumeci, A Belfiore, F Fonseca).

The Grotta del Faggio, another interesting cave on the Sciara del Follone lava flow (V. Gullotto, G. Priolo, A. Schilirò, E. Tosto).

AL-FAHDA FLOW, PYRODUCT AND ARCHAEOLOGY, JORDAN

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Abstract

The Harrat Al Shaam, the lava deserts of Jordan, is a vast lava field, in which we have explored and surveyed 23 lava caves with a total added length of 3164 m, as yet.

One of the latest eruptions, a fissure eruption, created a 32 km long lava field, the Al-Fahda lava flow, covering 227 km2. In the north, the field is up to 24 km wide, while towards the south the flow becomes restricted to one flow-lobe. This field, in contrast to the surrounding underlying lava flows, has developed only a marginal morphological drainage network. Within the flow, we have explored and surveyed Al-Fahda Cave, the longest lava cave yet discovered in Jordan. It is 924 m long, accessible through two entrance collapses. This cave represents the main pyroduct that served for the subsurface transport of lava from the vents to the flow front. Both ends of the cave are plugged by loess, washed-in from the surface. Human occupation left stacked walls and a large pile of rocks (“The Monument”) of unknown ages. A clay lamp documented use of the cave in Byzantine times.

The cave was used by hyenas, wolves and porcupines as dens all the way to their uphill and downhill ends. These left both their faeces as well as bones of their prey. Two decayed hyena or wolf corpses were found at the ends. A 6.3 km long, undated channel was dug in the intention to use the cave as a temporary cistern. The surface of the flow field also features numerous archaeological remains, the most specular are three groups of 98 (from E to W: 63, 27 and 8, respectively) Neolithic gazelle traps termed “desert kites” due to their similarities with children kites from the air.

Riassunto

L'Harrat Al Shaam, i deserti lavici della Giordania, sono un vasto campo di lava, in cui abbiamo esplorato e rilevato 23 grotte con una lunghezza totale, a oggi, di 3164 m.

Una delle ultime eruzioni, un episodio fissurale, ha creato un campo lavico lungo 32 km, il flusso lavico Al-Fahda, che copre 227 km^2. A nord, il campo è largo fino a 24 km, mentre verso sud il flusso si restringe assumendo una forma lobata. Questo campo, in contrasto con le colate laviche precedenti, ha sviluppato solo una rete di drenaggio morfologica marginale.

All'interno del flusso, abbiamo esplorato e osservato la grotta di Al-Fahda, la più lunga grotta di lava mai scoperta in Giordania. È lungo 924 m, accessibile attraverso due crolli d'ingresso. Questa grotta rappresenta il principale apporto sotterraneo della lava dalle bocche al fronte di colata. Entrambe le estremità della grotta sono tappate da loess, ablato dalla superficie. L'occupazione umana ha lasciato muri accatastati e un grande mucchio di rocce ("Il Monumento") di età sconosciute. Una lucerna in argilla documenta l'uso della grotta in epoca bizantina.

La grotta era frequentata da iene, lupi e istrici che vi hanno costruito le loro tane, per tutta la sua estensione. Questi frequentatori hanno lasciato sia le loro feci che le ossa della loro preda. Alle estremità sono stati trovati due carcasse di iena o di lupo in decomposizione.

Un canale non datato lungo 6,3 km è stato scavato con l'intenzione di utilizzare la grotta come cisterna temporanea.

La superficie del campo lavico presenta anche numerosi resti archeologici, i più peculiari sono tre gruppi di 98 (da E a O: 63, 27 e 8, rispettivamente) trappole neolitiche a gazzelle chiamate "desert kites" per le loro somiglianze gli aquiloni fatti volare dai bambini

Keywords: Jordan, lava caves, pyroducts, Al-Fahda flow field, archaeology, human usages, hyena, desert-kites

Introduction

Parallel to the Red-Sea/Dead-Sea Rift, the Arabian Plate features a series of intracontinental tholeiitic and alkalic basalt plateaus (e.g., CAMP & ROBOOK, 1992; PINT, 2006, Figure 1). The northern most of these plateaus is the 40 000 km^2 large Harrat Al-Shaam (Figure 1), stretching from Syria, through the eastern part of Jordan and into the northern part of Saudi Arabia. The dominant volcanic rock of these plateaus is lava from surface flows, many of them pyroduct-generated (for terms see KEMPE, 2003; LOCKWOOD & HAZLETT, 2010). Thus, the potential to find long lava caves is given. PINT (2003, 2006) reported a number of lava caves from Saudi Arabian plateaus. For the Harrat Al-Shaam caves are known from Syria and Jordan, but not from its Saudi Arabian section. TWAK et al. (2009) describe the 562 m long Ariqa Cave in Syria. It apparently is a section within a much longer pyroduct system, up to 20.5 km long (FRUMKIN, 2016). The authors explored and surveyed a total of 23 lava caves in Jordanian section of the Harrat (Table 1) totalling 3.61 km in length (KEMPE et al., 2009, 2012). Of these nine are sections of pyroducts, i.e., clearly showing conduit-sustained, lateral, subterraneous lava transport. Another ten are pressure ridge caves, an unusually large percentage of this cave type compared to other cave locations (KEMPE et al., 2010a, 2021). Three caves are of unknown origin, one largely artificial.

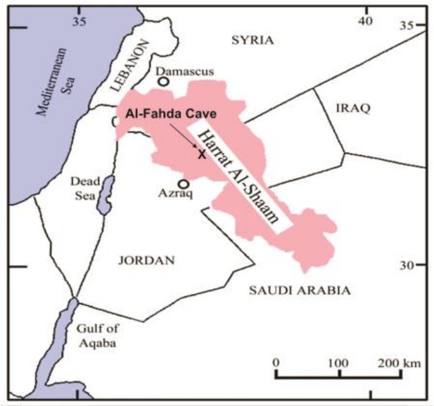

Figure 1: Map of the lava plateau of the Harrat Al-Shaam and location of Al-Fahda Cave.

Table 1

	Name of Cave	Stations	Length	Stations	Depth	Direction	Altitude	Type	Surveyed	Hyena Presence
1	Al-Fahda Cave	complex	**923.5**	2 to 54	6.7	SW-NE	792 m	Pyroduct	2005	xxx
2	Al-Badia Cave	32 to 23	445	1 to 23	17.2	NW-SE	783 m	Pyroduct	2003	no
3	Hashemite University Cave	21 to 35	231.1	1 to 23	10.0	NW-SE	787 m	Pyroduct	2005	xx
4	Al-Ameed Cave	complex	208	2 to 31	4.0	SW-NE	777 m	Pressure Ridge	2005	xxx
5	Dabie Cave	0 to 14	193.6	0 1to 13	1.8	NW-SE	881 m	Pyroduct	2004	xxx
6	Abu al Kursi East	20 to 34	153.7	1 to 34	12.2	W-E	883 m	Pyroduct	2003	xx
7	Kempe Cave	complex	139.4	Complex	11.5	N-S	939 m	Pyroduct	2007	xxx
8	Hammam Cave N	complex	123.4	0 to 28	4.5	NW-SE	780 m	Pressure Ridge	2009	xxx

9	Al-Jolous Cave	0-15	112.6	-	n.d.	NE-SW	799 m	Pyroduct	2007	xx
10	Al-Howa	complex	97.1	2 to 6	10.8	SW-NE	939 m	Pyroduct	2004	no
11	Al-Haya Cave	1 to 11	81.3	1to 9	4.2	NW-SE	902 m	Pressure Ridge	2005	xxx
12	Abu al Kursi West	2 to 18	77.1	2 to 18	8.1	N-S	883 m	Pyroduct	2003	xx
13	Haleem Cave	1 to 12.	70.7	1 to 12.	4.7	NW-SE	791 m	Pressure Ridge	2009	xxx
14	Obada Cave	complex	107.6	0 to 6	3.4	NW-SE	766 m	Pressure Ridge	2008	xxx
15	Azzam Cave	13 to 25	44.1	1 to 25	4.2	NNW-SSE	902 m	Pressure Ridge	2003	no
16	Al Ra'ye Cave	1 to 6	42	1 to 34	3.5	NW-SE	900 m	Pressure Ridge	2005	no
17	Dahdal Cave	5 to 12	28.9	1 to 12	0.0	SW-NE	920 m	Pressure Ridge	2003	x
18	Henschel Cave	complex	21		2.50	W-E	788 m	Pressure Ridge	2009	no
19	Eshaim Cave	1 to 3.	20.6	1 to 3.	0.0	N-S	1029 m	Artificial	2009	no
20	Hammam Cave S	2 to 5.	12.4	2 to 4	2.4	NW-SE	780 m	Pressure Ridge	2009	x
21	Uwaiyed Cave	diamete r	12		2.0	not def.	*681 m*	unknown	2008	xx
22	Beer al Wisad	chambe r	11.4	Depth	11.5	not def.	627 m	unknown	2006	no
23	Treasure Pit		7.2	1-10,11	5.8	not def.	928 m	Pyroduct?	2006	no
		Sum	3164							

The Al-Fahda Flow Field

With a large difference from the second longest cave (Table 1), 923.5 m-long Al-Fahda Cave (the "Lioness") currently is the longest lava cave in Jordan (AL-MALABEH et al., 2006; KEMPE et al., 2006). Its entrance has long been known to local Bedouins and was mentioned as Khsheifa Cave by Helms (1981, p. 138). It is situated north of Safawi (Figure 2) at the highway A10, the only road that crosses eastern Jordan towards the Iraqi border. So far, the cave is the only known one in the Al-Fahda flow field.

The Harrat Al-Fahda (HRF) flow field is up to 20 km wide in E-W direction and up to 32 km long in N-S extent (Figure 2). It also has been described as "younger Jawa flow" (FRUMKIN et al., 2008), and it is thought to originate from a "Jawa eruptive centre" (IBRAHIM & AL-MALABEH, 2005). However, Jawa is not situated on this flow field (Figure 2), but on 3 Ma older volcanic series (i.e., "older Jawa Flows"; ILANI et al., 2001; TARAWNEH et al., 2000). Jawa (HELMS, 1981), the famous bronze age "black city", sits on a panhandle between two deeply eroded wadies, while the HRF has not developed any apparent drainage pattern yet, suggesting that it is by far one of the youngest eruptions in Jordan. It is K-Ar dated to 0.46±0.1 Ma (ILANI et al., 2001; TARAWNEH et al., 2000).

Analysis of Google Earth pictures suggest that it originated at an "eruptive centre" in the farthest NW-corner of the HAF. It is a very low shield volcano that apparently did not produce any scoria and ash but poured out an enormous quantity of lava, rising less than 20 m above the surrounding. If there were other vents (a possible one is indicated on Figure 2) along a W-E-striking fissure remains open. The eruption is unusual as many other vents in the Harrat produced prominent volcanic edifices. The Harrat also has seen extensive fissure eruptions, one (Figure 2 upper right) is named "The Train", looking like a string of railway wagons from afar. Provisionally, this shield is called the "Al-Fahda Volcano", about 3 km SE of the site of Jawa. The Google Earth polygon function yields an area of the HAF of 226 km^2. IBRAHIM & AL-MALABEH (2006) report an area of 273 km^2. It is not clear where the large difference arises from, IBRAHIM & MALABEH may have added some areas along the eastern rim of the HAF, but this should not have amounted to nearly 50 km^2. These authors assume that the volcano produced three to five successive flows 10 to 30 m thick. Even with the minimum depth of 10 m (acknowledging that it may be more or less) the total volume can be estimated to 2.26 km^3, ten times of the eruption volume of the 1980 Mt. St. Helens Eruption (USGS, 2021). Even if lava depth would be only 1 m, Al-Fahda would still match the volume of that eruption. The Al-Fahda Volcano is situated at an elevation of 940 m above sea level (a.s.l.) and the southern end of the flow field is at 640 m a.s.l. The flow path is about 42 km long, yielding a slope of nearly 0.41°. This is a very low slope compared, e.g., to Hawaiian volcanoes but similar to pyroduct-sustained Undara

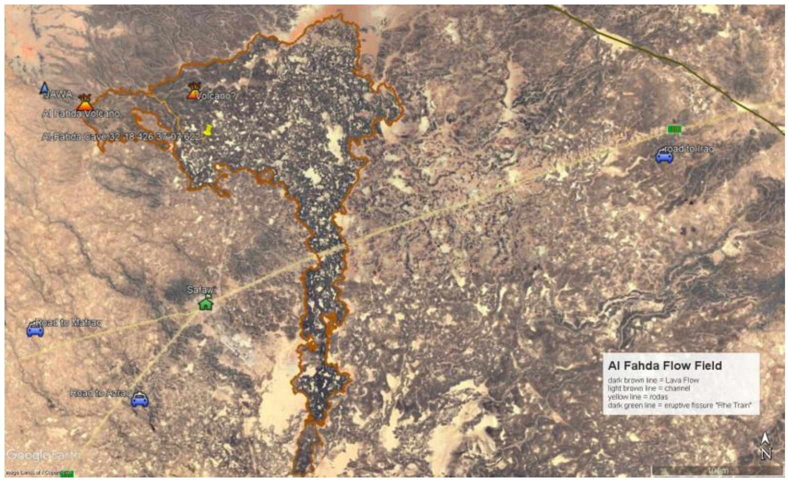

Figure 2: The flow field of Al-Fahda in the centre of the Jordanian Harrat.

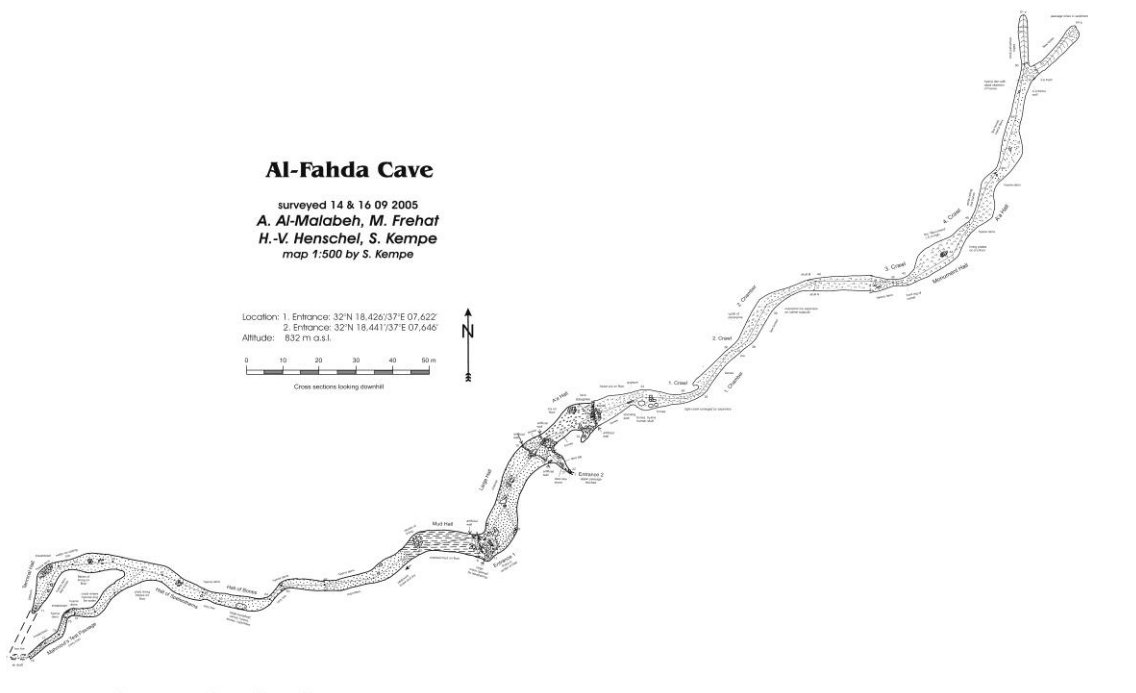

Figure 3: Composite map of Al-Fahda Cave

flows of 0.3° (e.g., PEARSON, 2010; MIDDLETON & KEMPE, 2020). All in all, the original pyroduct (aka "lava tube") was quite long, longer than the one described from Syria (FRUMKIN, 2016).

IBRAHIM & AL-MALABEH (2006) analysed nine rock samples from the HAF for main and trace elements. The SiO_2 and total alkali concentrations range from 46.58-47.88 and 3.74-4.44 wt %, respectively. Thus, all samples are alkali-basalts (alkali and sub-alkali olivine basalt) of very similar composition. The authors (p. 149) describe the lithology of the basalt as "melanocratic, dark grey and fine-grained with a mean grain size of < 1 mm. They contain clustered, fresh olivine phenocrysts (with grain sizes of up to 2 mm). Phenocrysts of pyroxene (up to 1.5 mm in size) occur in some samples. Bluish plagioclase occurs in phenocrysts, and in the groundmass as acicular laths, with intergranular and trachytic textures". The texture is often glomerophyric. "Modally, three petrotypes are recognized, including olivine-plagioclase basalt (20%), olivine-pyroxene basalt (25%) and olivine basalt (55%)." (p. 153). The above normal (for alkali basalts) Cr and Ni contents argue for a primary magma without differentiation or accumulation. The magma may be derived by the "low partial melting (5-9%) of an enriched garnet peridotite mantle with limited fractionation and crustal contamination" (IBRAHIM & AL-MALABEH, 2006, p. 153).

The surface of the HAF is rather flat with pressure ridges of low heights (1 to rarely 20 m) and moderate length. The analysis of 200 ridges showed that they strike perpendicular to flow direction in the centre of the flow and parallel or subparallel to the rim along the sides of the flow (IBRAHIM & AL-MALABEH (2006). The lava filled the former erosional valley of a wadi (most likely the precursor of the Wadi Rajil) and a smaller, 5 km long, SE trending wadi, in the NW, both the former continuation of wadies from the north. Overall, the HAF can be classified as a medium-sized lava field (IBRAHIM & AL-MALABEH, 2006). Overall, the surface is astonishingly flat, with its area covered by loess that has washed into the depressions (white patches on Figure 2) forming flat playas that may flood during heavy rains.

The Al-Fahda eruption apparently blocked the entire southward discharge, forcing the rivers to coalesce, forming the modern Wadi Rajil which flows along the northern border of the Al-Fahda field towards the NE and then joins other wadis to flow along the eastern rim of the HAF south.

Al-Fahda Cave

Al-Fahda Cave was explored and surveyed (Figure 3) on two days in September 2005, one day each for the two sections east and west of the entrance (AL-MALABEH & KEMPE, 2005; AL-MALABEH et al., 2008). A similar survey a year later was published by FRUMKIN et al., 2008. It is difficult to establish the lava flow direction in this pyroduct, since its slope is imperceivable while in the cave. Measurements yielded a vertical difference of only 8.41 m along the main passage (755.1 m) yielding a slope of 0.64°. Using the direct "as the crow flies" distance of (684 m) the slope is a bit higher at 0.7°. This is a little higher than the general slope of the flow, but we are still near to the vent of the Al-Fahda eruption (ca. 10 km). It is of note that the cave's direction is perpendicular to the general downhill slope, but this is probably due to the local topography of the original landscape. The sinuosity (755.1 m/684 m) of the main passage amounts to 1.10 which is comparable to other pyroducts.

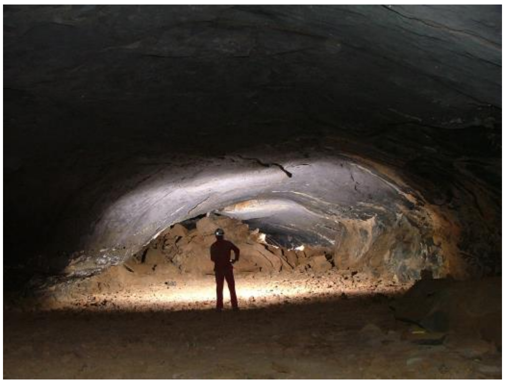

Figure 4: View of Al-Fahda Cave passage towards the entrance collapse from the east.

The morphology of the cave is that of a wide but very low arch (Figure 4). The average width of the 39 stations along the main passage amounts to 7.51 m with a maximal measure of 15.8 m and with several sections being less than 3.5 m wide. The height is 1.21 on average with many stations well below 1 m. The maximal height is 4.7 at the junction of the second entrance (see maps below). Only around the entrances is the passage of comfortable standing size. Under normal conditions in a lava conduit, it would be very difficult to crawl along low passages of such length due to a usually extremely rough floor. In Al-Fahda, the floor is mostly covered with washed-in silty loess that provides a comfortable floor to rest on. But some sections are so low that even crawling on hands and knees becomes impossible. But belly crawling is exhausting quickly so that one has to take refuge by rolling to make progress less strenuous. In some sections it is easier to crawl along the sides of the passage where hyenas have dug their dens.

Figures 5 to 8 show the details of the map to guide the reader through the following description. The cross-sections illustrate the general wide but low character of the passage. The longitudinal section shows that the cave is evenly descending at an exceptionally low gradient. The slope was not steep enough to cause lava falls to evolve that are common in many other pyroducts (compare KEMPE, 1997). Also, there are also no indications of secondary ceilings that form when the lava has eroded downward and forming a gas space of some size that would lead to the cooling of the flowing lava to form an intermediate ceiling or septum (compare KEMPE et al., 2021). have evolved.

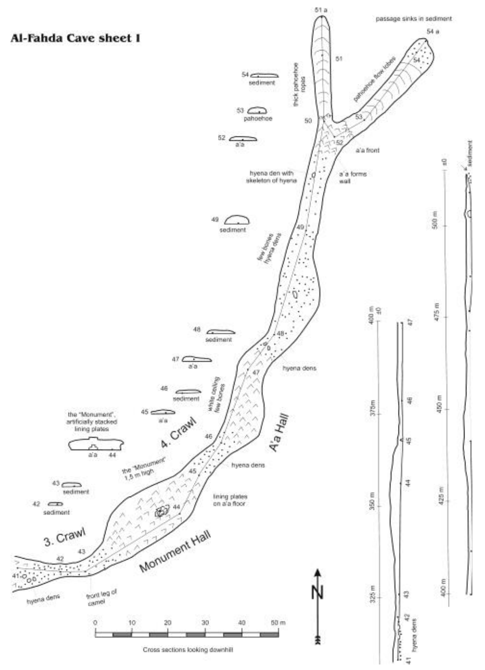

Figure 5: Lower section and end of Al-Fahda Cave.

The ceiling is only undulating up and down by a few decimetres at long wavelength, no substantial breakup cupolas have evolved.

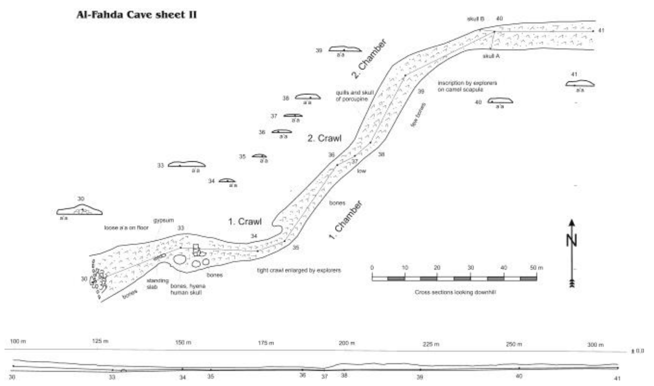

Figure 6: Second section of Al-Fahda Cave.

Geologically, the entrance to a lava cave is the most interesting site because it allows a view of the cross-section of the cave's roof (Figure 9 and inset Figure 7). The roof of Al-Fahda cave consists of two solid lava sheets. The upper one is 1.5 m, the lower one 1.2 m thick. The vesicles in the lower third of the sheets are elongated in the direction of flow (Figure 10), while the vesicles in the upper half are spherical. This pattern is typical for lava sheets emplaced by inflation, i.e., the upper sheet was deposited first and then the second sheet was inserted below the first one, causing drag on the lower part of the upper sheet. Also, the pattern that the upper sheet is thicker than the lower one is typical for inflationary cave roofs. Often roofs have more than two sheets and their thickness decreases downward (for more information on inflationary pāhoehoe sheets see HON et al. 1994, and on cave roofs see KEMPE 2019). With these observations it is clear that Al-Fahda Cave was created within an inflationary pāhoehoe flow and not as an "roofed-over" lava channel.

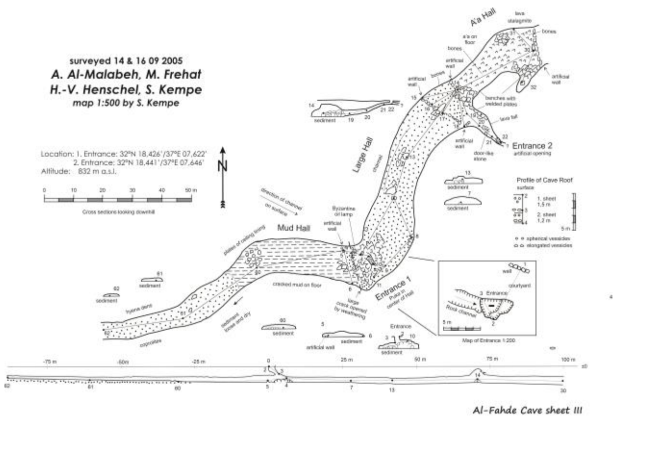

Figure 7: Third section of Al-Fahda Cave with entrances.

The main entrance to Al-Fahda Cave is comparatively small (Figure 9) but can easily be climbed. It opens centrally into the passage below and the metre-sized breakdown blocks offer steps. The entrance appears to be rather young, it certainly is a "cold entrance", meaning that it did not collapse during activity of the conduit. This is evident because all blocks of the roof-collapse are still present and were not taken away by the flowing lava. It is well possible that the entrance has been enlarged or even opened artificially. If it had been open for tens of thousands of years, loess would have filled the cave during the Last Glacial.

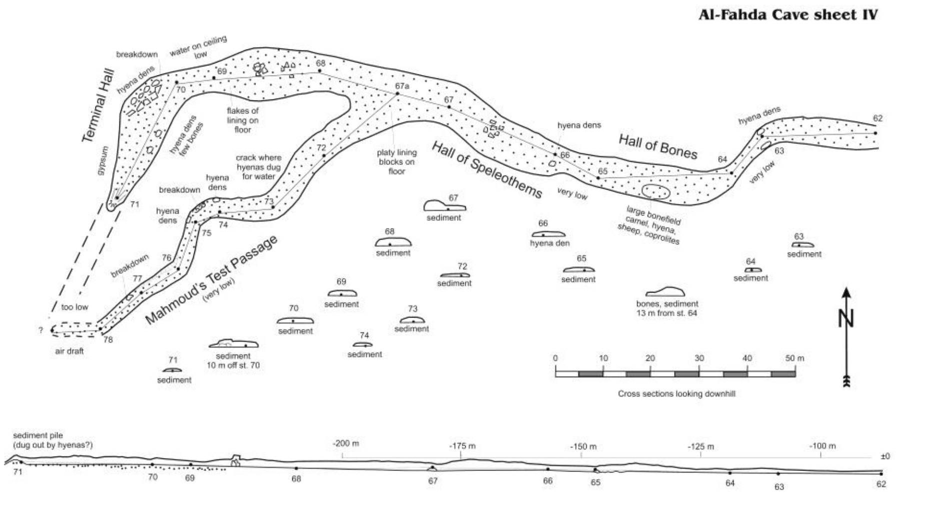

Figure 8: Fourth and uppermost section of Al-Fahda Cave.

Once in the cave (Figure 4), its flat floor is noticed. As shown on the maps, in many parts of the passage the floor is covered by washed-in loess, but there are sections where the original floor is visible. It is formed by partly welded, partly loose, small clinkers of ʻaʻā (Figure 11). This is an unusual situation, since ʻaʻā forms when lava is moving fast (so lava-threads can detach, forming loose fragments) but the cave's slope is very low and should not sustain rapid flow.

Figure 9: View into the entrance of Al-Fahda Cave with M. Frehat posing. Note the solid lava sheets, forming the roof of the cave.

Figure 10: Elongated vesicles of the upper lava sheet illustrating the drag of the underlying, younger sheet.

Figure 11: Floor of small ʻaʻā clinkers littered with bones (width of picture about 1.5 m).

On the other hand, ʻaʻā is often found in pyroducts as features of the terminal flow, when cooling set in and the lava becomes tough and can detach to form loose clinker. For Al-Fahda the last option seems to fit: during the final phases of the conduit activity the lava from upslope cooled enough to form loose clinkers and filled a once much larger cavity. Even with this hypothesis it is difficult to understand why the floor became flat, not showing a ridge at the centre of the passage, caused by the drag along the wall. At a few places that drag caused the formation of small, lateral dams, running in parallel to the wall (Figure 12).


Figure 12: Lateral dam at St. 40 (Figure 6) with ʻaʻā on both sides of it. Note human skull cap, notebook for scale.

That the hypothesis of a late ʻaʻā infilling phase is likely, is shown at the forking of the passage at the lower end of the cave (Figure 5): There the ʻaʻā infill ends, forming a small terminal wall. In contrast to the ʻaʻā floor, the floor beyond in the forked passages is characterized by dm-sized pāhoehoe flow lobes. This typical ropy texture with its downslope pointing convex curvature is ample proof that the lava flowed westward in the conduit (Figure 13).


Figure 13: Pāhoehoe flow lobes in the terminal passage at Al-Fahda's lower end. View looking downhill (width of picture about 2 m).

It is remarkable that the cave's arched roof, a mere 2.5 to 3 m thick, has only caved in at a few places. Breakdown is a rather uncommon feature in the cave, mostly concentrated at a few places at the entrance and west of it and in "Monument Hall" (Figure 14). Otherwise, the ceiling shows its original lining that often flakes off the ceiling (note the flat lining blocks stacked on top of "The Monument" Figure 14). At the uphill end of the cave, the lining appears to be deeply weathered undercutting the harder glazing (Figure 15). and forming tafoni-like cups and holes. The originally present glassy glazing is dull, crumbles and even peels off, not surprising considering the age of the flow (Figure 16). The weathering is most intense at the upper end of the cave. There we also noticed drip water, even though our visit in September fell at the end of a desert summer and even though the rest of the cave was dry. In contrast to the lower end of the cave, where gypsum crystals cover the ceiling, carbonate speleothems populate the upper section of the cave indicating a once higher moisture content. Flagstones, small curtains, crusts and coralloidals predominate (Figure 17). FRUMKIN et al. (2008) were able to date two samples by $230^{Th}/U$ from this site. Three growing intervals yielding ages of ca. 250-240, ca. 230-220 and ca. 80-70 Ka BP. Another, younger layer was too rich in detritus material to be dated.


Figure 14: Breakdown blocks, supplemented anthropogenically by slabs of lining, dubbed "the Monument". M. Frehat and A. Al-Malabeh for scale.


Figure 15: Ceiling lining weathered at the upper end of the cave (width of picture ca. 1 m).

Figure 17: Carbonate speleothems in the upper end of the cave. (Width of picture about 1 m). These formations were later removed and dated by FRUMKIN et al., 2008).

Figure 18: One of the few lava-drip stalagmites.

In contrast to this the absence of lava stalactites is astonishing. We noticed only a very few, cm long specimens. Stalagmites from dripping lava are also rare. The largest one measured about 40 cm in size (Figure 18), suggesting that the ceiling was hot enough to release melt, even after the final ʻaʻā was emplaced.

The archaeology and palaeontology of Al-Fahda Caves

Several observations and finds suggest that the cave has often been visited in the past. It is not only possible that the main entrance was anthropogenically modified, but the second entrance was dug for certain by humans (Figure 7, cross-section stations 14-21). It was created at a small lava tributary, which apparently delivered some melt, caught below the inflationary sheets at the flank of the main pyroduct. This backflow even left a small lava fall. The conduit is so small (Figure 19) that it cannot accommodate any ceiling breakdown blocks, they must have been taken out. Furthermore, remains of a wall around the hole, suggest that the entrance may have been covered by a hut (Figure 20). Could this have been a sort of air conditioning?

Figure 19: Second entrance to Al-Fahda that has been dug out. (Width of picture ca. 1.5 m).

Figure 20: The pit leading to the small second entrance with the remains of an embracing wall, a hut?

The entrance tunnel, only navigable by belly crawling, leads towards an area in the cave, with three rows of stacked rocks (Figure 7). One crosses the passages at stations 15-18, the next, at station 14, extends some breakdown blocks (Figure 21) and the third one, further in crosses the passage at station 30. These walls demarcate two sections in the cave, but the walls are not tall and thick enough to be called “defensive” and they are also not suitable to protect against hyenas or wolves. A quick search of the rocky floor did not yield any appreciable remains of flint, pot shards or charcoal that are so common on the surface around the entrances. Thus, the cave may never have housed people for extended stays.

One more feature is a sort of squared-off space at the second wall, that contains many big bones (Figure 21).

Figure 21: The wall that extends several breakdown blocks at station 14 by lining plates, view downslope. To the left an area seems to have been squared off (slabs now lying on the floor), that has been used by hyena to feed on camel bones.

The most striking anthropogenic feature is the stack of lining plates quite far in the cave at station 44 ("The Monument", Figures 5 & 14). This place can only be reached by tight belly crawls. There is currently no way to date such a structure.

The only datable find in the cave so far is a clay lamp (Figure 22), that stuck in the ceiling a few metres uphill of the entrance breakdown.

Figure 22: Clay lamp discovered in a ceiling pocket.

The pattern of the lamp suggests that it is of Byzantine age. Someone must have stored it there to be retrieved later without ever returning.

The cave was used throughout by hyenas (*Hyaena*, striped hyena) and (probably) wolves (KEMPE et al., 2006). They left a plethora of bones, many of them camel, including whole skulls and even legs that must have been articulated. Plenty of white hyena faeces litter the floor around the bone deposits. At both ends of the cave, partly mummified carcasses were found (Figure 23). From the pictures it is not quite clear if these are hyena or wolf. In the areas with ample sediment, dens are found, dug most likely by hyena. Al Fahda is, to our knowledge, the cave with the evidence of farthest hyena penetration underground. In addition, the bones and spines of a porcupine (Hystrix) were found. That animal may have had difficulty in exiting the cave.

The Al-Fahda Channel

Figure 24 shows a Google Earth image of the Al-Fahda channel. It starts at the Wadi Radjil at an altitude of 862 m a.s.l. and reaches, after 6.27 km, at the entrance of the Al-Fahda Cave at 794 m a.s.l. The elevation change is 75.5 m with a general slope of 1.4%. At 1.43 km above Al-Fahda, the channel shows two building phases, with an older, 275 m long section to the south. If one can believe the altitude measures of Google Earth, then this section rises from 803 m a.s.l. to 804 m in its centre, to descent to 803 m again, which would prevent water flow. The channel has for most parts one wall to its southwestern side.

Figure 23: Partly mummified carcass of a hyena (or wolf) found between station 49 and 50 near the lower end of the cave.

Two banks are only visible in a few places. It fades from view several times where it apparently can follow natural depressions that did not need shoring. The slope of the channel is quite high as it follows the slope of the lava field. The direct distance from source to sink of the channel is 5.4 km (slope) which yields a sinuosity of the channel of 1.16 (6.27/5.4).

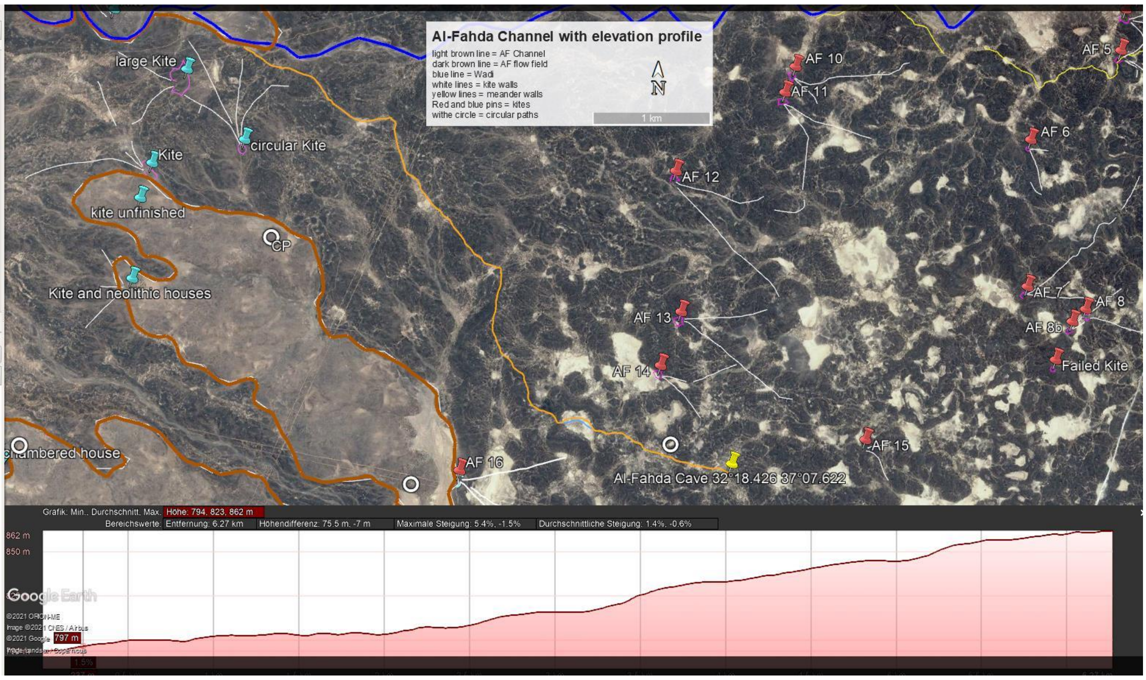

Figure 24: Google Earth picture of the Al-Fahda channel and its elevation profile.

It is, at present, not possible to date the channel. Its age could be Neolithic (there are remains of shelters at the entrance to the cave with flint chips), Bronze Age (in connection with the habitation phase of Jawa), as well as Byzantine (as indicated by the oil lamp found in the cave, see above), or even relatively recent. The end of the channel (Figure 25) is still visible near the cave entrance and that was how we first noticed its existence. The view north (Figure 26) shows two walls of stone shoring up its eastern (left) and western (right) sides. There appear to be more rocks than would have been present if just the centre of the channel was cleared of them. The function of this surplus material is not clear. Rocks alone do not retain water, thus they must have been set into a kind of loess "cement" to retain it (or most of it) in the channel. Inside of the cave, the floor of the immediate section to the west of the entrance shows mud cracks, as if even today water floods the floor from time to time (Figure 8).

Figure 25: The end of the channel at the entrance of the Al-Fahda Cave (marked by persons standing behind it). The right (eastern) side of the channel is well preserved. The view is to the south.

Figure 26: The channel near Al-Fahda Cave, viewed north. The stone walls to both sides of channel are still clearly discernable.

The channel is not the only large-scale anthropogenic construction on the Al-Fahda flow field: Along its eastern fringe, 63 kites were erected. These are, presumably Neolithic, hunting traps. Traps for migrating animals, such as gazelle. The name kite describes its structure in analogy to a children's kite, consisting of an enclosure, the kite, with two or more guiding walls leading towards it, the tails of the kite (Figure 24). An additional 27 kites, set in two chains, occur in the vicinity of the cave. A further eight are found on the eastern part of the flow field near to the volcano. All, apart from four of the latter group, are open to the east, to trap herds returning from the springtime grassing grounds in the desert (e.g., KEMPE & MALABEH, 2013).

Conclusions

The Al-Fahda Cave is, so far, the only known cave within the Al-Fahda Flow. Its two upper branches are clogged by sediment, of the two lower ones, one is also clogged by sediment, one ends in a lava seal. Thus, the cave is probably much longer, if not blocked by sediment. Potentially it represents the central pyroduct originally leading, for over 40 km, from the shield volcano in the NW corner of the flow field to the tip of the field south of Safawi. On the other hand, it is unlikely that such a conduit can be traced since open cave may be the exception and most of the original conduits may be sealed by the terminal lava flow within the conduit. Since no collapse pits are known, the chance to find additional open cave is minimal. Even for Al-Fahda, it is lucky that the entrance is probably of young, possibly Holocene age because otherwise the loess that covers the lava field could have filled the entrance. Also, the dominance of camel bones, dragged in by hyenas, is suggesting that the cave has been open only in the last few thousand years and not since its formation 460 000 years ago. With that age the cave is one of the oldest known worldwide. For comparison, on Hawaii, a cave 10 000 years old, counts among the oldest (KEMPE et al., 2010b)

Analysis of the genesis of Al Fahda Cave plus the low slope of the entire flow field show that the lava produced was pāhoehoe. Nevertheless, the surface of the lava is covered with loose stones. At first this appears like a contradiction but one has to realize that the eruption of the AL-Fahda volcano 460 000 years ago, falls into the Marine Isotope Stage (MIS) 12, a Glacial. Since then, also Glacials 10, 8, 6, and 2 (the last Glacial, LGM) came and went. Each brought intense frost also to the high desert of the Levant. Rocks were cracked and split. Loess was deposited and frost heaving moved the rocks. Furthermore, the Interglacials MIS 11, 9, 7 and 5 brought warm and hot conditions, causing further rocks to crack. Also, some intervals were wet, causing vegetation to spread. (see below). Bioturbation of soil by burrowing animals and toppled trees moved rocks as well. Thus, it is understandable that the surface of the thick pāhoehoe is covered by loose rocks.

It was remarkable that there was moisture at the cave's upper end in September 2005, while at its lower end gypsum grew and it was dry. It can be speculated that warmer air rises to the upper end, condensing there. The more intense weathering of the basalt and speleothems may be linked to this circulation. Also, FRUMKIN et al. (2008) noticed that the speleothems are showing evidence of redissolution. The speleothems were dated by these authors to the Interglacial MIS 7 and the transition of MIS 5 to 4 at around 75 ka BP. These times must have seen not only ample precipitation, to percolate through the overlying rock, but must have had enough CO_2 to dissolve the calcite contained in the loess. This, however, mandates a vegetation cover, so that roots and microbial respiration can produce a high PCO_2 within the thin loess cover. This is necessary not only to dissolve the calcite, but also to create a CO_2 pressure difference between the inflowing carbonate solution and the cave air to reach the necessary supersaturation triggering calcite precipitation. Specifically, the last date is interesting since it coincides with U/Th-dates obtained for high terraces for Lake Lisan, the precursor of the Dead Sea (ABU GHAZLEH & KEMPE, 2021), substantiating the conclusion of a humid climate at that time.

The 6.3 km long Al-Fahda Channel is a singular feature of the Jordanian Harrat. It is well visible on Google Earth and on the ground. Rocks had been cleared from the 1 to 2 m wide water course. In addition, the downslope bank had been shored up by additional stones, likely set in loess for water-proofing. Such work must have been carefully planned. Specifically, the course must have been staked out to begin with by using some sort of instrumentation. If the channel would have been built by trial and error, one would see cast-off dead-end sections. It is not impossible that the bronze age habitants of Jawa had the capacity to do this, but why would they try to use a cave, more than 12 km away from their city, as a cistern? They build a reservoir dam below the city and dug large ponds to store water in the Rajil Wadi (BETTS & HELMS, 1991). These had a much higher capacity then the volume of water that could possibly be stored in Al-Fahda Cave. It appears more likely that the channel dates to Roman time. They had the necessary instrumentation, experience and staff to stake out such a course. And they may have been interested in having a water reserve in the Harrat for troops moving from the Limes Arabica (for example from Burqu) in the east to the cities in the west (such as the 140 km distant Umm al Quttain). An intermediate stop to rewater horses and soldiers may have been an ample reason to dig the channel. In northern Jordan, the Romans constructed an extensive aqueduct system including tunnels with a length of up to 100 km to provide water to the Decapolis Cities (e.g., KEMPE & AL-MALABEH, 2017). A >6 km-long surface channel, that would bring water automatically to Al Fahda Cave when Wadi Rajil was in flood, would have been a small endeavour, compared to that. The finding of a Byzantine lamp in the cave adds a certain probability to this hypothesis. If the channel ever really worked is unclear, because there are no high-water marks on the cave walls. Only an area with mud cracks is witness to the occasional presence of a shallow water pool.

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THE KEY GEOHERITAGE AREA: A POTENTIAL NEW IUCN PROGRAMON GEOHERITAGE CONSERVATION

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Abstract

Geoheritage can be categorized into local, national, and international values and needs to be conserved for future generations because geosites cannot be restored once damaged. Thus, statutory protection measures and effective management of geosites must be established in each country. Unfortunately, the necessity for the conservation of geoheritage is not yet sufficiently recognized at national and international levels, compared to ecological and biodiversity values.

So far, there is no initiative to promote geoheritage management under international nature conservation policies. Despite the UNESCO’s international designations (World Heritage Sites and Global Geoparks) that recognise geoheritage, too many potential geosites representing the 4.6 billion years of the Earth history and evolution of life have been neglected and are being destroyed.

Therefore, a new programme – Key Geoheritage Area (KGA) – has been suggested in the last two years, corresponding to the Key Biodiversity Areas already running under IUCN.

The KGA should be primarily based on the scientific value of geological features. For an effective KGA designation, objective geological contexts with appropriate criteria should be developed, such as representativeness, rarity, and integrity. The expectation is that this new programme will contribute to conserving geoheritage worldwide. The KGA is a proposal that is being worked inside the WCPA’s Geoheritage Specialist Group (IUCN) but it will need the collaboration of other relevant organisations such as IUGS, ProGEO, and IAG, after its full adoption by IUCN.

Riassunto

Il geopatrimonio può essere classificato in valori locali, nazionali e internazionali e deve essere conservato per le generazioni future perché i geositi non possono essere ripristinati una volta danneggiati. Pertanto, in ogni paese devono essere stabilite misure di protezione legale e una gestione efficace dei geositi. Sfortunatamente, la necessità della conservazione del geopatrimonio non è ancora sufficientemente riconosciuta a livello nazionale e internazionale, rispetto ai valori ecologici e di biodiversità.

Finora, non esiste alcuna iniziativa per promuovere la gestione del geopatrimonio nell'ambito delle politiche internazionali di conservazione della natura. Nonostante le designazioni internazionali dell'UNESCO (World Heritage Sites e Global Geoparks) che riconoscono il geopatrimonio, troppi potenziali geositi che rappresentano i 4,6 miliardi di anni della storia della Terra e dell'evoluzione della vita sono stati trascurati e vengono distrutti. Pertanto, negli ultimi due anni è stato suggerito un nuovo programma – Key Geoheritage Area (KGA) – corrispondente alle Key Biodiversity Areas già in esecuzione nell'ambito dell'IUCN.

Il KGA dovrebbe essere basato principalmente sul valore scientifico delle caratteristiche geologiche. Per una designazione KGA efficace, dovrebbero essere sviluppati contesti geologici oggettivi con criteri appropriati, come rappresentatività, rarità e integrità. L'aspettativa se questo nuovo programma contribuirà a conservare il geopatrimonio mondiale.

Il KGA è una proposta che viene elaborata all'interno del Geoheritage Specialist Group (IUCN) del WCPA, ma richiederà la collaborazione di altre organizzazioni pertinenti come IUGS, ProGEO e IAG, dopo la sua piena adozione da parte dell'IUCN.

Keywords: Korea, lava caves, geopark, geoheritage

THE GROTTA DI SALVO, AN ANACIENT LAVA TUBE ON THE SOUTH SIDE OF MT. ETNA: NOTES ON MORPHOLOGY AND ARCHEOLOGICAL ASPECTS.

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Abstract

Mt. Etna is the highest active volcano in Europe and it features a great number of volcanic caves, both lava tubes and fracture caves. The Grotta Di Salvo is an interesting lava tube with passages on two levels; it was formed in a very old lava flow.

Inside the principal lava tube, many interesting discoveries have been made, such as a fragment of flint and many ceramic shards from various archaeological periods. This study, in addition to describing the volcanological and morphological aspects, adds a further element in the reconstruction of the history of our territory.

Riassunto

L'Etna è il vulcano attivo più alto d'Europa con una cospicua presenza di grotte vulcaniche sia di scorrimento lavico che di frattura. La Grotta di Salvo, sita nel territorio di Belpasso (CT), si aggiunge all'elenco delle nuove grotte scoperte sull'Etna con particolari ritrovamenti al suo interno quali un frammento di selce e molti cocci ceramici di vari periodi archeologici. Lo studio, oltre a descriverne gli aspetti vulcanologici e morfologici, aggiunge un ulteriore tassello nella ricostruzione della storia del nostro territorio.

Key words: cave, lava tube, archaeology, bronze age, Catania, Etna

Introduction

The lava flows of Mt. Etna contain two-hundred and more volcanic caves that were generated in different ways and show different morphologies.

The Grotta Di Salvo was named after Mr. Di Salvo who pointed out a new cave to Mimmo Guzzetta, a speleologist of *Gruppo Grotte Catania*, who was exploring the lava flows around Mt. Etna.

A team of *Gruppo Grotte Catania* members carried out the full exploration of the cave that immediately appeared very interesting for the rheologic morphologies and the archaeological evidence.

Archaeological history of Mt Etna's caves

Caves in a lava flow with remains from prehistoric times are a widespread phenomenon in the Etnean territory. The oldest traces of human presence within such caves date back to at least the Middle Neolithic (5500-4200 B.C.), as evidenced by some fragments recovered in the *Grotta delle Balze Soprane II* (*Bronte* – Figure 1) and continue consistently in the period between the end of the Copper Age and the Early Bronze Age (4500-1450 B.C.). They become very slight however, in the middle, late and final phases of the Bronze Age (1450-900 B.C.). Most of the caves that bear traces of human presence in prehistoric times are located in the area between 300 and 600 m a.s.l.; however, there are also examples at higher altitudes, up to over 1000 m a.s.l., in the territories of *Adrano, Bronte, Maletto, Randazzo* and *Castiglione*. It was possible to identify at least four large territorial groupings: the first is in the area between *Catania* and *Misterbianco*; the second is in the territories of *Biancavilla* and *Adrano*; the third is located between *Bronte* and *Maletto*; and the last one lies between *Randazzo* and *Castiglione* (Branca et al. 2021).

Figure 1: Grotta di Maniace, in the Balze Soprane archaeological area. In the picture Fabio Brunelli examines the fragments of a vase (ph. Scammacca, 1971).

We have no precise data on the function of the caves in the Neolithic period, due to the scarcity of finds. On the contrary, for the late Copper Age/early Bronze Age phase we are certain that they had a mainly funerary and ritual function. In fact, most of the caves in which archaeological investigations have been conducted have yielded human remains, depositions of grave goods or offerings, and residues of ceremonial actions, such as communal meals, attested by the fragments of pottery for food preparation and consumption and the numerous animal bones collected inside the cave (La Rosa, Privitera 2007).

In the *Belpasso* area, evidence from prehistoric times is mainly concentrated in the southern part, between *Valcorrente* and *Paternò* (Palio, Todaro, Turco 2020). They are primarily open-air settlements, distributed over a chronological span from the Middle Neolithic to the Middle Bronze Age. So far, no cave frequented in prehistoric times has been identified, with the sole exception of *Grotta Floresta*, in the locality of *Borrello* (Branca et al. 2021).

Geography and Geology of the area

The *Grotta Di Salvo* belongs to the territory of the municipality of *Belpasso*, in *Contrada Vitelleria*. The entrance to the cave opens inside a private property on *Viale Lunghe* at 603 m above sea level.

The cavity was generated in lavas that originated from an eruptive fracture that opened at an altitude of approximately 1400 m, also giving rise to the secondary cone of *Mt. Sona*. A large and rough lava field is on the lower slope of Sona.

The rocks are a product of an eruption that can be dated to the 11th Century; they are grey and show a porphyritic-textured with abundant plagioclases, lower pyroxenes content and rare millimetric-sized olivine. The lava flow is characterized by a predominant aa-type morphology, locally alternating with lava with 'toothpaste'-type morphology.

The lava flow is partially covered by a thin layer of soil. In the area of the *Grotta Di Salvo* the original lavas are extensively altered to the extent that the vegetation typical of the mesomediterranean belt has grown: mesophyll thickets of evergreen vegetation such as holm oaks (*Quercus ilex*) and a few scrubs of deciduous thermoniferous oaks of the *Quercus ruber* group are the dominant tree species. The area is also characterized by shrub consisting of broom (*Genista aetnensis*) and euphorbias (*Euphorbia dendroides*).

The high level of alteration has also allowed the planting of olive (*Olea europaea*) and prickly pear (*Opuntia ficus-indica*) trees and other, scattered fruit trees.

The "Grotta Di Salvo" cave and its morphologies

The *Grotta Di Salvo* is a typical Mt Etna lava tube. The access is through a large hole in the roof of the southwest branch of the cave. The cave opens into a large tunnel 1.80 m high leading to a space where two more tunnels criss-cross in an unusual way.(Figure 2). This interesting morphology can be seen in the only one large hall of the cave.

Figure 2: Grotta Di Salvo, the crossing intercept of lava tubes (ph. Priolo, 2013).

Going down about 2 m, it is possible to enter the lower lava tube, Westward oriented, very long and in some parts cramped. This tunnel is characterized by some reworked burials (Figure 3). This area of the cave was examined for archaeological purposes.

The exploration and the data collection have been carried out by a team of Gruppo Grotte Catania of Club Alpino Italiano on January 13, 2013. The tools that were used were a Suunto compass and inclinometer and a measuring wheel. The drawing was made by Giuseppe Priolo using cSurvey software. Figure 4 shows the survey of the cave.

Figure 3: The West gallery and one of its crawls (ph. Priolo, 2013).

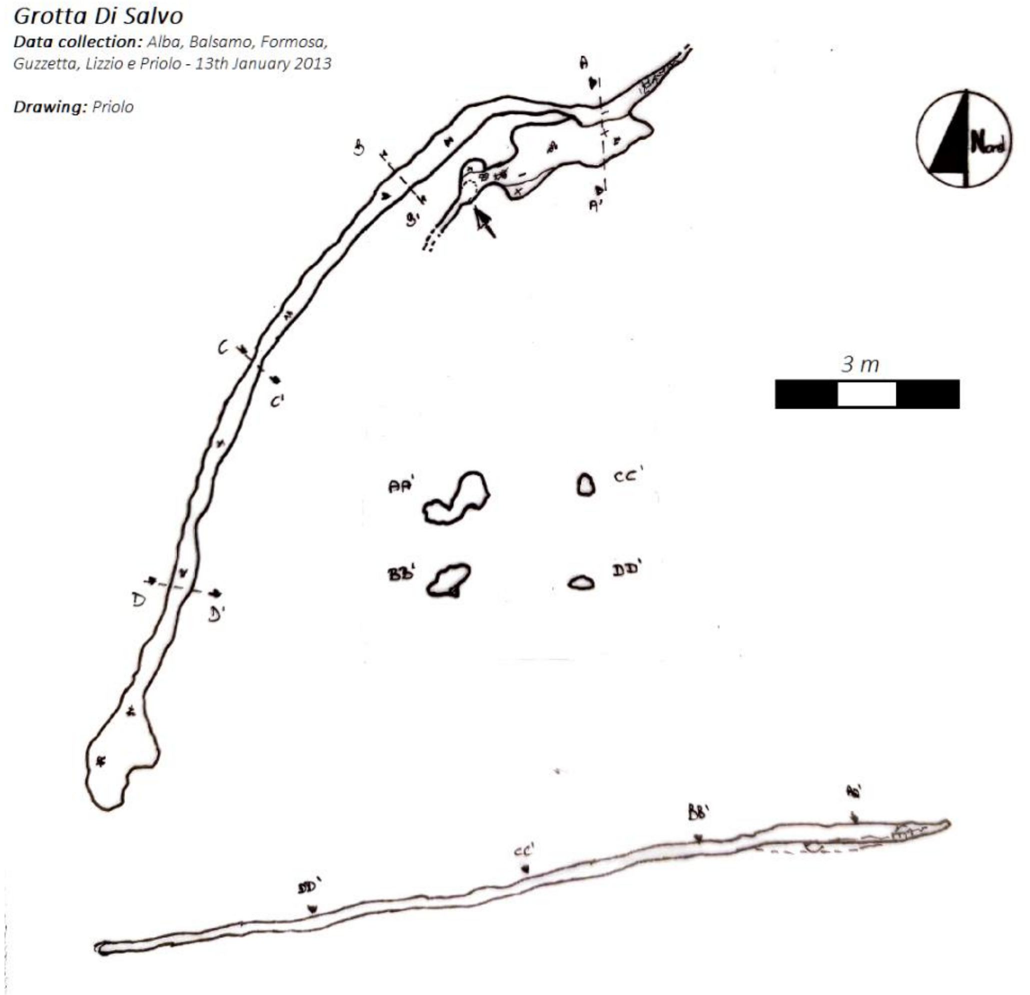

Figure 4: Grotta Di Salvo survey.

The refusion morphologies show the age of the cave: they are rounded and covered with a thin layer of white concretions (calcite and gypsum).

Archaeological finds and their study

The discovery of *Grotta Di Salvo* thus enriches our knowledge of the prehistoric phases in this area. Known since 2015, it was explored in the summer of 2021 by the *Soprintendenza per i Beni Culturali e Ambientali* of *Catania* together with the *Gruppo Grotte Catania* of the CAI, which reported it.

The archaeological context has been tampered with, probably by occasional visitors, also on account of the proximity to the road. The floor of the cave was covered by abundant stones, apparently not referable to any structure. However, amidst the stones there were many ceramic fragments, in an evidently secondary location, due to modern-day visitations. On the contrary, no bones or stone tools seem to be present, with the sole exception of a blade that we will refer to below.

At the time of the exploration, in order to be able to date the time when the cave was used, numerous ceramic fragments were collected, all dating from the Early Bronze Age. There are many medium-to-large vessel walls with no paint on the surfaces (jars and pithoi), in some cases with horizontal ribbing (Barone et al.); there are also fragments of vessels with red covered surfaces, some of which have black painted decoration on it (cups on feet, medium-sized vessels; there are no fragments of other open forms in the sample); the handles are mostly vertical, with a wide ribbon and a flattened oval section. The decorative motifs consist of vertical bands, triangles with reticulated or solid fields, all belonging to the repertoire of Early Bronze Age ceramic production in the Mt. Etna area (Figure 5). A small group of three sherds dates to modern times.

Figure 5: Ceramic fragments found in the cave.

At the time of the first discovery of the cave, a long, blond flint blade, probably of Hyblean origin (information by F. Nicoletti), with a trapezoidal cross-section, 14 cm long and 3 cm wide, had been taken (Figure 6). Flint blades of this same type recur in Ancient Bronze Age burials in south-eastern Sicily, deposited in contact with the skulls of the deceased, constituting the only individual grave goods (Orsi 1892).

Conclusions

The speleological and archaeological research on the *Grotta Di Salvo* have defined the date of the volcanic phenomena and the date of the human frequentation.

The *Grotta Di Salvo* is one of several Etna caves with archaeological evidence. Other observations and research will show other artefacts but this is difficult because the cave is much frequented, tomb raiders also.

Our heartfelt thanks go to the members of the Gruppo Grotte Catania of the Club Alpino Italiano who committed themselves to the days of exploration and surveying, enabling, in fact, the realization of this work.

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THE FIRST CENSUS OF VOLCANIC CAVES IN PANTELLERIA

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Abstract

The island of Pantelleria is located in the Sicily Channel Rift Zone (SCRZ) and represents the emerged tip of an underwater volcano complex with 72% lying below sea level, down to a depth of about 1200 m. Its origin is linked to the Pantelleria graben, one of the three main tectonic depressions of the NW-SE trending extensional area in the SCRZ. The rifting process has been active since the Late Miocene, accompanied by widespread volcanic activity mainly concentrated on the islands of Pantelleria and Linosa and the Bannock Seamount.

The last episode of eruptive activity, occurring in 1891, 5 Km NW offshore North of Pantelleria, showed that the volcanic activity is still present in the submerged part of the island.

To date, the volcanism of Pantelleria is still on-going with the presence of a natural spa, thermal springs, fumaroles, that are located along the main tectonic structures.

The island is famous for its beautiful landscapes with native flora and fauna, but especially for the typical buildings created by the man like the 'panteschi' and 'dammusi' gardens.

Even if the inhabitants know the existence of some caves, the territory has not been entirely explored yet. The purpose of this work is to discover the caves and conduct a census of all the caves in the island like lava flow caves and fracture caves.

Riassunto

L'isola di Pantelleria si trova nel rift del Canale di Sicilia, e rappresenta la punta emersa di un complesso vulcanico, con il 72% del complesso sotto il livello del mare, fino a una profondità di circa 1200 m. La sua origine è legata al graben di Pantelleria, una delle tre principali depressioni tettoniche dell'area estensionale ad andamento NW-SE nel rift del Canale di Sicilia. Il processo di rifting è attivo fin dal Miocene superiore, accompagnato da una diffusa attività vulcanica concentrata principalmente nelle isole di Pantelleria e Linosa e nel Bannock Seamount. L'ultimo episodio di attività eruttiva, avvenuto nel 1891, 5 Km NW al largo di Pantelleria, ha mostrato che l'attività vulcanica è ancora presente nella parte sommersa dell'isola.

Ad oggi il vulcanismo di Pantelleria è ancora in atto con la presenza di un centro termale naturale, sorgenti termali, fumarole, che si trovano lungo le principali strutture tettoniche.

L'isola è conosciuta per i bellissimi paesaggi con flora e fauna endemica ma soprattutto per le strutture tipiche del luogo create dall'uomo quali giardini panteschi e dammusi. Pur conoscendo, da parte degli isolani, la presenza di alcune grotte, il territorio non è del tutto stato esplorato. Scopo del lavoro è quello di conoscere e censire le grotte presenti nell'isola quali grotte di scorrimento lavico e grotte di frattura.

Key words: volcanic cave, lava tube, fracture, volcanic island, Pantelleria, Trapani.

Introduction:

The island of Pantelleria is not well-known for its caves but rather for its secondary activities like volcanic gases and hydrothermal waters. The island, a jewel in the sea, is an object of study of lots of researchers in the geologic and the biological area with different endemic species. There is no bibliography about speleology, but some caves in history have been used by different generations and some of them today are used for tourism.

The island of Pantelleria is a surfaced summit of an impressive underwater volcano that rises from the sea from a depth of about 2000 m (Orsi et al., 2008). The birth of the volcano is linked to the formation of a vast area of relaxation in the Sicily Strait with a NO-SE trend.

This distension process, active since the Pliocene, caused the formation of the rift of the strait of Sicily. Pantelleria is located in the south-west extremity of the strait (basin of Pantelleria) (Corti et al., 2006; Bosman et al., 2011; Figure 1).

The volcanic activity of the island of Pantelleria (that is of the " Emerged Sector" of the Volcanic Complex of Pantelleria) dates back to 320 thousand years ago, and it has been characterised by giant explosive events, sometimes followed by caldera collapses, interchanged with weak eruptions.

The last caldera collapse took place 44 thousand years ago (Orsi et al., 1991). The last episode of eruption activity occurred in the 1891 5 km away from Pantelleria Harbour showing in this way that there is still activity in the emerged part of the Island (Conte et al., 2014)

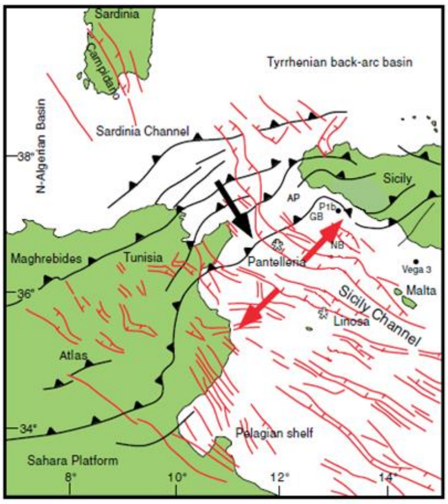

Figure 1: Tectonic map of the Strait of Sicily. In the picture the black arrow points the vergence pressure SE, whilst the red arrows point the NE-SW extension in this section of the Strait of Sicily. (Corti et al., 2006.)

Census of volcanic caves:

The tools used for the collection of data are the distance metre Leica A3 model, compass and inclinometer Suunto model. In the island there are lava flow caves and fracture caves.

Lava caves:

Grotta dei Briganti

One of the most famous caves is located in the highest part of the island in the Montagna Grande up to a level of 830 m a.s.l. in the ancient datable lava between 29-35 thousand years ago. The area is called 'Miliàc' (o Miliàcchi) which, in the dialect of Pantelleria ("pantesco"), means the peak of the big mountain. The name comes from the tragic episode that occurred during the Unification of Italy when a group of young people, after refusing to carry out the military service, hid themselves in the cave. Later, the local police found them and executed them in public. It is a lava flow cave of a biospeleological interest as it is situated in an old wood with holm oaks and strawberry trees and in the old lavas datable between 29-35 thousand years old. Indeed, inside the cave there are lots of natural organic materials like leaves and woods which enter from the main entrance in the cave and from the rifts in the vault.

In the cave there are a lot of spiders of the genus *Meta*, crickets and moths.

A significant relevance is reserved to the colony of bats of the African species recently discovered long-eared African bat (*Plecotus gaisleri*). There are lots of small mountains of guano and food rest like moths' wings. In the cave there are some bats of rinolofo minore (*Rhinolophus hipposideros*).

Regarding the fauna and the arthropoda, there are other guanobic species and others which must be an object of study as they could be endemic species.

The entrance in the cave is 3.3 metres wide and 1.24 metres high (Figure 2) and the direction of the cave is southwest. The cave has a depth of 12 metres and it gently slopes down for its whole length of 72 metres (Figure 3). After some metres after the entrance, you have to go down through the steps made with an aggregation of rocks. Afterwards, the cave becomes wider (up to 4.5 m) and higher (3.9 m). It is a typical lava cave with lateral banks in the walls of the vault (Figure 4) and the presence of collapses in the middle of the tunnel (Figure 5).

Figure 2: entrance in the cave (ph. C. Bucolo).

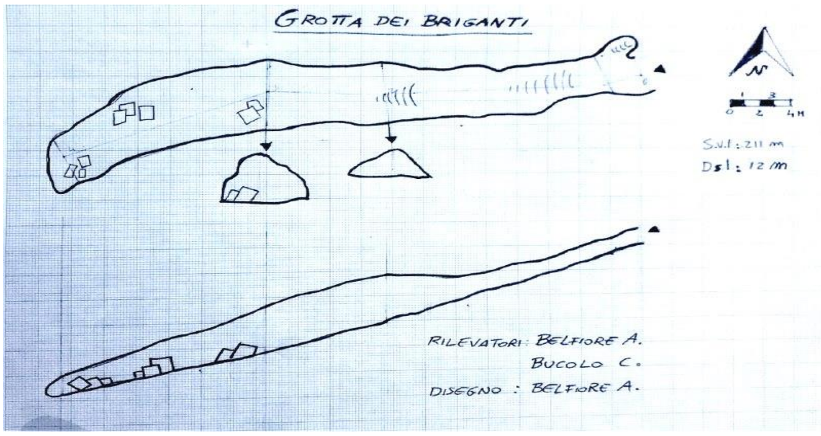

Figure 3: Survey of Grotta dei Briganti. Survey Belfiore & Bucolo, 2021.

Figure 4: Cross section of a lava flow cave (ph. Bucolo).

Figure 5: Aggregation of collapse in the middle of the tunnel (ph. Bucolo).

Grotta San Leonardo or M18:

It is a cave derived from lavas of 29 thousand years ago, it is situated in the coast of the San Leonardo district (next to the hospital of the island) from which it has taken the name. It is well-known as the cave M18 (Fonseca 2018). The cave is a traditional tunnel of lava inspected thanks to the collapse of the vault (Figure 6). It has an extension of 24 metres (Figure 7). Being near the sea, in the terminal part of the cave there is a small salt lake with an aggregation of debris and rubbish (Figure 8) brought by the waves from the main entrance. On the walls and vaults there are lots of lava stalactites created with the process of remelting.

Figure 6: Entrance of the cave (ph. Bucolo).

Figure 8: Small salt lake inside the cave (ph. Belfiore).

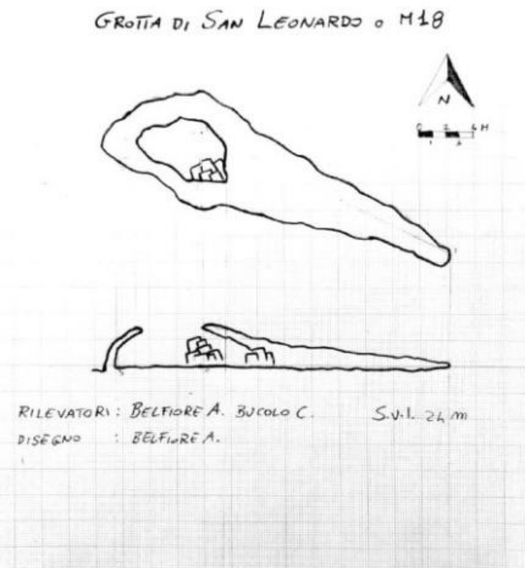

Figure 7: Grotta San Leonardo (Survey Belfiore A., Bucolo C. 2021).

<u>Fracture caves:</u>

Grotta del Bagno Asciutto or di Benikulà:

It is situated in the Sibà district between the lavas of about 29-35 thousand years ago. You can enter the cave from a fault in the rock. Since ancient times, the cave is made up of 2 spaces: an exterior part (frigidarium), with seats of lava stone (dukkéne) with a wide view on the plain of the Monastery; and an interior part of the cave in which, through the fault of the rock, water vapour comes out intermittently, with a temperature of about 40 degrees. The vapours have been analysed by the University of Palermo and they have proved the therapeutic effects. Today lots of tourists visit the cave and it is used as a natural sauna. The interior room is 5 metres wide, 1.60 metres high and 6.50 metres long (Figures 9-10).

In the outer part of the cave, there is another fault maybe used as a livestock shelter.

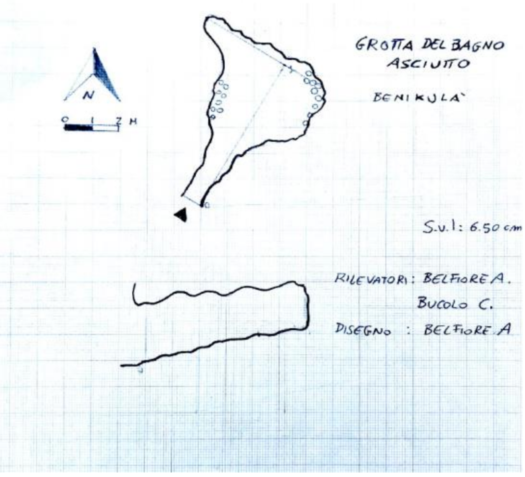

Figure 9: Grotta del Bagno Asciutto (Survey Belfiore A., Bucolo C. 2021).

Figure 10: Grotta del Bagno Asciutto, a room with vapour (ph. Belfiore).

Grotta del Freddo :

Called in the dialect of Pantelleria (pantesco dialect) "U pirtusu du nutaru", the notary's hole, stands in the Bukkuram district in a land of the notary Gaetano Valenza's property, in lavas of 15-20 thousand years ago. The entrance, characterised by a small window and with a lava stone seat in the sides (Figure 11) where you can take cover during hot summer days. Here the temperature remains 10° thanks to the air circulation and to the blowhole in the rock. The air blasts, which enter through the small fault, let the humidity evaporate creating more heat depending on the temperature of the air blasts inside the cave. The cold air which leaves the cave from the small "window" is more evident during hot days with sirocco when the temperature reaches 40° C.

Inside the rock there is a small oblique fault in the side with a length of 6,73 metres and a height of 4 metres (Figures 12-13). The floor is very dusty and inside there are lots of moths.

Figure 11: Grotta del Freddo, the entrance (ph. Belfiore).

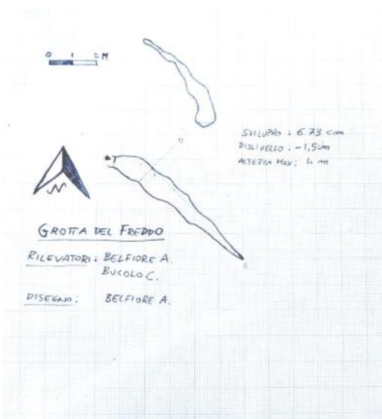

Figure 12: Grotta del Freddo (Survey Belfiore A., Bucolo C. 2021).

Figure 13: Grotta del Freddo, profile view of the cave (ph. Bucolo).

Frattura del Gelfiser:

From the Arabic "Gebel" mountain and "fizar" cracks, "Mountain of the cracks" or maybe "exploded Mountain" as the volcano which generated this lava flow, situated in the Siba and Khufirá districts, is completely exploded. It presents a fantastic path in the Mediterranean scrub between woods of holm oaks, ancient lavas from 15-20 thousand years ago, big crevices and big canyon (Figure 14). Historically, in the period of the Unification of Italy, the area was populated by groups of rebels (the famous bandits already mentioned in the cave of briganti) who had been holding out against carabinieri and bersaglieri for 3 years, before the defeat in the peak of the Big Mountain thanks to the betrayal of a supporter and to the Colonel Ehberard's impressive army (with 500 soldiers and 400 volunteers). Through the path you can see the refuges built with lava to use as drystone wall with small outbreaks and animal bones rests. The area is of speleological interest as there are lots of rifts. The main rift, called rift of Gelfiser, must have been a shelter for bandits and old farmer in the past. In the middle of the rift there is a collapse in 2 places. In the centre, on the floor, there is an aggregation of rocks where someone built a small oven. (Figure 15).

Figure 14.

Figure 15.

The well is 15 metres long. In the pit, various attachment points have been placed on the rock to rope progression. The well is characterised by collapses and walls with solid basalt and in some parts bends to 90°. There are karst phenomena, indeed, you can see the stalactites corals (or broccolini stalactites) (Figure 18) and calcite flows. In the deepest part of the rift there is an aggregation of collapses and animal bone remnants.

Figure 16.

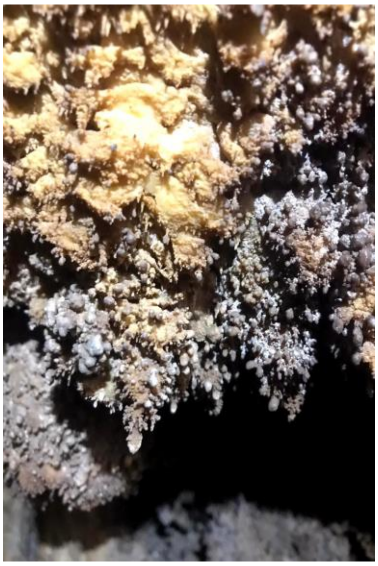

Figure 17.

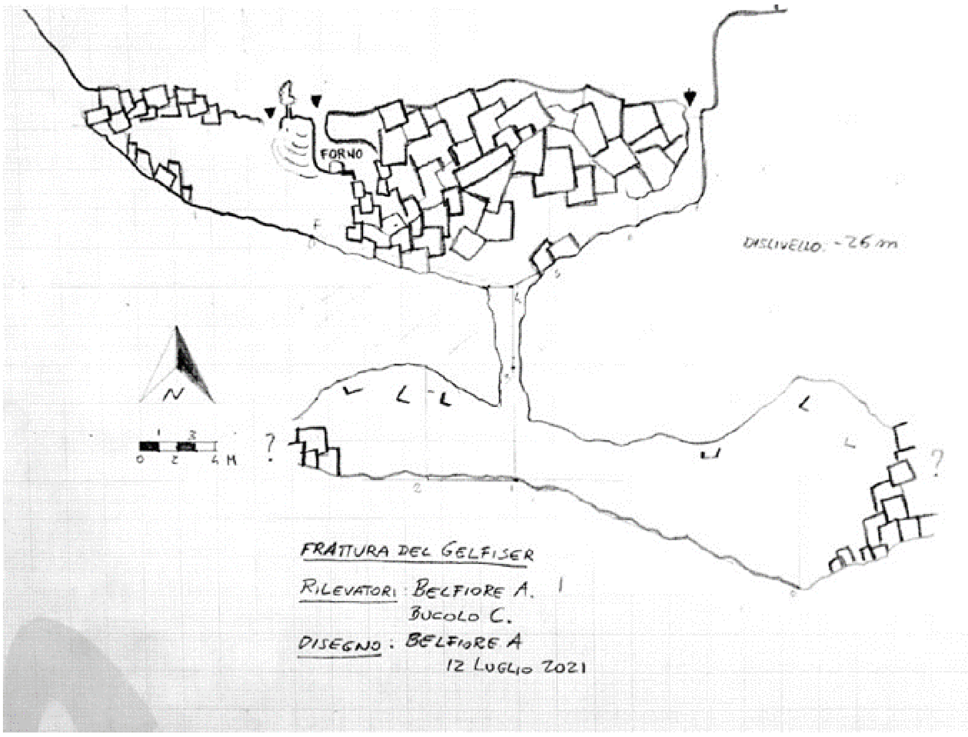

Figure 18.

Grotta della Cisterna

It is located behind the rift of Gelfiser, it has got a horizontal entrance with aggregations of rocks on the floor and with a low roof. Afterwards, the cave continues with a wide long well. It is characterised by aggregations of big collapses from which you can access to other rooms only slithering. The cave is well-structured as there are other wells (Figure 19) and some sections to climb back.

Lots of finds have been discovered inside the cave, finds like crocks of urns and amphoras (Figure 20), polished ceramics with nice garnishes (Figure 21), oil lamps (Figure 22), iron fragments like nails and probably a joint door (Figure 23), even a big tank maybe from the Punic period, with a big lava stone block and some steps with lava stone which conduct to this room (Figure 24) and an axe-shaped finding, with circles sculptures, maybe for fertility ceremonies or a possible clay horn (Figure 25).

Figure 19.

Figure 20.

Figure 21.

Figure 22.

Figure 23.

Figure 24.

Figure 25: A possible clay horn. (Bucolo C., 2021).

The acronym "IHS" found on the wall in the cave is very interesting. It presents a cross above the letter 'H' which is a religious symbol of the Middle Age (Figure 26). Besides, human bone remains, such as humerus, tibia and femur head, have been found here. (Figure 27).

Figure 26.

Figure 27.

The cave is very important for its naturalistic values. Even if it is a volcanic cave, speleothems have been discovered in this cave. Speleothems of karst origin like stalactites (Figure 28), calcite flow and scallops (Figure 29).

Figure 28.

Figure 29.

Regarding the fauna, it is important to report the first finding of bats found in the depths of the cave. These bats belong to the genus Myotis never reported in the island of Pantelleria. The presence of these chiroptera suggests that there must be an entrance in the depth of the cave, but it has not yet been discovered.

The cave is wide and it requires other explorations. Only some geographical features have been consigned to the authorities. The detailed topography of the cave has not been completed yet and today the cave is under duty. At the moment, only a geographical feature draft has been reported (Figure 30).

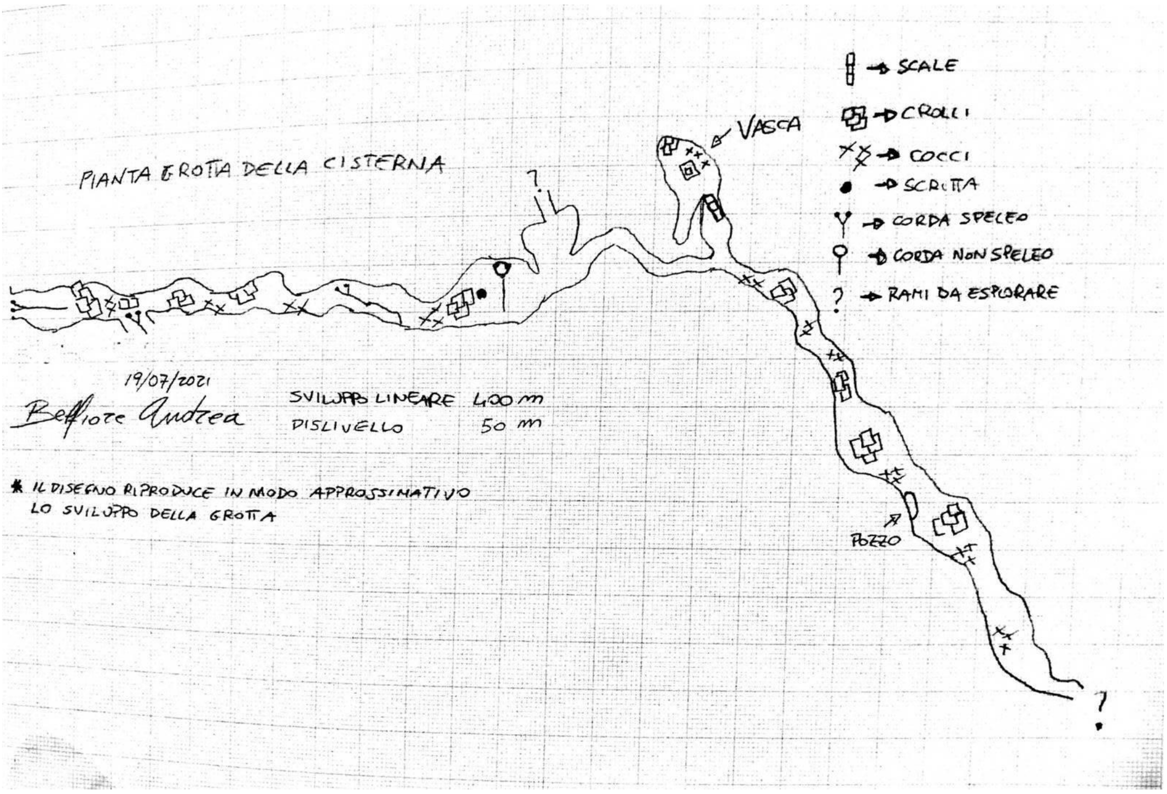

Figure 30.

Conclusions

Pantelleria is an Island where many populations and civilizations succeeded one another. These early studies are aimed at enriching the archaeological knowledge of this territory and of Sicily, in general. All the findings have been delivered to the National Park of the Island of Pantelleria. This temporarily closed access to the cave, in order to do a survey. No studies on the whole lava field of Gelfiser have been completed, therefore it is of great interest for our group to study the end of the cave and explore for new ones.

Special thanks

A heartfelt thanks goes to the National Park of the Island of Pantelleria, in particular the director Sonia Anelli, who granted the permits for our explorations.

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THE GROTTA DEL FAGGIO, ANOTHER INTERESTING CAVE ON THE SCIARA DEL FOLLONE LAVA FLOW, MT. ETNA (ITALY)

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Abstract

During his trekking along the northern side of Etna, Vincenzo Gullotto found and began the exploration of an unknown cave to which he gave the name of Grotta del Faggio. Realising the importance of his discovery, he involved his friends from the *Gruppo Grotte Catania* to complete the exploration and carry out topographic surveys in 2014.

The cave is developed in the lavas of 1614-1624 and it features interesting morphologies and a conspicuous planimetric development.

This paper illustrates the topographical survey and the main morphologies through a rich iconographic set.

Riassunto

Durante le sue escursioni lungo il versante Nord dell'Etna, Vincenzo Gullotto, riveniva e dava inizio alle esplorazioni di una grotta non conosciuta al cui diede il nome di Grotta del Faggio. Resosi conto dell'importanza della cavità scoperta coinvolgeva gli amici del Gruppo Grotte Catania per completare l'esplorazione ed effettuare i rilievi topografici realizzati nel 2014.

La cavità si sviluppa all'interno delle lave del 1614-1624 e presenta interessanti morfologie e un cospicuo sviluppo planimetrico. In questo lavoro viene illustrato il rilievo topografico e tramite un ricco corredo iconografico le morfologie principali.

Key words: lava tube, volcanic cave, Etna

Introduction

The lava flows of Mt. Etna are the container of two-hundred and more volcanic caves that were generated in different ways and show different morphologies.

Vincenzo Gullotto, during his explorations on the lava flow due to the eruption of 1614 – 1624 identified many new caves: one of these is the *Grotta del Faggio*.

In 2014 he joined his friends of *Gruppo Grotte Catania* of *Club Alpino Italiano, Sezione dell'Etna* to carry out the full exploration of the cave and to survey it. In May 2014, a team of Gruppo Grotte Catania, made up by Gullotto, Priolo, Tosto, organized the first expedition: they explored the cave and Emanuele Tosto found a second part of the lava tube over a very sharp bottleneck (Figure 1). At this point the team figured the *Grotta del Faggio* to be the most extensive lava tube known on Mt Etna.

A few days later (30th and 31st of August 2014), a new team, made up by Belfiore, Geraci, Priolo, Restivo, Russo G., Russo M., (Figure 2) went back into the cave to survey and explore the new part.

Figure 1: The bottleneck in the middle of the cave, (ph. Priolo, 2014).

Figure 2: The second expedition; the party relaxing near the entrance (Ph:. Priolo 2014).

Geography and Geology of the area

The 1614–1624 lava flow of Mt. Etna was formed during a long-duration flank eruption involving predominantly pahoehoe flows which produced unusual surface features including mega-tumuli and terraces.

The great eruption that characterized the first part of the 17th century began in July 1614, and like many others before, it included earthquake swarms, localized fractures and a large movement that split the ground on the north flank for kilometres, from 2550 metres down. Eruptive vents were formed (the *Crateri Deserti*) from which erupted rich lava flows consisting of fluid material which in some points created real sculptures of lava ropes.

That eruption changed not only the physical aspect of the volcano but man's relationship with it also. The eruption of July 1614 went on for ten years, ending only in 1624. Over a billion m^3 of lava covered a surface of 21 km^2.

This lava flow, now called *Sciara del Follone*, is where the highest number of volcanic caves (lava tubes and other types) is to be found on the North-East side of Mt. Etna: the Grotta *del Gelo,* the *Grotta di Aci,* the *Grotta dei Lamponi,* the *Grotta dei Tunnel* are some examples (Figure 3).

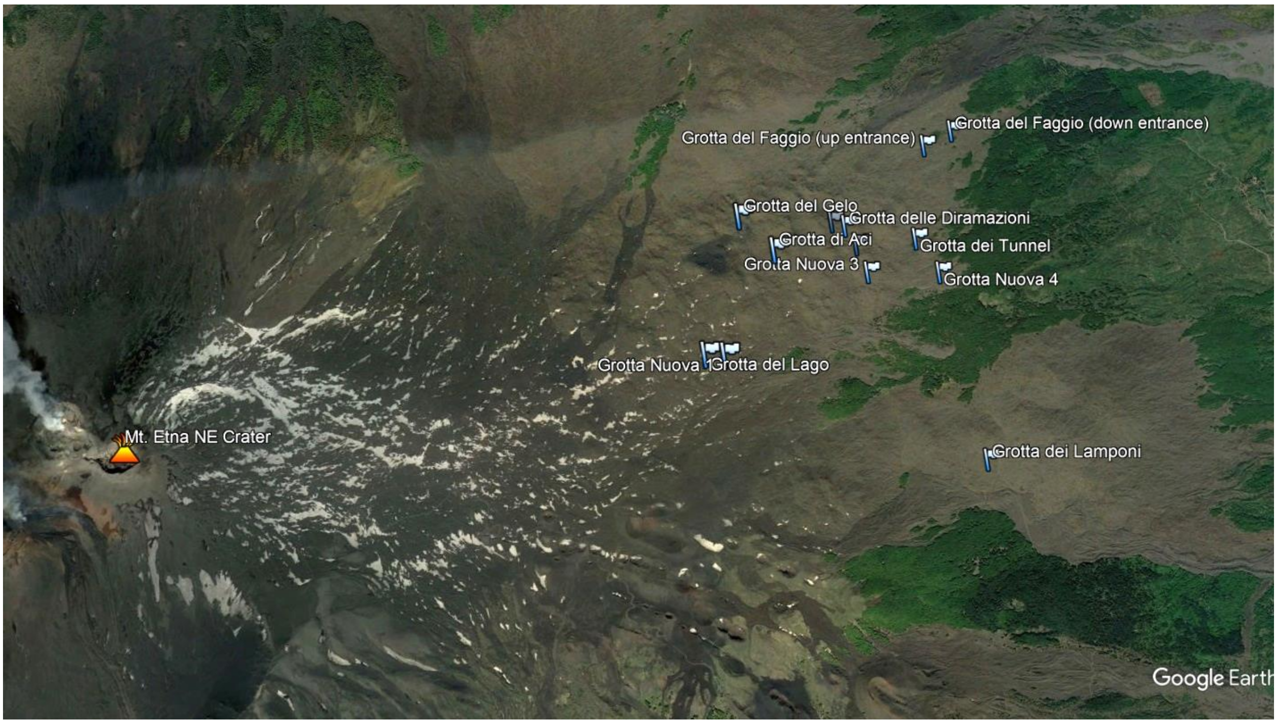

Figure 3: Satellite image of the area.

The lava flow of 1614-1624 is connected to the *Torre del Filosofo* formation. This formation is characterized by lava flows, scoria cones, spatter ramparts and pyroclastic fall deposits related to flank and summit eruptions that have occurred from 122 B.C., when *Il Piano* caldera collapsed, to today. The lava composition ranges from basalt to mugearite aphyric to highly porphyritic texture, with phenocrysts of plagioclases, pyroxenes, olivine, in variable quantity and size (Figure 4).

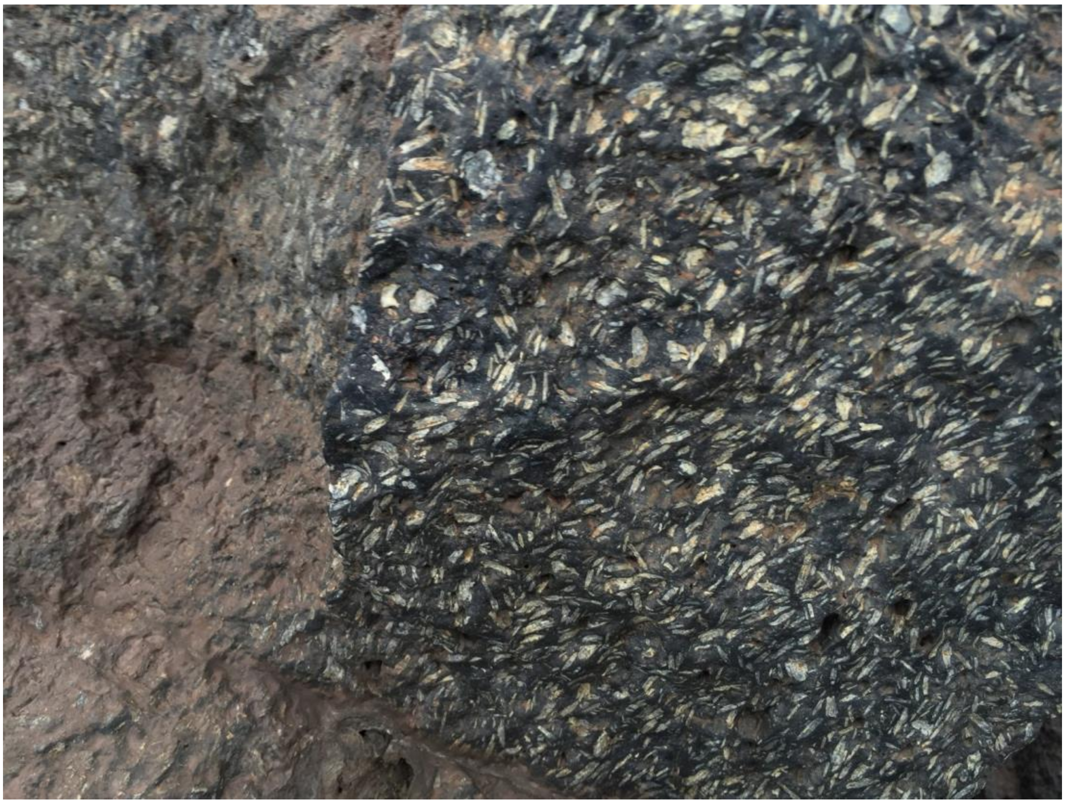

Figure 4: "Lava Cicirara" (ph. Priolo, 2018.

The lava flow in the cave area is characterized by pahoehoe morphologies, with some mega-tumuli and other minor morphologies. One of these is a small, nice, S-shaped lava channel (Figures 5 and 6).


Figure 5: The small "S" lava channel (ph. Priolo, 2014).


Figure 6: The area of the cave's entrance (ph. Priolo. 2014).


Figure 7: The lower entrance, in the picture Vincenzo Gullotto (ph. Priolo, 2014).

The lower entrance of the cave is in a mega-tumulo of lava, where a beech tree grows (Figure 7). Vincenzo Gullotto named the cave after that plant.

The "Grotta del Faggio" cave and its morphologies

The *Grotta del Faggio* is a typical Mt Etna lava tube, whose access is through a collapsed wall in the North part of tube. The access area separates two different sections of the tunnel: the Northern part is short and so low that you can only crawl in it (Figure. 8); the tube going in the opposite direction is very elegant, with interesting flow morphologies, and it is high enough to allow walking for over 200 m. Mosses and ferns are observed in this part of the tunnel, due to the light coming from outside (Figure 9).

Figure 8: Small north tunnel (ph. Priolo, 2014).

Figure 9: The silhouette of 1st part of the gallery.

Further south, the usual morphologies that owe their origin to remelt phenomena are encountered: stalactites, blisters; lava *aa* and *pahoehoe* characterize the floor. The height averages 2.20 m (Figure 10) with parts where it doubles (Figure 11).

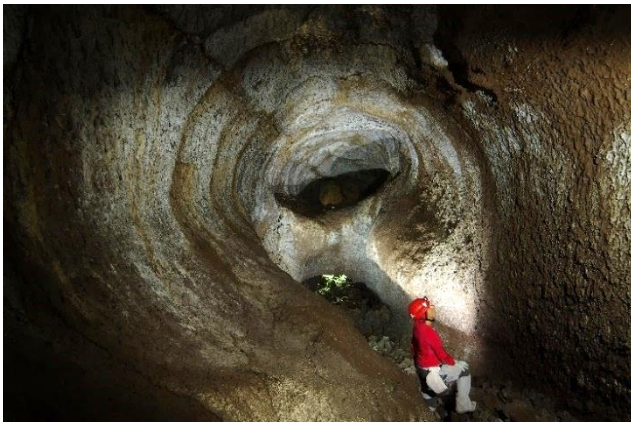

Figure 10: The double gallery (ph. Priolo, 2014).

Figure 11: The double gallery (ph. Priolo, 2014).

At about 200 m from the entrance, two different tunnels branch off the main one: the narrow one goes Eastward whereas a slightly larger one turns Northward with a development of more than 150 m and an average height of 1.40 m.

Past this fork, the tunnel goes on for about fifty metres to a narrow, cramped and rough bottleneck about 5 metres long (Figure 12), which separates this section of the cave from the second part of it.

Figure 12: The bottleneck (ph. Priolo, 2014).

Figure 13: The second entrance (ph. Priolo, 2014).

Beyond the bottleneck the cave changes morphology, becoming even wider and, in some cases, imposing. A second entrance, located about twenty meters further south along the lava channel, makes it possible to avoid the awkward bottleneck (Figure 13).

In this part of the cave, the longest, numerous markers of lava flow are observed in addition to characteristic recast morphologies (Figure 14).

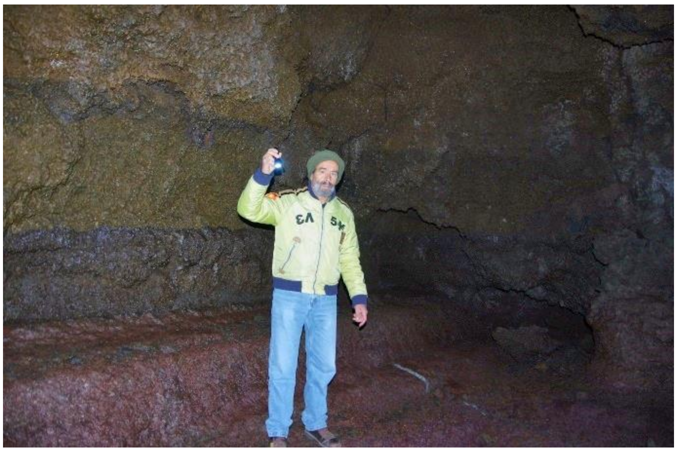

Figure 14: Recast morphologies and markers of flow (ph. Priolo, 2014).

Figure 15: Bats (Myotis sp.) in the cave (ph. Priolo, 2014)

During the explorations, the presence of some specimens of bats of the genus Myotis was found (Figure 15).

Surely words do not render the majesty of G*rotta del Faggio*, more comprehensive surely the topographic restitution of the survey made during the days of exploration (Figure 16).

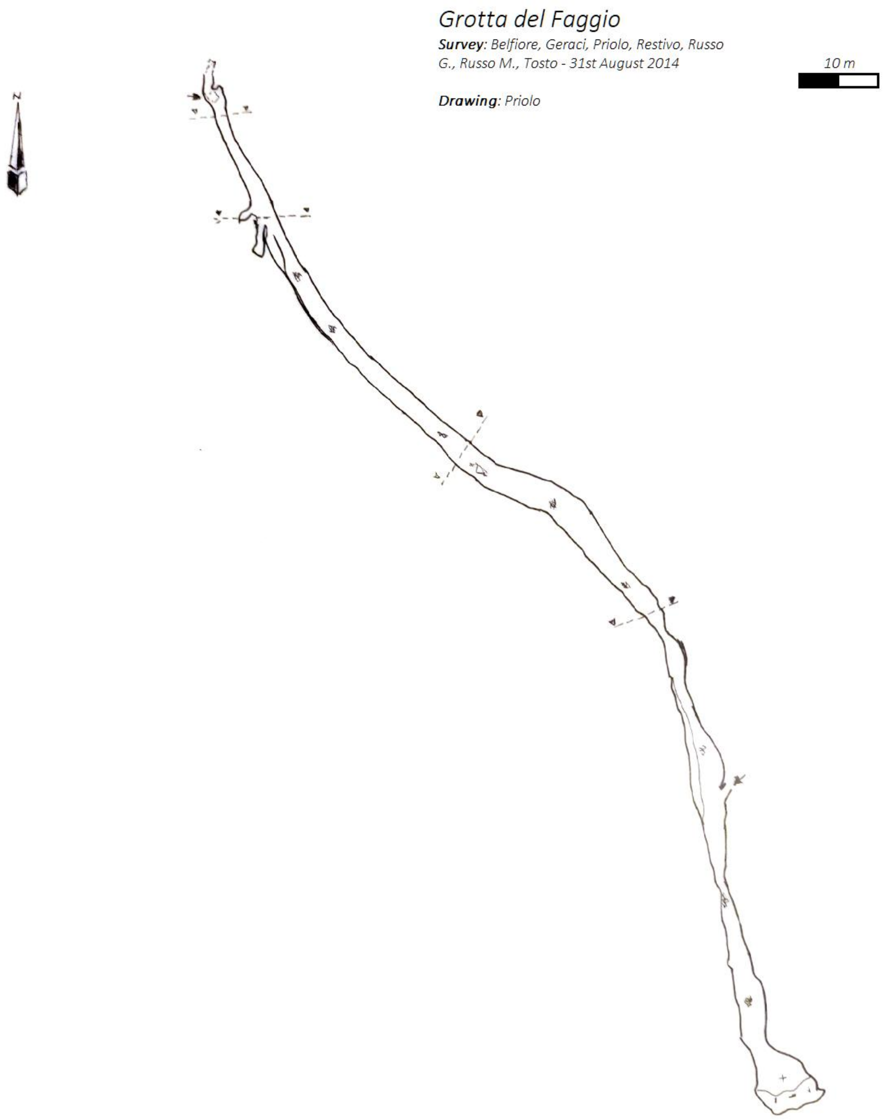

Figure 17: Grotta del Faggio survey.

Conclusions

As well as all the caves explored in the *Sciara del Follone*, the *Grotta del Faggio* is extremely extensive and impressive, preserving very comprehensive examples of the rheology of lava flows that characterized the activity of the eruptive scenario from 1614 to 1624.

There are numerous other cavities in the area, discovered by Vincenzo Gullotto who gave them their name: *Grotta del Mistero*, *Grotta delle Diramazioni*, and other cavities of lesser development some of which were retraced and explored during the 2014 campaign.

Our heartfelt thanks go to the members of the Gruppo Grotte Catania of the Club Alpino Italiano who committed themselves to the days of exploration and surveying, enabling, in fact, the realization of this work.

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Grotta del Faggio. Blister and refusion stalactites. Photo: Priolo G.,2014.

SYMPOSIUM DAY 3, WEDNESDAY 1 SEPTEMBER (continued)

PAPERS

Session 5: Other

The Grotta della Cisterna, San Giovanni Galermo, Catania, Italy (G Giudice, F Politano, A Cariola, S Tomasello).

"Ghiara" quarries on Etna: examples inside and outside the urban environment (Catania, Sicily) (Gaetano Giudice, Francesco Politano, Alfio Cariola).

Down the crater from Empedokles to Arni (Franz Lindenmayr).

Lineri Quarry: a resource for the inhabitants of Misterbianco after the 1669 eruption, the 1693 earthquake and the post-war (Carmelo Bucolo, Andrea Belfiore, Giuseppe Cantone).

The Piano Noce cave: from vandalism to dignity (Carmelo Bucolo, Francesco Caltabiano, Sebastiano Russo).

Grotta del Faggio, overlapping lava tubes near the exit. Author and year: Priolo G., 2014.

THE GROTTA DELLA CISTERNA, SAN GIOVANNI GALERMO, CATANIA (ITALY)

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Abstract

This work describes one of the lava tubes of Etna with the largest size of gallery, sometimes more than 20 metres wide, recently discovered with amazement and explored in San Giovanni Galermo, a quarter of Catania, used as bomb shelter during World War II. The cave opens inside the lava della Carvana, a prehistoric lava flow north-west of Catania town, and at the moment is surveyed for more than 200 m in length. The cave houses a singular cistern, dated 1882. It is not so common to see the external body of an underground cistern, because the external surface of the walls is usually in direct contact with the ground that hosts it, or because in other soils (especially calcareous) the walls of the container are hewn out of the rock itself, and then plastered. In the case described here, instead, the underground body of the cistern seen from inside the cave looks like a huge circular tower, about ten metres high, outside of which, buttresses built with lava stone and mortar are visible. Inside the cave, drains, debris and pollution are present, probably coming from old entrances now obstructed, but also pottery and stones from various periods, the oldest probably from the Bronze Age, and some stone enclosures delimiting sectors, still under study.

Riassunto

Questo lavoro descrive una delle grotte laviche di scorrimento dell'Etna con la più grande sezione di galleria, in alcuni punti con più di 20 metri di larghezza, recentemente scoperta con stupore ed esplorata a San Giovanni Galermo, un quartiere di Catania, utilizzato come rifugio antiaereo durante la seconda guerra mondiale. La grotta si apre all'interno della Lava della Carvana, una colata lavica preistorica a nord-ovest della città di Catania, ed è attualmente rilevata per oltre 200 m. La grotta ospita all'interno una singolare cisterna, datata 1882. La particolarità dell'opera consiste soprattutto nel fatto che di norma le cisterne sono scavate nella roccia che le contiene, mentre questa poggia sul pavimento della grotta lavica che la ospita, è stata costruita dal basso verso l'alto, e le sue pareti esterne sono ben visibili dall'interno della grotta. Nella grotta sono presenti in vari punti scarichi di liquami, acque bianche e detriti vari, questi ultimi provenienti da antichi ingressi oggi ostruiti, inoltre sono stati rinvenuti anche reperti ossei e ceramici ascrivibili a diverse epoche, i più antichi risalenti probabilmente all'Età del Bronzo, e alcune strutture di delimitazione degli ambienti ancora allo studio.

Key words: Cistern, Lava tube, San Giovanni Galermo, Bomb shelter, Etna

Foreword

On the slopes of Etna, north of Catania, there is an ancient urban centre already known by speleologists for the presence of huge lava flow cavities, whose name until the beginning of the twentieth century was San Giovanni di Galermo. Despite having been aggregated to the municipality of Catania since 1926, San Giovanni Galermo still maintains its well-defined identity (Figure 1). The name Galermo derives from the Arabic عين الماء (eayan alma) and literally means "eye of the water", referring to a probable source or stream that was believed to exist in ancient times.

In 2014 Salvatore Tomasello (student of Geology at the University of Catania and co-author of this work), during the editing of a feature film on the history of San Giovanni Galermo (Tomasello, 2020), became aware of a "legendary" cistern set in an immense cave. Tomasello, having identified the access to this cavity that develops just below the historic centre of the town (Figure 2), in the spring of 2018 turned to the Centro

Figure 1: Location of the quarter San Giovanni Galermo (drawing A. Cariola).

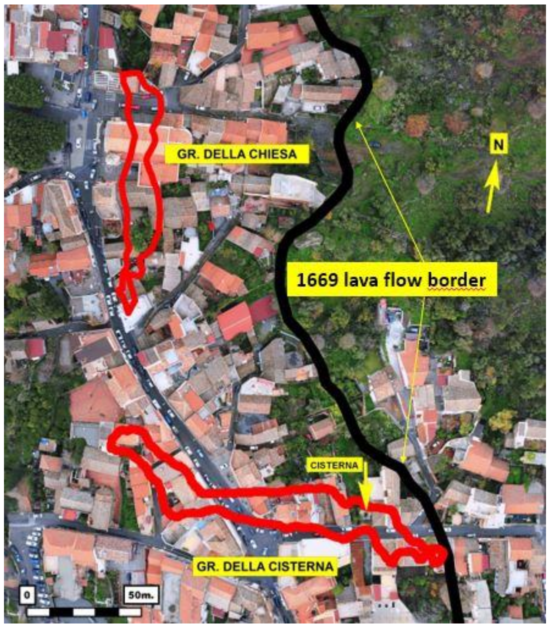
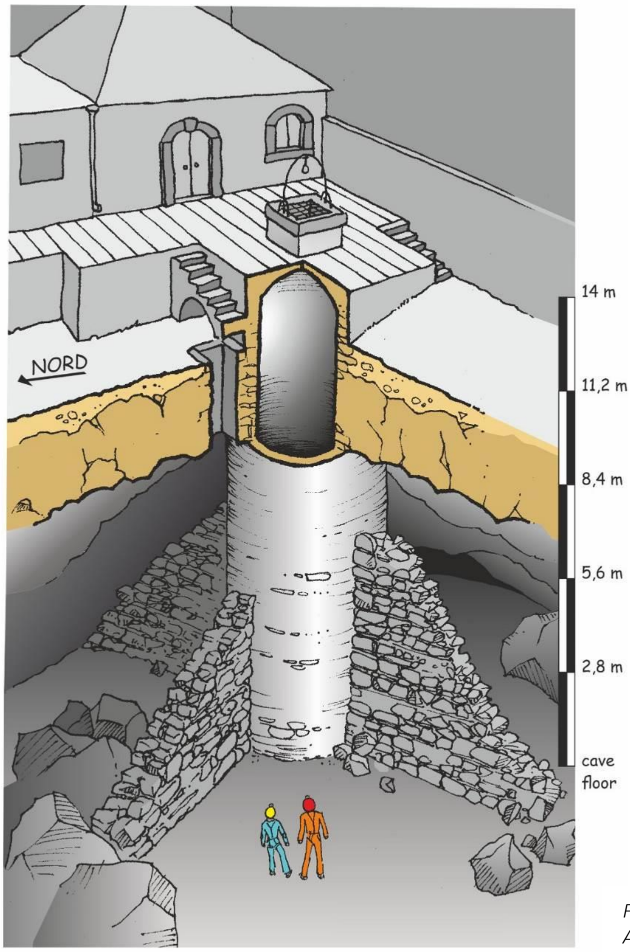


Figure 2: Position and aerial view of Grotta della Cisterna (ph S. Tomasello; drawing A. Cariola).

Speleologico Etneo, on the advice of Prof. Giuseppe Sperlinga, a naturalist from Catania. In synergy with the speleologists of the CSE, and thanks also to the collaboration of the owner Mrs. Maria Di Guardo, one of the largest lava flow tunnels of the Etna area was discovered with amazement, which houses inside a singular cistern, dated 1882 (Figure 3). The cave was also used as a bomb shelter during World War II (Tomasello, 2020), but incredibly remained unknown to the scientific community until 2018.



The Centro Speleologico Etneo, which became aware of the risk that some main branches of the peripheral belt of the building drain collector (Canale di Gronda), north-west of Catania, could intersect or overlap with different sectors of the hypogeum, reported, through the Soprintendenza BB.CC .AA. of Catania, the presence of this cavity both to the European Commissioner and to the designers of the drain collector.

Survey supplements are being planned to study the compatibility of what was designed with the underlying cavity and to identify variants and/or measures in order to avoid structural problems both in the project work and in the cave itself, which is characterized in various points from collapses and landslides, even of considerable entity.

This will allow implementation of appropriate safeguards and protection measures towards the cave and the work itself.

Figure 3: Sketch of entrance shaft and the cistern. Author and year drawing F. Petralia, 2020.

Geological framework and lava tubes

Etna is the volcano of continental Europe in which the phenomenon of the formation of lava caves is more widespread, both in terms of number and variety of types.

The erupted lava flows proceed on the ground following generally, but not only, the maximum slope line. The considerable thermal gradient existing between the casting and the outside (of the order of 1000 ° C) causes the erupted material to cool and solidify with considerable rapidity, forming dikes, solid crusts and pipes that enclose still hot masses able to flow. Once the feeding to the effusive outlets has ceased, the insulation characteristics of the already solidified lavas allow the fluid masses, contained inside the pipes, to continue to flow, emptying them partially or completely; this phenomenon leads to the formation of lava flow caves (Calvari & Puglisi, 1999).

In historical and prehistoric times, the area on which today's Catania stands has been invaded several times by lava flows from lateral eruptions of Etna, even at relatively low altitudes. Many prehistoric lavas are present in the upper area, to the north of today's city, where today there are the districts of Barriera del Bosco, Canalicchio and Picanello, and even further upstream, in the area of San Giovanni Galermo, thus forming a sort of band lava on the outskirts of Catania (Marino & Santi, 1999).

One of these lava flows, known as the Carvana, has pushed a little lower than today's Tondo Gioeni, a district in the northern outskirts of Catania. In this flow some cavities are present, which during the Bronze Age (third millennium BC) were largely inhabited and used as a place of worship or burial (Privitera, 1999). Among these are particularly significant the Caflisch Cave, the Nuovalucello I Cave and, above all, the Petralia Cave, which not only has great archaeological importance, but is also the longest lava tube known today at low altitude (Marino & Santi 1999) .

Also, in the area of the San Giovanni Galermo district, two large caves have been identified in the past, namely the Grotta della Chiesa and the Grotta Marrano (Cariola, 1981; Bella et al., 1982); both have important anthropic adaptations and remains of prehistoric presence. The cave described in this article is located between these two caves, closer to the Grotta della Chiesa (Figure 2), and it cannot be excluded that all these cavities were formed during the same prehistoric eruption.

Furthermore, in the area there are other artificial hypogea, especially quarries of "ghiara" or red sand, a sandy material with pozzolanic properties widely used in construction in the past (Belfiore et al., 2010; Giudice et al., 2020; Politano, 2012), which are dug under the lavas of the disastrous flow of the eruption of 1669, which also destroyed part of Catania. This flow reached an area near where the current entrance to the Grotta della Cisterna opens, only about 30 metres from it.

Cave description

The access to the cave (Figure 4) is located on private land, located in the historic centre of the quarter of San Giovanni Galermo, and consists of an artificial well about ten metres deep that comes out on the side of a large room, inside a big lava flow tunnel, in its easternmost sector (Figure 5).

Figure 4: The cave entrance (ph. F. Leone).

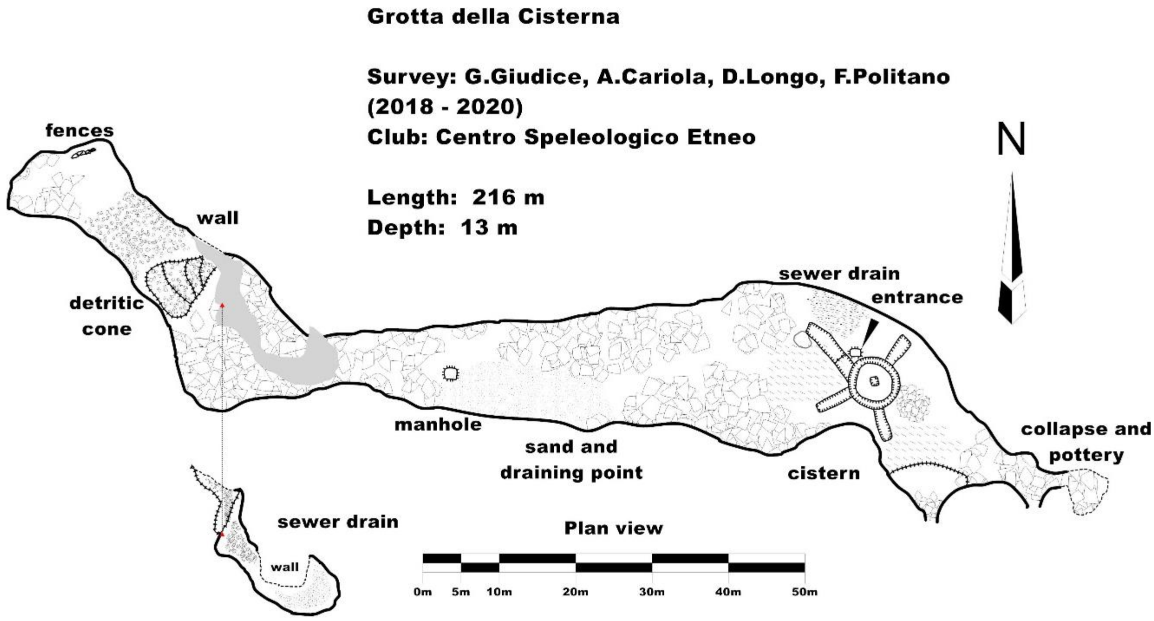


Figure 5: Plan view of Grotta della Cisterna (drawing G. Giudice; survey G.Giudice, A.Cariola, D.Longo, F.Politano - CSE).

The width of the gallery is such as to be able to comfortably accommodate a voluminous cistern for collecting rainwater (Figure 3), built in the second half of the nineteenth century. Proceeding west, the tunnel remains impressive in size, characterized by alternation of collapsed boulders and sandy deposits, flowed inside by some manhole on the ceiling, and by wastewater introduced by drains from the houses above. In particular, after the middle part, there is a consistent dripping from a manhole (Figure 6), which receives water from the street in periods of rain, and also from the discharge of a public fountain on the main street of the district.

In this sector, bone and ceramic fragments of probable prehistoric origin have been observed. Further west there is a large cone of debris, consisting of scraps of construction material and various waste, coming from an overlying level of the gallery, characterized by the presence of retaining walls, which are probable obstructions of ancient entrances, from which they flow, in several points, apparently white water discharges. The debris cone partially obstructs the tunnel, significantly reducing its width. Further to the west there is a section of an intact cave, slightly smaller than the previous sector and with the vault that is considerably lower. On the walking surface, alignments of stones were found like fences, with remains of

Figure 6: Water curtain from the storm drain in Piazza Grande, the cistern on background (ph. F. Fiorenza).

bones and pottery, which are being examined by the Soprintendenza BB.CC.AA. of Catania (Figure 7). A few metres further on, the vault lowers further and it is only possible to crawl through the collapsed boulders to cover the last passable metres of the cavity.

Figure 7: Stone enclosures on the west area (photo G. Giudice).

The opposite end of the cave, east of the entrance, can be reached after bypassing the cistern on the southern side and climbing one of its buttresses. We look out onto a large room with a low vault, which has a slide to the south, which leads to narrow passages that can be crossed for several metres in the midst of collapsed boulders, and to the east a series of narrow and interconnected environments, on an irregular platform of almost smooth solidified lava, where there are significant quantities of bone and ceramic finds, belonging to various eras.

These environments represent the easternmost explored extremity of the cave.

The cistern

The history of this singular cistern (Figure 8) has been reconstructed through the stories of the owner and some elderly people residing in the neighbourhood (Tomasello, 2020). In 1882 the owner Scalia wanted to dig a cistern to collect rainwater. The master tank excavator Giovanni Agosta (1860 - 1951), called "sciabulazza" from the dialectal name of a tool of his trade, was commissioned. During the excavation works, the cave was intercepted and then the large void below was exploited to build the cistern from the bottom of the cave to the external surface already excavated. After 26 years from its construction, it suffered the effects of the Messina earthquake of 1908. The memory of the loud noise of the "roar" of the water that was lost from the cracks formed, that were also heard from inside the houses in the surroundings, was preserved and is still alive in the descendants of the old inhabitants. The property was forced to carry out rehabilitation and consolidation works, building four buttresses to reinforce the tank against the pressure of the water, but also as a support function in the event of another strong earthquake.

Figure 8: The well's mouth of the cistern (photo A. Cariola).

It is difficult to see the external body of an underground cistern, precisely because the external surface of the walls is in direct contact with the ground that hosts it or because in other soils (especially calcareous) the walls of the container are hewn out of the rock itself, and then plastered. The underground body of the cistern, seen from the inside of the cavity, looks like a huge circular tower, about ten metres high, outside of which, buttresses built with lava stone and mortar are visible (Figure 9).

Figure 9: The cistern body view from west side (photo F. Fiorenza).

The artefact has the internal dimensions of about 5 metres in diameter and a height at the entrance neck of 16.75 metres and therefore could have a capacity of over 270 cubic metres of water. The level signs, painted in red and numbered on the internal wall of the cistern (Figure 10), would correspond to the Catania palm which is approximately 25.81 cm (https://www.sicilianiliberi.org/2016/08/06 /sistema-metrico-siculo), so each red mark indicates about 5 m^3 of water. Currently, the water level from the bottom is about 6 m, so the amount of water is about 117 m^3.

According to various sources (Tomasello 2020), the cistern was certainly also used for commercial purposes and was not an isolated case: in the vicinity of the two main roads of the quarter, there are about 15 other cisterns, most of which were used for domestic use while the largest were used to obtain commercial profit, a real "waterway" that leads to the discovery of cisterns from various eras (from 1754 to 1925). There are cisterns whose mouths are only 8 metres apart, always rigorously built near the road to facilitate the loading of quartare (earthenware amphorae) on carts. Particularly noteworthy is the large cistern of the Manganelli (name derived from the original property) which according to some writings is not only prior to 1669, but was the place where, during the terrible eruption, the veil of Sant'Agata was carried in procession to stop the lava (Tedeschi Paternò 1669, Massa 1709). This ancient cistern, still in use, is located just over 40 metres from the cistern of the cave and it has not yet been ascertained whether it is also interconnected with the cavity.

Evidence of prehistoric occupation

Other much older adaptations are visible in the rooms at the western end of the tunnel, alignments of rocks that resemble fences (Figure 7) that delimit areas with fragments of pottery and bones, probably from prehistoric times.

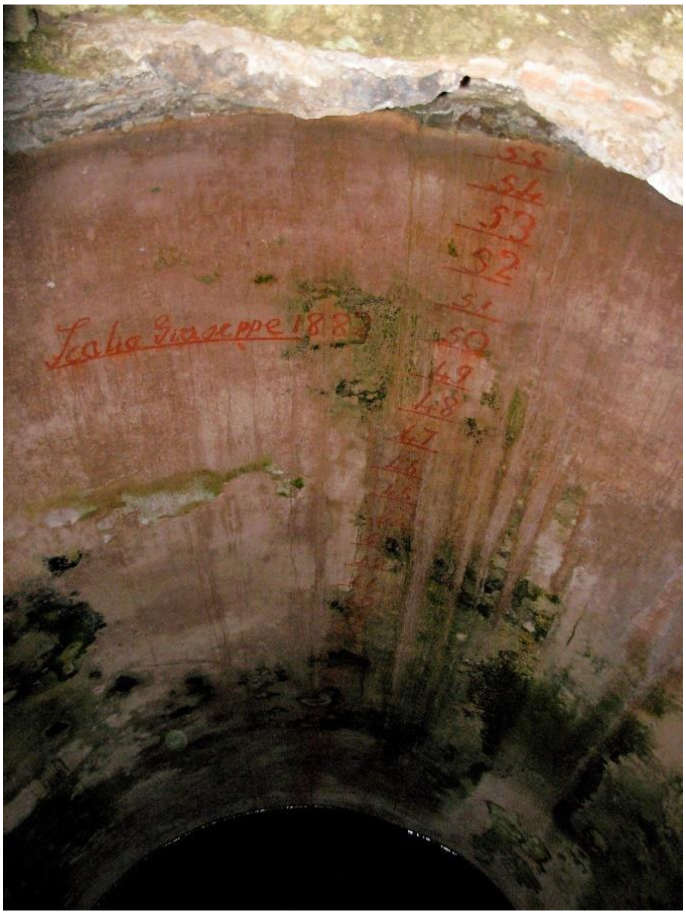


Figure 10: The well's interior of the cistern (photo A. Cariola).

These finds are not the only ones found inside the cave, in fact in several other areas fragments of pottery and bones have been found, and, from a preliminary inspection carried out with staff of the Soprintendenza of Catania, it seems that different eras are represented, from the more recent past perhaps back to the Bronze Age.

Conclusions

The large lava tube, probably hosting the widest section of lava tube of Etna and surprisingly not known by speleological and scientific people until 2018, with the particular cistern described in the article, represents a rare example of natural cave readapted by man with an underground hydraulic construction not made of recessed rocks. However, it is not the only sign of man presence found inside the large lava tunnel, as in various points there are more or less recent interventions, such as dry stone walls with the function of barrier, used to obstruct ancient entrances, or, unfortunately, waste water discharges and landfills of various materials, probably residues of constructions or adaptations carried out in the houses of the neighbourhood located above the cavity. It is not excluded that some of the artificial structures found are quite ancient. Although the survey works are only at the beginning, the site is of undoubted archaeological interest. There are also other artificial hypogea and other caves readjusted by man for various functions in the surroundings of the cave (for example the Grotta della Chiesa and the Grotta Marrano), which makes the area within and around the quarter of San Giovanni Galermo fertile ground for new discoveries and explorations.

Finally, we note the proposal for the establishment of a Metropolitan Vulcanospeleological Park in the Catania area, carried out by the "Stelle e Ambiente" association chaired by Prof. Giuseppe Sperlinga, which aims to protect, enhance and use the naturalistic heritage both from prehistoric and historical lava caves, many of which still preserve human burials, ceramic finds and tools dating back to the Ancient Bronze Age, and from uncultivated lavas rich in interesting surface morphologies (Sperlinga & Cavallaro, 2006).

Acknowledgments

A heartfelt thanks goes to all the members of the Centro Speleologico Etneo who participated to the work in this cave, and for the commitment and time they dedicate to researching and studying the caves scattered throughout the Etna area; to Mrs. Maria Di Guardo, owner of the land where the studies were carried out; to Prof. Giuseppe Sperlinga for precious suggestions; to Prof. Giuseppe Di Guardo, to Prof. Sergio Sciacca, to Giovannino Agosta, Agata Di Guardo, Salvatore Aiello, Agata Aiello and Caterina Rosaria Aiello for the historical information reported orally; to the officials of the Soprintendenza of Catania, for their collaboration in this as in many other studies underway in the province of Catania; to Francesco Petralia, who despite having never been in the cave, managed to masterfully produce the schematic drawing of the cistern; to Giovanna Musumeci, for her help in revising the article.

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"GHIARA" QUARRIES ON ETNA: EXAMPLES INSIDE AND OUTSIDE URBAN ENVIRONMENT (CATANIA, SICILY)

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Abstract

This work describes the discovery, exploration and survey of a couple of quarries used to extract the so-called "ghiara" from below old lava flows. These are particular artificial caves, mostly driven into oblivion, diffused in the underground of Catania (in some cases used as refuge during World War 2) and on Etna's surroundings. The *ghiara* or red sand is a sandy substance with pozzolanic properties, produced by a thermal metamorphism process due to the contact of paleo-soil with active lava flows. This sand was mixed with the lime in order to obtain ordinary mortars, which were widely used in the building industry as a binder, and for the preparation of the external plaster which gave the characteristic pink colour to historical buildings in the town. The extraction of this material was done by excavating labyrinths of narrow galleries, but also large rooms consolidated by pillars made of collapsed rocks. The search for these quarries, which began with the exploration of the underground of the city of Catania, was then extended to the entire Etna area with unexpected results both in terms of quantity and quality. In this work we will mention the peculiar characteristics of the extracted material, the gravel, its geogenesis and its use in construction, and then describe the method of excavation of the quarries and their diffusion in the city and in the Etna area. The study of two quarries falling in different areas of the territory and under different lava flows will also be presented: the "Grotta Lucente" quarry, located in a semi-peripheral area of the municipality of Catania, under a secondary branch of the lava flow of 1669, and the " Cava dell'Istrice", located near the village of Pedara, in the Tarderia district, extended under the Colata di Montarello of the 1270 eruption.

Riassunto

Il Centro Speleologico Etneo (CSE) svolge ormai da diversi anni ricerche finalizzate alla conoscenza e allo studio di un particolare tipo di cavità artificiale presente sotto le colate laviche etnee, e dalla quale in passato si estraeva un materiale sabbioso, noto come sabbia rossa o ghiara. Questa sabbia rossa ha caratteristiche pozzolaniche e si forma per azione di colate laviche sul terreno preesistente. Nell'area etnea la ghiara era largamente utilizzata negli edifici storici mista a calce per ottenere malte, e per la preparazione dell'intonaco esterno che ha conferito il caratteristico coloure rosato agli edifici storici. L'estrazione di questo materiale avveniva scavando labirinti di anguste gallerie, ma anche grandi ambienti consolidati da pilastri costruiti con le rocce di crollo. La ricerca di queste cave, iniziata con l'esplorazione del sottosuolo della città di Catania, si è poi estesa all'intera area etnea con risultati inaspettati sia in termini di quantità che di qualità (Bonaccorso & Lo Giudice, 1999). In questo lavoro citeremo le caratteristiche peculiari del materiale estratto, la ghiara, la sua geogenesi e il suo utilizzo in edilizia, per poi descrivere il metodo di scavo delle cave e la loro diffusione in città e nel territorio etneo. Verrà inoltre presentato lo studio di due cave ricadenti in zone diverse del territorio e sotto diverse colate laviche: la cava "Grotta Lucente", situata in una zona semiperiferica del comune di Catania, sotto un ramo secondario della colata lavica del 1669, e la "Cava dell'Istrice", situata nei pressi del paese di Pedara, in contrada Tarderia, estesa sotto la Colata di Montarello dell'eruzione del 1270.

Key words: Ghiara, Cave, Lava flow, Catania, Underground, Etna.

Summary

This work describes the discovery, exploration and survey of a couple of quarries used to extract the so called "ghiara" from below old lava flows. These are particular artificial caves, mostly driven into oblivion, diffused in the underground of Catania (in some cases used as refuge during World War II) and on Etna's surroundings. The ghiara or red sand is a sandy matter, with pozzolanic properties, produced by a thermal metamorphism process due to the contact of paleo-soil with active lava flows. This sand was mixed with the lime in order to obtain ordinary mortars, which were widely used in the building industry as a binder, and for the preparation of the external plaster which gave the characteristic pink colour to historical buildings in the town. The extraction of this material was done by excavating labyrinths of narrow galleries, but also large rooms consolidated by pillars made of collapsed rocks.

Background

For several years the Centro Speleologico Etneo (C.S.E.) has been carrying out research aimed at the knowledge and study of a particular type of artificial cavity present under the Etnean lava flows, and from which in the past a sandy material was extracted, known as red sand or ghiara. This red sand has pozzolanic characteristics and is formed by the action of lava flows on the pre-existing soil. In the Etna area, the ghiara was widely used in historic buildings mixed with lime to obtain mortars. The search for these quarries, which began with the exploration of the underground of Catania town, then extended to the entire Etna area with unexpected results both in terms of quantity and quality (Bonaccorso & Lo Giudice, 1999). In this work we will mention the peculiar characteristics of the extracted material, the ghiara, its geo-genesis and its use in construction, and then describe the method of excavation of the quarries and their diffusion in the city and in the Etna area. The study of two quarries falling in different areas of the territory and under different lava flows will also be presented: the "Grotta Lucente" quarry, located in a semi-peripheral area of Catania town, under a secondary branch of the 1669 lava flow, and the "Cava dell'Istrice", located in the neighbours of the village of Pedara, in the Tarderia district, and extended under the Colata di Montarello of the 1270 eruption.

The ghiara

The "ghiara", also known with different terms such as "agghiara", "agliara", "red sand", "la russa", is characterized by a variable colour from light pink to dark red and by a sandy-silty grain size, with the inclusion of lapilli and tuffs of size between 1 and 4 mm, greasy to the touch and tinting. As already mentioned, it is a cooking product (thermal metamorphism) due to the flow of lavas with a considerable mass and very high temperature (the temperature of the lava flows in the Etna area is between 800 and 900 °C, at distance from the eruptive systems) on agricultural or sandy soils which in turn are generally of volcanic origin. This red sand then lies at the base of the flows (Politano, 2012). The ghiara is a chemically active material as it contains silicates and aluminates. In the carbonation process (the chemical process, natural or artificial, whereby a substance, in the presence of carbon dioxide, gives rise to the formation of carbonates), silica reacts, in the presence of water, with calcium hydroxide (hydrated lime), creating calcium silicate, a resistant and insoluble compound in water which gives the ghiara pozzolanic characteristics (Belfiore et al., 2010). The red sand was widely used in construction until the first half of the 1900s. The reddish mortars in fact characterize most of the buildings in the historic centre of Catania and, in general, the Etnean building of the past. Subsequently, the use of this material declined because it was supplanted by the use of cement mortars, which are easier to find than gravel, the extraction of which involved multiple risks. The last quarries were definitively abandoned around 1970.

The quarries

We do not know from archival documents the period from which the use of the ghiara in construction started, but it is evident that it was widely used during the reconstruction of the inhabited villages and towns after the disastrous earthquake of 1693. During the eighteenth century it was therefore necessary to excavate vast quarries under the flows, inside the stone quarries already in use or by excavating from new gravel quarries wherever possible. To this end, at the conclusion of an eruptive event and after the time necessary for the complete cooling of the lavas, the flows were carefully inspected by the workers of the gravel quarries, called "ghiaioti", especially along the edges where the rock was less compact and they could more easily dig tunnels, often steep and meandering, until they reached the bottom of the flow (Politano, 2014). Here the tunnels were made in the directions in which the thickness of the original soil (the paleo soil), composed of small sediments and poor in crushed stone, was greater. Along the tunnels, in the points where the ghiara was more compact and abundant, large rooms were created (in the Cava dell'Orcio, near Pedara, there is an area about thirty metres wide and without any supporting pillars). As the excavation face advanced, the rooms obtained were filled with piles of waste stones and crushed stone obtained from a first rough screening of the gravel. These mounds were delimited by dry stone walls made from waste materials, which transformed the rooms into many short tunnels, normally just over a metre wide, which then joined together to create wide open spaces. The built walls also acted as a support for the roof normally made up of a very incoherent layer of slag and pumice. As these walls were built, the quarry became a real labyrinth. The height of the tunnels is due to the thickness of the quarried material, normally just a little bit over one meter, but which in some sections can even exceed two metres, especially where the very incoherent layer above the gravel has given way or has been deliberately removed to avoid sudden collapses. In some areas you can see the solid lava above, normally hidden by the scoria, strongly cracked, with enormous suspended and almost poised blocks. The quarries are often scattered with small or large collapses, also consisting of enormous boulders with perfectly smooth faces and sharp edges. The mining activity was rudimentary and rather heavy, accidents had to be frequent because both individual and structural security measures were non-existent. The excavation tools were the hoe, the pickaxe and the lantern. The ghiara separated from the stones was stuffed into wicker baskets called "corbe" and transported out by donkeys or children, the latter exploited for this very tiring work because their small size facilitated movement within the narrow passages of the quarry. The Italian writer Giovanni Verga, in the famous novel "Rosso Malpelo" describes the hard work that took place inside a quarry of this type. Outside, the ghiara was further selected, based on the greater or lesser fineness, with manual sieves called "crivi" having a wooden structure and metal plate. For sieving, various sieves were used, with holes of different diameters according to the final use, with holes of about 2 mm for plaster or finishing mortars, or from about 2 to 4 mm for masonry mortars. It is possible to note the considerable diffusion of the quarries of ghiara throughout the Etna area affected by lava flows, even in those of prehistoric times. Many quarries were dug near or even below inhabited centres to minimize transport costs. In Catania they are also present in the subsoil of the historic centre, and some are easily accessible directly from the cellar of the building above (eg: Convento dei Cappuccini in via Plebiscito). Finally, it is interesting to observe how, at the beginning and during the last world war, the largest quarries laying under the buildings were adapted to air-raid shelters. Often the ghiara is mixed with terracotta shards, bones, worked stones and sometimes even the remains of pre-existing buildings covered by the lava flow. An example is represented by the quarry below the Convento dei Cappuccini in Catania where a gallery shows pieces of brick walls and the remains of a grain mill probably from the Roman period. In other cases, in areas originally covered by woods, it is possible to see, in the vaults of the larger rooms, the so-called "pietre cannone" (cannon stones or tree mold caves), tubular cavities incorporated in solid lava originating from incinerated large tree trunks (Politano, 2014).

The Cava Grotta Lucenti

This cavity was one of the first quarries for the extraction of red sand to attract the attention of the cavers of the C.S.E. within the territory of the municipality of Catania: the first visits date back to early 90s. The cavity was already known at the time as "Grotta Lucenti", probably from the surname of the owner, and it has continued to be indicated in this way. The quarry is located inside the city, almost on the border between two districts (Cibali and San Luigi), within a large area of about 18 hectares not yet urbanized, with almost unchanged environmental characteristics. This large area has remained unchanged because in the Catania General Town Plan of 1969 the construction of the Cibali Business Center was foreseen. In the 80s of the last century, a group of construction companies bought this land and set up the Cibali Consortium, which after many vicissitudes is now under the supervision of the Bank of Italy (Stanghellini, 2016). At the beginning of 2016, the Centro Direzionale Cibali Consortium launched a public consultation for the collection and selection of proposals for the use of its areas. Some proposals have been considered relevant, we cite one in particular, presented by the cultural association "Le Cave di Rosso Malpelo", engaged in the protection and safeguarding of the red sand quarries in the Catania area, which proposed the establishment of a mining park through which it is possible to enhance the geological, archaeological and historical elements of the "Grotta Lucenti" quarry.

Description of the hypogeum

The entrance

The "Grotta Lucenti" quarry has two narrow entrances (closed with gates for some years) not far from each other (Figure 1), close to the end of via Aspromonte in Catania. The accesses open as usual right at the edge of the flow, the northern in particular is located close to a flat land covered by grassy vegetation (Figure 2), while on the flow there are bushes of gorse and an oak grove, which unfortunately in 2018 was damaged by a fire. These accesses lead directly to the slopes, which are rather steep and narrow, and force to crawl to continue. The descents continue with low but easily passable tunnels, which then merge into a main larger tunnel. As with almost all the quarries explored so far, there is almost no information on the owners, on the companies that worked there, or on the time of excavation, but from some observed details it seems that pneumatic equipment was used for the excavation, at least for a time, and this suggests that it has been excavated in relatively recent years.

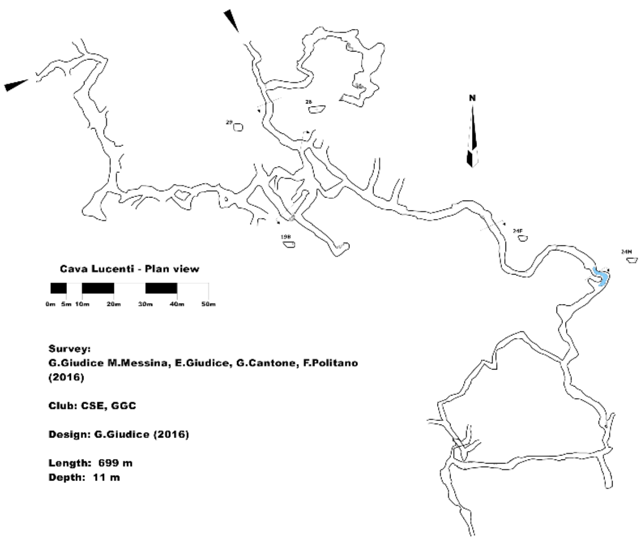

Figure 1: Map of the Cava Lucenti.

Figure 2: Entrance to Cava Lucenti. (Photo: Gaetano Giudice, 2019).

The interior

The quarry has a main tunnel that is relatively easy to walk through (Figure 3), even if there are several collapses of the walls or of the vault. The tunnel develops with a meandering trend for several tens of meters, with some sections partially flooded due to infiltrations (Figure 4), probably white water leakage from the houses above, which form muddy puddles. The red colour is dominant everywhere. As can be seen from the topography (Figure 1), along the route the beginnings of several secondary galleries are present, which lead to the environments where the red sand was dug following the most abundant layers of deposit. These are generally areas really risky for collapse, because extraction was exploited as much as possible, creating large and low environments often in precarious static conditions, so that as the excavation progressed, buttresses or pillars were made in various points with waste stones, thus making these areas more stable, but at the same time creating real labyrinths. Samples were taken from this cavity for studies on the composition of the ghiara (Figure 5).

Figure 3.

Figure 4.

Figure 5.

The Cava dell'Istrice

The Istrice quarry (plan view in Figure 6) is located in the territory of the municipality of Pedara (Catania province) in the Tarderia district. The Pedara territory, which extends to the foot of Etna, has been affected over time by several lava flows and is scattered with adventitious volcanic cones, which have deposited impressive layers of pyroclastic products in the surroundings. These soils, under the thermal action of subsequent lava expansions, gave rise to thick deposits of red sand. The Cava dell'Istrice, like many other quarries discovered in the surroundings (for example the Cava dell'Orcio, the Cava della Volpe and the Cava della Piramide), is characterized by wide and high galleries just like the useful layer to be quarried. Oral sources say that some of the red sand quarries in the Tarderia district remained active until the early 70s. The Cava dell'Istrice (Porcupine Cave) was so named because, as you can guess, the interior is littered with the characteristic quills of this rodent.

Description of the hypogeum

The entrance

There is only one entrance to the Cava dell'Istrice (Figure 7), which is located inside a wood that runs along Via Tarderia to the west. The access path through the vegetation starts from a large clearing close to a road intersection. The quarry has a wide, low entrance that forces you to crawl. After passing the entrance, the vault after a few meters rises and allows easy progression, along the walls there are short galleries, probably tests carried out by quarrymen to identify richer layers of material. Some of these secondary tunnels close on collapses or piles of rubble, but in various points, in the midst of the collapses, passages can be seen beyond which further environments could be present.

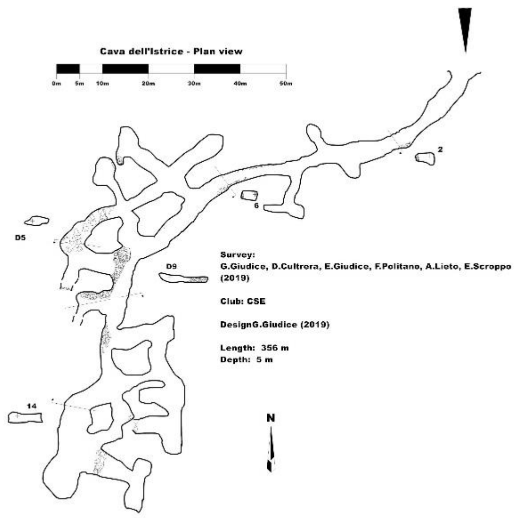

Figure 6.

Figure 7: The entrance to Cava dell'Istrice. Author and year: Giuseppe Conti, 2020.

The interior

The main tunnel (Figure 8) is about fifty metres long and leads to the area where the workers came across a very rich layer of red sand. The quarrymen tried to extract the maximum amount of useful material, even at the cost of jeopardizing the stability of the work, in fact they left very large rooms without any trace of shoring of the vaults. Also, in the terminal area of the quarry there are tunnels interrupted by collapses, and the continuations that can be seen are not easy to overcome, because the vaults are conspicuously cracked and unsafe (Figure 9).

Figure 8.

Figure 9.

Conclusions

This contribution is aimed at bringing to the knowledge of researchers the existence of a significant historical and speleological heritage almost forgotten, witness to a past now preserved only in the local toponomastics and in the still vivid memories of the few elderly quarrymen still alive. In addition to the evident historical-social value that this type of artificial cavity has, because it is connected to a flourishing economic activity of the past that has now disappeared, the considerable diffusion of these cavities in the urban underground imposes the need for greater attention also for the purposes of Civil Protection , as a function of a more careful assessment of the risk induced by the presence of "unstable" cavities that often extend to a few meters deep in areas which, if deserted at the time of the excavations, are today intensely urbanized.

Acknowledgements

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DOWN THE CRATER, FROM EMPEDOKLES TO ARNI

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Abstract

I want to present in 9 examples from history and literature different human approaches to volcano craters and abysses, concentrating mainly on the descent into them.

Riassunto

Voglio presentare, in 9 esempi tratti dalla storia e dalla letteratura, i diversi approcci umani ai crateri e agli abissi vulcanici, concentrandomi principalmente sulla discesa in essi.

Keywords: volcano craters, decent techniques, vertical volcanoanthropospeleology

Kirkjan Cave, Iceland. Photo: Franz Lindenmayr

Introduction

"Down, down, down" That is what Alice thinks while she is falling down the abyss behind the rabbit hole. "I must be getting somewhere near the centre of the earth. Let me see…" Lewis Carrol wrote in 1865 these classic lines in *Alice's Adventures in Wonderland*. She is lucky, she lands on "a heap of sticks and dry leaves, and the fall was over". Others were not always so lucky and history and literature is full of further examples.

In the beginning ….

Empedokles (494-443 BC), a Greek pre-Socratic philosopher from Agrigent in Sicily, died, according to one version, through a leap into the crater of Etna around 443 BC. Others claim that he left secretly for the Peloponnese and lived there happily until he died of old age, and others say he died in a carriage race. As a sign of his suicide, he left a sandal which was later found by his adherents. You can see in him as the first dedicated vulcanospeleologist who wanted a break-through experience. He claimed to be a god and believed in reincarnation, so his disappearance was not for ever. Many writers and artists used this story and retold it again and again. Just to name a few: Friedrich Hölderlin in *Der Tod des Empedokles*, Berthold Brecht with *Die Sandalen des Empedokles* and Jean-Marie Straub/Danielle Huillet *Schwarze Sünde.*

Martin Curtius (X - 362 BC) is a mythological Roman soldier who sacrificed himself, according to the legend, for the sake of the Roman Empire. Varro and at length Livius mention this moment. After an earthquake in 362 BC, a huge deep pit opened in the Forum Romanum, the centre of ancient Rome. All attempts to fill it in again failed. The augurs were consulted. Their answer: The gods demand the most precious possession of the empire. What was it? The young soldier Martin Curtius thought it was the bravery and courage of the Roman soldiers and offered himself as a sacrifice. He put on his arms, climbed onto his horse and jumped into the chasm, which closed immediately over him. A return to the surface was not intended. Only a ring of stone at the Forum reminds us still of this mythological event. During the Renaissance, this story of self-sacrifice for a higher purpose became very popular again and especially many artists created dramatic works which showcase the event. Lucas Cranach the Elder (1507-1508), Lambert van Noort, Luigi Garzi, Jean-Léon Gérôme and others. The depictions are often variations of a bas-relief, found in 1553 near the Forum Romanum, dating from the Early Empire.

Athanasius Kircher (1602-1680), a German Jesuit scholar, published 40 major works during his lifetime. His main fields of interest were comparative religion, geology and medicine. His geology studies included volcanoes and fossils. In 1638 after having visited Etna and Stromboli he also wanted to study Vesuvius. At Porticus he hired "an honest country-man, for a true and skilful companion and guide of the ways, ascended at midnight the mountain through difficult, rough, uneven, and steep passages. At whose crater or mouth, when I arrived, I saw what is horrible to be expressed, I saw it all over of a light fire, with a horrible combustion, and stench of Sulphur and burning Bitumen. Here forthwith being astonished at the unusual sight of the thing; Methoughts I beheld the habitation of Hell; wherein nothing else seemed to be much wanting, besides the horrid fantasisms and apparitions of Devils. There were perceived horrible bellowings and roaring of the Mountain; An unexpressible stink; Smoaks mixt with darkish globes of Fires". The next morning, he "went down unto it. In the Centre of the Bottom, Nature seem'd to have constituted, as it were, her Harth of Fire: And to say truth, a Shop or Workhouse to make a Vulcanian Kitchin; boyling with an everlasting gushing forth, and streamings of smoak and flames….being shook in pieces, and loosened by the trembling; and so falling like Hills, into the bottom of the Hellish Gulph; did from that various reflextion of the sound, stir up that crackling noise: So great and fearful a one, as that any, even of the stoutest and most undaunted heart, would scarce venture to suffer" In contrast to the heroes of the past, Kirchner doesn't throw himself into the lava but writes "Having taken a view of all these things duly and returning to Naples". Science doesn't always demand complete heroism.

Edgar Allan Poe (1809-1849), an American writer, editor and literary critic, is best known for his short stories, particularly his tales of mystery and macabre. *A Descent into the Maelström* is a short story published in 1841. A man recounts how he survived a shipwreck and a whirlpool. It is inspired by the Moskstraumen, a whirlpool of a diameter between 40 and 50 metres which "sucks in various small microorganisms, thereby attracting fish and fishing boats, which could be in danger even in modern times" WIKIPEDIA. The ship was caught in the vortex. His brother was pulled into the water, the other one was driven mad, he was saved because he abandoned the ship and held on to a cylindrical barrel until he was saved when the whirlpool temporarily subsided and he was rescued by some fishermen. You don't need any special equipment to go downwards in the story, you are sucked in and thrown out again by the overwhelming natural forces.

George Sand (1804-1876) was a French novelist, memoirist and journalist. Her short novel *Laura, voyage dans le cristal*, published in January 1864, was forgotten for a long time but got rediscovered in the 1970s. When you read it you are often reminded of a much more famous book. Jules Verne who published *Voyage to the Centre of the Earth* in November 1874 used a lot of the plot in his story without having asked Sand whether she liked it or not. A classical travel story: Alexis, a young German student of mineralogy falls in love with his cousin Laura, who is in love with another man. The father of Laura, Nasias, wants to go on an expedition to the North Pole to find the mysterious land of crystals. Alexis accompanies Nasias and after a thousand adventures they arrive at the promised area near a volcano-like landscape. There is a drop which they have to tackle and one of them finds long roots which they knot together to get down. Afterwards they cut them off because they might need them again for the next overhang. They also discover that they are edible; their only food. The group of two comes to a plain with a very thin stony cover. It cracks and underneath is a huge crystal abyss. Nasias gets crazy and jumps into the void. Turn the page: Alexis wakes up and the story goes on in another level.

Jules Verne (1828-1905) is now the second most-translated author in the world (after Agatha Christie). In the series *Voyages extraordinaires*, *Voyage au centre de la Terre* was published for the first time in 1864 (reissued in a revised and expanded version in 1867). A German professor, Otto Lidenbrock, believes that there are volcanic tubes that reach to the very centre of the earth. Accompanied by his nephew Axel and the Icelandic guide Hans, they "rappel into Iceland's celebrated inactive volcano Snaefellsjökull" WIKIPEDIA. "Rappel"? How do they get down into an unknown crater? Hans fixes the doubled rope and they climb down with the help of it. In one hand they have the ropes and in the other one a walking stick! When they come to the end of the rope, Hans has to undo the fixation of the ropes and find a new opportunity to refix it. And that for a depth of 900 meters! The walls can always only be sloping. If they were vertical or overhanging you would need at least two hands to hold onto the ropes. The luggage is not on their back but already thrown down into the abyss of unknown depth. According to Bozonnet the technique of roping down was invented in 1876 in France alpinism. Verne seems to have known of it 12 years before. Pulling down the rope means that there is in 99 percent of cases, no way to return again. The point of no return is passed and you are forced to continue – the ultimate adventure. After 14 times of refixing the rope and 7 hours of downclimbing they had finally reached the bottom of the shaft. It is very instructive to see how in the 13 film versions of the novel the descent into the crater is filmed. In 1959 the old technique of the miners was used: people were lowered on a rope sitting on a wooden bar. But how to get the rope again free? In the 1999 film, three persons abseil at the same time on three different ropes into the abyss. Imagine the amount of rope you need and who had to carry all the weight to the entrance of the crater! Further on another abyss has to be survived. The lid on top of it consisted of crystals which suddenly broke and the group of three just fell into it and fell and fell, without parachutes – until they got to a water level at the bottom which helped them to continue living after the crash into it.

Lewis Carroll (1832-1898), the famous English writer of children's stories, chose a similar way to show how one can get down an extreme shaft and survive. In the 1865 novel *Alice's Adventures in Wonderland* a young girl named Alice falls through a rabbit hole into a subterranean fantasy world. "Alice went after it, never once considering how in the world she was to get out again". She has nothing to do, just fall and fall. On her way down she thought: "I wonder if I shall fall right through the earth! How funny it'll seem to come out among the people that walk with their heads downwards! The antipathies….I shall have to ask them what the name of the country is, you know" Here, the going down the hole is completely easy. No worries about ropes, falling stones or anything.

Leon Creux (1875 – 1938) was an engineer and French writer. He was the inventor of the principle of the spiral compressor. In his book *Le voyage de l'Isabella au centre de la terre*, published in 1922 he used this idea to open a new dimension in getting to the centre of the earth. When the persons in Jules Vernes stories still had to find first a volcano pit to get there, the new solution was to build an artificial shaft with the help of a machine. With the help of it, it was possible to get to the core under controllable conditions and not depend on nature's peculiarities. Science makes it finally possible to open the doors to technological paradises.

Arni Stefansson, a doctor in Reykjavik and a lifelong cave enthusiast, was the first person who went down the 121 m deep entrance shaft of Thrinukagigur (Three Peaks Crater) in Iceland. He got the information from Einar Olafsson who led a party of the Icelandic Alpine Club to the area near Rejkjavik in 1973. At first he and his brother threw stones into the abyss and tried to measure with a line the depth of it. In summer 1974 with the help of a 200 m long rope, a self-made sitting harness and a pulley system Arni landed after 121 m metres on a cone of stones and was a short while later pulled up again. No jump, no fall, just a rational approach with a 'return ticket'. Since 2012, it has been possible for tourists to enter the huge magma chamber by an elevator, no ropes, no ladders are necessary anymore. Just do what the guide tells you to do. Put on a plastic helmet and a harness. The real adventure is gone, replaced by knowledge and money.

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LINERI QUARRY: A RESOURCE FOR THE INHABITANTS OF MISTERBIANCO AFTER THE 1669 ERUPTION, THE 1693 EARTHQUAKE AND THE POSTWAR

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Abstract

The 1669 eruption was one of the most catastrophic lava flows that struck 16 districts in Catania, including Misterbianco. The inhabitants of this small town, among the sciaras of Lineri's area, have been able to exploit the territory digging long and meandering caves of ghiara from which they could extract the red sand. It is called "ghiara" and is a sand of a typical red colour obtained by heating the palaeosol in contact with the lava. It was used in the construction industry to obtain the cements to create the plasters for building exteriors, "half plaster" for the interior plasters and "battume" to waterproof the coverings.

Riassunto

L'eruzione del 1669 è stata una delle colate laviche più catastrofiche che ha colpito 16 comuni catanesi tra i quali Misterbianco. La popolazione misterbianchese, tra le sue sciare del territorio di Lineri, ha potuto sfruttare al meglio il territorio scavando lunghe e tortuose cave di ghiara dalle quali veniva estratta la rena rossa. Chiamata "ghiara" è una sabbia dal tipico coloure rosso ottenuto da un processo di riscaldamento del paleosuolo a contatto con la lava soprastante e veniva utilizzata in edilizia per ottenere le malte per la formazione di intonaci per esterni, del "mezzo stucco" per gli intonaci interni e del "battume" per l'impermeabilizzazione delle coperture.

Key words: ghiara, quarry, eruption of 1669, Misterbianco, Etna.

A round room with some stones obtained by the excavating. They are used to create columns and small walls. Author and year: Bucolo C. 2020.

Premise

The Etna volcano Etna is rich in many natural caves, both lava tubes and pit caves. These are not the only volcanic tunnels you can find in Etna's territory. Man, many years ago, used natural lava fields to extract rocks that could be useful for construction. This artificial caves' name is *Ghiara's Quarry,* where "ghiara" is the name of the material similar to gravel but of volcanic origin.

The extraction and trade of red gravel originated in the eighteenth century, when this kind of gravel was known by many different names in different dialects. It represented a lucrative activity until the 1950s, as it was mixed with lime to obtain a type of mortar for construction use.

Gravel was used in order to create plaster for exterior use and a kind of stucco for inside plasters and a kind of impasto useful for the waterproofing of buildings.

Etna’s ghiara is a reddish ash, finely sandy, that has the property of turning a deep red colour if you touch it. It originates when an active lava flow heats the ground it is moving over to a temperature of 800-900 degrees.

Mortar obtained was known as “pozzolanica”, coming from the first impasto (paste) used by the Romans, made with lime and Pozzuoli’s ground. Pozzolanic products contain amorphous silicates that originate when silica reaches a temperature between 500 and 900 degrees. At this temperature the silica reacts with the mortar to form a calcium silicate that is insoluble in water and resistant to even to aggressive water. Red ghiara gravel was mixed with hydrated lime in a ratio 2:1 by volume for common mortars used for wall building. The ratio was 7 parts gravel to 4 parts of hydrated lime, if mixed for hydraulic mortars, intended for external plasters. These kinds of mortars were totally replaced by cement-based mortars after the second world war because of difficulty and high cost of the gravel extraction.

In order to locate the deposits of gravel under a lava field, excavations of short, wide galleries on the edge of the lava flows were dug.

It was hard and dangerous work because miners had to dig little tunnels in the lava field for access. The tunnels curved back as the digging progressed, while children and donkeys pulled the product out of the tunnels, a typical scene we can find in Giovanni Verga’s famous novel “Rosso Malpelo”. In older times, this work involved illegal recruitment of workers and harsh rules. The first workers to arrive at the ghiara quarry in the morning were employed. All the others who came later received no work and had to try again the next day. In order to avoid all this, many workers used to sleep inside the ghiara quarry. If someone was not expert in distinguishing between the many little tunnels that created a kind of underground labyrinth, there was a danger of getting lost and the possibility of death. Workers used acetylene lamps to light the tunnels. These extinguished very often. When the fuel ran out, the worker had to grasp a donkey’s tail to lead him through the darkness to the exit. Local people tell stories about a cave located between Lineri and Montepalma, called “ U puzzu de capareddi”, where a donkey was put in a pit in order to make transport throughout the galleries easier and they filled baskets called “cufini” or "corpello" with ghiara (Figure 1), hanging on the donkeys’ sides. Then with big winches rotated by hand or by donkeys, they hauled the red ghiara stones and ash out.

Sometimes they made the donkey go out for fresh air and water, or for hoof-shoeing or sometimes just because of its death. Finally, the ghiara extracted was sorted with handy sieves called “crivi” made up of wood and metal.

Figure 1: "Cufino": typical basket obtained by intertwining canes of willow or elm (Bucolo C., 2020).

History of the territory and geographical framing

The name *Lineri quarry* comes from the place where this artificial cave originates. Lineri is a district of the municipality Misterbianco (CT), located 108 metres above sea level (asl). The place name *Lineri* has a historical origin, comes from the fact that the area surrounding the present fraction of Misterbianco was crossed by the river Amenano, so it was a fertile area where people cultivated flax (Figure 2). The flax was a good textile fibre and the people who cultivated it were named "lineroti".

Figure 2: Old drawing of Misterbianco with ancient walls and the Amenano river with typical fluvial vegetation (Bucolo C., 2020).

Today there is nothing left of this because of the catastrophic eruption of 1669, that struck 16 municipalities, including Misterbianco. This eruption originated in the slopes of Nicolosi, on March 11 and reached Catania on September 11 of the same year, and there extinguished itself. The eruption lasted four months: the crater erupted about 600 million m^3 of lava, approximately 58 m^3 per second, which are among the highest values recorded in the last 400 years. This eruption created a very wide lava field with an area of 40 km^2 and a maximum length of 17 km; it is the longest lava flow ever recorded in the geological history of Etna over the last 15000 years. (Branca S. et al 2013) (Figures 3 & 4).

Figure 3: Giacinto Platania, Catania was reached by the lava during the 1669 eruption of Mount Etna. Fresco in the Cathedral of Catania.

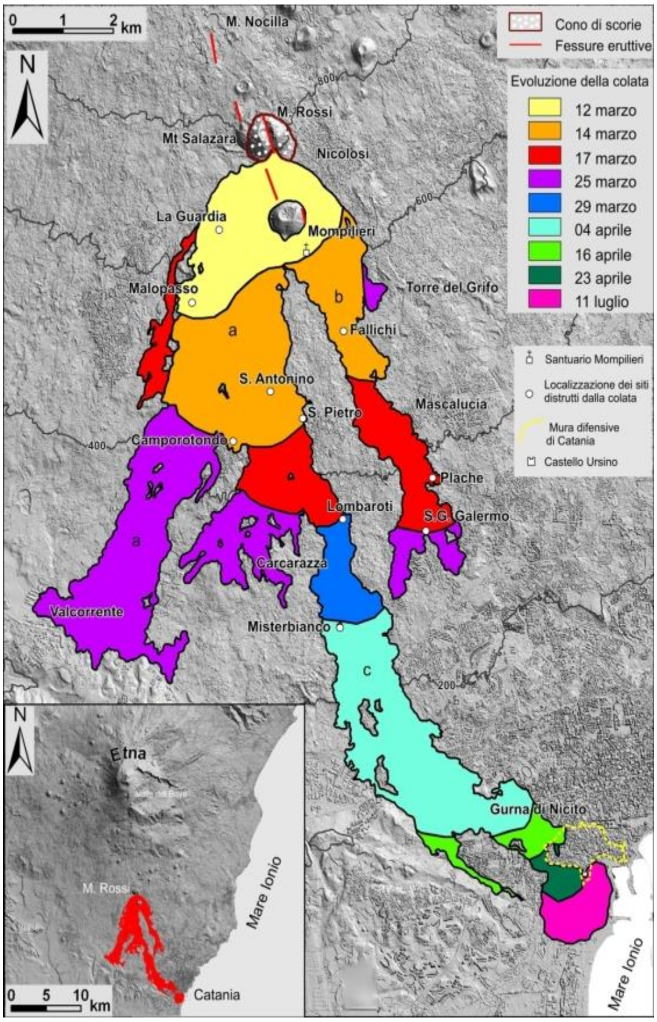

Figure 4: Evolution of the lava field of the 1669 eruption reconstructed by Branca et al. (2013), with the location of the inhabited centres and the main localities affected by the flow. Lava arms: a) western, b) eastern, c) south-eastern.

In Lineri's land, the lava flow buried all the flax fields, many vineyards, and the probable creek Amenano. The citizens had to get busy to plant the only fruits and vegetables that had a possibility of growing in a lava field: blackberry, mulberry and prickly pear; and they also used the lava field for rabbit hunting. A new attitude developed among Etna's people, "the art of fend". Local people were named "People of the lava fields" (Figure 5a & b) and, especially in the post-war years of 1950-1951, they resettled these areas, both for cultivation and for buildings, but most of all for red ghiara extraction, in the ghiara's quarries and they began to build the first houses (Figures 6-8).

Figure 5a&b: "People of the lava fields": typical family of the time where women helped in manual construction work by mixing lime (below) and children played in the lava fields (right). (Bongiorno family, 1950-1960).

Figure 6: Milazzo family house dating back to 1959 (Milazzo, 1950-1960).

Figure 8 (below): Old house still present in the territory of Lineri (Fichera V., 2011).

Figure 7: (below): First houses in masonry of lava blocks and mixed with mortar and red gravel (Bongiorno family, 1950-1960).

Lineri quarry had its origins in those years and it represents, today, the only remaining example in the hinterland, thanks to its peripheral location. Most of the other ghiara's quarries were hidden under the buildings erected above them, over the following years.

Lineri quarry

There is not much information available about Lineri quarry, but bibliographical sources tell us that red ghiara extractions started at the beginning of the 1700s (the eighteenth century) and ended between the 1950s and 1960s, when the use of azolo mortars replaced those based on ghiara. The years when Lineri quarry was actually operational are uncertain but it was built in an area that was not sufficiently productive.

We can read the geological reasons for this choice in the publication "Note illustrative della Carta Geologica D'Italia alla scala 1: 50.000- foglio 634- Catania" , where it says that lava flow in the district Quartararo "is locally covered by few dozen centimetres of sole", so it means that the gravel workers realized too late that this site was not good for excavations because not much material was available (Musarra F. 2015).

The quarry is close to the Strada Pezza Mandra, next to private land with photovoltaic panels. The entry of the quarry faces west and it is situated on the edges of the 1669 lava flow that, in the relevant part, overlooks ancient lava flows of a time frame between 15ka and 3,9ka. There is still a little dagala present (remnant vegetation spared by the lava flow) with downy oaks (*Quercus pubescens*). Actually, it is possible to see, in the first part of the galleries near the entrance, the roots of one of these trees, not only on the sides of the passage but also on the soil (Figure 9).

Figure 9: Oak root present at the edge and in the centre of the gallery (Belfiore A. 2020).

In most of the tunnels there are piles of stones from the excavation, accumulated at the sides of the tunnel to support the roof. We found a wedge beside the root. In modern building activity it has the role of locking the panels that confine concrete. Here it probably has another function. The hole on the wedge and its position on the top of the tunnel, let us suppose that workers inserted a rope inside the hole to cling or to pull out the "Cufini" full of ghiara. (Figures 10-11).

The height of the tunnels (1-2 metres) was determined by the thickness of the lava flow. In the principal gallery there is a big circular room where we can see piles of lava blocks stacked on one side of the gallery, certainly because at this point the ghiara was more compact and abundant (Figure 12).

Figure 10 a & b: Wedge with hole embedded in the soil near the root (left). Cone length (right) (Belfiore A. 2020).

Figure 11: Inclined tunnel where at the top there is the wedge where a rope was probably fixed (Belfiore A., 2020).

The height of the tunnels (1-2 metres) was determined by the thickness of the lava flow. In the principal gallery there is a big circular room where we can see piles of lava blocks stacked on one side of the gallery, certainly because at this point the ghiara was more compact and abundant (Figure 12).

Figure 12: Detail of the circular gallery with large blocks of lava arranged along the walls (Bucolo C., 2020).

At the end of the main tunnel there are two layers clearly visible. The upper black layer is the lava from the 1669 eruption. The lower red layer is the old ground, pre-dating the eruption, from which the ghiara originated as a consequence of contact with the high temperature of the lava flowing over it (Figure 13).

The quarry has a length of 110 metres (Figure 14).

Figure 13: Wall in the final section of the gallery where it is possible to observe the two different layers (Bucolo C., 2020)

Conclusion

This is the first study for Lineri's territory. This is an important work of social and cultural interest for the area.

We know that there are many other quarries not yet explored, under houses and private buildings, so we want to go to study and to catalogue them. Unfortunately, we know that one quarry is located below a school and it is not possible to visit it.

Special thanks

A special thanks to Dr.ssa Angela Nastasi, responsible for the Historical archive of Misterbianco, and who made it possible to meet Vito Fichera and see his work and his precious testimonies.

Another thanks to the CSE (Etnean Speleological Center) and to Franco Politano for his work of cataloguing of the caves in our territory, during all these years, so also our speleological group, with this work initiated the interesting study of urban caving.

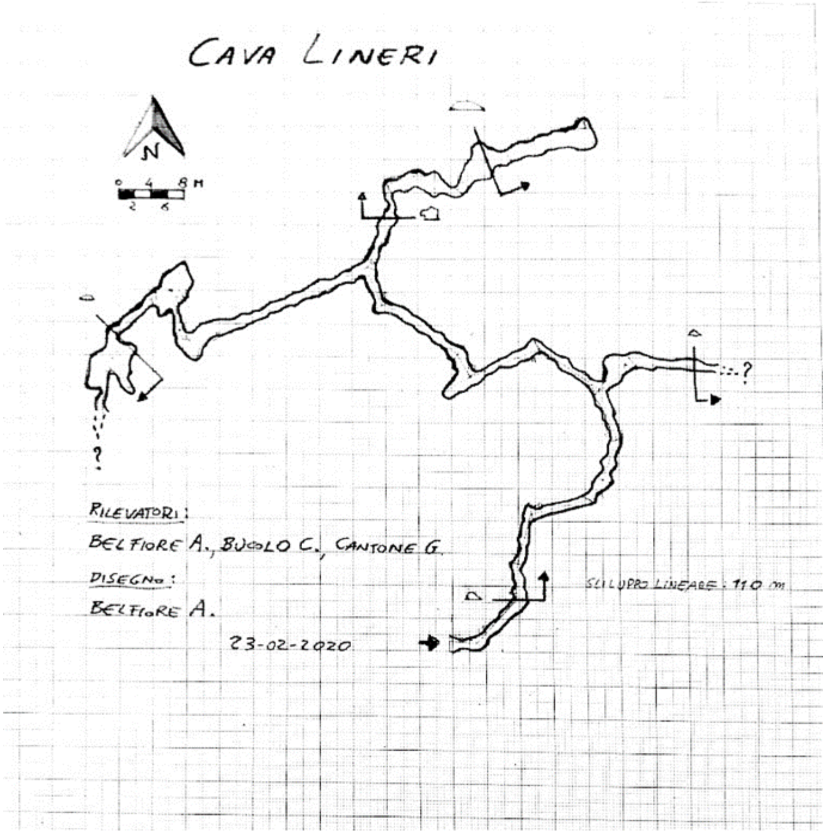

Figure 14: Survey of Lineri quarry (Belfiore A., Bucolo C., Cantone G., 2020).

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Sitography

https://www.etnanatura.it/paginasentiero.php?nome=Cava_Lineri

THE PIANO NOCE CAVE: FROM VANDALISM TO DIGNITY

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Abstract

A typical lava flow cave with speleothems is located on the North-East side of Etna at 1,195 metres above sea level and in the Piedimonte Etneo territory. Unfortunately, the cave has been damaged by vandals; there are many inscriptions written with spray paint on its interior walls. This cave has become sadly famous to the public for a massive spread of pictures showing the above-mentioned acts of vandalism. The goal of this project is to give back to this cave its dignity and original beauty after being profaned and defaced for too long. The purpose is to make the Piano Noce Cave known to everybody for its geological and biological features of huge naturalistic value rather than for the human damages.

Riassunto

Tipica grotta di scorrimento lavico situata sul versante nord est dell'Etna a quota 1195 m.s.l.m. e ricadente nel territorio di Piedimonte Etneo, con tipici speleotemi. Purtroppo la grotta è stata oggetto di vandalismo in quanto all'interno è possibile osservare sulle pareti tantissime scritte riportate con bombolette spray. Tale grotta si è resa tristemente nota al pubblico a causa della divulgazione massiva di foto riportanti i suddetti atti vandalici. In questo progetto si vuole dunque ridare dignità ad una grotta profanata e deturpata, rendendola nota a tutti per gli aspetti geologici e biologici di grande valore naturalistico, piuttosto che per le nefandezze dell'uomo.

Key words: cave, lava tube, conservation, Catania, Etna.

Detail of the final part of cave with some inscriptions on the inner walls.
Author and year: *Privitera Angelo 2019.*

Introduction

On 27 January 2019, during an excursion on the north side of Etna, we made a horrible discovery. Francesco Caltabiano and Sebastiano Russo, founding members of Sicilywalking association, entered the cave and unfortunately found the walls of the cave covered with various writings bearing people's names using red and white spray paint. Near the entrance, the inscription "*Grotta del Sughio*" can be seen. According to popular tradition, the 'sugghio' is a legendary monster that inhabits the coastal areas, marshes and swamps of numerous villages and districts on the island. The body of this monster is half man and half reptile, it is said to emit a terrifying sound between the grunting of a pig and the braying of a donkey. Traces of its presumed sightings have been found, since the early 19th century, in the municipalities of the Alcantara Valley, Torre

Archirafi (a hamlet of Riposto), Brolo, in the Madonie woods and in some districts of Palermo such as Arancio bridge. There are also legends about it in the Agrigento and Ragusa areas.

The incident was immediately reported both on social networks and to the competent authorities. On the 6th of February 2019, a meeting was convened by the Etna Park Authority. The pro tempore director Mrs. Tiziana Flora Lucchesi and the manager Mr. Salvatore Caffo, invited the Sicilywalking association and some members of the Catania Cave Group of the Italian Alpine Club Catania Section of Etna, to report on the extent of the damage and possible solutions to be implemented to clean up the cave. Grinding and sandblasting or covering the writings with black spray paint, so as to minimise the visual impact of the red writing, were immediately ruled out. The use of solvents used on protected monuments with a very low environmental impact and without chemical solvents was considered, but after a long and intense debate, they too would have affected the fragile balance of life in this underground environment. It was soon realised that most of the proposed solutions could cause even more damage to the cave's fragile ecosystem and that the benefits were far less than the new damage that would be caused. The only solution, therefore, is to restore dignity to a desecrated and disfigured cave, making it known to all for its geological and biological aspects of great naturalistic value, rather than for the nefariousness of man. Since it was not included in the register of Etna's caves, it was decided to reproduce the topography and emphasise the geological and biological aspects of the cave.

Geographical overview and biological aspects:

The Piano Noce Cave is located on the north-eastern slope of Etna at an altitude of 1195 metres above sea level, in the Piedimonte Etneo (CT) area, in the *"Turkey oak forest".* It is property of *the Azienda Demanio Foreste Regione Siciliana.* The environment is characterised by an ancient lava flow dating back some 3.9 thousand years to 122 B.C., known as the Crisimo flow. Being an ancient lava flow, the plants have had time to colonise the area, and indeed there is a dense wood of turkey oaks (*Quercus cerris*). The Etna vegetation belt of interest to us is the mesomediterranean belt characterised by the presence of holm oaks (*Quercus ilex*), but in this area the turkey oaks predominate and it is possible to observe some holm oaks and some plants from the higher vegetation belt called supramediterranean, i.e., downy oaks (*Quercus pubescens*), birches (*Betulla aetnensis*), larch pines (*Pinus nigra*) and broom (*Genista aetnensis*). As previously mentioned, it was decided not to intervene with any cleaning methods inside the cave as the cave has a fairly active ecosystem. Being an ancient cave and below a forest, there will most likely be endemic species (especially arthropodofauna) which are very sensitive to external actions such as the percolation of solvents from the walls. The cave is very 'active' as it has many fractures in the vault where there is active dripping and root penetration. The soil of the cave is characterised by an accumulation of humus, mud and guano and in some places, there are puddles. It is worth mentioning the presence of a new endemic species *Solariola bucolourum* in the Piano Porcaria cave, about 2 km from the cave. It is very likely that the species could also be present in the Piano Noce cave, as the same environmental characteristics are present. Not to forget the possible presence of the carabid *Duvalius hartigi* found both in the Piano Porcaria cave and in the Grotta dei Ladri cave, also in the same area. It is necessary to preserve this particular environment and to proceed with accurate biospeleological studies.

At first glance, several individuals of spiders of the genus *Meta*, a slug of the genus *Limax* and a Greater Rhinolophus bat (*Rhinolophus ferrumequinum*) were identified.

Materials and methods

Instrumentation used to carry out the polygonal survey inside the cave, evaluating angles, azimuth and zenith by means of a digital goniometer (Bosch Professional Goniometer And Inclinometer GAM 270 MFL), height differences by means of an optical level (Figure 2) - (Bosch professional gol 32 g optical level), longitudinal lengths by means of a metre and a roller (Rotella metrica mt. 50 MASS 408F), as well as all the deviations and heights with respect to the axis of each polygonal section, while for the cross-sections, we used a photographic technique (Canon EOS80D) with a high exposure time coupled with the use of a laser (Bosch PLL 360° laser level) (Figure 3) to define the shape and size of the section (Figure 4) and then recalculate it in autocad as a raster image (Figure 5) and scaled with the accuracy more than 10 cm (Figure 4).

Figure 2: The optical level used for determining height differences during the survey.

Figure 3a: Shape and size of the cave section, highlighted by the laser technique.

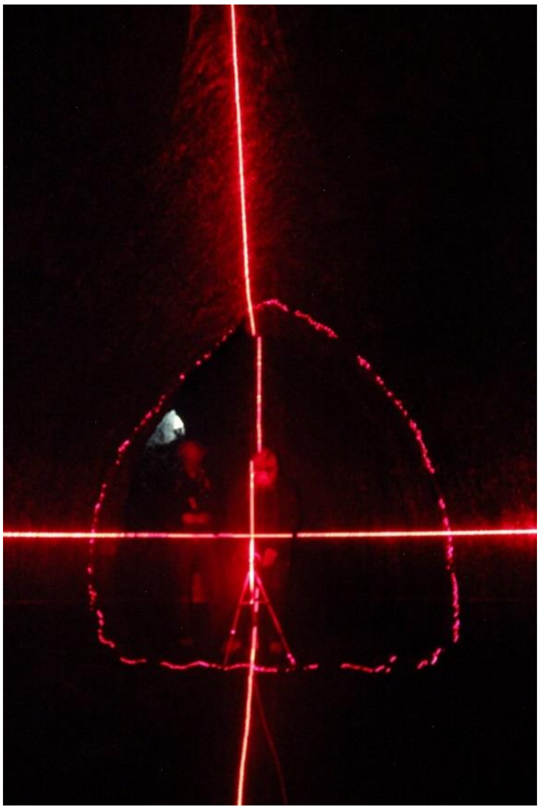

Figure 3b: Shape and size of the cave section, highlighted by the laser technique.

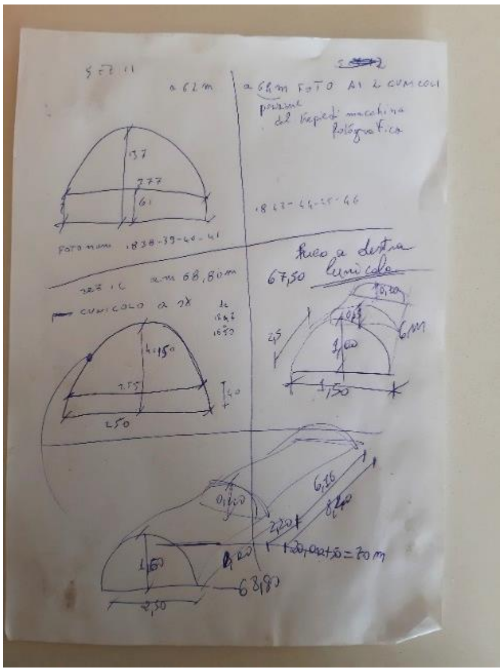

Figure 4 (left).

Figure 5 (above): Resizing of the section of the cave using a raster image with autocad.

Description and topography

The cave has a depth of about 33 metres and a total passage length of about 170 metres (Figure 6). It is a lava flow cave. The small entrance opens on the side of the cave following a collapse, the portions of which are clearly visible inside the cave. From this first room, which allows for a standing position, two sections of gallery branch off. The first, which is oriented towards the west (upstream) and is about 68 m long, is very fractured in its development. It presents a first sub-horizontal section, with a linear floor, regular and high sections that allow a standing posture. About 2/3 of the way along the tunnel, the inclination changes vertiginously upstream, presenting a floor consisting of an accumulation of rocks and debris. This last section, which has a section very similar to that of the *Serracozzo cave*, with an inverted keyhole shape, has a very narrow exit at the top, where it is necessary to crawl, exiting right near an old ruined cottage that was once used as a *"mannera" or "pagghiaro"* by shepherds, accredited by the presence of a sheepfold a little further downslope. To confirm the presence of a strong shepherd activity. There is, again to the west of the exit of the first section, adjacent to the ruin, a very large cavity, measuring about 5 m x 4 m and 3 m high, continuing upslope from the lava tunnel. This cavity was probably used in the past as a stable or storeroom for the "*pagghiaro*", but today it is covered by thorns and vegetation. The second section of the cave (downstream) runs eastwards and is about 104 metres long with very short branches downstream. This second section has very varied cross-sections; first it is regular and high, then low and wide, leading to a first large room with two branches and pillars (Figure 7). Two short branches run to the right, while the gallery continues to the left. This, after a low section, the shape changes again to allow an upright position; up to another room that presents, again on the right, a branch at a different height, very short. The tunnel continues to the left side, with a narrow and low section, with a floor full of sand and guano where it is necessary to almost crawl, and then reaches the last section of the tunnel, once again on a human scale. Here there is a strong presence of root curtains on the vault. In the cave there are characteristic speleothems such as remnant stalactites, dog's teeth and blisters.

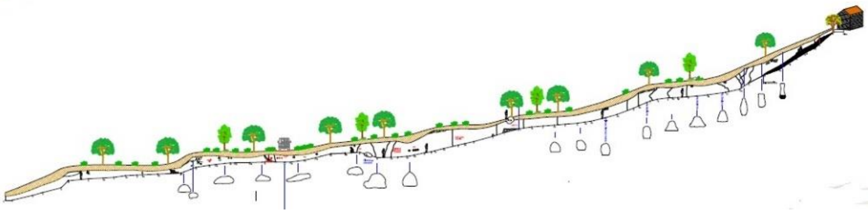

Figure 6: Longitudinal section of the cave.

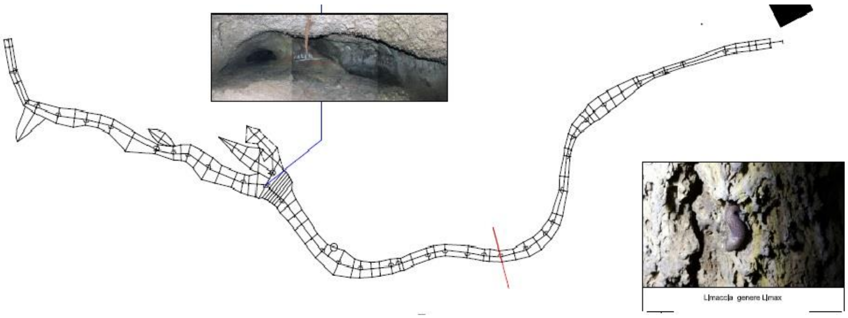

Figure 7: Planimetric shape of the cave.

Lunghezza / length [m]	174
Dislivello totale / total height difference [m]	33.50
Sezione più alta / highest section [m]	3.90
Sezione più bassa / lowest section [m]	0.66
Numero di sezioni / No. of sections	75

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GALA BANQUET

Mt. Etna rose from the sea over 500, 000 years ago. The Gala Banquet of 19th Symposium had a lovely location: a typical Sicilian restaurant along the seaside. The best site for the most important gastronomic appointment of Symposium.

On the north side of Capomulini Gulf, at Al Mulino restaurant, Alfio and his staff suggested an appetizing dinner based on seafood: starters, pasta, fish, all "watered" with an Etna wine.

There was also an alternative menu for those who didn't love fish, for vegetarians, vegans and others.

The view from the location of the Gala Banquet – ph. G. Priolo, 2021.

SYMPOSIUM DAY 4, THURSDAY 2 SEPTEMBER

GENERAL EXCURSION

Visit to the "Valle Del Bove" for all participants.

EVENING PROGRAM at GGC Arena

Sicilian Granita Time

GENERAL EXCURSION – VISIT OF "VALLE DEL BOVE"

Mt. Etna is an active volcano. From the summit craters there is often the emission of gases and steam. During periods of high activity, the hike to the craters is strictly forbidden.

Figure 1: General excursion route.

Since the recent eruptive activity of the volcano, visitors are not allowed to make the ascent to the central crater, so all participants were taken to visit the Valle del Bove instead. The Valle del Bove is a big depression on the eastern slope of the volcano where most of the lava flows stop.

Participants reached the parking place near "Piano dei Pompieri" (Firefighter's Plain) at 1.850 m a.s.l. by minibus (Figure 1).

From that place a long and winding track named "Sentiero della Schiena dell'Asino" led us to a panoramic point at 2.050 m a.s.l. where there was the possibility to see the inside of the depression called "Valle del Bove".

From the panoramic point it was possible to see the most spectacular features of the valley: hornitos, lava bridges, a small graben and the little cave called Grotta di Pitagora (Figures 2 & 3).

Figure 2: Grotta di Pitagora, outside view. ph G. Priolo, 2014.

Figure 3: Grotta di Pitagora, inside view. ph G. Priolo, 2014.

THE SICILIAN GRANITA

Granita is a semi-frozen dessert made from sugar, water and various flavourings. Originally from Sicily, it is not an ice-cream because it doesn't include milk or cream. The Catania's granita is available in many flavours. The most typical are almonds, black mulberries, coffee, peach, strawberry and other fruit flavours.

Guests enjoyed one of the best slushes on the GGC terrace.

SYMPOSIUM DAY 5, FRIDAY 3 SEPTEMBER

CAVING EXCURSION

The Organizing Committee selected four caves that were representative of the special features of the Mount Etna environment.

Two of them were near the town and could be visited in a half day trip: Grotta Catanese I and Grotta Intralio.

The other two were far from the town and to visit them required a full day: Grotta di Serracozzo and Grotta di Piano Porcaria.

Participants had to have their own clothing, gloves and shoes. In order to prevent the spread of White Nose Disease (WND) they had to very carefully clean their gear before arriving in Italy even if it had only been used in an area free from WND.

Helmets, lights and gloves could be rented from the GGC caving group.

None of the caves needed the use of vertical gear.

Participants also needed rescue insurance cover in case of accident. For those without suitable insurance, it was possible to purchase day cover at the ISV.

All the caving excursions ended in Catania in time for participants to get to the Farewell Party.

INTRODUCTION

More than 300 volcanic caves are known on Mount Etna, scattered on the slopes of the mountain, from the upper part of the volcanic cones to the dark beaches on the seaside.

The caves of the upper part of the volcano are either very far from the roads or dangerous because of the volcano activity. Moreover, the highest part of the volcano is included in the Park of Etna and the access is subject to restrictions due to the danger of the volcano itself. For that very reason it was not possible to visit the highest caves of the Etna during the ISV.

For the "caving day" of the Symposium, the organizing team selected several caves of the Mt Etna area that were close to the town and easy-to-walk-to so that participants could discover the typical features of the Etna caves.

Near the town of Catania there is an area in which some simple caves have been equipped for educational purposes (Grotte di San Gregorio). Access to this area was possible for all participants during the Symposium days.

SELECTED CAVES

The visits to these wild caves took place with the support of members of the Gruppo Grotte Catania.

In accordance with the guidelines for speleological activities during the pandemic period, special arrangements were made to limit groups size and ensure the rules for interpersonal distancing were respected.

GROTTE CATANESE

The two Catanese caves are in the township of Ragalna. The first one is a lava tube characterized by a room that is among the largest known on Mt. Etna. Passing the entrance, there is a descent on large collapsed blocks to a vast bell-shaped room. The floor, at the lowest point of the room, is of earth mixed with stones and plant debris. On the south side it rises abruptly until it forms the back wall of the room; the lava appears here with a surface made up of formations of ropes and edges. It is easy to climb up this lava slope to a characteristic hollow almost at the height of the ceiling, from which there is a commanding view. On all walls there is a great number of small protruding sheets; on the west side near the entrance there are any shallow grooves, parallel to each other, which abruptly change direction bending downwards at an angle of 140 °. At the foot of the wall, on the south side, the lava formed large blocks that might seem collapsed, but which actually are huge irregularly crumpled sheets. From this first large room the cave continues, through a narrow passage at the base of the east wall, with a tunnel about 70 m long. Some prehistoric human bones and many small ceramic fragments were found in this gallery. Numerous bats of the genera Myotis and Rhinolophus still inhabit the cavity.

Grotta Catanese I – ph. S. Nicoletti, 2021

The second cave consists of a single tunnel just over 20 m long. It is entered by descending a chaotic mass of collapsed blocks. The floor, after the first section, appears flat with compacted earth and stones; towards the bottom it is possible to observe lava with a joint surface. On the walls there are numerous sheets of lava of different thickness and folded in various ways. The section of the cave has a characteristic pointed arch shape, but not symmetrical as is normally observed in other cavities. The southwest wall is overhanging while the northeast is an inclined plane on which it is easy to climb.

GROTTA INTRALIO

The cave consists of a set of lava flow galleries of various sizes located at different levels and variously oriented. Near the entrance of the northeast gallery there is a small altar.

This gallery is about 40 m long. On the opposite side there are three overlapping galleries.

The upper gallery is 13 m long. The lower one is about 30 m long; it begins with a slope of large boulders that ends in a large room, several metres high, where there are two large lava rolls, among the largest known to us, and numerous

Grotta dell'Intralio, the biggest lava tube - ph. G. Priolo.

large sheets protruding from the walls. The intermediate cavity is the longest of the three branches and begins with a tunnel about 30 m long, over 2 m high, with a flat floor on which two rolls can be seen, smaller than the previous ones but longer. Further on, this gallery is divided into three branches located at different heights. The eastern branch, at a lower altitude, is very short and has an accentuated slope, the central branch is 50 m long and its ceiling is low, so that it is necessary to crawl here and there; in some places it presents domes where it is possible to stand; the floor of this gallery is flat and consists of slag partly welded and partly movable. The third branch has the same configuration of the previous one; in this branch a wedge-shaped boulder, detached from the ceiling, almost completely obstructs the passage, about halfway. The three branches end up with the ceiling and the floor joining together.

GROTTA DI PIANO PORCARIA

This is an interesting cavity in ancient lavas. The small entrance open on one side of the cavity leads to a first room characterized by massive collapses. Three sections of the tunnel branch off from this first room. The first is oriented towards the west, about fifteen metres long, the floor of which is covered with debris and sand; there are impressive collapses. The vault does not always allow an upright posture and in the terminal part imposes a progression on all fours or even belly to the ground. The second section of the tunnel faces southeast and is about forty metres long. The vault allows the upright posture for a good half of the development while it becomes low, about one metre, in the terminal section. The floor is constantly covered with debris and sand, there are numerous collapses both from the vault and from the walls.

In the final section of the tunnel a copious presence of pulmunate molluscs, arthropods and other small species were found. There are numerous root curtains. The third section of the tunnel, oriented to the north, has a development of over eighty metres and a morphologically different aspect from the two previous sections. The first section is broad and morphologically similar to the previous ones. At the bottom there is a small gallery whose access is just over sixty centimetres high. From this point on, almost constantly, the height of the vault does not allow an upright posture and one is often forced to proceed on all fours. The heavily bristling scoriae lava floor is only rarely covered with sand or debris. At the end of the gallery there is another narrow transept gallery which extends for over fifty metres both to the west and to the east. The east section becomes so narrow that it is impossible to proceed after about thirty metres.

Figure 10: Grotta di Piano Porcaria – ph. S. Nicoletti

GROTTA DI SERRACOZZO

This cave, in the upstream section, is contained into an eruptive fissure and has a lock-shaped section with a height of several metres and is no more than 3 m wide. Openings can be seen on the vault. The downstream section is a steeply sloping flow tunnel, 350 m long, 2 to 3 metres wide with the floor made up of coriaceous lava. In the first section the walls are opaque but further on they still retain a glassy aspect.

Grotta di Serracozzo I – ph. B. Scammacca.

CLOSING CEREMONIES

FRIDAY SEPTEMBER 3RD

Closing of the exhibition: "The Fingal cave, between history and legend"

Closing ceremony of the Symposium **at** GGC terraces

Farewell Party at GGC Terraces

FAREWELL PARTY

It was the last meeting before departure. This was the opportunity to take stock of all that this Symposium had given us.

This was a time when resolutions were made for new studies and new explorations, perhaps to be carried out together in the future.

An appetizing dish and a good glass of wine helped to remove the sadness that accompanied every farewell.

But this was not a goodbye, rather a "see you at the next Symposium".

CATANIA'S NATURAL AND CULTURAL HERITAGE

Catania was founded in the 8th century BC by Chalcidians, a Greek population coming from Thrace. In 1434, the first university in Sicily was founded in the city. In the 14th century and into the Renaissance period, Catania was one of Italy's most important cultural, artistic and political centres.

The city is well known for its history, culture, architecture and gastronomy. Its old town, on account of its spectacular baroque architecture, is a World Heritage Site, protected by UNESCO.

LOCAL EXCURSIONS, CANTANIA

During the Symposium, after the lectures, there were short afternoon trips to visit artistic or scenic places selected because they are connected with the volcanic features of the area:

Katane – the Greek and Roman city

Exploring the ruins of the first settlements.

The city reconstruction after 1669 earthquake – the Catanese Baroque

A wonderful walk in the centre of the town.

Historical Museum of the 1943 landing in Sicily & Cinema Museum

A full immersion experience in the time of World War II

Reconstructions of scenes from famous movies shot in Catania

Guided tour of Catania botanical gardens

With all Mt Etna's endemic species.

The caves of San Gregorio

The natural reserve is characterized by the presence of numerous lava flow caves in a relatively small area. The reserve was established in order to "preserve and protect the important complex of lava flow caves colonized by cave fauna and bat colonies".

TAORMINA AND ALCANTARA GORGES

All day excursion specially organized for accompanying members.

Taormina is a hill town on the east coast of Sicily. The city is known for the Ancient Theatre of Taormina, an ancient Greek-Roman Theatre still in operation today. Near the theatre, the cliffs that descend to the sea form inlets with sandy beaches. A narrow strip of sand connects to the tiny Isola Bella, which is a natural reserve.

Unique in the Italian and European natural landscape, the Alcantara Gorges are one of the must-see attractions of Sicily. Located about 20 km from Taormina, the gorges are real canyons made of black lava walls up to 50 metres high, in the typical shape of a prism that the rocks have taken during the cooling process. Within the grooves, the toning and crystal-clear waters of the river Alcantara run surrounded by an unspoiled landscape, with rare flora and fauna. The hidden position of the gorges has protected it; until the fifties in fact this site was completely unknown. The Alcantara Gorges have by now become a famous attraction even beyond national borders, and it is considered one of the most beautiful natural sites in Italy.

SIRACUSE AND NOTO

An all-day excursion specially organized for accompanying members.

Siracusa is a city on the Ionian coast of Sicily. It is known for the ruins of antiquity. The central Archaeological Park of Neapolis encloses the Roman amphitheatre, the Greek Theatre and the Ear of Dionysius, a cave carved into the limestone in the shape of a human ear. The Paolo Orsi Regional Archaeological Museum exhibits terracotta finds, portraits from the Roman period and scenes from the Old Testament carved in white marble.

Noto: This small town in the south-east was founded again in the 1700's. It is the heart and at the same time the starting point for a visit to the valley of the Sicilian Baroque. Its cathedral, also perfectly rebuilt after 10 years of hard work, was included in the UNESCO World Heritage Sites.

Piazza Armerina: The Villa del Casale recognized by UNESCO and included in the "World Heritage", with its 3500 square metres of mosaic floors famous throughout the world, hunting lodge of Massimiliano Erculeo, is evidence of life in Roman times ...

19TH INTERNATIONAL SYMPOSIUM ON VULCANOSPELEOLOGY

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International Year of Caves and Karst 2021

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