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PROCEEDINGS

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Keynote lectures
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Session 01: History of Speleology, Arts and Letters
Session 02: Cave Archaeology
Session 03:Cave Paleontology
Session 04: Cave Mineralogy and Sediments
Session 05: Geochronology, Paleoclimatology, and Climate Change

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FOREWORD

The proceedings of the 19th International Congress of Speleology, held in Belo Horizonte (Brazil) from July 20 to 27, 2025, comprise seven volumes that gather over 400 scientific papers (extended abstracts) distributed across sixteen thematic sessions. These works were evaluated by an extensive group of reviewers, each guided by a Brazilian and a foreign coordinator, aiming to ensure their collective relevance, proper presentation, and compliance with the UIS Code of Ethics. The layout of the articles was prepared by the authors themselves and is their sole responsibility; however, the editorial team made an extra effort to maintain a minimum standard in their presentation.

These proceedings represent the work of more than a hundred individuals—scientists, technicians, and explorers who voluntarily dedicated thousands of hours to their production. To all of them, our heartfelt thanks. We hope you enjoy it and that the science compiled herein broadens the technical and academic horizons of karst and cave science.

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KEYNOTE LECTURES

Living with karst: results and possibilities of the international year of caves and karst

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Abstract

The International Year of Caves and Karst (IYCK) was planned for 2021 and extended through 2022 due to the COVID-19 pandemic. It was organized by the International Union of Speleology (UIS) to teach the world about the generally poorly known importance of caves and karst areas, and their sensitivity to damage. UIS was joined by 263 partner organizations from 51 countries to organize at least 1,491 events that contacted almost 321 million people. A wide array of accomplishments were achieved, which will have long-lasting benefits for speleology. Millions of people are now at least basically informed about caves and karst, and many are inspired to explore, study, and protect them. Speleologists are encouraged to work with non-speleologists to continue organizing more cave and karst promotional events. The UIS has developed high-level connections with various institutions, most notably the United National Educational, Scientific, and Cultural Organization (UNESCO) which is encouraging UIS to establish a UNESCO-recognized International Day of Caves and Karst that will carry on the IYCK's message in getting caves and karst recognized annually through the world's national governments and supporting organizations.

1. Introduction

The International Year of Caves and Karst (IYCK) was established by the International Union of Speleology (UIS) to better inform the world about the importance and vulnerabilities of caves and karst. The IYCK was originally planned for 2021 but was expanded to included 2022 due to the COVID-19 pandemic.

The theme of the IYCK was: Explore, Understand, Protect. Exploration is necessary for the research that makes effective protection and management possible. The UIS is a global organization of cave and karst explorers, scientists, managers, and many more things, and was best capable to bring everyone together to conduct the IYCK. UIS established an IYCK website, a logo (Fig. 1), guidelines for how to support and participate in the IYCK, and it reached out to its 57 member countries and other organizations to partner with the UIS and support the IYCK.

Initially, the UIS sought formal recognition of the IYCK from the United Nations and the United Nations Educational, Scientific, and Cultural Organization (UNESCO), but for political reasons within those organizations, and deadlines missed by the UIS, that was not possible. However, UNESCO encouraged UIS to continue organizing the IYCK with its own members and partners and invited UIS to officially open the IYCK at UNESCO Headquarters in Paris, France.

Partner support of the IYCK involved promoting it through their websites, social media, and publications, including the free use of the IYCK logo, plus leaflets and organizing events designed to educate scientists, land managers, lawmakers, and especially the general public about caves and karst. Many examples of "events" were provided by UIS guidebooks on how to support the IYCK, which included but were not limited to: classes for students, conferences, lectures, celebrations, cave restoration and cleaning, creation of cave protection laws, contests, and demonstrations of rope and other caving skills.

This paper summarizes some of the major results of the IYCK. VENI (2025) provides a thorough history of the IYCK, and VENI (in preparation) is developing a detailed review of the IYCK's events and results. This paper explorer what those results may lead to in the years ahead.

Figure 1: *Logo of the International Year of Caves and Karst.*

2. IYCK Results

As 1 January 2021 approached, there was concern within the UIS that the IYCK might be a failure. The COVID-19 pandemic had closed the world to meetings and working together in person. Many partners contacted the UIS, wanting to support the IYCK, but were uncertain how to proceed. Virtual meetings were technically possible when COVID struck, but seldom used by most people.

During the first few days of 2021, the mood about the IYCK changed in the UIS. Dozens of messages began to arrive from people who, like the UIS, decided to organize many events virtually and were learning how to do that. The UIS held its Opening Ceremony virtually. It was

watched live by about 600 people from 40 countries and within three days was watched by over 5,000 people. Within the first three months of the start of the IYCK, 249 events were organized that reached over 22 million people, and the numbers kept growing.

In 2022, fewer events were organized but more people were informed about caves and karst through more extensive use of news media. By the end of the IYCK, the UIS had 263 partner organizations from 51 countries. Together they organized 1,491 events that made nearly 321 million contacts ("contacts" because it is impossible to know how many individual people were reached by the IYCK, since some were involved in multiple events). But these numbers are minimum figures as many events were not reported to UIS, and the number of contacts does not include sharing of website, social media, and other information.

By these numbers alone, the IYCK is a resounding success. But the level of success increases when the number and types of events are examined:

- 30 art contests and projects
- 104 books and other publications
- 34 caver training sessions
- 106 celebrations
- 41 classes
- 79 conferences
- 90 exhibits
- 93 field trips
- 2 fund-raising programs
- 8 laws or other government actions
- 380 lectures
- 54 news media reports
- 25 podcast/news media interviews with speleologists
- 9 proclamations by governments recognizing the IYCK
- 35 research and exploration/survey expeditions
- 102 restoration projects to clean and repair caves and karst areas
- 147 social media sites celebrating and providing IYCK information
- 77 videos created on caves and karst
- 32 websites
- 41 workshops

The next section of this paper examines what these events might mean for the future of speleology

3. Possibilities for Speleology from the IYCK

Few major changes in societies occur without broad public support. While most IYCK events do not appear significant individually, as lectures, classes, books, trips, and other activities, together they reached hundreds of millions of people. Some were contacted only once and others several times, with each contact being a seed of greater understanding. Some of those seeds will not grow but with millions planted, many will bear fruit.

Colombia created a national cave protection law during the IYCK as a result of long-term growing understanding of caves and karst in that country. As understanding grows in other countries, it will lead to new laws and regulations for better management. Some countries and/or their private organizations will increase funding for cave and karst research and the creation of new cave and karst parks and nature preserves. Responsible exploration will be increasingly welcomed as exploration is understood as the first critically important step toward research and better management.

Most changes will occur slowly, and perhaps the most important changes will occur in 30-50 years. Even if people did not realize that an event they attended was part of the IYCK, many were inspired, especially young people trying to decide on a career. Some will study the sciences or environmental management with a focus on speleology. Others will work in politics and governmental agencies where they will be able to exert positive influences on policies affecting caves and karst. Others will focus on news and social media, which have the loudest voices in educating the public.

Most people's careers will not be changed by the IYCK, but they will be more informed in how they vote on issues that may affect caves and karst. Some of those people will become cavers, and existing cavers will be reenergized to continue exploration by seeing the great value of their work.

And then there are the children, who are too young to think about careers but who were impressed and excited by what they saw and learned during the IYCK. Many of them will follow today's university students. They will become yet another generation of leaders and champions for caves and karst.

An important factor in the speed and growth of speleology in the years ahead will be how often events are organized to continue the work of the IYCK. Certainly, the frequency of events is unlikely to match the average of two per day, as occurred during the IYCK in 2021-2022, but if speleologists continue to see the benefits of their events, they will continue organizing more, and with non-speleological partners so non-speleologists can learn and appreciate caves and karst too.

Without a doubt, the most important event for the future of speleology occurred on 13 September 2021 with a non-speleological partner. COVID-19 canceled the opening ceremonies planned at UNESCO Headquarters, but as health and travel restrictions were eased, UNESCO invited UIS to hold a celebration of the IYCK on this date at UNESCO Headquarters. For the first time in history, the high value and great needs of caves and karst were presented to governmental leaders from around the world, both in the room and virtually.

This celebration and associated meetings led to two important outcomes. First, the International Science Council, the most influential and prestigious international organization for science, invited UIS to join as a full member. Second, UNESCO invited UIS to return and organize a special session on karst aquifers at the United Nations' First Groundwater Summit on 6-9 December 2022, three weeks before the end of the IYCK. This summit and special session were also conducted at UNESCO Headquarters.

These continued high-level communications between UIS and international agencies and organizations led to UNESCO inviting the UIS to organize an International Day of Caves and Karst, with UNESCO recognition and support. At this time of this writing, the International Day is not yet confirmed as a UNESCO event. The efforts toward that goal are led by UIS President Dr. Nadja ZUPAN HAJNA (Slovenia), with the support of the rest of the UIS Bureau and partners from many countries who have sent letters of support. If they are successful, caves and karst will be celebrated each year on 13 September, the anniversary of when the IYCK reached leaders of the world at UNESCO. The celebrations will not be just by speleologists but by governments and non-governmental partners internationally. Exploration, research, and proper management of caves and karst will be encouraged and supported as the public and its leaders learn more about these amazing natural features and resources. The bright headlamp for future of speleology is just being lit.

4. Conclusions

The IYCK of 2021-2022 was amazingly successful, especially considering that it was organized and most of the work conducted and funded by volunteers in the UIS and its member countries. At least 1,491 events were organized by UIS and its 263 partner organizations. Nearly 321 million contacts were made around the world through these events, which will have far-reaching benefits to caves and karst, both in the near future and decades to come. The currently proposed International Day of Caves and Karst will continue to expand those benefits greatly, if it is accepted by UNESCO. Regardless of that decision, it is vital for speleologists to continue organizing events in the spirit of the IYCK to teach the world about caves and karst and include as many non-speleologists in those events as well for future generations to continue to Explore, Understand, and Protect.

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UNESCO World Heritage caves and karst: present situation and future prospects

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1. Introduction

This review concerns the conservation of our planet's best cave and karst resources. It involves archaeology, biology, types of caves, cave palaeo-environmental records, karst landscapes, karst hydrogeology and water resources.

Karst and caves are mainly developed in carbonate rocks that are exposed over about 19.3 million km2 of the ice-free continental area (14% of the ice-free land) (Stevanović 2019). Subsurface karst rocks considerably extend the active karst realm, so the figures above constitute the minimum area that is subject to karstification.

The conservation value of many cave and karst sites has already been recognised by many governments, resulting in their formal legal protection in national parks, and in natural and scenic reserves. The level of legal and practical protection is so comprehensive in some jurisdictions that little or no other protection is required.

But in addition to the legal protection available in nation states, there are also international conventions that permit still higher levels of protection, although whether or not this is in practice achieved depends on the actual on-the-ground conservation activity by the State Party. The highest levels of protection are afforded under the UNESCO World Heritage Convention (2024) and by UNESCO Global Geoparks. The World Heritage convention recognises three categories of properties: cultural, natural and mixed. In 2024 there were 1223 properties that the World Heritage committee considered to have Outstanding Universal Value. These include 952 cultural, 231 natural and 40 mixed properties. As of October 2024, the UNESCO World Heritage Convention was ratified by 196 independent States, and the listed properties occurred in 168 of them. World Heritage properties can comprise an individual site, a series of separate but related sites (serial nomination), or sites that cross international borders (transnational properties).

In addition, in 2024 there were 213 UNESCO Global Geoparks in 48 countries. Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development. There are regional geopark networks in Asia, Europe, Latin America & Caribbean, and Africa.

When one examines global maps of World Heritage properties on the UNESCO website, it is evident that some State Parties place more emphasis on conservation of cultural properties than on their natural environmental features. This may be justified because cultural properties are often more vulnerable to decay and damage, but may also arise from the value of some important natural sites not being fully appreciated. Economic and prestige considerations may also enter into the decision of whether or not a State Party nominates a property for recognition, because the UNESCO brand signifies quality and so may attract significant revenue from international tourism. In some properties there is risk of tourism and related infrastructure development getting out of control to the detriment of the heritage values of the site. So UNESCO recognition is not without its problems.

2. Cave and Karst World Heritage: present situation

In 2007, following a report from the International Union for the Conservation of Nature (IUCN), the World Heritage Committee noted that:

"Karst systems (including caves) are relatively well represented on the World Heritage List. Worldwide there are a large number of protected karst landscapes with caves and at a detailed level every one of these can assert that it is in some way unique. Therefore in the interests of maintaining the credibility of the World Heritage List, IUCN considers that there is increasingly limited scope for recommending further karst nominations for inclusion on the World Heritage List."

This signalled a recognition that there were already numerous karst sites on the World Heritage List and consequently that only very special cases would merit future inclusion on the List. So to identify gaps in the coverage and reveal places where future inscriptions might be merited, IUCN undertook a global review of existing World Heritage cave and karst properties (Williams 2008). This identified the geographical distribution of karst sites across the globe and also mapped their distribution according to climatic zone, since the style of karst landscape development can be closely related to climatic conditions during its evolution. However, there is no reason to expect an even geographical distribution of karst World Heritage properties around the globe, because karst mainly follows the occurrence of carbonate and evaporite rocks.

In the 17 years since the global review by IUCN, new cave and karst properties have been added to the List. So a follow-up global review would be helpful to determine if there are still significant gaps in coverage and where they might be. Figure 1 shows the global distribution of cave and karst World Heritage properties in 2024 plotted on a map of limestone and evaporite outcrops (BGR et al 2017). Sites are subdivided into those recognised to be of Outstanding Universal Value for their archaeology, biospeleology, or caves and karst. Property numbers mapped refer to those listed in Appendix 1, which provides details of each locality.

World Heritage natural sites are recognised under criterion viii of the World Heritage Convention and under 11 themes, of which Caves and Karst is Theme 6 (Williams and Woo 2021). On the World Heritage List in 2020 there were 11 properties in which caves and karst was the primary theme and 6 more in which caves and karst was the secondary theme, e.g. Nahanni National Park, Canada. Since then two more have been added: Evaporite Karst and Caves of Northern Apennines, Italy, and the biospeleology site of Vjetrenica Cave, Bosnia and Herzegovina. But

many other properties also have exceptional karst of international significance. Consequently, in total there are 55 World Heritage properties with karst of international significance. Those with cave and karst features of Outstanding Universal Value include properties recognised for their cave archaeology (4), cave biology (3), carbonate caves & karst (28), silicate fluvio-karst (3), volcano-karst (1), and evaporite caves & karst (1). Many other World Heritage properties have karsts of national importance, e.g. Les Causses et les Cevennes in France, inscribed on the World Heritage List for its cultural landscape but also having excellent caves and karst.

3. Identifying the Gaps

Figure 2 shows the distribution of natural World Heritage karsts according to the climatic regime in which they are situated although, because of climate change over millions of years, their main phase of development may have been under conditions different in the past to those that prevail today. Property numbers on Figure 2 are as listed in Appendix 1. Those plotted in red were inscribed by 2008 and those in yellow depict six cave and karst properties inscribed in the interval 2009-2024. One may note that karst sites remain under-represented in some climatic regimes, as identified on Figure 2 and listed in Table 1. These are the most obvious gaps in karst World Heritage coverage. The bold yellow arrows on Figure 3 indicate on a global map where such sites might be located.

Table 1: *Styles of karst under-represented in natural World Heritage properties and some regions where suitable sites might be located.*

STYLE OF KARST	REGION
Arid - seasonally arid karst	Brazil, N. Africa/SW Africa, Middle East-Central Asia, Australia
Super-humid temperate karst	Patagonian Chile
Evaporite karst	Iran – Saudi Arabia

In addition, we might ask ourselves what big stories about the natural world are overlooked for which caves and karst might contain the evidence? One answer is the story of the evolution of natural environments that is contained in and can be interpreted from dateable deposits that accumulate in caves. We are familiar with cave hominid and fossil sites, e.g. 'Australian Fossil Mammal Sites' and South African 'Fossil Homid Sites of Sterkfontein, Swartkrans, Kromdraai, and Environs', but there is also a big story to be revealed and told about continental palaeo-climate, palaeo-vegetation and landscape evolution going back millions of years. Important sites with natural archives in caves that reveal this are already being investigated in Australia and Southern Africa, and there must be other significant sites in the Arabian Peninsula and Central Asia. These are places that are arid now, but at times in the past have been much more humid (for example see Sniderman et al. 2016).

We might also consider if there are Tentative List properties that might help fill some of these gaps.

On the basis of karst geo-diversity (World Heritage criteria vii, viii)

> Band-E-Amir (Afghanistan), Gcwihaba Caves (Botswana), Canyon du Rio Peruaçu (Brazil), Velebit Mountain (Croatia), Salt Domes of Iran (Islamic Republic of Iran), Ring of Cenotes of Chicxulub Crater, Yucatan (Mexico).

On the basis of biodiversity and their wider geodiversity, including karst (criteria vii-x)

> Great Desert Landscapes (Egypt), Réserve de la Biosphère Selva El Ocote (Mexico), Parc Natural de Talassemtane (Morocco), Kahurangi National Park (New Zealand), Svalbard Archipelago (Norway), Bashkir Ural (Russian Federation).
>
> In Papua New Guinea, the Huon Terraces, Kikori River, and Sublime Karsts could form the basis of a serial nomination.
>
> In Chile, Torres del Paine and Bernardo O'Higgins National Parks are on the Tentative List and with adjustment of the park boundary could include nearby Madre del Dios, an extraordinary superhumid karst that probably experiences the highest carbonate dissolution rate in the world.

An obvious site to provide an outstanding, internationally significant 'big story' is the Nullarbor Plain in Australia, but it does not yet feature on the Tentative List. Because of its large size, the case might best be presented as a serial nomination.

4. Dinaric Karst Type Site

We might also ask why the European type-site of karst, the 'Classical Karst' from which it derived its name and many scientific concepts, has not been nominated for World Heritage. The type-site is the belt of limestone ranges located to the east of the Adriatic Sea known as the Dinaric Alps, that extend from Slovenia in the north-west to Montenegro in the south-east. The region has four World Heritage properties in four different States and two further Tentative List properties (Table 2). All were nominated independently and there has been no formal international overview of what would be required to adequately represent and illustrate the scientific notion of Dinaric Karst, although there were exploratory discussions about this a few years ago.

Table 2: *World Heritage Properties and Tentative List sites in the 'classical' Dinaric Karst.*

DINARIC KARST The type-site of European karst and cradle of karst and cave research	
Existing World Heritage properties	
Bosnia and Herzegovina	Vjetrenica Cave (2024)
Croatia	Plitvice Lakes National Park (1979)
Montenegro	Durmitor National Park (1980)
Slovenia	Skocjan Caves (1986)
Tentative List properties	
Bosnia and Herzegovina	Martin Brod-Una National Park
Croatia	Velebit Mountain

International cooperation to achieve a nomination remains a challenge that is more political than scientific, although there are also financial considertions. A trans-national serial nomination is required that coordinates complementary karst values in existing and new sites. A successful strategy would involve a step-by-step process that uses re-nomination of existing sites to facilitate extensions and new nominations. The end result would be a series of sites with coordinated but independent management conceptually similar to arrangements in the South China Karst – which is the type-site of humid tropical/subtropical karst.

5. Inscription of Properties on the World Heritage List

In order to secure support for nomination, prospective World Heritage properties must be mentally and physically accessible to the public and will often have visually inspiring or memorable features that capture and secure public interest. In the mainstream of global conservation, it can be challenging to achieve recognition of the value of geodiversity (Larwood et al 2013), and this is especially the case for caves and their sometimes difficult to access environments.

The first problem is to achieve sufficient local support to have a site entered on the country's (State Party's) Tentative List. Once submitted, it will be published by the World Heritage Centre on the Tentative Lists of States Parties order to ensure transparency, access to information and to facilitate harmonization of Tentative Lists at regional and thematic levels.

A year after the Tentative List property has been notified, it can be nominated for World Heritage recognition. The procedure to be followed is explained in the Operational Guidelines for the Implementation of the World Heritage Convention (UNESCO 2024) and it is schematically illustrated in Figure 4.

The second problem is clarifying if a property could be considered to have Outstanding Universal Value. This is the most fundamental part of the nomination process (McKeever & Narbonne 2021). Until potential attributes that convey this value have been defined, it is not possible to develop other essential aspects of the nomination, including (i) the comparative analysis, (ii) the definition of boundaries and (iii) the protection and management (which should reflect the extent and character of the attributes that convey the outstanding value).

McKeever & Narbonne (2021) also point out that since uniqueness does not automatically equate with Outstanding Universal Value, an essential step is to identify those values of the property that fulfil World Heritage criteria (especially criteria (viii) in the case of cave and karst properties) and thus justify recognising the property as having Outstanding Universal Value. For this process, it is helpful to map out all geo-values of the property and evaluate these based on the 11 themes presented in McKeever & Narbonne (2021) for criterion viii. This will help to clarify if the identified values could potentially close one or more of the gaps on the World Heritage List.

A definition of the potentially outstanding value that is proposed to fulfil the criterion and a description of the attributes that convey this value can then be set out in a short text which will form the basis for the comparative analysis and eventually will form part of the Statement of Outstanding Universal Value for the nomination.

If the State Party is unsure about the significance of the values and thus the suitability of a property for nomination, it can obtain advice from the World Heritage Centre prior to submitting a nomination. This avenue for obtaining early advice is considered an Upstream Process and is available to reduce significant problems that might otherwise be encountered during the evaluation of the more challenging nominations. This consultation may lead to a formal Preliminary Assessment of the property.

6. Important cave and karst sites outside the World Heritage Convention

Should some internationally significant sites be considered inappropriate for World Heritage nomination, perhaps because they duplicate values already recognised in existing World Heritage properties or because they are rather small in area, then other avenues are available for international recognition. In the case of caves and karst, the most important of these is recognition as a UNESCO Global Geopark. McKeever and Narbonne (2021) explain and discuss the relationship between World Heritage properties and UNESCO Global Geoparks.

Information on the UNESCO assisted Global Network of National Geoparks is available from: http://www.unesco.org/en/iggp/geoparks/

7. Conclusions

1. There is limited scope for new cave/karst sites on the World Heritage List.
2. Highest priorities for filling gaps in the World Heritage List are
    - Karsts in under-represented regions, especially in Middle East and Central Asia, Africa and South America
    - Karsts that might be considered type-sites of landform development in (a) semi-arid tropical/subtropical and (b) super-humid temperate zones
    - Salt glaciers and other evaporite karsts
    - Palaeokarsts that contain the record of globally important environmental stories.
    - Dinaric Karst: a re-imagined transnational serial property of the European karst type-site.
3. Elsewhere expand existing World Heritage properties to incorporate neighbouring karst areas.
4. Achieve cave and karst conservation outside of the World Heritage Convention through recognition as UNESCO Global Geoparks.

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Global conservation of subterranean biodiversity

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Hidden beneath Earth's surface lies a vast and intricate network of caves, voids, and rock fractures, formed within sedimentary, igneous, or metamorphic rocks. While much of this subterranean world remains inaccessible to people, it harbors an extraordinary—yet largely undocumented—biodiversity. The continental subsurface supports a significant share of Earth's prokaryotic biomass, including an immense diversity of Bacteria and Archaea that remain poorly understood (Edwards et al., 2012; Magnabosco et al., 2018). The diversity of multicellular life in these environments is equally remarkable, with representatives from across the tree of life adapted to life underground (Deharveng and Bedos, 2019; Martínez et al., 2024). This specialized fauna constitutes a unique fraction of global taxonomic, phylogenetic, and functional diversity, playing key ecological roles and offering important benefits to human societies.

Worryingly, subterranean ecosystems and their biodiversity are increasingly threatened by human activities (Mammola et al., 2019). Surface-level pressures—ranging from land-use change (e.g., urbanization, deforestation, intensive agriculture, mining) to various forms of pollution—can percolate downward, altering the fragile environments beneath. These large-scale impacts are compounded by direct disturbances from subterranean-specific actions, such as the overexploitation of resources (e.g., bat guano), poaching, and heavy human visitation in show caves. These direct and indirect stressors are further amplified by the overarching effects of climate change, which is transforming subterranean ecosystems in complex and poorly understood ways (Vaccarelli et al., 2023).

Amid these challenges, we are left to grapple with pressing questions: Is subterranean biodiversity already responding to these threats? Are we witnessing extinctions without even realizing it?

Unfortunately, the answer is: we don't really know. Most of our understanding of human impacts on subterranean ecosystems comes from local-scale studies, with limited scalability to broader contexts. With few exceptions, long-term data series tracking biodiversity trends are rare, and comprehensive monitoring programs are largely lacking. This scarcity of quantitative data—both on threats and biodiversity patterns—combined with the logistical challenges of mapping and exploring subterranean habitats, severely limits our capacity to design and implement evidence-based conservation strategies (Mammola et al., 2022). In such data-poor scenarios, and until better information becomes available, expert judgment may serve as a practical guide—especially when applying the precautionary principle. A recent expert survey identified two key ingredients essential for the effective conservation of subterranean biodiversity, regardless of specific species or locations (Nanni et al., 2023).

The first is space. Conserving subterranean biodiversity requires dedicating land—at various scales—for protection. Currently, only about 6.9% of known subterranean ecosystems overlap with the global network of protected areas (Sánchez-Fernández et al., 2021). However, international agreements and frameworks exist to rapidly expand protected area coverage, and this presents a valuable opportunity to include more subterranean systems in conservation planning. Notably, the Kunming-Montreal Global Biodiversity Framework, adopted at COP15 in December 2022, commits signatory countries to protect at least 30% of the world's terrestrial, inland water, and marine areas by 2030 ("30 by 30" target). This global target provides a timely policy window to recognize and prioritize the inclusion of subterranean ecosystems—often overlooked in conventional spatial planning—within national biodiversity strategies and protected area networks. By explicitly integrating these hidden habitats into the implementation of Target 3 of the framework, conservation efforts can become more representative of the full spectrum of Earth's biodiversity.

The second is public awareness. Conservation only advances when people understand and value nature. Raising awareness about the importance of subterranean ecosystems is thus critical. Creative outreach approaches—such as artistic representations of caves and their fauna (Gleeson, 2024; Mammola et al., 2025), citizen science initiatives (Alther et al., 2021), and sustainable tourism that allow non-experts to experience caves (Chiarini et al., 2022)—can help engage the public. Importantly, speleologists can play a key role in raising awareness. As explorers and deep connoisseurs of the underground world, they serve as a vital bridge between science and the general public. They can actively contribute to conservation not only by collecting valuable data for research—such as reports of new species, environmental changes, or emerging threats—but also by promoting a respectful and informed approach to cave exploration. By organizing outreach activities, courses, public events, and collaborating with schools and local authorities, speleologists can help foster a grassroots conservation culture capable of generating real impact.

While the effectiveness of these education strategies for long-term conservation outcomes has yet to be rigorously evaluated (Mammola et al., 2022), it is reasonable to assume that direct exposure to the subterranean environment and its unique lifeforms can foster a deeper sense of connection and concern. Because when people care about nature and advocate for its protection, change becomes possible—even for ecosystems as hidden and unfamiliar to most as caves and their fragile biota (Gavish-Regev et al., 2023).

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Cave Microbes: How caves are going to save us all

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Summary

Prior to the 1970s, microbiologists did not consider caves particularly interesting – they were either a poor version of soil microbiology or contaminated by microorganisms carried by visiting cavers. Nonetheless, in the 1980s researchers revealed that pristine cave environments demonstrated the presence of species subsisting entirely on chemistries found within the rock. In the last 40 years there has been an explosion in the study of caves, demonstrating their importance as conduits to study the microbiology of the subsurface. Research has demonstrated that chemistries beyond carbon and sulfur (including iron, manganese, and nitrogen) may be responsible for cave formation and enlargement. The unique adaptions that allow microorganisms to survive within caves also have the potential to solve some of our greatest societal challenges, from carbon sequestration to nylon recycling, while providing clues for the potential of life beyond our planet, and even beyond our star.

Abstract for Plenary/Keynote Lecture - The Largest Caves in the World

Andy Eavis

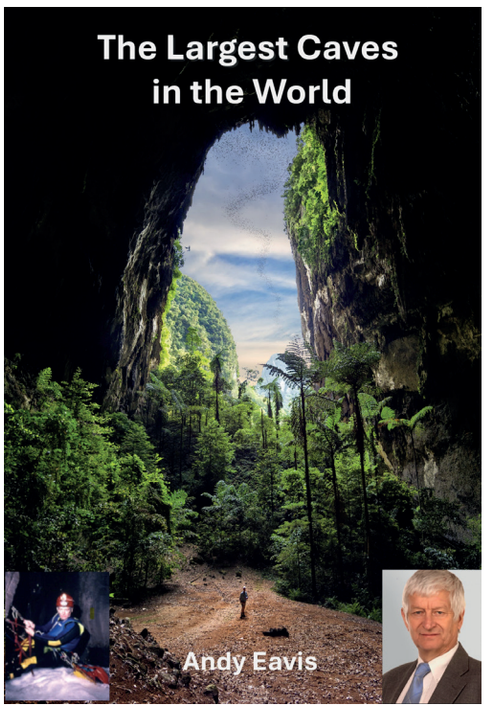
Andy Eavis and Pat Kambesis have nominally led a UIS commission called The Longest, Largest and Deepest Caves. It does very little between international congresses but exists to help compile the statistics.

As part of this process Andy Eavis worked with a group of British cavers to laser scan the largest chambers in the world. 10 chambers were originally planned based on Caver Bobs information from the internet. This was originally compiled by Bob Golden within the geology and geography section of the National Speleological Society. Bob worked tirelessly for decades maintaining the lists. Since he passed away Paul Burger has taken over and continues to do an excellent, although somewhat slightly US biased job, with some miss interpretations.

The laser scanning project was initiated at the 2013 international congress in Brno and started soon after that. After a few chambers it was realised that several were not as large as expected, and indeed at least one much larger than expected, so adjustments had to be made to the programme.

In addition, during the scanning period a couple of huge new chambers were discovered, so, in the end 15 chambers were laser scanned all around the world and the results presented. Pictorials and 3D models have also been produced and also a number of big cave passages explored, and laser scanned.

Finally, some of the latest information on deep and long caves will be presented plus a discussion on when does a passage become a chamber, and what is the largest cave in the world by volume. By way of conclusion other superlatives in caves will also be mentioned.



The Largest Caves in the World

At the international congress in Brno in 2013, Andy Eavis decided to put some science behind discussions on the largest caves, so with others he embarked upon a laser scanning project which was hoped could be completed in 2 years, in reality, it is still going on today 2025 – twelve years later.

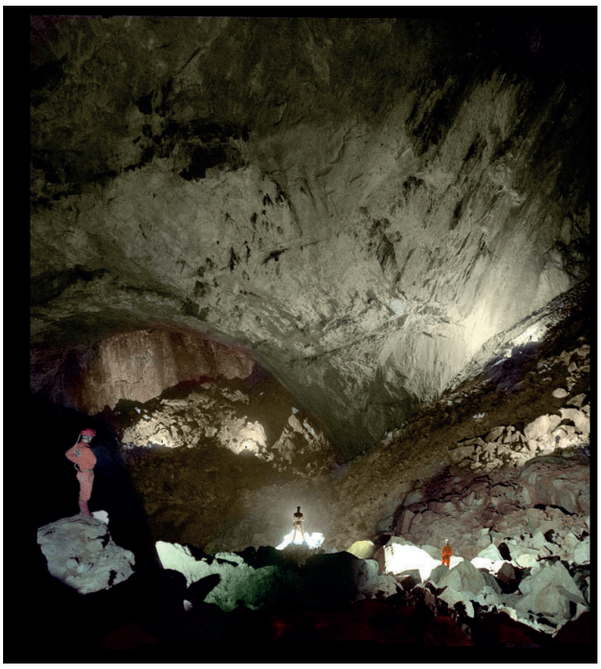
In the autumn of 2013 a Riegel RZ400 laser scanner was bought

This was selected as the best machine available based on its 400 meter range, which in reality is rather more, indeed up to 700 meters, and also its Austrian robustness, not on price as it was rather expensive.

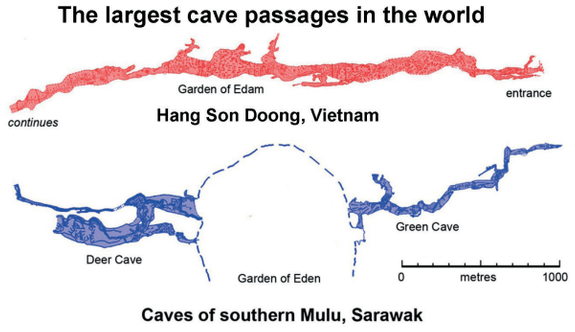
The Riegel RZ400 in operation. Photo: Andy Eavis.

In October 2013 Sarawak Chamber in Malaysia was the first target. We had already done a pilot project in Sarawak chamber using an old short range laser scanner with Kevin Dixon, this certainly showed the viability of the technology.

Sarawak Chamber from the top. Photo: Jerry Wooldridge.



The classic photo of Sarawak Chamber. Photo: Jerry Wooldridge.



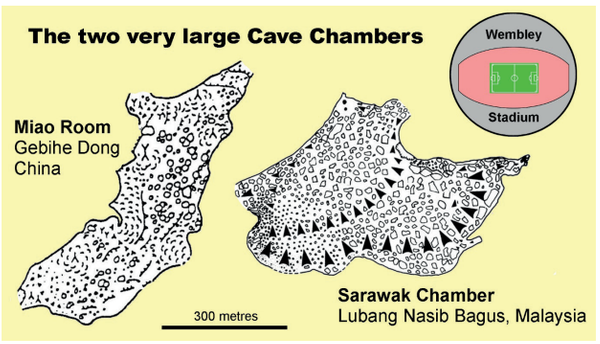
We will come back to passages later.

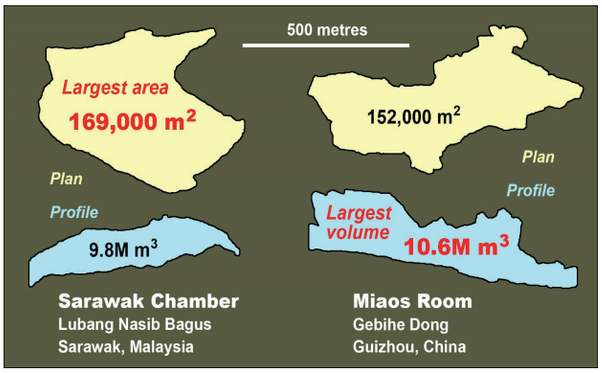
After this initial project, it was decided to start tackling all the largest known chambers in China. Miaos Chamber in Gebihe was known to be world class so this was next on the list with several other Chinese Chambers considered. The author has spent a considerable amount of time In China and was lucky enough to have a lot of contacts in China.

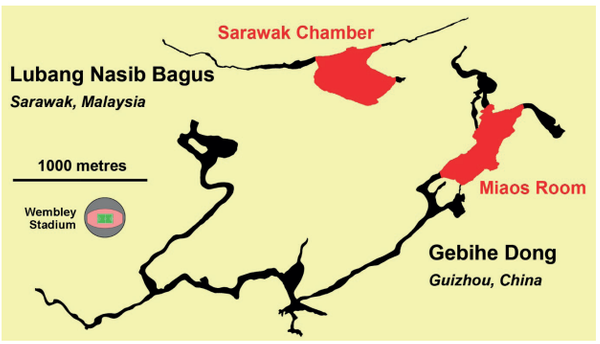
Up to half of the 10 largest known chambers in the world were believed to be in China. Maios scanning was supported by the National Geographic magazine, and we were accompanied by Carsten Peters, one of their photographers who indeed came on several more trips after that.

(In the presentation a fly through of Miaos Chamber will be shown)

An amusing incident in Miaos while the laser scanning survey also took place. Pete Smart was doing a structural analysis of the big chambers as part of the programme, Carsten taking photographs and others holding flash guns and checking out to make sure there weren't any side passages worth scanning. The scanner operator, who, on this occasion happened to be the author of this paper succeeded in putting the £100,000 laser scanner down between very large boulders and spent the next two hours trying to find it. Eventually, he had to give in and radio other members to help him come and search. These are huge places and walking through the boulders an interesting occupation,







While in China a number of other chambers were visited, the first was Hong Meigue, then The Funnel of Light, followed by Cloud Ladder Hall .

Cloud Ladder Hall. Photo: Robbie Shone.

This is one of a number of these big chambers where you can abseil in through the ceiling. Cloud Ladder Hall does have an alternative way in through the passage at the bottom, but the 250 m abseil is rather impressive.

The last China chamber to be visited at this time was Titan. The name comes from the fact that there are 2 huge, nicely rounded stalagmites

with small dimples on top, you can make your own conclusion.

Things after China got interesting with a trip to Mexico to look at La Muneca Fea, with the help of a Belgium expedition. Again, another lovely caving experience and a very nice descending passage with some small parts even squeezing to get down to the rather gigantic chamber.

France and Spain then followed. La Verna in Pierre San-Martin Southern France had for several decades been considered to be the largest chamber in the world, it was somewhere the author worked many years ago when he was a minging engineer. The mining engineer did calculations which showed nothing could be larger than La Verna in Pierre San-Martin, low and behold Sarawak Chamber was 3 times as big. Theoretical rock mechanics just doesn't work on caves.

Spain and France has an interesting situation similar to China and Malaysia.

Sarawak Chamber is substantially bigger than Miaos Room if you take floor area, however, volume wise depending how far you go up and down the Miaos Room passages the volume is bigger for China. A similar situation is in France and Spain. La Verna is larger by volume but little more than half the size by floor area. The whole thing is governed by chamber height, hence the requirement of a long-range laser.

That leads onto a return to Mulu.

Api Chamber was debated as to whether it was worth laser scanning, it's a days tough caving from the surface to get to it, the most arduous approach of any of the chambers scanned. Eventually it was decided to do the passage approaching it as well as the chamber itself. The first scan on entry through a squeeze into the chamber suggested that the scanner was malfunctioning as it showed out of range at 600+ metres. After a few more scan positions it was realised that Api Chamber is incredibly high, and the angle from the entrance was indeed over 600 metres, total height of the chamber over 300 metres (1000 ft). A typical Tienken in the making.

The author scanning in entrance to Api Chamber. Photo: Andy Eavis.

Looking down Api Chamber. Photo: Robbie Shone.

The extreme height putting Api Chamber into the top 10, which amazed all concerned.

Travels then took the scanning team to Oman and Iran, both wonderful chambers entered by abseiling in through the roof.

Ghar-e-Dosar in Iran being particularly impressive as in complete darkness and landing right in the centre of nothingness. The whole Iran experience was spectacular with great help being given to the team by wonderful Iranians who provided the most delicious red wine (Shiraz) and living in Estefan, one of the most beautiful cities in the world - shame about the politics.

Oman however was also fantastic and memorable. Majlis al Jinn is nearly as big as Ghar-e-Dosar, but at certain times of the day a remarkable amount of light enters in. There are a couple of small holes in the roof through which you abseil. The surface is desert on top of the mountain with a small village siting on top of the chamber, all giving a rather interesting situation. The dry dusty weather conditions make the atmosphere slightly hazy and the direct sunlight down the small shafts acts like giant fluorescent light tubes, the effect is a wonderfully illuminated underground cavity, possibly the most beautiful chamber the team entered.

Majlis 2 (Majlis flythrough at the presentation).

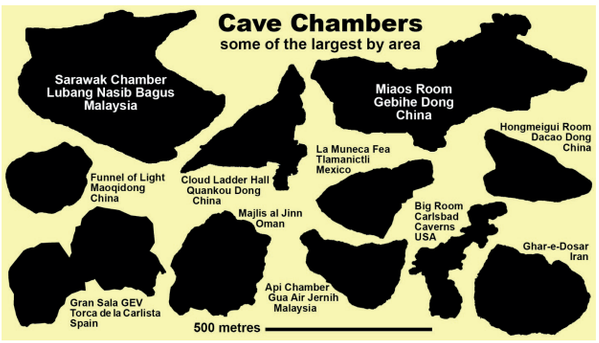
Things now became interesting as it was felt Big Room in Carlsbad caverns should be scanned as we were going to Belize to do a big chamber there and could cover both things at the same time, and the Big Room had been considered to be the largest cave chamber in the world for many years. So these were both looked at, both proved to be lovely but not as big as had been expected.

At this stage, things got even more interesting as 2 more chambers in China were discovered and became the 16th and 17th chambers that were scanned.

Marco Polo turned out to be something of a speleothem quarry, although we understand mining has now stopped. Some of the stalagmites and stalactites that had been removed were over 500 kg in weight. Geomorphologically it was also very interesting with a floor of boulders and large stalagmites which were gently collapsing being eroded by the underground river, the overall effect was wonderful.

The last chamber to be scanned in the programme was Hong Kong Chamber that had been recently discovered it is very memorable because the hike up the mountain gave access to the top of the chamber, but the bottom was very near to a village in the valley below, with a short tunnel it would make a wonderful showcave.

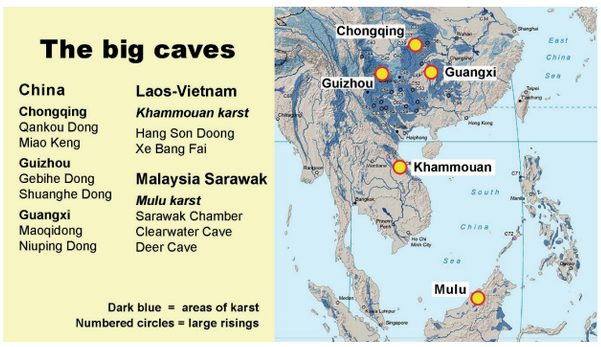
Clearly analysing the results is a very interesting and subjective exercise, largest by volume and largest by floor area??



List 1

Order by Volume	Chamber Name	Cave	Vol (x106m3)	Order by Floor Area	Plan Area (x103m2)	Country	Location
1	Miao Room	Gebihe	10.59	2	151.99	China	Ziyun County, Guizhou
2	Sarawak Chamber	Nasib Bagus	9.81	1	168.87	Malaysia	Mulu National Park, Sarawak
3	Cloud Ladder Hall	Quankou Dong	6.23	8	56.74	China	Tongzi, Wulong County, Chongqing
4	Funnel of Light	Maoqidong	6.13	15	39.85	China	Leye County, Guangxi
5	La Muneca Fea	Tlamanictli-TZ1	5.90	5	65.06	Mexico	Tepepan, Zaragosa, Puelba
6	Hong Meigui	Niu Ping Dong	5.56	6	62.70	China	Leye County, Guangxi
7	Ghar-e-Dosar	Ghar-e-Dosar	4.33	4	79.14	Iran	Mehrib, Yadz
8	Majlis al Jinn	Majlis al Jinn	4.11	7	59.41	Oman	Selma Plateau
9	Salle de la Verna	Reseau de la Pierre San Martin	3.65	13	43.15	France	Sainte-Engrace, Pyrénées-Atlantiques
10	Api Chamber	Whiterock Clearwater System	2.89	14	42.73	Malaysia	Mulu National Park, Sarawak
11	Martel Chamber	Skocjanska Jame	2.55	16	32.89	Slovenia	Divača
12	Titan Chamber	Ban Dong Xinu - Chu Yan Dong	2.43	9	52.81	China	Doshan, Anlong County, Guizhou
13	Gran Sala GEV	Torca de la Carlista	2.14	3	84.31	Spain	Cantabria
14	Marco Polo	Nongluidong	1.44	11	45.69	China	Dinlong, Jinya, Fengshan District, Guangxi
15	The Big Room	Carlsbad Caverns	0.93	12	45.36	USA	New Mexico
16	Belize Chamber	Chiquibul Cave	0.81	10	46.38	Belize	Chiquibul

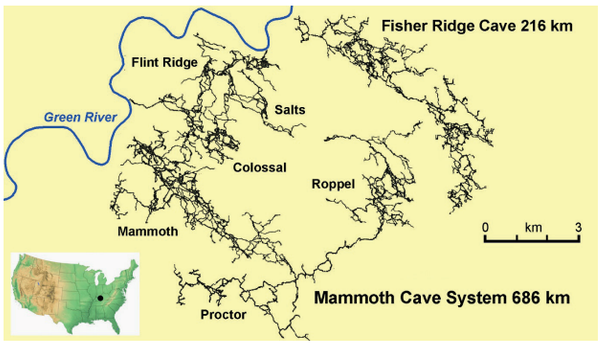
Both are subjected to how far you take the chamber size up and down, the incoming and outgoing passages.



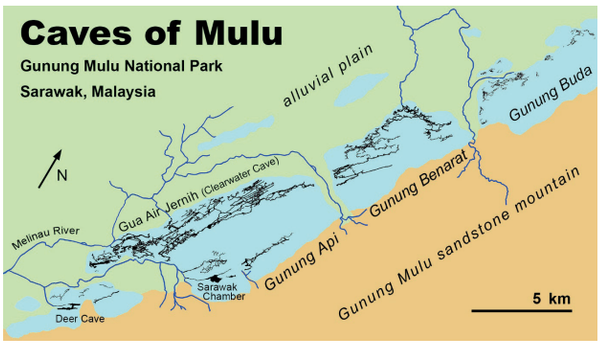
Currently as can be seen many of the world's "big caves" are in SE Asia. Hang Son Doong is widely recognised as "The largest Cave in the World", this of course is subjective. It could claim to be the largest cave passage in the world, also possibly the most beautiful large, long cave in the world, a fantastic piece of cave formation. Clearwater Cave where we have now scanned 15 km and this section is over 20 million cubic meters, and the volume that we have scanned is only about a 1/10th of the total volume. Total volume will be way over 45 million cubic metres. Volume wise this will take some beating.

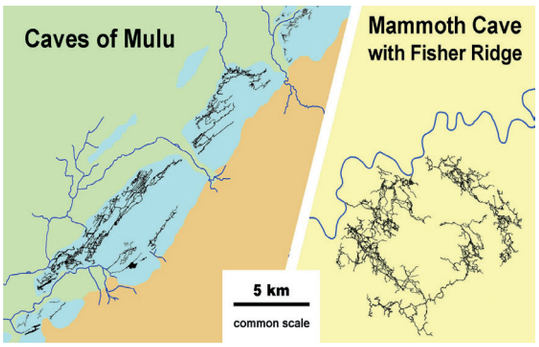
The Longest Caves in the World

Certainly the mammoth cave system at 686 km will take some beating but it is all fairly small passage.



Interestingly, if Clearwater could go under the Melinau Gorge connecting Gunung Api and Gunung Benerat the length could be up to 400 km with a huge amount more to be discovered. How wonderful are caves.

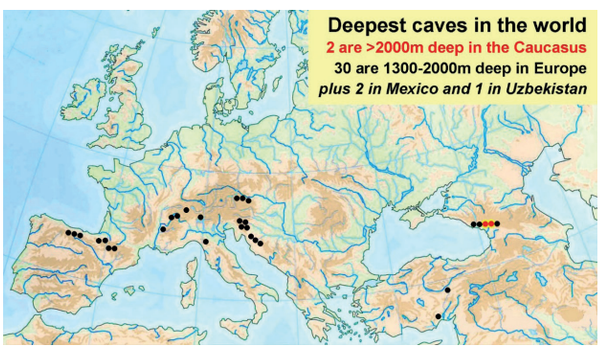


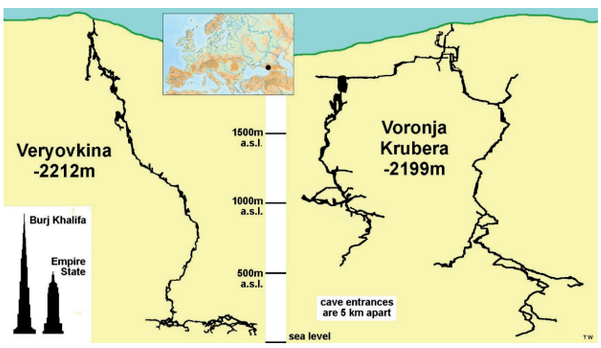


Comparison of Mulu and Mammoth Caves at the same scale.

The Deepest Caves in the World

Currently most of the very deep caves are in Europe, unfortunately several in a rather politically dodgy part of the world in north Turkey - Southern Georgia. Currently only 1 of the top 10 deepest caves in the world is outside of Europe and that is of course in Mexico. Georgia has the deepest at over 2 km deep.



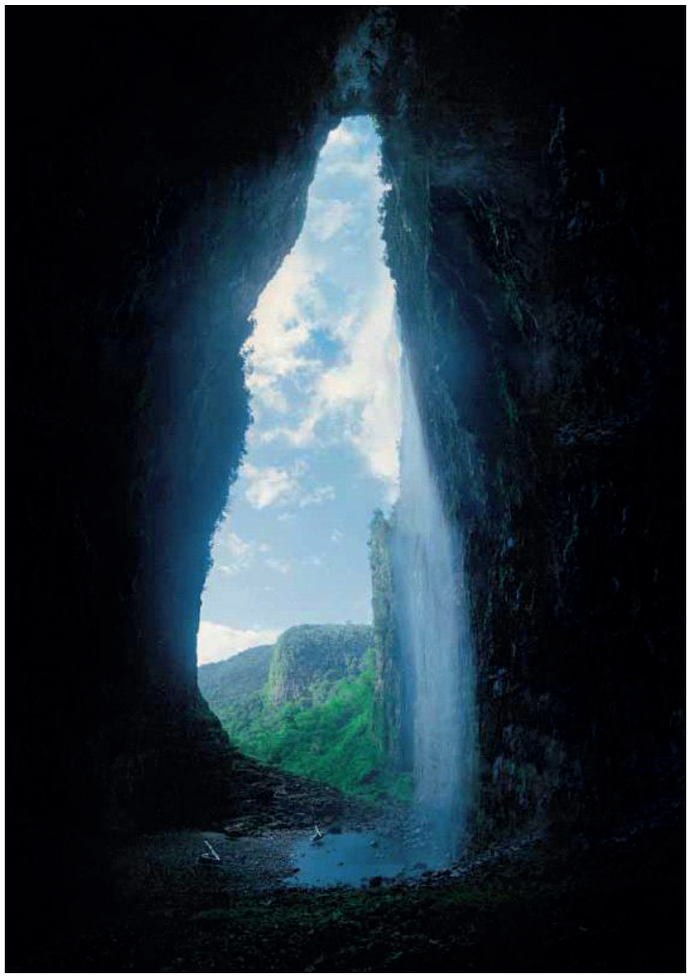


Cross sections of the deepest caves in the world current

Apparently after a resurveying exercise Krubera is deeper than Veryovkina. Finally, a few other superlatives. Mulu claims the longest straw stalactite in the world at over 8m that's nearly 30 feet in length and as you stand by it talking makes it sway with the movement of your breath, it won't be there all that much longer, although its in one of the most remote caves so far explored anywhere in the world.

8 metres plus straw stalactite in Wonder Cave, Mulu. Photo: Jeff Wade.

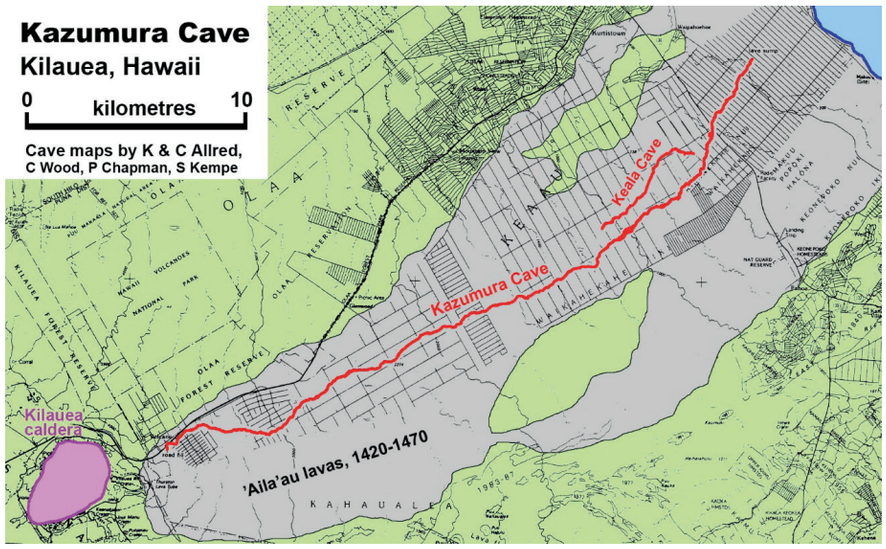
The Largest Cave Entrances



Large cave entrance in venezuala (Note the helicopters). Photo: Robbie Shone.

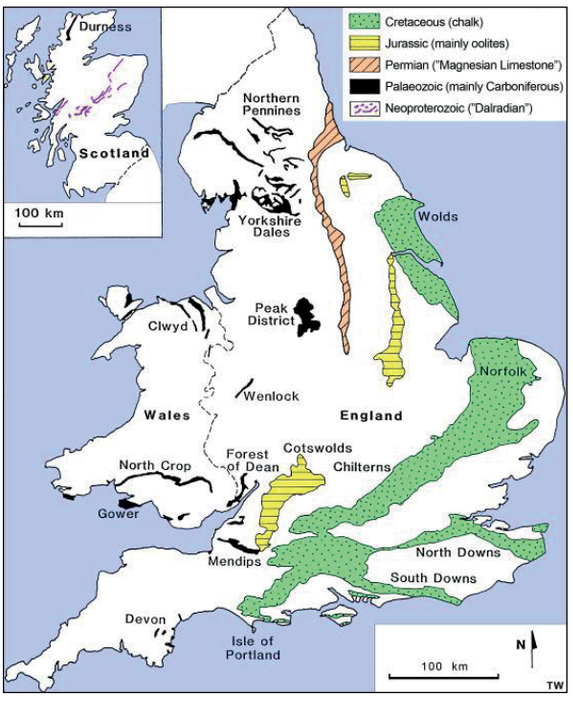
Large trunk passages we could speak about lava tubes, the longest and most impressive being in Hawaii but not particularly the subject of this lecture.

Kazumura Hawaii.Lava tube. Photo Unknown.



Lava Tube In Geju, South Korea.

We should finish with a few words on Britain where we have the most diverse caves in the world from large volcanic caves to long limestone caves in almost every type of limestone. Britain could possibly claim to be the most diverse caving area in the world.



A cave in late holocene freshwater carbonates less than 150,000 years old. Photo: Robert Eavis.

John Gunn in a cave formed in dalradian metacarbonates over 1 billion years old. Photo: Ivan Young.

Great Britain is a land area of about 200,000 km2 of which there are over 5,500 caves with a combined length of over 1,000 km. Every year the number of caves and particularly the length increases as a result of industrious and sometimes almost industrial digging by British cavers.

Between 1989 and 2016 the length of cave in Britain grew on average by nearly 13 km a year a total of over 351 km. Great Britain is the home of the science of geology and there is a remarkable range of carbonate rocks. From freshwater carbonates of only 100,000 years or so to the oldest known being Neoproterozoic metacarbonates that formed over a billion years ago. There are caves in rocks in both of these periods with other rocks from most periods over the geological column, most caves in Britian however are in carboniferous limestone.

Acknowledgements

The author would like to thank the photographers who are mostly credited on the pictures, but include Jerry Wooldridge, Robbie Shone, Carsten Peters, Jeff Wade, Robert Eavis, Bartek Biela, Tony Waltham, Ivan Young.

In addition, great thanks are due to Tony Waltham for many of the charts, diagrams and maps. John Gunn for considerable amount of help and information generally but particularly on caves of Britain. Richard Walters for maps and animations that will go with the live presentation.

Finally, the author's son Robert Eavis for lots of help and advice.

Movimientos de agua subterránea a gran escala en la Península de Yucatán

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Resumen

En los últimos 25 años de exploración de cenotes en la Península de Yucatán, distintos grupos de buceo han documentado un estimado de 2,000 kilómetros lineales de cuevas saturadas con agua dulce a nivel superficial y agua salada a mayor profundidad. Por diversas razones, creemos que dicha extensión lineal es únicamente una consecuencia colateral de la circulación de importantes flujos de agua subterráneos que van en dirección Oeste-Este y Sur-Norte a través de fallas geológicas que cruzan toda la Península de Yucatán. Mediante fotografía satelital, mapas de los sistemas de cuevas, modelos hidrogeológicos de investigaciones previas, colectas de muestras de agua, técnicas avanzadas de buceo en cuevas y registro subacuático de imagen, hemos documentado flujos de agua subterránea a gran escala que van desde el Golfo de México hasta el Sur de Quintana Roo, desde Belice y Guatemala hasta el área de Holbox y de Akumal hasta Isla Mujeres.

Abstract:

In the last 25 years of Cenotes exploration in the Yucatan Peninsula, various dive teams have documented an estimated 1,300 linear miles (2,000 kilometers) of cave passages saturated with superficial freshwater and saltwater at greater depths. For several reasons, we believe that this linear extent is just a collateral consequence of the movement of considerable Groundwater Flows running West-East and South-North directions through Geological faults that crisscross the entire Yucatan Peninsula. Through satellite photography, submerge cave system maps, hydrogeological models of previous research, water sample collection, advanced cave diving techniques, and underwater image capturing, we have documented Large-Scale Groundwater flows from the Gulf of Mexico to Southern Quintana Roo, from Belize and Guatemala to Holbox area, and from Akumal area to Isla Mujeres.

Introducción

En los últimos 42 años de exploración de cuevas sumergidas en Yucatán, diferentes equipos de buceadores han cartografiado un estimado de 2,000 kilómetros de cuevas sumergidas -en su mayoría de agua dulce- en un área lineal de 340 kilómetros ubicada entre la ciudad de Cancún y el pueblo de Xcalak cerca de Belice.

Hasta el día de hoy, estos esfuerzos de exploración aislados y separados han compuesto involuntariamente un extenso mapa al que sólo unos pocos han prestado atención, y nadie ha mirado en una visión global para crear un panorama completo o "*The big picture*".

Cuando empezamos esta investigación, surgieron las preguntas ¿de dónde viene toda el agua? ¿los 2,000 kilómetros de cuevas inundadas y esos millones y millones de litros de agua dulce, encima de la capa de agua salada, se llenan con las precipitaciones directas al final de cada temporada de lluvias?

Es evidente que esto no era posible, dado que se ha documentado que el agua dulce de la mayoría de los sistemas de cuevas conocidos se desplaza en dirección Noroeste-Sudeste hacia el océano y drena continuamente hacia el Mar Caribe en grandes cantidades.

Por este motivo, nuestra hipótesis central se basa en la premisa de que toda el agua dulce que fluye por los sistemas de cuevas se acumula obviamente por la precipitación pluvial por filtración, pero debido a la gran magnitud, este hecho debe estar ocurriendo en un área mucho mayor de lo que se propone.

Esto, a su vez, exige que las aguas subterráneas que se acumulan deban desplazarse a mayores distancias. Para que esto sea posible, pensamos que los sistemas de cuevas inundadas son mucho más grandes, están mucho más ramificados y están más interconectados de lo que se conocía hasta ahora.

Por varias razones, creemos que el aumento de la cavitación y del agua dulce contenida en estos 2,000 kilómetros de cuevas inundada es un subproducto, "un daño colateral" de la interconexión de las principales fallas geológicas (Falla de Holbox, Falla de Río Hondo, Falla de Sierrita de Ticul). Fallas geológicas que constituyen un sistema de cuevas per se que canaliza inmensas cantidades de agua dulce desde Belice y Guatemala y el centro de la Península, primero cerca de la costa del Caribe y luego junto con la misma, hasta el extremo Noreste de la Península, hasta el Canal de Yucatán.

En este trabajo presentamos datos basados en la observación directa (empírica) utilizando técnicas avanzadas de buceo en cuevas sobre el comportamiento de las aguas subterráneas en lo que creemos que son las principales fallas geológicas de la Península de Yucatán.

En este sentido, los objetivos de esta investigación son:

1. Definir la geolocalización y la interconexión de las fallas generales (Holbox, Sierrita de Ticul, Río Hondo, Anillo de los Cenotes, Falla de Akumal)
2. Bucear y documentar las fallas.
3. Definir y documentar la dirección del flujo en las fallas principales.
4. Demostrar gráficamente los movimientos, direcciones y velocidad del flujo de agua en el interior de las fallas.
5. Obtener evidencias de cómo el flujo de agua que discurre junto

a la falla influye, crea y/o modifica el proceso de formación de cuevas en la región.

6. Demostrar que la dirección del flujo de agua en el interior de las fallas de Río Hondo y Holbox va del Suroeste al Noreste; lo contrario de todo lo identificado anteriormente con respecto a la dirección del flujo de agua en los sistemas de cuevas sumergidas de la región.
7. Demostrar la dirección del flujo de agua dentro de la Falla Sierrita de Ticul. Del Noroeste al Sureste, hacia la costa del Caribe.
8. Obtener y documentar variables contrastables en otras cuevas sumergidas (sitios de buceo) que puedan probar o refutar nuestra hipótesis central.
9. Crear una base de datos de muestras de agua a largo plazo. Con el fin de probar la calidad del agua, pero también las direcciones del flujo.

Materiales y Métodos

Durante la temporada de campo de buceo del 15 de abril al 15 de mayo de 2022, se recolectaron datos empíricos en dos puntos estratégicos en cuevas sumergidas de la zona de Tulum (Sur y Norte), donde identificamos la ubicación de la falla de Holbox y algunas dinámicas de flujo de agua muy particulares.

Durante la Etapa (1) de investigación en gabinete, el método de aproximación para rastrear la falla geológica se basó originalmente en la observación de fotografías satelitales utilizando el software Google Earth Pro® para observar las áreas potenciales de exploración y las interconexiones de los sistemas de cuevas sumergidas. Este método, nos permite identificar las afluencias sub-superficiales (cenotes) que, en este caso, crean una clara alineación (falla geológica) que va de Sur a Norte desde Belice y Guatemala hacia Chiquilá Quintana Roo (véase: Fig.1).

La Etapa (2) de investigación en gabinete, se trató de consultar una extensa base de datos de mapas de cuevas sumergidas de los últimos 30 años de buceo en la zona de Tulum colectados en la base de datos de la *Quintana Roo Speleological Survey (QRSS)*. Esto nos permitió confirmar que efectivamente existen túneles bajo la selva maya que ya han sido buceados y que ciertamente conectan miles de cenotes en dirección Sur-Norte.

Posteriormente, en la Etapa (3) de validación en campo se hicieron uso de técnicas avanzadas de buceo en cuevas con tanques de aire comprimido laterales e independientes, y mezclas de gases como *Nitrox* y *Trimix* que permiten prolongar los tiempos de fondo y reducir la descompresión, trajes secos *Fourth Element* para permanecer más tiempo y más calientes bajo el agua, y máscaras de cara completa *Interspiro* para comunicarse bajo el agua, salimos al campo para obtener evidencia empírica de lo que observamos a gran escala en los mapas de cuevas y en la fotografía satelital.

Para la obtención de imágenes digitalizadas en 1080 (Full HD) 24 fotogramas por segundo, utilizamos una cámara *Canon 5D III* con objetivo zoom EF 16 -35mm, 1:28 L II USM con una carcasa *UK- Germany 2017*, y cámaras *Go Pro 10* con soportes estabilizadores diseñados por nosotros mismos con PVC para acoplar computadoras de buceo *Shearwater* que nos permiten mostrar en el encuadre las distintas profundidades y orientaciones en el compas mientras que al mismo tiempo documentamos la evidencia.

El primer punto de documentación se localizó al sur de Tulum en el sistema de cuevas inundadas *Chan Hol*: 16 Q: 0440524.56 m E / UTM: 2229078.00 N. Una vez que identificamos en el mapa una clara trayectoria Suroeste-Noreste en una sección de la cueva de *Chan Hol*, planteamos la posibilidad de que el flujo de agua fuera a mantener una dirección Suroeste-Noreste con alguna posibilidad de tener un flujo de agua abundante (véase: Fig.2).

Si esto era así, necesitábamos obtener pruebas de ello. Por este motivo, nos dimos a la tarea de idear un método-técnica que nos permitiera mostrar claramente el movimiento del agua. La técnica se planificó con un tinte orgánico comestible no agresivo a base de propilenglicol, colorante artificial (FD&C rojo nº 40), citrato de sodio, ácido cítrico, benzoato de sodio y sorbato de potasio (véase: Fig.3). Una técnica de rastreo de tintes en cuevas que ya se ha utilizado en estudios hidrogeológicos previos en todo el mundo (Franks 2022: 27-74; Gouzie et al., 2015; Lauber et al., 2014:335-445).

Con estas herramientas, lo siguiente fue bucear una sección del Sistema Chan Hol que parecía coincidir con la ubicación de la falla de Holbox. Esperábamos que la posibilidad de que el agua fluyera en dirección Suroeste-Noreste provocara-coincidiera con la orientación de la Falla de Holbox, por lo que colocamos una escala subacuática de tres metros de largo y una brújula que mostraría si efectivamente había un flujo de agua, la velocidad de su movimiento y la dirección en la que se movía. Datos que serían evidentes al observar-registrar el comportamiento del tinte.

A continuación, reprodujimos la misma técnica en Akumal un punto más al Norte de Tulum en una sección del Sistema *Murena-Aak Kimin*: 16Q: 0467832,67 m E / UTM: 2256549,10 m N (véase: Fig.4) en donde también se colocó una regleta subacuática de tres metros de longitud y una brújula subacuática en el fondo de la cueva para medir la velocidad y la dirección del flujo de agua a través del tinte.

En ambos registros se colocaron cámaras subacuáticas fijas en el punto más al Norte de la escala para asegurar que el tinte se había movido efectivamente en la dirección de la imagen captada en la cámara (Norte) y que se podía ver en el resultado gráfico final en el que siempre había un punto fijo-anclado que captara el movimiento del tinte en dirección Sur-Norte (véase: Fig.5).

Resultados y discusión

La meseta caliza de la Península de Yucatán está surcada por varias fracturas de gran tamaño (véase: fig.6). Estas pueden haber sido causadas por movimientos tectónicos o por el enorme impacto del meteorito de *Chicxulub* hace unos 66 millones de años. Este último es definitivamente el caso del "Anillo de Cenotes" que describe el cráter de impacto del meteorito (Lefticariu et al., 2006; Monroy-Ríos, 2020; Perry et al.,1995).

La otra parte de la fractura circular está oculta en las aguas someras del Golfo de México. La falla de la Sierrita de Ticul comienza en el lado Oeste de la Falla del Anillo de Cenotes en el Noroeste de Yucatán y cruza en diagonal hacia el Sureste, donde se une a la falla de Río Hondo cerca de la costa del Caribe, que se extiende desde Belice y Guatemala, desde el suroeste hasta el noreste (Bauer-Gottwein et al., 2011).

Como es posible observar en la Figura 7, nuestra hipótesis se sustenta en esta imagen al plantear la posibilidad de que existe una conexión de la Falla de Holbox con las otras cuatro fallas principales como una sola, en un punto convergente que hemos identificado en el poblado de Limones Quintana Roo, al Norte de la Laguna de Bacalar.: 16Q: 383127.50/ UTM: 2103979.60.

Conociendo la dirección del flujo en la Falla del Río Hondo y la Falla de Holbox -de Suroeste a Noreste- a la par de la premisa de conexión entre las diferentes fallas, esto podría explicar de dónde proviene la inmensa cantidad de agua dulce que se escapa al mar en varias salidas

a lo largo de la costa del Caribe y el Golfo de México.

Las precipitaciones pluviales de toda la Península de Yucatán pueden reunirse ahora en las principales fallas, dirigirse a un centro cerca de la costa caribeña, y luego dirigirse, junto con la misma falla, en dirección Noreste hacia la parte superior (Norte) de la Península.

La fuerza que desvía las enormes masas de agua dulce y que ahora "tira" de ellas hacia el Noreste puede encontrarse en la dirección principal del flujo de la corriente Ecuatorial Sur-Norte y del Golfo (véase: Fig.7 y 8).

Gigantescas masas de agua salada se canalizan a través de un amplio y profundo canal entre las islas del Caribe y el continente centroamericano. Este canal se aplana y se estrecha hacia el Norte y está provisto de una "restricción" (Canal de Yucatán) en la transición del Mar Caribe al Golfo de México.

Dado que enormes cantidades de agua procedentes de la corriente ecuatorial del Sur empujan con fuerza, la presión del agua y, por tanto, la velocidad de flujo del agua que atraviesa el Canal de Yucatán aumenta enormemente.

Así, el agua se inyecta como por un embudo con velocidades máximas de 120 millas náuticas en el Golfo de México que a su vez sólo tiene una opción de salida, a través de otra restricción, el Estrecho de Florida. Debido a este accidente geográfico, se forma un vórtice colosal que crea una inmensa succión (véase: Fig.8). Esta succión crea un efecto Venturi "XXL" que retira las precipitaciones de la Península de Yucatán a través de la falla de Holbox, pero sobre todo a través de la Falla de Akumal (información más adelante en este documento).

En nuestra opinión, media docena de cenotes "especiales" juegan un papel crucial en este proceso de extracción, ya que son probablemente los extremos abiertos de dos fracturas principales. Esos cenotes no están incrustados en la densa selva como es habitual, sino a kilómetros de la costa de Cancún 30 metros del fondo marino (Rodrigo Friscione, comunicación personal)

Por estas aberturas se escapan enormes cantidades de agua dulce hacia el mar. La única explicación lógica de este fenómeno es la existencia de un conducto de desagüe natural, en forma de una falla geológica hasta ahora desconocido, el cual hemos recientemente registrado mediante técnicas avanzadas de buceo en cueva y hemos denominado como la "Falla de Akumal". Fractura geológica que se extiende desde tierra firme bajo el lecho marino hasta los cenotes marinos detrás de Isla Mujeres en Cancún (véase: Fig.4 y 9).

La falla geológica existe físicamente y está definida en su recorrido por el pueblo de Akumal, en el que el curso de la cueva describe una línea de cinco kilómetros en forma de flecha (véase: Fig.4). Por esta razón, hemos denominado la falla con el nombre del pequeño pueblo.

Las evidencias de la falla se extienden mucho hacia el sur. Creemos haber encontrado el origen de la fractura de Akumal en una bifurcación de la fractura de Holbox, aproximadamente a 3,9 km al Oeste del centro de Tulum (16Q: 0447769 m E / UTM: 2234760 m N).

En este punto, las masas de agua procedentes del Suroeste se dividen, siguiendo la falla de Holbox hacia el Noreste y siguiendo la falla de Akumal hacia el Este (véase: Fig.9).

Desafortunadamente, no pudimos seguir el curso del agua justo debajo del centro de Tulum debido a la fuerte contaminación (Metcalfe et al., 2011) pero logramos determinar la corriente proveniente del Oeste en el lado Este de la ciudad de Tulum, en el Sistema de Cuevas de Sac Actun (área de Abejas), y seguirla más allá en dirección Noreste, desde aquí encontramos evidencia continua de túneles relacionados con fracturas y patrones de flujo en varios sistemas de cuevas en dirección Noreste a lo largo de la costa del Caribe hasta la fractura epónima en el pueblo de Akumal.

La orientación de la Falla de Holbox, pero específicamente de la Falla de Akumal, se asemeja a un "popote" en un vaso de agua, permitiendo la extracción del agua dulce de la Península a través de la enorme succión del vórtice (véase: Fig. 8). Flujo de agua que fue documentado en fotografía y video durante esta investigación.

Creemos que es principalmente la Falla de Akumal la que alimenta estos cenotes en medio del lecho marino, ya que la Falla de Holbox se aleja cada vez más de la costa del Caribe en su camino hacia el Noroeste. El curso de la fractura de Holbox se encuentra en la misma latitud que la ciudad de Cancún y los cenotes marítimos a unos 60 km hacia al este, hacia el exterior de la Península, y en una posición de 90° con respecto a la dirección del flujo de agua de la Falla de Holbox (véase: Fig.9).

Otras pruebas de que el agua dulce migra del Suroeste al Noreste revelan una serie de muestras de agua que colectamos en cenotes estratégicos durante la Expedición *Xunaan Ha* Otoño-2021, que fue financiada por el Proyecto.

La selección de los puntos de muestreo está relacionada con el curso de la Falla de Holbox y la Falla de Akumal. De acuerdo con nuestra hipótesis, el agua dulce proveniente del Suroeste de Tulum debería entrar "limpia" por debajo de la ciudad de Tulum, contaminarse por debajo de la ciudad y salir contaminada por el lado Noreste de la zona urbana de Tulum (véase Fig.10).

Nuestra premisa fue confirmada y al mismo tiempo probamos la posibilidad de utilizar la contaminación metropolitana como método de rastreo de los flujos de agua subterráneos.

Otro ejemplo de uso de este método para documentar no sólo el grado de contaminación sino también el curso del flujo de las aguas subterráneas se encuentra en la Reserva de la Biosfera de Sian Ka'an, protegida por la UNESCO (TNC et al., 2009).

Según diversas publicaciones de organizaciones privadas y gubernamentales (*The Nature Conservancy*, Amigos de Sian Ka'an, RDLB Sian Ka'an, CONANP) y entrevistas que llevamos a cabo con el director de la reserva de Sian Ka'an el Biólogo A. Omar Ortiz; en la reserva de la Biosfera de Sian Ka'an existe evidencia de contaminación que se relaciona directa y claramente con la practica de la agricultura (TNC et al., 2009:50).

Sin embargo, no hay agricultura intensiva alrededor de la Reserva de la Biosfera de Sian Ka'an (véase la Fig. 11). Las principales zonas agrícolas más cercanas que podrían explicar la contaminación encontrada se encuentran al menos a 60 km de distancia, en el Suroeste de la reserva en una zona en la que se cultiva caña de azúcar a gran escala, y en el Noroeste, donde se encuentran decenas de grandes granjas porcinas (Drucker et al. 2003).

Conclusión

No es posible que los 2,000 kilómetros de cuevas sumergidas -en su mayoría de agua dulce- se llenen año tras año sólo con precipitación pluvial directa. Al no ser cuerpos de agua aislados -sino con un flujo constante de agua- los cenotes no pueden almacenar el agua de lluvia al final de cada temporada de lluvias. Por lo tanto, es obvio que no pueden mantenerse a su máxima capacidad año tras año sin obtener un recurso de agua dulce proveniente de otro lugar.

Desde hace algún tiempo, varios exploradores pensaron que el agua dulce debía provenir de otra parte y que probablemente fuera a través de la falla de Holbox. Al habernos dado a la tarea de buscar físicamente en todas partes y con todos los recursos a nuestro alcance ésta y otras 4 fracturas, estamos dando un cambio de rumbo en los estudios hidrogeológicos de la Península de Yucatán, ya que los modelos hipotéticos hidrogeológicos anteriores a este trabajo son ahora corroborados directamente bajo el método empírico.

Si bien ya se había propuesto que la piedra caliza funciona más o menos como una "almohada húmeda" y que el agua está presente en todos los estratos geológicos, no se había propuesto antes que los 2,000 km de pasajes de cuevas inundadas en la zona de Tulum eran sólo una consecuencia colateral de las principales fallas geológicas que transpor-

tan grandes cantidades de agua dulce en la dirección Sur-Norte, misma dirección de las corrientes oceánicas en el Caribe mexicano.

Al facilitar un mayor movimiento y un mayor flujo de agua dulce a través de las enormes fracturas que conforman la falla de Ticul, la falla del Río Hondo y la falla de Holbox, hacia la zona de Limones cerca de Bacalar, la falla de Holbox sigue transportando toda esa agua en dirección Sur-Norte hacia la zona de Tulum donde se bifurca hacia la falla de Akumal y continúa hacia arriba hacia los cenotes documentados en Isla Mujeres.

Cuanto más grande es la abertura, más grande es la falla geológica y más cerca de las corrientes del Canal de Yucatán, mayor es el movimiento y el flujo de agua dulce en dirección Sur-Norte. Esta es la razón del gran número de cuevas inundadas en la zona de Tulum, un área y estrato geológico situado en la falla de Holbox y justo al lado del Caribe mexicano.

Estas características hidrogeológicas combinadas con la dinámica diaria del Mar Caribe (las mareas se mueven hacia adentro y hacia afuera en dirección Este-Oeste, de ida y vuelta) hacen que el agua dulce que se mueve a través de las grandes fracturas sea arrastrada también en dirección Este-Oeste-Este, frotando las grietas (cuevas) que hoy conocemos Sistema Sac Actun, Sistema Ox bel Ha, Sistema Koox Baal, por mencionar algunas.

No importa dónde llegue la contaminación al suelo en Yucatán, definitivamente no se quedará ahí. Es comparable a una sustancia inyectada en un sistema cardiovascular, allí se esparce y afecta a todo el cuerpo. De este modo, la contaminación se introduce en todos los ecosistemas de la región y provoca daños contundentes en ellos.

Cada asentamiento o ciudad contamina las aguas subterráneas que corren hacia el Noreste. Una parte de la contaminación se desvía hacia el mar a través de diversos desagües (cuevas de la zona de Tulum), otra parte es absorbida y limpiada por diversos ecosistemas y otra parte corre hacia la siguiente ciudad. Por debajo, la contaminación se refuerza y sale por el otro lado, el mismo procedimiento se repite hasta llegar al extremo Noreste de la Península donde esto llega a su fin y el agua y la contaminación terminan definitivamente en el mar.

Figuras

Figura 1: *Alineación de cenotes y cuerpos de agua que definen la Falla de Holbox. Google Earth. Modificada por los autores.*

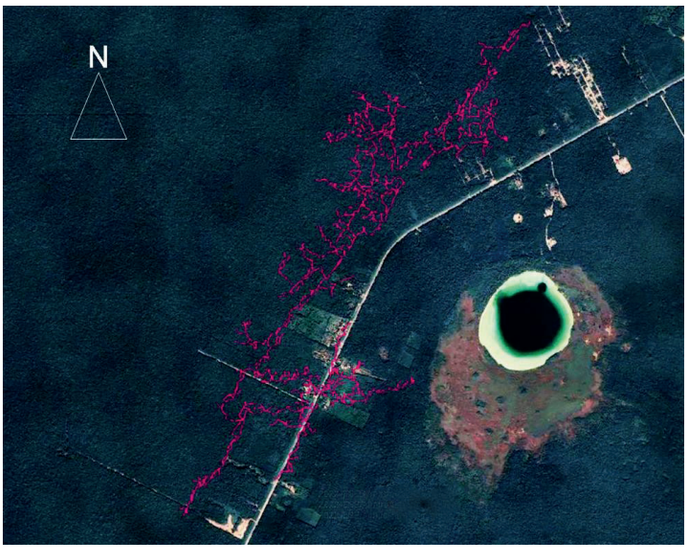

Figura 2: *Orientación Suroeste-Noreste del Sistema Chan Hol. Sur de Tulum. Google Earth. Modificada por los autores.*

Figura 3: *Tinte orgánico comestible. Foto: Dante García.*

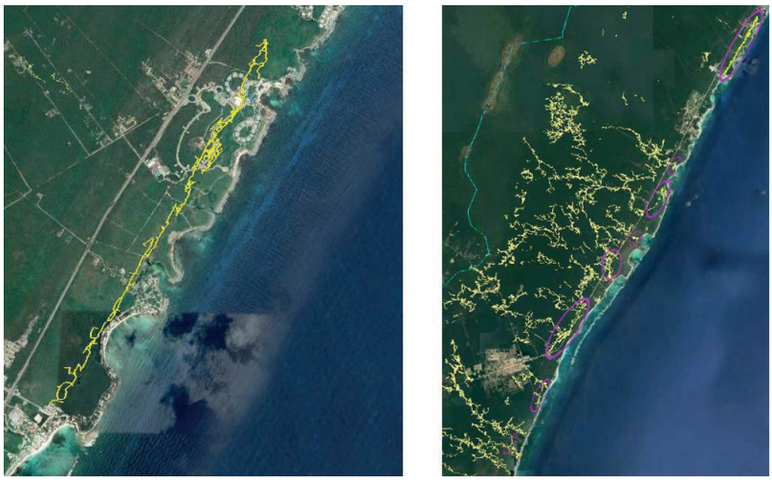

Figura 4: *Replica Suroeste-Noreste del Sistema Murena-Aak Kimin. Norte de Tulum. Google Earth. Modificada por los autores.*

Figura 5: *Metodología empleada para registrar desplazamientos de agua subterránea. Foto: Richard Schmittner.*

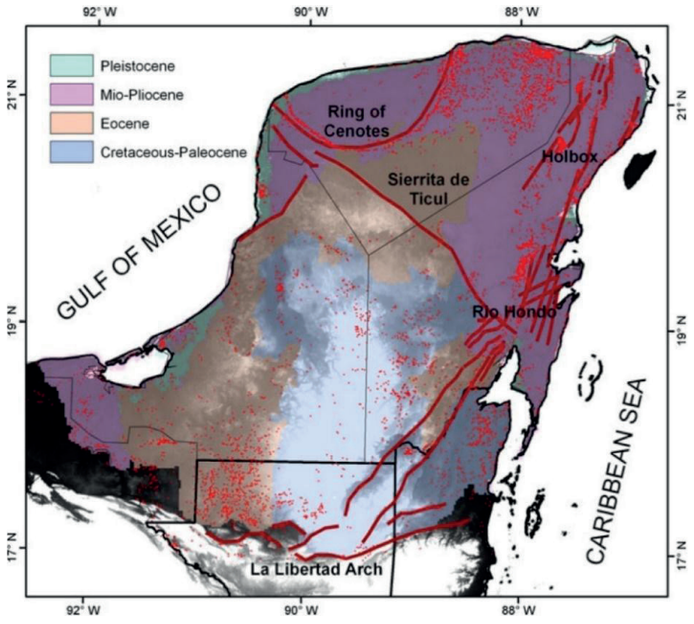

Figura 6: *Principales fallas geológicas de la Península de Yucatán. Bauer-Gottwein et al. 2011:509.*

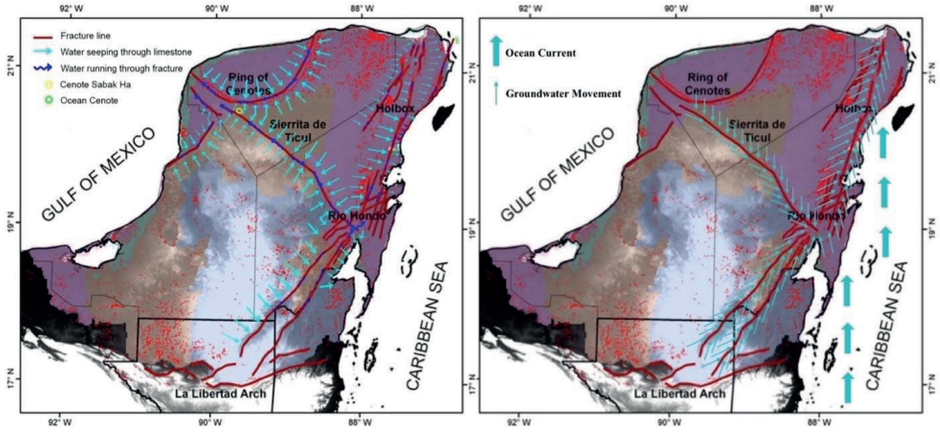

Figura 7: *Confluencia de las precipitaciones pluviales. Bauer-Gottwein et al. 2011:509. Modificada por los autores.*

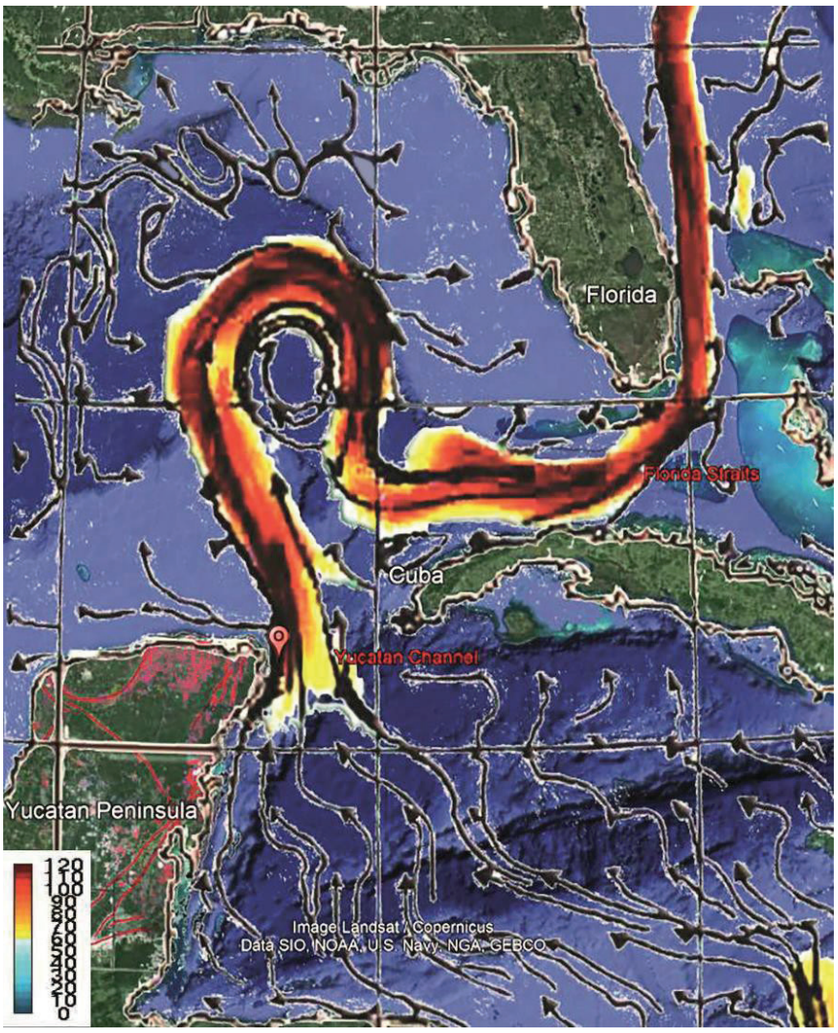

Figura 8: *Principales corrientes del Mar Caribe. Velocidades de las corrientes. Cenotes oceánicos Google Earth. Modificada por los autores.*

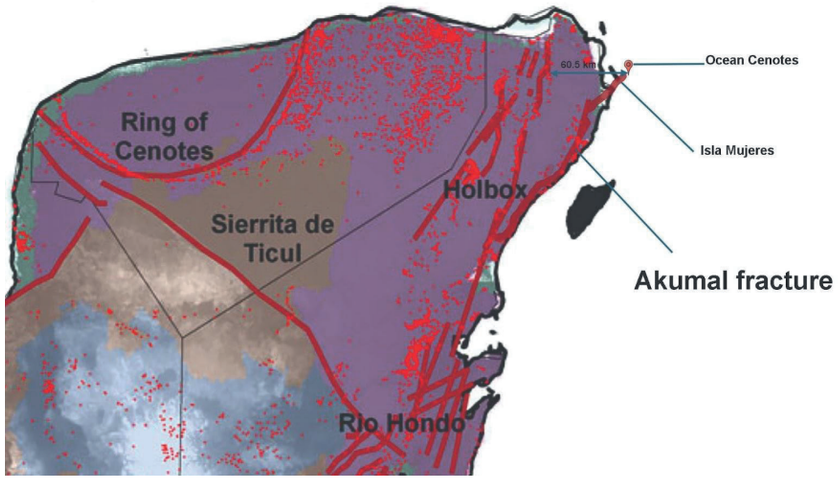

Figura 9:*. Relación entre la Falla de Akumal y la Falla de Holbox. Bauer-Gottwein et al. 2011:509. Modificada por los autores.*

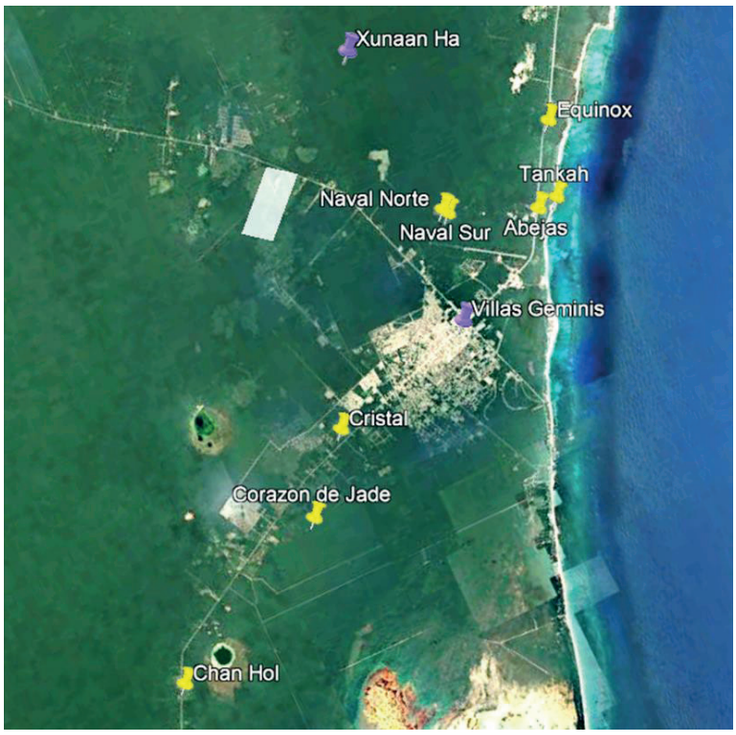

Figura 10: *Proyecto: Rolex Perpetual Planet. Expedición Xunaan Ha. Google Earth y Dra. Patricia Beddows.*

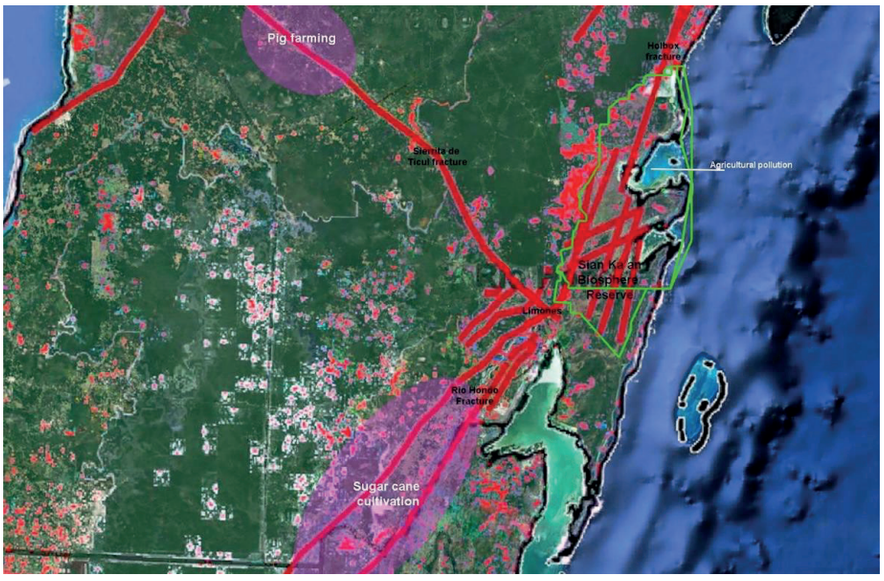

Figura 11: *Relación de la Reserva de la Biosfera de Sian Ka'an y actividades agropecuarias. Google Earth. Modificada por los autores.*

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SYMPOSIA

Symposium on caves in ferruginous rocks

Summary

The symposium on caves in ferruginous rocks is organized around two principal themes. The first aims to discuss the speleogenesis of these peculiar features in light of various models of genesis and development; the second, focusing on the biodiversity of subterranean environments, will provide a comprehensive assessment of distribution patterns using genomics.

Coordinator: Dr. Allan Calux (Karst Applied Research Centre/Brazil)

Speakers (round table Speleogenesis on caves in ferruginous rocks)

Dr. Iuri Brandi (Vale/Brazil)
Lecture: Contributions of the Geotechnical Cave Index (IGC) to understanding the dynamics of “incasão” in ferruginous rock caves

Dr. Enrico Bernard (Universidade Federal de Pernambuco/Brazil)
Lecture: Bats as ecosystem engineers in iron ore caves in the Caraja´s National Forest

Dr. Hazel Barton (University of Alabama/USA)
Lecture: The Role of Chemosynthetic Microorganisms in the Formation of Caves in Ferruginous Rocks

Speakers (round table Biodiversity on caves in ferruginous rocks)

Dr. Santelmo Selmo de Vasconcelos Júnior (Instituto Tecnológico Vale/Brazil)
Lecture: Using genomics to understand biodiversity distribution patterns in ferruginous Brazilian caves

Dr. Leonardo Carreira Trevelin (Instituto Tecnológico Vale/Brazil)
Lecture: How unique are subterranean biological communities in ferruginous caves across the Amazon? Species-area relationships and ecological similarity in the Carajás speleological province.

Symposium on cave paleontology

Summary

The symposium will feature three lectures presenting updates and proposals on important themes for Cave Paleontology (Taxonomy and Paleoecology), with leading experts in each of these fields in Brazil.

Coordinator: Dr. Mário Dantas (Universidade Federal da Bahia (IMS/CAT)/Brazil

Speakers

Dr. Rodrigo Parisi Dutra (Pontifícia Universidade Católica de Minas Gerais/Brazil)
Lecture: A contribuição da Paleontologia de cavernas para a história evolutiva dos Tayassuidae sul-americanos

Dr. André Vieira Araújo (Universidade Federal do Sertão Pernambucano/Brazil)
Lecture: Macacos, cavernas e florestas: os depósitos espeleológicos e a Primatologia Neotropical

Dr. Mário André Trindade Dantas (Universidade Federal da Bahia IMS/CAT/Brazil)
Lecture: Retratos do passado: composição e Paleoecologia da megafauna da Região Intertropical Brasileira

Symposium on chiropterofauna Caves and bats, bats and caves

Summary

Caves and bats, bats and caves" Symposium - There is an intrinsic relationship between caves and bats and, around the world, hundreds of species of bats find their unique or priority shelters in caves. Bats are essential as transporters of organic matter into caves, and thousands of other cave-dwelling species benefit from the bat guano. This guano is also equally important in chemical and physical reactions capable of influencing the formation of minerals, speleothems, and the structure and dynamics of the caves themselves. The relationship between caves and bats needs to be better understood, especially at a time when both caves and their bat populations are suffering from several threats. This symposium will bring together experts from different areas who study the various aspects of the interaction between bats and caves. Aspects of the role of guano in cave chemistry, long-term monitoring experiences with lessons learned, and cave conservation strategies essential for the maintenance of endangered bat species will be addressed. The symposium is structured with two main lectures and a round table, followed by a question-and-answer session.

Coordinator: Dr. Enrico Bernard (Universidade Federal do Pernambuco/Brazil)

Speakers

Dr. Donald McFarlane (Pitzer Professor of Biology, Pitzer and Scripps Colleges/USA)
*Lecture:*The impact of topical bat colonies on caves

Dr. Jon Flander (Bat Conservation International/USA)
Lecture: Designing cave conservation measures for some of the worlds most endangered species of bats

Speakers (round table)

Dr. Enrico Bernard (Universidade Federal de Pernambuco/Brazil)
Lecture: Premises for bat and cave conservation

Dr. Valéria Tavares (Instituto Tecnológico Vale/Brazil)
Lecture: Dissipating the shades and perceiving the nuances in the dark: boosting our perception and solutions to conserve cave bats

Nicola Judy Bail (The University of Adelaide, Zoos Victoria - Coordinator of the Southern Bent-wing Bat National Recovery Team)
Lecture: Long-term monitoring of Southern Bent-wing Bat population size and dynamics at Naracoorte/South Australia.

Symposium on karst geology

Summary

The Karst Geology Symposium is structured as a sequence of six lectures from internationally recognized authors who made significant contributions to the evolution of thought in karst geology. The topics to be discussed include advances in speleogenesis, cave sedimentology, speleothem records, and site examples of karst diversity. This symposium will be a great opportunity for academic researchers, students, cave explorers, company owners, and employees to learn from and interact directly with great researchers in karst geology. Every lecture will be delivered in 35 minutes plus 5 minutes for questions and comments from the audience. In the middle of the session, there will be a 15-minute break for coffee and snacks.

Coordinator: Dr. Lucas Padoan de Sá Godinho

Speakers

Dr. Patricia Kambesis - Western Kentucky University, Bowling Green/USA
Lecture: Cave Form as a Geological Signature: How Lithology and Speleogenetic Mode Shape Subterranean Architecture

Dr. Augusto Auler - Karst Institute/Brazil
Lecture: Brazilian Karst and Speleology

Dr. Philippe Audra- Université Côte d'Azur, Nice/France
Lecture: Hypogene Speleogenesis - Hydrogeology, Cave Pattern and Morphology

Dr. Rachel Bosch- Aecom, Cincinnati/USA
Lecture: Cave Sedimentology: History and Recent Advances

Dr. Nicolás Misailidis Stríkis - Universidade de São Paulo/Brazil
Lecture: Anthropogenic Drought Captured in the Southern American Speleothem Record

Dr. John Gunn - University of Birmingham/UK
Lecture: Contrasts between British Carbonate Karst Areas

Symposium of the Protection and Management of Caves and Karst Environments

Summary

The Symposium on the Protection and Management of Caves and Karst Environments will bring together experts, researchers, and environmental managers in two roundtable discussions, preceded by keynote lectures. One of the lectures will address the current state of speleological legislation in reference countries, while the other will focus on the management and use of karst areas. These activities will explore priority issues for the conservation and sustainable use of these environments. The event will also be an opportunity for the speleological community, both national and international, to interact directly with renowned speakers, fostering enriching dialogue and the sharing of ideas and experiences.

The symposium aims to strengthen the integration between science, public policies, and management, offering a platform for building collaborative networks and advancing global strategies for the conservation and management of karst environments.

Coordinator: Jocy Brandão Cruz (Coordinator of the National Center for Cave Research and Conservation (ICMBio/Cecav), Brazil)

Speakers (Legislation)

Marcelo Marcelino (Director of Biodiversity Research, Assessment, and Monitoring at the Chico Mendes Institute for Biodiversity Conservation (ICMBio/MMA),Brazil)

Dr. Nathalia Uasapud (Geologist, Delegate of the International Union of Speleology for Colombia,Colombia)

Speakers (Management)

Kevin Downey (Cave photographer with a background in geology, film, and photographic sciences from the University of Massachusetts, United States)

Pedro de Castro da Cunha e Menezes (Director of the Department of Protected Areas at the Ministry of the Environment and Climate Change, Brazil)

Ros Fatihah Muhammad (President of the Malaysian Cave and Karst Conservancy, Malaya)

Symposium on subterranean biology

Summary

The symposium aims to provide discussions on the challenges for the conservation of subterranean ecosystems (except bats, discussed in another specific smposium) based on different points of view around the world: researchers, conservation institute, entreperneur and consultancy agency.

Coordinators: Dr. Rafaela Pietrobon (Samarco S.A./ Brazil) and Dr. Diego Bento (CECAV/ICMBio/Brazil)

Speakers

Dr. Stefano Mammola (Water Research Institute/Italy)
Lecture: Five global challenges hindering effective conservation of subterranean ecosystems

Dr. Alberto Sendra (Universidad de Alcala/Spain)
Lecture: Threats and proposals for protection measures in caves in northern Spain

Dr. Pablo Barranco (Universidad de Almeria/Spain)
Lecture: Threats and proposals for protection measures in caves in Southern Spain

Dr. Diego Bento (CECAV/ICMBio/Brazil)
Lecture: Balancing uncertainty and irreplaceability: A governmental perspective on subterranean biodiversity conservation

M. Sc. Xavier Prous (Vale/Brazil)
Lecture: From Rock Exploration to Cave Conservation: Bridging Mining and Conservation Practices to Preserve Cave and Karst Heritage

Dr. Marcus Oliveira (BioEspeleo Consultoria Ambiental/Brazil)
Lecture: Species, Scales and Schedules: How regulatory frameworks and sampling design shape conservation outcomes

Session 01

HISTORY OF SPELEOLOGY, ARTS AND LETTERS

EspeleoArte: a fusão entre arte e espeleologia. Resultados 2023 e perspectivas futuras

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Resumo

No ano de 2023, a cidade de Curitiba sediou o 37º Congresso Brasileiro de Espeleologia (CBE) o qual junto a sua programação apresentou um evento inédito que uniu ciência, arte e conscientização ambiental: o Espeleoarte 2023. Realizado em diversos pontos turísticos e históricos de Curitiba, o evento teve como objetivo principal sensibilizar a sociedade civil sobre a relevância da espeleologia por meio de expressões artísticas diversas. O EspeleoArte 2023 foi um evento inovador que uniu arte e espeleologia mostrando a importância das cavernas e sua preservação. O evento contou com exposições artísticas, palestras científicas e atividades interativas. Este artigo apresenta os resultados obtidos, o impacto na conscientização ambiental e as perspectivas para futuras edições.

Abstract

In 2023, the city of Curitiba hosted the 37th Brazilian Speleology Congress (CBE), which, alongside its program, presented a unique event that brought together science, art, and environmental awareness: Espeleoarte 2023. Held at various tourist and historical sites in Curitiba, the main goal of the event was to raise public awareness about the relevance of speleology through diverse artistic expressions. Espeleoarte 2023 was an innovative event that combined art and speleology to highlight the importance of caves and their preservation. The event featured art exhibitions, scientific lectures, and interactive activities. This article presents the results achieved, the impact on environmental awareness, and the perspectives for future editions.

Resumen

En 2023, la ville de Curitiba a accueilli le 37e Congrès Brésilien de Spéléologie (CBE), qui, en plus de son programme, a présenté un événement inédit réunissant science, art et sensibilisation environnementale : l'Espeleoarte 2023. Organisé dans divers sites touristiques et historiques de Curitiba, l'objectif principal de l'événement était de sensibiliser la société à la pertinence de la spéléologie à travers diverses expressions artistiques. L'Espeleoarte 2023 a été un événement innovant qui a combiné art et spéléologie pour mettre en avant l'importance des grottes et leur préservation. L'événement a présenté des expositions artistiques, des conférences scientifiques et des activités interactives. Cet article présente les résultats obtenus, l'impact sur la sensibilisation environnementale et les perspectives pour les éditions futures.

1. Introdução

As diversas expressões artísticas, como a pintura, música, teatro, dança, fotografia e outras, desempenham um papel crucial na disseminação de informações para a sociedade. A arte tem o poder de comunicar ideias e emoções de maneira acessível e envolvente, o que facilita a compreensão de temas complexos. Ela atrai diferentes públicos e pode abordar questões sociais, culturais, ambientais e científicas de forma criativa, impactante e memorável. Além disso, a arte permite que as informações sejam apresentadas de forma visual e sensorial, tornando o aprendizado mais eficaz e promovendo a reflexão crítica. Dessa forma, a arte não só educa, mas também inspira e motiva ações transformadoras na sociedade.

A espeleologia é a ciência que estuda cavernas e seus ecossistemas, sendo um campo de grande importância ambiental. Entretanto, sua relevância muitas vezes passa despercebida pela sociedade. O EspeleoArte surgiu com o propósito de aproximar a arte da ciência, utilizando expressões artísticas para tornar o conhecimento acessível e inspirador.

O EspeleoArte foi uma inovação que o 37º Congresso Brasileiro de Espeleologia apresentou em nível nacional, e contou com o apoio da Sociedade Brasileira de Espeleologia (SBE), Centro Nacional de Pesquisa e Conservação de Cavernas (CECAV), Prefeitura Municipal de Curitiba, Fundação Cultural de Curitiba e Secretaria de Estado da Cultura do Paraná

O referido evento teve por objetivo expandir as fronteiras do Congresso, visto já ser consagrado o entendimento do fundamental papel das artes na sociedade como um veículo sensibilizador, por meio da conexão em nível sutil e vibracional que ela cria, entre o produto do artista e o apreciador.

O Espeleoarte 2023 reuniu artistas, cientistas, ambientalistas e entusiastas das cavernas em uma programação rica e imersiva. O evento contou com exposições de pinturas, fotografias, esculturas e instalações multimídia inspiradas no mundo subterrâneo. As obras destacaram a beleza das cavernas, suas formações geológicas únicas e a biodiversidade pouco conhecida que habita esses ecossistemas frágeis.

2. Materiais e Métodos

2.1. Criação da identidade visual (logomarca)

A relação entre a arte e as cavernas remonta aos primórdios da humanidade. Os primeiros registros artísticos conhecidos são as pinturas rupestres, encontradas em cavernas ao redor do mundo, como em Lascaux, na França, e Altamira, na Espanha. Essas manifestações artísticas, datadas de milhares de anos atrás, revelam a estreita conexão entre os seres humanos e o mundo subterrâneo. Utilizando pigmentos naturais, os homens das cavernas retratavam cenas de caça, animais e figuras abstratas, expressando não apenas sua visão de mundo, mas também sua relação com o meio ambiente. Sendo assim a ideia de retratar e identificar o EspeleoArte através de pinturas rupestres locais e/ou nacionais podendo assim interagir com a região ao qual o evento seja realizado. (Figura – 1)

Figura 1: *Logo EspeleoArte 2023.*

Antes das exposições, os artistas foram convidados a conhecer uma caverna, com o objetivo de capturar imagens e ideias de suas formações rochosas e da atmosfera singular que as rodeia.(Figura 2)

Figura 2: *Artistas reunidos em uma caverna para imersão artística, espeleológica.*

Em sequência deu se início a diversas reuniões e visitas para escolha dos diversos locais de exposição e experiencias, levando sempre em consideração as obras dos artistas (pinturas, esculturas, instalações), bem como, painéis, suportes para exposições e Iluminação adequada para destacar as obras.

Para as atividades interativas, foram disponibilizados equipamentos audiovisuais (projetores, telas, microfones), materiais de apresentação (slides, folhetos, cartazes), bem como, materiais para atividades práticas (kits de espeleologia, materiais recicláveis).

Os material de divulgação, tiveram uma crucial importância na difusão, atração e interação com o público, a produção de um mapa da cidade de Curitiba com os pontos de exposição do EspeleoArte, bem como a transmissão áudio visual em coletivos públicos da cidade foram fundamentais para atingir toda a comunidade. A produção de Flyers, posters e banners para promover o evento, a criação de uma página de redes sociais para atualizações e informações, bem como a disponibilização de materiais educativos sobre espeleologia e conservação ambiental.

A participação de voluntários, bem como os artistas foram de total importância para a realização do evento.

Alguns métodos para a Realização do Evento, foram fundamentais, tais como:

Planejamento Prévio:

Definição das datas, locais e duração das exposições, a concepção de parcerias com instituições de ensino, ONGs e associações espeleológicas. A busca por constituir uma programação abrangente, interativa e diversificada.

Captação de Recursos:

A busca por patrocínios e apoios financeiros, entre outras formas de arrecadação.

Divulgação:

Utilizar redes sociais, imprensa local e comunidades online para promover o evento, o envio de convites para escolas, universidades e grupos de interesse, da mesma forma que líderes comunitários, entidades governamentais e representantes políticos.

Após o evento, coletar feedback de participantes e colaboradores

Avaliar o impacto do evento em relação aos objetivos propostos (conscientização, participação, etc.)

Essa abordagem abrangente pode contribuir para o sucesso do evento, integrando de forma eficaz arte, ciência e educação ambiental.

3. Resultados

O EspeleoArte 2023 recebeu um público de aproximadamente meio milhão de visitantes, incluindo estudantes, pesquisadores e entusiastas da arte e ciência. A exposição sensorial imersiva como a caverna artificial no Museu de História Natural do Paraná, com 85% dos participantes classificando-as como “excelentes”.

As exposições e os workshops interativos também obtiveram alta participação, com mais de milhares de pessoas engajadas em atividades como pintura inspirada em cavernas, modelagem de formações geológicas e fotografia espeleológica. Além disso, a experiência de realidade virtual, que permitiu a exploração de cavernas remotas, foi considerada inovadora e impactante por 92% dos entrevistados.

O evento também teve ampla repercussão nas redes sociais e na mídia especializada. Foram registrados mais de 10.000 compartilhamentos de conteúdos relacionados ao EspeleoArte e uma audiência digital de cerca de 100.000 pessoas acompanhando transmissões ao vivo e postagens sobre as atrações. A cobertura da imprensa incluiu matérias em veículos de grande circulação e entrevistas com especialistas e artistas participantes.

Um dos impactos mais significativos foi a conscientização sobre a preservação das cavernas. Antes do evento, apenas 10% dos entrevis-

tados afirmaram ter conhecimento sobre a importância da espeleologia e os riscos ambientais enfrentados pelas cavernas. Após a participação no EspeleoArte, esse número subiu para cerca de 80%, demonstrando o sucesso da abordagem educativa e artística do evento.

Os resultados demonstram que a abordagem interdisciplinar do EspeleoArte foi eficaz na disseminação do conhecimento espeleológico. A arte mostrou-se uma ferramenta poderosa para a sensibilização ambiental, permitindo que um público diverso se conectasse com a temática das cavernas de forma emocional e intelectual. Entretanto, desafios como financiamento e infraestrutura foram identificados e deverão ser trabalhados para futuras edições.

Figura 3: *Mapa de localização e os diversos espaços expositivos do EspeleoArte 2023.*

4. Discussão

Os resultados demonstram que a abordagem interdisciplinar do EspeleoArte foi eficaz na disseminação do conhecimento espeleológico. A arte mostrou-se uma ferramenta poderosa para a sensibilização ambiental, permitindo que um público diverso se conectasse com a temática das cavernas de forma emocional e intelectual. Entretanto, desafios como financiamento e infraestrutura foram identificados e deverão ser trabalhados para futuras edições.

Além disso, os avanços obtidos pelo EspeleoArte 2023 abriram espaço para sua apresentação no Congresso Internacional de Espeleologia, que será realizado em julho de 2025, em Belo Horizonte. Esse evento representará uma oportunidade única para divulgar os impactos e as metodologias do EspeleoArte para a comunidade científica e artística global. Espera-se que essa participação fortaleça parcerias internacionais, amplie o reconhecimento do evento e inspire a implementação de projetos semelhantes em outras regiões do mundo. A presença do EspeleoArte no congresso reforça seu papel como iniciativa inovadora na interface entre arte e ciência, consolidando-o como um modelo de sensibilização ambiental por meio da expressão artística.

5. Conclusão

O EspeleoArte 2023 cumpriu seu objetivo de promover a espeleologia por meio da arte, tornando-se um marco na sensibilização sobre a importância das cavernas. O evento não apenas despertou o interesse do público pela ciência espeleológica, mas também fomentou um diálogo entre arte, meio ambiente e preservação, incentivando novas abordagens educativas e culturais.

Com base nos resultados obtidos, pretende-se expandir o evento para outras regiões, tornando-o itinerante e acessível a um público ainda mais amplo. Além disso, futuras edições buscarão incorporar novas tecnologias interativas, como inteligência artificial e realidade aumentada, para enriquecer a experiência do público e ampliar o impacto da conscientização ambiental.

Um dos grandes marcos do EspeleoArte será sua edição no Congresso Internacional de Espeleologia 2025, que oferecerá uma vitrine global para o evento. A participação nesse congresso representará uma oportunidade para demonstrar a relevância da fusão entre arte e ciência no campo da espeleologia, promovendo o intercâmbio de experiências e fortalecendo colaborações internacionais. Com essa visibilidade, o EspeleoArte poderá expandir sua atuação para além das fronteiras nacionais, consolidando-se como uma iniciativa de referência mundial na preservação e valorização das cavernas por meio da arte. Por fim, espera-se que o evento continue a evoluir como um espaço de expressão, pesquisa e conservação, promovendo a sensibilização ambiental em novas perspectivas e contextos globais.

Agradecimentos

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El uso de las cuevas en Puerto Rico

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Abstract

Caves have been used in Puerto Rico for many purposes. We can separate this uses in two periods: before and after colonization. Previous colonization Puerto Rico's native Indian used cave as a sacred place, evidence on caves walls evidence it. After colonization cave had been used as shelter for hurricanes, pseudo-church, refuge for *cimarrón* slave, clandestine rum destiliing and Social and Night Clubs.

Resumen

Las cuevas han sido utilizadas en Puerto Rico para varios propósitos. Podemos separar sus usos en dos periodos: antes y después de la colonización. Previo a la colonización los indios nativos de Puerto Rico usaban las cuevas como lugar sagrado, evidencia de esto está en las paredes de las cuevas. Después de la colonización las cuevas han sido utilizadas como refugio para huracanes, pseudo-iglesias, refugios para esclavos cimarrones, destilado clandestino de ron y clubes nocturnos y sociales.

Las cuevas han tenido una gran variedad de usos a través de la historia. Desde lugares mitológicos/religiosos hasta el desarrollo de actividades comerciales. "En todas las regiones del planeta donde hay cuevas (particularmente en las formaciones sedimentarias de topografía cársica) es frecuente encontrar evidencia del uso de estas actividades como sitios de vivienda y otros fines culturales." (DÁVILA, 1999). En Puerto Rico (P.R.) el uso de las cuevas lo podemos separar en dos periodos: pre-colonización y post colonización. Previo a la llegada de España a la isla de Puerto Rico el 19 de noviembre de 1493, nuestros primeros pobladores, los indígenas, utilizaban las cuevas como lugar sagrado (Dávila, 1991). Evidencia de esto es la concentración de arte rupestre que se ha identificado en el área centro-norte de la Isla en la región caliza. Estas manifestaciones de arte rupestre abarcan pictografías (pinturas indígenas), petroglifos (grabados en rocas) y pictoglifos (mezcla de grabado y pintura) (DÁVILA, 1991; MARTÍNEZ, 1994; MARTÍNEZ 1995; DÁVILA, 1999; PENCHI, 2002; del VALLE, 2007; SAMSON *et al.*, 2013; ACOSTA & RODRÍGUEZ, 2022). Muchos investigadores coinciden en que estas manifestaciones de arte rupestre corresponden a las manifestaciones culturales que se dan entre los años 600 d.C. y 1500 d.C. (PÉREZ, 2010). Estas muestras de arte rupestre abarcan representaciones antropomorfas (humanas), zoomorfas (animales), antropozoomorfas (mezclan rasgos humanos y animales) y fitomorfas (semejan flora). También se han encontrado formas geométricas variadas y trazos que han sido clasificados como "abstractos" por no conocerse su significado. Todas estas representaciones tienen un carácter simbólico. Este simbolismo tiene sus motivaciones en la práctica y ceremonias de alto contenido religioso como lo eran los areytos y las ceremonias secretas de los bohiques (MARTÍNEZ, 1995). Las representaciones antropo-zoomorfas deben tener relación estrecha con los conceptos de la divinidad en la religión indígena (MARTÍNEZ, 1995). Aunque cargados de simbolismo estas representaciones de arte rupestre no son narraciones de eventos como se puede interpretar en pictografías en otras cuevas del mundo. En la representación zoomorfa destaca la fauna autóctona: ranas, múcaros, arácnidos, etc., mientras que en la representación antropomorfa abundan los rostros "barbados", los cuales se estipula que pudiesen ser representaciones de aquellas personas blancas y con barbas que "trajeron la civilización al primitivo hombre del Nuevo Mundo" (MARTÍNEZ, 1995).

Adicionalmente a las manifestaciones de arte rupestre, también se ha encontrado cenizas, bocas de buruquenas, conchas marinas y artefactos de piedra trabajada, lo que demuestra que nuestras cuevas habían sido habitadas por nuestros indios en tiempos prehistóricos (DÁVILA, 1991). Entre las cuevas con mayor evidencia y que más se han estudiado destacan Cueva del Indio (Arecibo), Cueva María Soto (Arecibo), Cueva Maeson (Lares), Cueva de los Gemelos (Morovis), Cueva del Chimino (Florida) y Cueva Maldita (Vega Baja).

Luego de 1493, periodo llamado Postcolonización, las cuevas tomaron otro desempeño en la nueva sociedad que se iba formando en la Isla. Los diferentes sucesos históricos que se iban dando en el país fueron dictaminando nuevos usos a las cuevas de la Isla. Durante los años de conquista española y la esclavitud (1493 – 1873) las cuevas sirvieron de refugio a los indios en eventos de tormentas y huracanes (DÁVILA, 1991; Domínguez Cristóbal, 2007; Torres, 2018) y negros esclavos que huían de sus amos (COLL Y TOSTE, 1924; GONCEBAT, 1999; TORRES, 2018). Estos fugitivos eran conocidos como *cimarrones*, los cuales huían del maltrato y esclavitud al que eran sometidos y se internaban en los montes de la isla donde se alimentaban de los frutos silvestres que pudieran conseguir y se albergaban en las cuevas del interior de la isla (COLL Y TOSTE, 1924). Domínguez Cristóbal (2007) también señala que los taínos usaban las cuevas como depósitos de sus reliquias y tesoros religiosos y culturales ante la conquista militar española. Cuando la esclavitud fue abolida en Puerto Rico en 1873 poco a poco estos cimarrones dejaron el monte y regresaban a las zonas pobladas. La Cueva María de la Cruz (dada a conocer en 1948) en Loíza es uno de los mejores ejemplos documentado de una cueva usada por esclavos cimarrones (CALLEJEANDOPR, 2014; TORRES, 2018).

Con el pasar de los años y con el incremento poblacional de la isla, las cuevas tomaron un nuevo desempeño y para muchos campesinos fueron refugios durante los huracanes que azotaban a la isla. Así lo narra don Juan Rosado Hernández, vecino del barrio Judea en Utuado, al decir "que su papá le contó que durante el Huracán San Ciprián (septiembre de 1932) lo pasó en una cueva cerca de su casa" (CORTÉS ROSADO, 2013). Así mismo PASTOR *et al.* (1977) nos narra como don Agrapino (un hacendado) y sus agregados pasaron una tormenta en una cueva cerca de sus casas, ya que el viento tan fuerte que soplaba arrasó con sus viviendas y la hacienda de don Agrapino, donde habían ido a refugiarse. Permanecieron en la cueva hasta la mañana del siguiente día cuando la lluvia y el viento habían terminado.

Ovidio (1999) informa que para el 1936 el Dr. Irving Rouse, de la Universidad de Yale, realizó excavaciones en la cueva Carmona, en Canóvanas, pero la excavación fue limitada ya que la cueva estaba habitada por un individuo.

En la década de 1950, durante la revuelta nacionalista, las cuevas de Aguas Buenas fueron el escondite secreto de Pedro Albizu Campos (PÉREZ, 1994); También para los 1860's estas cuevas fueron el hogar del "mago de Aguas Buenas"; curandero que, entre otras cosas, predijo la caída del trono de la reina Isabel II de España (COLL Y TOSTE, 1925; PÉREZ, 1994).

El noticiero de WAPA televisión documenta en el 2017 que don Alfredo lleva varios años viviendo en una cueva en Manatí. En las imágenes se puede apreciar a don Alfredo sentado en su silla, una cama, víveres y un perchero con ganchos de ropa (WAPAtv, 2017).

En tiempos contemporáneos se dice de una ermitaña que utilizaba la Cueva María de la Cruz en Loíza como su vivienda (CALLEJEANDO, 2014).

Una comunicación personal con Marcelino Fuentes (2015), del pueblo de Lares, nos informa que en ocasiones cuando la iglesia de un poblado fue afectada por alguno de estos fenómenos naturales las cuevas eran usadas como lugar de congregación donde se reunían los feligreses a llevar a cabo su servicio religioso.

La Revolución Industrial y sus avances en tecnología provocaron una agricultura intensiva. Además el crecimiento poblacional, el agotamiento de las tierras disponibles y la ampliación y diversificación de cosechas puso a los agricultores a buscar la manera de incrementar su producción en tierras ya desgastadas. Las propiedades del guano habían pasado desapercibidas hasta que en 1804 el naturalista Alexander von Humboldt se interesó por su naturaleza y recolectó muestras para su estudio y análisis, que envió a los laboratorios de Francia (CERONI, 2012). Los resultados de los estudios hicieron evidentes sus propiedades químicas como fertilizante agrícola por su alto contenido en nitrógeno y fósforo. Los resultados tuvieron una rápida difusión y la demanda de guano por parte de los países europeos como Inglaterra, Holanda, Alemania y Francia no se hizo esperar. Ante la demanda y la competencia económica, España realiza tres expediciones oficiales entre 1856 y 1883, a la isla de Mona para evaluar y examinar sus abastos de guano. Es así como en la década de 1870 España otorga la concesión oficial para la explotación del guano, generando una próspera industria que abarcó desde 1877 – 1927. Se calcula que en estos 50 años se extrajeron aproximadamente (solo de isla Mona) unas 147,903 toneladas métricas de guano (FRANK, 1998; WADSWORTH, 1973).

La extracción de guano también se dio en cuevas del interior de la isla de Puerto Rico, así se informa de cueva del Negro en Ciales (AYES-SUAREZ & OTERO-LÓPEZ, 1986) y para cueva Abono en Utuado (ACOSTA-COLÓN & RODRÍGUEZ-RAMOS, 2022).

Puerto Rico es conocida como "la Capital Mundial del Ron", por la gran variedad de rones que se producen en la isla: más de 20 marcas distintas con sobre 66 variedades (HERNÁNDEZ, 2023). Entre ellos destaca uno que por siglos ha sido confeccionado de manera artesanal y denominado por el gobierno como ilegal; conocido como ron caña, pitorro, pitrinche, pitriche, cañita, lágrima de monte, romo, traspaso, entre otros (TRELLES, 2013; RÍOS, 2015; HERNÁNDEZ, 2023), es un espíritu destilado que proviene de la caña de azúcar. Los orígenes del ron se remontan al siglo 17 y desde entonces ha tenido una larga historia de prohibición. En una serie de ensayos sobre la historia del ron caña en Puerto Rico, Luis Trelles (2014) informa que "la venta y producción del ron estaba prohibida por las autoridades españolas. Antes del siglo 19, todo el ron que se producía en la Isla era clandestino." (RÍOS, 2015) A principios del siglo 20 y hasta 2007 los impuestos del ron eran el mayor ingreso del gobierno (TRELLES, 2014; HERNÁNDEZ, 2023). Sin embargo, con la prohibición federal del alcohol en el 1920 regresó el pitorro al campo, a los alambiques caseros y a la clandestinidad (TRELLES 2014). Así las cuevas toman un nuevo rol en la historia cultural de Puerto Rico. El difícil acceso a las cuevas en Puerto Rico y lo monte adentro que se ubican las mismas contribuyó a la creación de destilerías clandestinas (alambiques), donde nuestros campesinos hacían el ron y guarecían su maquinaria de la ley (TRELLES, 2013). Aún cuando la prohibición terminó en 1933, los productores de pitorro prefirieron permanecer en el anonimato y clandestinaje. El pitorro es ilegal porque no paga impuestos al gobierno (al Departamento de Hacienda) y no cumple con los requisitos de salubridad y controles de calidad que impone el Departamento de Salud a las destilerías (RÍOS, 2015). De esta manera las cuevas resguardan estas destilerías lejos del ojo de los agentes del orden público. Aún hay cuevas con alambiques activos y en otras se ven los restos de drones, tanques y serpentinas de alambiques clandestinos que han sido abandonados.

El uso comercial de las cuevas en Puerto Rico se ha podido registrar a finales del 1950's. (SANTIAGO, 1968). Para la época de 1960 a 1990 existían en Puerto Rico dos cuevas de uso comercial que eran usadas como club nocturno o club social. Estas eran Cueva Pajita (en Lares) y la Cueva de Camuy (en Camuy). Cueva Pajita abrió operaciones en el 1958 (SANTIAGO, 1968). El interior de estas cuevas estaba habilitado con barra, mesas, sillas y pista de baile (MARTI, J., ????). Gran parte de las ocasiones había música en vivo. Según se desprende de la información de GURNEE (1988) la Cueva de Camuy operaba desde el 1981. Operaba en un horario dual; por el día la Cueva de Camuy ofrecía un pequeño recorrido por la cavidad, que está abierta en ambos extremos, donde ofrecían información sobre los murciélagos, las estalactitas, lo que es una cueva y narraban dos leyendas de la cueva: la primera decía que a medianoche se oían doce campanadas en la cueva y la segunda que en las noches de poca luna se veía entrar una yunta de bueyes sin cabeza que desaparecían antes de salir por el otro extremo de la cueva (memorias del autor). En las afueras de la cueva había piscinas, área para cabalgar en poni y pista para go-karts y fourtrack. En la noche la cueva se convertía en centro de baile, tan reciente como en 2010 celebraron un party de música electrónica (ra.co, 2010). En la actualidad ambas cuevas están cerradas y en desuso; quedando como recuerdos de los inicios del espeleoturismo en Puerto Rico.

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To what extent could speleology become intangible heritage for humanity with UNESCO?

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Abstract

After defining caving and speleology, both science and sport, we will see their cultural aspect, their origin and the universal values on which they are based and those they convey.
Originating in Europe, caving is no less present in the form of ancestral practices motivated by cosmogony but also by the daily life of the first peoples of the entire planet. Paradoxically, modern forms, which originated in learned societies and then groups of sporting adventurers, date back only a little more than a century and a half, following Western and Eastern sketches from the 17th century. The colonization of territories was sometimes accompanied by a «colonial» practice of caving.An NGO like the International Union of Speleology has been proving, for 60 years, by the federation of all these karst and non-karst nations, that caving is more than anything one expects, that is to say a real philosophical culture through its fraternal values, making it a world intangible and cultural heritage worthy of consideration by UNESCO.

Résumé

Après avoir défini la spéléologie, à la fois science et sport, nous verrons son aspect culturel, son origine et les valeurs universelles sur lesquelles elle s'appuie et celles qu'elle véhicule.Issue de l'Europe, la spéléologie n'en est pas moins présente sous forme de pratiques ancestrales motivées par la cosmogonie mais aussi par la vie quotidienne des peuples premiers de toute la planète. Paradoxalement, les formes modernes, issues des sociétés savantes puis des groupes d'aventuriers sportifs ne remontent qu'à un peu plus d'un siècle et demi, suivant des ébauches occidentales comme orientales dès le 17ème siècle. La colonisation des territoires s'est parfois accompagnée d'une pratique « coloniale » de la spéléologie. Une ONG comme l'Union Internationale de Spéléologie prouve par la fédération depuis 60 ans de toutes ces nations karstiques ou non que la spéléologie est plus que tout ce à quoi on s'attend, c'est à dire une véritable culture philosophique à travers ses valeurs confraternelles faisant d'elle un patrimoine immatériel et culturel mondial digne d'être pris en considération par l'UNESCO.

1. Introduction: what is speleology?

Caving involves visiting underground cavities, whatever your motivation. The emphasis is on exploration (discovery), accompanied by observation and planning. Caving is most often carried out in karst, but also in any rock or material containing voids. According to NADJA ZUPAN HAJNA (2021), President of the Union Internationale de Spéléologie, cavers explore, understand and protect an environment on behalf of society. Speleologists of the world over form a community, drawn from the clubs and groups of specialized or mountain federations. They are represented by the Union Internationale de Spéléologie (UIS), based in Slovenia, at Postojna. Some sixty countries are members of this NGO, which is used to working with UNESCO to classify sites and caves, geoparks or for flagship actions such as the International Year of Caves and Karst (IYCK) in 2021-2022. The UIS is currently supporting a project to establish an International Day of Caves and Karst on September 13.

2. Who is involved in the world of caving?

The caving community is made up of ordinary citizens who devote their time to discovering caves. In the truest sense of the word, cave exploration is still widespread throughout the world, given the planet's wealth of unknown caves - an eighth continent, some would say. Men and women (CHIROL, 2021) unite their efforts, courage and ingenuity to penetrate the mysteries of the underground, some of them simply walking in the footsteps of site inventors (Fig.1). Since prehistoric times, our ancestors have explored the world of caves, obeying primary motivations of survival or celebration. According to LE QUELLEC (2022), cave art is a multi-millennial expression of a conception of the primordial emergence of life from the interior of the Earth. Despite all the superstitions and ancestral legends, humans have always retained this curiosity, this instinct to explore. Vernacular cave practices are widespread throughout the world. Communities have formed around a practice that may be multifaceted, but is embodied in values and traditions. Cavers are often looked upon by their fellow citizens as originals, usually with kindness, but sometimes as people apart: they have a singular identity. This is due to the a priori hostile environment in which they evolve, which immediately frightens humans (cold, darkness, emptiness, humidity, beasts, etc.). Unlike the mountain, which easily attracts neophytes, with the development of hiking, the underground mountain is not very popular, apart from show-caves, another means of popularizing underground tourism throughout the world, thanks to the ISCA since 1990. Potholing is also practised by private citizens, guiding professionals and scientific researchers. What's remarkable is that this whole cave world rubs shoulders, frequents, respects and collaborates, with beginners finding themselves in the company of the elite on one occasion or another. The fraternity is real. The pedagogy of the Ecole Française de Spéléologie is well established, and its methods and manuals have been used around the world.

Figure 1: *Women's caving gathering at El Moncada near Vinales with the Cuban Caving Society in 2018. SEC.*

3. How speleological practices originated

We have to go back to the Pleistocene or even earlier to find the origin of human incursions into the depths of the Earth (sometimes accidentally!). There are a number of reasons for this: protection (habitats of course usually remain at the entrances), curiosity (as we've seen, the celebration of myths about origins) and the need for water. Many other uses of caves have made our fellow creatures explorers before their time, in historical times, the essence of which can be found in SHAW (1994) and GAUCHON (1997). What's interesting for our discipline is to follow its evolution in parallel with the progress and evolution of human societies. No continent escapes this development. Convergences are driven by the very nature of the human phenomenon, by the circulation of information, writings and, above all, books throughout Europe. But China, as we know, has had its pioneers since Antiquity, eventually providing us with one of the most extraordinary cave travellers, Xu Xiake, around the middle of the 17th century (MAIRE, 1993). A slightly more modest equivalent can be found at the same time in a little-known karst region of the southern Jura in Ain (France). Samuel Guichenon inventoried these legendary underground curiosities (GUICHENON, 1650). It was during this seventeenth century that a number of works attempting to explain the underground world flourished: cf Kircher, Valvasor, following on from the previous generations of da Vinci Palissy, and so on. It was on these published foundations, based on the science of the ancients or on new experiments, that the seeds of scholarly but still field-based speleology germinated, with experiments such as Dumolin's in 1739 in Saône-et-Loire (BARRIQUAND, 2015) or, better still, the monumental unpublished work that Stephan Kempe and Joannes Mattes are in the process of reviving, I'm referring to the unique manuscript recounting the journeys commissioned by Emperor Francis in Austria-Hungary to study the karsts and caves of Central Europe thanks to mathematician Anton Nagel before 1750 (Fig.2). We've leapt forward a century since Xu Xiake, and we're about to leap back again to pay homage to SCHMIDL (1854), Martel's father of speleology. Not that nothing happened between these crucial periods!

For centuries now, caves have been mapped (BUONDELMONTI, 1415), as did Georg AGRICOLA (1546) and the Santa Rosalia cave in Sicily, topographed around 1627. Here's a key element of underground exploration, topography, which must be carried out first. A long tradition, from rudimentary surveying instruments to theodolites to disto x and beyond... Caving has many specialties in its panoply. Tourist caves really took off in the early 19th century, spreading a better understanding of the world below. The nineteenth century confirmed the growth of the discipline begun in the Age of Enlightenment, a period of learned societies prefiguring the great parent societies of speleology (geology, archaeology, entomology, botany, paleontology, etc.).

But this didn't prevent caving from having a very independent spirit, driven by the individual initiatives of workers, priests, miners and pharmacists, who made their mark in their villages and mountain ranges, even before the term "speleology" was coined by prehistorian Emile Rivière (1890), and above all before Edouard-Alfred Martel's founding act in France at the Bramabiau cave (Gard) in 1888. The fraternity of thinkers in the discipline was fostered by the development of postal services, the spread of the written word and access to far-flung travel. They sometimes explored together, publishing in the international journal Spelunca set up by Martel. At a time when the German language was an international scientific language, caving was certainly bringing countries closer together, ignoring political problems, as speleology took this scientific turn, but the mixing of social classes was also possible here, as Martel worked with peasants and workers. Even in the service of the expedition leader, everyone sweated, soiled their clothes and suffered to reveal this ignored world. Long before

1900, the first treatises on speleology (Austria, UK, France, USA), the first articles in the Alpine Club yearbook, the first advertisements for karst regions accessible by rail and the first nature protection measures (parks and sites) were published. The first real caving societies were founded in Switzerland (1860), Austria (1879), Italy (1883) and France (1895). The vocabulary of karst was, not without some debate, adopted worldwide by the Slovenian Cvijic (1890).

The first technical manuals were published at the beginning of the 20th century in Italy (1906), France (1937), the USA, etc. Links had already been forged in the 19th century, with numerous congresses of learned societies attracting large numbers of people, as did the Universal Exhibitions for the general public. Globalization was underway. The first real caving congresses were on their way, and in France Associations under the 1901 law were flourishing.

In 1927, 70 speleologists from Central Europe met in Hungary. The Spéléo Club de France (Montpellier, 1930), which became the Société Spéléologique de France in 1936 (forerunner of the French federation), held its congress in 1939 in Mazamet (Tarn). Nowadays, various groupings of large world regions organize congresses in Asia, Latin America, Europe (Fig.3) or even Central Europe (Balkans). Congresses are sometimes solemn, but they are also popular occasions for bringing together practitioners and their friends, making these privileged moments of togetherness even more convivial, such as the French "Le Caussenard", a successful annual congress in Occitania. The festive spirit of these great kermesses crystallizes the spirit of caving, even outside its "playground".

The Italians, whose first national convention was held in 1933 in Trieste with 58 groups, beat all attendance records, as in Casola where over 2200 people were counted after 2010. The NSS Conventions in the USA are great moments...

A caving convention is characterized by multidisciplinarity, mixing different practices, selling specialized "gear" which, 50 years ago, was only available there (no or few stores). It's worth remembering that ingenious DIY cavers created their equipment in the 1960s. Industrial production didn't begin until the 1970s in France. Prior to rope access techniques (SRT), people made their own aluminum ladders (in clubs) after de Joly made them available in France in the 1930s. These flexible ladders were produced by the Germans and Italians in the 1920s. Groupe Vulcain of Lyon manufactured and sold a complete topo box in the 1970s and beyond. We've seen how important these topos are, as explorers take their dates from them.

A caving convention also means books, photos, works of art, films and lectures. Catering is of paramount importance, as is the bar. This is also what caving conviviality is all about, with its obstacle-clearing, pallet-course and other events, competition not having been adopted in France in 1992. A good-natured spirit reigns among the camping tents, reminiscent of the scouting to which caving owes so much from the first half of the 20th century. The tasting of Casola's collective potion, cooked in a large cauldron, remains a great moment in Italy.

Jeskyně Výpustek při návštěvě císaře Františka I.
Josef Fischer, tempera na papíře, 52 x 77 cm, z roku 1804 (obraz z expozice „Romantismus 19. stol. v evropském umění" na Státním zámku Lednice)

Figure 2: *The beginning of the 18th century was an important turning point in the scientific and tourist approach to caves (Cz).*

4. The values of speleology

We understand the world we're dealing with. For a better assessment of this public, turn to works such as those by JOVIGNOT (1997) or SCHUT (2005). The main values of these communities, which may differ from one another, nonetheless have much in common: their attachment to nature, to karst, whether their own or that of others, their attachment to friendship, the meeting of generations, not forgetting the great loyalty of members who remain so until their death.

The solidarity that these mountaineers call upon in their explorations, where the work of all counts, particularly in their most surprising singularity in France, but also obeying logic and pragmatism, I'm talking

about underground rescue, for which the FFS has representatives in each department with the SDIS.

Rescue workers are volunteers who go underground to look for their colleagues in difficulty. Accidents are rare, but always possible. We've seen French rescuers go on missions abroad, particularly in underground diving.An operation like that of the young footballers trapped in underground water in Thailand owes its success to international cooperation.

Speleologists have a code of honor and ethics. They must respect the primacy of a discovery and not claim it for themselves (see code of ethics). The quest is for length, depth and underground volume! They also name the sites.

Caving also has its martyrs, who bind a community together. We remember Marcel Loubens at the Pierre Saint-Martin in 1952, but how can we not celebrate the Austrian heroine Poldi Furich, who disappeared in action in 1926, or the American Floyd Collins in 1925. The caving community, like so many others, has come together around these high-profile events.

More cheerful were the children and teenagers who, like the scouts and éclaireurs (BARONE, 1944), discovered all the richness of caving at vacation centers or with their schools.

Unforgettable moments. The educational value of caving is well established, and even the rehabilitation of young people can benefit from it. So it's easy to understand why what some call a virus is so hard to get rid of in the course of a caving life!

What remains is for this particular world to become officially and institutionally recognized as that of experts in the environment and caves, so that from being simple sports adventurers in the 20th century, they can become scientists and reference points for the major challenges of preserving our planet in the 21st century, during these upheavals in climate and the search for water resources. Caving, and more specifically speleological exploration as practised and appropriated by communities worldwide, contributes to the construction of territorial singularities which in fact constitute a universal heritage, a cultural legacy worthy of being taken into account by UNESCO.

Figure 3: *The Italian Congress was attended by 2500 people at Casola 2013. SSI.*

5. Procedures for classification as Intangible Cultural Heritage (ICH)

A few years ago, I got the whim to want caving, along with mountaineering in 2019, to be classified as an International Intangible Cultural Heritage with UNESCO. After a quick initial telephone conversation with the ministerial secretariat, I waited a few months for an appointment with Lily Martinet, the project manager who oversees these files.

5.1. A long-term project

To achieve such a goal (international intangible cultural heritage), we're going to have to be patient, but Ms Martinet feels that putting together our dossier would be justified.

The process could take up to ten years!

For example, in 2009, the mountaineering association, supported by Italy, Switzerland and France, initially sought to have Mont Blanc classified, but Lily believes that this was unsuccessful. In 2015, they doubled their demand for recognition of mountaineering, which would be successful 4 years later. We recall Bernard Debarbieux's 1990 and 2020 books on these projects and the ultimate success of mountaineering.

5.2. A national process first

In fact, the first step is to apply for "inclusion in the national heritage inventory", which is already a laborious process, under the supervision of the Ministerial Department, which enables the application to be readjusted so that it can be submitted to a highly specialized committee. This committee meets 3 or 4 times a year. There are 540 classifications, 40 of which are also UNESCO PCI. The ethnographic aspect seems to be important, as well as the anchoring in a particular territory (Fig.4).

5.3. An international approach

Once the national application has been launched, or in parallel with it, to reach an even more prestigious Grail, we'll need to internationalize the application, inviting partner countries to do the same (Slovenia, Belgium, Italy, Germany, Switzerland, etc.): a preliminary recognition of caving as a national heritage. And off we go again, this time with a new UNESCO application.

5.4. Motivations and driving forces behind this process

Only the caving community's determination can bring such a project to fruition.

It will have to be participatory, transparent, transgenerational, and accompanied by writings produced by the different specialties of the co-postulants. It should draw on our status as experts recognized by politicians, scientists and environmentalists. Emphasis will be placed on transmission through schools, professionals and caving managers. In questioning the legitimacy of our heritage, we need to focus on the regions and their specific features, which contribute to the common heritage. We must not position ourselves as a sport/leisure activity! Values and traditions must take precedence!

Figure 4: *Caving as a popular activity with the Groupe d'Hauteville in Oncieu (Ain, France) around 1950 © GSHL.*

6. Conclusion

This work involves a whole community, with international aims, and must be supported by the speleological structure or structures. Several people in agreement must participate. We can rely on the French government to guide us towards success.

As far as the FFS is concerned, various divisions are involved (Education, Environment, Scientific, Heritage, etc.).

This project must escape me if it is to succeed. I would be all the more satisfied...

Acknowledgments

To all the colleagues who have shared their knowledge with me, encouraging my studies and to those who support this classification process, to the ICH Department of the French Ministry of Culture, Thank you!

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For a history of the ghostrock concept (Fantomisation)

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Abstract

There was a French Congress devoted to the problematic of speleogenesis linked to ghost-rocks in 2014 (CHIROL,2014). It is the occasion here in Belo Horizonte to share a French approach of this concept and to confirm its importance in Karstology. A historical way is proposed ,remembering that this notion owes to very ancient scientists even the term itself was used in 1968 by Jean Corbel about 27 years before the well known diffusion of ghost-rock karstification by Quinif's team.

Résumé

Un congrès français a été consacré à la problématique de la spéléogenèse liée aux fantômes de roches en 2014 (CHIROL,2014). C'est l'occasion ici à Belo Horizonte de partager une approche française de ce concept et de confirmer son importance en karstologie. Une approche historique est proposée, rappelant que cette notion est due à des scientifiques très anciens et que le terme lui-même a été utilisé en 1968 par Jean Corbel, environ 27 ans avant la diffusion bien connue de la fantômisation par l'équipe de Yves Quinif.

1. Introduction

The karstology of the late 20th century has seen the emergence of new paradigms involved in cave excavation, parageneses, the Messinian crisis, hypogenesis, bio- and condensation-corrosion. Among them, let's take a look at what lies behind the evocative term "ghost-rocks". In speleogenesis, the alteration of rocks is fundamental. We've come to realize that we need to take this into account, even in cavities whose existence had hitherto been considered solely on the basis of phreatic and/or tectonic action.

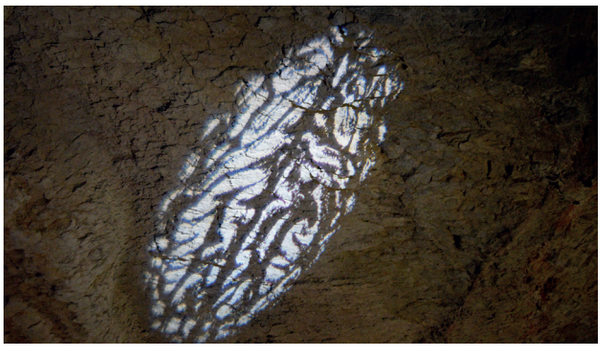

Figure 0: *Fantome (ghost-rock)at the Mas d'Azil Cave (Ariège, France). From Richard Maire.*

2. A little geology

There's an ancient concept known as "metasomatosis". It refers to allochemical or metasomatic metamorphism, accompanied by a change in the chemical composition of the original rocks (according to Foucault and Raoult, Dictionnaire de géologie, p. 201, 1984). In petrography, it's called epigenesis, the slow replacement of one mineral by another.There are many terms referring to rock alteration phenomena.

Figure 1: *Richard Maire.*

3. The origin of the paradigm

According to Richard Maire (Fig. 1), on page 7 of the preface to Karstologia Mémoires n° 18 (2010), it all began near Tournai, Belgium, in 1980. Georges Toubeau, manager of the Milieu quarry, alerted the Mons faculty: the quarry had just intersected a strange cave.The cave had domed walls and, on the outside, a disturbing facies: locally, the limestone was gradually changing from a healthy rock to a porous one. But it wasn't until 15 years later, with the discovery of the fake Pic à glace cave in the Milieu quarry, that the key to the enigma was found, thanks to researchers from this faculty, notably Anne Vergari [Fig.2].At the time, Yves Quinif was supervising Anne Vergari's thesis (1996). After careful observation, she showed that the filling of the presumed gallery was not transported sediment, but altered rock in place (isovolume), where we can follow the beds of cherts. These false caves are known as "pseudo-endokarsts".The void at the top is due to the settling of the alterite [Fig.3]. All that remained was to observe the phenomenon from a dynamic angle and convince the most reluctant (QUINIF, 2010).

Figure 2: *Anne Vergari in 2000 Quenast quarry (Belgium).*

4. At the origin of the origin

In 2009, Yves Quinif himself paid tribute to Henri Erhart (1898-1982) (1955 and 1967), "the brilliant founder of the theory of biorhexistasia, which can be considered the mother of karstification by ghosting". See Karstologia Mémoire n° 18 p. 6 (QUINIF,2010).

5. The term ghost-rock

This term was used by karstologist Jean Corbel [Fig.4] on page 474 of Norois 15/n°60 (1968). In his article "Karsts et glaciers quaternaires", Corbel uses the term "fantômes de roches cristallines" to describe the alteration of feldspars, giving the appearance of "white mud" in a section.

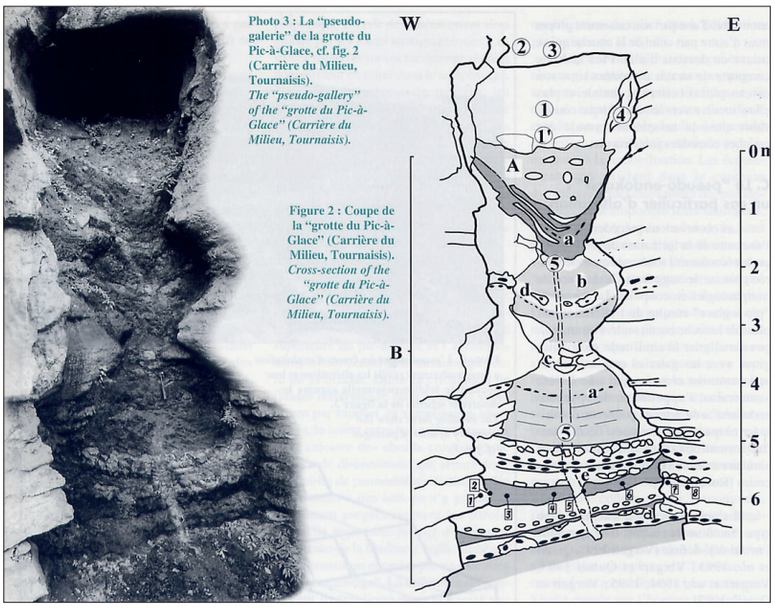

Figure 3: *Left : ghost-rock in the « carrière du Milieu » Tournaisis (Belgium) from Vergari in Karstologia 31 (1998).*

Figure 4: *Jean Corbel a French karstologist bringing debates during the sixties.BC.*

6. Preparing the concept

Descriptions of independent alteration of karstification by water circulation should be sought. There's no doubt that ancient authors (Lucretius, Agricola, Sténon, etc.) can provide hints and drawings of alteration. Baltasar Hacquet (1739/40-1815), the man who identified dolomite, described alterations in his karstic studies (KRANJC & GAUCHON,2013) & Fig. 5. Victor Caumartin (1913-1997) was the precursor of the study of rock alteration associated with micro-organisms (bio-chemical corrosion). See biography in Spéléo 01 n° 26, 2014.

He himself pays tribute to Bory de Saint-Vincent, the 1821 pioneer of underground microbiology (and karstology, according to Renault) in Spelunca 2 p 36-38 (1968).

Among the modern inspirers we must mention the American V. A. Schmidt at Laurel Caves, Pennsylvania (1974).

7. Paul Fénelon's observations

Special mention must be made of Paul Fénelon (1903-1993), whose importance was brought to my attention by Gehrard Rüegg, a regular at the Rencontres d'Octobre. As early as 1945, Fénelon foresaw the profound changes affecting the physiognomy of the "pechs" of the Sarladais region. But it was in Norois (No. 92, 1976) that a note by Fénelon appeared on this theme, which had the merit of moving on from the karstic landscape outside to the endokarst and even the caves [Fig.7]. Fénelon considers the influence of uplift and variations in base level, and mentions the work of colleagues: Jean Hazera in Spain, the Belgians F. Corin and J. Hugue in the Congo, and Americans providing analyses at the molecular level for the ionic migrations presiding over the alteration which, according to Fénelon, "prepares the future underground karsts". We're right in the thick of it...

Finally, a special mention for Joël Rodet (1996 and 1999), in Normandy, for his "altérite tassée par effondrement du squelette de roche, dégagerant un espace sommital aéré (isaltérite puis alloterite) and notion de primokarst dans les labyrinthes d'altération de la craie, grotte de la Mansonnière) » (RODET, 1996).

To complete the papers of Quinif' school Fig. 6 & 8, read also MARTIN LAVERTY (2012) from England.

Figure 5: *Balthasar Hacquet.*

Figure 6: *Yves Quinif in the Clypot quarry (Belgium). From Karstologia 57 (2011).*

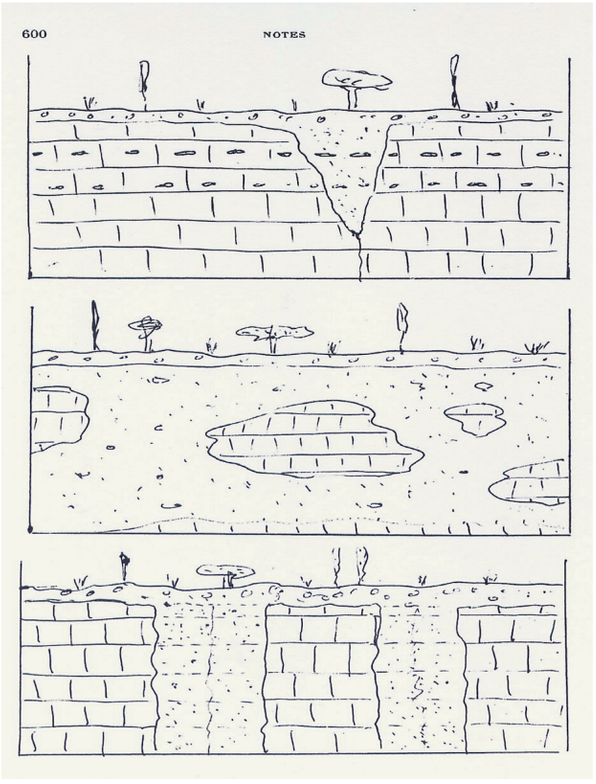

Figure 7 : *Fenelon's cut (1976) in Noroisn°92.*

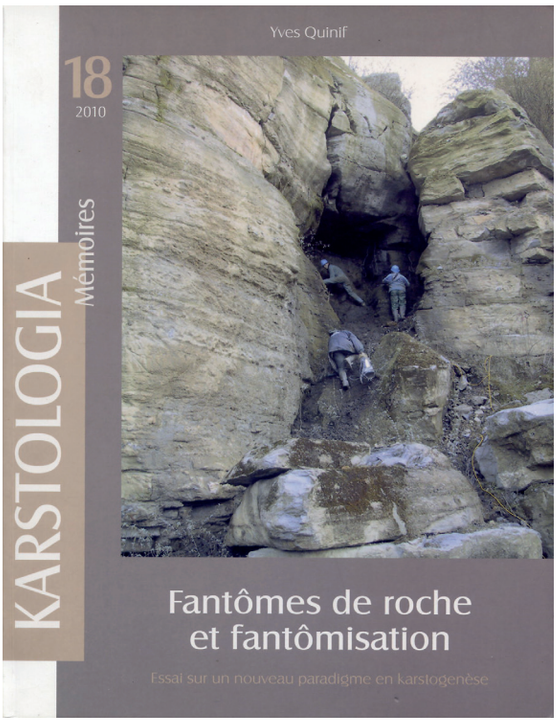

Figure 8 :*Hainaut Quarry (QUINIF, 2010).*

8. The many articles published in Karstologia magazine

In Karstologia magazine, one article after another deals with ghosting (n° 31, 39, 57, 58, 59, 60).

See also Géomorphologie, the journal of the Groupe français de géomorphologie (GFG), featuring Quinif and Bruxelles's article on "ghostrock" weathering processes, No. 4, pp.349-358, Oct.-Dec. 2011.

9. Some current research

In 2014, Laurent Bruxelles deciphered a sedimentary sequence (Fig. 9) with prior rock ghosting from Silberberg Cave in Sterkfontein (South Africa) and published the chronological results obtained in Bordeaux (Journal of HumanEvolution).

In September 2014, Laurent Bruxelles and Hubert Camus organized the Association française de karstologie (AFK) days in the Grands Causses: a visit to the St Paul des Fonts Cabane (cave) beneath Larzac, where ghosting can be seen in a gallery resulting from polygenic excavation.

In Azé showcaves, the 24th Rencontre d'Octobre, where benevolent ghosts are among us... And the arrival here of the concept within the reach of the general public, thanks to a dynamic established between seasoned cavers and the wise management authorities of Saône-et-Loire.

Figure 9 : *Australopithecus from Sterkfontein (3,67 Ma) was in a stratigraphic context with ghost-rocks. Photo L. Bruxelles.*

10. Conclusion

As far as I know,occidental Europe is not the only place where the ghost-rocks (fantômisation) is highlighted. We have seen that the USA contributed and the English karstology takes part to it with Laverty (2012)

Acknowledgments

Thanks to the organizers of the meeting « fantômisation » in Azé (71, France) and to those of the Belo Horizonte Congress.

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Carlos Goicoechea Carranza: A Visionary Legacy in Speleology, Costa Rican Caves, and Karst Conservation

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Abstract

Carlos Goicoechea Carranza (1945–2022) was a Costa Rican speleologist, author, and educator whose contributions have significantly developed the exploration and conservation of subterranean landscapes. This article traces his journey from his early life in Canada to his impactful work in Costa Rica, highlighting his multidisciplinary approach and dedication to karst systems. Through the establishment of the Grupo Espeleológico Anthros (GEA) and collaborations with international organizations, Goicoechea played a pivotal role in the development of speleology in Latin America. His legacy includes the creation of comprehensive karst databases, mentorship of young speleologists, and advocacy for sustainable management of karst environments.

Résumé

Carlos Goicoechea Carranza (1945–2022) était un spéléologue, auteur et éducateur costaricien dont les contributions ont considérablement fait progresser l'exploration et la conservation des paysages souterrains. Cet article retrace son parcours depuis ses débuts au Canada jusqu'à son travail influent au Costa Rica, mettant en lumière son approche multidisciplinaire et son dévouement aux systèmes karstiques. Grâce à la création du Grupo Espeleológico Anthros (GEA) et à des collaborations avec des organisations internationales, Goicoechea a joué un rôle clé dans le développement de la spéléologie en Amérique latine. Son héritage comprend la création de bases de données karstiques complètes, le mentorat de jeunes spéléologues et la promotion d'une gestion durable des environnements karstiques.

Resumen

Carlos Goicoechea Carranza (1945–2022) fue un espeleólogo, autor y educador costarricense cuyas contribuciones han avanzado significativamente la exploración y conservación de paisajes subterráneos. Este artículo traza su viaje desde su vida temprana en Canadá hasta su trabajo impactante en Costa Rica, destacando su enfoque multidisciplinario y dedicación a los sistemas kársticos. A través de la fundación del Grupo Espeleológico Anthros (GEA) y colaboraciones con organizaciones internacionales, Goicoechea desempeñó un papel fundamental en el desarrollo de la espeleología en América Latina. Su legado incluye la creación de bases de datos de fenómenos kársticas, la formación de jóvenes espeleólogos y la defensa de la gestión sostenible de los entornos kársticos.

1. Introduction

The 19th International Congress of Speleology (ICS), hosted by the Brazilian Speleological Society (SBE) and the National Cave Research and Conservation Center (ICMBio/CECAV), will be held in 2025 in Belo Horizonte, Minas Gerais, Brazil. This landmark event, themed "60 Years of the UIS: History for the Future". It provides an unique opportunity to honor the individuals who have shaped the field of speleology. Among these figures is Carlos Goicoechea Carranza (1945–2022), a Costa Rican speleologist, author, and educator, whose contributions continue to inspire the exploration and conservation of subterranean landscapes.

Carlos Goicoechea's life began in Canada, where he was born on July 31, 1945, before moving to Costa Rica, where he was granted citizenship at the age of two. His academic pursuits included diverse fields such as literature, English, tourism, mountaineering, and topography, reflecting his multidisciplinary approach to understanding and appreciating the natural world. As a member of the National Speleological Society (NSS) since 1988, Goicoechea's passion for caves and karst systems was deeply ingrained in his life and work.

The importance of documentation in caving cannot be overstated. Accurate and detailed records of cave systems are essential for several reasons. Firstly, they provide critical information for future explorations, ensuring that cavers can navigate safely and efficiently. Secondly, documentation contributes to the scientific understanding of karst environments, offering insights into geological formations, hydrology, and biodiversity. Thirdly, well-maintained records support conservation efforts by highlighting the ecological significance of caves and the need for their protection.

Goicoechea's dedication to documentation is evident in his extensive body of work, which includes numerous publications and collaborative projects. His efforts to create comprehensive databases, such as the Registro Karstico Nacional (RKN) and the Registro de Cavernas de Centroamérica (RCC), have provided invaluable resources for researchers and conservationists. These databases facilitate the sharing of information and foster collaboration among speleologists, both locally and internationally.

Goicoechea's collaborations with international authors and researchers, such as Pierre Strinati and American cavers, further underscore the global impact of his work. His contributions to scientific journals and conference proceedings have enriched the field of speleology and inspired a new generation of explorers and scientists. By integrating scientific rigor with storytelling, Goicoechea made complex concepts accessible to a broader audience, fostering a deeper appreciation for subterranean landscapes.

Figure 1: *Carlos Goicoechea Carranza: A Visionary Legacy in Speleology and Costa Rica Caves and Karst Conservation.*

2. Materials and methods

This article draws on primary and secondary sources to trace the evolution of speleology in Costa Rica through the lens of Carlos Goicoechea's contributions. Materials consulted include:

Published works by Goicoechea, such as La Serpiente Dormida (1998) and La Caverna de Gabinarraca (2008).

Local caving exploration newsletter published as Speleo Informe Costa Rica (1989-2022)

Archival records and historical accounts from the Grupo Espeleológico Anthros (GEA).

Interviews with collaborators and researchers involved in Costa Rica's karst studies.

Data from the Registro Kárstico Nacional (RKN) and the Registro de Cavernas de Centroamérica (RCC).

Scientific articles and conference proceedings documenting Costa Rican karst exploration.

Methods involved qualitative analysis of these sources, including thematic categorization of historical milestones, conservation strategies, and educational initiatives led or influenced by Goicoechea. Key themes were analyzed within a chronological framework to highlight the evolution of karst conservation efforts.

3. Results

The study identified significant milestones in the development of Costa Rican speleology:

a. Empirical Beginnings (16th Century–1960): Initial anecdotal accounts and limited exploration, with little scientific basis.

b. Scientific Foundations (1960–1980): Establishment of organized speleology with the Grupo Espeleológico del Club de Montañeros, and Asociacion Espeleologica Costarricense AEC, the declaration of Barra Honda National Park, and early collaborations with international groups like the National Speleological Society.

c. Modern Expansion (1980–2005): Formation of the GEA (1995) and the Anthros Costa Rica Grotto of the National Speleological Society (1998), the establishment of databases such as the RKN, and public outreach through courses and publications.

d. International Integration (2005–2015): Increased collaboration with international organizations, including expeditions to Central America and partnerships with *La Venta Esplorazioni Geografiche*.

e. Legacy and Mentorship (2015–2022): A focus on mentoring new speleologists and advocating for sustainable management of karst ecosystems.

Carlos Goicoechea Carranza has more than 40 publications and books published. Here are the major topics he included in his works:

Major Topics:

1. Karst Systems and Phenomenology:
   - "Macizos Calcáreos y Fenomenología Kárstica de C. R." (1967-1971)
   - "El Sistema Kárstico de Barrahonda y Vecindades" (1990/1993)
   - "El Sistema Kárstico del Pacífico Sur" (1989)
   - "El Sistema Kárstico del Pacífico Sur: Exploraciones Espeleológicas" (1991)
2. Cave Exploration and Documentation:
   - "La Caverna de Gabinarraca y Karst Aledaño" (1987/1992)
   - "La Zona Calcáreo/Kárstica de Malpaís, Pen. de Nicoya" (1992)
   - "La Expedición NSS Costa Rica 1990 a la Cuenca del Río Corredores" (1990)
   - "Speleo Informe Costa Rica", newsletter of cave expeditions (1989-2022)
3. Guides and Bibliographies:
   - "Guía Kárstica de C. R., Libro Primero: Guanacaste: Karst por Explorar" (1994)
   - "Guía Kárstica de C. R., Libro Segundo: Pacífico Ctl. y Valle Ctl: Karst por Explorar" (1994)
   - "Guía Kárstica de C. R., Libro Tercero: Turrialba/Atlántico, Aisladas y Otras: Karst por Explorar" (1994)
   - "Bibliografía General Relativa al Calcáreo y Karst de C. R." (1991)
4. Thermal Springs and Hydrogeology:
   - "Las Fuentes Termales de Agua Caliente de San Carlos" (1967, 1994)
5. Scientific and Technical Reports:
   - "Registro Kárstico de Costa Rica (RKN)" (1974)
   - "Algunos Informes sobre Espeleología Costarricense" (1993)
6. Collaborative Works with International Authors:
   - "Quelques Grottes du C. R. et leur Faune" with Pierre Strinati (1998)
   - "Explorations dans les Karsts Tropicaux du C. R." with R. Hapka, J. Brassey, P. I. Jeanin, and V. Jeanin (1992)
7. Articles in Scientific Journals:
   - Various articles in *Biocenosis* (1993-1995)
   - "Perspectivas Carso-Espeleológicas que ofrece Costa Rica"

in *Mundos Subterráneos* (2010)
- "The Dark Side of Caving" in *NSS News* (1998)
- "New discoveries in Carma and Bananal caves, Costa Rica" in *NSS News* (2011)

8. Educational and Introductory Texts:
   - "Introducción a la Espeleología en Costa Rica" (2006)
   - "Guía Espeleológica de Barra Honda" (2007)

9. Literary Works:
   - "La Serpiente Dormida" (1998)
   - "El Río del Encanto" (2004/2018, unpublished)
   - Various poetry and short story collections (unpublished)

10. Geo-Tourism and Conservation:
    - "Grottes au Costa Rica; Comment allier Conservation de la Nature et développement Touristique?" with Ferdinando Didonna (2017)
    - "Geo-Tourism Potential of Underground Sites in Costa Rica" with Andrés Ulloa (2013)

The evolution of national speleology was documented by Carlos Goicoechea Carranza since its origins. This was 58 years ago during the exploration of the site in Cerro Barra Honda, near the town of the same name, east of Nicoya, Guanacaste.

Figure 2: *On the plateau of Mount Barra Honda appear the speleologists Dr. William Mena, Guillermo Cortés, the photographer Isaac Levín and a companion nicknamed 'the Argentine' (Photo J. González, GE).*

The actors or protagonists were a handful of newly formed speleologists who integrated as the "Grupo Espeleológico" (GE) of the Club de Montañeros de Costa Rica. Since the end of 1966, some of its members were fascinated and trained by the professional speleologist Julián González Mateos, a member of the Grup d'Espeleologia de Badalona (GEB) (Catalonia), Spain. In a short time, they managed to obtain some of the necessary equipment and empirically constructed a 30-meter-long ladder made of 8 mm dynamic Nylon ropes and wooden rungs placed every 30 cm. This was something that defied all established safety norms but was the most accessible at that time!

Thanks to information provided by journalist Yehudi Monestel from La Prensa Libre, Cerro Barra Honda in Nicoya was chosen as the destination, as it was said to have "large vertical volcanic chimneys" (the 'volcanic' aspect was a myth passed down through many generations!). The participants of that first exploration were: Guillermo Cortés (director), Julián González (expert), Rafael Vargas (nicknamed 'Tractorcito'), Yehudi Monestel, Álvaro Chávez (transport), and Miguel Aguilar.

Once at Cerro Barra Honda, guides Bonifacio Orias and Mario Acuña (natives of Santa Ana de Nicoya) were chosen to lead them to where the "holes" were. The randomly chosen 'threatening' and impressive mouth was named "Pozo Uno" at that moment for obvious reasons (later, after descending, it was called 'Pozo 110' according to its supposed depth).

The descent itself took place on September 16, 1967; Guillermo Cortés led the actions, managing to descend to -40 meters, with the serious inconvenience that when he got off the ladder, it acted like a spring and was expelled to its true length of 30 meters, leaving the explorer astonished and helpless! (the elasticity factor of that Nylon was very high). It was then Julián's turn to descend, and when he reached Cortés, before getting off the ladder, they tied it to a promontory. The cave continued downward in the form of a steep rocky ramp, leading them to about -50 meters, the maximum depth reached. The Catalan climbed back up without problems, but when Cortés was climbing out, it started to rain heavily outside, and the rainwater channeled into the pit in streams. This, plus Cortés' lack of skill in climbing using only his feet, resulted in a sprain in one of his arms. Almost an hour later, he managed to reach the top, almost being pulled up with the safety rope. Occupational hazards!

From the surface, "Pozo Uno" (nowadays 'Pozo 110') plunges in an initial vertical drop of -41 meters, followed by a series of ramps and 'stepped' pits leading to the bottom at -98 meters (depth corrected in 1982 by the National Speleological Society - NSS).

The GE continued exploring the surface of Cerro Barra Honda until around 1973, discovering 20 significant vertical cavities and another 25 consisting of water sinks, blind pits, and unexplored cavities. The GE conducted at least 28 fully documented expeditions and produced very accurate maps of the main discovered caves. During expeditions No. 21 and 22, fossilized human remains were discovered in the Nicoa cave, which, after much 'going back and forth,' were estimated to be from around 300 BC – 300 AD.

Thanks to the tireless work of the GE from 1967 to 1972 and the subsequent geo-hydrological study of 1974 by the Cave Research Foundation (CRF), the Legislative Assembly of Costa Rica declared Cerro Barra Honda and the three immediate hills (Corralillo, Quebrada Honda, and Caballito) as a National Park on August 20, 1974 (Law No. 5558: "Law of the Barra Honda National Park"). This CRF study had a scientific and comprehensive tone, highlighting the importance of these hills as an aquifer, an anthropo-archaeological complex, also a tourist attraction, among other things, recommending their protection.

Around 1984, several former GE members reunited and agreed to resume 'speleological' activity, founding the Asociación Espeleológica Costarricense (AEC), which continued its visits to the caves of Barra Honda. Also, the association modestly began exploring caves and pits in the southern zone of the country. In 1985, Carlos Goicoechea joined the AEC, and he began making trip reports, rough maps of the explored caves, and established communication with speleological groups and societies in Europe and America. Thanks to this, Swiss speleo-biologist Pierre Strinati conducted studies of cave's fauna in the southern zone of the country and the Venado cave in San Carlos; his findings were presented at the 8th National Swiss Congress of Speleology in September 1987.

In December 1987, the pre-expedition CR-1987 of the NSS, composed of three specialists, took place. Their report was highly favorable, and the "NSS Costa Rica Project" was established, a five-year work plan (1987, 88, 89, 90, and 91). Later, iIn the summer of 1988, an expedition of seven Italian speleologists from the Gruppo Grotte Carlo Debeljak, Trieste (GGCD), and

The expeditions carried out by the NSS from 1988 to 1991 studied and quantified the karst of Costa Rica's southern zone with great precision, producing beautiful maps of the main caves, thoroughly studying the underground hydrology of the area, and highlighting the enormous importance of its preservation.

Carlos Goicoechea Carranza's extensive body of work reflects his multidisciplinary approach and his dedication to the exploration, documentation, and conservation of karst systems and caves. His contributions have had a lasting impact on the field of speleology in Costa Rica and beyond.

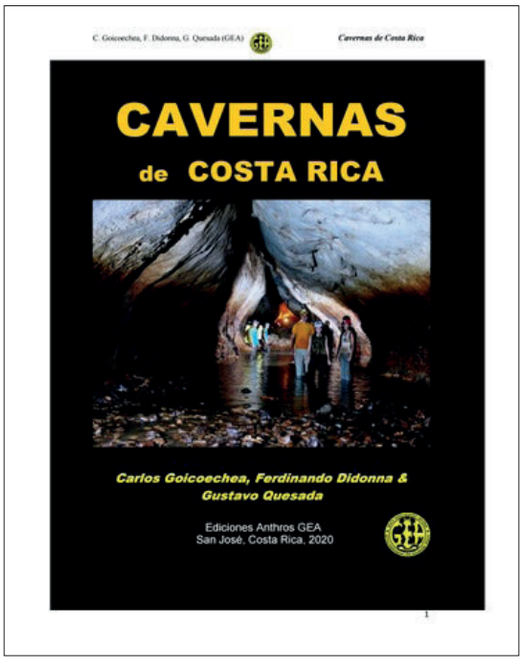

Figure 3: *Carlos Goicoechea last effort the book Cavernas de Costa Rica.*

11. Discussion

Carlos Goicoechea's dedicated documentation and contributions to speleology exemplify the interplay between exploration, education, and conservation. His efforts to document Costa Rica's karst systems laid the groundwork for sustainable management and international recognition. The creation of the RKN and RCC facilitated regional collaboration and data standardization, enabling researchers to build on a shared foundation of knowledge.

Goicoechea's approach integrated scientific rigor with storytelling, making complex concepts accessible to a broader audience. His literary works not only educated readers about speleology but also inspired them to appreciate, protect and explore the subterranean landscapes. By mentoring young explorers and fostering international partnerships, he ensured the continuity of Costa Rica's speleological legacy.

The evolution of karst conservation in Costa Rica, as illustrated by Goicoechea's life work, highlights the importance of balancing exploration with stewardship. His advocacy for the protection of karst environments underscores the need for policies that align scientific research with conservation goals.

Cave Conservancy

In addition to Goicoechea's local efforts, the broader field of cave conservancy has seen significant contributions from international organizations such as NSS and UIS.

GEA supports research, education, and the development of conservation partnerships, making grants and offering fellowship programs to advance the field. Focuses on protecting and managing caves and karst resources in Costa Rica, contributing to educational, research, and environmental protection projects.

Expansion of Speleology in Latin America

Carlos Goicoechea's influence extended beyond Costa Rica, fostering the growth of speleology throughout Latin America. His efforts in establishing the Grupo Espeleológico Anthros (GEA) in 1996 marked a significant milestone. The GEA's activities included extensive exploration and documentation of karst systems in Costa Rica and Central America, contributing to a deeper understanding of these environments. Carlos translated the code to Spanish version of the Speleobase cave system (2012) developed by Paul DeBie from Speleoclub Avalon and made it available for Spanish speaking cavers, then GEA performed teaching in different latin countries to properly registry caves data.

The GEA's collaboration with international organizations, such as the National Speleological Society (NSS) and La Venta Esplorazioni Geografiche, facilitated knowledge exchange and technical support. These partnerships enabled the GEA to conduct joint expeditions, scientific studies, and training programs, enhancing the region's speleological capabilities.

Goicoechea's role in organizing with GEA the 1st Central American Congress of Speleology in 2006 further demonstrated his commitment to regional integration. This event brought together speleologists from various countries, promoting collaboration and sharing of best practices. The establishment of the Central American Karst and Speleological Studies Institute (ICEKE) in 2002, with Goicoechea's involvement, provided a platform for coordinated research and conservation efforts across the region.

Contributions to Science

Carlos Goicoechea's contributions to science are evident in his extensive documentation of karst systems and his efforts to standardize data collection. The creation of the Registro Kárstico Nacional (RKN) and the Registro de Cavernas de Centroamérica (RCC) provided comprehensive databases that facilitated research and conservation planning.

His publications, such as the newsletter Speleo Informe Costa Rica, La Serpiente Dormida and La Caverna de Gabinarraca, combined rigorous expeditions research with engaging narratives, making complex geological concepts accessible to a wider audience. Goicoechea's work in documenting the biodiversity of karst environments, including collaborations with biologists and ecologists, highlighted the ecological significance of these systems.

Goicoechea's mentorship of young speleologists and his involvement in educational initiatives, such as the first public speleology course in

Costa Rica in 2002, enforced by Ferdinando Didonna in his arrival to the country, ensured the continuity of scientific inquiry and conservation efforts. His legacy is reflected in the ongoing research and exploration activities of the GEA and other speleological groups in the region.

Goicoechea collaborated with notable international authors and researchers, including Pierre Strinati, with whom he co-authored "Quelques Grottes du C. R. et leur Faune" (1998), and American cavers such as R. Hapka and J. Brassey, contributing to the article "Explorations dans les Karsts Tropicaux du C. R." (1992). These collaborations enriched the scientific community's understanding of Costa Rica's karst systems and underscored the importance of international cooperation in speleological research.

Figure 4: *Carlos Goicoechea at Costa Rica Speleoolympics 2011 with Ferdinando Didonna. Gustavo Quesada and Danny Brizuela.*

12. Conclusion

Carlos Goicoechea Carranza's legacy is a testament to the transformative power of passion and knowledge. His work not only enriched the field of speleology but also laid a foundation for future explorations and conservation efforts. As the ICS celebrates "60 Years of the UIS," it is fitting to honor Goicoechea's contributions, ensuring that his vision for sustainable karst management and education continues to inspire. Goicoechea passed away on December 9, 2022, leaving behind a profound legacy that continues to influence speleologists and conservationists in Central America. His dedication to the exploration and documentation of karst systems has provided invaluable resources for researchers and has fostered a deeper understanding of subterranean environments. His efforts in mentoring young speleologists and advocating for the protection of karst landscapes have ensured that his work will endure through the generations. The enduring relevance of his works, from scientific articles to poetic musings, reflects the depth and breadth of his commitment to understanding and protecting the subterranean world. His collaborations with international researchers and his role in establishing comprehensive karst databases have significantly advanced the field of speleology. Goicoechea's life's work serves as a guide for those who seek to balance exploration with conservation, ensuring that future generations can continue to marvel at the wonders of karst landscapes.

One of the remarkable aspects of Goicoechea's legacy is the importance of his publications, many of which were produced as typewritten or manually crafted documents. These works, created with meticulous care and dedication, are now treasured sources of knowledge for cave and karst protection. They provide invaluable insights into the early explorations and scientific observations of Costa Rica's karst systems, serving as foundational references for contemporary researchers and conservationists.

Goicoechea was not only an explorer, but also a technically advanced speleologist and loyal friend. Throughout his career, he embraced the evolution of speleological techniques over the last 60 years. From the early days of basic rope techniques and hand-drawn maps to the modern use of advanced surveying equipment, digital mapping, and environmental monitoring technologies, Goicoechea remained at the forefront of technical advancements in the field. His ability to adapt and integrate new methods into his work ensured that his contributions remained relevant and impactful.

As we remember Carlos Goicoechea Carranza, we celebrate his contributions to evolution of caving technique, science, education, and conservation. His legacy is a reminder of the importance of passion, dedication, and collaboration in advancing our understanding of the natural world. The impact of his work will continue to be felt for years to come, inspiring new generations of explorers and conservationists to follow in his footsteps.

Figure 5: *Carlos Goicoechea at one of his several Costa Rica caving expeditions.*

Acknowledgments

We express our gratitude to the Goicoechea family and friends for their support in compiling this tribute. We also acknowledge the Grupo Espeleológico Anthros, the National Speleological Society, and the Editorial Universidad Estatal a Distancia for preserving and promoting Goicoechea's work. Special thanks to the organizers of the 19th ICS for providing a platform to celebrate his enduring impact.

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Lava tube discoveries in Hawai‘i made by Civil Defense for the nuclear fallout shelter program

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Abstract

People have used caves for refuge and shelter throughout millennia. However, the deliberate work of United States government agencies to find and prepare lava tubes for its nuclear fallout shelter program was unmatched in history. In Hawai‘i, with few buildings suitable as shelters, and with no one to speak out for the protection of significant archaeological, cultural, geological, and biological resources found in lava tubes, the Office of Civil Defense actively searched for lava tubes to add to the fallout shelter inventory. From 1961 through the mid-1970s, Civil Defense discovered and explored dozens of lava tubes. Here, based on local newspaper stories and Civil Defense literature, a timeline about the shelter program and its discovered lava tubes is presented. On Hawai‘i Island, 43% of the shelter spaces, for over 50,000 people, would have been in 28 different lava tube systems. Only 4% of the shelter spaces on Maui and 14.6% on Kaua‘i would have been in lava tubes. In time, the shelter program failed and shelters were not needed. However, we have the fallout shelter program to thank for finding some of the most significant lava tubes in Hawai‘i, from which a legacy of exploration and scientific study would begin.

1. Abbreviated Civil Defense timeline in the United States and Hawai‘i

Following the illegal overthrow of the Kingdom of Hawai‘i’s monarchy by the United States (U.S.) in 1893, the Republic of Hawai‘i was annexed as the Territory of Hawai‘i in 1898.

As a Territory, Hawai‘i opened its own civil defense office on 7 December 1941 when Pearl Harbor was attacked. After Japan surrendered in 1945, civil defense offices closed in celebration. But peace would be short-lived.

Panic spread in 1949 after the Soviet Union tested an atomic bomb. President Truman responded by deciding to develop the hydrogen bomb and invest in thermonuclear weapons. Additionally, Truman signed the Federal Civil Defense Act of 1950. Its goal was to protect life from enemy attack by monitoring hazards and planning for emergency services, which included initiating a national fallout shelter system as a “duck and cover” response [YOSHPE, 1981].

The Territory of Hawai‘i established the Hawaii Civil Defense Administration in 1950. One of its first actions was to identify bomb shelters [ANONYMOUS, 1950], but these activities were not widely disclosed to the public.

For nearly a decade, the federally-financed fallout shelter program remained poorly funded and received mixed attention from each new administration [YOSHPE, 1981; BLANCHARD, 1985]. After Hawai‘i became the 50th U.S. State in 1959, and after more bomb tests, President Kennedy breathed new life and money into the shelter program in 1961. Kennedy moved the Office of Civil Defense to the Defense Department and involved the Army and Navy in the National Fallout Shelter Survey. Its goal was to identify and stock 50 million shelter spaces by December 1962, then 235 million spaces by 1967. Yet, budgets were limited to modify buildings or construct and stock shelters. Instead, private citizens were encouraged to prepare family shelters, sparking “shelter mania” in the U.S. [BLANCHARD, 1985].

Following President Kennedy’s assassination, President Johnson moved the Office of Civil Defense to the Office of the Secretary of the Army and reduced its budget [YOSHPE, 1981]. Johnson also signed the 1963 Test Ban Treaty, which broadly diminished the risk of nuclear attack [YOSHPE, 1981; BLANCHARD, 1985]. Funding for civil defense would reach an all-time low when the U.S. became involved in the Vietnam War (1965–1973) under President Nixon. On 5 May 1972, the national Office of Civil Defense was disestablished, and the Civil Preparedness Agency was created. Fallout shelter program activities ended in nearly every state, and civil defense offices were transitioned to a new focus, natural emergency preparedness and crisis management.

2. Caves as fallout shelters

The first President of the National Speleological Society (NSS) in the U.S., William J. Stephenson, wrote a letter in 1940 to the Chairman of the Advisory Committee to the Council of National Defense that explained how caves could be used during wartime, including, as an example, “… as air-raid and permanent shelters for evacuated civilian population[s]” [VARIOUS AUTHORS, 1940]. This patriotic action made the NSS the official authority on caves in the U.S. The NSS would go on to help several government agencies, like the U.S. Army Corps of Engineers and U.S. Army, to identify and classify caves [DOUGLAS, 1996]. By 1946, the NSS and the Joint Army–Navy Munitions Board, with their Underground Sites Committee, worked to identify commercial and government-owned caves that could be used for military operations and shelters [DOUGLAS, 1996].

In early 1946, the Underground Sites Committee published high-profile newspaper and magazine articles to catch the public’s attention. The articles touted how caves could be used for war and peacetime enterprises. Some claims were even made by NSS leadership and members, including a statement in *The New York Times Magazine*, “…that there is room for the entire population of the United States to hide in deep, safe shelters if atomic bombs are ever to be used against us” [PERRY, 1946].

By the mid-1960s, coincident with gaps in national leadership and

diminishing financial support for the shelter program, the NSS was also playing a more active role in pushing to end assigning caves to the shelter program. Many explained why caves should be excluded [DOUGLAS, 1996]. NSS President Russell Gurnee expressed as much in a news release on 11 February 1962,

> Periodically some well-meaning person suggests the possibility of using natural caves as fall-out shelters. Ten years ago this suggestion was advanced, explored and abandoned as an impractical solution to the shelter problem. Every year someone renews the plan and it is again reviewed and abandoned. … The vote was unanimous that natural caves were unsuitable for shelters for large numbers of people [GURNEE, 1962].

Reasons why caves would be poor shelters included their remote locations, unstable ceilings and floors, cool and damp temperatures, and ventilation tied to barometric pressure. Fractures that connect to the surface, as well as streams and dripwater, could provide paths for radiation and contamination [GURNEE, 1962; DOUGLAS, 1996]. Moreover, scientists reinforced the fact that caves house irreplaceable geological, biological, and cultural resources that would be destroyed if caves were used for shelters. This information was sent to members of Congress, the U.S. Army Corps of Engineers, and numerous engineering firms subcontracted by the Army [DOUGLAS, 1996]. It is unclear if, or how, offices in Hawai'i received this information.

3. Lava tube shelters on Hawai'i Island

Volcanic in origin, lava tubes form in large lava flows during long--duration eruptions. Hawai'i Island (referred to as the Big Island) is the youngest in the chain and has the most lava tubes compared to older islands where erosional processes have heavily fragmented tubes or filled them with sediment. Kīlauea and Mauna Loa are the two youngest volcanoes on Hawai'i Island. About 80% of Kīlauea's surface likely formed by tube-fed lava flows [GREELEY, 1987] compared to about 42% of Mauna Loa's surface [CLAGUE et al., 1999].

One of the earliest references to using lava tubes in Hawai'i as fallout shelters was published in *The Honolulu Advertiser* in 1946 [JONES, 1946]. Jones reported that an "authority" on lava tubes said he would be one of the first to take up residence in "the biggest tubes" on the Big Island if there was an attack. According to him, "thousands of people" could seek shelter in lava tubes, as "…during Kamehameha's warring days, hundreds of women and children were sent underground to escape attacking troops, but that was before the caves were made sacred as burying grounds." He considered burials to be one reason why caves might not make suitable shelters, as disturbing burials is illegal.

Based on prior surveys as the Territory of Hawai'i in the 1950s, Civil Defense found few buildings that could serve as adequate public fallout shelters. By 1961, with the new push by the Kennedy administration for a national shelter program, Civil Defense in Hawai'i quickly scrambled to find shelters [WILHELM, 1961]. Hawai'i's first Governor, William F. Quinn, gave a spirited speech on 7 December 1961 that described his support for the shelter program, stating that Civil Defense would take "…into account the protection offered by caves and tunnels…" [ANONYMOUS, 1961a].

Myron O. Isherwood Sr. served as the first administrator of Hawai'i Island's new Civil Defense Agency. In addition to handling emergencies caused by severe weather, floods, volcanic activity, earthquakes, and tsunamis, Isherwood would play a key role in introducing the Big Island's "natural shelters" [WILHELM, 1961] to the world.

Local residents were updated frequently about Isherwood's progress. Locations and names of caves were often listed in the local newspapers. Most of the first caves that Civil Defense identified were known about for generations, as they had been used for water collection, refuge, sleeping, or burial [BOLLT, 2005] by Hawai'i's first cave explorers, the Native Hawaiians. However, despite local laws protecting burials, antiquities, and other features in caves, no one in Civil Defense appeared responsible for assessing if lava tubes had cultural, archeological, geological, or biological resources that should be preserved [DOUGLAS, 1996].

One of the first lava tubes listed as a potential fallout shelter was near the town of Pāhoa, being "large enough to take care of all the residents of eastern Puna" [District] [WILHELM, 1961]. Decades later, **Pāhoa Cave** would be mapped to 16+ km and be known to contain significant cultural resources, including burials, and heiau (temple) and platform structures [McELDOWNEY & STONE, 1991].

Other lava tubes made known to Civil Defense were near the towns of Keauhou, Kurtistown, Hōnaunau, and Honoka'a, as well as Thurston Lava Tube (renamed **Nāhuku**) in Hawai'i Volcanoes National Park [WILHELM, 1961]. Isherwood described that each cave "…has its drawbacks: immediate accessibility by road, adequate ventilation, and sufficient entrances. Each cave will have to be surveyed" [WILHELM, 1961]. Moreover, despite a report that "…famed Kaumana Caves above Hilo are too wet for shelters" [McMURRAY, 1961], **Ka'ūmana Cave** was listed, with room for 393 people.

Lava tubes in Pā'auhau and Hāmākua, near former sugar plantation villages on the northern coast of the Big Island, were prepared by their local communities [McMURRAY, 1961]. *The Hilo Herald-Tribune* printed photographs of local residents in the cave [ANONYMOUS, 1961b], which is now known as the **Pā'auhau Civil Defense Cave**. This lava tube is one of only a few known on Mauna Kea Volcano and has cultural and geological significance [KEMPE et al., 2003].

By early 1962, despite clear resistance throughout the continental U.S., specifically that caves should not be included in the shelter program, Isherwood had examined 12 lava tubes and had 19 more to see [McMURRAY, 1962]. According to Isherwood, "All of them turn at least once after you get inside, making a natural baffle… some of the caves branch out. There are two which are actually double-deckers… once you get inside, they open into two caves, one above the other." He also boldly stated that, "The Big Island has enough caves to shelter its entire population of 63,400 from nuclear attack" [ANONYMOUS, 1962a].

Federal Civil Defense officials toured Big Island caves with Isherwood in 1962 [WILHELM, 1962]. This story in the *Hilo Tribune-Herald* is notable because it was one of the first to print photographs of Civil Defense officials inside Pāhoa Cave. Some officials thought that the lava tube was suitable as a shelter [ANONYMOUS, 1962b], but others thought it needed modified entrances for easier access [WILHELM, 1962]. Isherwood described the cave as having "…pahoehoe floor" and "…over-all dimensions of…25 feet wide and 10 feet high," likely to convince the public that it was spacious [ANONYMOUS, 1962b]. A different photograph of Civil Defense agents inside Pāhoa Cave was also printed by the *Hilo Tribune-Herald* in 1963, this time showing abundant roots hanging from the ceiling [ANONYMOUS, 1963].

Starting in March and April 1963, the Civil Defense and Disaster Relief Agency of the County of Hawai'i would start leasing (for 50 years) several properties with caves, including Pāhoa Cave, Ka'ūmana Cave, and **MacKenzie Cave** in the Puna District, and **Pu'u Anahulu Cave** and **Pigeon Cave** in the North Kona District [ANNUAL REPORT, 1972-73].

Regardless of significant program weakening at the national level in 1964, Big Island Civil Defense continued to expand its shelter numbers and spaces. In February, Civil Defense had 20,000 spaces in lava tubes, 500 spaces in buildings, and enough supplies for 7,000 people [ANONYMOUS, 1964a]. By December, there were 32,000 spaces in four buildings, 18 lava tubes, and 18 water tunnels used for irrigation by the Kohala Sugar Company [ANONYMOUS, 1964b]. Isherwood reported, "The Big Island is in pretty good shape for fallout shelters, thanks largely to Pele's plumbing" [ANONYMOUS, 1964c]. He also claimed to have examined 123 lava tubes but considered 40 to be usable as shelters. He said that Civil Defense used inmates from the Kulani Honor Camp to improve the Pāhoa Cave entrance, and that the cave would hold a staggering 4,800 people, but perhaps up to 25,000 with additional ventilation and lighting. Isherwood had also counted at least 1,000 private shelters,

enough for 5,000 people, either being manmade or using smaller lava tubes [ANONYMOUS, 1964b]. Compared to the neighboring islands [ALTONN, 1964], the Big Island was fortunate to have "the advantage of numerous natural shelters, caves, and tunnels" [ANONYMOUS, 1964b], and was "especially blessed by Pele" [BYRAN, 1964]. The BRYAN [1964] story printed a photograph of people at the entrance to Nāhuku.

The discovery of lava tubes in the Hawaiian Acres subdivision of Mountain View was a game-changer for Civil Defense [ANONYMOUS, 1965a], as well as for future cavers in Hawai'i. The president of the Hawaiian Acres Community Association, Martin Valentine, discovered a cave entrance in August 1965 near the southern border of the subdivision while searching for firewood. Isherwood and his assistant, Sonny S.G. Kim, explored more than a mile of passage with Valentine and a resident, Alec Ha, according to the January 1966 community association newsletter [ANONYMOUS, 1966]. The cave was described as being relatively dry compared to other lava tubes, having smooth floors and wide passages. Moreover, "[r]oot tentacles from surface vegetation hung from the roof at intervals" [ANONYMOUS, 1965]. This discovery would become **Kazumura Cave**, now known to be the longest lava tube system in the world, with 41.8 km of contiguous passage and 65.5 km of mapped passages overall [ALLRED & ALLRED, 2002]. For the first time, this article also hinted to lava tube biology, which would eventually result in the discovery of unique cave-adapted animals in Hawai'i in 1971 [HOWARTH, 1972].

Newspaper stories and reports were printed about the cultural usage of caves in Hawai'i, even as Civil Defense seemed to be ignoring such resources. For instance, a story in the *Hawaii Tribune-Herald* [ANONYMOUS, 1965] stated,

> Big Islanders have long sought uses for these cool, dark, and moist caverns that are a byproduct of Pele's pyromania. Ancient Hawaiians in the more arid sections of Puna, Kau [sic] and Kona used them as water sources. Locating the deeper tubes, they placed calabashes under drip points and collected water that filtered down from surface rainfall days or weeks earlier.

In July 1966, *The Honolulu Advertiser* reported that the fallout shelter survey for the Big Island was complete [SOUTHWARD, 1966], although there were only 39,000 spaces and enough supplies for 27,000, which was obviously not enough to protect the island's residents. By December 1966, space increased to 43,000 [CLARK, 1966]. The largest lava tube sheltering population would have been in Pāhoa Cave, at 4,800. Kazumura Cave would be 2nd largest cave-sheltering population, at 4,768 spaces. The 3rd largest cave-dwelling population would have been in lava tubes near Kurtistown, having capacity for 2,000 [SOUTHWARD, 1966]. Civil Defense split the system into two segments, with four entrances becoming **Orchid Land Estates Caves** and having 1,917 spaces. Another three entrances would become the **Kurtistown Caves** for 332 people. The 4th largest cave shelter would have been in Hoʻokena, having 1,588 spaces. This system is now referred to as **Hoʻokena Civil Defense Cave** and has over 7 km of passages surveyed to date.

A large cave in the Kaʻū District was listed by Civil Defense as Kaalualu Bay Cave, and it would have been the 5th largest cave-sheltering population on the island (1,435 spaces). This cave is known today as **Lua Nunu o Kamakalepo**. Native Hawaiians extensively used the cave, decorated the cave walls and lava flow field with petroglyphs, and built walls, heiau, and dozens of platform structures. Since the early 1960s, archaeologists have considered this cave to be among the most significant sites on Hawai'i Island [BONK, 1969; KEMPE et al., 2006].

Civil Defense also assessed underground water tunnels used for irrigation, mostly developed and used by sugar plant-ations prior to the 1960s. These places would have also had large sheltering populations. In sum, 18 tunnels in Kohala had 12,646 spaces and 31 tunnels on the Hāmākua coast had over 8,000 spaces. At the time, and even today, these areas are not heavily populated, so people would have needed to find and use these tunnel shelters purposefully.

By June 1967, Civil Defense began distributing literature about the fallout shelters on Hawai'i Island [ANONYMOUS, 1967]. Most of the licensed lava tubes were on private property, except for the few with Civil Defense leases [ANNUAL REPORT, 1972-73]. Landowners had to give Civil Defense permission to clear the jungle, create roads, make paths or bridges, and mark entrances with fallout shelter signs. They also posted signs on electrical poles along roads.

Isherwood reported in 1968 that there were 109 shelters, nearly all being lava tubes or water tunnels, that could hold up to 49,895 people. Supplies, however, were only available for 33,000 [BRYAN, 1968]. Throughout the year, several more caves were added to the supposedly finished program. Shelter space increased to 51,166, or roughly enough for about 80% of the island's resident population (i.e., not visitors or tourists) [ANONYMOUS, 1968a]. Two-hundred more spaces came from a "cave of refuge" used by Native Hawaiian in Kalapana [BRYAN, 1968], being a "…fortified lava tube or tunnel in which the women and children of Old Hawaii were safeguarded while the men fought off invasions of their village." Today, this cave is **Hakuma Cave**, which had been previously studied for its burials and steps built by Native Hawaiians [KEKAHUNA & KELSEY, 1952; KEMPE et al., 1993]. Other new lava tubes included **Blair Cave**, and Dr. Bellou Cave and Hawaiian Acres Cave #1, which were separate entrance names that would eventually be tied into the Kazumura Cave system [ALLRED AND ALLRED, 2002].

Releasing shelter information and maps would take two more years, with reports starting in February 1970 that booklets and map sheets were going to be given to local residents [ANONYMOUS, 1970]. However, a year later, newspapers reported that maps were mailed to postal patrons on the Big Island and to residents on neighboring islands [ANONYMOUS, 1971a, 1971b].

Publication dates for all the maps are unknown, but the most likely print year, and the one used by the Hawaiian & Pacific Collections library on the University of Hawai'i at Mānoa campus, is 1971.

In total, 52,996 shelter spaces were identified for the Big Island [HAWAIʻI, 1971]. Lava tubes accounted for 22,828 spaces, or 43% of all the shelters. There were 39 lava tube entrances listed that belonged to 28 different systems, including five sections to Kazumura Cave (i.e., Kazumura, Dr. Bellou, Hawaiian Acres #1 & #2, Eldon English, & Hongo Store). Although roughly 39.9% of the spaces were in water tunnels, Pāhoa and Kazumura lava tubes would have had the largest populations of any single site on the island.

News about the shelter program fell off precipitously once the maps were distributed, which almost certainly coincided with diminishing nuclear risks, shifting national attention, and the lack of financial and political support. Nationally, Civil Defense offices were disestablished by May 1972. By 1974, one of the last news reports about shelters throughout the Hawaiian Islands stated, "…shelters in buildings, lava tubes or other places… offered some protection for 640,000 people, or 85 per cent of Hawaii's population" [NELSON, 1974].

4. Shelter caves on the Neighboring Islands

Although there are both lava tubes and limestone caves on Oʻahu, no records could be found that any were listed as fallout shelters. Building structures surveyed in Honolulu in 1960 and 1961 identified only 57,822 shelter spaces for over 224,000 people, which was not enough for the daily population of the city [PLANNING DEPARTMENT, 1961]. By 1965, the estimate was that public shelters could hold 30% of the island's population [Anonymous 1965b]. In 1968, the Oahu Civil Defense Agency published the Fallout Shelter Plan [OAHU CIVIL DEFENSE AGENCY, 1968]. The manual included lists of supplies that would or would not be provided by the county and outlined thorough recommendations on how to manage shelter life.

Local newspapers on Maui and Kauaʻi islands did not report about Civil Defense agency activities as often as was done for Hawaiʻi Island, but both island agencies included lava tubes on their fallout shelter list. Most of the shelters on Maui and Kauaʻi were in hotels, plantation storage buildings, or in water tunnels used to irrigating agricultural fields. For instance, the largest shelter on Maui had 1,227 spaces in the Halimeile Water Tunnel, which was used to distribute water to pineapple fields [MAUI, 1971]. Much of the residents and visitors on Maui would have been without shelter, as criticized in 1978, "The civil defense system in Maui County is not up to par… In a letter to the Council, the commission pointed out that it has learned the civil defense shelters in Maui 'are not uniformly spread out' " [McCABE, 1978].

On Maui, only 4.1% of the 6,367 spaces for the island were in lava tubes. The two lava tube systems listed as shelters were **'Ulupalakua Caves #1 and #2**, with 141 spaces, and Hana Field 38 Lava Tube, with 118 spaces. The Hana lava tube, today being the longest mapped system on Maui, has had several other names. One entrance was used from 1950s through 1970s by a slaughterhouse to dispose of bones and waste. From this, biospeleologists referred to the lava tube as "Offal Cave" [HOWARTH, 1972]. The Civil Defense map notes a "…long stepladder is needed to make entrance to shelter easier and safer" [MAUI, 1971]; however, it is surprising there was no warning about the cave's offal-ness. In 1998, the cave was restored to pre-slaughterhouse days to host commercial operations and is now referred to as **Kaʻelekū Caverns**.

From a 1962 shelter survey conducted by the Kauaʻi Civil Defense, "…there seems to be enough caves and tunnels to accommodate the population" of Kauai's west side [ANONYMOUS, 1962c]. In total, roughly 14.6% of the 7,245 shelter spaces on Kauaʻi were in three different cave systems [KAUAʻI, 1971], including 276 spaces in **Haena or Maniniholo Dry Cave**. This cave is located near the beach, has a sandy floor, and most of the cave is in twilight because of its huge entrance. It would have been an unsuitable shelter without modifications, which were never done.

The **McBryde Lava Tubes** had 161 spaces on sugar plantation lands, and have been referred to by different names, including the Koloa Caves. These lava tubes have become important for local activists today because many were used for burials and have since been impacted by urban sprawl and resort development. Moreover, two native cave-adapted species live in the caves, the peʻe peʻe maka ʻole (Kauaʻi cave wolf spider, Adelocosa anops) and the ʻuku noho ana (Kauaʻi cave amphipod, Spelaeorchestia koloana). In 2000, both became the first (and, so far, only) cave animals in Hawaiʻi to be listed as Endangered Species under the U.S. Endangered Species Act.

Lastly, **Grove Farm Caves #1 and #2** on Kauaʻi had 622 spaces, and would have had the 3rd largest shelter-dwelling population on the island, after Grove Farm Truck Tunnel (1,800 spaces) and Grove Farm Water Tunnel (3,000 spaces). The 622 spaces in the Grove Farm lava tubes suggest that it was a large system, with a size comparable to, but still larger than, Nāhuku (with 572 spaces) on Hawaiʻi Island. But, these large caves are not known today, an issue that perplexed Dr. Halliday, as he wrote in an unpublished report [HALLIDAY, 1992],

> The location is …in an area of Koloa volcanics like the McBryde Caves to the west. The shelter area of these caves was said to be about four times that of the McBryde Caves, so that these should be the largest caves in the Koloa area. Local cavers have been unable to find them, and local inquiry suggests that their entrances were filled during subdivision construction.

5. Conclusions

Nuclear fallout shelters were supposed to be livable, but livability would have been a significant issue for cave-sheltering populations in Hawaiʻi. Isherwood claimed, "Some of the shelters would be uncomfortable and incon-venient to stay in for one or two weeks" [ANONYMOUS, 1970], which was the time estimated for short-lived radiation to decay. In December 1966, Hawaiʻi County Civil Defense used Nāhuku to simulate shelter use after a bomb might have been dropped on Oʻahu [CLARK, 1966], where radioactive fallout would reach the Big Island in a "minimum of five hours" [WILHELM, 1962]. During the exercise, a participant was unhappy with the "damp and dripping cave" [CLARK, 1966]. The Hawaiʻi Island map sheet even stated, "All but two of the lava tubes or caves have a continual, small, irritating drip from their ceilings" [HAWAIʻI, 1971].

People evacuating to lava tubes were told to bring raincoats, tarps, inflatable mattresses, and folding cots. Supplied food and water was meant to keep people alive, but people were expected to lose "about five pounds in two weeks" [CLARK, 1966]. The situation would have been bleak, but people would be alive. The caves, however, would never have recovered if used as shelters for thousands of people.

Today, cavers and caving groups around the world are generally secretive about sharing cave locations. But, thanks to the Civil Defense in Hawaiʻi, we were not only told about the extensive lava tubes on the islands, but were given maps to locate them. Altogether, directions for 46 lava tube entrances were included on three map sheets. Fortunately, these extraordinary caves were never needed as fallout shelters, but it is no coincidence that some of the first caves explored and surveyed were those listed on the Civil Defense maps. Moreover, many of the lava tubes have since become significant exemplars in the world for their unique geological, biological, and cultural resources.

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Sônia Macedo de Oliveira – pioneirismo feminino na espeleologia Brasileira

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Resumo

Este artigo resgata a história de Sonia Macedo de Oliveira, a primeira espeleóloga brasileira e sul-americana. Em 1958, com o apoio de Jean-Louis Christinat, ela concluiu o Curso de Espeleologia do Centro Excursionista Pico de Itatiaia, superando barreiras e preconceitos em um universo predominantemente masculino. A determinação de Sonia a impulsionaram a desafiar os estereótipos de gênero e a abrir caminho para outras mulheres na espeleologia. Ao resgatar sua história, o artigo busca inspirar novas gerações de espeleólogas e relembrar a importância de figuras como Sonia e Christinat para o desenvolvimento da espeleologia moderna no Brasil.

Abstract

This article recovers the history of Sonia Macedo de Oliveira, the first Brazilian and South American female speleologist. In 1958, with the support of Jean-Louis Christinat, she completed the Speleology Course at the Centro Excursionista Pico de Itatiaia, overcoming barriers and prejudices in a predominantly male universe. Sonia's determination propelled her to challenge gender stereotypes and pave the way for other women in speleology. By recovering her story, this article aims to inspire new generations of female speleologists and remind us of the importance of figures like Sonia and Christinat for the development of modern speleology in Brazil.

1. Introdução

No Brasil, o início do protagonismo feminino, nos esportes em atividades ao ar livre, embora carente de registros, são contemporâneos ao nascimento de uma Espeleologia nacional. O estudo das cavernas e o Excursionismo (vamos entender, neste texto, a ''atividade excursionista'' como sinônimo para montanhismo, alpinismo ou mesmo o hábito de realizar expedições, caminhadas e travessias em ambientes abertos como matas, montanhas, praias e rios) caminharam juntos em um primeiro momento. A conquista da natureza se confunde, na primeira metade do século XX no Rio de Janeiro, com a época em que jornais, revistas e programas de rádio davam destaque às conquistas dos membros de clubes excursionistas cariocas, que escalavam montanhas, percorriam trilhas, faziam travessias e revelavam novos achados e caminhos, e rotas naturais.

A tendência desta época era equivalente a uma proposta internacional de atividades de lazer que tentavam ligar novamente o ser humano à natureza. Foi assim que Alfredo Jahn (1940) definiu o que era o Excursionismo:

> As exigências da vida moderna, ao modificarem hábitos e costumes e ao substituirem o trabalho manual pelo trabalho mecânico na sua crescente industrialização, afastaram um número considerável de homens e mulheres do contacto imediato com a natureza, limitando as suas atividades às populações, onde são obrigados a levar uma vida de relativa reclusão em escritórios e oficinas... De todos os exercícios que podem ser praticados para dinamizar todo o corpo, o exercício em montanhas é o desporto por excelência: põe em actividade todo o sistema muscular do nosso corpo, abre os poros à transpiração saudável, dilata os pulmões a um ritmo acelerado, tornando inalamos o ar puro das alturas e permite-nos expor a pele à ação altamente desinfetante e revigorante dos raios ultravioleta, intensificados nas camadas superiores da atmosfera. Nas montanhas entramos em contacto íntimo com a Natureza.

Ao mesmo tempo, na Europa, a Espeleologia era cada vez mais divulgada e almejava o ''desenvolvimento e a legitimação do estudo de cavernas como uma disciplina científica acadêmica do final do século XIX até a Segunda Guerra Mundial'' (MATTES, 2015).

É neste cenário que ocorre o encontro entre duas atividades, o Excursionismo e a Espeleologia, além do encontro entre duas personagens imensamente relevantes à história destas atividades: Sônia Macedo de Oliveira (1937-2023) e Jean-Louis Christinat (1933-2001). Este artigo pretende discutir a ligação entre o estudo de cavernas e as atividades de clubes de montanhismo no Rio de Janeiro, além de apresentar e destacar duas grandes personalidades da nossa Espeleologia que ainda merecem ser lembrados por seu pioneirismo, principalmente na atuação de Sônia Macedo de Oliveira, a primeira mulher a se formar espeleóloga no Brasil e na America Latina, graças à sua perseverança e ao apoio de Jean-Louis Christinat.

2. Materiais e Métodos

Este trabalho contou com a revisão de publicações disponíveis na Hemeroteca Nacional, com diversos jornais e revistas cariocas digitalizados e disponíveis em plataformas online (BIBLIOTECA NACIONAL, sd.). Sobre Jean-Louis Christinat, foram

usados seus próprios depoimentos além de artigos escritos pelo próprio e divulgados em artigos internacionais e um livro autobiográfico. Contamos ainda com depoimentos e o acervo familiar de Sônia Macedo de Oliveira disponibilizados por sua filha, Sônia Eymard, a quem homenageamos desde já como primeira autora deste trabalho.

3. Relatos

3.1. O Eexcursionismo no Rio de Janeiro

As primeiras explorações e escaladas de montanhas no Rio de Janeiro surgem no século XIX e tinham como objetivo o pioneirismo das pesquisas, os levantamentos climatológicos e a topografia dos acidentes geográficos do entorno da cidade que ainda era o centro político do Brasil. A cidade é cercada de montanhas e por décadas foram abundandes os registros de excursões ao 'Maciço da Tijuca' e à 'Serra da Carioca'. A exploração destes locais, por conta de pessoas que não estavam exatamente ligadas a centros acadêmicos, ganhava cada vez mais força e adeptos que no século XX extimularam a formação dos clubes de excursionismo.

A necessidade de organizar pessoas interessadas por práticas ao ar livre levou à fundação do Centro Excursionista Brasileiro (CEB), o primeiro clube de montanhismo do Brasil, fundado em 1 de novembro de 1919. Seu emblema impresso em simbologias e bandeiras é o 'Dedo de Deus', pico conquistado por cinco brasileiros em 1912.

O excursionistas do CEB conquistaram várias montanhas no Estado do Rio de Janeiro, e a partir dos anos 30 estimularam a criação de outros clubes e agremiações. O Centro Excursionistaa Rio de Janeiro (CERJ), por exemplo, foi fundado em 1939. Em 5 de dezembro de 1945 foi fundado o Centro Excursionista Pico de Itatiaia (CEPI, Figura 1) e no ano o seguinte o Centro Excursionista Carioca (CEC), fundado no dia 21 de fevereiro de 1946. Os primeiros registros de atividade do Centro Excursionista Light (CEL) datam de 14 de novembro de 1956. A exceção do CEPI, todos os outros clubes excursionistas existem até hoje e continuam em plena atividade, conquistando novas trilhas, novos picos e novas vias de escalada.

Se por um lado, escalar as montanhas e realizar novas conquistas de trilhas e vias de escaladas já se tornavam comum no dia a dia do caroca, poucos eram os aventureiros que ousavam praticar o ''alpinismo ao contráro'', forma como Jean-Louis Christinat usava para se referir à espeleologia que trazia da Europa como representante da *Societé Suiss de Speleologie*.

3.2. Jean-Louis Christinat

Jean-Louis Christinat nasceu em em 03 de dezembro de 1933 em Genebra, cidade suíça rodeada pelas montanhas dos Alpes e do Jura que divisam o país com a França. Logo cedo se interessou pela espeleologia que era praticada na sua região (Faria, 2025).

Semanas após chegar no RJ, em 1956, contratado para trabalhar como vitrinista, Christinat publicou um recorte jornalístico na revista Manchete, convocando quem, como ele, tivesse interesse na espeleologia para juntos formar grupos para explorar cavernas no Brasil. O presidente do Centro Excursionista Pico de Itatiaia entra em contato como o suíço e demostra interesse pela prática. No entanto, para isso o Christinat teria que formar os primeiros especialistas em exploração subterrânea, uma vez que poucas iniciativas anteriores no Brasil haviam obtido sucesso em se aventurar pelo ambiente subterrâneo. Christinat realiza o primeiro Curso de Espeleologia no Brasil em parceria com o CEPI e protagoniza o início da espeleologia esportiva no Brasil.

Em maio de 1958, Christinat relata a realização de esforços para a fundação próxima da Sociedade Brasileira de Espeleologia, e declara sua intenção de dar prosseguimento aos cursos de formação espeleológica no CEPI, na época presidido por Albiges dos Santos Braga, antigo aluno de Christinat no Curso de Espeleologia. Christinat introduz uma pequena mudança no programa de prática espeleológica, visando ''eliminar os alunos que não apresentassem capacidade técnica''. Neste mesmo ano, no curso que ofereceria, um interessante fato colcoaria à prova a espeleologia nacional que dava os primeiros passos no Rio de Janeiro com o pedido de uma mulher pioneira.

3.3. Sônia Macedo de Oliveira

Sônia nasceu em São Paulo, no ano de 1937. Seu pai, Trajano Soares, era médico e proprietário rural em Miguelópolis, interior de São Paulo. Sua mãe era ''do lar'' e após a morte do marido, sem conseguir se sustentar em São Paulo, viúva com três filhas, vai para o Rio de Janeiro com a familia, para trabalhar. Por anos trabalhou como costureira, forrando botões e, mais tarde, tornou-se secretária administrativa. Sônia manteve-se na escola e exerceu a licenciatura após se formar. Trabalhou com educaçao de deficientes auditivos no INES, o Instituto Nacional de Educação de Surdos no Rio de Janeiro.

Os familiares relatam a dificuldade da livre participação de Sônia e de suas irmãs nas atividades do Centro Excursionista Pico de Itatiaia (CEPI), no final dos anos 50. Tinham que apresentar autorização de um responsável: pai, irmão ou marido. Sônia, a mais velha das três irmãs, Célia dois anos mais nova e Clélia 4 anos mais nova eram todas solteiras e com o pai já havia falecido. Nesta época era o tio quem assumia a responsabilidade pela participação das três sobrinhas nas atividades do CEPI, apesar mesmo de Sônia já contar 18 anos de idade e poder ser responsável, juridicamente, nos dias de hoje, por suas irmãs. Naquela época, no entanto, mesmo a responsabilidade penal sendo de 18 anos, a responsabilidade civil era de 21 anos, entendendo-se como responsabilidade civil a capacidade de praticar todos os atos da vida civil sem depender de autorização dos pais ou responsáveis legais.

Sonia Macedo de Oliveira resolveu se inscrever no terceiro curso de espeleologia, oferecido pelo CEPI em parceria com o CEL, segundo Sônia Eymard (2024) ''porque era insistente e queria muito fazer este curso''. Christinat (1965) dá outra versão ao caso e indica que Sônia Macedo ''queria acompanhar seu noivo''. Sônia era noiva de Ailton Eymard com quem veio a se casar anos mais tarde.

Como apresentado anteriormente, em alguns momentos a história de Sonia Macedo se entrelaça com a história de Christinat, e é através de seu artigo em francês ''Espeleologia no Brasil'', publicada em 1965 no boletim no 04 de dezembro de 1965 'Les BOUEUX' (Os Enlameados) que temos acesso a fatos que registram a misoginia presente na sociedade carioca/brasileira, e também na espeleologia da época.

As inscrições para o novo curso de Espeleologia começam enquanto Christinat se ocupa do planejamento de uma expedição a gruta de Ubajara, no Ceará. O suíço relata ter sido convocado pelo comitê de espeleologia ''para uma reunião extrordinária''. ''O que estrá se passando ?'', Christinat se pergunta, e segue com seu relato:

> Na hora prevista, chego ao local da reunião, onde sou informado que uma jovem quis se inscrever no meu curso! Mas, os brasileiros estão completamente atordodados e me dizem que não sabem como resolver este grave problema. Como diretor da Divisão de Espeleologia, eles pedem minha opinião ''O que fazer?''. Todos os rostos estão muito sérios. Eu explodo numa sonora gargalhada e respondo ''Diga a ela que o curso começa no dia 21 de junho. Isso é tudo'' (CHRISTINAT, 1965).

Christinat descreve, ainda, os protestos que correram, na assistência, contrários à participaçção feminina no Curso de Espeleologia: *''as*

mulheres não têm nada que fazer nas cavernas"; e mais outro comentário como: *''a opinião pública nunca admitirá uma coisa dessas ''*. Comentários sexistas que denotam uma mentalidade excludente que reinou durante muitos anos nos mais variados ambientes esportivos e profissionais, e que, infelizmente, até os dias de hoje, ainda é posível registarar alguns casos no ambiente da espeleologia e do excursionismo brasileiro. Diante do último comentário de que a participação de uma mulher no curso de espeleologia ''faria mal ao clube'' Christinat se levanta da cadeira, o silêncio se faz na sala, e o europeu então argumenta:

> Vocês sabem, melhor do que eu, que a opinião pública não admitia a espeleologia, assim como não admitia o excursionismo, no entanto, hoje vocês têm, somente no Rio de Janeiro, onze clubes de excursionismo. Por outro lado a espelologia já foi adotada. Vamos deixar a opinião pública de lado. Vocês dizem que uma mulher não tem nada para fazer dentro de uma caverna. Por que razão? Vocês não acreditam que ela seja capaz? ou acham que ela possa se sair melhor do que vocês no curso.

Braga, o presidente do CEPI tomou a palavra: ''Vamos votar. Aqueles que são sontra a admissão do elemento feminino no Curso de Espeleologia, que levantem a mão''. As pessoas permaneceram imóveis e Sônia Macedo de Oliveira, que, aos 20 anos de idade havia pleiteado sua inscrição no terceiro de Espeleologia, para também, segundo Christinat, acompanhar seu noivo que já estava inscrito no curso, foi admitida. Christinat relata, ainda, que após sairem da sala, Juarez, aluno seu em um curso anterior, se aproximou e disse: ''Aposto com você que ela desisitirá do curso na segunda aula prática''. No entanto Juarez perderia a aposta .

O curso teve início em 21 de junho de 1958. O grupo era formado por catorze participantes: oito integrantes do CEPI, três do CEL e três bombeiros militares. O curso terminou no final de agosto com a desistência de quatro participantes. Para a surpresa de todos, Sônia continuou até o fim (Fig. 1).

CENTRO EXCURSIONISTA PICO DO ITATJAIA

Departamento Técnico de Espeleologia

CERTIFICADO

O Centro Excursionista Pico do Itatiaia, confere à Srta. Sonia Macedo Oliveira o presente Certificado por haver concluido com aproveitamento o Curso Especializado de Espeleologia do ano de 1958

N.º 10

PRESIDENTE

DIRETOR DO DEP. TÉCNICO DE ESPELEOLOGIA

Figure 1: *certificado emitido a Sônia M. de Oliveira pela conclusão no curso de espeleologia, assinado por Albiges dos Santos Braga e Jean Louis Christinat.*

Sônia encerrou o curso com méritos após a prova prática intermediária na Gruta do Mero, que fica aos pés do Pão de Açúcar, onde os grupos anteriores de alunos haviam sofrido bastante no ano anterior por conta das condições adversas do mar. Neste ano o mar estava mais calmo e a caverna já era bem descrita. Christinat que relata:

> mesmo assim era preciso uma dose de coragem e de conhecimento técnico para afrontar essa caverna. Sônia, junto aos nove alunos restantes, triunfa brilhantemente na prova (CHRISTINAT, 1958).

Em outros relatos, Christinat relata as dificuldades de se adentrar a Gruta do Mero pois a cavidade apresentava dificuldades aos espeleólogos pois *''O movimento das ondas, trocos atravessados, a quantidade de mariscos presos às rochas, enfim nada fácil''* (Fig. 2). Por seu pioneirismo, após concluir o Curso de Espeleologia, Sônia conquistou seu diploma e foi matéria de jornais e revistas (Figs. 3 e 4). Concluiu, ainda, e já casada, o 'Curso Técnico de Guias de Montanha' do CEL, tornando-se guia do clube em 1962 (Fig. 5). Se nos dias de hoje as mulheres ainda são minoria nos corpos técnicos de guias de todos os clubes excursionistas, na década de 60 era ainda mais raro, constatação que ratifica o pioneirismo de Sônia também no excursionismo.

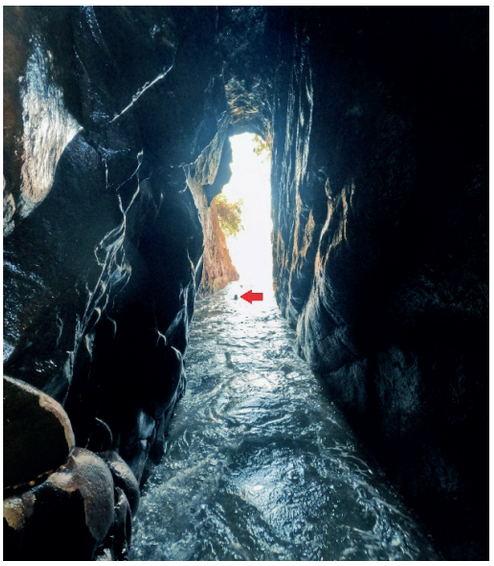

Figura 2: *imagem interna da gruta do Mero, no Rio de Janeiro (na seta vermelha, destaque para a imagem de um mergulhador profissional).*

Domingo, 26 de Outubro de 1958

Diário Excursionista

C. M. Bandeira

SÔNIA MACEDO DE OLIVEIRA A PRIMEIRA ESPELEÓLOGA DO BRASIL E DA AMÉRICA

Sônia, A Primeira Espeleóloca

Figura 3: *recorte de jornal que aponta o pioneirismo de Sônia Macedo de Oliveira (acervo familiar).*

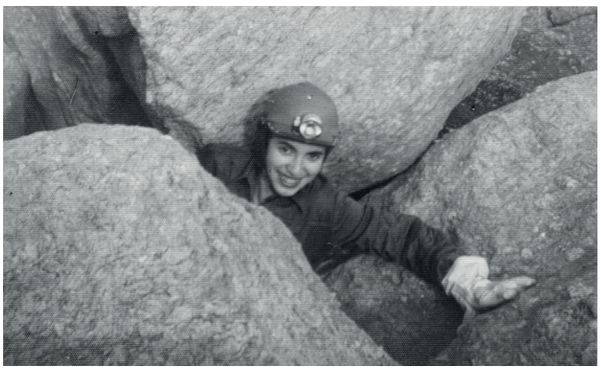

Figura 4: *Sônia Macedo de Oliveira surge dentre as pedras em fotografia do acervo da família (1958) e foto que circulou nas mídias impressas do Rio de Janeiro.*

CLUBE EXCURSIONISTA LIGHT

EXCURSIONISMO — MONTANHISMO — ESPELEOLOGIA — CIÊNCIA

CERTIFICADO

A Diretoria do Clube Excursionista Light, tem a honra de conceder o presente certificado a

Sonia Oliveira Eymard, Guia Montanhista. Diplomada pela E.T.G.E. no ano de 1961

Rio de Janeiro, E. G. 18 de Janeiro de 1962

Presidente

Diretor Técnico Geral

Sonia Oliveira Eymard
Associado

Figura 6: *diploma conferido a Sônia após etar casada com Aylton Eymard .*

4. Considerações finais

Ao buscar resgatar o pioneirismo de Sônia Macedo de Oliveira nos deparamos com uma realidade não muito distante de nossos dias, sendo impossível desvincular sua história da sociedade patriacal machista dos anos 50. Sua filha relata a orientação da mãe da importância do voto e de se votar em candidatas mulheres. Ainda hoje, as mulheres ainda são minoria no meio dos espeleólogos, escaladores e de todos os outros chamados ‘’esportes de aventura’’ muito por conta também de uma educação esterotipada, preparando as futuras mulheres para serem esposas e mães: meninas brincam com bonecas (futuras filhas) e homens brincam com bolas e carrinhos. Em 1941 o Presidente Getúlio Vargas assinou um decreto-lei (32.199 art. 54) que excluía as mulheres de praticarem esportes que não fossem ‘’adequados à sua natureza’’. O Conselho Nacional de Desportos publicou, então, uma lista de esportes que não poderiam ser praticados por mulheres, entre os quais o futebol, o beisebol, o halterofilismo e as lutas. Argumentava-se que estes esportes poderiam levar a alterações orgânicas, ‘’afetar o equilíbrio psicológico e prejudicar a capacidade das mulheres de serem mães’’. De acordo com Vilela (2023) ‘’tudo não passou de uma tática para limitar a liberdade das mulheres, suas atividades no tempo livre e suas capacidades de expressão’’. Esse decreto foi revogado somente em 1979 e o futebol feminino regulamentado em 1983 (Vilela, 2023). Poderíamos falar também em um medo cultural da mulher: as meninas são criadas mais presas, mais impedidas de correr riscos naturais. Frases que até hoje ecoam na sociedade e orientam mais as meninas do que por meninos, tais como: ‘’Não corra, você pode se machucar !’’, ou ‘’não suba aí nessa árvore, você vai cair’’ ou ‘’Não fica bem para uma menina ficar subindo em árvores’’. A superproteção das meninas acaba criando um medo cultural do risco e o esterótipo: ‘’Isso não é coisas de menina’’ e também contribuem para uma falta de mais iniciativas e ações independentes e aventureiras no mundo feminino.

Felizmente vemos várias mulheres escaladoras conquistando vias difíceis, assim como espeleólogas destemidas explorando cavernas perigosas e altamente técnicas. Contudo, no Brasil, as mulheres ainda são minoria. O Censo Espeleológico de 2018 revelou que apenas 27% dos praticantes da espeleologia são mulheres e 73% são do gênero masculino, ou seja, apenas um 1/4 dos praticantes da espeleologia são mulheres. Uma das autoras desse artigo fez a ‘Escola de Guias de Montanha da Federação de Montanhismo do Rio de Janeiro’ em 1979 e foi a única aluna mulher em um universo de catorze alunos. Hoje a Sociedade Brasileira de Espeleoloiga e o Centro Excursionista Carioca no Rio de Janeioro contam com uma diretoria exclusivamente feminina, no entanto, contrastando com esse fato a presença feminina nos corpos técnicos de guias em atividade regular nos clubes excursionistas do Rio de Janeiro não chega a um quarto do total de guias, inclusive existe um centro excursionista no Rio de Janeiro que conta apenas com uma mulher no Corpo Técnico de Guias guiando regularmente excursões e escaladas.

Esse panorama vem se transformando aos poucos, e cada vez mais vemos mais mulheres ocupando espaços nos chamados « esportes de aventura ». Hoje as mulheres espeleólogas e as mulheres escaladoras encorajam suas filhas. Acreditamos que em um futuro próximo alcancemos uma paridade, graças a caminhos abertos por mulheres como Sônia Macedo de Oliveira que com sua garra e teimosia provou que lugar de mulher é onde ela quiser, inclusive na caverna!

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Contributions to the Biography of Speleologist Jean-Louis Christinat

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Abstract

Jean-Louis Christinat, a Swiss speleologist, played a crucial role in introducing and developing speleology in Brazil. Arriving in the country in late 1956, in a few weeks he became involved with enthusiasts of sports like excursionism and began offering speleology courses and leading expeditions. Christinat was a pioneer in several areas, such as promoting speleology through the media, training new speleologists, and founding a Brazilian Speleological Society (SBE) in 1958, although the attempt was not sustained. Additionally, his research and publications significantly contributed to the knowledge of Brazil's speleological heritage and history. Beyond caves, he was a researcher in ethnology and a great promoter of cordel literature, as well as a defender of caves in Switzerland. Christinat's story is an inspiring example of how passion for speleology and the desire to share knowledge can transform a country.

Resumo

Jean-Louis Christinat, espeleólogo suíço, desempenhou um papel crucial na introdução e desenvolvimento da espeleologia no Brasil. Chegando ao país no final de 1956, poucas semanas depois se envolveu com interessados de modalidades esportivas como o excursionimo e passou a oferecer cursos de espeleologia e liderando expedições. Christinat foi pioneiro em diversas áreas, como a divulgação da espeleologia através da mídia, a formação de novos espeleólogos e a criação de uma Sociedade Brasileira de Espeleologia (SBE), em 1958, embora a tentativa não tenha tido continuidade. Além disso, suas pesquisas e publicações contribuíram significativamente para o conhecimento sobre o patrimônio e história da espeleologia brasileira. Para além das cavernas, foi um pesquisador em etnologia e grande incentivador da literatura de cordel, além de defensor das cavernas na Suíça. A história de Christinat é um exemplo inspirador de como a paixão pela espeleologia e a vontade de compartilhar conhecimento podem transformar um país.

1. Introduction

Brazilian speleology has a long history related to the sciences developed in Europe. The first scientific studies of caves in the 18th century, conducted by Alexandre Rodrigues Ferreira (1756–1815) - a Brazilian explorer who studied at the University of Coimbra and brought back the naturalist ideals of understanding nature to exploit it - in his Viagens Filosóficas, revealed curious cavities in the state of Mato Grosso do Sul that were used in the service of national border demarcation (Lima et al., 2015). Also a naturalist, José Vieira Couto (1752–1827), a contemporary of Alexandre Rodrigues who also studied in Portugal, explored caves in Minas Gerais (MG) with the aim of extracting saltpetre, a strategic mineral used in the manufacture of gunpowder (Faria & Filgueiras, 2021).

In the 19th century, the works of the Danish naturalist Peter W. Lund (1801–1880) stand out. He produced the first maps and reports on the caves of the 'Rio das Velhas' valley, thus developing speleology as a tool for the search for fossilized remains. The descriptions and maps of the caves he explored still serve as a guide for the visitation and rediscovery of numerous caves, among which the important Gruta do Maquiné, MG, stands out (Fernandes & Faria, 2024). Similar inspiration was given to the speleology of São Paulo state (SP) by Richard Krone (1861–1917), the German who studied the caves of the 'Rio Ribeira' valley (Martins, 2023), in the south of the state, a place that today houses one of the most important conservation units focused on cave preservation, the 'Parque Estadual Turístico do Alto Ribeira' (PETAR).

Still in SP, it was through the efforts of French speleologists that the initiative to form the Brazilian Speleological Society (SBE) as we know it today took shape. Its foundation in 1969 was thanks to Michel Le Bret and Pierre Martin, Frenchmen who received support from the 'Sociedade Excursionista e Espeleológica' (SEE) in the city of Ouro Preto (MG) in organizing events that made it possible to bring together Brazilian speleologists. However, before this date, the Swiss Jean-Louis Christinat had already attempted to create a national society focused on speleology in Brazil, starting in Rio de Janeiro. This article aims to retell this story, previously narrated by Felizardo (2013), expanding on the references to facts and news related to Christinat in Brazil, which greatly influenced speleology as both a sport and a science as we know it today in our country.

2. Materials and Methods

This work is based on a series of bibliographies that, although known, were little explored by historians of Brazilian speleology but still reveal much about the formation, work in Switzerland and Brazil, and continuity of Jean-Louis Christinat's efforts. The originals in French or German were translated with the help of online translators, which did not hinder the historical analysis of the facts.

Articles from magazines and newspapers contemporary to the years of greatest intensity of Christinat's work upon arriving in Brazil in the late 1950s were consulted at the 'Hemeroteca Nacional' of the 'Biblioteca National' of Rio de Janeiro. Most of these texts were aligned with content published in other languages.

3. Results

Among the bibliographic sources consulted, the one that provided the most information about the life of Jean-Louis Christinat came from the stanzas of a *Cordel* (a popular Brazilian literary genre characterized by verses, rhymes, singing, music, and illustration; as we will see later, Christinat found in *cordel* literature a great source of research). The biographical verses address the place and date of his birth, Geneva - December 3, 1933 - the fact that he was an only child, and that he completed a vocational course, becoming an important decorator in a short time (Silva, n.d.). In his book *Höhlen, Urwald und Indianer*, Christinat (1969) states that he was 17 years old when he was still an apprentice visual merchandiser, the same age at which he made contact with the Geneva section of the Société Suisse de Spéléologie (SSS), which at the time was presided over by Charles Roth. His passion for the caves of the Alps and Jura mountains made him a voracious reader of the books of Norbert Casteret and Felix Trombe-Payout. In a short time, he became an active member of the SSS's field activities, which allowed him to explore a series of caves and abysses, such as the one where he found "Alfred"—the skull of a French militiaman (Fig. 1), likely killed during World War II (PHC, 2012).

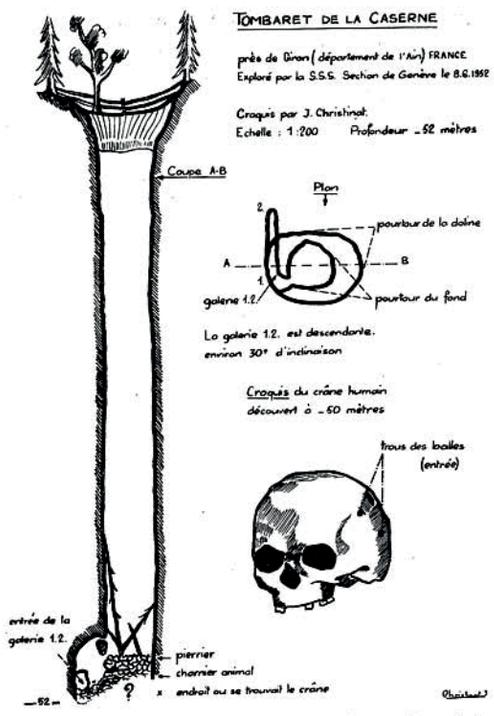

Figure 1: *Sketch drawn by Christinat of the Buclaloup Abyss, with a detail of a human skull with "bullet holes" (PHC, 2012).*

After five years of intense activities with the SSS in the caves of the Geneva region, Christinat decided to take a different path in life and accepted a position as a merchandiser in RJ, where he departed on December 6, 1956. In his luggage, in addition to his speleology equipment and books, Christinat brought a letter of recommendation from the SSS to become the delegate of Swiss speleology in South America. Without speaking Portuguese, the young speleologist sought information about caves or speleological associations in Brazil in books and scientific articles. The few accounts he found only described tourist caves that were still little explored. He then decided to take a more aggressive approach and requested the publication of a small note in the January 19, 1957, issue of Manchete magazine to «get in touch with Brazilian 'elements' interested in the subject" (Fig. 2).

UM HOMEM DAS CAVERNAS

Está no Rio, vindo de Genebra, o jovem suiço Jean Chrispinat (23 anos), decorador, que vem colaborar com uma grande loja da cidade. Mas foi também enviado pela Societé Suisse de Spéléologie, para entrar em contato com os elementos brasileiros interessados no assunto. Tentará demonstrar a utilidade que podem oferecer as explorações de cavernas naturais do subsolo. Com sete anos de atividade, já participou de numerosas explorações, na Suiça e na França, dirigindo algumas. É autor de reportagens sôbre essas explorações, sôbre as quais trouxe documentação completa, além do material necessário para realizá-las no Brasil.

Figure 2: *Article in Manchete magazine highlighting Christinat's arrival in Rio de Janeiro.*

Thanks to this article, members of the Centro Excursionista Pico do Itatiaia (CEPI) sought Christinat to instruct the "first speleologists in South America." Agenor G. R. Mariz was the president of the CEPI and acted as the Swiss's interpreter during the period when he was responsible for the "speleology section of the CEPI" to help train the first group of young people interested in exploring caves. Still in 1957, weeks after his arrival, Christinat began organizing the course and encountered obstacles he could not overcome: the difficulty in acquiring equipment (such as lanterns, coveralls, and helmets) and the near absence of caves in Rio de Janeiro that could serve as a test for the first students.

In addition to training new speleologists, Christinat was determined to promote the science to attract public attention and, in this way, achieve his ultimate goal of creating a Brazilian speleological association. Thus, his course and the support he offered to excursionist clubs in RJ were constantly featured in newspapers. But it was the final field test of the course that garnered the most media attention at the time. In the absence of larger caves, such as the limestone caves of his homeland, Christinat and the students decided to explore the "Gruta do Mero," a granite fissure at the base of Pão de Açúcar, at Praia Vermelha. The same Manchete magazine reported the adventure: «Worm-men pierce Pão de Açúcar." The article continued to speak of the imminent risk and Christinat's skill in accessing the cave by climbing the east wall of the cavity, which is at sea level. The waves hitting the rock, sharp molluscs shells, and logs stuck in the surf were the greatest obstacles for him and his students (Fig. 3).

Figure 3: *Christinat inside Gruta do Mero (above) and a sketch of the 47 meter cave where they conducted the topography. Source: Manchete, 1957.*

Christinat redescribed his adventure in training the students in 1985, providing details about the Pão de Açúcar cave, which now measures "four meters wide... eight meters long, open to the sky, and after another 11 meters, it plunges under the mountain" (Christinat, 1985). The graduates of this course included Agenor G. R. Mariz, Albigez S. Braga, Antonio F. Radetic, Fred V. Wuensche, Jair Moura dos Santos, Jorge Juarez de Sousa, Reinaldo G. Soares, and Fludi V. Ceccon (some names are misspelled in the text of the Diário de Notícias from March 16, 1957). However, Christinat did not consider this number of students sufficient but understood that it would be better to offer another course only the following year.

In August 1957, another mission was proposed - to evaluate a cave reported in newspapers on 'Morro do Itapicuru' in Rio de Janeiro. The news spoke of a cave where murmurs and fire came from the interior of a cavity that seemed endless. Excited by the challenge, the Swiss and his students invited a team of journalists and photographers and went to the site at night, near a typical Rio 'favela'. His description of the rock equates it to weathered gneiss, and the "cave" was rarely more than 80 cm wide (Fig. 4). The strangeness of the place, the pickaxe marks, food remains, drinks, and candles led to the conclusion that the 400 meter "cave" was actually a tunnel dug by criminals, serving only as a hideout during police searches in the community (Christinat, 1969; Christinat, 1986). Days later, it was destroyed by local police.

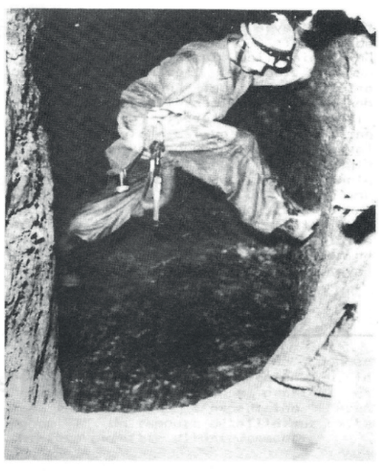

Figure 4: *Photo of one of Christinat's students exploring the artificial cavity of Itapiru, RJ.*

In January 1958, Christinat and his team decided to offer the second edition of the speleology course, aiming to have enough trained individuals to initiate a national speleological association. For this, more excursionists became students. At this time, the European no longer worked as a visual merchandiser and survived thanks to articles and texts about Brazil that he wrote for newspapers in his homeland. Before him now was a major project: to film inside of Gruta do Maquiné, about 400 km from RJ, in Minas Gerais (MG). A team from Tupi television was interested in the subject as it would be the "first underground filming in Brazilian TV". This would be the second time Christinat visited the cave, as in 1957 he made a four-day expedition during which he explored the cave and found "previously unrecorded underground conduits" that extended Maquiné by 100 meters (Christinat, 1969). However, these corridors referred to by Christinat were not found in modern works (Fernandes & Faria, 2024). Enthused by the presence of Professor Carlos de Paula Couto (1910–1982) from the Museu Nacional of RJ and with the encouragement of government institutions, Christinat created a poster to promote the expedition, writing alongside the title "Expedition to Gruta de Maquiné" the names "Brazilian Speleological Society – National Museum – TV Tupi" (Christinat, 1969).

In Gruta do Maquiné, the filming proceeded slowly due to the need for lighting powered by heavy generators, while Paula Couto's work focused on studying the cave's bats. The film reels captured beautiful images of rare and delicate speleothems, as well as the efforts of the speleologists in search of new corridors in the cave. The filming was a great national success and was featured in Rio de Janeiro's printed newspapers (Fig. 5) for several months. Unfortunately, it appears that the film reels were lost from the archives of Tupi television, which was later extinguished, and its deposit was the target of fires.

Gruta de Maquiné: Natureza Produz Obra Prima em Minas

Reportagem de SILVIO REMER

Curiosas figuras são formadas pela rocha úmida.

Os estalagtites representam grande atrativo.

Figure 5: *Excerpt from the newspaper A Noite highlighting the Tupi television feature, aired in Rio de Janeiro on March 17, 1961; note the text pointing out that "it was organized before the inauguration of the S.B.E., an expedition to the cave."*

After the filming, the CEPI prepared for another speleology course, the third, and an expedition to 'Gruta do Ubajara' in the state of Ceará, which could solve the problem of previous expeditions that failed to explore "a vertical chimney through which a waterfall flows" and which had been the stopping point for previous explorers (Christinat, 1969). Unfortunately, the expedition to Ceará never materialized.

Before starting the course, Christinat was called to resolve a "problem" that mobilized the entire CEPI board and created tension among members: a woman - Sônia Macedo de Oliveira - had signed up for the new speleology course scheduled for mid-1958. In the tense meeting that would decide the issue, the Swiss "burst into laughter" and commented: "Just let the girl know that the course starts on July 21. And that's it!" (Christinat, 1969). The CEPI members main concern was that

"public opinion" would not allow such an activity and that "caves were no place for women." The group finally agreed to Sônia's enrolment, believing she would "drop out after the second practical exercise." Sônia Macedo de Oliveira completed her course after all the rigorous theoretical and practical tests that Christinat offered (and for which he became known as the "crazy Swiss" among students). Her graduation, instead of receiving criticism, was one of the most praiseworthy initiatives of the time, garnering attention on radio and newspapers as the "first female speleologist in South America." The following year, Sônia married Aylton Eymard, both from the Centro Excursionista Light (CEL), and her daughter, Sonia Eymard, still keeps her mother's memories alive as a pioneer of Brazilian excursionism (Fig. 6).

SÔNIA MACEDO DE OLIVEIRA A PRIMEIRA ESPELEÓLOGA DO BRASIL E DA AMÉRICA

"CAVERNOSA"

PELA primeira vez no Brasil e na América do Sul, formam-se um técnico em espeleologia do sexo feminino, colocando o nosso país em condições de igualdade com as nações mais adiantadas do velho mundo. O Centro Excursionista Pico do Itaiaia e Clube Excursionista Light, por intermédio de seus Cursos Especializados de Espeleologia, em conjunto, acabam de jogar a segunda turma de Técnicos Espeleólogos (1.º do C.E.L.), tendo a glória de ser o precursor da introdução da mulher brasileira na prática dêste esporte-ciência no continente americano.

A láurea cabe à jovem brasileira, professôra do Instituto dos Surdos-Mudos, senhorita Sônia Macedo de Oliveira, entusiasta do Montanhismo e Excursionismo, participando de várias dezenas de escaladas nas nossas principais montanhas, sócia do Clube Excursionista Light, desde junho de 1957.

Sônia, A Primeira Espeleóloca

Praticando e aprendendo um ramo, de esporte e misto de ciência, a jovem sônia, após vencer os mais difíceis lances de caráter técnico, realizando descidas em perigosas fendas vochosas, grotões de grande profundidade, passagens estreitíssimas e tortuosas, escalou de paredões verticais e

Figure 6: *Montage of newspaper clippings from 1958-1959.*

Having trained three groups of new speleologists, Christinat believed he could now count on a good number of practitioners to continue the creation of the SBE - the Brazilian Speleological Society, as he had planned. However, he was concerned about the involvement of scientific institutions in RJ in organizing the society, as he envisioned an association with an ambiguous character between sport and science. As the foundation of the SBE was taking shape, it would be solely academics responsible for the new institution. Nevertheless, he understood that this association could give governmental validity to the SBE and contributed to its creation, helping draft the statute and design a logo.

On August 14, 1958, a meeting at the CEPI headquarters with a hundred people marked the beginning of the SBE (Fig. 7). Groups of cave enthusiasts (who watched in awe the film about Gruta do Maquiné) in São Paulo, Ceará, Minas Gerais, Bahia, Mato Grosso, and Santa Catarina states already showed interest in joining the SBE. The periodical O Jornal of August 24, 1958, highlights that:

> ''The new society has as its objectives the exploration of caves, surveys of anti-atomic shelters, the underground hydrological system, and the promotion of tourism... Elected as president was Raymundo Pimentel Gomes, geographer and agronomist... vice-president Professor Carlos de Paula Couto... and composed of six department directors" (O Jornal, 1958).

The board would have a two-year term, from August 14, 1958, to December 31, 1960. Throughout 1958, the Rio de Janeiro media echoed notes and decisions published by the SBE, reporting on headquarters addresses, new members and directors, sections to be opened in other cities, and even the justification for not attending the International Congress of the UIS in Bari, Italy, in 1958 (a letter was sent explaining the absence).

Na foto, o sr. Agenor Gastão de Roure Mariz, um dos diretores da SBE, quando discursava no ato inaugural da referida sociedade.

Figure 7: *Inauguration of the SBE directors in 1958.*

In the three years that followed, newspapers reported the constant change of the headquarters address and provided little news about the Society's actions. From 1962 onward, no reported actions of the SBE were found, suggesting it was disbanded. According to Pierre Martin (1979):

> "Unfortunately, due to adverse circumstances, the SBE's plans were far more ambitious than its achievements, which were limited to a few explorations in Minas Gerais and the surroundings of Rio de Janeiro, as published in periodicals of the time".

Christinat never pointed out in his articles or book the reasons for the end of the SBE, which he helped found, and limited himself to describing that he withdrew from the society because he never cared for bureaucratic work and believed it was now up to Brazilians to continue the efforts. He proposed only to contribute through expeditions and courses. Christinat felt trapped in the big city and, as his new activity as a journalistic correspondent allowed, he wanted to explore the hinterlands and jungles of Brazil. On March 25, 1959, just over two years after his arrival in Rio, he boarded a plane and travelled to the interior of the state of Mato Grosso (MT) to join the 'Fundação Brasil Central' and support the work of Catholic missionaries. He spent almost a year among the Xavante indigenous people, on the banks of the Rio das Mortes, and had the opportunity to explore a limestone cave he named 'Gruta Santa Terezinha.' This cave is likely the one registered under the code MT-35 in the National Cave Registry (CNC), and the description of its interior matches what Christinat narrated:

> A first chamber about 100 meters wide. The dark mass of the irregular ceiling rises about 60 meters above me. This hall still receives some light from the entrance, filtered through the vines... Suddenly, I see a deep, clear lake to the left. It is impossible for me to discern the extent of the lake because it disappears into the darkness of invisible vaults (CHRISTINAT, 1969).

However, despite this new discovery, Christinat was even more impressed by life among the indigenous people. Their primitive way of life, their communities, and their personal habits would change his professional perspective, and from then on, he was determined to evaluate cultural and social aspects, issues that only ethnology could help him understand. In early 1960, after eleven months in MT, he returned to Rio de Janeiro to work as an editor but soon accepted a job for a few months in Bahia to support the construction of a section of the road linking the state to Rio de Janeiro, the BR-116 (CHRISTINAT, 1969; SILVA, n.d.).

In 1960, Christinat made an important scientific contribution by publishing the article "Speleology" in the 'Geographic Bulletin' of the 'National

Geography Council of Brazil' of the IBGE, in the section 'Contributions to Geographic Science.' He stated that the article was "to guide those who wish to increase their knowledge about underground exploration" (CHRISTINAT, 1960). In the text, he instructs speleologists and speleists (amateurs who explore caves) on the purposes and uses of the science in the search for water resources, fertilizers (guano), tourism, fauna, paleontology, and archaeology. Throughout the article, images and diagrams demonstrate cave exploration and how to represent cavities through maps and profiles. Above all, the message remains about the need to support the study of caves as a "matter of national interest" (CHRISTINAT, 1960).

Also in 1960, Christinat and Michel Le Bret made contact. The Frenchman, who would later found the SBE as we know it today, tried to correspond with the Swiss to seek support in exploring caves in the south of the state of São Paulo (SP), where he and other members of the Clube Alpino Paulista were exploring caves of great relevance. Le Bret learned about the Christinat while still in Paris, and his studies in the city of Apiaí (SP) revealed caves spanning 2 km (CHRISTINAT, 1967). Back in Switzerland in 1961, he gave lectures about his experiences in Brazil but returned in 1962, now hired by the Museum and Institute of Ethnography in Geneva, to study the Erigpactsá indigenous tribe, a small and unknown community near the Juruena river, MT. Among further contributions to the Museum or even serving as a newspaper correspondent during his travels to other countries (such as Greece, Egypt, Israel, and Lebanon), his new contact with speleology in South America was in Peru, where he was once again hired by the Museum to study Andean populations. In 1967, he described this contact in "First Impressions of Peruvian Speleology":

> "Being in charge of a mission in a Latin American country where speleology is not yet practiced does not mean arriving with a helmet, lantern, and ladders to descend into the first hole that presents itself. My task is not to accumulate discoveries and underground explorations but to work to promote speleology, explaining its objectives, methods, and techniques, placing my knowledge and experience at the service of Peruvian institutions in the field, whether scientific or lay. Nor should we neglect what has been done by Peruvians or foreigners, even if the few works carried out cannot be qualified as 'speleological work'" (CHRISTINAT, 1967).

The Swiss seemed want to use his experience with Brazilian speleology to meticulously approach the proposal of helping to found more societies in countries across the Americas. For this, he contacted the head of the 'Sociedad Geografica de Lima', Mr. Emilio Romero, who promised to support his attempt to establish another association. Christinat's *modus operandi* was once again to draw public attention to caves, requesting that photos of the caves he explored in Switzerland be published in prominent periodicals in the Peruvian capital. This action secured the front page of the newspaper with the headline "The Entrails of the Earth", along with two pages of text and images. However, Christinat (1967) does not describe visiting any of the caves in Peru and only concludes the text by affirming the need to create a Peruvian speleological society to focus on the country's vast speleological heritage.

Back in Geneva, Christinat dedicated himself to the Museum of Ethnology as its Director of Expeditions and became active again in the speleology of his country, contributing to newspapers and bulletins of the associations he was part of. His connection with Brazil, however, was never severed, and he always returned in search of new research subjects. For a long time, he was the main promoter of Cordel literature, which he discovered in Rio de Janeiro during a visit to the 'Academia Brasileira da Literatura de Cordel'. His name and image (Fig. 8) are associated with numerous verses, and three booklets tell of his biography (SILVA, n.d.), his passion for cordel (SILVA, 1996), and even an incident where he was victimized by thieves in Northeast Brazil while researching local culture (SILVA, 2000).

Figure 8: *Photograph of Christinat featured in the cordel "The Life of Dr. Jean Louis Christinat" (SILVA, n.d.).*

Among his many achievements, Jean Louis Christinat was an honorary member of the SSS, a member of the Spéléo-Club des Montagnes Neuchâteloises (SCMN), accepted as a member of the Speleo Club of Paris, President of the Association of Friends of the Museum of Neuchatel, father of four girls, a protector of Swiss caves against pollution and their use as garbage dumps, and a great promoter of *cordel* literature in Brazil (having been a sponsor and honoured in several poems).

4. Final Considerations

It is impossible to talk about Christinat in just six pages. The magnitude of the man and his work transcended borders and languages, earning him the sympathy and respect of his colleagues and helping to write an important chapter in global speleology. May Christinat's example serve as a reference in seeking knowledge to share it, promoting the importance of caves even without financial support, and balancing boldness and respect in the pursuit of protecting speleological.

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Caves and underground world in literature and cinema based on classical works: karst landscape and cultural speleology

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Abstract

The aim of the work was to analyze the representations of the underground world in literature and cinema, verifying the caves and the karst landscape in their geographicity. The theoretical basis was Gaston Bachelard's phenomenology of poetic imagination and ecogeopoetics, with contributions from Cultural Geography and the multi-referential approach. The idea was to delve into real and metaphorical caves, highlighting the classic authors of best-sellers related to science fiction, fantasy and adventure, which were transferred to the cinema: 1) Jules Verne (*Journey to the Center of the Earth*, 1864); 2) Mark Twain (*The Adventures of Tom Sawyer*, 1876); 3) J.R.R. Tolkien (The *Hobbit*, 1937 and *The Lord of the Rings*, 1937-1949-production, 1954-1955, publication) and 4) Frank Herbert (*Dune*, 1965 to 1985). We sought to describe the rational and symbolic landscapes involved with the natural cavities present in the selected works. A diversity of views was observed that contextualize the role of caves in the plot, highlighting: adventure, fantasy, trials, mystery, struggles, treasures, portals, spiritual and sacred aspects. These literary-cinematographic works allow reflections on the cave environment and can be used in environmental education activities and the dissemination of speleological practices, in order to rethink the world experienced and represented.

Resumen

El objetivo del estudio fue analizar las representaciones del mundo subterráneo en la literatura y el cine, verificando las cuevas y el paisaje kárstico en su geograficidad. La base teórica fue la fenomenología de la imaginación poética de Gaston Bachelard, ecogeopoética y la multirreferencialidad. Se trató de adentrar en cavernas reales y metafóricas, destacando los autores clásicos de best-sellers relacionados con la ciencia ficción, fantasía y aventura, que fueron trasladados al cine: 1) Julio Verne (*Viaje al Centro de la Tierra*, 1864); 2) Mark Twain (*Las Aventuras de Tom Sawyer*, 1876); 3) J. R.R. Tolkien (*El Hobbit*, 1937 y *El Señor de los Anillos*, 1937-1949-producción, 1954-1955, publicación) y 4) Frank Herbert (*Duna*, 1965 a 1985). Se describió los paisajes racionales y simbólicos involucrados con las cavidades naturales presentes en las obras seleccionadas, provenientes de la imaginación textual o de las imágenes utilizadas. Hubo diversidad de visiones que contextualizan el papel de las cuevas en la trama, destacando: morada, aventura, fantástico, calvario, misterio, luchas, tesoros, portales y el sagrado. Estas obras literario-cinematográficas permiten reflexionar sobre el medio cavernario. pudiendo ser utilizadas en actividades de educación ambiental, difusión de las prácticas espeleológicas, permitiendo un repensar del mundo vivido y percibido.

Resumo

O objetivo do trabalho foi analisar as representações do mundo subterrâneo na literatura e no cinema, verificando as cavernas e a paisagem cárstica em sua geograficidade. A base teórica foi a fenomenologia da imaginação poética de Gaston Bachelard e a ecogeopoética, com contribuições da Geografia Cultural e da abordagem multirrefencial. Procurou-se adentrar em cavernas metafóricas e reais e destacar os autores clássicos de best sellers relacionados com ficção científica, fantasia e aventura e que foram transpostos para o cinema: 1) Júlio Verne (*Viagem ao Centro da Terra*, 1864); 2) Mark Twain (*As Aventuras de Tom Sawyer*, 1876); 3) J, R. R. Tolkien (*O Hobbit*, 1937 e *O Senhor dos Anéis*, 1937-1949-produção, 1954-1955, publicação) e 4) Frank Herbert (*Duna*, 1965-1985). Procurou-se descrever as paisagens racionais e simbólicas envolvidas com as cavidades naturais presentes nas obras selecionadas. Observou-se uma diversidade de visões que contextualizam o papel das cavernas no enredo, destacando-se: aventura, fantástico, provação, mistério, lutas, tesouros, portais, aspectos espirituais e do sagrado. Essas obras literário-cinematográficas permitem reflexões sobre o ambiente cavernícola e podem ser utilizadas em atividades da educação ambiental e difusão das práticas espeleológicas, possibilitando um repensar sobre o mundo vivido e representado.

1. Introduction

Literature and cinema are artistic cultural expressions, much sought after by society in general, and both can create substantial links, providing situations for reflection, relaxation, diverse emotions, knowledge, and entertainment. However, at the same time, they have their own autonomy and characteristics. Literature is the art of words and cinema is moving images. In literary works, a good dose of imagination is required, while in the movies, some things are guided by ready-made images, in some cases they will depend on the interpretation, taste, and understanding

of the spectator. There are necessary conditions to convert a novel into a movie, generating interartistic relationships united by a narrative structure. In the possibility of a good adaptation of literary works, a relationship of proximity and confrontation often persists. The artistic appeal creates moments of harmony with the reader or viewer, however, it can also generate noises of fidelity and understanding and, often, conflicting distances. (GUALDA, 2010; FIGUEIREDO V., 2011; SOTTA, 2015; RANGEL & CURCINO, 2019).

Symbolic landscapes stand out in both artistic-image spaces, aiming to create an environment for the plot of the work and captivate the reader/viewer. The degree of detail in the background of the stories will allow us to stimulate sensory aspects that help us to glimpse details of those environments in which the scene unfolds. BACHELARD (1990, 1998) provides us with important philosophical elements in this sense, with his phenomenology of poetic imagination, which he developed from a reinterpretation of the four elements of the natural world suggested by Empedocles (ancient Greece): air, water, earth and fire. Bachelard is an author who moves between scientific rationality and poetic reveries. He inspired me in previous studies that I had done on the theme of caves in literature and cinema, bringing elements for reflection (FIGUEIREDO L., 2009, 2010, 2011, 2012, 2013).

The research followed Bachelard's phenomenological approach and also geopoetics (WHITE, n.d., 1991; GRATÃO, 2006) or eco-geopoetics (FIGUEIREDO L., 2022).

Regarding the relationship between literature and cultural geography, BROSSEAU (2007, p. 19-20) argues that literary production can be a source *"capable of evaluating the originality and personality of places (sense of place)"* and provide us with eloquent examples of personal appreciation of the landscape, in its broadest sense. Humanist Geography also moved towards the symbolic, identifying and valuing a geography of places, such as the concept of topophilia, affection for places (TUAN, 1980, 2006).

Cinema is also a privileged means of investigating symbolic landscapes, based on images of the places themselves or scenographic landscapes. This medium also allows for approaches to environmental themes, enabling its use in educational activities and scientific dissemination. (BENTE, 2008, FIGUEIREDO L., 2013, FERNEDA, 2017, SILVA-JUNIOR et al, 2023).

Many literary and cinematographic works have speleological content. In previous works and by other authors, elements were observed to understand the symbolic function of the landscape and its relations with literature and cinema. (STEWARD, 2004; PECKHAM, 2004; TRAVASSOS, 2007; FIGUEIREDO L., 2009, 2010, 2011, 2012, 2013).

In the present study, we sought to enter metaphorical and real caves to highlight the classic authors of best sellers in literature related to science fiction, fantasy and adventure and which were transposed into cinema. Among them: Jules Verne (*Journey to the Center of the Earth*); Mark Twain (*The Adventures of Tom Sawyer*); J. R. R. Tolkien (*The Hobbit* and *The Lord of the Rings*); Frank Herbert (*Dune*).

Sometimes the available resources are not adequate to convert a novel into a film, due to a lack of appropriate conditions or technologies, as was the case with Lord of the Rings, The Hobbit, Dune and even Journey to the Center of the Earth. For some works, new versions are made, either due to the impact and interest in the production or to improve the final format.

Therefore, the research objectives were:

- to analyze the representations of the underground world from a multi-referential perspective (BARBOSA, 1998);
- to examine the caves in their geographicity and as a symbolic landscape;
- to recognize the limits between reality and imagination in fantastic and fictional narratives;
- to conduct a plural reading of the underground landscape present in literature and cinema, based on classic works.
- to reflect on the potential for carrying out actions in environmental education and speleological dissemination.

2. Methodological Aspects

For this study, classic works of literature and cinema were analyzed (Fig. 1; Fig. 2). The books and the movies were reviewed several times, identifying the cave scenes and underground symbolism.

In the literature, we sought to highlight textual passages with symbolism or descriptions of caves and the karst landscape in general, using previous work on caves in literature as a support basis (FIGUEIREDO L., 2011). With regard to cinema, we sought scenes from the perspective of film analysis, as proposed by VANOYE & GOLIOT-LÉTÉ (1994) and the work of SILVA-JUNIOR et al. (2023).

The works analyzed were:

1. **Jules Verne (The Journey to the Center of the Earth, 1864)** (Movie: 1959 e 2008). (Science Fiction, a geological expedition to the center of Earth, science and e fantasy) (VERNE, 1994).
2. **Mark Twain (The Adventures of Tom Sawyer, 1876)** (Movie: 1930, 1938, 1973, 1995). (Literary classic, tells us the story of a naughty boy, and his adventures inside a cave). (TWAIN, 1980)
3. **J, R. R. Tolkien (The Hobbit, 1937 and The Lord of the Rings, 1954-1955)** (Movie: 2001-2003; 2012-2014). (Epic-fantastic saga. Imaginary World where men and various fictional beings live together, full of underground worlds). (TOLKIEN, 2001, 2009).
4. **Frank Herbert (Dune, 1965-1985)** (Movie: 1984, 2021). (Classic of science fiction literature. Sociopolitical, religious and environmental saga on a desert planet where water is precious). (HERBERT, 1984).

Figure 1: *Caves in literature-classical works (covers).*

The research was based on my doctoral research in Geography on caves as rational and symbolic landscapes and also on the articles I wrote on the theme of caves in literature and cinema. (FIGUEIREDO, 2010, 2011; 2013).

Figure 2: Caves in the cinema-classical works (posters).

This study proposes to expand the analyses carried out and to deepen the discussions on part of the material collected, focusing specifically on classical works. This option was chosen because, at some point, they stimulated the imagination of people who work in speleology and study caves. And because of works that reached a massive audience (best-sellers).

3. Results: Caves in literature and cinema based on classic works

3.1. Journey to the Center of the Earth (Jules Verne)

The book *Journey to the Center of the Earth*, by Jules Verne (1828-1905), originally published in 1864, is a classic work that had a wide appeal for young readers and even adults. Without a doubt, people interested in caves have already read it or are familiar with the story. Verne creates a text full of adventures and filled with underground passages, allowing visitors to pass through rational and symbolic landscapes. (VERNE, 1994).

Brazilian literary critic Geraldo G. FERRAZ (1994) points out that the text was written as a kind of informal manual to teach young people about the importance of science through literature. Since there was no photography or cinema in Verne's time, illustrations played a fundamental role (Fig. 3). He was a visionary.

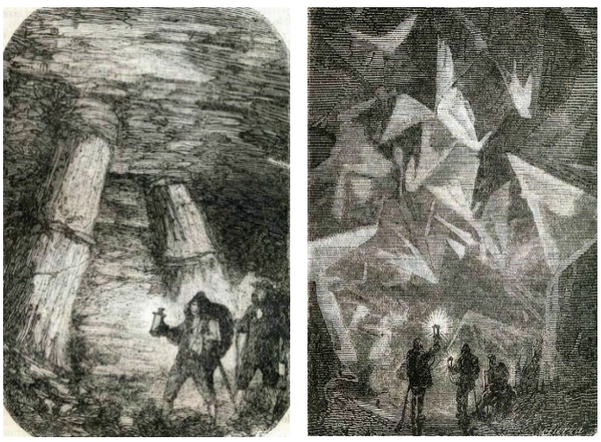

Figure 3: Illustrations from the book "Journey to the Center of the Earth".

The story tells of an expedition carried out by German geologist Professor Lidenbrock, his nephew Axel and a local guide, Hans. The idea was very creative: to descend through a crack in the crater of a volcano in Iceland, reaching the center of the Earth. Diversity of themes: rocks, minerals, underground ocean, missing link, extinct creatures, interspersed with adventures, overcoming difficulties, conflicts between characters, were the fundamental premises for creating a popular book.

The work has been adapted for film on a few occasions. The 1959 version followed the idea of the book more closely, while the 2008 version created a story within the story, based on the concept of the Vernian follower. (Fig. 4).

Figure 4: "Journey to the Center of the Earth": Images from the movies.

3.2. The Adventures of Tom Sawyer (Mark Twain)

In *The Adventures of Tom Sawyer*, originally published in 1876, Mark Twain (1835-1910) presents adventure, caves, games, and a youthful romance interspersed with pirates, treasures, bandits, labyrinths, trials, and friendships. McDougal's Cave, mentioned in the book, is real and is part of the author's life story. It has been open to tourists since 1886. The name of the cave was changed to Mark Twain Cave, located in Hannibal (Missouri, USA). It is still widely visited today due to the notoriety acquired by the famous writer, who is considered the first legitimately American author. (TWAIN, 1980).

Mark Twain's description of the cave demonstrates its labyrinthine characteristics, a very interesting factor in speleological practices. The cave appears in the book as a picnic for teenagers, a moment of joy and freedom. At the same time, the cave is evoked as a game, fun, under the candlelight hiding in the corridors. Nevertheless, the children get lost and end up involved in a rescue situation and a intrigue with a bandit and hidden treasure.

In cinema the work was adapted several times (1930, 1938, 1973, 1995, among others, even in German). (Fig. 5).

Figure 5: *Images from the movie The Adventures of Tom Sawyer.*

3.3. The Hobbit and The Lord of the Rings (J. R. R. Tolkien)

3.3.1. The Hobbit

The first book by J. R. R. Tolkien (1892-1973) was *The Hobbit*, published in 1937, and was well received and publicized, despite being less well known. In this book, Bilbo Baggins lives peacefully in a period before the saga of *The Lord of the Rings*, when he is unexpectedly invited by Gandalf, the wizard, and a group of dwarves to go on an expedition to steal gold from a large and dangerous dragon that lives in a cave in the Lonely Mountain. Several chapters give examples of the adventures and the symbolic underground perspective in the construction of the plot, from the cave-house in Hobbiton, the passages in the mountain, and the treasure found in this cave, an ancient citadel of the dwarves, protected by the merciless Smaug, considered the last of the dragons of Middle-earth. (TOLKIEN, 2009; STANTON, 2002).

The dwarves' songs provoked feelings of adventure, the search for treasure, but also the fear that awaited them. Thus, the intrepid adventurers set off on their journey. In the chapter *Up the Mountain, Into the Mountain*, several passages, suggested by the title itself, are related to caves and all their symbolic aspects. The cave is a shelter to escape the stormy wind and at the same time a place of the unknown. Gandalf does not want to take risks, because the danger is that *"...one does not know how deep they are, or where a corridor may lead, or what is waiting inside"*. After the moment of discomfort caused by the unknown in the underground environment, it immediately transforms into a protective and comfortable shelter, only after a thorough investigation with Gandalf's magic staff. The cavity was *"...of a reasonable size, but not too large or mysterious"*. (TOLKIEN, 2009, p. 59). On the other hand, the cave provided Bilbo with terrible dreams, between the imaginary and "reality". And the adventure begins there. After all, what was a dream or reality, because soon after part of the group was captured by orcs, who took them through an underground labyrinth.

Despite being the first book written by Tolkien, The Hobbit was only made into a film in 2012. (Fig. 6).

Figure 6: *Images from the movie The Hobbit.*

3.3.2. The Lord of the Rings

The book *The Lord of the Rings* was published by Tolkien between 1954-1955, and is full of cave passages. I had already studied caves as literary/cinematic landscapes and highlighted this epic-fantastic work, winner of several Oscars®. (FIGUEIREDO; 2010; 2013).

There is a strong connection between Tolkien and caves, perhaps because they are abundant and studied in England. Colbert (2002) created a guide to answer questions about *The Lord of the Rings*. Among the various themes, the following stands out: Why does Frodo go into caves so many times? The symbolic force used by Tolkien about the trials resulting from passages through the underworld, generally represented by terrifying spaces, can be seen: *"...entering a cave is daring to face the darkest parts of our own mind and soul"* (COLBERT, 2002, p. 45). In the cave, darkness and the unknown test the hero's bravery and weaknesses, opening passages in the mountain and situations that will test you.

In cinema, Tolkien's work was well received with *The Lord of the Rings* trilogy (2001, 2002 and 2003), a while after this triumph came *The Hobbit*, also as a trilogy (2012, 2013, 2014). (Fig. 7-8). And now it is unfolding in the series for streaming platform, with the successful *The Rings of Power*.

Figure 7: *Movie posters of The Lord of the Rings.*

Figure 8: *Images from The Lord of the Rings (Gollum).*

3.4. Dune (Frank Herbert)

In the line of science fiction, Frank Herbert's book, Dune, and the entire series of 6 books (1965-1985) stand out. This work won the most coveted awards in this literary genre, Nebula (1965) and Hugo (1966). The author takes us to the planet Arrakis, known as Dune, which is a gigantic desert and home to the Atreides, the Fremens (or wild men) and the giant and sacred sandworms (Shai-Hulud).

The Fremens live on the political fringes, but have developed superior capabilities for survival in the absence of water, such as the stillsuit, which transforms all excreta into water. In their religious rituals, there is a whole way of preserving water, hiding enormous underground water sources, which will only be used in the future, in order to change life on the planet. (HERBERT, 1985)

The saga tells the story of the struggle, survival and sociopolitical and environmental conflicts of an advanced world, but free of intelligent technologies and computers, where a feudal intergalactic empire reigns, in which several Houses of nobility coexist: Corrino, Atreides, Harkonen, Fenring, along with the female order of warriors, the Bene Gesserit. These Houses fight for control of Arrakis (Dune), the only planet in the universe that has a rare concentration of a spice (Mélange) that is capable of prolonging the user's life, in addition to allowing clairvoyance, sensory expansion and fuel for spaceships.

The cave is where the Fremen live. There they carry out their activities, rest, but also practice their purification and preparation rituals. The water is sacred, few people have contact with it and it is hidden in an underground lake inside the sandstone cave.

Two versions have been made for the cinema. In 1984, the film was produced by Dino De Laurentis and directed by David Lynch. The other, from 2021, was made as a trilogy, produced and directed by Denis Villeneuve, a version that has been better accepted by the public, whether by the actors or by the available technology. (Fig. 9).

Figure 9: *Images from the movie Dune.*

4. Discussão

Table 1 summarizes the literary and cinematographic works selected for the study, characterizing the scientific themes involved, the landscape typologies, speleological aspects and associated subjective and symbolic issues.

Despite the diversity of images (literary and cinematographic) in the works studied, it was observed that there are some similarities in symbolic aspects, such as: adventure, friendship, leadership, perseverance, challenges, heroism, struggles, power, greed and the need for social organization to overcome oppression. However, there are specificities in the typology of the underground landscape.

Regarding the typology of the caves and the surrounding landscape, it is clear that in Journey to the Center of the Earth a mountainous landscape predominates, composed of igneous rocks, lava tubes and quartz crystals. In The Adventures of Tom Sawyer, the features are typical of a karst landscape on a mountainous escarpment near the Mississippi River. The presence of large halls, decorated with stalactites, stalagmites, curtains, travertines and columns highlight the caves in carbonate rocks.

In The Hobbit and The Lord of the Rings, the caves are more fantastical, they are gigantic underground worlds occupied by various beings such as dwarves, elves, orcs and other monsters, and many challenges, adventures, battles, conflicts and overcoming. As an example of the symbolic role of the cave, the moment of falling into the abyss in Moria (Khazad dûm) does not mean the death of Gandalf the Grey but rather a process of transformation, with the emergence of Gandalf the White.

In the case of Dune, the cave occupies a secondary position in the plot, but it is crucial to the story portrayed in the book and the film, since the cave is where the Fremens, the only natives of Arrakis, live and organize themselves, having adapted to a very unique life, without any water. The water exists in an underground lake, however, only for ritualistic purposes and rites of passage, with religious connotations. This water is the best kept secret and allows the Fremens to go against their oppressors.

The cave appears in all the books as an important backdrop to the stories portrayed. All of these works provide scientific themes that can be used to teach Natural Sciences and Environmental Education; however, they have a strong interdisciplinary appeal and cover a wide range of themes: politics, economics, psychology, technology, etc.

This subject provides reflections on the role of human beings or even inhuman beings, as described in the books, on the future of the planet we live on and how the countless conflicts compromise the experience of well-being and coexistence in difference, translating a lot about the situation of the current world.

From a more technical point of view, the works also encourage observation of the types of caves, the degrees of difficulty, exploration and safety issues. The places described also stimulate speleotourism trips.

Table 1: *Comparative characteristics of the literary works analyzed (alphabetical order).*

Author / Parameters	Jules VERNE Journey to the Center of the Earth (1864)	Mark TWAIN The Adventures of Tom Sawyer (1876)	J. R. R. TOLKIEN The Hobbit (1937)/The Lord of the Rings (1954-55)	Frank HERBERT Dune (Saga, 1965-1985)
Scientific Thematic	• Caves • Evolution • Scientific Expedition • Fauna (prehistoric) • Physics (magnetism, free fall) • Forests, fungi • Laboratory, chemical elements • Rocks and minerals • Volcanism (eruption)	• Caves • Metals • Mountains • River • Rocks	• Caves • Chemical elements • Forests (Deforestation) • Medicines/poisons • Metals • Mountains • Rivers • Substances • Volcanism (eruption)	• Caves • Desertification • Fauna • Hallucinogens • Metals • Rocks/minerals • Technology • Water
Landscape	• Iceland • Italy • Natural cavity • Urban landscape (19th century) • Volcan	• Forests • Hannibal (Missouri) • Mississippi River • Natural cavity • Urban landscape (19th century) • Watershed	• Forests • Mountain Ranges • Natural cavity • New Zealand • Rivers • Urban landscape (medieval)	• Desert • Dunes • Natural cavity • Urban landscapes
Speleology	• Crystals • Galleries/conduits • Halls • Speleothems • Volcanic cone	• Abyss • Entrance portico (several) • Galleries • Halls • Labyrinths • Landslide • Speleothems • Underground river	• Abyss • Climbing • Entrance portico • Galleries/conduits • Halls (enormous) • Karst Landscape • Labyrinths • Landslide • Narrow passages • Underground River	• Cracks/crevices • Entrance portico • Galleries • Halls • Sandstone • Underground lake
Social Aspects **Subjectivities**	• Adventure • Atlantis • Conflicts • Fights • Friendship • Heroism • Monsters (prehistoric) • Mystical aspects • Rivalries • Romance • Survivor • The Missing Link • Underground world	• Adventure • Conflicts • Crime • Friendship • Greed • Romance • Social organization • Treasure	• Adventure • Conflicts • Dangers • Fear • Fights/Battles • Fraternity • Friendship • Greed • Heroism/bravery • Leadership • Magic • Monsters • Responsibility • Rivalries • Sacrifice • Saga/epic • Skills • Social organization • Traps • Treasure	• Adventure • Challenges • Conflicts • Domain • Fights/battles • Friendship • Heroism • Magic • Messiah • Policy • Power/Greed • Premonition • Prescience • Prophecy • Religion • Rivalries • Romance • Skills • Social organization • Supernatural powers • Training

5. Conclusion

A diversity of views was observed that contextualize the role of caves in the plot of the works analyzed, highlighting: adventure, fantasy, ordeal, mystery, struggles, treasures, portals, trials, spiritual aspects and those related to the sacred. Monsters, heroes and adventures are abundant in literature and cinema. Almost all works use underground metaphors in some way.

These literary-cinematographic works allow reflections on the cave environment and can be used in environmental education activities and dissemination of speleological practices, even to demystify the idea of caves and the underground, in order to rethink the lived and represented world, allowing good reflections on karst landscapes and human survival.

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Espeleologia e ativismo socioambiental: 40 anos do grupo de estudos ambientais da serra do mar (gesmar) entre a ciência e a aventura

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Abstract

Speleology and socio-environmental activism: 40 years of the Serra do Mar Environmental Studies Group (GESMAR) between science and adventure. This paper describes the 40-year history of the Serra do Mar Environmental Studies Group (GESMAR, 1984), a speleological organization in São Paulo, Brazil. The aim was to understand the motivations and characteristics of its participants and what defines us as speleologists/cavers. The study is qualitative and exploratory, using: documentary, bibliographic, and web graphic analysis, photographs, and autobiographical accounts of the eight authors who are members of the group. GESMAR has always had a broader, socio-environmental focus, but speleology and caves ended up standing out. Along with the adventure in nature came environmental education actions, training programs, community actions, and collaborative activities with other groups, such as: projects, intergroup expeditions (e.g.: PROCAD, PROESPELEOTINS). The group has contributed to the following research topics: history of speleology, the imaginary of caves, environmental education, speleotourism, biospeleology, among others. Since 1984, 150 people living in the Metropolitan Region of São Paulo have participated, each bringing their own contribution. This strengthens the work of a group that has science and adventure in the relationship, the search for knowledge and the protection of Brazil's speleological heritage.

Resumen

Espeleología y activismo socioambiental: 40 años del Grupo de Estudios Ambientales de la Serra do Mar (GESMAR) entre la ciencia y la aventura. El trabajo describe la trayectoria de 40 años del Grupo de Estudios Ambientales de Serra do Mar (GESMAR, 1984), entidad espeleológica de São Paulo (Brasil). Buscamos comprender las motivaciones y características de sus participantes y lo que nos define como espeleólogos/cavernistas. El estudio es cualitativo y exploratorio, utilizando: análisis documental, bibliográfico, webgráfico, fotografías y relatos autobiográficos de los ocho autores integrantes del grupo. GESMAR siempre ha tenido un enfoque más integral, socioambiental, pero acabó destacando la espeleología y las cuevas. Junto con la aventura en la naturaleza vinieron acciones de educación ambiental, programas de formación, acciones comunitarias, actividades de colaboración con otros grupos, como: proyectos, expediciones intergrupales (ej: PROCAD, PROESPELEOTINS). El grupo ha contribuido a los siguientes temas de investigación: historia de la espeleología, imaginería rupestre, educación ambiental, espeleoturismo, bioespeleología, entre otros. Desde 1984 han participado 150 personas, residentes en la Región Metropolitana de São Paulo, cada una aportando su propia contribución. Esto fortalece las actividades de un grupo cuyo vínculo entre ciencia y aventura es la búsqueda del conocimiento y la protección del patrimonio espeleológico brasileño.

Resumo

O trabalho descreve a trajetória de 40 anos do Grupo de Estudos Ambientais da Serra do Mar (GESMAR), entidade espeleológica de São Paulo (Brasil), fundada em 1984. Procurou-se entender as motivações e as características de seus participantes e o que nos define como espeleólogos/cavernistas. O estudo é qualitativo e exploratório, utilizando-se: análise documental, bibliográfica, webgráfica, fotografias e relatos autobiográficos dos oito autores, integrantes do grupo. O GESMAR sempre teve um enfoque mais abrangente, socioambientalista, tendo a espeleologia como destaque neste contexto. Junto com a aventura na natureza vieram ações de educação ambiental, programas formativos, ações comunitárias, atividades colaborativas com outros grupos, tais como: projetos, expedições intergrupos (ex.: PROCAD, PROESPELEOTINS). O grupo tem contribuído com os seguintes temas de pesquisa: história da espeleologia, imaginário das cavernas, educação ambiental, espeleoturismo, bioespeleologia, entre outros. Desde 1984 participaram 150 pessoas, que vivem na Região Metropolitana de São Paulo, cada uma trazendo a sua contribuição. Com isso fortalece a atuação de um grupo que tem na relação ciência e aventura a busca pelo conhecimento e a proteção do patrimônio espeleológico brasileiro.

1. Introdução

A espeleologia é a ciência que estuda as cavidades naturais subterrâneas (cavernas), entretanto, está carregada de sentidos: científico, técnico, conservação ambiental, aspectos culturais, aventura e interações interpessoais, tendo em vista que sempre deve ser realizada em grupos.

A aventura está sempre associada a esse tipo de atividade e por implicar em riscos à saúde, isso deve ser controlado. As práticas espeleológicas voltadas para a atividade de aventura e o ecoturismo utilizam a denominação de cavernismo (*caving*) ou mesmo espeleísmo (LOBO et al., 2010; MENDES et al, 2018). Internacionalmente existe essa separação entre o cientista, espeleólogo (*speleologist*) e o cavernista (*caver*). No Brasil se usa o termo espeleólogo de forma indistinta, gerando muitas vezes conflitos de identidade. Porém, isso favorece a integração entre leigos-praticantes e cientistas. Os espeleólogos estão organizados em sociedades, federações, grupos e mesmo independentes (FIGUEIREDO, 2010).

A Espeleologia surgiu na Europa no séc. XIX, destacando a iniciativa do francês Martel e seus colaboradores, aproveitando experiências do montanhismo e das caminhadas. Ele foi responsável por criar uma das primeiras sociedades de cientistas e explorados totalmente dedicados ao estudo das cavernas (SCHUT, 2006; MATTES, 2015).

Para explorar uma caverna estão envolvidos aspectos de motricidade humana, pois implicam em caminhadas, escaladas, canionismo (seguindo um curso d'água), natação, rastejamentos, e outras adversidades. Por haver escuridão total em boa parte destas cavernas, há limitação visual e é necessário o uso de lanternas, gerando elementos entre necessidade, objetividade e simbolismos.

No âmbito internacional temos a aglutinação de diferentes federações em torno da Union Internationale de Spéléologie (UIS, criação 1965), já no Brasil a entidade nacional é a Sociedade Brasileira de Espeleologia (SBE, criação 1969), a qual por sua vez congrega dezenas de grupos de espeleologia além de sócios individuais.

O presente trabalho propõe analisar a trajetória de 40 anos de um grupo espeleológico paulista, *Grupo de Estudos Ambientais da Serra do Mar (GESMAR)*, fundado em 1984, do qual os autores fazem parte, de modo a entender as motivações para essa prática e as características de seus praticantes, além do que nos define como espeleólogos/cavernistas.

2. Metodologia

O estudo é de natureza qualitativa, exploratória e descritiva.

Análise Documental

Foram examinados documentos históricos e institucionais relacionados ao GESMAR, incluindo atas, registros internos, relatórios de expedições, materiais de divulgação, publicações científicas, mapas e projetos desenvolvidos ao longo das últimas quatro décadas. Esses documentos permitiram traçar a evolução do grupo.

Revisão Bibliográfica e Webgráfica

O estudo foi embasado em um levantamento bibliográfico e webgráfico, contemplando literatura acadêmica, artigos científicos, teses, dissertações e publicações sobre espeleologia, educação ambiental, espeleoturismo, bioespeleologia e demais temáticas abordadas pelo grupo.

Registro Fotográfico

As fotografias foram utilizadas como fonte documental e como ferramenta de análise visual, ajudando a evidenciar as atividades desenvolvidas pelo grupo, as paisagens exploradas e os contextos sociais e ambientais envolvidos nas expedições e ações educativas.

Relatos Autobiográficos

Os oito autores do estudo, todos integrantes do GESMAR, contribuíram com relatos autobiográficos que refletem suas experiências, trajetórias e percepções sobre a espeleologia e a atuação do grupo. Essas narrativas foram fundamentais para compreender as motivações individuais e coletivas que impulsionaram a criação e as atividades do GESMAR e sua evolução histórica.

Dados Secundários

Informações já publicadas anteriormente por FIGUEIREDO (1988, 1994, 1998, 2009, 2010, 2011, 2012, 2016, 2022a, 2022b), por FIGUEIREDO et al. (1999, 2003, 2007, 2011), por ZAMPAULO et al. (2003), SILVA & FIGUEIREDO (2011) e FERREIRA & FIGUEIREDO (2019) foram incorporadas à análise, contendo dados da trajetória de pesquisa do Grupo.

Procedimentos de Análise

Os dados coletados foram organizados e analisados por meio de uma abordagem interpretativa e descritiva, considerando as seguintes etapas:

- Categorização dos documentos conforme sua tipos e relevância para trajetória do GESMAR;
- Análise comparativa dos registros fotográficos visa identificar as práticas realizadas;
- Interpretação dos relatos autobiográficos com base na história oral;
- Correlação entre os dados primários e secundários, buscando conexões entre os relatos individuais e coletivos.

Justificativa Metodológica

A combinação dessas estratégias metodológicas permitiu uma visão abrangente e multidimensional sobre o GESMAR, articulando aspectos históricos, sociais, ambientais e científicos. O estudo não apenas documenta a trajetória do grupo, mas também oferece uma reflexão sobre o papel da espeleologia na interface entre ciência, aventura e conservação ambiental, evidenciando como a experiência prática e a pesquisa acadêmica se entrelaçam na proteção do patrimônio espeleológico brasileiro.

3. Resultados e discussão

3.1. GESMAR primórdios: excursionismo e trilhas

Os documentos, relatos dos participantes fotografias permitem identificar que o período inicial do GESMAR, entre 1984-1986, foi uma fase mais informal, basicamente conformada por parentes e amigos. O foco inicial era o excursionista, realizando trilhas, acompanhando rios da Serra do Mar, avaliando o potencial educativo desses espaços, porém, predominava a atividade de aventura e contato com a natureza, como o trekking, camping selvagem, cascading e as cavernadas. (Fig. 1 e 2).

Figura 1: *Membros do GESMAR em 1985, os dois ao centro são os fundadores e continuam ativos. Detalhe dos equipamentos improvisados.*

Em uma das entrevistas realizadas com um dos fundadores do GESMAR, ZAVF afirmava que ser espeleólogo: *"É ter responsabilidade, companheirismo, saber seus limites, ter coragem e determinação"*. E complementava sobre o papel da espeleologia em sua história pessoal: *"Um crescimento interior, amor e respeito à natureza e todos os seres que nela habita. O contato com as pessoas, as amizades. Até hoje nos faz reviver aqueles bons momentos."*

Figura 2: *Expedição em 1985, parceria com alunos da Geologia da USP, que posteriormente criaram o GGEO-USP.*

3.2. GESMAR: Vínculo universitário, espeleologia, excursões

O GESMAR começa a se conformar como grupo de estudos ambientais a partir do vínculo com uma instituição universitária, sendo essa a principal forma de acesso de pessoas interessadas ao Grupo.

A instituição inicial de conexão foi o Centro Universitário Fundação Santo André (FSA), na Região Metropolitana de São Paulo, onde o segundo autor foi professor-pesquisador da área de geociências, educação científica e ambiental e ciências ambientais, por 35 anos. (Fig. 3).

Figura 3: *Reunião do GESMAR utilizando o espaço Laboratório de Ensino de Ciências da FSA. (LAVF, 2011).*

No grupo, todavia, sempre existiram pessoas leigas, bastante atuantes, ao longo de toda a trajetória da entidade, e que tiveram um papel fundamental para o fortalecimento da nossa atuação.

O GESMAR sempre teve um enfoque mais abrangente, socioambientalista, mas a espeleologia acabou se destacando e com isso as cavernas e as paisagens cársticas. Junto com a aventura na natureza vieram ações de educação ambiental, programas formativos e ações comunitárias.

A partir dos anos 1990, já com o grupo mais consolidado, percebemos o papel do grupo na história pessoal de dois ex-presidentes do grupo. Apresentamos seus depoimentos, coletados em 2008. Um deles, JFS, que é químico, começou no grupo em 1995, motivado por uma excursão para a Caverna do Diabo. *"Certamente o que me atraiu para o mundo da espeleologia, foi a forma amiga e descontraída de receber os novatos e a paixão que os veteranos ainda demonstravam em conhecer novas grutas".*

O outro entrevistado, RAZ, iniciou suas atividades em 2001, mesmo tendo conhecido cavernas no ensino médio ainda em 1998. Seus primeiros contatos com as cavernas surgiram por meio de uma viagem para um congresso internacional de espeleologia no Brasil, que ele participou, aproveitando o incentivo de um docente da universidade onde ele estudava Biologia, também membro do GESMAR. Ele afirma que as atividades de espeleologia: *"representam hoje uma oportunidade profissional, já que estou me especializando em ecologia de ecossistemas cavernícolas"*. Sobre a relação com as cavernas, ele ressalta:

> "Entrar em uma caverna é acessar um novo mundo através de uma janela que nos permite chegar ao subterrâneo. Lá embaixo tudo é diferente de qualquer coisa que vemos no meio externo [...] Agora, impressionante mesmo, é imaginar que em cima destes condutos subterrâneos pode haver toneladas de rochas, solo e muitas vezes, como é o caso do PETAR, uma exuberante floresta atlântica"

O GESMAR sempre esteve envolvido com pesquisas, publicações, cursos e palestras de divulgação da espeleologia e congressos. (Fig. 4).

Figura 4: *Preparando uma apresentação de trabalho para o Congresso Brasileiro de Espeleologia (2003).*

3.3. GESMAR: parcerias e expedições intergrupos

As atividades colaborativas foram sempre vistas pelos membros do GESMAR como fundamentais para a proteção do patrimônio espeleológico e desenvolvimento da espeleologia nacional por meio do fortalecimento da Sociedade Brasileira de Espeleologia (SBE). De fato, somos poucos e com uma enorme tarefa para identificar, reconhecer, cadastrar e investigar cavernas em um país de território continental, em inúmeras litologias distintas. Por isso, diversas atividades/expedições intergrupos foram realizadas em diferentes regiões do país, como o Projeto Caverna do Diabo (PROCAD) (FIGUEIREDO et al., 1999; 2007). (Fig.5)

Figura 5: *Expedição intergrupos à Caverna do Diabo (1990).*

Outra ação intergrupos corresponde ao Projeto Tocantins, realizado nos municípios de Dianópolis, Novo Jardim, Arraias e Aurora do Tocantins (PROESPELEOTINS) (ZAMPAULO et al., 2007, FIGUEIREDO & LORÍA-UC, 2015, FIGUEIREDO et al, 2017). (Fig. 6 a 9)

Figura 6: *Expedição do PROESPELEOTINS (Luiz Afonso V.Figueiredo-LAVF, 2008).*

Figura 7: *Expedição PROESPELEOTINS. (LAVF, 2007).*

Figura 8: *Expedição PROESPELEOTINS. Gruta das Rãs (Alan Santos, 2007).*

Figura 9: *Expedição PROESPELEOTINS (LAVF, 2017).*

3.4. GESMAR: atividades formativas e excursões didáticas

Um dos focos importantes do Grupo e que sempre foram fundamentais para atrair novos integrantes foram as excursões didáticas, oferecidas em disciplinas por integrantes do grupo docentes da FSA ou de outras instituições (PUCSP, IFSP), tendo em vista que dois participantes do Grupo foram docentes nessas instituições. Os trabalhos de campo realizados geraram produções sobre o papel do grupo na área da educação ambiental, ecoturismo, com ênfase em espeleoturismo e processos formativos de caráter socioambiental, envolvendo moradores do entorno de sítios espeleológicos, professores e estudantes universitários, incluindo a temática da aventura para pessoas com deficiência (MARINHO et al., 1997, NUNES et al., 2008, FIGUEIREDO, 2009, 2016; 2022b, FIGUEIREDO et al., 2011, FERREIRA & FIGUEIREDO, 2019). (Fig. 10 a 13).

Figura 10: *Excursão didática com alunos da FSA para a Caverna do Diabo.*

Figura 11: *Excursão didática com alunos da FSA no Parque Estadual da Caverna do Diabo (2019).*

Figura 12: *Excursão didática-alunos da FSA-PETAR (2003).*

Figura 13: *Excursão, cadeirante, Erika Nunes-PETAR (2003).*

3.5. GESMAR: perfil dos participantes

No total, passaram 150 pessoas pelo GESMAR, durante esses 40 anos. Com relação ao gênero, observou-se que a divisão é bastante igualitária, 50%. Em 2025, o grupo contava com 25 participantes, todavia apenas 11 estão entre os mais ativos. A maioria iniciou as atividades nos anos 1990-2000.

O perfil dos participantes do Grupo é bastante interessante, predominando universitários, a maioria do Centro Universitário Fundação Santo André (FSA), dos cursos de Biologia e Química, entretanto, contou também com alunos dos cursos de Geografia, História, Matemática, Engenharia, entre outros, sendo que mais de 80% dos participantes possuem algum nível de graduação universitária.

Com relação ao total geral, mais de 16% de todos os participantes possuíam um curso de pós-graduação (especialização, mestrado, doutorado), incluindo um dos fundadores que está fazendo pós-doutorado. Em 2025 esse valor aumentou significativamente, para 52% dos integrantes. Isso significa que houve avanços nos processos formativos, no entanto, são poucos os membros do grupo que investigam temas relacionados diretamente com as cavernas ou patrimônio espeleológico. O foco é educação ambiental, história da espeleologia e bioespeleologia. Na parte técnica destaca-se a produção de equipamentos com a criação da Mono® Equipamentos e Aventuras pelo primeiro autor, também fundador do Grupo. (Fig. 14).

Figura 14: *a) Expedição Luminárias, aqui os irmãos fundadores do GESMAR. b) Teste de mochilas e macacões desenvolvidos pelo primeiro autor (Mono®).*

Na Figura 14 registra-se a diversidade de atividades já realizadas pelo GESMAR.

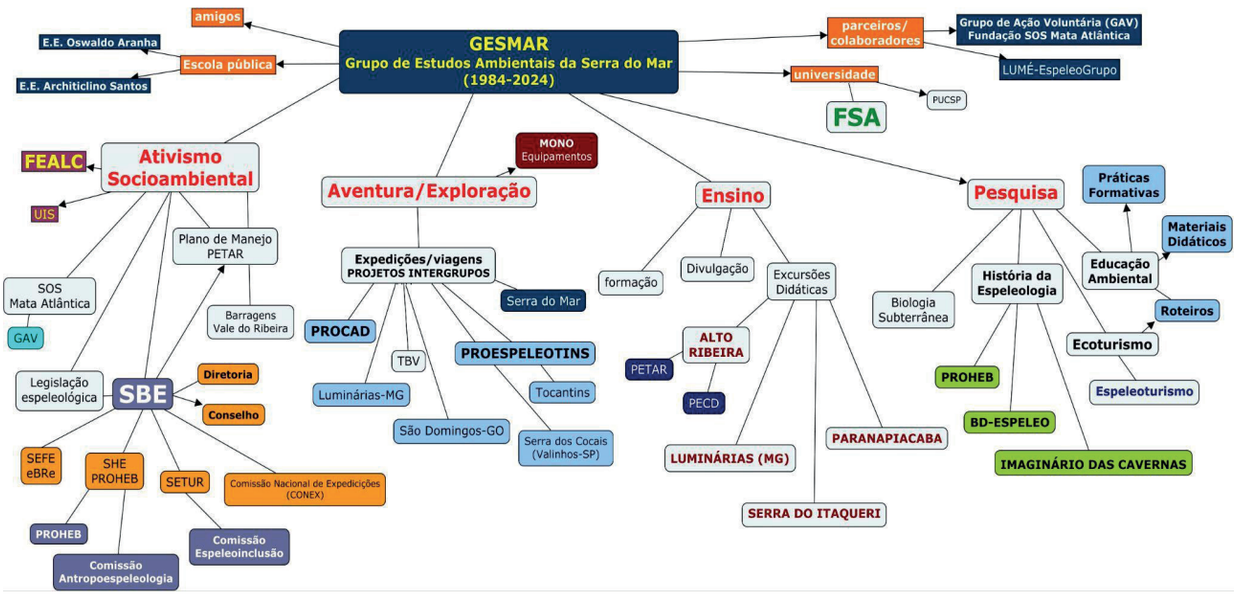

Figura 14: Mapa conceitual com síntese da atuação do GESMAR (40 anos: 1984-2024).

4. Conclusão

Esse artigo resgata a trajetória de 40 anos de um grupo de amigos, que viraram espeleólogos e ambientalistas, e que resistem atuando em uma organização não governamental voluntária, que tem como foco principal manter o grupo unido em solidariedade, práticas so-

cioambientais, pesquisa científica e subsídios para o conhecimento e proteção do patrimônio espeleológico brasileiro e também ações de educação ambiental.

Um fato importante é a participação direta de membros do GESMAR na criação e consolidação de diversas Seções da SBE, além da proposição e participação direta na criação da Comissão de Espeleoinclusão, com uma participante PcD, também coordenadora da Comissão. (NUNES et al., 2008).

A compreensão do ser espeleólogo abrange aspectos racionais e subjetividades, perpassando pelas ideias de conhecimento científico, paixão, aventura, técnica, contato íntimo com a natureza. Por isso a Espeleologia se torna uma atividade rica em possibilidades e componentes biopsicossociais, que vão da atuação ambientalista, a investigação científica (geociências, biociências, educação ambiental, ecoturismo, entre outros), as práticas corporais, a técnica exploratória e de progressão na caverna, a gestão de risco e a busca pelo próprio eu.

Agradecimentos

Agradecemos a todos os membros do Grupo de Estudos Ambientais da Serra do Mar (GESMAR), por sua contribuição direta ou indireta para fortalecimento do grupo e nos manter ativos por 40 anos. Também o apoio do Centro Universitário Fundação Santo André (FSA), da Sociedade Brasileira de Espeleologia (SBE) e de tantos/as companheiros/as do mundo subterrâneo.

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The caves of the greek revolution within and without the theatre

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Abstract

In the Greek plays about the era of the Greek Revolution of 1821, caves are described as lairs, as refuges for women and children, or even as the homes of the revolutionaries and their families. In some cases, even, the cave acquires an important role in the play. Based on several references to caves which we find in Christoforos Samartsidis's *Armatoloi kai Kleptai* (and in his prototype, Georgios Zalokostas's «little poem» with the same title), but also in plays by Ioannis Zambelios (*Odysseus Androussou, Markos Vossaris*), as well as in Antonios Antoniadis's *Odysseus Androutsos*, Timoleon Ambelas's *Oi Martyres tou Arkadiou* and elsewhere, we shall attempt to trace the historical reality behind these references, paying a visit to some of the caves that were used as lairs, shelters, or homes of the revolutionaries during the Greek War of Independence. Among them Odysseas Androutsos's famous "Mavri Troupa" ["Black Hole"] in Tithorea (Velitsa), mentioned by Zambelios and Antoniadis.

Résumé

Dans les pièces de théâtre grecques sur l' époque de la révolution grecque de 1821, les grottes sont décrites comme des tanières, comme des refuges pout les femmes et les enfants, ou même comme les maisons des révolutionnaires et de leurs familles. Dans quelques cas, même, la grotte joue un rôle important dans la pièce. S' appuyant sur plusieurs références à des grottes qu' on trouve dans *Armatoloi kai Kleptai* de Christoforos Samartsidis (et dans son prototype, le "petit poème" de Georgios Zalokostas du même titre), mais aussi dans des pièces de Ioannis Zambélios (*Odysseus Androussou, Markos Vossaris*), ainsi que dans *Odysseus Androutsos* de Antonios Antoniadis, *Oi Martyres tou Arkadiou* de Timoléon Ambélas et ailleurs, on va essayer de retracer la réalité historique derrière ces références, en visitant quelques grottes qui ont servi de tanières, d' abris, ou de maisons aux révolutionnaires pendant la guerre d' indépendence grecque. Parmi eux, la célèbre "Mavri Troupa" ["Trou Noir"] d' Odysseas Androutsos à Tithoréa (Velitsa), mentionnée par Zambélios et Antoniadis.

1. Introduction

Officially, the Greek Revolution started in 1821 (although this was not the Greeks' first attempt to free themselves from the Turks), just a few months before the Brazilian War of Indepence began, in a period when several wars of independence broke out in Latin America.

The Greek War of Independence became a popular theme among Greek dramatists, who often focused on the story of a particular hero of the Revolution, as the plays' titles illustrate (Odysseus Androutsos, Markos Vossaris etc.).

Given the important role of the caves as hiding places or refuges before and during the Greek Revolution, it is no wonder that they are mentioned in quite a few plays inspired by this particular part of modern Greek history. Some of these caves are anonymous, but others are famous, like "Mavri Troupa" [the "Black Hole"], where the rebel Odysseas Androutsos resided with his family.

This presentation will attempt to trace the historical reality behind the references to caves in plays about the Greek Revolution of 1821.

2. Looking for caves, real and fictional

This presentation combines my research for my work (as an academic at the Department of Theatre Studies of the National and Kapodistrian Univeristy of Athens, Greece) and for my hobby as a caver (as a member of SP.EL.E.O.).

In 2020, during the covid pandemic, taking advantage of the time slots when we were allowed to move outside our area of residence, I visited several caves that were related to the Greek Revolution of 1821, but also to the "Orlofika", an earlier attempt for independence, instigated by the Orlov brothers in 1770, during the Russo-Turkish wars of 1768-1774. My aim, at this first stage, was to collect enough material for a 2021 calendar of my caving club (SP.EL.E.O., the oldest Greek caving club), dedicated to the 200th anniversary of the start of the Greek Revolution.

Prior to my trips (mainly to the Peloponnese, south of Athens, where I reside), I collected information about caves that were related to the Greek Independence War and the years that preceded, largely from the Library of the Greek Parliament (provided by my fellow caver and researcher Thomas Theodosiadis, who works there).

On the other hand, as a drama teacher and researcher, I wondered whether the use of caves by the Greek revolutionaries was mirrored in the plays based on their stories and the Greek Revolution at large. This spurred a new research, which included not only dramatic texts, but also other literary works related to the matter, such as poems, but also memoirs by revolutionaries written during the Greek Independence War.

3. Caves of the Greek Independence War, in drama and history

The caves in the dramatic texts that deal with the Greek Revolution are not used symbolically; their mention rather depicts the reality of the time, but it certainly adds to the atmosphere of the plays, too.

In his play *Armatoloi kai Kleptai* [*armatoloi* and *kleftes* were two different groups of Greeks during the Turkish regime, the former more "legitimate", the latter regarded as outlaws], Christoforos Samartsidis describes a dark cave illuminated by resin, somewhere in Epirus, in Western Greece. The relations between the who groups of *armatoloi* and *kleftes* is also illustrated in the context of the cave, in a scene where an *armatolos* is taken deep inside the cave by the *kleftes* to be tortured (SAMARTSIDIS, 1864).

In Samartsidis's prototype, Georgios Zalokostas's "little poem" with the same title, the cave is also described as "deep". Zalokostas's cave also hosts a nocturnal bird that emerges from the cave's "black chasms" and flies under its "dome" and in its "thick darkness" (ZALOKOSTAS, 1853). Such birds are found even today in caves that were used as hiding places during the Greek Revolution.

Samartsidis's cave is situated on a steep mountain slope, and is apparently hard to reach, which makes the rebels confident about their safety. One of them says that looking down makes you dizzy, and that to reach the cave one needs a ladder of at least fifty meters. The cave in Samartsidis's play as well as in Zalokostas's poem is anonymous; however, similar caves were used by revolutionaries all over Greece.

The most famous cave of the sort is "Mavri Troupa" [the "Black Hole"], near Tithorea (Velitsa), on the mount Parnassus (Fig. 1). This cave was used as a refuge by the people of the area, and was the lair but also the home of the famous revolutionary Odysseas Androutsos and his family from 1822 το 1825.

In the prologue of his play *Odysseus Androussou*, Ioannis Zambelios reproduces a description of Mavri Troupa by the English traveler James Emerson. According to Emerson, the cave, about 100 feet from the bottom of the rock, was hard to reach; it could accommodate 2000 men, and a spring inside the cave provided fresh water. In his own description of Androutsos's cave in his play, Zambelios includes both arms hanging from the walls and household utensils, and the sleeping baby at a corner further illustrates the use of the cave as both a den and a home for Androutsos's family (ZAMBELIOS, 1860, vol. B).

In Antoniadis's *Odysseus Androutsos* the famous rebel's wife Eleni argues that they should build up the entrance of the cave and kill their enemies from there (ANTONIADIS, 1886). Although in the play Androutsos does not agree with his wife, the building of a wall at the cave's entrance to protect the rebels from the Turks and their allies was rather common, as we can see in several cases of caves used as lairs during the Greek Independence War.

Elsewhere caves are mentioned as refuges for women and children, as in Zambelios's *Markos Vossaris* (ZAMBELIOS, 1860, vol. A) or Timoleon Ambelas's *Oi Martyres tou Arkadiou* [*The Martyrs of Arkadi*] (AMBELAS, 1867).

Most of the plays about the Greek Independence War were written in the 19th century; however, the topic seems to be popular even in the 21st century. In his play *The Souls of the Greeks* or *The Holocaust of Vrontamas* (15-16 Sept. 1825), published in 2003 in his book *Flowers of the Stone. Forgotten or Unknown Real Heroes and Heroines of the Revolution of 1821-1827*, Kyriakos Kassis deals with a less known event from the Greek Revolution. The holocaust of Vrontamas took place in Paleomonastiro, a monastery built in a cave, near Vrontamas, in Lakonia. The cave described here consists of two distinct parts on two different levels; the upper part is where the rebels take their places for battle, whereas the lower part is where the civilians take refuge (KASSIS, 2003).

During the Greek Revolution there were more monasteries in caves that were used by the rebels to repel the Turks, as well as Ibrahim and his men, who came from Egypt to assist them. One of them was the monastery of St Nicholas in Valtessiniko, in Arcadia. A poem by Grigoris Kribas, born in Valtessiniko in 1934, mentions the "dark caves" of St Nicholas, where the locals took refuge. In the poem the caves around the monastery resound the battle between the locals and Ibrahim's men.

During the main revolution, as well as during the "Orlofika" of 1770, another monastery built in a cave, St Jerusalem in Argolis, whose entrance was also built up with a big wall, was used by the rebels to repel their enemies, whereas the cave behind the monastery of St John (Prodromos) near the village of Kastri in Kynouria, in Arcadia, became a natural shelter for the rebels' families.

Figure 1: *Mavri Troupa, the famous cave of Odysseas Androutsos mentioned in Greek plays about the Revolution of 1821. (Photograph by Vassilis Tountopoulos.).*

4. Epilogue

The caves, warm during the winter and cool during the summer, became a comfortable refuge for the rebels and their families during (but also before) the Greek Revolution. However, some of them became sites of martyrdom.

In any case, the importance of the caves at the time is underscored by their presence in several plays, and in literature at large, inspired by the Greeks' struggle for freedom.

In these works the references to caves do not acquire a symbolic character; they rather reflect the reality of the time. Still, it seems that the cave remains a charming space for literature, even today.

Acknowledgments

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Stillwater Facets, 200 Years of Research – a Short History

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Abstract

In 1913, the tip-down triangular profile with sidewalls sloping at about 45° and a horizontal solution ceiling were described by K. Gripp for the first time from the newly discovered Segeberger Höhle, N-Germany. In 1931, W. Biese observed these sidewalls in South Harz gypsum caves, naming them 'facets'. Several genetic hypotheses were suggested. They appear to be key morphological features of caves forming by buoyancy-driven laminar convection and occur in salt, sulphate and carbonate rocks. Such settings are characteristic for hypogenic speleogenesis as observed in 'Schlotten', anhydrite cavities discovered by mining in the South and East Harz since the 18th century far below the natural ground water level. The physical details of facet formation are still unresolved.

Résumé

En 1913, K. Gripp a décrit pour la première fois le profil triangulaire avec des parois latérales inclinées à environ 45° et un plafond de solution horizontal dans la grotte Segeberger Höhle, récemment découverte en Allemagne du Nord. En 1931, W. Biese a observé ces parois latérales dans les grottes de gypse du Harz méridional et les a nommées « facettes ». Plusieurs hypothèses génétiques ont été proposées. Il semble qu'il s'agisse de caractéristiques morphologiques essentielles des grottes qui se forment par convection laminaire sous l'effet de la poussée d'Archimède et qui se rencontrent dans les roches salines, sulfatées et carbonatées. De tels contextes sont caractéristiques de la spéléogenèse hypogène, comme on l'observe dans les « Schlotten », des cavités d'anhydrite découvertes par l'exploitation minière dans le sud et l'est du Harz depuis le XVIIIe siècle, bien en dessous du niveau naturel de la nappe phréatique. Les détails physiques de la formation des facettes ne sont pas encore élucidés.

Resumen

Em 1913, K. Gripp descreveu pela primeira vez o perfil triangular de ponta para baixo com paredes laterais inclinadas em cerca de 45° e um teto de solução horizontal na recém-descoberta Segeberger Höhle, na Alemanha do Norte. Em 1931, W. Biese observou essas paredes laterais nas cavernas de gipsita de South Harz, denominando-as "facetas". Várias hipóteses genéticas foram sugeridas. Elas parecem ser as principais características morfológicas das cavernas formadas por convecção laminar impulsionada por flutuação e ocorrem em rochas de sal, sulfato e carbonato. Esses ambientes são característicos da espeleogênese hipogênica, conforme observado em "Schlotten", cavidades de anidrita descobertas pela mineração no sul e leste de Harz desde o século 18, muito abaixo do nível natural do lençol freático. Os detalhes físicos da formação das facetas ainda não foram resolvidos.

Figure 1: *Marthahöhle, Hainholz, South Harz, on the right: stillwater facets sloping with ca. 45° and horizontal solution ceiling, Photo S. Wielert.*

1. Introduction

Epigene and hypogene caves are both solutional, depending on the origin of the *"cave forming agent"* (*sensu* KLIMCHOUK 2012). Surface "agents" include sinking water, biogene or atmogene CO_2, while subsurface "agents" may be rising water (thermal or not), CO_2, H_2S, CH_4 or the weathering of siderite. Therefore, most epigene caves are created by water flowing from sink to source gravitationally and turbulently, while hypogene caves form by buoyancy-driven laminar convection. Both realms have developed their specific cave morphologies (Fig. 2).

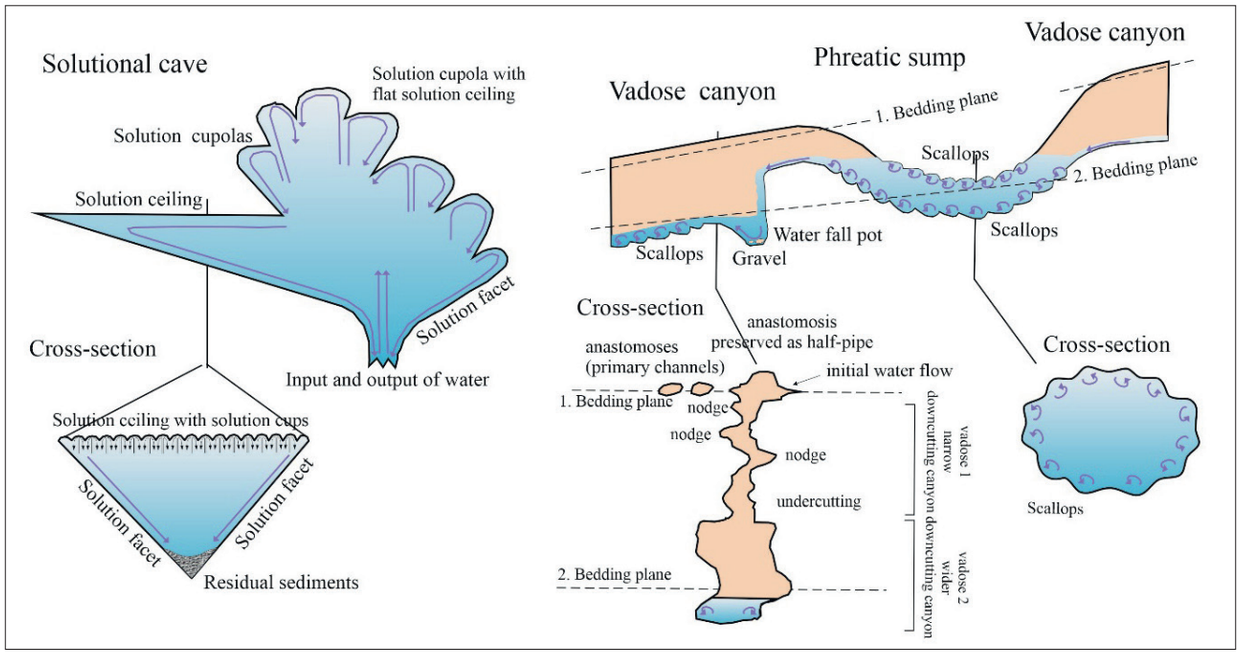

Figure. 2: *Comparison between hypogene, laminar and convection driven (left) and epigene, turbulent, gravitational flow (right) cave morphology (after KEMPE 2008).*

2. Schlotten Caves

Active hypogene caves were entered and recognized by copper-shale miners in the South and East Harz Region latest by the 18th century, if not earlier. They named them "Schlotten", fearing them because their foul air could suffocate them and their water could cause havoc and flood mines, if such a cavity was intercepted by chance.

Over 200 of these have been recorded in anhydrite or gypsum (e.g., KNOLLE 2021), which was contemporarily called "Schlotten Gips", now known as the Upper Permian Zechstein Formation. The first geologist to consider Schlotten genesis was Johann C. FREIESLEBEN (1774-1846), who thought, referring to his teacher Abraham G. WERNER (1749-1817), that the caves were former salt deposits, washed out. He vaguely alluded to them as "temple-like" halls connected by narrow slots, through which the salt-waters must have escaped (FREIESLEBEN 1809: 206). He recognized the stillwater conditions of their genesis when writing (FREIESLEBEN 1809: 171): *"Die ganze Form der Höhlungen, besonders aber die Beschaffenheit ihrer Wände, weist auf ihre Entstehung hin, die man sich nicht anders denken kann als durch allmählige Auswaschung oder Abnagung, bewirkt durch eine ruhige Wassermasse, die nur so viel Zu- und Abfluss hatte, um mit ihrer Auflösung verhältnismäßig fortwirken zu können..."* (The entire form of the cavities, specifically of their walls, is indicative of their origin, which cannot be thought other than by gradual elution or erosion, caused by an unperturbed mass of water, that had only as much in- as outflow as to continue its solution proportionally). Nevertheless, Freiesleben failed to describe the details, the seemingly polished sidewalls, sloping at ca. 45°, and a fractal set of cupolas ranging from centimetres to decametres interrupted by flat ceilings (Figs. 1, 3, 4).

Figure 3: *Wimmelburger Schlotte, showing typical facets and associated cupolas; a horizontal solution ceiling is not developed. Photo S. Kempe.*

3. Gripp and Biese

A century later, young Karl GRIPP (1891-1985) of the University of Hamburg, went a step further. In 1913, he was called-upon, when quarry men of the anhydrite mine at Segeberg, a salt-dome caprock, broke through the ceiling of a cavity. What they found was described by GRIPP (1913): a maze of passages all with smooth, sloping sidewalls grading into flat ceilings (Fig. 4).

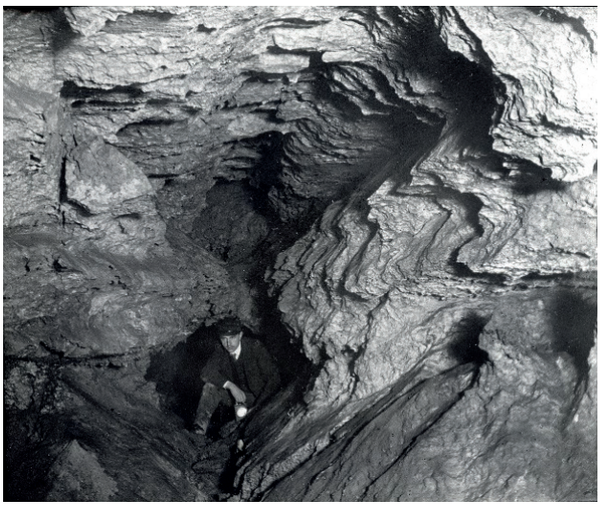

Figure 4: *Triple facets and solution ceiling in the 1913 newly discovered Segeberger Kalkberghöhle (mostly in anhydrite). Photo Archive Segeberger Kalkberghöhle.*

In an idealized cross-section, the Segeberg passages display a tip-down triangle. Gripp understood that the cave must have been water-filled until recently (we still cannot date its drainage), that there was no evidence of river action and that thus, the cave is purely solutional in origin. He also understood that in such a setting, dissolution would start convective currents.

Gripp assumed that the bottom water would be more saturated than at the top and that therefore the walls of a fissure would recede faster above than below, leading to a gradual tilting of the walls. He also assumed and tried to prove that by surveys that the tiers of facets are the consequence of the salt dome still rising. Nevertheless, Gripp's paper did not find any echo internationally.

However, in the Harz Mountains Friedrich STOLBERG (1892-1975) began to survey the gypsum caves systematically in the 1920s. With this material at hand, Walter BIESE (1895-1960; KNOLLE 2014, KNOLLE et al. 2022), a geologist from Berlin, made the link to Gripp, noting that the morphological elements described for Segeberg also applied for many of the newly surveyed gypsum caves in the South Harz. He also made the link to the salt mines in the Alps, that leached salt in underground lakes that develop flat ceilings, called "Himmel" ("heaven").

In his hall-mark book, Biese tried to summarize his findings, calling this cave type "Laughöhle" (solution cave), the horizontal ceiling "Laugdecke" (solutional ceiling) and the sloping sidewalls "facets" (BIESE 1931: 18), quite obviously after the polished surfaces of gemstones. He also showed that facets and solutional ceilings are common in other gypsum or anhydrite caves in the Kyffhäuser and in southern Germany, thus broadening the scope from that isolated salt dome cave in Segeberg nationally.

In principle, Biese accepted Gripp's view that "the facet slope is a graphic representation of the density gradient in the cave water column" (BIESE 1931: 48).

That the South Harz became the "classic gypsum karst area" and that "facets" an internationally accepted term are Biese's legacy.

All three of these early cave researchers had also to cope with the Third Reich: Gripp temporarily lost his position at Hamburg, Stolberg wrote critical poems and Biese left Germany for Chile, where he died after WWII.

4. Lange, Goodman and Reinboth

In the 1960s, the general interest in facets and solutional caves revived in the USA and Germany. LANGE (1962, 1963), GOODMAN (1964, 1969) and REINBOTH (1968, 1992) argued that the facets are inactive "planes of repose"; i.e. the sediments on the facets protect it from further solution. Consequently, the facet can only extent upward in congruence with the upward recession of the solutional ceiling.

The facet angle is defined by the sliding angle of these residues (Fig. 5 B).

The topic was also discussed in several ICS talks and panels, e.g. ICS 5 (Stuttgart), 6 (Olomouc), 7 (Sheffield), 8 (Bowling Green), and 12 (La Chaux-de-Fonds).

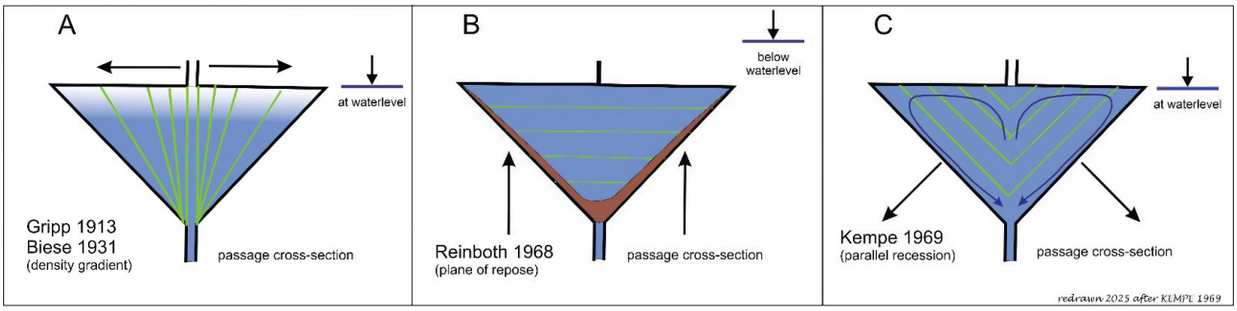

Figure 5: *Facet models by GRIPP/BIESE (A), REINBOTH (B) and KEMPE. (C) Black arrows indicate direction of enlargement. Green lines mark consecutive stages of enlargement. Brown are residual sediments blocking effectively facet dissolution. They may be present in the other models but are considered slowing but not hindering facet dissolution.*

5. Convection Hypotheses

In 1968 a team of high-school students re-surveyed the Jettenhöhle, Hainholz, South Harz (KEMPE et al. 1968). They also analysed water hardness, finding that karstic springs and cave pools had quite different values and that hardness increased down-ward in the pools. This prompted a more detailed study of gypsum cave genesis, function of facets and water movements in the current pools (Kempe 1969). Analysis of typical passages in Segeberg (compare Fig. 3) shows that passage widens by a recession of the facets (Fig. 4, comparing them to the previous hypothesis; adopted from Kempe 1969a). Later, in-situ dye injection showed that thin water films sink density-driven downward on the facet, causing a slow convection in the cave pool (compare Fig. 1; KEMPE 1970, 1975, 1981; KEMPE et al. 1975; BRANDT et al. 1976, KEMPE & HARTMANN 1977). At the same time the solution ceiling, if below the water table, is dissolved by small density cells, similar to Bernoulli cells, forming cup-like depressions, called solution cups (Kempe 1969b).

Since then, the convection hypothesis is considered the most plausible. REINBOTH (1992) published a critical review of the growing number of publications dealing with facets. KLIMCHOUK (1996, 1997, 2007) described facets from the hypogene gypsum karst of the Ukraine and from other cave areas.

It has also become clear, that facets are not limited to gypsum caves, where originally described, or salt, but that they are common for limestone and even dolomite, a fact BIESE already noted in his second book (1933: 161). Their occurrence signals laminar conditions. In fact, they are typical for hypogene caves that meet these conditions such as descripted as “stillwater facets” by KNOLLE (1985) for the Kubacher Crystal cave and a series of other hypogene caves in Germany (KEMPE 2008, 2014; KEMPE et al. 2016, 2017). A further summary with a critical review of the literature on the topic, supplemented by case studies from the Slovak Republic, was given by BELLA (2013). Hypogene caves with facets are also known from many other places world-wide, e.g. from Israel (Frumkin & Gvirtzman 2006), Jordan (Kempe et al. 2006) and in the famous cave area of the Guadelupe Mountains including Carlsbad Cavern and Lechuguilla.

6. Laboratory Research and Outlook

Early laboratory experiments with salt and plaster by GRIPP (1913), KEMPE (1969a), KEMPE & HARTMANN (1977) and REINBOTH (1992) were directed to reproduce facets and measure dissolution velocities. As expected, the solution velocity (i.e. mass of gypsum per time and area) rises as the angle of the exposed surface increases from 0° (flat bottom) to 180° (solution ceiling). A maximum at around 45° is not apparent. However, when the experiment starts with a vertical surface, then multiple notches develop that have facet-like lower lips, similar to the elongated side of scallops (REINBOTH 1992). These notches then enlarge, the larger cannibalizing the smaller; each showing mini-facets, such as can be found on gypsum blocks in cave pools.

GECHTER (2008; GECHTER et al. 2008) was the first to investigate the facet-problem in a doctoral thesis. It involved physical experimentation and modelling to reproduce semi-triangular profiles using salt drill cores as a substrate. By pumping slowly water through vertical and horizontal holes, he produced cm-sized, tip-down conical or prismatic cavities. He could show that dissolution was driven by buoyancy convection driven by dense, salty films gliding down the facet-like sidewalls. He also produced solution cups along the evolving flat ceiling. Cavities enlarge by the rising of the ceiling and by the recession of the facets. In this way and based on the model of Kempe (Fig. 1), the active concave grooves at the facet/solution ceiling transition, the solution cups on the solution ceiling, the sediment coverings on the lower parts of the facets and also the solution behind facets can be easily explained.

In Gechter et al. (2008) the flat ceiling is created by the interface between the salty bottom waters and the freshwater lens on top of it. This interface is naturally horizontal. The freshwater above is actively dissolving the ceiling which therefore is also horizontal.

Thus, internal density stratification should be the cause for the development of solution ceilings. On the other hand, as REINBOTH (1992) points out, the solution ceiling can only grow as high as a highwater stand. Still, the experiments do not offer a full physical model of the predominance of smooth facets with an angel of about 45° that are observed in rock salt, gypsum, anhydrite, limestone and dolomite alike. Physical modelling so far has not been conducted, limited not only by a missing physical understanding, as well as by computer capacity.

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Down the crater – a short history of vertical volcano anthropospeleology

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Abstract

"Tout est l'âbime." Charles Baudelaire

In only 9 examples from history and literature I want to present different human approaches to volcano craters and other abysses, concentrating mainly on the descent into them, the psychological and sociological background and the used access devices and techniques. There are a lot of other places, events and persons to be mentioned all over the world – indeed the topic is a treasure trove with no bottom in sight.

1. Through the Ages

„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.

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 Peleponnes 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 the first dedicated vulcanospelologist 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 mit „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 devoted 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 Aetna and Stromboli he also wanted to study the Vesuv. At Porticus he hired „an honest country-man, for a true and skillful 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 an horrible combustion, and stench of Sulphur and burning Bitumen. Here forthwhich being astonished at the unusual sight of the thing; Me thoughts I beheld the habitation of Hell; wherein nothing else seemed to be much wanting, besides the horrid fantasms and apparitions of Devils. There were perceived horrible bellowings and roaring of the Mountain; An inexpressible stink; Smoaks mixt with darkish globes of Fires". The next morning he „ went down unto it. „In the Center 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 reflexion 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 und a whirlpool. It is inspired by the Moskstraumen, a whirlpool of a diameter between 40 and 50 meter which „sucks in various small microorganisms, thereby attracting fishand 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, memorist and journalist. Her short novel „Laura, voyage dans le cristal", published in January 1864, was forgotten for a long time but got rediscovered since the 1970s. When you read it you are often reminded of a much more famous book. Jules Verne who published „Voyage to the Center 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 cristals. Alexis accompanies Nasias and after a thousand adventures they arrive at the promised area near a volcanolike 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 eatable, their only food. The group of two comes to a plain with a very thin stony cover. It cracks and underneath is a huge cristal 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 (1867 reissued in a revised and expanded version). A German professor, Otto Lidenbrock, believes that there are volcanic tubes that reach to the very center of the earth. Accompanied by his nephew Axel and the Icelandic guide Hans they „rappel into Iceland's celebrated inactive volcano Snaefellsjökull". „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 a 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 technic of roping down was invented in 1876 in France alpinism. Verne seems to have known 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 technic 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 center 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 artifical 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 oddnesses. 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 the121 m deep entrance shaft of Thrinukagigur (Three Peaks) 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 meters 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's 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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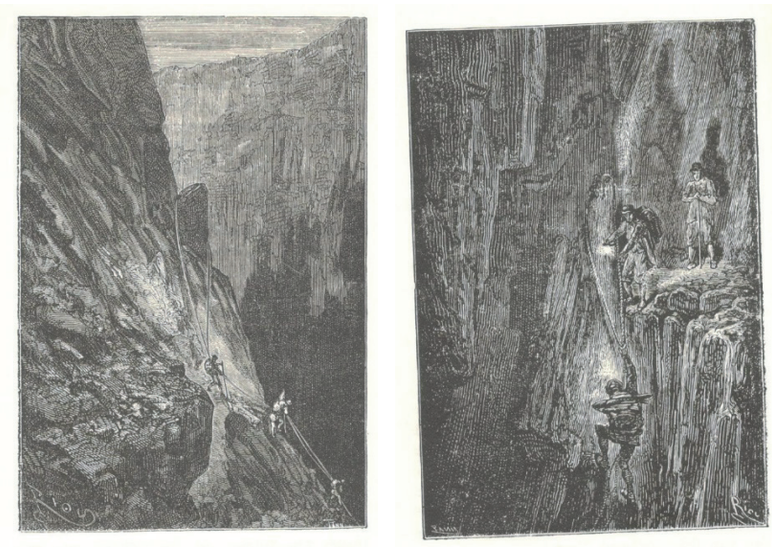

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Prihnukargigur 2015, Foto Franz Lindenmayr.

Reflexiones sobre las mujeres en la historia de la espeleología: trayectoria y protagonismo en el Grupo Ajau (Yucatán, México)

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Abstract

The objective of this work is to analyze the role of women in the consolidation of the Ajau Speleological Group. Based on the available sources, it has been observed that, in Mexico, caving has been carried out mostly by men. This can be verified in the archives of the Mexican Union of Speleological Groups (2019). This situation may be due to various causes, for example, lack of opportunities provided to the female gender, in caving and in many other activities. This has been changing gradually and currently a greater participation of women in caving has been observed, although there is still a long way to go to achieve true equality. In this study, was used a quali-quantitative, exploratory and descriptive approach and the chronological dimension involved was taken into account. In the history that supports 28 years of activities of the Ajau Speleological Group, state of Yucatan (Mexico), the situation is different. In this group since its beginnings there has always been a majority of women and it is evident that the group's leadership is also headed by them.

Resumen

El objetivo del presente trabajo es analizar el desempeño de la mujer en la consolidación del Grupo Espeleológico Ajau. A partir de las fuentes disponibles se ha observado que, en México, la práctica espeleológica ha sido realizada en su mayoría por los hombres. Esto se puede constatar en los archivos de la Unión Mexicana de Agrupaciones Espeleológicas (2019). Esta situación puede deberse a diversas causas, por ejemplo, falta de oportunidades brindadas al género femenino, en la espeleología y en muchas otras actividades. Esto ha estado cambiando paulatinamente y en la actualidad se ha observado una mayor participación de las mujeres en la espeleología, aunque todavía falta para llegar a una verdadera equidad. En el presente estudio se utilizó un abordaje cuali-cuantitativo, exploratorio y descriptivo, tomando en cuenta la dimensión cronológica implicada. En la historia que sustenta 28 años de actividades del Grupo Espeleológico Ajau, estado de Yucatán (México), la situación es diferente. En esta agrupación desde sus inicios siempre ha existido una mayoría de mujeres y es patente que la dirección del grupo es encabezada también por ellas.

Resumo

O objetivo deste trabalho é analisar a atuação das mulheres na consolidação do Grupo Espeleológico Ajau. Das fontes disponíveis, observou-se que, no México, a exploração de cavernas tem sido realizada principalmente por homens. Isso pode ser verificado nos arquivos da União Mexicana de Associações Espeleológicas (2019). Essa situação pode ser devida a várias causas, por exemplo, a falta de oportunidades oferecidas ao gênero feminino na espeleologia e em muitas outras atividades. Isso vem mudando gradativamente e atualmente tem havido uma maior participação de mulheres na espeleologia, embora ainda haja um longo caminho a percorrer para alcançar a verdadeira igualdade. Neste estudo, foi utilizada uma abordagem quali-quantitativa, exploratória e descritiva, considerada a dimensão cronológica envolvida. Na história que sustenta 28 anos de atividades do Grupo Espeleológico de Ajau, estado de Yucatán (México), a situação é diferente. Neste grupo, desde o seu início, sempre houve uma maioria de mulheres e é evidente que a liderança do grupo também é encabeçada por elas.

1. Introducción

A nivel internacional, la espeleología ha sido percibida como un campo dominado por hombres, posiblemente debido a la idea de que se requiere fuerza física y resistencia extrema. Esta situación responde a múltiples factores, entre ellos, estereotipos culturales que se viene repitiendo desde los estudios de prehistoria, la falta de oportunidades brindadas al género femenino en la exploración e investigación de los subterráneos, así como en muchas otras actividades tradicionalmente masculinizadas(CHIROL, 2022).

Sin embargo, en las últimas décadas, esta narrativa ha comenzado a cambiar en el mundo, las mujeres van tomando fuerza y presencia en diferentes foros y puestos como se demuestra en diversas agrupaciones de mujeres espeleólogas, como el grupo Caverneiras-Brasil, (CRUZ et al., 2019, OLIVEIRA et al., 2022). Actualmente hay mujeres ocupando importantes cargos directivos como en la Unión Internacional de Espeleología y la Unión Mexicana de Agrupaciones Espeleológicas. Otro caso es la Sociedad Brasileña de Espeleología, conformada exclusivamente por mu-

jeres. Ejemplos significativos también fueron el encuentro Internacional de Mujeres en Francia en 2010, con 300 participantes (CHIROL, 2022) y la realización del Primer Taller Internacional de la Mujer Espeleóloga en América Latina en Cuba en el año 2019, por mencionar unos ejemplos.

En México, cada vez más mujeres han ganado reconocimiento dejado una huella significativa en el mundo subterráneo. Su participación en las expediciones ha aumentado considerablemente, y muchas han asumido roles de liderazgo dentro de sus grupos. Además el número de científicas e investigadoras incrementó, contribuyendo de manera sustancial al avance de la espeleológica en el país.

Este cambio también ha sido particularmente notable en la península de Yucatán, una región rica en sistemas kársticos y con presencia de muchas cuevas, donde el Grupo Espeleológico Ajau se destaca como ejemplo emblemático de este cambio de paradigma. Durante años, ha sido liderado principalmente por mujeres, quienes han guiado expediciones, apoyado e impulsado investigaciones, participando en documentales tanto locales como internacionales y han promovido la conservación de estos espacios a través del trabajo comunitario.

El presente trabajo surge de la inquietud por establecer un contraste entre la participación de las mujeres en el ámbito espeleológico a nivel nacional y la participación de las mujeres del Grupo Espeleológico AJAU, seleccionado como estudio de caso.

La Unión Mexicana de Agrupaciones Espeleológicas (UMAE), organismo que agrupa y representa a espeleólogos y espeleólogas del país, desde su fundación en 1990, publicó un estudio en la revista Mundos Subterráneos (TEC-POOL & MIGUEL-NIETO, 2019), señalando que se percibía poca presencia femenina en las exploraciones de México. No obstante, para el año 2019, las mujeres representaban ya el 31 % de los integrantes de la UMAE, equivalente a 90 espeleólogas de un total de 278 personas registradas en la organización. Es decir, que el papel de las mujeres estaba visibilizándose, cuando antes, no figuró tanto.

En este contexto, el Grupo Espeleológico Ajau constituye un referente singular. Fundado el 25 de febrero de 1997 por la iniciativa de un grupo de estudiantes y un profesor universitario. El grupo centró inicialmente su interés en la exploración de cuevas desde una perspectiva orientada a la aventura. No obstante, desde sus primeros años, el grupo mostró un incipiente rigor y disciplina en la aplicación de técnicas para la exploración de grutas y la elaboración de registros sistemáticos que permitieran la descripción de las cavernas exploradas. Paralelamente, se fomentó e implementó prácticas más disciplinadas en la logística de las expediciones, seguridad, equipo adecuado, la redacción de bitácoras y el cumplimiento de las tareas asignadas para llevar con éxito las exploraciones.

Desde ese entonces, el grupo estaba conformado con una diferencia numérica entre hombres y mujeres, ligera mayoría femenina. Con el tiempo, esta tendencia se consolidó, dando lugar a un predominio claro de mujeres en la organización. La persistencia de las integrantes de Ajau en las exploraciones de los subterráneos naturales condujo al grupo a buscar la capacitación con personas especializadas en la materia. Por lo que, poco a poco se adquirieron y mejoraron las técnicas espeleológicas; aumentó la calidad de los registros con instrumentos de mayor precisión lográndose la elaboración de planos topográficos y una constante profesionalización.

La agrupación en proceso de consolidación atrajo a estudiantes y profesionistas de diversas áreas del conocimiento como Arqueología, Historia, Turismo, Biología, Derecho y Áreas de la salud; todos unidos por un interés común: el estudio y protección de las cavernas.

A partir de este análisis, se busca evidenciar una dinámica distinta a la tendencia nacional, contextualizando su relevancia para la historia de la participación femenina en la espeleología de México.

2. Metodología de la Investigación

La investigación realizada es de tipo cuali-cuantitativo, exploratorio y descriptivo, siendo de carácter histórico y con un sentido cronológico. Los datos fueron recolectados por medio de revisión hemerográfica, bibliográfica y medios electrónicos. El periodo abarcado incluye los datos más antiguos, desde el primer semestre de 1997 hasta el término del año 2024.

El análisis realizado consideró una revisión de las actividades iniciales del grupo hasta las más recientes para comparar y establecer con fundamentos la mayoría femenina del Grupo Ajau. Los parámetros que se tomaron en cuenta fueron:

- número de mujeres
- participación en expediciones
- perfil académico

Para verificar el número implicado de mujeres participantes del grupo en las expediciones, se hizo un análisis que abarcó un periodo de 14 años comprendido entre el 2010 y el 2024 de los datos registrados en el Currículo General de las

actividades del Grupo Ajau. Pese a que la muestra no es probabilística, sí es representativa pues comprende a la segunda mitad de la existencia del grupo.

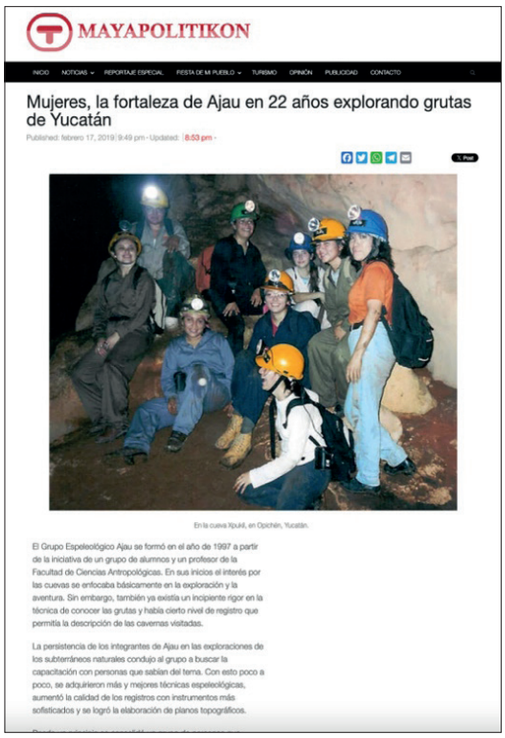
3. Resultado

3.1. Historia de las actividades del grupo

El Grupo Espeleológico Ajau tiene documentado su primera expedición en febrero de 1997, en la cueva Xpukil, Opichén, Yucatán, donde participaron siete hombres y nueve mujeres (Figura 1).

Figura 1: *Primera expedición 25 de febrero de 1997.*

En octubre del mismo año se presentó su primera ponencia colectiva llamada “Baño de cenote” en el marco del aniversario XXVII de la Facultad de Ciencias Antropológicas, como producto de las subsiguientes expediciones realizadas en la que sólo participaron 3 hombres y 5 mujeres, esto significa que desde el primer año de actividades Ajau ya se concretaban los resultados de su labor. El equipo continuó desarrollando actividades espeleológicas en las que las mujeres llegaron a conformar el 98 % de los integrantes, (Figura 2). A través de los años, Ajau prosiguió sus labores con el predomino de la intervención femenina, incluyendo la organización del XI Congreso Nacional Mexicano de Espeleología en el 2013 (Figura 3), así como la coordinación de expediciones internacionales, trabajos de diagnóstico para el cuidado y protección de las cuevas, entre otros (Figuras 4 y 5).


MAYAPOLITIKON

Mujeres, la fortaleza de Ajau en 22 años explorando grutas de Yucatán

En la cueva Xpuhil, en Opichén, Yucatán.

El Grupo Espeleológico Ajau se formó en el año de 1997 a partir de la iniciativa de un grupo de alumnos y un profesor de la Facultad de Ciencias Antropológicas. En sus inicios el interés por las cuevas se enfocaba básicamente en la exploración y la aventura. Sin embargo, también ya existía un incipiente rigor en la técnica de conocer las grutas y había cierto nivel de registro que permitía la descripción de las cavernas visitadas.

La persistencia de los integrantes de Ajau en las exploraciones de los subterráneos naturales condujo al grupo a buscar la capacitación con personas que sabían del tema. Con esto poco a poco, se adquirieron más y mejores técnicas espeleológicas, aumentó la calidad de los registros con instrumentos más sofisticados y se logró la elaboración de planos topográficos.

Figura 2: *Ajau 22 años.*

Figura 3: *XI Congreso Nacional Mexicano de Espeleología (2013).*

Figura 4: *Cueva La Reina, Maxcanú, Yucatán (2018).*

NOVEDADES YUCATÁN

Yucatán: Espeleólogos exploran una cueva que hay debajo de la plaza principal de Santa Elena

Una cascada de agua escurre en la cavidad

Cascada el final de la cueva

MÉRIDA, Yuc.- En meses pasados, autoridades del municipio de **Santa Elena** dieron a conocer la existencia de una **cavidad subterránea** ubicada en la **plaza central**, cuyas fotos de reconocimiento fueron compartidas este viernes por el **Grupo Espeleológico Ajau**.

Según las redes sociales de dicha agrupación, a solicitud del presidente municipal, Luis Alberto Sansores Marn, en noviembre del 2020 el grupo realizó una exploración a dicha cueva.

Indican que los objetivos de la expedición fueron realizar el reconocimiento, registro y mapeo topográfico del Lugar para conocer sus características morfológicas, y realizar recomendaciones acerca de los riesgos potenciales durante el ingreso de personas.

El grupo Ajau explicó que llama la atención este evento, ya que las corrientes de agua con la velocidad de flujo observada no son comunes en la Península, dado el relieve poco pronunciado de nuestro territorio, y siendo que no llovió al momento de su incursión, ni en días anteriores.

Concluida la topografía, los espeleólogos determinaron que el subterráneo tiene una longitud de 135 metros y una profundidad de 34 metros hasta llegar al nivel freático.

Al parecer, el sitio explorado fue parte de un sistema hidráulico subterráneo, construido para drenar el agua pluvial mediante la modificación del terreno natural, el cual fue excavado y adaptado por medio de un túnel que conduce el agua hasta la parte más profunda de la cavidad.

Los integrantes del equipo multidisciplinario de exploración fueron: Marcelo González Rodríguez, María José Gómez Cobá, Fátima Tec Pool, Addy Loría Uc, Pía McManus Gómez y Luiz Afonso Figueiredo.

Figura 5: *Noticia expedición Ajau, 2020.*

3.2. Participación de la mujer en expediciones

En el periodo revisado de 14 años, se registraron 135 expediciones a cavernas, en las cuales se observó la participación de 350 de integrantes Ajau, de los cuales, 305 fueron de mujeres y 145 de hombres.

Es decir, que, del total de participaciones en expediciones en ese periodo, el 87.1% resultó por presencia del género femenino (Figura 6 y 7).

AÑO	N. EXP.	PART. MAS	PART. FEM	PART. TOTAL	% PART. FEM.
2010	7	10	12	22	54.5
2011	6	8	2	10	20.0
2012	9	12	13	25	52.0
2013	11	7	31	38	81.6
2014	23	14	70	84	83.3
2015	4	4	13	17	76.5
2016	10	6	26	32	81.3
2017	11	7	17	24	70.8
2018	7	8	18	26	69.2
2019	15	11	27	38	71.1
2020	2	3	6	9	66.7
2021	2	3	3	6	50
2022	6	15	13	28	46.4
2023	14	23	36	59	61
2024	7	14	18	32	56.2
TOTAL	**134**	**145**	**305**	**350**	**87.1**

Figura 6: *Tabla de participación en expediciones por género.*

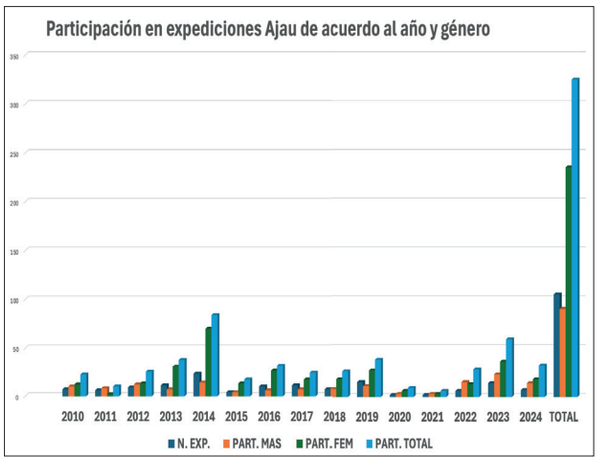


Figura 7: *Gráfica participación en expediciones por género.*

3.3. Perfil académico

Durante el mismo periodo se registraron 15 integrantes mujeres de las cuales 10 contaban con nivel licenciatura, 4 con maestría y una con doctorado (Figura 8).

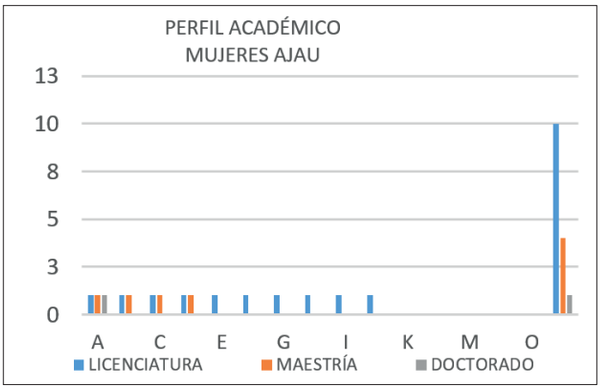


Figura 8: *Perfil Académico de las mujeres del Grupo Ajau.*

Es relevante mencionar que la presidencia del grupo ha sido comandada en dos periodos por hombres y cuatro por mujeres, incluso hasta el presente año. Cabe resaltar que una de ellas fue presidenta de la UMAE (2018 a 2022) y otra secretaria general de la FEALC (2018-2025).

Dentro de los principales productos obtenidos en la actividad espeleológica femenina del grupo, se incluyen organización de congresos, simposios, artículos, capítulos de libros, entrevistas, tesis, conferencias, cursos de capacitación, reportes, documentales y diagnósticos de cuevas para estudios de sustentabilidad. La incansable labor del grupo los ha llevado a tener el reconocimiento de la sociedad civil y durante la Feria Internacional de la Lectura Yucatán, se les hizo una conmemoración por su XX Aniversario de trayectoria espeleológica, (Figuras 9 y 10).

Figura 9: *Reconocimiento de Ajau en la FILEY 2017.*

Figura 10: *Entrevista Ajau, 2024.*

4. Discusiones

En muchos países la espeleología es considerada como un pasatiempo o deporte extremo. No todos sus practicantes contemplan el trabajo de gabinete o la investigación formal que respalde la actividad de su trabajo de campo. En México la espeleología va ganando espacios y los resultados se transforman en aportaciones que pueden servir a la ciencia. Aunque, esto no sucede con todos los grupos espeleológicos.

Desde la experiencia del Grupo Ajau y con base en la cantidad de integrantes que han ingresado y desertado a lo largo del tiempo, se ha observado que, desde su creación, el interés por explorar y preservar las cuevas es compartido por ambos sexos. Sin embargo, la disciplina que caracteriza a Ajau va más allá de la exploración, pues el grupo enfatiza la importancia de contribuir constante a la espeleología desde distintas vertientes científicas. Curiosamente, este requisito ha funcionado como un filtro donde la mayoría de los hombres no lograron superar, ya que tienden a declinar su participación, a diferencia de las mujeres, quienes destacan por su capacidad de proponer, organizar y mantener las actividades del grupo.

Para ellas, este compromiso no representa un obstáculo, sino una motivación que fortalece su permanencia y liderazgo dentro de la agrupación. En contraste con los hombres, las mujeres que ingresaron en la etapa inicial no solo permanecieron en el equipo, sino que también destacaron por su compromiso y desempeño académico, consolidándose como pilares fundamentales en el desarrollo del Grupo.

5. Conclusión

La práctica y el avance de la espeleología son distintos en los diferentes países del mundo y seguramente varían en cada una de sus regiones. En México, por lo general, los grupos de esta disciplina están conformados por una mayoría de hombres. Las mujeres participan, pero en un menor porcentaje. Ahora bien, en los últimos tiempos ellas han ganado terreno en muchas actividades económicas, deportivas y científicas. La espeleología no es la excepción, pues como se ha demostrado en este trabajo la participación de los elementos femeninos fue un factor importante para la integración y desarrollo del Grupo Espeleológico Ajau.

Es significativo hacer notar que las mujeres que conformaron desde su inicio el Grupo fueron disciplinadas tanto para la exploración como para el estudio formal de las cuevas. Fueron muy dedicadas para el trabajo espeleológico de campo, también muy rigurosas en la observancia de las medidas de seguridad y sobresalieron en el trabajo de gabinete, que requiere una formación académica suficiente para lograr resultados más allá de la aventura en el mundo subterráneo. Si bien, en los últimos tres años se han incorporado más hombres al grupo, el porcentaje de participaciones en las expediciones y la producción continúa siendo superado por las mujeres.

Es conveniente señalar que esta conclusión no sugiere una superioridad intrínseca de las mujeres con respecto a los hombres, sino que, en este grupo de espeleología, en particular, las chicas demostraron que en condiciones de igualdad supieron aplicar sus atributos necesarios para que la actividad científica, productiva y de protección a las cuevas, se instalara definitivamente en Yucatán.

Agradecimientos

Nos gustaría de agradecer a Carlos Evia Cervantes, Luiz Afonso V. Figueiredo y demás miembros del Grupo AJAU por que creyeron en la temática de las mujeres en la espeleología y por el apoyo a la elaboración del presente artículo.

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Demonstrações de fé na Casa de Pedra São Geraldo do Araguaia – PA

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Resumo

O Festejo do Divino Espírito Santo na Casa de Pedra, localizada na Serra das Andorinhas (PA), representa uma das mais significativas manifestações religiosas da região, reunindo romeiros que percorrem longas distâncias para cumprir promessas e expressar sua fé. Além do aspecto espiritual, o evento fortalece a identidade cultural local, preservando tradições herdadas de migrantes e adaptadas ao contexto amazônico. A celebração, marcada por rituais, cantos e procissões, ocorre em um ambiente de grande valor arqueológico e natural, demandando ações de conscientização ambiental e proteção do patrimônio. Assim, o festejo transcende a religiosidade, consolidando-se como um elemento essencial da memória coletiva, da cultura imaterial e da relação entre devoção e preservação ambiental na região.

Abstract

The Celebration of Divino Espírito Santo at Casa de Pedra, located in Serra das Andorinhas (PA), represents one of the most significant religious manifestations in the region, bringing together pilgrims who travel long distances to fulfill promises and express their faith. In addition to the spiritual aspect, the event strengthens local cultural identity, preserving traditions inherited from migrants and adapted to the Amazonian context. The celebration, marked by rituals, songs and processions, takes place in an environment of great archaeological and natural value, requiring actions to raise environmental awareness and protect heritage. Thus, the celebration transcends religiosity, consolidating itself as an essential element of collective memory, intangible culture and the relationship between devotion and environmental preservation in the region.

1. Introdução

Um elemento comum nas cavernas em diversas culturas é a variedade de sentimentos que elas despertam, que vão do medo ao encantamento. Esses espaços, ao longo da história, foram marcados pela presença humana, carregando significados que transcendem o material e se entrelaçam com o simbólico e o espiritual. A versatilidade das cavernas – ora como abrigo, ora como esconderijo ou local sagrado – explica sua recorrente associação a mitologias, lendas e práticas religiosas em diversas sociedades PEREIRA (2021).

Na tradição judaico-cristã, por exemplo, as cavernas são mencionadas em diversas passagens bíblicas. Davi encontrou refúgio na caverna de Adulão (1 Samuel 22:1-2), enquanto Elias teve uma experiência espiritual no monte Horebe (1 Reis 19:9-13). Para os cristãos, a gruta de Belém, onde Jesus nasceu, é um símbolo de fé e devoção (Lucas 2:6-8). Ao longo dos séculos, algumas dessas cavernas foram transformadas em templos e santuários, tornando-se destinos de peregrinação e devoção religiosa PEREIRA (2021).

No Brasil, a Casa de Pedra, localizada na Serra das Andorinhas, em São Geraldo do Araguaia (PA), é um exemplo dessa ressignificação dos espaços cavernícolas. Situada a 600 metros de altitude, essa cavidade tem sido objeto de estudo desde 1986 e apresenta vestígios arqueológicos, incluindo pinturas rupestres, que sugerem seu uso ritualístico desde tempos pré-históricos. Atualmente, a Casa de Pedra continua sendo um local de manifestação da fé, servindo como centro religioso para a comunidade local. Um dos momentos mais significativos dessa tradição é o Festejo do Divino, realizado anualmente, reunindo fiéis em celebrações que reforçam a conexão entre o sagrado e a natureza.

Diante desse contexto, este trabalho tem como objetivo analisar o uso das cavidades naturais como espaços sagrados, com ênfase no Festejo do Divino na Casa de Pedra, destacando a continuidade das práticas religiosas nesse ambiente e sua importância cultural para a comunidade de São Geraldo do Araguaia – PA.

2. Materiais e Métodos

A Serra das Andorinhas está localizada no município de São Geraldo do Araguaia, a sudoeste do estado do Pará, na fronteira com o Tocantins, na margem esquerda do rio Araguaia. Com uma área aproximada de 60 mil hectares, a região apresenta uma transição entre os biomas Cerrado e Amazônia, além de uma geografia marcada por grandes elevações, formações quartzíticas e um relevo acidentado, com altitudes que chegam a 600 metros. A geomorfologia da área é caracterizada pela formação Morro do Campo, com extensos paredões de rochas quartzíticas e estruturas ruiniformes resultantes da dissecação do relevo, que contribuem para a presença de inúmeras cavidades geológicas NAEA (2006) & MORAES (2008).

Diante da relevância ambiental e cultural da Serra das Andorinhas, em 22 de setembro de 1989, a Fundação Casa da Cultura de Marabá (FCCM) solicitou seu tombamento junto à Secretaria de Estado de Cultura do Pará. Esse reconhecimento levou à criação do Parque Estadual Serra dos Martírios/Andorinhas (PESAM) e da Área de Proteção Ambiental (APA) de São Geraldo do Araguaia, por meio das Leis nº 5.982 e nº 5.983, respectivamente, em 25 de julho de 1996 MORAES (2008).

O parque abriga uma diversidade de atrações naturais e culturais, incluindo mais de 30 cachoeiras de águas cristalinas, praias formadas pelo rio Araguaia e um vasto patrimônio arqueológico. Foram identificados mais de 100 sítios arqueológicos com cerca de 5.500 pinturas e gravuras

rupestres, evidenciando a ocupação humana desde tempos remotos. Além disso, o local tem grande importância histórica, pois serviu de refúgio para guerrilheiros durante a Guerrilha do Araguaia, sendo hoje reconhecido como patrimônio histórico nacional.

Entre as cavernas da região, destaca-se a Casa de Pedra, situada a aproximadamente 600 metros de altitude na porção norte do parque. O acesso ao local é desafiador, exigindo uma caminhada de cerca de 5 km por trilhas íngremes a partir da residência de um morador local, conhecida como «Zeca do Jorge» (SBE, 2011).

A caverna possui grande significado religioso para a comunidade, sendo o principal cenário do Festejo do Divino, celebrado anualmente em maio. Durante esse período, grupos de fiéis percorrem longas distâncias, vindos de diversas localidades da Serra das Andorinhas, São Geraldo do Araguaia, Orilândia do Norte e até do estado do Tocantins. A difícil jornada até o santuário, para muitos romeiros, representa um ato de fé e cumprimento de promessas MORAES (2008).

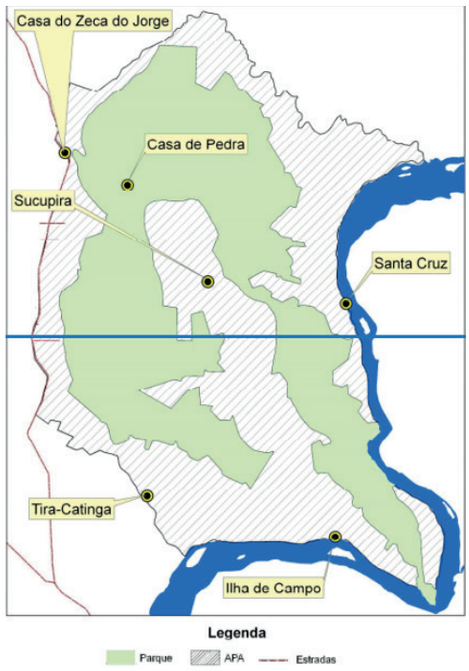

Figura 1: *Mapa de Localização da Casa de Pedra e das Comunidades ao seu Entorno. SEMA/PESAM - MORAES (2008).*

3. Resultados

A Casa de Pedra se tornou um dos principais centros de manifestações religiosas da região, sendo palco do *Festejo do Divino Espírito Santo. De acordo com Moraes (2008), comunidades ao redor do abrigo realizam romarias anualmente nas primeiras semanas de maio. Os fiéis percorrem trilhas íngremes da Serra das Andorinhas, organizados em grupos, até alcançarem o santuário, situado a aproximadamente 600 metros de altitude.

O festejo tem origem em promessas feitas por devotos desde 1966, conforme relato do senhor Zeca do Jorge, que testemunhou as primeiras celebrações no local. No entanto, a tradição se consolidou em 1989, quando um grupo liderado por Dona Zefona e outros romeiros relatou ter visto imagens nas paredes da Casa de Pedra, interpretadas como a representação da pomba do Divino. Esse evento foi determinante para que o espaço fosse reconhecido como a «Igreja da Trindade», levando à construção de um altar no interior da caverna, adornado com a pomba do Divino e as bandeiras sagradas MORAES (2008).

Durante o festejo, dezenas de homens, mulheres e crianças alojam-se nas cavernas e abrigos naturais da serra. O evento é marcado por rezas, procissões, terços cantados e apresentações musicais. As celebrações iniciam ao amanhecer e ao anoitecer, com o som de caixas e foguetes, convocando os fiéis para o santuário. No início da cerimônia, são entoados cânticos acompanhados por caixas e sanfona, enquanto a bandeira branca do Divino tremula, simbolizando a Trindade. Os devotos beijam a bandeira em sinal de devoção e, em seguida, rezam o terço, finalizando com novos cânticos.

Outro momento significativo é o Encontro das Bandeiras, que ocorre quando um novo grupo de romeiros se aproxima da Casa de Pedra. Ao ouvir o soar da caixa ao longe, os fiéis já reunidos saem ao encontro dos recém-chegados, carregando bandeiras e salvas. Esse ritual representa a recepção dos devotos e a união entre as diferentes comunidades participantes do festejo MORAES (2008).

A tradição do Divino Espírito Santo tem raízes na cultura lusitana e foi trazida ao Brasil pelos colonizadores. Segundo Vieira Filho (1977), essa celebração popular tem uma forte ligação com promessas e ex-votos, mesclando elementos religiosos e profanos. No sudoeste do Pará, essa tradição se manteve viva devido à influência de migrantes goianos e nordestinos que chegaram à região no final do século XIX. O festejo na Casa de Pedra preserva características das celebrações de Goiás e do Norte de Minas Gerais, diferenciando-se de outras manifestações religiosas do estado do Pará, onde a festividade não é comum MATTOS (1999).

A Folia do Divino, ao longo do tempo, sofreu transformações em virtude do progresso urbano e das mudanças nos padrões sociais. No entanto, permanece como um importante elemento da memória folclórica e religiosa, reafirmando a identidade cultural da região MATTOS (1999).

A festividade não apenas reúne fiéis em romaria, mas fortalece os laços comunitários e reforça a transmissão de valores e tradições entre gerações.

Além da celebração religiosa, o festejo incorpora atividades culturais como apresentações de carimbó, salambisco, teatro, cinema e festas juninas. Paralelamente, ocorrem ações de conscientização ambiental, promovidas pelo IDEFLOR-Bio, em parceria com o Batalhão de Policiamento Ambiental (BPA), a Prefeitura de São Geraldo do Araguaia e entidades privadas.

Entre as iniciativas voltadas à preservação ambiental, destacam-se:

- Instalação de lixeiras temporárias e apoio logístico com fornecimento de água;
- Palestras sobre prevenção de incêndios e combate à caça ilegal;
- Isolamento de sítios arqueológicos para evitar danos às pinturas rupestres;
- Ações lúdicas de conscientização, incluindo teatro, oficinas de artesanato e recreação para crianças.

Segundo Laís Mercedes (2023), «o objetivo é fortalecer a cultura religiosa, aliada à preservação do meio ambiente», garantindo que as futuras gerações continuem a vivenciar essa manifestação de fé sem comprometer o patrimônio natural e arqueológico da Serra das Andorinhas.

A seguir, são apresentadas imagens de diferentes períodos do Festejo do Divino na Casa de Pedra, ilustrando sua evolução e a participação crescente dos romeiros ao longo das décadas:

Figura 2: *Entrada de romeiros na Casa da Pedra. Fonte: Noé von Atzingen, 1992 (NAEA, 2006).*

Figura 3: *Aspecto da chegada de romeiros na área da Casa da Pedra. Fonte: Noé von Atzingen, 1992 (NAEA, 2006).*

Figura 4: *Altar existente na Casa de Pedra. Fonte: L. Simonian, 2005 (NAEA, 2006).*

Figura 5: *Após o Encontro das Bandeiras os romeiros cantam e ajoelham-se diante do cruzeiro. MORAES (2008).*

Figura 6: *Folia do Divino na Casa da Pedra. Fonte: Vinícius Leal (IDEFLO-R-BIO - 2023).*

4. Discussão

As cavernas, ao longo da história, desempenharam um papel essencial como abrigo e refúgio dos primeiros grupos humanos. Com o desenvolvimento das civilizações, passaram a ter novos significados e funções, sendo utilizadas como tumbas, esconderijos, locais de armazenamento e, principalmente, espaços sagrados PEREIRA (2021). Esses ambientes naturais não apenas preservam vestígios da vida humana primitiva, mas também resguardam narrativas coletivas, tornando-se cenários de rituais e tradições que atravessam gerações.

Na Casa de Pedra, essa dimensão simbólica se manifesta de forma intensa. O local, situado no topo da Serra das Andorinhas, tornou-se centro de devoção e peregrinação, onde os romeiros buscam renovar sua fé e cumprir promessas feitas ao Divino Espírito Santo. A relação da comunidade com esse espaço sagrado não se limita à religiosidade, mas se estende à identidade cultural e social dos moradores da região. O festejo não apenas reforça laços comunitários, mas também perpetua uma tradição que ultrapassa o tempo, preservando costumes e valores

herdados de gerações passadas.

Ao mesmo tempo, a manifestação religiosa na Casa de Pedra possui um aspecto educativo relevante, tanto do ponto de vista social quanto ambiental. Durante as celebrações, ocorrem atividades voltadas à conscientização ecológica, promovidas por órgãos ambientais e entidades locais. Ações como a proteção dos sítios arqueológicos, campanhas de limpeza e palestras sobre conservação reforçam a importância da preservação do patrimônio natural e histórico da serra. Assim, o festejo se torna também um instrumento de educação, sensibilizando a comunidade para a necessidade de equilíbrio entre fé, cultura e meio ambiente.

Dessa forma, a Casa de Pedra não é apenas um cenário geológico imponente, mas um espaço de transcendência e pertencimento, onde a espiritualidade se entrelaça com a história e a identidade da população local. Como bem expressa Hebreus 11:1: "Ora, a fé é a certeza daquilo que esperamos e a prova das coisas que não vemos", reafirmando que, mais do que um local de culto, a Casa de Pedra representa uma experiência coletiva de conexão com o sagrado e com a natureza, mantendo viva uma tradição que se renova a cada romaria.

5. Conclusão

A Casa de Pedra, na Serra das Andorinhas, é um importante centro de manifestação religiosa, onde o Festejo do Divino Espírito Santo reafirma tradições de fé e pertencimento comunitário. O evento fortalece laços sociais e culturais, evidenciando a continuidade de práticas herdadas de migrantes e adaptadas ao contexto local.

Além do seu significado religioso, o festejo tem impacto na preservação do patrimônio histórico e ambiental da região. A mobilização de órgãos públicos e voluntários demonstra a preocupação com a conservação das cavernas e sítios arqueológicos, promovendo um equilíbrio entre devoção e sustentabilidade.

O evento também se destaca como espaço de educação e transmissão cultural, onde ritos, cantos e procissões garantem a permanência dessa tradição ao longo das gerações. A participação de diferentes grupos fortalece a identidade regional, consolidando a Casa de Pedra como um patrimônio imaterial do Pará.

Dessa forma, a celebração transcende seu caráter religioso, tornando-se um símbolo da interação entre cultura, história e meio ambiente. Preservar essa manifestação significa reconhecer sua relevância na construção da memória coletiva e garantir que sua essência continue viva para as futuras gerações.

Agradecimentos

Agradecemos aos colegas e professores da Especialização em Patrimônio Espeleológico, da Universidade de Passo Fundo – UPF, que nos apresentaram a Casa de Pedra, da qual o interesse fez com que buscássemos informações e aprofundássemos nossos conhecimentos. Agradecemos, também, pela troca de experiências e pela motivação constante para o estudo e valorização do patrimônio natural e cultural. Este aprendizado contribuiu significativamente para o nosso crescimento acadêmico e profissional, além de fortalecer nossa conexão com o legado histórico e ambiental que estamos comprometidas a preservar.

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An introduction to Cecília de Castro Torres' speleological journey

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Resumo

A espeleologia é um ramo das ciências predominantemente masculina, não somente nas atividades de campo, como também na produção científica. Esta realidade vem mudando gradativamente, porém há ainda um longo caminho a ser percorrido, sendo necessário que se produzam pesquisas voltadas para a visibilidade feminina nesta área. Deste modo, o objetivo deste trabalho é apresentar um pouco da história da espeleologia nacional, em especial, valorizando a participação de uma destas mulheres e refletir sobre a participação feminina na espeleologia brasileira, bem como, as implicações de gênero que influenciaram suas trajetórias e contribuições, buscando a superação de estereótipos de gênero. Esta pesquisa tem caráter qualitativo, exploratório, construcionista e interpretacionista e se fundamenta a partir do campo teórico dos estudos feministas e de gênero na ciência e na discussão sobre decolonialidade. O trabalho e as contribuições de Cecília de Castro Torres na espeleologia, em especial à biologia subterrânea, evidenciam sua dedicação à pesquisa científica brasileira. Suas publicações continuam a ser referências para estudantes e pesquisadores interessados na biodiversidade das cavernas. Consideramos que histórias como a dela, podem oportunizar reflexões críticas que permitam a meninas e mulheres descobrirem-se enquanto sujeitos históricos capazes de compreender, intervir e modificar sua realidade.

Abstract

Speleology is a predominantly male branch of science, not only in field activities but also in scientific production. This reality has been gradually changing, but there is still a long way to go, making it necessary to conduct research aimed at increasing the visibility of women in this field. Thus, the objective of this study is to present a brief history of national speleology, especially highlighting the participation of one of these women, and to reflect on the role of women in Brazilian speleology, as well as the gender implications that have influenced their trajectories and contributions, aiming to overcome gender stereotypes. This research is qualitative, exploratory, constructionist, and interpretivist in nature, and it is based on the theoretical framework of feminist and gender studies in science, as well as discussions on decoloniality. The work and contributions of Cecília de Castro Torres to speleology, particularly to subterranean biology, demonstrate her dedication to Brazilian scientific research. Her publications remain key references for students and researchers interested in cave biodiversity. We believe that stories like hers can provide critical reflections that inspire girls and women to see themselves as historical subjects capable of understanding, intervening in, and transforming their reality.

Resumen

La espeleología es un campo de las ciencias predominantemente masculino, tanto en las actividades de campo como en la producción científica. Aunque esta realidad ha cambiado gradualmente, aún queda mucho por hacer para visibilizar a las mujeres en esta área. Este trabajo tiene como objetivo presentar parte de la historia de la espeleología nacional, destacando la participación de una mujer y reflexionando sobre el rol femenino en la espeleología brasileña, así como sobre las implicaciones de género que han influido en sus trayectorias y contribuciones, buscando superar los estereotipos de género. La investigación es cualitativa, exploratoria, construccionista e interpretativa, fundamentada en los estudios feministas y de género en la ciencia, y en la decolonialidad. Las contribuciones de Cecília de Castro Torres a la espeleología, especialmente en la biología subterránea, reflejan su compromiso con la investigación científica brasileña. Sus publicaciones son referencias clave para quienes estudian la biodiversidad de las cavernas. Historias como la suya invitan a reflexionar críticamente, motivando a niñas y mujeres a verse como sujetos históricos capaces de comprender, intervenir y transformar su realidad, promoviendo así una mayor equidad de género en la ciencia y la superación de barreras históricas.

1. Introdução

Revisitando diversos trabalhos de história das ciências, em especial aqueles que tratam das geociências e da espeleologia, percebemos ausências de mulheres, de negros, de índios e de latinos. Estas personagens aparecem pouco e quase sempre como coadjuvantes no processo de construção da ciência.

MATOS & SOUSA, 2022, apontam sobre as razões que levaram a estas ausências e destacam que a eliminação dos contextos políticos e culturais da produção do conhecimento conduziu à ilusão de neutralidade científica. Esta suposta neutralidade, na verdade, permitiu que se estabelecesse uma relação entre a dominação econômica, política

e cultural e a dominação epistemológica, que hierarquizou os saberes e negou a diversidade.

As relações entre gênero e ciência é um tema que tem gerado muitas discussões na atualidade, é possível observar um crescente movimento de visibilidade feminina na atuação científica em diversos campos. Estes movimentos buscam preencher lacunas e mostrar a efetiva contribuição feminina na produção de conhecimento científico, porém, apesar de todos estes esforços, o que observamos é que os valores ainda presentes e que prevalecem sobre as ciências são masculinos e, em muitos casos, desfavoráveis à participação feminina.

A espeleologia é uma área das ciências predominantemente masculina, não somente nas atividades de campo, como também na produção científica. Esta realidade vem mudando aos poucos, porém há ainda um longo caminho a ser percorrido. O objetivo deste trabalho é apresentar uma destas mulheres, Cecília de Castro Torres, espeleóloga, membro do CEU – Clube Excurcionista Universitário, através da história da espeleologia e refletir sobre a participação feminina na história da espeleologia brasileira, bem como, as implicações de gênero que influenciaram suas histórias e contribuições, buscando a superação de estereótipos de gênero. Esta pesquisa tem caráter qualitativo, exploratório, construcionista e interpretacionista e se fundamenta a partir do campo teórico dos estudos feministas e de gênero na ciência e decolonialidade.

2. Materiais e Métodos

Para o desenvolvimento deste trabalho, optou-se por uma abordagem, exploratória, construcionista e interpretacionista, onde busca-se entender o significado que emerge a partir de nossa interação com a realidade, diferentemente do interesse positivista pela descrição e explicação do mundo (ESTEBAN, 2010). Utilizamos também a pesquisa documental para levantar os documentos históricos que trazem as histórias das mulheres que fizeram ciência, de acordo com as concepções de MARCONI & LAKATOS (2019), que considera como principal característica da pesquisa documental a tomada como fonte de coleta de dados documentos escritos ou não como fontes primárias, que podem ter sido feitas no momento em que o fato ocorreu ou depois, e a história oral de acordo com LOZANO (2006) que nos permite operar com o inacabado, com o não essencial, sobretudo, com a pluralidade de vozes e afetos que produz e é produzido por meio da relação pesquisa-pesquisador-cenário investigativo.

3. Resultados

3.1. Adentrando nos meandros da história da Espeleologia

Não é possível falar da história da humanidade sem falar em cavernas. A relação entre a nossa espécie e estes ambientes está intimamente ligada. Sempre que nos remetemos à pré-história, é comum nos deparamos com o termo “homem das cavernas” para estabelecer um período primitivo e remoto, mas a verdade é que a relação entre o homem e as cavernas sempre foi de grande importância, seja na busca por abrigo ou pelo desconhecido e sobrenatural.

As cavernas também foram um dos primeiros lugares a serem habitados e, de certo modo um dos primeiros a agruparem diferentes indivíduos, dando início a uma sociedade que surge a partir do convívio em grupo buscando a sobrevivência (GAMBARINI, 2012). Boa parte das ossadas humanas mais antigas de que se tem história foram encontradas em cavernas, com seus amplos espaços subterrâneos e escuros, seu silêncio atormentador e sua beleza expressa em ornamentações minerais, as grutas e abismos fazem parte do desenvolvimento do homem como ser cultural(LINO, 2009).

É neste ambiente também que surgem as primeiras formas de comunicação escrita da sociedade, a arte rupestre, que nos traz evidências importantes da evolução escrita e artística da humanidade, além de nos apresentar diferentes técnicas e materiais que evoluíram juntamente com o homem. As diferentes representações que vão de simples formas geométricas até o realismo do desenho das rotinas cotidianas expressam a passagem do estágio de simples coleta e caça para a agricultura e demais manifestações socioculturais (GAMBARINI, 2012)

A história da espeleologia é ainda um campo muito carente de trabalhos sistemáticos à luz da historiografia. Segundo FIGUEIREDO (2010) os poucos trabalhos neste campo nos apresentam uma descrição de ricos cenários da exploração da paisagem cárstica, além de documentos históricos dos grupos espeleológicos e informações sobre os momentos mais significativos que registram a ciência espeleológica, apresentam uma importância educativa enorme, além de contribuir para a divulgação científica e resgate da memória, tão necessários para a preservação do patrimônio espeleológico.

Em 1994 foi criada a seção de História da Espeleologia da Sociedade Brasileira de Espeleologia (SBE), que desenvolveu uma extensa pesquisa para o Projeto História da Espeleologia Brasileira (PROHEB), projeto este ainda em curso, porém, devido os recursos escassos, a falta de estímulos e incentivos financeiros, bem como o pequeno número de pesquisadores qualificados para tal pleito, são poucos os dados registrados e/ou conservados. Sem contar às dificuldades para a reconstrução das origens da atividade espeleológica, tendo em vista seu caráter multidisciplinar e documentação em posse de grupos extintos ou modificados ao longo dos anos, requerendo um trabalho de “garimpo”, intenso e cuidadoso (FIGUEIREDO et.al, 1997; FIGUEIREDO et.al, 2005; FIGUEIREDO, 2010).

O termo espeleologia apenas se concretizou em meados do século XIX, porém não faltaram explorações e tentativas de explicação da gênese das cavernas e suas ornamentações por parte de naturalistas e estudiosos durante o período entre os séculos XVI e XVIII. Os mais mencionados dentre estes documentos são os trabalhos agrícolas entre 1546 e 1549 e o tratado denominado “Mundus Subterraneus” de 1659, que mencionavam o processo de infiltração e circulação de água subterrânea bem como as possibilidades de formação das ornamentações (LLOPIS-LLADÒ, 1970; SHAW, 1986; WHITE, 2007).

No século XVII a obra “Le Monde Sousterrein” apresentou a primeira classificação de cavernas, no entanto na obra ainda havia o predomínio dos aspectos de magia e ocultismo. Outra obra importante deste período foi “A Glória do Ducado de Carniola” que descreveu utilizando ilustrações os elementos formadores de cavernas e a presença de estalagmites e colunas, destacando o papel da água no processo. (SHAW, 1986). Para FIGUEIREDO (2010), o primeiro livro a tratar quase exclusivamente de cavernas foi “A Tour to the Caves”, publicado em 1780, este livro foi considerado um marco para a história da espeleologia mundial, pois seu potencial científico com o reconhecimento e ampliação da exploração das cavidades naturais viria propor o desenvolvimento de atividade turística em cavernas.

A visitação e exploração de cavernas passou a aumentar sistematicamente em todo o mundo e as Américas apresentavam um potencial imenso na exploração destes ambientes em busca de salitre. A Mammoth Cave, nos Estados Unidos, uma das maiores cavernas do mundo com mais de 600km foi muito explorada para este fim durante o século XIX, destacando que a extração mineral foi uma das principais formas de exploração do mundo subterrâneo no continente americano. No Brasil esta situação não foi diferente, muitas cavernas foram exploradas para

obtenção de minérios assim como em toda América Latina. (LINO & ALLIEVI; 1980, FIGUEIREDO, 2010).

Em 1854, surgem os primeiros trabalhos de estudos biológicos em cavernas, dando uma primeira proposta de classificação aos seus habitantes, no entanto, apenas no início séc. XX os estudos em biologia subterrânea ganham de fato espaço nas universidades, dando origem a Bioespeleologia, porém é apenas em 1907 que a bioespeleologia ganha visibilidade com uma nova classificação dos animais subterrâneos. No ano de 1930, surge a "Societè Speleologique de France", uma das primeiras sociedades espeleológicas do mundo, esta sociedade dá início ao reconhecimento das espeleologia como atividade técnica e científica, orientada por um viés interdisciplinar (DEQUECH, 2000; TRAJANO & BICHUETTE, 2006).

No Brasil, existem vários indícios de que a atividade em cavernas tenha se iniciado antes do séc. XVI, estas atividades estão relacionadas a moradias e rituais indígenas dos povos originários, porém a primeira referência histórica data de 1717 com a descrição da Lapa do Bom Jesus na Bahia, esta caverna é visitada provavelmente desde 1690 de forma religiosa e atualmente abriga um santuário católico. (FIGUEIREDO, 2010 ; PIRES, 1922; LINO, 1989). Durante o Brasil Colonial as cavernas brasileiras eram exploradas em busca de terra salitrosa para produção de pólvora, exploração que não se mostrou eficiente dada a inviabilidade de transporte e distância a serem vencidas.

Muitos naturalistas brasileiros e estrangeiros tiveram um papel importante no registro de cavernas, expedições de 1783 à 1792 revelaram a grandeza e diversidade de ambientes subterrâneos no Brasil, a "Viagem Filosófica" reuniu uma equipe de mais de 100 pessoas que fizeram um amplo levantamento político-científico de várias regiões, em especial a Amazônica. Em 1805 temos as primeiras descrições de cavernas paulistas no diário de uma viagem Mineralógica pela Provincia de São Paulo (FIGUEIREDO et.al., 1997).

Além da atuação dos naturalistas brasileiros, houve uma profunda influência dos naturalistas estrangeiros, em 1833 houve a publicação do livro "Pluto Brasiliensis" resultado de uma expedição de 1810 à 1821, descrevendo inúmeras grutas espalhas pelo Brasil. A atuação dos naturalistas estrangeiros está arraigada nas histórias e percursos de grupos espeleológicos espalhados pelo Brasil, de forma que muitos deles tem nomes em homenagem a eles. Em 1937 funda-se a Sociedade Excursionista e Speleológica – SEE ligada a Escola Nacional de Minas e Metalurgia de Ouro Preto, primeira entidade espeleológica do Brasil e da América Latina (FIGUEIREDO, 2010)

A SEE tem um papel muito importante na espeleologia brasileira, pois desde sua formação havia o enfoque multidisciplinar tão característico a atividade em cavernas, os trabalhos deste grupo envolviam geologia, biologia, arqueologia, hidrografia, entre outros, as expedições que realizaram no Vale do Rio das Velhas em Minas Gerais e no Vale do Ribeira em São Paulo, levaram a elaboração de vários outros estudos comparativos e detalhados das regiões pesquisadas (DEQUECH, 1987, FIGUEIREDO, 2010)

Em 1939 o Instituto Brasileiro de Geografia e Estatística – IBGE, publica "As Grutas de Minas Gerais" uma importante obra de divulgação das cavernas brasileiras da época, em 1940 temos a primeira edição do livro "Geologia do Brasil" que descreve algumas grutas de São Paulo e Minas Gerais, sendo um marco nas investigações geológicas do Brasil além da proposta de criação de um parque nacional englobando as cavernas da região de Iporanga-SP (FIGUEIREDO, 2010)

O crescimento da atividade espeleológica no Brasil, bem como da atividade científica e a criação de parques nacionais englobando cavernas mobiliza então espeleólogos em todo o país, de forma que em 1958, surge uma primeira versão do que será a "Sociedade Brasileira de Espeleologia - SBE". Nesta época surgem diversos grupos espeleológicos em todo o país, fortalecendo a atividade e dando origem ao Primeiro Congresso Brasileiro de Espeleologia – CBE em 1964. Durante o IV Congresso Brasileiro de Espeleologia em 1969 é fundada efetivamente a Sociedade Brasileira de Espeleologia, um importante passo para a institucionalização da espeleologia nacional e, em 1970, temos a criação do primeiro Boletim informativo sobre espeleologia em nível nacional o "Espelo-Tema", boletim este que se encontra ativo até hoje, sendo a revista científica da SBE (FIGUEIRED et.al., 1997; FIGUEIREDO, 2010).

A espeleologia é uma área predominantemente masculina, esta realidade está mudando gradativamente e as mulheres têm conquistado cada vez mais espaço no universo espeleológico, porém a visibilidade feminina ainda é pequena. São poucas as mulheres a frente de grupos espeleológicos e menos ainda aquelas em altos escalões e representatividade nas sociedades de classe, como a SBE e Centro Nacional de Pesquisa e Conservação de Cavernas – CECAV, muito embora existam inúmeras mulheres fazendo pesquisas de qualidade nesta área. É necessário e urgente resgatar a história das mulheres na espeleologia, pois ao entender as histórias dessas diferentes mulheres e encontrar suas experiências torna-se possível compreender que elas também estiveram presentes nos processos importantes para o desenvolvimento e consolidação desta ciência, assim como as formas e estratégias utilizadas para realizar suas expedições científicas e dar luz às suas pesquisas.

As mulheres na espeleologia nacional têm desempenhado papéis fundamentais em pesquisas científicas e explorações de relevância ímpar. Suas contribuições vão desde a cartografia detalhada de cavernas até a descoberta de novas formações geológicas e ecossistemas subterrâneos. Cientistas como Cecília de Castro Torres se destacaram pela excelência em seus estudos relacionados à biologia subterrânea e à geologia cárstica, proporcionando avanços significativos no entendimento dos ecossistemas que habitam o mundo subterrâneo.

Além de suas realizações científicas, muitas mulheres também têm desempenhado um papel crucial na preservação de cavernas e na educação ambiental. Elas promovem práticas de visitação sustentável e sensibilizando o público sobre a importância da conservação desses ecossistemas únicos. A conscientização ambiental liderada por mulheres espelólogas contribui para a preservação não apenas das cavernas, mas também dos ecossistemas conectados a elas.

3.2. Cecília de Castro Torres e seu legado espeleológico

Cecília de Castro Torres foi uma renomada bióloga brasileira, especialista em zoologia, falecida em 1985 cuja trajetória acadêmica e pesquisa na área de primatologia e ecologia tem contribuído significativamente para o entendimento da fauna e ecossistemas brasileiros. Seu percurso acadêmico pode ser dividido em etapas distintas, marcadas por formação acadêmica, pesquisa de campo e contribuições valiosas para a literatura científica, em especial à espeleologia.

Em 1971, ainda estudante, Cecília ingressou no CEU – Centro Excursionista Universitário, um grupo que tinha por finalidade reunir universitários interessados em atividades como alpinismo, canoismo e espeleologia, estas atividades, além de fazerem parte dos chamados esportes radicais, despertam em seus adeptos um alto interesse científico como ocorre especialmente na espeleologia. Cecília é descrita por seus companheiros de grupo como alguém dinâmica, apaixonada, pesquisadora incansável e sobretudo, uma vanguardista na consolidação da espeleologia paulista.

Em 1972, surge a "Operação Tatus" projeto que tinha por objetivo observar o comportamento humano longe da luz solar por um longo período, o projeto só foi realizado em 1975 devido aos equipamentos e recursos humanos necessários à empreitada (TRAJANO & RODRIGUES, 2018), Cecília Torres foi uma das biólogas que participaram da experiência, sendo responsável por parte dos estudos e coleta de dados de bio-espeleologia em conjunto com outra bióloga Maria Thereza Temperini e duas estudantes de biologia: Eleonora Trajano e Marietta Salles Silva, além de outros estudantes e profissionais de diferentes áreas.

Mesmo deixando de cumprir alguns objetivos propostos, a Operação Tatus foi um marco na Espeleologia do Centro Excursionista Universitário

pois nunca se havia realizado antes de um projeto que exigisse uma mobilização geral de todos os seus sócios, além de outras entidades e firmas particulares que colaboraram. (TRAJANO & RODRIGUES, 2018, p. 46)

Figura 1: *Cecília Castro Torres, 1973 – Bethary/SP (Fonte : Hélio Shimada).*

Em 1972/73, o espeleólogos e espelólogas do CEU realizam os primeiros trabalhos de exploração, mapeamento e biologia da caverna "Gruta dos Paivas", localizada no extremo norte do município de Iporanga/SP (LIMA et.al., 2003), dentre eles está Cecília Torres. Outras grutas exploradas nesta época foram: a "Gruta Colorida, localizada em Capão Bonito-SP e Gruta da Figueira em Iporanga – SP, onde Cecília foi parte importante do levantamento bioespeleológico, divulgando seus achados na Revista Espeleo-Tema volume 10 de 1976.

Entre 1976 e 1977, fez pós-graduação em zoologia na Universidade de Edimburgo, Durante esse período, Cecília de Castro Torres concluiu um curso de Pós-Graduação em Zoologia na Universidade de Edimburgo. Sua monografia, intitulada «Attention Structure in Monkeys: A Search for a Common Trend,» foi posteriormente publicada na revista Folia Primatol em 1979.

De 1978 à 1983 fez doutorado em Zoologia na Universidade de Edimburgo, Torres realizou uma pesquisa significativa intitulada «An Ecological Study of the Primates of Southeastern Brazil, with a Reappraisal of Cebus apella Races.» A pesquisa incluiu um extenso trabalho de campo na Fazenda Barreiro Rico, SP, Brasil, durante o ano de 1979. Sua tese de doutorado foi concluída em 1983. Durante esse período, Torres contribuiu com publicações importantes: «Cebus apella and Brachyteles arachnoides (Cebidae) as Potential Pollinators of Mabea fistulifera (Euphorbiaceae)» no Journal of Mammalogy (1981, Vol. 62, No. 2: 386-388). «Ecological and behavioural information on Brachyteles arachnoides» publicado em Primates (1983, vol. 24, páginas 584–593). c) «Descrição das matas da Fazenda Barreiro Rico, Estado de São Paulo» em Revista Brasileira de Botânica (1982, vol. 5: 53-66).

Após seu doutorado, Torres continuou sua pesquisa como bolsista de pós-doutorado na Universidade Federal da Paraíba (UFPB) em Campina Grande, entre 1983 e 1984 e posteriormente, entre 1984 e 1985, Cecília de Castro Torres continuou seu desenvolvimento acadêmico como bolsista de pós-doutorado no Departamento de Zoologia da Universidade de São Paulo (USP).

O trabalho e as contribuições de Cecília de Castro Torres na área de espeleologia, em especial à biologia subterrânea, zoologia e ecologia evidenciam sua dedicação à pesquisa científica brasileira. Suas publicações continuam a ser referências para estudantes e pesquisadores interessados na biodiversidade das cavernas.

Figura 2: *Caverna Santana, 1971 (Fonte: Hélio Shimada).*

4. Discussão

O presente trabalho traz à tona uma discussão frequentemente negligenciada: a questão de gênero nas ciências. Historicamente, as mulheres foram marginalizadas na produção científica, especialmente em campos como a espeleologia, onde predominam valores e práticas masculinas. A história da ciência é marcada por um silenciamento sistemático das contribuições femininas. Este fenômeno, apontado por autores feministas e decoloniais, resulta de uma estrutura de dominação cultural e epistemológica que hierarquiza saberes e exclui vozes que não pertencem à elite masculina branca.

Tal estrutura perpetuou uma ilusão de neutralidade na ciência, escondendo o impacto do contexto político e cultural na construção do conhecimento. Na espeleologia, essa exclusão é ainda mais evidente, por ser uma área que combina pesquisa científica com atividades de campo frequentemente associadas a esportes radicais, as barreiras culturais e sociais para a participação feminina foram amplificadas. Apesar disso, mulheres como Cecília de Castro Torres desafiaram as expectativas e abriram caminhos em um campo historicamente dominado por homens.

Cecília de Castro Torres foi um exemplo notável de resistência e excelência, sua trajetória na espeleologia, assim como a de outras cientistas, não apenas contribuiu para avanços significativos na compreensão de ecossistemas subterrâneos, mas também demonstrou que as mulheres podem desempenhar papéis fundamentais em todas as etapas do processo científico. Desde a topografia de cavernas até a pesquisa em biologia subterrânea, suas contribuições foram essenciais para o desenvolvimento do campo no Brasil. Entretanto, o reconhecimento dessas realizações ainda é limitado. A falta de visibilidade não só desvaloriza os feitos dessas cientistas como também perpetua estereótipos de gênero que desencorajam outras mulheres a ingressarem na área. Para romper esse ciclo, é fundamental resgatar e divulgar a história de mulheres como Cecília, criando um legado que inspire futuras gerações.

O resgate da história feminina na ciência também exige uma abordagem decolonial. Ao questionar as estruturas de poder que ditaram o que é

considerado conhecimento válido, a perspectiva decolonial busca incluir narrativas marginalizadas e valorizar saberes que foram historicamente relegados a um segundo plano. No contexto da espeleologia, isso significa reconhecer não apenas a participação feminina, mas também a influência de outros grupos historicamente excluídos. Este processo não é apenas uma questão de justiça histórica, mas também uma estratégia para enriquecer o próprio campo científico. A diversidade de perspectivas e experiências permite abordagens mais abrangentes e inovadoras, ampliando os horizontes da pesquisa e promovendo soluções mais inclusivas e sustentáveis.

Para promover uma maior inclusão de mulheres na ciência, é necessário adotar medidas concretas que combatam as barreiras estruturais e culturais. Isso inclui desde iniciativas educacionais que incentivem meninas a seguir carreiras científicas até políticas institucionais que garantam igualdade de oportunidades e reconhecimento.

No âmbito da educação, histórias como a de Cecília Torres podem servir como ferramentas poderosas para inspirar novas gerações a desconstruir estereótipos de gênero além de fomentar a diversidade na ciência. Em um contexto mais amplo, é necessário que as instituições acadêmicas e científicas adotem uma postura ativa na promoção da equidade de gênero. Isso inclui garantir a presença de mulheres em posições de liderança, fomentar redes de apoio e mentorias, e implementar políticas que combatam a discriminação e o assédio no ambiente acadêmico.

5. Conclusão

A espeleologia pode parecer uma área restrita, pois apesar dos avanços ainda é uma área do conhecimento pouco difundida, muito embora tenha uma trajetória marcante e importante no Brasil e no mundo. O potencial historiográfico desta área é enorme, haja visto a escassez de trabalhos neste âmbito, portanto, é necessário ampliar a divulgação científica nacional da Espeleologia e difusão da memória espeleológica para o conhecimento e proteção real das cavernas. É importante destacar também seu potencial educativo, pesquisadores e pesquisadoras, as populações do entorno e todas as pessoas preocupadas e interessadas na conservação do patrimônio espeleológico, devem conhecer sua história e importância, pois as cavernas costumam ficar situadas em regiões de grande vulnerabilidade social.

Apesar de ainda ser uma área predominantemente masculina, muitas foram e ainda são as mulheres que praticam espeleologia, desta forma, é necessário e urgente, resgatar a história destas mulheres e seu papel fundamental na consolidação da ciência espeleológica. Assim ao tomarmos posse da pesquisa histórica e da utilização história das ciências sob uma perspectiva decolonial é possível contribuir para a alterar o quadro de escassez de narrativas sobre a participação feminina na espeleologia, trazendo ao conhecimento as experiências dessas personagens, apresentando as formas como se envolveram nas práticas científicas e até mesmo os motivos pelos quais foram esquecidas ou excluídas, desta forma será possível entender cada vez mais aspectos sobre a própria construção das ciências e sobre a atuação dos diversos atores envolvidos ou propositalmente afastados desse processo (OLIVEIRA & ALVIM, 2022).

Histórias como a de Cecília Torres, mostram que as mulheres sempre estiveram presentes e atuantes, mesmo que invisibilizadas, e reforçam a importância de uma perspectiva decolonial para reescrever a história da ciência, além disto, podem nos permitir mostrar às meninas e mulheres a influência das classes dominantes em todos os campos, a forma como eles nos aprisionaram e ainda os fazem e propor alternativas para quebra do ciclo, oportunizando reflexões críticas que permitam a elas descobrirem-se sujeitos históricos capazes de modificar sua realidade.

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The italian speleological documentation center “Franco Anelli” fifty years after its creation

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Abstract

The first Italian speleological library was created in 1927 in Postojna but in 1945 all its materials were deposited at the University of Bologna. In 1975, the Italian Institute of Speleology started to reorganize its library. Currently the book heritage consists of over 30,000 volumes. Almost 1500 speleological magazines from the whole planet are strored in the library. Its historical section is very important, containing over 2000 volumes from XVII to the end of the First World War. Since 1984 the library has a computer-based catalog to allow easy access consultation, even from remote. In the same year the Center started to collect also non-book material. Among those collections: the newspaper library (5000 newspaper articles from the last decades of the 19th century), ancient engravings (over 1000 starting from the 17th century), and postcards (over 10,000 from all over the world) to name just the most important ones.

Thus, the Center’s library quickly became one of the largest in the world and it is part of a system of a Worldwide Speleological Documentation Centers. Finally, in the new millennium, the Center created and manages a shared catalog of Italian speleological libraries.

1. Introduction

The first national speleological library was created in 1927 in Postojna within the newly founded Italian Institute of Speleology (IIS). At the end of the Second World War, the Institute ceased to operate in Postojna and the peace agreements divided its assets between Italy and Yugoslavia. The Postojna library arrived at the Institute of Geology of the University of Bologna at the beginning of the 50’s of the last century where, in 1955, the IIS was reborn, at least ‘on paper’. However, all this material remained in its original boxes until the IIS began truly to operate in 1975.

The first concern of the IIS was to catalog all the books arrived in Bologna from Postojna to organize a thematic library on speleology. However, it was immediately clear that, without the contribution of recent material, the thematic library on karst and speleology would have never been able to carry out its dissemination task. Therefore, in the same year, the IIS signed an agreement with the Italian Speleological Society (SSI) so that the two libraries, complementary to each other, merged into a single one under the aegis of the SSI, giving rise to the “Speleological Documentation Centre”.

2. 50 years of fast development

Right from the start, the IIS-SSI library was welcomed with pleasure by all of Italian speleology, which therefore allowed its rapid development. After half a century, the library is still growing with the same speed.

In 1978 the new library included the one once located in Castellana Grotte. In the same year, the IIS and SSI decided to deposit the materials at the Geological Institute of the University of Bologna in order to make it easier for all Italian cavers (and for anyone) to consult it. This decision was the basis of the success of what later became the Italian Speleological Documentation Center of the SSI.

In the same year a first catalog was printed listing the over 8000 volumes actually present in the library (FORTI, 1978), with the declared aim of making the library increasingly accessible even from a distance, activating also a photocopy service. In those times, the increasing number of books was guaranteed primarily by exchanges mainly based on the magazines respectively of the SSI (Notiziario and Speleologia) and the IIS (Grotte d’Italia and Memoirs). The «tumultuous» growth of the library required the close printing of three additions to the first catalogue: in 1981 when the heritage was 12,000 volumes (FORTI, 1981) and in 1984 (FORTI, 1984) when it was rose to 20,000 and finally in 1986 when it had reached 22,000 (FORTI, 1986).

Since 1986, even with partial support of the Italian Ministry of Cultural Heritage, computer cataloging began, which made it useless printing further catalogues. In 1981, the Library changed its name into “Franco Anelli Speleological Documentation Centre”, named after Prof. Franco Anelli, the former head of the IIS of Postojna who was the first to donate, upon his death, his entire large caving library to the Centre. Italian speleologists, and not only them, immediately appreciated the services provided, so much that from 1981 until today, the Center has obtained, through bequests or donations, both from individuals and from speleological associations, the material of as many as 30 libraries (Fig. 1). Currently its book heritage consists of over 30,000 volumes and of an even larger number of issues of the almost 1500 speleological magazines.

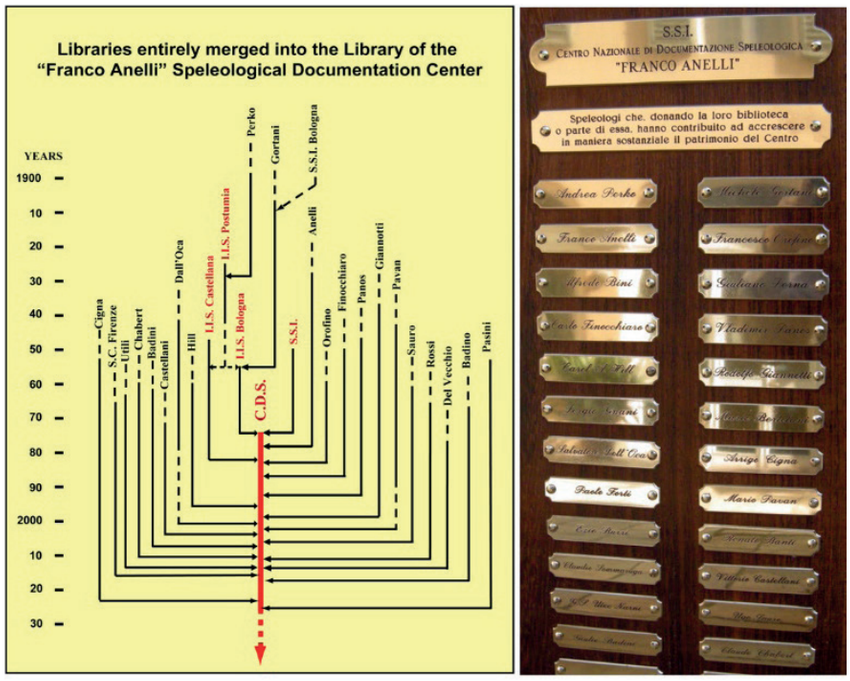

Figure 9: *on the left, the flow chard depicting the evolution of the libraries (in red) merged into the Speleological Documentation Centro "Franco Anelli; on the right the plaque with the names of the people and/or associations who donated their library to the Centre.*

Since the 1984, the SSI implemented a computer-based catalog of the library to allow anyone to access to the consistency of the library. Thus, the Center's library has quickly become one of the largest in the world and, since then, it is part with 12 other libraries of a system of the "Worldwide Speleological Documentation Centers" of the UIS (International Union of Speleology).

In the early 2000's, the library also joined the SBN network ("Servizio Bibliotecario Nazionale"), gaining more relevance and prestige with the entry in the national Italian catalog (SIVELLI, 2013).

After having increased its heritage several times, since 2015 the Center has finally found its definitive location in three rooms (over 140 m2 of cumulative area) of the BIGEA Department of the University of Bologna (Fig.1). Now it covers cumulatively an area of approximately 120 m2, guaranteeing enough space to allow its development for at least other 15-20 years at the current rate of acquisition of new materials. At the end of 2024, about 70.000 items (books, offprints and journal' issues) are available for direct reading.

The historical section, where the books and offprints from 16th to 19th century are stored, is one of the largest collections of such items in the world. The great importance of this historical section lies on the fact that all the materials refer to a period when speleology was still lacking a modern organization. Therefore, most of karst and cave

papers were scattered inside non-speleological publications and/or they were printed in very few copies, mostly unavailable or of difficult consultation.

Among the most precious volumes owned by the Documentation Center we must certainly cite Kircher's Mundus Subterraneous in 12 libros digestus (1678) (Fig. 3A) and Nova & parallela Latii tum veteris tum novi descriptio (1679), Agricola's De re metallica libri 12 (1657) (Fig. 3B), Aldrovandi's Museum Metallicum (1648), Herbin's Dissertationes de admirandis mundi cataractis supra & subterraneis.

But the rarest and most valuable work is certainly the 5 volumes of "Die Ehre des Hertzogthums Crain" written by Johan Valvasor in 1689 (Fig. 3C).

The work deals specifically with the Classical Karst, to which it dedicates an impressive iconography, partly dedicated to the very famous caves and karst phenomena (such as the Caves of San Canziano, Postumia and Castel Lueghi). This book was originally printend in only 500 copies: however, unfortunately, over the centuries the majority of these copies have been dismembered to separately sell the over 600 engravings it contains. The copy of this book owned by the Center, in fact, is the only one complete that went up for auction between the end of the Second World War and today. Finally, since the early years of the new millennium, the Center implemented an all-encompassing catalog of thematic libraries on speleology spread across Italy: currently over 20 associations have joined and their number is constantly growing. Finally, from the 80s of the last centuries, the Center started to collect also non-book material, but only related to speleology.

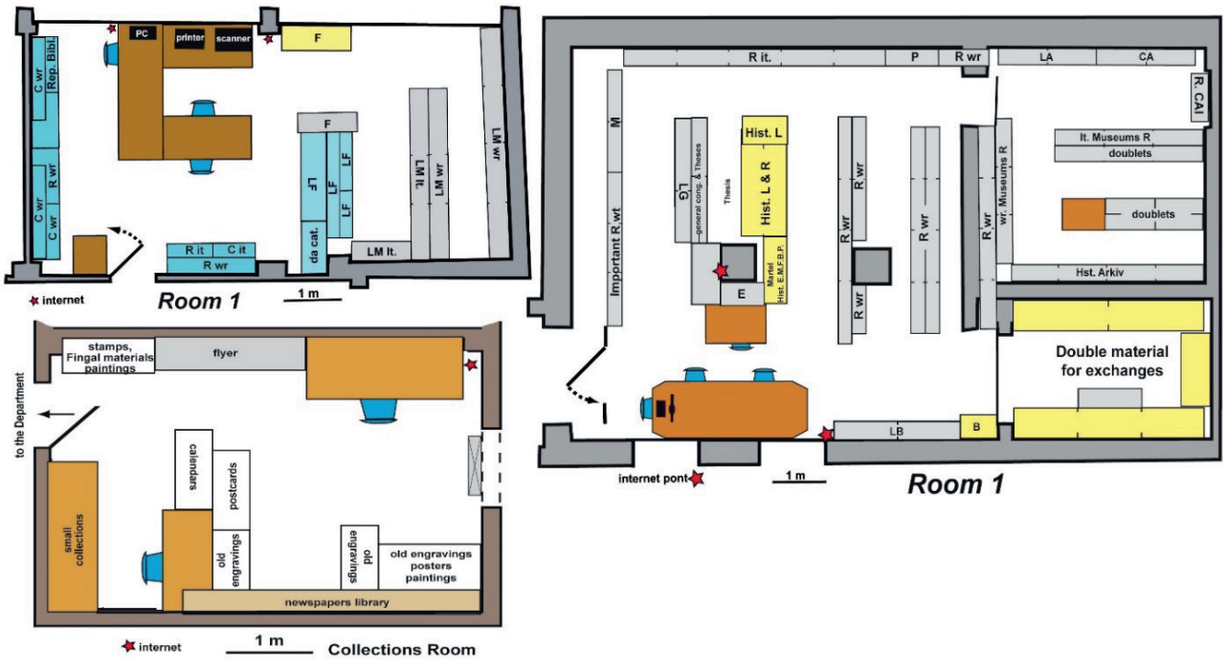

Figure 2: The three rooms of the BIGEA Department of the University of Bologna dedicated to the Speleological Documentation Centre.

Figure 3: Frontispieces of Mundus Subterraneous (A), Museum Metallicum (B) and Die Ehre des Hertzogthums Crain (C).

3. Other sections of the Documentation Centre

Today the "F. Anelli" Documentation Center is much more than a library: in fact, since the last decade of the 20th Century, it has progressively widened its interests toward different items –mainly printed– related to karst and caves (like: Christmas cards, business cards, stickers, flyers, calendars, coasters, paintings, medals, pins, coins etc.). The following are the five most important "side collections" of the Center, which still waits to be inserted in its database.

The "Emeroteca"

Articles and news related to karst and caves printed on any kind of Italian or foreign newspapers and journals are collected. Actually, this section consists of over 7000 items from 1877 up to present.

This section is fundamental for people interested to study and document how the perception of speleology by "normal people" had changed through time: focusing, time by time, over the danger, the mystery, the scientific interest, the friendship and "heroism".

All of these aspects are magnificently abstracted in the color covers of some weekly's periodicals (first but not least the "Domenica del Corriere") dedicated to speleological events globally perceived as "strange or astonishing", but in any case, regarded as "fundamental" (Fig. 4).

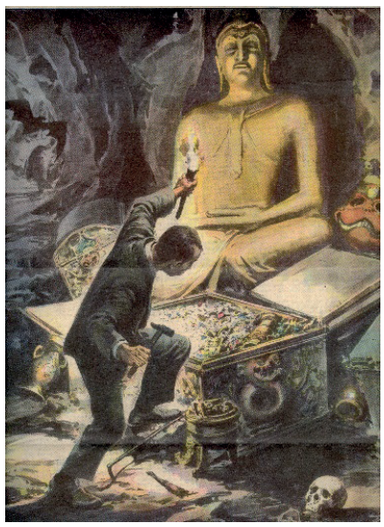

Figure 4: *The front page of "Domenica del Corriere" depicting the discovery occurred in 1962 inside a small cave in the Riu Kiu isle of Japan an astonishing treasure of an approximate value of over 100 million dollars.*

The show caves documentation

An organized cave tourism reasonably started in the 18th century even if a few cavities, like Postojna in the Classical Karst, were already visited since several hundred years.

The transformation of a 'wild' cave into a show cave rather simultaneously induced most of the cave owners to print descriptive materials to be given or sold to the visitors. They were usually cave guidebooks, but often also booklets, folders and leaflets. Some of these publications, especially the oldest ones, are true masterpieces for the printing techniques and the quality of the engravings (Fig. 5).

Figure 5: *Anonymous watercolor of the middle of XIX Century depicting a tourist visit to the Corniale cave.*

In some of these materials, sometimes written by worldwide renowned cavers, interesting and important data may be found related to the in-time transformation of the methods and tools used to plan, implement and manage a show cave. However, even more important, it is also possible to follow the evolution of all the side activities, which presently characterize the cave tourism.

The materials of this section refer to a few hundreds of show caves located in four different continents and cover a time interval of around 250 years. Beside Italy, the best-documented Countries are France, Germany, United States and Great Britain.

The old engravings

Since the old times, caves gave rise to curiosity and interest far beyond the small community of scientists and explorers. So, immediately after the development of the printing technics, cave engravings were often present in naturalistic, scientific and journey books (the peak occurring between the half of 18th and the end of 19th Century) (Fig. 6).

Figure 6: *This woodcut image was made in the middle XIX Century, by the famous Japanese artist Katsushika Hokusai for the boo "Hundred views of Mt Fujio": it represents two lumberjacks resting at the entrance of a cave and looking a flock of wild geese flying over the Fuji.*

This precious visual documentation is important from an historical-documentary point of view; thus, since its first years, the "F. Anelli" Center collected these engravings in a specific archive. Many caves are documented, most of them from Europe, but several images are also present from North America, India, Japan and Australia.

The map of the Santa Rosalia cave in Palermo is worth to mention because, being printed in the middle of the 16th Century, it is the first cave map ever printed in the world (FORTI, 2013).

Very rich is also the collection of engravings depicting the Fingal Cave (Ebridi Islands), which is perhaps the most illustrated cave of the world (FORTI, 2021).

In this section, several images of speleothems, bats and paleontological remains (mainly of cave bear's bones) are stored. Some curios images are also present, like a leaflet of a whisky produced, once upon a time, inside a Scottish cave to prevent to pay tolls to England.

Today the Center hosts about 1500 engravings and other kind of illustrations (among which some daguerreotypes of the second half of 19th century are worth to mention).

The postcards

Collecting postcards is a common hobby also among cavers, who often search only those of their "territorial" (local, regional, national) caves. The postcards devoted to some of the most renowned show caves often cover periods largely exceeding a century. Thus, they represent a

fundamental tool to reconstruct their evolution induced by subsequent anthropic process to enhance the tourism, or, sometimes, also caused by tragic events like war. In many cases, postcards are the sole existing documentation on natural caves of extremely remote regions or countries.

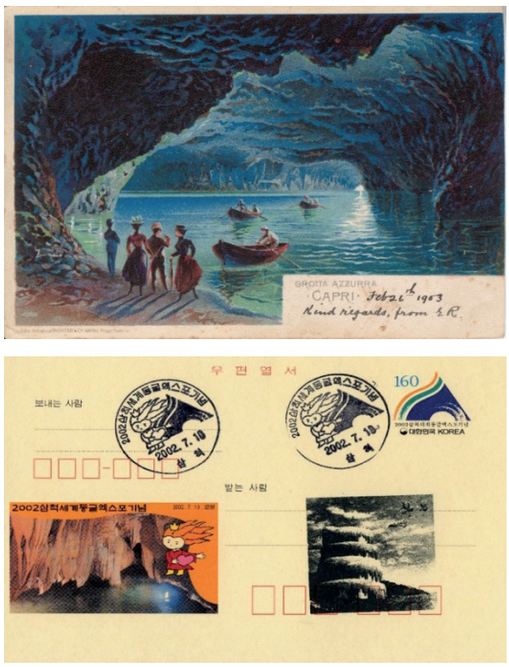

Figure 7: *Top: a postcard from Blue Grotto of Capri (early XX Century); down: a postcard issued in 2002 for the Samcheok International Cave Expo in South Korea.*

Even if this section is one of the youngest at the "Franco Anelli" Center, probably it is now one of the most important: it's over 12000 postcards document hundreds of show and wild caves in all the five Continents. Among them, it is worth mentioning an ice cave of Antarctica. A large majority of the Italian show caves are represented together with some of the most important wild caves: a few of these postcards were specifically printed to celebrate speleological expeditions and/or Symposia and Congresses (Fig. 7).

In this section the most represented country beside Italy is France (with over 2500 items). This is because the "Chabert's archive", donated to the Center in 2011, hosted a huge collection of postcards, the majority coming from France. The most documented cave (with over 400 postcards) is Castellana cave (Italy) followed by Postojna (Slovenia) and Padirac (France).

The posters

There are two main types of speleological posters related to different activities: the first one regards show caves and cave tourism, while the second refers to public events organized by caving associations.

Even large or very large posters (up to 2 square meters or more) belong to the first category, which started to be printed in the second half of the 19th century: the most famous and very artistic ones were realized in France and Belgium during the "Belle époque" and "Floral" periods (Fig. 8).

Posters printed by caving clubs are normally smaller and more recent: they started to be printed after the Second World War. They are devoted to advertise training activities of the club, like basic courses on speleology, Symposia and congresses, and any kind of activity directly related to caves and karst.

Recently, posters stressing the speleological actions in the protection and safeguard of caves and karst environment started to be printed. Today, the "F. Anelli" Centre's hosts around 900 posters, among which a dozen with historical and artistic relevance.

Figure 8: *Large posters advertising show caves in the early XX Century from Belgium and Czech Republic.*

The stamps

It is the last important section of the Speleological Documentation Center, added only in 2023 thanks to the donation made by Arrigo Cigna, former President of the SSI and of the International Union of Speleology (UIS).

It is a set of several hundred stamps, "first day" covers and philatelic cancellations from all over the world. This particular collection testifies the importance given to caves and karst through this mean of diffusion.

Among the most curious materials, it is worth mentioning the complete collection of unofficial "local stamps" dedicated to Fingal's Cave on the Isle of Staffa in the North of Scotland (Fig. 9).

Figure 9: *First local stamp with a photo of Fingal's Cave entrance (8.8 x 5.5 cm) issued in 1973.*

In the middle of the last century, they were directly printed by the Lord who owned the island. Tourists who visited the cave were allowed to use them in their correspondence, which was then accepted by the English Royal Mail.

4. Conclusions

Since the merging of the two libraries of the IIS and the SSI to create the Speleological Documentation Centre, this has experienced, in its half-century of activity, a rapid quantitative and qualitative growth.

Thanks to constant donations and acquisitions it has become one of the most important speleological thematic libraries in the world.

However, much is still required in terms of cataloging and digitali-

zation, which must concern not only the existing book heritage, but also the archive sections. Therefore, the future will require an even greater effort for the «Franco Anelli» Documentation Center.

In fact, it will be essential to proceed with the complete digitalization of all those works, especially from the 19th century or earlier, which are not available on the internet. The digitalization project will focus on the most relevant historical materials, as well as in completing the acquisition of the publications printed by the IIS and SSI and the national speleological congresses.

Furthermore, the creation of a catalog relating to the sections of non-book materials, will be fundamental to allow its consultation.

Thanks to the constant commitment of the Italian Speleological Society and all its members, we are certain that these ambitious goals will be achieved. Therefore, in the next half-century of activity, the «Franco Anelli» Speleological Documentation Center will continue to grow and provide even greater and better services to cavers and researchers from any part of the world.

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Aspectos Históricos, Sociais Míticos e Folclóricos sobre Romarias em Cavernas na Bahia

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Abstract

Cave`s romaria in Bahia reflect the deep connection between natural spaces and popular spirituality, dating back to the 17th century. Key sites include the Sanctuary of Bom Jesus da Lapa, the Grotto of the Sacred Heart of Jesus, and the Lapa da Mangabeira. These practices are rooted in the distinction between pilgrimage (long journeys to sacred places) and romaria (short-distance religious processions of Iberian origin, prevalent in Brazil due to Portuguese colonization). Catholicism shaped these traditions, with caves serving as both sacred spaces, akin to Gothic cathedrals, and symbolic portals between the living and the dead. For devotees, they are places of spiritual purification, protection from evil, and renewal of faith. These pilgrimages highlight the religious symbolism of natural spaces, uniting nature, culture, and spirituality. They attract thousands annually, preserving a tradition that blends faith, folklore, and community identity. Rooted in myths, these practices are integral to Brazilian folklore, acting as structuring elements of popular culture. Myths transmit values, beliefs, and traditions, ensuring their endurance. Pilgrimages to Bahia's caves exemplify how folklore intertwines with popular religiosity, showcasing the relationship between symbolic narratives, religious practices, and humanity's connection to the sacred and natural worlds. This living tradition underscores the enduring power of faith and cultural heritage in shaping collective identity.

1. Introdução

As romarias em cavernas possuem uma rica história, que refletem a profunda conexão entre espaços naturais e a espiritualidade popular que remontam ao século XVII e ainda continuam a atrair milhares de fiéis anualmente.

Neste artigo, foi realizada uma breve análise teórica do significado das romarias para o cristianismo, em especial para o catolicismo além da relevância importância dessas romarias para algumas cavernas da Bahia, em especial para o Santuário do Bom Jesus da Lapa (município de Bom Jesus da Lapa), a Gruta do Sagrado Coração de Jesus (Gruta de Patamuté, município de Curaçá) e a Lapa da Mangabeira (município de Ituaçu).

Para falar sobre as devoções cristãs em cavernas, em especial algumas da Bahia, faz-se necessário estabelecer uma diferença entre peregrinação e romaria.

O processo de peregrinação surge dos deslocamentos de grupos humanos para celebrações litúrgicas relacionadas aos ciclos agrícolas nas sociedades que já estavam na etapa da formação urbana (Nadais, 2010). Assim, o ato de peregrinar envolve a "busca da vida que supera a simples sobrevivência" (Oliveira, 2004, p. 15). Desse modo, as peregrinações, tanto as primitivas quanto as cristãs tradicionais ou de outras tradições religiosas, originalmente não necessitavam de infraestruturas complexas ou de condições técnicas e ambientais para que elas existissem (Rocha & Belchior, 2016). Resumidamente, podemos definir uma peregrinação como sendo processo de deslocamento de grupos humanos para manifestar a sua crença ou fé, em locais com características específicas e que possam ser associados com o sagrado.

Uma romaria, historicamente, está relacionada ao ato de viajar à Roma como um sinal de devoção cristã, logo após a transformação do cristianismo em religião oficial no antigo Império Romano. O termo vem de romeno ou romeiro, pessoa que viaja à Roma. Com o passar do tempo, tornou-se, principalmente para os habitantes da Península Ibérica, uma espécie de peregrinação religiosa de curta distância (Santos, 2016).

Essa diferenciação está marcada pela forte relação com a antiga colonização portuguesa no Brasil, além da prevalência do termo romaria sobre peregrinação. Por isso, mesmo que os viajantes religiosos se desloquem por longas distâncias para visitar cavernas sagradas, eles são chamados de romeiros, e não de peregrinos. As romarias são manifestações de fé que remontam ao período colonial e continuam vivas na cultura brasileira, demonstrando a influência profunda e duradoura do catolicismo na formação da identidade religiosa e cultural do país.

Faz-se necessário também estabelecer que, a romaria pode ser vista como um fato folclórico, pois envolve práticas coletivas, tradicionais e funcionais, transmitidas oralmente e adaptadas ao longo do tempo, refletindo a identidade e a espiritualidade de uma comunidade. As romarias objeto desse ensaio surgiram a partir de mitos, que desempenham um papel fundamental no folclore brasileiro, atuando como um elemento estruturante da cultura popular e da identidade coletiva de um povo, tornando-as um exemplo vivo de como o folclore se manifesta na religiosidade popular.

A partir desses fatos, a caverna então passa a possuir um duplo sentido espacial, onde ao mesmo tempo que é o espaço sagrado, com semelhanças das catedrais góticas descritas por Panofsky (1959) e o espaço laico ou impuro, onde se consegue penetrar nas trevas, sair do mundo dos vivos e atingir o reino dos mortos. Aqui, o maravilhoso e o extraordinário se confundem e neste caso a santidade *depois de ter adquirido o domínio da natureza em si e à sua volta (…) põe o seu poder a serviço dos homens* (Vauchez, 1987, p. 290).

Nas romarias para cavernas, os fiéis buscam o divino em meio à grandiosidade da natureza, onde a crença no "fardo do pecado original" motiva a busca por redenção e purificação, tornando-as jornadas de fé, onde os peregrinos se afastam das "tentações do mundo" para se conectar com Deus.

As cavernas, com sua aura de mistério, são vistas como portais entre o mundo material e o espiritual. A entrada da caverna, em particular, representa um ponto de transição, onde o bem e o mal se confrontam. Ao

se aventurar na escuridão, o romeiro demonstra sua fé e busca proteção contra as forças negativas.

As romarias para as cavernas da Bahia são um testemunho da força da fé e da busca por transcendência. Em meio à beleza natural e ao simbolismo religioso, os peregrinos encontram um espaço de conexão com o divino e de renovação espiritual.

2. Materiais e Métodos

A pesquisa sobre as romarias em cavernas na Bahia foi conduzida em áreas específicas, previamente selecionadas, consolidando-se como um fragmento de um estudo mais amplo que vem sendo desenvolvido ao longo de aproximadamente 20 anos. A escolha das cavernas analisadas baseou-se em critérios históricos, culturais e religiosos, considerando sua relevância para a prática das romarias e seu impacto na religiosidade popular da região.

A metodologia adotada foi de caráter qualitativo, envolvendo levantamento bibliográfico, análise documental e trabalho de campo. A pesquisa bibliográfica incluiu estudos acadêmicos sobre peregrinações, romarias e religiosidade popular, além de fontes históricas e registros oficiais sobre as cavernas escolhidas. A análise documental foi realizada a partir de relatos de fiéis, registros eclesiásticos e fontes jornalísticas, buscando compreender a evolução histórica das romarias nesses espaços.

O trabalho de campo consistiu na observação direta das práticas religiosas e entrevistas semiestruturadas com romeiros, lideranças religiosas e moradores locais. As entrevistas tiveram como objetivo captar as motivações dos fiéis, a simbologia atribuída às cavernas e a estrutura das romarias. A observação etnográfica permitiu compreender as dinâmicas dos rituais realizadas nesses espaços sagrados, evidenciando a relação entre fé, paisagem natural e tradição cultural.

Dessa forma, a pesquisa se insere em um contexto mais amplo de estudos sobre religiosidade em ambientes cársticos, contribuindo para o entendimento da importância das cavernas enquanto espaços de devoção e experiência mística no Nordeste brasileiro.

3. Resultados

As romarias em cavernas na Bahia são uma manifestação de fé enraizada na história e cultura da região. Esses locais, marcados pela grandiosidade da natureza e pelo simbolismo religioso, atraem milhares de fiéis em busca de conexão com o divino e renovação espiritual.

Dentre os centros de romarias em cavernas na Bahia, destacam-se:

- **Santuário do Bom Jesus da Lapa:** Localizado em Bom Jesus da Lapa, a romaria ao Santuário de Bom Jesus da Lapa tem suas origens no século XVII. A história do santuário está ligada à figura de Francisco Mendonça Mar, um português que, em 1691, decidiu se retirar para uma vida de eremita após uma série de dificuldades pessoais. Ele se estabeleceu em uma gruta natural na região, onde colocou uma imagem do Bom Jesus, iniciando assim uma tradição de devoção no local. A gruta, que já era conhecida pelos indígenas e sertanejos da região, rapidamente ganhou fama como local sagrado, atraindo fiéis que buscavam cura, proteção e consolo espiritual. A devoção ao Bom Jesus da Lapa cresceu ao longo dos anos, e o local se tornou um dos principais centros de peregrinação do Nordeste brasileiro. A romaria oficial ao Santuário de Bom Jesus da Lapa foi consolidada no século XVIII, com a construção de uma capela e a organização de festividades religiosas. Atualmente, a romaria ocorre principalmente no mês de agosto, quando milhares de romeiros de todo o Brasil se reúnem para participar de missas, procissões e outras atividades religiosas. O santuário é conhecido por sua grandiosidade, com várias grutas e capelas no interior da formação rochosa, além de uma vista impressionante do Rio São Francisco. A romaria ao Santuário de Bom Jesus da Lapa é uma das mais antigas e significativas do Brasil, refletindo a profunda conexão entre a fé católica e as tradições populares, além de destacar a importância dos espaços naturais como locais de espiritualidade e devoção.
- **Gruta do Sagrado Coração de Jesus (Gruta de Patamuté):** Situada em Curaçá, a romaria para essa gruta começou no século XIX, mais precisamente em 1872, quando um fazendeiro local, chamado João Francisco, encontrou uma imagem do Sagrado Coração de Jesus dentro da caverna. Esse achado foi interpretado como um sinal divino, e a gruta passou a ser considerada um local sagrado, onde logo se tornou um ponto de devoção e romaria, atraindo fiéis de diversas regiões da Bahia e de outros estados. A romaria à Gruta de Patamuté é realizada anualmente, geralmente no mês de junho, coincidindo com as festividades do Sagrado Coração de Jesus, uma tradição católica. Durante o evento, os romeiros participam de missas, procissões e outras atividades religiosas, além de aproveitar o ambiente natural da gruta para reflexão e oração.
- **Lapa da Mangabeira:** Situada em Ituaçu, na Chapada Diamantina, a romaria ao Santuário do Sagrado Coração de Jesus da Gruta da Mangabeira, tem sua origem profundamente enraizada nas tradições orais e nos mitos do sertão baiano, especialmente aqueles ligados à figura do vaqueiro, um ícone cultural e histórico da região. Segundo as narrativas transmitidas oralmente, a origem da romaria está associada a um vaqueiro que, ao procurar uma rês (animal) desgarrada de seu rebanho, acabou caindo do cavalo e sendo arremessado para o interior da caverna. Durante a queda, em um momento de desespero, ele teria invocado o Sagrado Coração de Jesus. Milagrosamente, o vaqueiro saiu ileso do acidente, um fato que foi interpretado como um sinal divino. Esse evento transformou a gruta em um local sagrado, atraindo a atenção e a devoção de moradores da região. No local onde o vaqueiro teria caído, a aproximadamente 500 metros da entrada da caverna, foi erguido um cruzeiro, que se tornou um marco simbólico e um ponto de referência para os fiéis. Esse cruzeiro ainda hoje é visitado pelos romeiros, que ali fazem suas orações e agradecimentos.

Os exemplos de romarias em cavernas na Bahia configuram-se como um importante patrimônio cultural e religioso, que transcende fronteiras e atrai fiéis de diversas partes do Brasil e do mundo. Esses locais sagrados, marcados pela fé, pela história e pela beleza natural, representam muito mais que destinos de peregrinação: são espaços de conexão entre o humano e o divino, convidando à reflexão, à espiritualidade e à renovação interior.

As romarias, como as que ocorrem no Santuário de Bom Jesus da Lapa, na Gruta do Sagrado Coração de Jesus (Gruta de Patamuté) e na Lapa da Mangabeira, são expressões vivas da religiosidade popular brasileira. Elas remontam a séculos de tradição, desde o período colonial, e carregam consigo histórias de milagres, devoção e superação. Cada gruta, com sua atmosfera única, oferece um ambiente propício para o encontro consigo mesmo e com o sagrado, seja por meio de orações, procissões ou simplesmente pela contemplação da grandiosidade da natureza.

Além do aspecto religioso, essas romarias são também um testemunho da riqueza cultural do sertão baiano. Elas reúnem elementos do catolicismo, do sincretismo religioso e das tradições locais, criando

uma experiência única que reflete a diversidade e a complexidade da identidade brasileira. A presença de romeiros, que muitas vezes percorrem longas distâncias a pé, demonstra a força da fé e a importância desses locais como pontos de encontro e renovação espiritual.

Portanto, as romarias em cavernas na Bahia não são apenas eventos religiosos, mas também manifestações culturais que preservam e celebram a história, o folclore a fé e a relação do ser humano com a natureza. Elas nos lembram da capacidade humana de transformar espaços naturais em lugares de significado profundo, onde a espiritualidade e a cultura se entrelaçam de maneira singular e inspiradora.

Figura 1: *Exterior do Santuário do Bom Jesus da Lapa. Fotografia (Elvis Barbosa).*

Figura 2: *Altar do Sagrado Coração de Jesus. Fotografia (Elvis Barbosa).*

Figura 3: *Lapa da Mangabeira, Missa solene, devotos. Fotografia (Elvis Barbosa).*

4. Discussão

As romarias as cavernas na Bahia se consolidam um fenômeno cultural e religioso que reflete a intrincada relação entre o ser humano, a natureza e o sagrado. Essas práticas foram analisadas à luz do conceito de folclore proposto por Câmara Cascudo (2017), onde o folclore é a expressão viva da tradição, transmitida oralmente e coletivamente, que se manifesta em costumes, crenças, ritos e narrativas de um povo.

Nesse contexto é possível identificar elementos que se enquadram nessa definição, uma vez que essas formações naturais são frequentemente percebidas como lugares misteriosos e sagrados, cenários de rituais e práticas espirituais que remontam a tradições ancestrais que remontam ao século XVII, inserindo-se no contexto da colonização portuguesa e da consolidação do catolicismo no Brasil. Esses espaços são impregnados de simbolismo, representando portais para o divino, locais de cura ou pontos de conexão com forças espirituais, consolidando-se como lugares de profunda significação religiosa e cultural.

Para Câmara Cascudo (op.cit), o folclore não é estático, mas dinâmico, adaptando-se ao longo do tempo enquanto mantém sua essência.

Nas romarias baianas, essa dinâmica fica evidente ao se observar a rica mistura de influências indígenas, africanas e europeias, que se fundem em práticas únicas e sincréticas. Um exemplo marcante é a coexistência da devoção a santos católicos com rituais de matriz africana ou indígena, demonstrando como tradições distintas se entrelaçam, criando expressões culturais e religiosas que refletem a pluralidade e a complexidade da identidade brasileira.

No decorrer dos séculos as cavernas objetos de estudo do presente artigo se tornaram locais sagrados, reforçando a dualidade do espaço subterrâneo: ao mesmo tempo em que simboliza escuridão e morte, representa refúgio e transcendência (Vauchez, 1987). Essa transformação se assemelha à sacralização das catedrais góticas, onde a arquitetura remete ao divino (Panofsky, 1959).

A prática de recolher fragmentos das cavernas, como estalagmites e estalactites, reflete a tentativa dos fiéis de materializar o sagrado, assimilando a fé a um objeto físico (Stewart, 2007). Tal fenômeno é comparável ao uso de relíquias na tradição cristã, evidenciando a crença na presença divina nos elementos naturais (Calavia Sáez, 2009).

Com o tempo, a modernização e o turismo religioso alteraram a dinâmica das romarias, influenciando a economia local e ampliando a visibilidade desses espaços (Steil, 1998). Entretanto, surgem desafios como o impacto ambiental da retirada de elementos naturais, gerando um embate entre fé e conservação ambiental. Assim, as cavernas permanecem como locais de devoção e transformação, onde a fé se entrelaça com a história, a natureza e a cultura popular, demonstrando o sincretismo religioso característico da cultura brasileira.

Além disso, as histórias e lendas associadas a essas cavernas — como aparições de entidades, milagres ou eventos sobrenaturais — reforçam o caráter folclórico dessas práticas. Essas narrativas, transmitidas de geração em geração, alimentam a espiritualidade popular e justificam a continuidade das romarias.

Em resumo, as romarias em cavernas na Bahia exemplificam a visão de Câmara Cascudo sobre o folclore como uma manifestação cultural profundamente enraizada na vida das pessoas, que integra natureza, espiritualidade e tradição. Essas práticas não apenas preservam o patrimônio imaterial da região, mas também revelam a capacidade humana de atribuir significado e sacralidade aos espaços naturais.

5. Conclusão

Esses exemplos ilustram a importância das cavernas como espaços sagrados e de devoção na Bahia, evidenciando a interseção entre geografia, história, folclore e religiosidade popular.

Sem fronteiras claras, o desconhecido mundo subterrâneo apresenta-se como algo inusitado e dentro desta condição onde a imaginação popular encontra um espaço novo para formular as suas próprias ideias a respeito dos seres fantásticos que povoam este universo diferente.

Somente em alguns casos, e em poucas áreas distantes dos grandes centros urbanos, é que estes locais escuros, úmidos e inseguros ganham ares especiais e passam a fazer parte do universo mítico da população local. Nestes casos, a mudança de paradigma ocorre quando há uma combinação entre conveniência material e necessidade metafísica para justificar que tal mudança seja provocada pela busca de explicação do improvável ou pela proliferação dos chamados mitos religiosos. Assim, *"as peregrinações desses homens "santos" e de seus seguidores para lugares afastados da vida social aparecem então como metáfora da busca do sagrado que, através da experiência penitencial, pretende transcender o tempo e o espaço ordinários"* (Steil, 1998, p. 36).

Estes locais são marcados pelas constantes romarias que os diversos fiéis realizam durante todo o ano, principalmente no período de comemoração das datas do lugar. Ao realizar uma romaria e participar de um ato de comemoração coletiva, o indivíduo consegue exteriorizar todo um sentimento de fé que se materializa através da representação do mito no qual ele deposita os anseios religiosos e as suas experiências de vida.

O mito como peça central no folclore, não apenas explica o mundo e preserva a memória cultural, mas também reforça a identidade coletiva, transmite valores e conecta as pessoas ao sagrado. No contexto brasileiro, os mitos indígenas, africanos e europeus se fundiram, criando um rico repertório de narrativas que continuam a influenciar a cultura popular e a espiritualidade do país.

Neste sentido, longe da importância que as cavernas tiveram para os homens na aurora da civilização, elas agora se traduzem como ponto de ligação entre o material e o imaterial (sagrado), seja do ponto de vista mitológico ou religioso. Elas deixam de ser o local das trevas, o portal do inferno e se transformam num espaço sagrado, onde é possível sentir a presença de Deus.

Herberich e Rapahel (1982) consideram o espaço da liturgia como um locus sagrado, pois ali estão agendados a liturgia, as cerimônias, os rituais e os acontecimentos que ocorrem no local não podem ser executados em qualquer ambiente, eles precisam de uma "definição" de sagrado para poderem ocorrer como algo natural. É aqui que o ambiente comum, natural de uma caverna se transforma, se sacraliza.

Os fiéis ao se deslocarem para o interior de uma "caverna santuário", buscam este espaço sagrado. Vão à procura não apenas de uma graça, de um milagre, mas de estarem presentes naquele local que é considerado um ambiente de Deus, ou como alguns peregrinos gostam de afirmar que *aquilo ali é obra de Deus, portanto é sagrado*. Assim, é possível concordar com Calavia Sáez que o *contato entre Deus e o fiel é traçado a uma distância que equivale à que existe entre o sujeito e o objeto: crer, criar, adorar, são ações que unem sujeitos e objetos – nome e complementos diretos* (2009, p. 2004).

Ir à caverna trazer um pedaço dela tem um significado todo especial para os peregrinos. Mais que um pedaço de rocha inerte, é um pedaço de um espaço sagrado, é a domesticação do grotesco (Stewart, 2007). Um pequeno pedaço de estalagmite (que brota do chão) ou da estalactite (que pende do teto) tem valores especiais para o peregrino que vai a uma caverna. É a materialização do seu desejo de possuir uma lembrança do sagrado, como se fosse um troféu. Mais do que isto, é a sua marca de purificação, de passagem e de consagração.

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Session 02

CAVE ARCHAEOLOGY

Historical rock records in brazilian natural cavities: the case of Tigre e Cascavel Cave

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Abstract

This article sheds light on a topic that receives little attention in Brazil: the need to carefully identify, study and protect colonial-era records found on the walls of the country's caves. While prehistoric rock art tends to have its importance recognized, rock records made after the country's colonization by the Portuguese is generally treated as the product of vandalism, and sometimes removed without any prior study. This paper examines the specific case of Tigre e Cascavel Cave, in the state of Minas Gerais, Brazil, and its highly relevant historical rock records as an example of the importance of studying and valuing such registers.

Resumo

Este artigo traz à luz uma questão que recebe pouca atenção no Brasil: a necessidade de identificar, estudar e proteger cuidadosamente os registros gráficos da era colonial encontrados nas paredes das cavernas do país. Embora a arte rupestre pré-histórica tenda a ter a sua importância reconhecida, os registros rupestres feitos após a colonização do país pelos portugueses são normalmente tratados como produto de vandalismo e por vezes são removidos sem qualquer estudo prévio. Neste artigo aborda-se o caso específico da Gruta Tigre e Cascavel, em Minas Gerais, com seus registros rupestres históricos de alta relevância, como um exemplo da importância de estudar e valorizar tais registros.

1. Introduction

Prehistoric rock art in Brazilian caves, such as paintings and incisions, is usually treated with attention and is generally recognized as important, at least in scientific circles. On the other hand, rock records from the historical period (i.e., after the year 1.500, when Portuguese navigators first arrived to the Brazilian coast, or later, in the interior of the country) is often characterized as mere graffiti and product of vandalism, and not worthy of any kind of analysis or preservation; in some cases, it is even removed without further study.

However, some of these relatively recent records have high historical and cultural relevance and provide important insights about the different uses of these caves throughout the historical period, as we have seen in our research activities in the quartzite caves of Ibitipoca and Serra Negra da Mantiqueira, in Minas Gerais, Brazil (BAETA & AZEVEDO, 2025). Those records provide information about the ancient users of these caves in the historical period, revealing a surprising variety: Indians, religious people, mystics, hunters, miners, military personnel, scouts, farmers, ranchers, tourists, artists, adventurers, travellers, fugitives, ancient researchers...

Although there are many caves with important historical rock records in that region, in this article we chose to address a specific case: the Tigre e Cascavel (Tiger and Rattlesnake) Cave, as it is perhaps the most fascinating and vulnerable found to date. The Tigre e Cascavel Cave is located in the heart of the Serra Negra da Mantiqueira State Park (PESNM), in the southeastern portion of the state of Minas Gerais, close to the border with the state of Rio de Janeiro and about 30 km from the Ibitipoca State Park (PEIb), with which it shares many biotic, historical and physical aspects, including the presence of a large number of quartzite caves. In fact, the Sociedade Carioca de Pesquisas Espeleológicas – SPEC, which has been conducting research in the caves of the area, estimates that the total number of natural cavities in the PESNM and adjacent areas amounts to a few hundred (KHALED et al., 2023; RAHMAN et al., 2025).

The following sections present a brief description of the history and environment of Serra Negra da Mantiqueira and the Tigre e Cascavel Cave, followed by an analysis of the historical rock records found in that cave. The article concludes by reinforcing the need to properly value historical rock records in caves and the need of developing a methodology to classify the relevance of such registers.

2. Serra Negra da Mantiqueira: A History of Isolation and Clandestine Trails

In part of the southeastern region of Brazil, the 500 km long mountain Serra da Mantiqueira was one of the obstacles that kept Portuguese colonizers restricted to the coast for almost two centuries after their arrival in the year 1500 (Figure 1). It was only at the end of the 17th century, with the discovery of gold and precious stones, that large-scale and uncontrolled colonization of the region that currently makes up the state of Minas Gerais began. The fact that the Serra da Mantiqueira was a natural obstacle was then used by the Portuguese Crown to its advantage, as it allowed it to monitor the official access routes in order to better control the collection of taxes on the mineral wealth extracted. Unofficial routes were prohibited, and the occupation of vast areas of the Mantiqueira was declared illegal and punishable for more than four decades since 1736 (MAGALHÃES, 2018).

The ban, however, did not prevent the trails in the region, generally opened by the indigenous people who had lived there for a long time, from continuing to be used as routes for smuggling minerals extracted in the interior of the state of Minas Gerais, thus avoiding the payment of taxes to the Portuguese Crown. It is likely that some of the hundreds of caves in the region were then used as shelter and hiding places by smugglers.

Figure 1: *The Serra da Mantiqueira was an obstacle to the entry of Portuguese colonizers into the interior of the country (APM, 1790) – edited by Carlos Eduardo Miranda.*

3. The Tigre e Cascavel Cave

The Tigre e Cascavel Cave (Figure 2) is located in the Serra Negra da Mantiqueira State Park, formally created in 2018 with 4,204 hectares and currently in the initial phase of implementation (PREA, 2025). The cave is still poorly known and rarely visited to date, which contributed to the good preservation of its fragile rock records. Its entrance is in a depression on the northern face of the mountain range. The cave has a low slope, and a horizontal development of approximately 60 m and an area of about 200 m^2, with a colony of Desmodus rotundus bats. The main conduit is continuous and has not yet been fully explored. Figure 2 shows a simple map of the cave, which needs to be redone and expanded. For security reasons, the cave's coordinates will not be disclosed here.

Part of its walls are covered with caneluras (solution flutes, scanellature, canelleurs or Rillenkarren), a fragile natural formation that has been used as substract for rock art and graffiti. Caneluras are groups of vertical, parallel lines that occur naturally in feldspathic quartzites, where the feldspars are altered into kaolinite, allowing, where the rock is saturated, a flow of water by exudation on the high walls of the caves, whose droplets coalesce and flow down the walls. This flow erodes the fine particles of kaolinite, forming small lapiazes, morphologically similar to some that occur in limestones, although in these the main phenomenon is dissolution and not erosion.

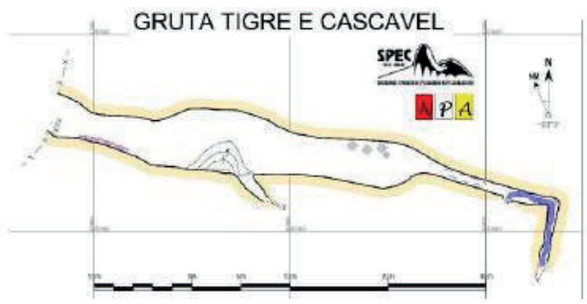

Figure 2: *Floor plant of the Tigre e Cascavel Cave.*

The walls of the cave have three panels with inscriptions, the main one (Figure 3) being a few metres to the right of the entrance, in the twilight zone. In front of it, across the conduit, is a smaller panel with inscriptions that appear to be relatively recent; further inside the cave, when it turns right, there is another small panel. At the entrance to the cave there is a small wall of stacked stones, the purpose of which is unknown. In dozens of other caves in the region there are similar stone walls used as traps for hunting pacas (Cuniculus paca, a rodent that may weigh up to 12 kg according to PÉREZ, 1992), but this does not seem to be the case in this cave, since the wall in its current configuration would not impede the passage of the animals.

The cave has a spring inside it, which disappears into a sinkhole after a few meters. Oral tradition reports that this spring shares religious traditions with the several "holy water caves" in the region, with miraculous healing properties attributed to the water collected inside. This tradition seems to have weakened in the last decades, but it is obviously related to the large number of religious symbols drawn on the main panel and to a small wooden cross placed in front of it.

The name of the cave derives from the drawings of snakes and felines on the main panel, giving clues as to the antiquity of the cave's use. Until the 18th century, it was common to use the noun "tigre" (tiger, an animal that does not exist in Brazil) to refer to the jaguar, and "leão" (lion) to refer to the puma (PAPAVERO, 2017). This nomenclature fell into disuse later, replaced by «onça pintada» and «onça parda». The fact that the drawings of felines led to the name "tigre" for the cave suggests that both the drawings and the name date back to the 18th century. The cave is the scene of oral stories relating its name to the hiding place of fugitives from justice or from military conscription to fight in revolutions; however, it is likely that there was a fusion between different stories derived from real events.

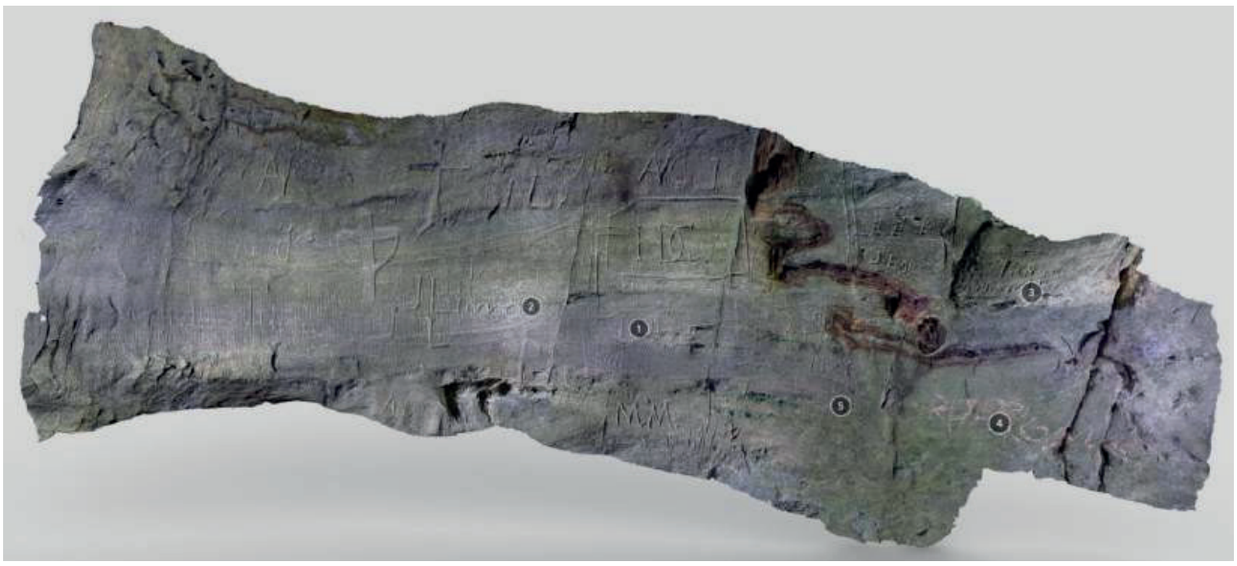

Figure 3: *3D model of part of the main panel, available at https://skfb.ly/owW8B, developed by Paulo Simões in Sketchpad from photos by Guilherme Salgado.*

4. The Historical Rock Records

The graphics on the panels include drawings of animals and plants, Christian symbols, pentagrams, initials, names, dates, phrases, and several still unidentified symbols. They were photographed on three occasions by the authors, and some of the images obtained were used for the application of Reflectance Transformation Imaging (CHI, 2013) and for the generation of a 3D model.

The drawings of animals are concentrated on the main panel and include at least four snakes, a deer head, a feline (ocelot?), and another feline that is probably a jaguar (Figure 4). It is very likely that these drawings were made at the same time by a single person, with the possible exception of the deer head.

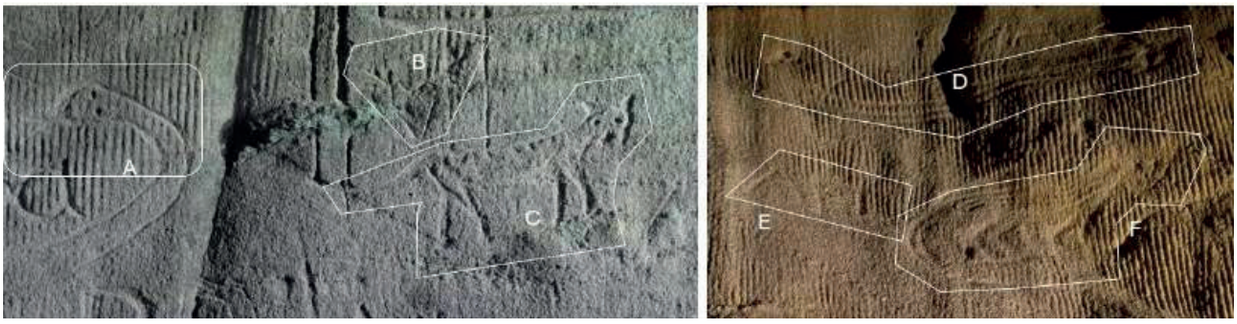

Figure 4: *Some of the drawings of animals: A – a snake, with a forked tongue; B – the head of a deer; C – a jaguar; D – another snake; E – «AFL», the initials of the artist; F – an ocelot.*

The difference in the colour of the substrate comes from the type of light used on each photo.

Some of the animal drawings were made in a high area of the panel that is relatively difficult to access, suggesting that some kind of ladder or scaffolding was used. This is reinforced by the fact that there are no later records in that area. In that section, there is a set of initials that obviously belong to the artist of the drawings: "AFL". These initials coincide with those of the greatest visual artist from Minas Gerais in the 18th century, Antonio Francisco Lisboa, known as "Aleijadinho" due to physical deformities caused by a slowly progressing disease (SOUZA MIRANDA, 2024). However, aside from the coincidence between the initials and the temporal compatibility, there are no other elements that would allow us to attribute the authorship of the drawings to him. There are no records of his presence there (not even in search of relief for his illness from the healing properties attributed to the cave's waters), nor known drawings by him that would allow comparisons; and even among his sculptures, there are no examples of works signed with his initials or name.

Figure 5: *On the left, part of the main panel with several different crosses indicated. On the right, a starred cross.*

Figure 6: *On the left, ancient «crosses of the converts» drawn on the portals of homes of New Christians in Northern Portugal (FONSECA MORETÓN, 2004); on the right, similar symbols found in Tigre e Cascavel Cave.*

The religious symbols, especially the crosses, are abundant and were made on different occasions (Figure 5). Some of the crosses correspond to the "cross of the convert" (Figure 6) and resemble the symbols used on the portals of homes of New Christians (mostly jews that were forced to convert to Christianity) in Portugal from the 15th to the 18th century (FONSECA MORETÓN, 2004; BALESTEROS, 1997); but, in this context, there is not yet any explanation for such symbols being drawn in a cave.

Although a more detailed analysis of the overlap between the drawings and their respective patinas is still needed, the examination based on the photographs (Figure 7) suggests that some of the crosses are among the oldest drawings, followed by the drawings of felines and snakes. In other words, when the animals were drawn – which likely occurred in the 18th century – the cave was already a place of religious significance.

Figure 7: *The arrows indicate points of overlap between the drawings, which can help determine their relative chronology.*

Figure 8: *A – Two pentagrams just below a snake; B – a pentagram within a circle and with a cross on one edge, near a snake's head; C – a finely drawn pentagram above a cross; D – a poorly drawn pentagram within the same box as finely drawn initials.*

Other drawings that appear at different points on the main panel are the pentagrams (Figure 8). The same symbols, made with a different technique, appear in Gruta da Água Santa dos Moreiras, another cave where there is also a spring attributed with miraculous properties. In Christianity, one of the most common interpretations of the pentagram is the representation of the five wounds of Christ, which could be a clue to explain its presence in caves whose water would have healing properties. Some unidentified symbols, shown in Figure 9, appear in different parts of the cave.

Some more recent rock records also provide interesting information about the uses of the cave, including names of local authorities and politicians (Figure 10). The presence of these individuals in a location that is difficult and arduous to access confirms that this cave was a place of special interest among the many others in the region. One of these records contains the name of a former landowner where the cave is located (item 3 of Figure 3 and Figure 10), which is associated with stories from oral tradition: "TANCREDO ALVES 25-4-37". Tancredo Alves was a judge and an influential figure in the region during his time; the fact that the date corresponds to a Sunday suggests a leisure expedition to the cave. The name "Nominato" written in elaborate handwriting, suggests the presence of Nominato de Paiva Duque, a doctor and politician active in the region during the first half of the 20th century. There are also other names and initials that suggest the presence of more people from the local elite from the same period in the cave.

There is a single recent piece of graffiti that should be considered vandalism and would be a candidate for removal (item 4 of Figure 3). However, such an operation would have to be carried out with specialized supervision and examining the possibility of existence of older records in the same spot.

Figure 9: *Unidentified symbols that appear in different parts of the cave.*

Figure 10: *At the top, the name «Nominato» damaged by a later religious graphism and the photograph of the doctor and politician Nominato de Paiva Duque. Below, judge Tancredo Alves and a graffiti with his name.*

5. Conclusions

The rock registers from the historical period found inside speleological sites, such as caves and shelters, should not be considered, in a general and preconceived way, as mere graffiti produced by vandalism (CARVALHO, 2024). Instead, one should try to identify the contexts in which they were drawn and recover the information they provide about the uses of the cave during the historical period.

The analysis of the rock registers found in quartzite caves in the region of Ibitipoca and Serra Negra da Mantiqueira (BAETA & AZEVEDO, 2025), in Minas Gerais, leads us to conclude that they are carriers of meanings that help in determining the temporality of past visitation and illustrate the profile of visitors and the uses of the caves, as well as providing information of high cultural relevance about ceremonial and religious uses.

In fact, the information obtained from the study of such records can be surprising, even enabling the classification of a cave as of maximum relevance due to its "outstanding historical-cultural or religious relevance" (art. 3, XI, of Normative Instruction 02/2017, of the Ministry of the Environment, Brazil).

While it is true that the pre-existence of graffiti on the walls of a cave can encourage new graffiti by vandals - now an environmental crime according to Brazilian law - on the other hand, the fight against this behaviour should preferably be based on educational actions and not on the indiscriminate removal of pre-existing rock registers.

It is necessary to define a methodology to classify the relevance of historical rock registers in caves in order to define the actions to be taken in each case, ranging from total removal to the adoption of strong preservation measures. Such methodology must consider the age of the records, their connection with the history of the cave and of the region, their association with cultural attributes such as oral tradition, ceremonial or religious significance, as well as the possibility of overlapping rock

registers from different periods and relevance. As shown in the previous sections, the Tigre e Cascavel Cave is a good example of a natural cavity containing historical rock records of enormous cultural relevance and high vulnerability, deserving serious measures for their preservation.

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Identificação dos Restos Faunísticos na Gruta dos Fósseis, Cocalinho/MT e sua Contribuição para a Zooarqueologia

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Abstract

Identification of Faunistic Remains in Gruta dos Fósseis, Cocalinho/MT and its Contribution to Zooarchaeology.

The “Gruta dos Fósseis”, located in Cocalinho/MT, is a multi-component and complex archaeological site. “Station 7/11” is just one of the 24 submerged stations within this site, where human remains were found alongside various faunal bones, raising a key question: does this represent (i) an intentional association of faunal remains with human remains, or (ii) a natural deposition of non-cave-dwelling fauna coincidentally adjacent to a burial? This study focuses on identifying the faunal bones recovered during the exhumation of human remains and seeking an answer to the question posed above. So far, 2/5 of the material exhumed from Station 7/11 has been analyzed, and among the faunal remains, we have identified bird bones and bones from various small, medium, and large mammals. Based on macroscopic analyses, no evidence of human manipulation was found on the non-human animal bones. However, the high concentration of these animal bones adjacent to the human remains—distinct from the surrounding areas of Station 7/11—seems to suggest an intentional association. The continuation of studies on the material from Station 7/11 and other stations within the cave will be crucial for understanding the possible mortuary rituals associated with this site.

Resumo

A Gruta dos Fósseis, localizada em Cocalinho/MT, é um sítio arqueológico multicomponencial e complexo. A “Estação 7/11” é apenas uma das 24 estações submersas deste sítio e nela foram encontrados remanescentes humanos avizinhados a ossos de fauna diversos, levantando uma questão: trata-se de (i) uma associação intencional dos restos faunísticos com os remanescentes humanos ou de (ii) uma deposição natural daquela fauna não-cavernícola coincidentemente ao lado de um sepultamento? Este trabalho tem como foco a identificação dos ossos de fauna resgatados durante a exumação dos remanescentes humanos e a busca pela resposta da questão acima posta. Até o momento foram analisados 2/5 do material exumado na Estação 7/11 e entre os remanescentes faunísticos encontramos ossos de aves e de diversos mamíferos de pequeno, médio e grande porte. Diante das análises macroscópicas do material, não foram encontradas evidências de manipulação humana sobre os ossos dos animais não-humanos. No entanto, a grande concentração dos ossos desses animais contíguos aos remanescentes humanos, distinta das áreas vizinhas à Estação 7/11, parece sugerir uma intencionalidade dessa associação. A continuidade dos estudos sobre o material da Estação 7/11 e demais estações da Gruta dos Fósseis será determinante para a compreensão dos possíveis rituais mortuários desse sítio.

1. Introdução

A Gruta dos Fósseis é um sítio arqueológico, paleontológico e paleoclimático de grande relevância, fornecendo subsídios para a compreensão das atividades humanas e possivelmente, da interação desta com a fauna regional durante o Holoceno (SCHIRATO et al. 2024). O sítio está localizado no carste de Cocalinho, no leste do estado do Mato Grosso, próximo à fronteira com Goiás. A região possui formações calcárias do Proterozóico Superior, atraindo mineradoras, incluindo a Mineradora Serra Dourada, propriedade na qual a gruta está situada (HARDT 2005).

A Gruta dos Fósseis é uma cavidade natural com uma entrada de aproximadamente 50 metros de largura por 20 metros de altura. Dentro, encontra-se uma lagoa de águas cristalinas, também conhecida como “Lagoa Azul”, que se estende por 100 metros de largura e 30 metros de comprimento, atingindo profundidades de até 20 metros. Dessa lagoa partem condutos submersos labirínticos, que chegam a 47 metros de profundidade com condições físico-químicas peculiares, criando um ambiente de excepcional preservação física dos remanescentes ósseos humanos e de fauna, principalmente na parte do sítio submersa (SCHIRATO et al. 2024).

As datações obtidas apontam para diferentes períodos de ocupação humana. A análise radiocarbônica (C14) indicou ocupações no último milênio, com uma amostra datada 1040 ± 30 anos AP (GF-19). No entanto, a baixa preservação de colágeno para datação exigiu subsequentes coletas para a criação de um panorama cronológico mais preciso. A datação por luminescência opticamente estimulada (OSL) de fragmentos cerâmicos

das Zonas 1 e 2 revelou idades entre 305 e 770 anos AP, reforçando a presença humana contínua ao longo do Holoceno tardio. Além disso, um osso de megafauna encontrado foi datado em 26.281 ± 587 anos AP pelo método de Urânio-Tório (U/Th), confirmando a presença de fauna pleistocênica no sítio. Este mesmo método foi aplicado sobre esqueletos humanos, sugerindo a presença humana no sítio também durante o Holoceno Inicial (10.900 e 8.600 anos AP) (SCHIRATO et al. 2024).

Este estudo concentra-se na identificação e análise dos ossos de animais recuperados na Estação 7/11, localizada em área submersa e na transição entre o lago e a zona afótica da gruta. As evidências e dados sugerem que esses remanescentes pertencem à primeira das duas prováveis ocupações humanas da gruta, ocorridas durante um período de estiagem, com o nível da água mais baixo que o atual, permitindo o acesso às galerias mais profundas. A presença de restos faunísticos associados a vestígios humanos levanta duas hipóteses: (i) o uso da gruta para rituais mortuários, evidenciado pela possível associação do sepultamento e dos remanescentes faunísticos; ou (ii) a deposição natural de fauna, levados pela água ou que aproveitaram do mesmo período de seca local, sem associação com os remanescentes humanos.

2. Materiais e Métodos

Os remanescentes ósseos da Estação 7/11 foram armazenados em cinco caixas plásticas com dimensões de 60x40x10 cm, preenchidas com água da gruta para o transporte e a preservação inicial do material. Até o momento, duas dessas caixas foram abertas e investigadas, contendo predominantemente ossos de menor porte. Dessa forma, presume-se que a maioria dos ossos de maior dimensão ainda se encontra nas três caixas não abertas, aguardando análise subsequente.

2.1. Dessalinização

Embora a água da Gruta Azul seja doce, a dissolução de minerais das rochas calcárias do maciço disponibiliza sais na água da lagoa e, consequentemente, na matriz e superfície dos ossos e materiais cerâmicos arqueológicos encontrados no sítio. Além disso, a interação da água subterrânea com os minerais de todo o sistema cárstico aumenta a concentração de eletrólitos, favorecendo o acúmulo de compostos nos materiais submersos. Esse processo pode levar à cristalização e expansão desses sais após a secagem, resultando em fragilização, fissuras e possível desintegração dos ossos (RECIO 2017). Para evitar esses danos e preservar a integridade dos materiais, os ossos resgatados que, inicialmente, foram mantidos nas caixas de transporte com a água da própria gruta, passaram pelo processo de dessalinização gradual, seguindo o protocolo do Proyecto Arqueológico Subacuático Hoyo Negro (PASHN), com trocas frequentes do líquido solvente (água destilada) e um monitoramento da salinidade (RECIO 2017). O processo continuou até que não houvesse mais sobrenadante visível na água, indicando a remoção eficaz dos sais residuais. Somente após essa etapa, os materiais foram secos de forma controlada para evitar a cristalização de sais, garantindo sua preservação. Em todas as etapas de troca, foram coletadas amostras da solução para posterior análise química dos minerais liberado durante o processo, trabalho que se encontra em andamento.

2.2. Secagem

A secagem dos ossos foi realizada em gavetas especiais de secagem, com o fundo de tela que evita a manutenção da umidade residual sob os ossos ali acondicionados. As amostras permaneceram nessas gavetas por um período mínimo de 48 horas ou até a secagem total das superfícies, garantindo a remoção gradual da umidade sem comprometer a integridade estrutural deles. Após esse período, os materiais foram organizados e expostos na bancada de trabalho para a finalização do processo de secagem sob condições naturais (LESSA 2011, NEVES 1988).

2.3. Identificação da coleção faunística da Estação 7/11

A primeira triagem buscou distinguir os ossos de fauna de outros materiais presentes nas caixas. Contudo, alguns ossos humanos (um calcâneo, uma epífise distal de úmero, um metatarso, e um fragmento de uma mandíbula), além de alguns poucos fragmentos cerâmicos foram identificados e mantidos separados dos separados do material zooarqueológico. Na segunda triagem, a fauna da Estação 7/11 foi organizada em mesas de trabalho para a separação de acordo com diferentes categorias taxonômicas, agrupando-se os ossos de mamíferos, aves e outros vertebrados. Dentro desses grupos, os ossos foram classificados conforme sua identificação anatômica, distinguindo elementos como tíbias, falanges e temporais. Esta metodologia permitiu uma organização mais eficiente dos materiais, facilitando análises detalhadas e comparações com coleções de referência, além de possibilitar a estimativa do Número Mínimo de Indivíduos (NMI) (BEISAW 2022, CHIM 2018, MINGATOS & OKUMURA 2016).

Nos casos em que as evidências disponíveis não permitiam uma categorização detalhada, optou-se por uma classificação mais genérica. Especial atenção foi dada aos ossos bem preservados de mamíferos e de aves maiores, pois sua identificação favoreceria a compreensão de uma possível interação com as atividades humanas no sítio.

2.4. Reconstrução de Ossos Fragmentados

Alguns ossos que estavam fragmentados foram cuidadosamente reconstituídos, quando possível, utilizando fita crepe como suporte temporário, visando preservar sua integridade estrutural durante as análises. A reconstrução definitiva foi feita com cola branca, protocolo aplicado em nosso laboratório que facilita a montagem adequada dos fragmentos unidos e possibilitando a separação dos mesmos de forma simples, caso seja necessário (NEVES 1988).

3. Resultados

3.1. Aves

Foi identificada uma diversidade significativa de aves de diferentes portes, com um Número Mínimo de Indivíduos (NMI) de 15, com base no osso mais representado, o úmero direito, que totalizou 15 exemplares. Os vestígios são, em sua maioria, elementos anatômicos de aves de médio porte, possivelmente associadas às famílias Psittacidae e Anatidae, além de fragmentos pertencentes a aves menores. Os ossos mais frequentemente encontrados incluem tibiotarsos (17 exemplares), rádios (15 exemplares) e úmeros (24 exemplares no total, sendo 15 direitos e 9 esquerdos). Além disso, a presença de crânio e fragmentos de bicos de psitacídeos sugere que o resgate dos esqueletos de alguns indivíduos deste grupo foi quase completo. Entre os ossos identificados, destacam-se fragmentos de crânios e mandíbulas, além de estruturas apendiculares como úmeros, rádios, ulnas, coracoides e fêmures. Também foram registrados tibiotarsos, tarso-metatarsos, palatinos, escápulas

e fragmentos de esterno (BEISAW 2022, BROUGHTON & MILLER 2016, COHEN & SERJEANTSON 2015).

3.2. Mamíferos

Foram identificados alguns remanescentes de pequenos roedores, bem como ossos pertencentes a pelo menos duas antas jovens (Tapirus terrestris). Entre os vestígios de roedores, foram identificados crânios, mandíbulas, dentes, pelves e complexos tíbio-fibulares. No caso dos restos de anta, os ossos incluem escápulas, vértebras cervicais e torácicas, tíbias, metacarpos, fragmentos de sacro e dois crânios parciais (BEISAW 2022, BROUGHTON & MILLER 2016, OLSEN 2018).

4. Discussão

A presença de restos mortais de humanos e de fauna na Estação 7/11 avizinhados caracteriza uma associação entre eles. A intencionalidade ou a casualidade de tal associação é o objetivo do atual estudo.

A posição e a localização dos remanescentes humanos, além da presença quase total dos ossos desse esqueleto, indicam a forma cuidadosa com que os restos mortais foram assentados intencionalmente.

A análise da dispersão dos ossos de fauna na área do sepultamento humano, assim como no seu arredor, auxilia na compreensão da associação casual ou não dos remanescentes ósseos ali encontrados. Além disso, a distribuição, a abundância e diversidade dos restos faunísticos indicam um contexto arqueológico complexo, no qual a fatores naturais se somam às interações humanas no atual cenário encontrado no sítio. A ausência de indícios de transporte hídrico na região da Estação 7/11 ajuda a reforçar a baixa probabilidade de o acúmulo dos ossos de fauna próximos aos humanos ter ocorrido de forma natural.

Marcas de corte ou arranhaduras, compatíveis com o uso de ferramentas líticas ou metálicas, poderiam indicar ação humana no processamento dos corpos e carcaças para o consumo ou em rituais. Da mesma forma, queimaduras e outras alterações térmicas poderiam sugerir cozimento, descarte de restos ou rituais envolvendo cremação parcial. No entanto, nós não temos, até o momento, evidências que corroborem para tais práticas sobre os ossos analisados. Sinais de predação não-humanos, como marcas de carnívoros ou carniceiros, estão ausentes no material analisado.

Pequenos roedores são bastante comuns em ambientes de lapas e cavernas nos ambientes cársticos, assim como a busca de água nas grutas pode explicar a presença dos remanescentes das duas antas jovens (*Tapirus terrestris*) na

amostra da Estação 7/11. No entanto, conforme informamos acima, a concentração de ossos próximos aos restos humanos e fora da passagem principal do conduto ou de um fluxo hídrico sugerem uma deposição artificial e intencional dos ossos de fauna estudados neste trabalho.

No entanto, as limitações de nossas intepretações reforçam a necessidade de análises complementares para avaliar padrões de deposição e à ação tafonômica sobre os remanescentes humanos e não-humanos. A continuidade das escavações e as investigações bioarqueológicas poderão fornecer informações mais detalhadas sobre os processos que levaram à formação desse sítio.

Novas datas radiocarbônicas (C14) e/ou por termoluminescência opticamente estimulada (OSL) serão essenciais para refinar a cronologia do sítio, ampliando a compreensão das dinâmicas históricas, ecológicas e também culturais associadas à ocupação da Gruta dos Fósseis.

Estudos de outros sítios arqueológicos e/ou paleontológicos próximos à Gruta dos Fósseis poderão ampliar o entendimento sobre a ocupação humana e a sua interação com o ambiente cárstico ao longo de todo o Holoceno.

5. Conclusão

A identificação dos restos faunísticos na Gruta dos Fósseis representa um importante avanço na compreensão das interações entre fauna e humanos ao longo do Holoceno naquela região. A presença de aves e mamíferos de grande porte associados aos remanescentes humanos reforça a hipótese de um contexto funerário, no qual certos animais poderiam ter sido incorporados como oferendas ou consumidos durante eventos rituais.

A proximidade espacial entre os ossos humanos e faunísticos é um dado crucial para futuras investigações, pois parece indicar um vínculo direto entre as ocupações humanas e a fauna presente na gruta. A busca por evidências de manipulação direta dos animais nestes rituais como o descarne ou preparação dos corpos animais com intervenções mais contundentes colaborará para o entendimento dos possíveis rituais que ali foram praticados pelos habitantes da região.

Assim, a curadoria e análise dos remanescentes acondicionados nas últimas três caixas de material a serem triadas, são justificadas para a confirmação ou não das conclusões deste trabalho. Conclusões estas propostas sobre uma amostra parcial de todo o complexo funerário presente na Estação 7/11.

Apesar de estarmos cientes da limitação e incompletude do material aqui exposto, acreditamos que a divulgação dos resultados preliminares é importante como forma de compartilhar com nossos colegas o trabalho em progresso e disponibilizar à comunidade acadêmica as complexidades enfrentadas neste projeto. Além disso, possibilita a troca de experiências entre pesquisadores e reforça nossa crença no trabalho colaborativo. Não menos importante é a nossa preocupação de alertar para a importância do sítio e a necessidade de proteção da área, sendo que o conhecimento do patrimônio ali depositado é peça chave para o envolvimento de pesquisadores e interessados na história local e no entendimento da ocupação da região centro-oeste brasileira.

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Indices of Human Frequentation Deduced from Speleothems, Examples from SE France

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Abstract

It is possible to detect human use of caves from broken speleothems. This is an approach still reserved for a small number of specialists who are familiar with the formation of caves and speleothems. Three examples of broken speleothems found in caves in the south-east of France are presented.

The formation of speleothems in the Mas de Rouquet cave (Hérault), the Léo cave (Ardèche) and the Mounios cave (Hérault) are explained before interpreting the observed breakages.

Résumé

Il est possible de déceler une fréquentation humaine des grottes à partir de spéléothèmes brisés. Il s'agit d'une approche encore réservée à un petit nombre de spécialistes connaissant bien la formation des cavernes et des spéléothèmes. Trois exemples de spéléothèmes brisés relevés dans des grottes du sud-est de la France sont présentés.

La formation des spéléothèmes dans les grottes du Mas de Rouquet (Hérault), la grotte de Léo (Ardèche) et la grotte de Mounios (Hérault) sont expliqués avant d'interpréter les bris observés.

1. Mas de Rouquet Cave

At around -65 m in the Mas de Rouquet cave (Pégairolles-de-l'Escalette, Hérault), numerous fragments of speleothems can be seen littering the floor.

These are not natural breakages, but speleofacts, i.e. speleothems that have been broken and used by man.

Above a flowstone, speleothem fragments were placed to divert and channel the water (fig. 1) towards a sort of pouring spout (Bigot, 2021).

Upstream of this spout, a stalagmite fragment is blocked between in an alignment of stalagmites.

Figure 1: *Arrangement built above a flowstone. Fragments of speleothems arranged V-shaped (pouring spout) to channel water, Mas de Rouquet cave, Pégairolles-de-l'Escalette, Hérault.*

This alignment has the disadvantage of separating water flows that used to trickle down on either side of the speleothems (fig. 2).

To divert water to the spout's drainage basin, a stalagmite serving as a dripstone was installed to catch the water that fell on the other side of the speleothem alignment.

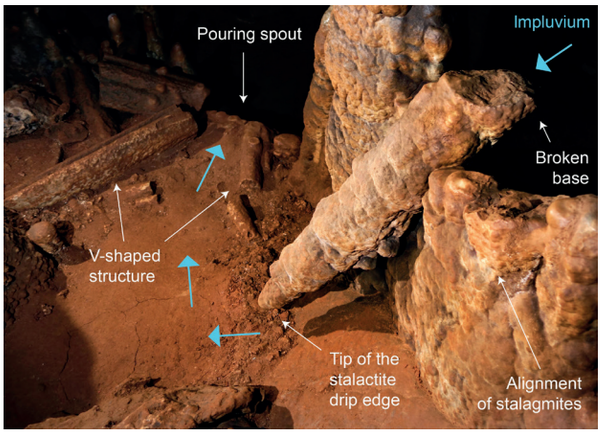

Figure 2: *A stalagmite has been broken, then wedged in between an alignment of stalagmites.*
On the left, two fragments of speleothems can be seen on the floor, arranged in a V shape to channel water into a spout, Mas de Rouquet cave, Pégairolles-de-l'Escalette, Hérault.

This water detour system was possibly supplemented upstream by an impluvium (skins or stretched canvas) of perishable material.

Stalagmites develop from bottom to top of cave ceilings, generally under trickle from fissures.

In this particular case, a straight crack in the ceiling is the source of the stalagmite alignment.

The position of the broken stalagmite, trapped in between aligned stalagmites, cannot be natural.

The stalagmite is completely upside down, and its fall would inevitably have broken it into several fragments.

However, the end of the stalagmite is intact, demonstrating the care taken by prehistoric people who built the cave.

2. Léo Cave

The Léo cave (Vallon-Pont-d'Arc, Ardèche) is a cave with Bronze Age remnants.

Since then, the entrance to the cave has been sealed off. Deep inside, in the Pearls Chamber (fig. 3), the floor is strewn with cave pearls (Bigot et al., 2023).

Figure 3: *The abnormal position of the pearls on a stalagmitic pillar on the ground arouses curiosity. This is not a natural phenomenon, but an anthropogenic action. The black tarpaulin demarcates the path to follow so as not to dirty the floor of the Pearls Chamber, Léo cave, Vallon-Pont-d'Arc, Ardèche.*

Generally, flat-bottomed rimstones give the pearls their flattened shape (fig. 4).

These pearls are mobile.

The water slowly flowing through the basins tends to move them and polish their lower face in contact (erosion) with the bottom of the rimstone (base).

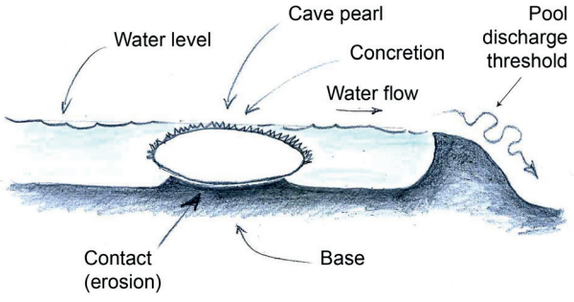

Figure 4: *Cave pearl formation in a shallow rimstone.*

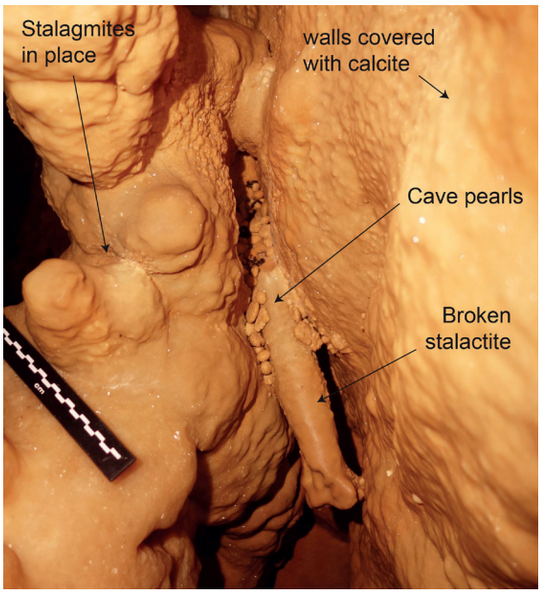

Figure 5: *Cave pearls wedged between stalagmites and other debris, Léo cave, Vallon-Pont-d'Arc, Ardèche.*

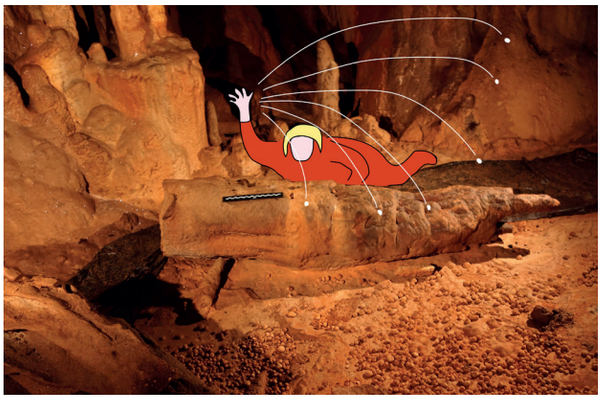

Figure 6: *Reconstruction of the "Battle of the Pearls" according to the elements found on the site, Léo cave, Vallon-Pont-d'Arc, Ardèche.*

On the other hand, since the pearl is only seasonally submerged, its upper part is gradually covered by concentric calcite deposition around the original core (Bigot, 2024).

The presence of pearls on surfaces other than rimstones is likely to attract the attention of cavers familiar with cave decorations.

Since cave pearls are only formed inside rimstones and on cave floor, if they are found elsewhere, they must have been displaced from their original context. In fact, a rain of pearls fell on the surrounding speleothems.

At various points, hollows in the wall have trapped pearls thrown into the air (fig. 5).

The number of projectiles scattered around the chamber attests to a "battle of the pearls". It's more a question of a game played by children in the cave (fig. 6).

3. Mounios Cave

In the Mounios cave (Le Cros, Hérault), Gallic offerings and coins attest to an ancient cult. Later, the cave was used as a burial site (Gallic and Gallo-Roman periods).

In the deep part of the cave (fig. 7), stalagmites have been broken for no apparent reason (Bigot, 2014).

Figure 7 : *The gallery where there are many broken stalagmites, Mounios cave, Le Cros, Hérault.*

At the end of the cave, a small stalagmite was intentionally placed in a niche in the wall, and is now sealed by calcite.

On top, stalagmitic regrowth suggests a head, which rests against calcite slabs from a stalagmitic floor (fig. 8).

Figure 8: *Viewed from the side, the regrowth of a stalagmite suggests a human head, Mounios cave, Le Cros, Hérault.*

The setting formed by the calcite plates does not appear natural. Examination of the micro-rimstone on the surface of three slabs shows that at least one of them is not in a normal position. In fact, it has been rotated by 90° to provide a setting for an anthropomorphic stalagmite, which is also not in its original position.

There are at least two arguments to support the view that the speleothems are artificially arranged: firstly, the absence of a chamfer at the base of the anthropomorphic stalagmite, and secondly, the arrangement of the calcite plates forming the case.

- The base of the stalagmite has no connecting chamfer between its base and the floor below. However, all stalagmites have a basal chamfer resulting from thickening of the growth rings at the base.
- At least one of the elements of a flowstone has been displaced to form a constructed arrangement that serves as a case for the anthropomorphic stalagmite.

The characteristic shapes of the micro-rimstones (crescents) that develop on the surface of the calcite slabs indicate the direction of the initial slope of the flowstone (fig. 9).

Plates 1 and 2, although abnormally inclined, could have a natural origin; but plate n° 3 can in no way result from gravitational movement, as its orientation is 90° different from that of its original formation.

We conclude that the arrangement of the calcite elements, namely the anthropomorphic stalagmite and the plates forming a case, is at least partly the result of an anthropogenic action.

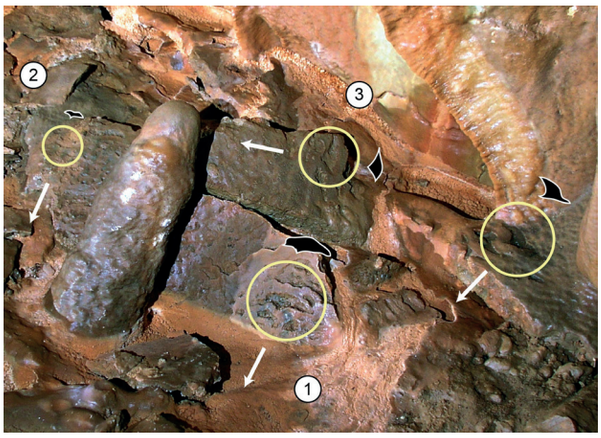

Figure 9 : *The arrangement of plates 1 and 2 is consistent to the direction of the slope of the flowstone (arrows), but plate n° 3 shows a 90° rotation (crescent of micro-rimstone oriented to the left), which cannot be natural.*

On the right-hand side of the photo, crescent shapes can be seen in the flowstone still in place.

4. Conclusion

My first speleo-archaeological observations of speleofacts from speleothems date back more than 10 years.

They didn't convince or awaken everyone's conscience, simply because they weren't understood.

In fact, you need firstly to know how caves and speleothems are formed in order to distinguish between what is natural and what is not.

Of course, we can try to train people to recognize clues or anomalies in caves, but it would be better to work with specialists who can "read" cave walls and floors directly.

Speleo-archaeology is based on logical findings and deductions, even if some people still consider it to be an obscure specialty of geoarchaeology.

Acknowledgments

Danièle Domeyne, who accompanied me underground into the Mas de Rouquet cave (Hérault).

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An Alternative to Ceramics: the Underground Water Basins Built and Dug

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Abstract

Ceramic jars are not the only way to store water underground. There are many other techniques that can increase water resources, in particular by building basins for water collection in situ. Of course, it is always possible to take advantage of existing natural pools, but they may be insufficient. In which case they can have their capacity increased by damming or raising the level of a gour (pool), or by digging holes in a clayey substrate. Some examples from French caves allow us to understand the different techniques used by prehistoric men underground. First, we will see the built basins of Sot Manit cave and Counterfeit Money cave. Then, we will see the basins dug in clay of the Saw cave, Bear cave and Faux-monnayeurs cave.

Résumé

La céramique n'est pas le seul moyen de stocker de l'eau sous terre, il existe bien d'autres techniques qui permettent d'accroître la ressource en eau, notamment en construisant des bassins pour la recueillir. Certes, il est toujours possible de profiter de bassins naturels existants, mais on peut les multiplier en barrant ou en rehaussant le seuil d'un gour, ou encore en creusant des trous dans un substrat argileux. Quelques exemples de cavités françaises permettent de comprendre les différentes techniques utilisées en grotte par les hommes de la Préhistoire.

1. Introduction

In France, large vases are emblematic objects of Final Neolithic archeology. Corded jars, sometimes still in place in the caves, constituting pieces worthy of being exhibited in museums (fig. 1).

But what do we know about the use of these vases and the techniques used by prehistoric people to collect and retain water in caves?

In fact, not much, because observations were often limited to the ceramics, and little consideration was given to the context in which they were discovered.

However, prehistoric people did not only use ceramics to collect water from caves.

They sometimes created receptacles by damming natural channels or by digging in the clay to enlarge natural basins and increase their water resources.

Figure 1: *Corded jars extracted from the Claux cave and on display in Lattes museum (Hérault, France).*

2. Built Basins

Diversions of water trickles and constructed basins were observed in the Sot Manit cave (Saint-Maurice-Navacelles, Hérault).

The most imposing construction is undoubtedly the "great pool barred" by an enormous fragment of a stalagmitic column (fig. 2).

Figure 2 : *"Great pool barred" by a section of stalagmitic column (Sot Manit cave, Hérault, France).*

This fragment, which weighs several hundred kilos, was placed across the cave passage to form a large basin. Any gaps were probably sealed with clay to allow impounding of water (Bigot, 2018).

In the Counterfeit Money cave (Mas-de-Londres, Hérault), the main gallery was blocked by fragments of broken concretions to form a dam.

Of course, the water reservoir thus created is not very deep, but still sufficient to be effective.

Stones, today contained within the calcite of the pool, show that the builders of the basin did not want to contaminate the water during its use (fig. 3).

Figure 3: *The gour and the stones which prevent the water resource from being contaminated. At the bottom, we see fragments of stalagmites which dam the pool (Counterfeit Money cave, Hérault, France).*

3. Basins Dug in Clay

Another technique consists of digging the bottom of a low point of a cave to recover all of the existing water flows.

Indeed, digging a hole can extend the water withdrawal period to include the dry season.

This technique was used in the Saw cave (Saint-Remèze, Ardèche) where a pit collected trickles of water coming from different places in the cave (fig. 4 & 5).

In a low point of Bear cave (Saint-Jean-de-Buèges, Hérault), basins were dug in the clay soil to collect water flowing from different places (fig. 6).

Figure 4: *View of the chamber where the pit dug in the clay soil is located (Saw cave, Ardèche, France).*

The excavated holes, four in number, are located on the path of trickles of water sometimes diverted by small dams specifically to facilitate filling of these basins.

The principle was simple: the more holes excavated, the more abundant the water resource.

Figure 5: Pit dug in clay to collect water (Saw cave, Ardèche, France).

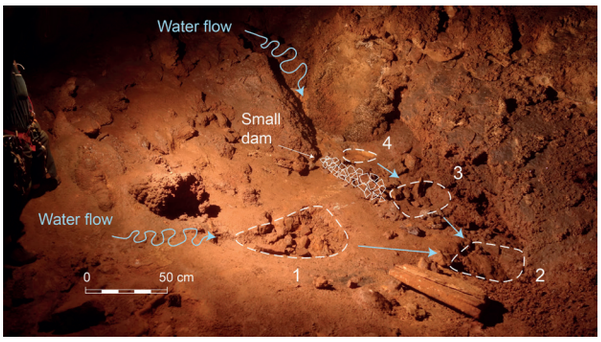

Figure 6: *Overview of the pools located at the bottom of a clayey area of Bear cave (Hérault, France).*

In Faux-monnayeurs cave (Millau, Aveyron), two circular holes were made at the bottom of a large temporary lake.

Indeed, a plan by Louis Balsan (1931) indicates the contours of a lake in summer and winter (Bigot et al., 2022).

Obviously, environmental conditions have changed since the 1930s. The two holes are the same shape and do not evoke natural formation at all. The calcite crust, covering the bottom of the lake, was smashed to create two holes, approximately 50 to 60 cm deep. Dug by human hands and comparable to wells, they are today entirely covered with calcite (fig. 7 & 8).

Digging holes at the bottom of the low points of a cave to find water hidden in the ground is a very old technique.

Prehistoric people know that digging holes can extend the water collection period from just the wet season, longer into the dry season.

A similar process is used by wild animals in Africa, when they dig dry river beds to find water.

Figure 7: *One of the two dug wells in the clay after breaking the floor calcite which dominates the hole (cast shadow), Faux-monnayeurs cave (Aveyron, France).*

Figure 8: *In the foreground, the two wells dug at the bottom of a temporary lake (Faux-monnayeurs cave, Aveyron, France).*

4. Conclusion

Ceramics are not the only remarkable elements of the caves. There are many interesting and different arrangements of excavations and damming techniques which allow water to be diverted and collected in retention basins.

However, the particular application of ceramics remains to be clarified. This is because their size and fragility do not allow them to be adapted to all situations encountered underground.

The corded vases collecting water falling from the ceiling are perhaps only an idealized vision of prehistoric caves.

Additionally, these vases are also found in completely dry parts of caves. This suggests that perhaps they were used in other ways.

An alterntative would be to see these vases as reservoirs of water stored in caves. In the wet season, they were regularly filled with water taken elsewhere to faciliate the availability of sufficient supplies for the dry season.

Thus, the water would first have been taken from natural or artificial basins, then stored in corded jars.

Built or dug basins and well-filled jars ensured the survival of the group.

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Rock art records in Caetanos, Bahia, Brazil

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Abstract

The rock shelter Toca da Onça, located in the rural area of Caetanos, Bahia, is situated on a granite outcrop on the eastern bank of the Riacho do Cipó. The site has a history of possible human occupation and is associated with Indigenous peoples, the cangaço, and the presence of rifle shell casings as well as human and animal remains. Initially focused on fossil prospecting, an exploration of the area led to the discovery of rock inscriptions by a team from the Universidade Federal da Bahia. The outcrop contains two cavities. The first, significantly altered by human activity, features a rock barrier and does not contain any rock inscriptions. The second shelter, better preserved and more difficult to access, contains geometric engravings located in an elevated area. These paintings have been classified within the São Francisco and Geometric Traditions, which are common in Bahia, and exhibit features similar to those recorded in the Sete Cidades National Park, in Piauí. The discovery of these engravings expands knowledge about human occupations in the region and reinforces the significance of the Toca da Onça shelter as an important archaeological site, highlighting the need for further studies on its history and conservation.

Resumen

L'abri sous roche Toca da Onça, situé dans la zone rurale de Caetanos, en Bahia, se trouve sur un affleurement granitique sur la rive est du Riacho do Cipó. Le site présente des indices d'une possible occupation humaine et est associé aux peuples autochtones, au cangaço, ainsi qu'à la présence de douilles de fusil et de restes humains et animaux. Initialement orientée vers la recherche de fossiles, la prospection de la zone a conduit à la découverte d'inscriptions rupestres par une équipe de l'Université fédérale de Bahia. L'affleurement abrite deux cavités. La première, fortement modifiée par l'activité humaine, comporte une barrière de roches et ne présente aucune inscription rupestre. Le second abri, mieux préservé et plus difficile d'accès, contient des gravures géométriques situées dans une zone surélevée. Ces peintures ont été classées dans les traditions São Francisco et Géométrique, courantes en Bahia, et présentent des similitudes avec celles enregistrées dans le Parc national de Sete Cidades, dans le Piauí. La découverte de ces gravures enrichit les connaissances sur les occupations humaines dans la région et renforce l'importance de l'abri Toca da Onça en tant que site archéologique majeur, soulignant la nécessité d'études approfondies sur son histoire et sa conservation.

1. Introduction

The current territory of the state of Bahia stands out in pre-colonial archaeological research, particularly in the study of Rock Art. According to MARTIN (1996), the first attempts to systematize and study rock art representations in Bahia were carried out by Valentin Calderón in 1970, when he worked with the notion of "tradition."

The analysis of rock art through classification into "traditions" and "styles" is based on the identification of different phases (CAVALCANTI, 1982), considering aspects such as technique, support, raw material, site selection, morphological and aesthetic characteristics, scale, and temporality, among others. Thus, "tradition" can be defined as a "broad category, implying a certain permanence of distinctive traits, usually thematic, while 'styles' are often subdivisions, particularly based on technical criteria [...]" (PROUS, 1992, p. 511).

The occurrence of rock art in caves is well known in the world's scientific literature (e.g., GREER & GREER, 1997). However, in Brazil there are few approachs that deal exclusively with rock art in caves (e.g., AGUIAR & LIMA, 2012 ; TRAVASSOS, 2013). Prospects for rock art in twilight and afotic zones are scarce, given the need for very specific knowledge, wich combines the fields of Archaeology and Speleology.

This study aims to present new records of rock paintings in the municipality of Caetanos, Bahia, and identify their respective "tradition" seeking to enhance the archaeological significance of the region and contribute to its preservation.

2. Materials and Methods

The rock shelter Toca da Onça (Figure 1) is located on Fazenda Toca da Onça (14°16'54"S, 40°48'44"W), in the rural area of the municipality of Caetanos, Bahia. This small property is traversed by Riacho do Cipó, which flows into Rio do Peixe, a temporary tributary of Rio das Contas. On the eastern bank of the stream, there is an outcrop of granitic rocks whose characteristics favored the formation of shelters, making possible the potential anthropic occupation in past times.

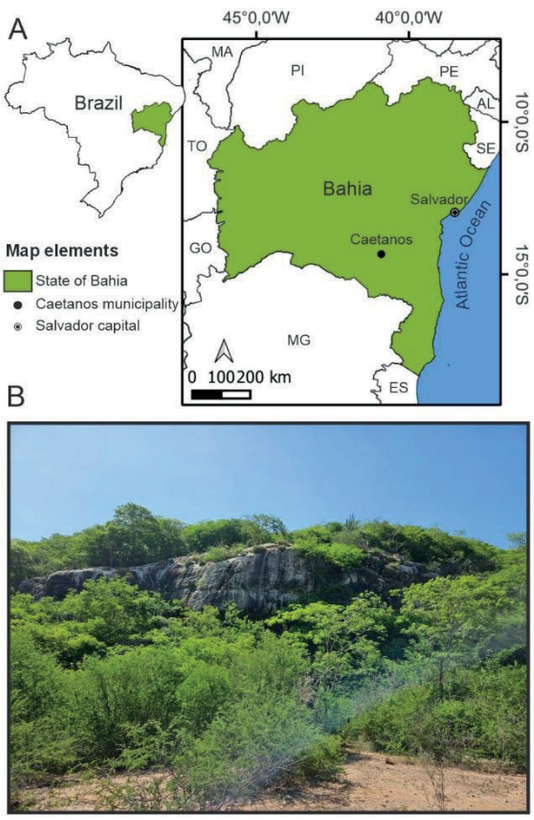

Figure 1: Location map of the Toca da Onça Rock Shelter. (A) Location of the municipality of Caetanos, Bahia; (B) Toca da Onça rock shelter (Photo : Antônio de Pádua, 2025).

The prospecting of natural rock tanks in search of fossils led to the discovery of stories involving the Toca da Onça rock shelter and sparked the interest of a research team from the Laboratório de Ecologia & Geociência at the *Universidade Federal da Bahia*, Campus Anísio Teixeira, in Vitória da Conquista. This team visited the site in search of potential fossils.

The stories about Toca da Onça include accounts of its past use as a shelter by Indigenous groups, a refuge for cangaço bandits, and a site where rifle cartridges, as well as human, goat, pig, bird, and small rodent remains, were found. Until the research team's visit, there were no known records of rock inscriptions in the shelter. However, during the prospecting activities, geometric engravings were identified, along with some animal remains, likely from modern times.

The rock outcrop contains two cavities. The first, located further south, shows significant anthropic modifications. A rock barrier was built to block access to the interior of the shelter, and no rock inscriptions were found in this area.

The second shelter, located further north in the outcrop, is the best-preserved and contains the inscriptions. It has a low ceiling, making access to the interior difficult, and the engravings are located in an elevated section of the shelter.

The classification of the paintings was conducted through a review of academic studies on pre-colonial archaeological sites featuring rock art in Bahia, as well as by consulting records from the *Cadastro Nacional de Sítios Arqueológicos* (CNSA). This digital tool, managed by the *Instituto do Patrimônio Histórico e Artístico Nacional* (IPHAN), allows for the organization and management of information on archaeological sites identified throughout Brazil. Based on these data, it was possible to gain insights into the pre-colonial archaeology of the southwestern region of Bahia, where the municipality of Caetanos is located.

3. Results

In the municipality of Caetanos, at the surveyed site, the presence of pictographs on an external rock surface of the cave was documented (Figure 2A). The shelter measures 3.90 m in height and 8.90 m in depth, with the images located 1.90 m above the ground.

As observed in Figure 2B-C, isolated motifs are present, where the rock engravings appear arranged in parallel, in a monochromatic reddish hue. These markings likely represent a dyad in a darker tone, possibly resulting from a mixture of iron oxide with another substance, the composition of which can only be confirmed through archaeometric analysis. Thick strokes are also evident, with the upper image displaying a circular triadic form, while the lower one features predominantly rectilinear strokes. Together, these shapes measure approximately 85.6 mm in length by 53.98 mm in width.

In Figure 2D-E, paintings depicting possible unidirectional arrows are observed. Both representations are in an evident state of degradation, suggesting a correlation with local physical factors such as direct exposure to wind, rain, and sunlight.

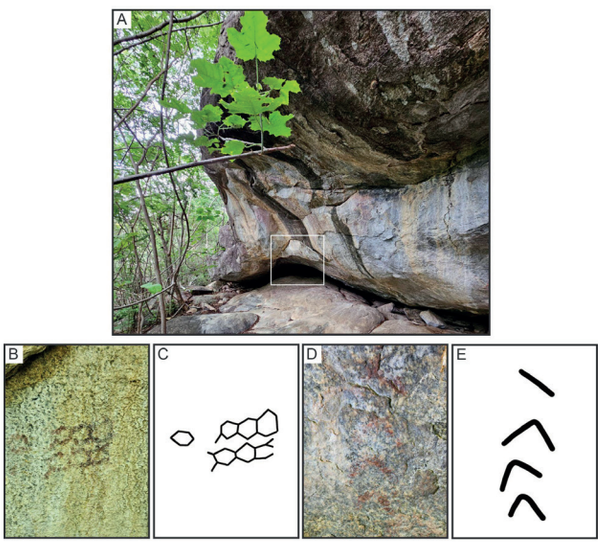

Figure 2: Evidence of pictographs. (A) Location of the paintings; (B) and (D) traces of the paintings; (C) and (E) graphical representation of the paintings (Photos by Antonio de Pádua).

4. Discussion

Among the known rock painting "traditions," the *Nordeste Tradition* stands out, initially defined based on archaeological sites in the state of Piauí by Dra. Niéde Guidon. This tradition is characterized by the presence of anthropomorphic figures (human representations, many forming scenes) and zoomorphic figures (ostriches, deer, and small quadrupeds), often associated with geometric signs.

The *Agreste Tradition* predominantly features large geometric figures, as well as biomorphic, zoomorphic, and large anthropomorphic figures. This tradition is primarily found in the states of Ceará, Paraíba, Pernambuco, Piauí, and Rio Grande do Norte.

The *Planalto Tradition*, mainly located in the Central Plateau, consists essentially of monochromatic zoomorphic figures (birds, fish, and deer) and geometric figures, with fewer anthropomorphic representations. A distinctive feature of this tradition is the so-called "Ballet Faces," which depict supposedly human figures lined up with raised arms and legs.

In the *São Francisco Tradition*, abstract geometric figures are predominant, along with zoomorphic representations (fish, birds, snakes, and saurians), with fewer anthropomorphic figures. A striking characteristic of this tradition is the use of bichromy.

Finally, the *Geometric Tradition*, as its name suggests, consists of geometric engravings, including triangles, curvilinear figures, and footprints. These representations were created on rock surfaces near water sources and are found mainly in the northeastern states and the Santa Catarina Plateau.

Thus, ecological, geomorphological, climatic, and cultural factors of a region—such as the composition of rock surfaces, the type of pigment used, the possible tools employed for painting and/or engraving, the selection of the site, and even the state of preservation of the representations—become essential elements in the study of rock art.

The analysis of these representations involves their identification, recording, description, classification, systematization, dating, and interpretation, assisting archaeologists in understanding the ethnic groups that produced these records.

In the archaeological context of the state of Bahia, a significant number of pre-colonial sites have been registered by the *Instituto do Patrimônio Histórico e Artístico Nacional* (IPHAN) through the *Cadastro Nacional de Sítios Arqueológicos* (CNSA). To date, 837 pre-colonial sites have been identified across more than 74 municipalities in Bahia, reaffirming their widespread distribution. This data suggests that the groups responsible for the rock art developed ways of life adaptable to different ecological variations, moving through environments that, if not identical, at least shared similar biotic characteristics (ETCHEVARNE et al., 2011, p. 47).

Research in the Bahia region indicates that most rock art sites are found in shelters, caves, grottoes, dolines, cliffs, and canyons composed of sandstone, limestone, or granite. The pictographs and engravings recorded in these locations mostly belong to the *São Francisco* and *Geometric* Traditions.

In the southwestern region of the state, where the municipality of Caetanos is located, notable archaeological rock painting sites, according to CNSA-SGPA data from IPHAN, include *Pedra Arenosa* in Licínio de Almeida, as well as *Abrigos do Gavião I and II, Toca do Teixeira* in Jacaraci, and *Angicos* in the municipality of Ituaçu.

The *Pedra Arenosa* site is a rock painting site located in a sandstone shelter on public land, predominantly featuring geometric figures. The panel measures 11.3 m in length and was recorded in 2007 by archaeologist Carlos A. Etchevarne.

The *Abrigo do Gavião I* is a rock shelter containing rock painting panels associated with the São Francisco, Geometric, and Agreste Traditions. It is situated 20 m from the *Rio Gavião*, along a dirt road, on private land. The site was recorded by Alexandre Rocha Colpas from the IPHAN Superintendency of Bahia in 2011.

The *Abrigo do Gavião II* is also a rock shelter featuring pictographs belonging to the *São Francisco*, *Astronomical*, *Geometric*, and *Agreste* Traditions. It is located on a mid-slope near the *Rio Gavião* and was recorded by Alexandre Rocha Colpas in 2011.

The *Toca do Teixeira* site is a rock shelter with pictographs, located on a mid-slope approximately 300 m from the *Rio Gavião*, on private land. Like the previously mentioned sites, it was recorded by Alexandre Rocha Colpas from the IPHAN Superintendency of Bahia in 2011.

The Angicos site is a rock shelter with pictographs, situated in a protected area measuring 20 m in length, at the entrance to a cave and a chamber, on a mid-slope near the *Rio Mato Grosso*, on private land. According to Fabiana Comerlato and Fernando Ferreira de Santana, who recorded the site in 2009 as part of the *Projeto de Diagnóstico e Levantamento Arqueológico nas Áreas de RC-06, RC-11, RC-12 e RC-13 para Lavra de Calcário pela Cimento Nassau, Ituaçu, Bahia*, the paintings belong to the São Francisco Tradition and are in good condition despite rock surface exfoliation caused by human activity.

It is observed that all the aforementioned archaeological sites share certain characteristics, such as topography, proximity to water sources, and the classification of pictographs.

With geometric features (Figure 2C–E), the paintings found can be classified within the *São Francisco* and *Geometric* Traditions, which are widely present in the state of Bahia. Their patterns follow a style similar to that of paintings identified in the *Sete Cidades National Park*, located in the central-northern region of the state of Piauí, as illustrated in Figure 3.

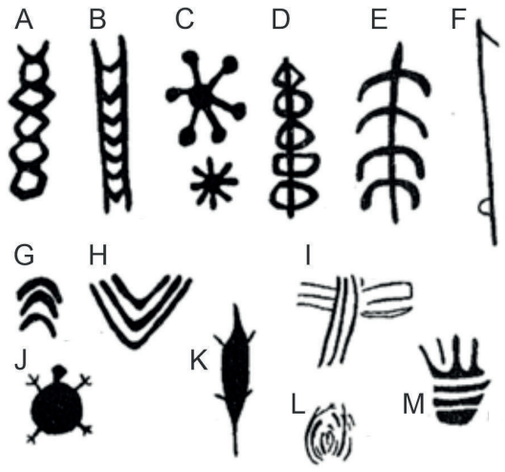

Figure 3: *Representations of rock engravings from Sete Cidades. (A–M) São Francisco / Geometric Traditions; (L) Carimbo Tradition. Adapted from Prous (1992).*

5. Conclusion

The discovery of rock engravings at the Toca da Onça shelter in Caetanos, Bahia, expands the understanding of human occupations in the region and reinforces the site's importance as a relevant archaeological area. The identification of inscriptions associated with the São Francisco and Geometric Traditions highlights recurring patterns in Bahian rock art and enables comparisons with other sites in the Brazilian Northeast. In addition to contributing to the understanding of past cultural dynamics, these findings emphasize the need for measures aimed at preserving archaeological heritage, ensuring that this legacy continues to support future studies on the symbolic expressions of prehistoric societies.

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Pinturas rupestres no Carste do Alto do Rio São Francisco: possibilidades de pesquisa

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Resumo expandido

O patrimônio espeleológico na região cárstica de Arcos, Pains e Doresópolis no sudoeste mineiro é amplamente conhecido em âmbito nacional, possuindo o maior contingente de cavidades naturais subterrâneas cadastradas em território nacional segundo o Cadastro Nacional de Informações Espeleológicas (CANIE, 2022). O patrimônio arqueológico nesta região também é bastante conhecido pelos sítios arqueológicos, tendo sido identificados artefatos pré-coloniais e coloniais, dentre eles destacam-se os artefatos cerâmicos pré-coloniais e às minerações coloniais. Também foram identificados líticos, gravuras e pinturas. Os sítios arqueológicos da região foram alvo de pesquisa ao longo dos anos principalmente pelos processos de licenciamento ambiental da mineradoras, porém também houveram pesquisas acadêmicas (PROAPE, 2012; KOOLE,2007 e 2014; Henriques, 2001 e 2006).

A região deste estudo possui empreendimentos de mineração da rocha calcária de diferentes portes (PROAPE, 2012), os quais possuem grande ocorrência nesta região cárstica a um período superior a 50 anos. Ocorrem aproximadamente 40 minas de calcário ativas na região, o que pode ocasionar severos impactos ambientais aos sítios arqueológicos na região, os quais em uma breve consulta em bases de dados, ocorrem com uma distribuição regular. Sítios arqueológicos que possuam pinturas rupestres possuem uma alta vulnerabilidade quando se trata de alguns impactos relacionados a mineração calcária, como por exemplo a dispersão de material particulado (Bacci et al., 2006), os quais recobrem superfícies e por vezes dificultando ou até mesmo impedindo a plena visualização de um suporte para estas pinturas. Outro impacto ambiental muito relacionado as atividades de mineração calcária são fissuras e até mesmo destruição de corpos rochosos os quais podem estar relacionados ou por vezes conter pinturas rupestres ou demais sítios arqueológicos, isto se deve ao fato do aspecto da mineração calcária em utilizar material explosivo para realizar o desmonte de corpos rochosos (Silva, 2023), procedimento indispensável para a mineração calcária na região, ocasionando vibrações que interferem em corpos rochosos dependendo da intensidade e proximidade deste com o local da explosão/desmonte. Além do impacto físico que essa atividade pode gerar nos sítios de pintura, em geral os relatórios se detém ao registro dos grafismos rupestres, já que o órgão não exige este tipo de análise mais aprofundadas dos grafismos rupestres, como tem acontecido em outras regiões de Minas Gerais, como Diamantina (Linke et al., 2020) e o Parque das Cavernas do Peruaçu (Isnardis, 2004).

Os sítios de pintura rupestre mais conhecidos da região são Posse Grande (Figura 1) e a Gruta do Marinheiro. Em Posse Grande há um grande paredão pintado de grandes dimensões. A Gruta do Marinheiro, além das gravuras e pinturas rupestres apresenta também cerâmicas e líticos (PROAPE, 2012). A região possui museus os quais recebem e mantem em exposição parte dos materiais arqueológicos resgatados na região, sendo um destes o Museu do Carste do Alto São Francisco localizado em Pains e Estação Ecológica de Corumbá, localizada em Arcos. Mais a norte temos dois sítios no Morro do Quenta Sol com pinturas rupestre, sendo que um deles (Lapa das Abelhas I) não foi possível encontrar nos dados de localização geográfica. Não foram realizadas datações nesta área. Destaca-se o sítio arqueológico Antônio Vitalino (figura 3), uma gruta cuja entrada se conforma em uma ampla zona abrigada com cerca de 350 m² de área. Na zona abrigada há artefatos arqueológicos como pinturas rupestres, fragmentos de cerâmica e material lítico. Na região há dois tipos de tradição, Planalto e São Francisco, que assim como as tradições cerâmicas se confundem por serem categorias êmicas da arqueologia (Prous, 1999).

Figura 1: *Sítio Arqueológico da Posse Grande. FOTO: Ataliba Coelho (Piló e Cruz, 2022).*

O objetivo deste estudo é apresentar áreas com potencial para presença de sítios arqueológicos que possuam pinturas rupestres na

região correspondente a micro bacia do Córrego Santo Antônio, do Rio São Miguel, Córrego das Pedrinhas e Córrego Candongas, todos afluentes do Rio São Francisco e através deste potencial correlacionar através de geoprocessamento para entender a inserção dos sítios arqueológicos nas paisagens cársticas da região, e relacionar este dado geográfico às pinturas rupestres, enquanto seu modo de fazer (Linke et al., 2020) e sua importância enquanto testemunha da história indígena milenar (Diniz, 2020). No mapa abaixo é possível observar os sítios de pintura rupestre que estão cadastrados nos bancos de dados no PROAPE (2012) e do Instituto Pristino (2025):

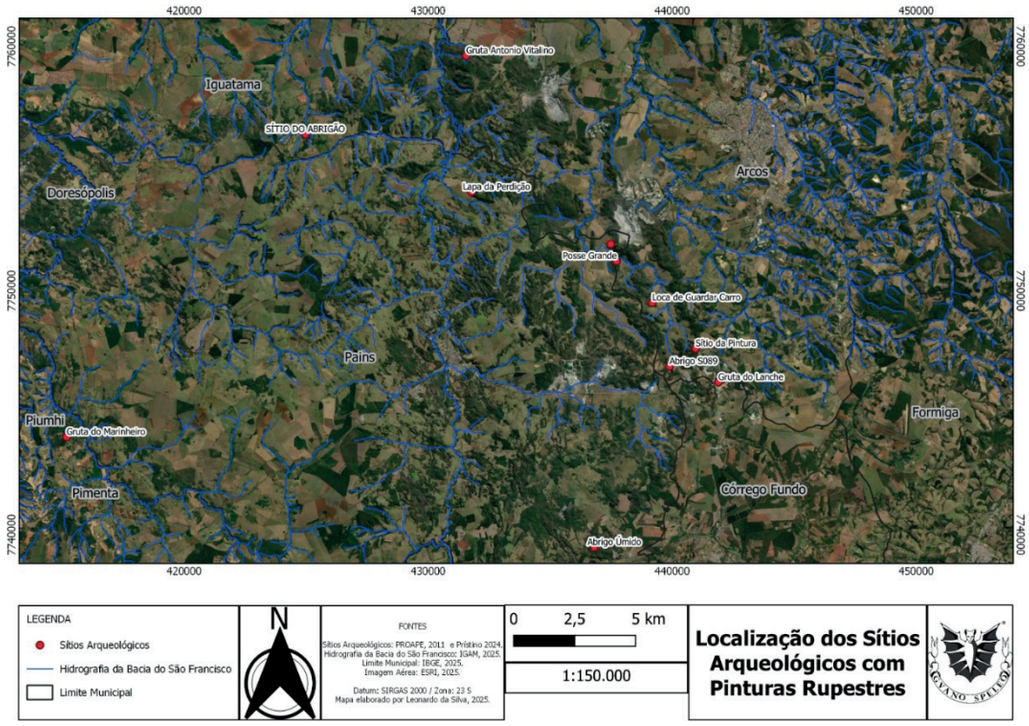

Figura 2: *Mapa dos Sítios Arqueológicos com Pinturas Rupestres e afluentes do Rio São Francisco.*

Grande parte das localidades com alto potencial de ocorrência de sítios arqueológicos e/ou cavidades naturais subterrâneas estão em propriedades particulares pertencentes a mineradoras, resultando em negativas ou entraves para a visita *in loco*. Com o geoprocessamento e com os dados de referência já disponíveis sobre a arqueologia regional é possível entender os locais de potencial de ocorrência de sítios arqueológicos que possam conter pinturas rupestres. O geoprocessamento e imageamento por satélites ou drones, permitem uma visualização destas áreas e através de análise multicritérios. Uma vez definido o grau de potencialidade de ocorrência destes sítios arqueológicos, certamente se faz necessário um estudo *in loco* para corroborar os resultados obtidos no geoprocessamento através de dados secundários, com este refinamento posterior a etapa de pesquisa, se pode ter uma noção se os critérios de áreas com mais probabilidade de ter sítios de pintura são realmente recorrentes e quais são os casos de desvio.

Alguns fatores foram selecionados para o devido nivelamento de grau de potencialidade de ocorrência de pinturas rupestres como: contexto litológico, relevo, proximidade de cursos d'água, cobertura vegetal e uso e ocupação do solo. Cada um destes fatores foi analisado individualmente e posteriormente sobrepostos para se definir áreas focais e que permitissem a definição do grau de potencialidade. Locais que apresentem, por exemplo, afloramentos de rocha calcária, com uma considerável declividade, podem conter paredões rochosos adequados para proporcionarem suporte para painéis de pinturas rupestres. O sítio Posse Grande (Figura 1) é um bom exemplo de paredão de pintura como descrito acima, onde as pinturas podem ser vistas de uma área mais ampla, porém também temos sítios como a Gruta de Antônio Vitalino (Figura 3), cuja entrada tem uma zona abrigada de 350 m² de área e todas as pinturas se encontram no teto da porção interna da gruta.

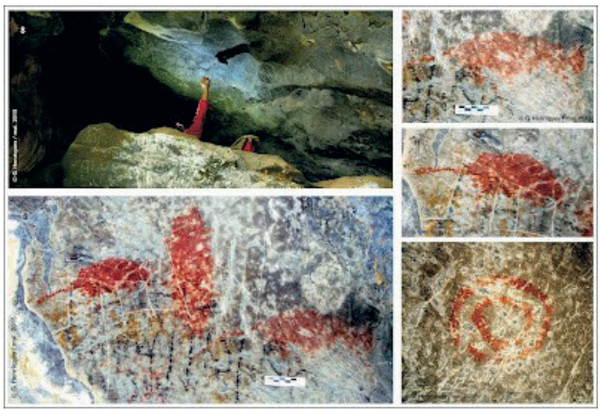

Figura 3: *Fotos das pinturas rupestres do Sítio Arqueológico Antônio Vitalineo. (MAC, 2025).*

Sobre as pinturas rupestre da região que encontramos imagens, é possível perceber que há a utilização de diferentes tintas e sobreposições, informações que tem sido muito importante para os estudos de pintura rupestre, em especial as pesquisas desenvolvidas no âmbito de Minas Gerais, pelo Museu de História Natural e Jardim Botânico da Universidade Federal de Minas Gerais (Isnardis, 2020). Para além de entender a cronologia relativa do painel, é possível entendermos os modos de composição dos painéis e relacionar este painel não enquanto uma figura final mas enquanto um processo indígena de construção de mundo (Linke et al., 2020).

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Indigenous Exploration at Helms Deep Cave, Tennessee: Late Archaic Radiocarbon Dates from River Cane Torches

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Abstract

In 2020, cavers discovered an extensive (>106 km) maze in Helms Deep Cave, Tennessee with abundant evidence for ancient Native American exploration in the southern sections. Between 2021 and 2023, the authors collected samples of charcoal from the cave substrate; seven were submitted for radiocarbon dating using AMS. Six samples were river cane (Arundinaria gigantea) charcoal from torches, while the seventh was unidentified charcoal from a stationary fire in the first room of the maze. Three samples were selected for their general locations in the maze and four for their proximity to features such as footprints. The 14C results for all seven samples are conventional radiocarbon dates between 3320 and 3025 BP. When calibrated, this places the Indigenous exploration from the late 17th to 13th centuries BC, in the latter part of the Late Archaic Period. The three youngest dates are statistically identical, but the other dates suggest three or four periods of exploration over a 400-year period, after which all visitation ceased. Compared to other regional Late Archaic deep cave sites, exploration in Helms Deep Cave was very extensive but limited in time, and mineral mining was not a significant activity.

1. Introduction

Ever since the 2020 discovery of extensive Native American exploration in the paleo-maze of Helms Deep Cave, people have wondered who these explorers were, and when they made their underground forays. While the first question is complex and will require much additional research, we can begin to answer the second, about the site chronology. As the early visitors utilized river cane (*Arundinaria sp.*) torch technology, there are significant deposits of associated charcoal scattered throughout the southern and central maze, as well as some associated torch stoke marks. There is also a thin scatter of charcoal in the Jeffrey Room, which we interpret as a stationary fire or hearth. These charcoal deposits allow the radiocarbon dating of the Indigenous activity in the cave. The presence of cane charcoal, along with other indicators, is also key to documenting which cave passages were explored prehistorically.

Helms Deep Cave is located in the uplands of the Western Highland Rim physiographic province in Perry County, Tennessee. The cave is primarily developed in Silurian limestones, although overlaying Mississippian shales are exposed in many areas. The large sinkhole entrance opens into a short pit followed by a steep breakdown slope extending down to a major stream passage at -50m. The passage can be followed about 130 meters upstream to a sump while the downstream end is eventually choked by breakdown. Although long known to local inhabitants, and used both for a water source and recreational outings in the Twentieth Century, no previous archaeological work has been conducted at the site. Jerald Ledbetter reported the cave to the Tennessee Cave Survey in 1974, along with a simple map, but he did not note any cultural or historic material. Over the next twenty-five years, cavers occasionally visited the site but little else was found. Even including the crawlways in the entrance breakdown, the cave was estimated at less than 450 meters long. TENNESSEE CAVE SURVEY (2016)

In 2020, four cavers found an inconspicuous climb-up on the entrance chamber wall 18 meters above the stream level, and at the top of the short climb they found a crawlway leading into an extensive maze with evidence of prehistoric (but not historic or contemporary) exploration. Over the next few months, they explored over five kilometers of passages and began a cartographic survey, recruiting other teams of cavers to join the them. Formalized as the Helms Deep Cave Project, by late 2024 the cave was over 106 kilometers long.

The Indigenous archaeology of Helms Deep Cave includes five main categories of interest: burnt material from river cane torches, stones placed to serve as land marks or trail-markers, human footprints, cave art, and human remains. This paper focuses on the charcoal from cane torches, the which were used for cave lighting in the southeastern United States from at least the Middle Archaic Period into the Nineteenth Century. These torches usually consisted of tied bundles of 6-10 dried river cane stems or culms, which provided a consistent and effective, if smoky, light. As the torches burned, the burnt ends were brushed or stoked against rock to knock off the burnt end and reinvigorate the flames, leaving distinctive and diagnostic marks on the passage walls as well as charcoal on the cave floor. Cane charcoal is frequently used in eastern North America to both document the extent of Native American exploration and to establish chronology. WATSON (1974)

2. Materials and methods

From early 2021 to 2023, the authors collected 10 samples of charcoal for possible radiocarbon dating. Small amounts of materials were collected using tweezers, selected from substantial concentrations of charcoal, so that most of each deposit remains on site. Each sample was placed in a sterile container, labelled, and placed in packs before removal from the cave. Each collection spot was marked with flagging tape, photographed, and located relative to the nearest survey station. Of the ten samples, seven were subsequently submitted for AMS radiocarbon dating by Direct AMS Radiocarbon Dating Service, Inc.

Several factors besides the size of the deposit informed our choice of charcoal to collect, since they are ubiquitous in the southern maze. We focused on well-preserved scatters of visually identifiable river cane charcoal from torch debris contexts. Hoping to cover a wide area, samples #1, #2, and #7 were selected in part because of their general locations, representing the entrance (east) maze, a passage 300 meters north, and a passage 120 meters south. Samples #3 and #6 are from passages with multiple human footprints, Hobbit Hall and the BEG Footprint Passage. Sample #4 is from a junction room further east in the entrance maze, along one of the routes to the Glyph Gallery, a low, damp passage with cave art but no extant charcoal. Figure 1.

Figure 1: *River cane charcoal at Sample site #4.*

Sample #5 is different from the other samples, being taken from a stationary fire rather than from torch debris. This was collected from the first room in the maze, the Jeffrey Room, in front of the passage leading to the cave entrance. The deposit is a wide, thin scatter of charcoal, which may be river cane but which is too fine to visually identify and is inconsistent with torch debris.

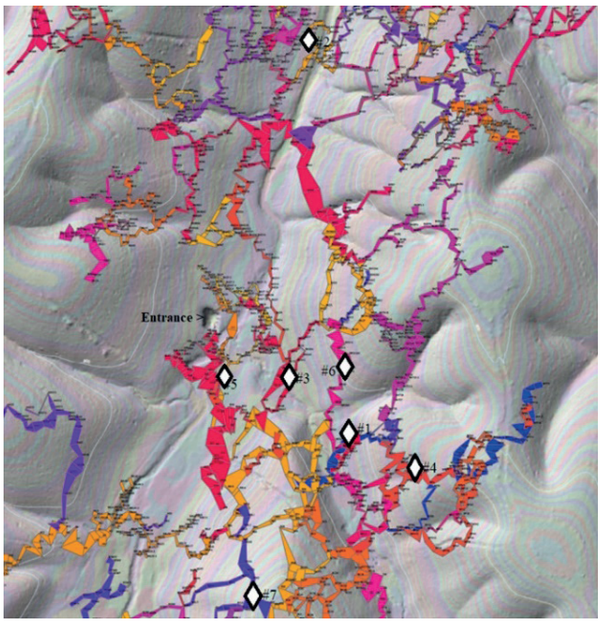

Figure 2: *Plot of charcoal samples selected for ^{14}C dating.*

3. Results

The laboratory results from the seven charcoal samples are all from the Late Archaic Period. Corrected for isotopic fractionation, the AMS conventional radiocarbon dates are from 3025 BP to 3320 BP. The standard deviations range from 17 to 29. When calibrated using Calib rev8.2 with IntCal 20, at two sigma the possible chronological range is 1622 BC to 1202 BC, except for Sample #7 whose possible date also extends into the 12 century BC. The data are arranged chronologically from oldest to youngest in Table 1. STUIVER & REIMER (1993)

The three youngest dates are statistically identical and come from the three non-contiguous passages in the eastern and southern mazes. The two oldest dates also have considerable statistical overlap and come from two adjacent passages in the eastern maze. The results for the stationary fire in the Jeffrey Room is in line with the dates from torch debris. Individual means for the seven calibrated radiocarbon dates extend from 1577 BC to 1276 BC. The calibrated dates represent at least three periods of exploration over about four hundred years. Then exploration seems to have ceased altogether. There are no later Woodland, Mississippian, or historic components in the maze.

Based on footprints and other evidence, It seems that multiple generations of men, women, and children, perhaps from a single group, visited and extensively explored Helms Deep Cave. While we do not presume to have captured either the earliest or latest dates for Indigenous visitation, the consistent radiocarbon results, from two different laboratories, Direct AMS Radiocarbon Services, Inc. and Penn State University, give us confidence in the Late Archaic chronology for the site.

Laboratory No.	Material (Context)	Location (Survey Station)	Conventional Radiocarbon Age BP	+/-	Calibrated Dates BC at 2 σ	Median Probability
PSUAMS 12179 and D-AMS 048551	cane charcoal (torch debris)	BEG Footprint Area 1 (BEG-11)	3320	17	1621-1533 (100%)	1577 BC
D-AMS 041231	cane charcoal (torch debris)	BEA Passage (BEA-7)	3297	27	1618-1507 (100%)	1565 BC
D-AMS 041729	cane charcoal (torch debris)	BKK Passage (BKK-14)	3167	29	1502-1397 (99.3%) 1331-1327 (00.7%)	1445 BC
D-AMS 044045	charcoal (hearth)	Jeffrey Room (B-9)	3093	22	1421-1289 (100%)	1347 BC
D-AMS 042286	cane charcoal (torch debris)	Hobbit Hall (BKA-2)	3027	22	1388-1338 (26.6%) 1320-1212 (73.4%)	1279 BC
D-AMS 051430	cane charcoal (torch debris)	B Passage south of Midland Maze (B-47B)	3026	29	1395-1334 (27.1%) 1325-1197 (70.9%) 1171-1164 (00.8%) 1141-1132 (01.1%)	1279 BC
D-AMS 042287	cane charcoal (torch debris)	Bone Room (BFD-1)	3025	23	1388-1338 (25.2%) 1320-1202 (74.8%)	1276 BC

Table 1 : *AMS radiocarbon dates from Helms Deep Cave, Tennessee. Calibrated using Calib v. 8.2, with IntCal 20. STUIVER & REIMER (1993).*

4. Discussion

At Helms Deep Cave, Indigenous exploration and visitation seem restricted to the last four hundred years of the Late Archaic. Whether the people moved, knowledge of the cave was lost, it became a taboo site, or if the key crawl was sealed by natural processes, or by deliberate human activity, is not known. When the first modern cavers climbed up into the key crawl, the passage leading out the crawl toward the cave entrance was mostly plugged with fill, although they could squeeze through at the top. We would note that while much of the former sediment plug has been dug out to enlarge entry, the remnants that remain along the north wall contain many flecks of cane charcoal, suggesting it may be anthropogenic or at least human modified. Additional research is warranted. Regardless why, prehistoric visitation totally ceased, at least in the maze. This makes the chronology of Helms Deep Cave distinctive compared to most contemporary sites.

The Late Archaic was a time of increased underground activity by Native Americans across the region, a trend which continued in the Early Woodland period, after 3000 BP, although with different emphases. In their 2002 summary of Eastern North American cave archaeology, Crothers and colleagues identified ten underground sites with Late Archaic dates. Six of these have conventional radiocarbon dates contemporaneous with Helms Deep Cave, between 3000 and 3400 BP : 3rd Unnamed Cave, Tn., Wyandotte Cave, In., Mammoth Cave, Ky., Fisher Ridge Cave, Ky., Salts Cave, Ky., and Big Bone Cave, Tn. Subsequently, two additional contemporaneous sites in central Tennessee have been identified : Caney Hollow Cave and Skeleton Cave. None of these sites are within 160 Km of Helms Deep, being widely spread across five physiographic regions in the Interior Lowlands and Appalachian Plateau of Eastern North America. CROTHERS et al (2002), DOUGLAS (2011), DOUGLAS et al (2013)

A comparison with other deep cave sites in eastern North America with contemporaneous radiocarbon dates, from the last four hundred years of the Late Archaic, highlights commonalities but also reveals the distinctive aspects of the Indigenous exploration of Helms Deep Cave. The seven Helms Deep Cave dates agree well with six of the seven Late Archaic radiocarbon dates from 3rd Unnamed Cave. However, 3rd Unnamed Cave, along with Wyandotte and Mammoth caves, saw a period of earlier indigenuous visitation a thousand years prior, which is not seen at Helms Deep Cave. Six of the cave sites also experienced significant later use in the Woodland Period. Additonally, five of the caves were mined for important minerals in the Late Archaic or Early Woodland periods: 3rd Unnamed, Wyandotte, Mammoth, Salts, and Big Bone. In contrast, Helms Deep Cave was not mined for minerals, despite having abundant gypsum, and has a relatively restricted, single component chronology.

Regionally, the Poverty Point Culture in Louisiana was still in full swing when the exploration of Helms Deep Cave commenced. The Shell Mound Archaic also persisted along the Tennessee and other rivers. Lacking cultural markers such as pottery, tying the dates from Helms Deep Cave, and the people who explored it, to the broader regional history is a challenging task for the long-term.

5. Conclusion

Evidence for river cane torches shows that Native people in the Late Archaic Period explored most of the southern maze, and adjacent parts of the central maze, these being the more accessible parts of Helms Deep Cave from the sinkhole entrance. The extent of exploration is comparable with the most significant deep cave sites in the United States, such as Mammoth Cave, Big Bone Cave, and Salts Cave. The ^{14}C results for seven samples of river cane charcoal yielded conventional radiocarbon dates between 3320 and 3025 BP. When calibrated, this places the exploration of Helms Deep Cave from the late 17th to 13th centuries BC, in the latter part of the Late Archaic Period. Additional radiocarbon data will help further refine the site chronology.

Multiple generations of men, women, and children, perhaps from a single group, visited and extensively explored Helms Deep Cave over an approximate 400-year time span in the Late Archaic Period. The chronology of the site adds to the archaeological record of high interest in cave across Eastern North America during the Later Archaic Period. The exact purpose for the explorations remains elusive, as there is no sign of significant mining or economic exploitation.

Helms Deep Cave, with its human footprints, cave art, and stone trail markers, as well as cane torch technology, retains enormous research potential. Big questions still need answering. Were these shell-mound people from the Tennessee River valley visiting the upland cave? What importance did caves in general, and this cave specifically, have in their culture? We look forward to a new generation of researchers answering these and other questions.

Acknowledgments

We thank Jonathan Cover and family for permission to work on the site. Kristen Bobo, Alan Cressler, Clinton Elmore, Jim Honaker, Hailey Jackson, Anthony Olberding, and Jan Simek assisted in the sample collections. The Helms Deep Cave Project cavers also provided partial funding for the laboratory analysis.

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Formation of the Dead Sea Scrolls caves

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Abstract

The Qumran caves, famous for the Dead Sea Scrolls discovery, comprise four distinct geological types: natural caves in hard rocks of the Dead Sea escarpment, artificial caves in the Lisan terrace, natural caves in the Lisan terrace formed by piping, and hybrid caves that developed from artificial structures through subsequent natural processes. The natural escarpment caves, formed primarily through hypogenic karst dissolution during the Oligocene to early Miocene periods, are dispersed along several kilometers of dolomitic bedrock and have been used since Neolithic times. These caves, including the significant scroll caves 1Q, 2Q, 3Q, 6Q, and 11Q, have remained relatively stable due to their hard rock composition. In contrast, the artificial and natural caves in the soft Lisan terrace are concentrated near the Qumran settlement, demonstrating clear anthropogenic association but showing greater instability due to their less cohesive sediments. Dating evidence from various sources, including cosmogenic isotopes, Th-U dating of stromatolites, and radiocarbon dating, provides a comprehensive chronology of cave formation and usage. This geological classification helps explain the varying states of scroll preservation and provides insights into the settlement's deliberate use of both natural and artificial underground voids.

1. Introduction

The Dead Sea Scrolls were found in Qumran caves at the northern Judean Desert. The scrolls date from approximately 250 BCE to 68 CE, providing invaluable insights into Second Temple Judaism and the origins of Christianity. They include biblical texts (representing every book of the Hebrew Bible except Esther), sectarian documents, and other religious writings. Their research comprises hundreds of books (including 40 volumes of the official Dead Sea Scrolls publication series «Discoveries in the Judaean Desert») and tens thousands of papers, while new publications continue at a rate of several hundred per year. Yet the geology of the caves attracted little attention. This is the aim of the present paper, following an intensive field work.

2. The history of the Dead Sea Scrolls discoveries

The story of the Dead Sea Scrolls begins in 1947 whenBedouin shepherds discovered the first scrolls in what would later be designated as Cave 1, near Qumran. According to accounts from the time, a young shepherd named Muhammad edh-Dhib threw a stone into a cave and heard pottery breaking. Inside, he found clay jars containing ancient scrolls (DE-VAUX 1959).

The initial discovery led to further exploration between 1947 and 1956, ultimately revealing 11 caves containing scrolls and fragments.

Cave 1Q (discovered on 1947): Yielded seven major scrolls, including the Isaiah Scroll, the Community Rule, and the Habakkuk Commentary. These were among the best-preserved findings.

Caves 2Q, 3Q, and 4Q (discovered 1952): Cave 4 proved particularly significant, containing fragments from approximately 600 manuscripts. This cave alone provided about 40% of all Dead Sea Scroll material.

Caves 5Q and 6Q (discovered 1952): Discovered shortly after Cave 4, containing additional manuscript fragments.

Caves 7Q-10Q (discovered 1955): These caves contained fewer materials, though Cave 7 is notable for containing Greek texts.

Cave 11Q (discovered 1956): The last major discovery, yielding important texts including the Temple Scroll and the Psalms Scroll.

Modern research continues to yield new findings. In 2017, a 12th cave was discovered, though it had been looted in the mid-20th century. Archaeological evidence suggested it once contained scrolls.

3. Geology of the caves

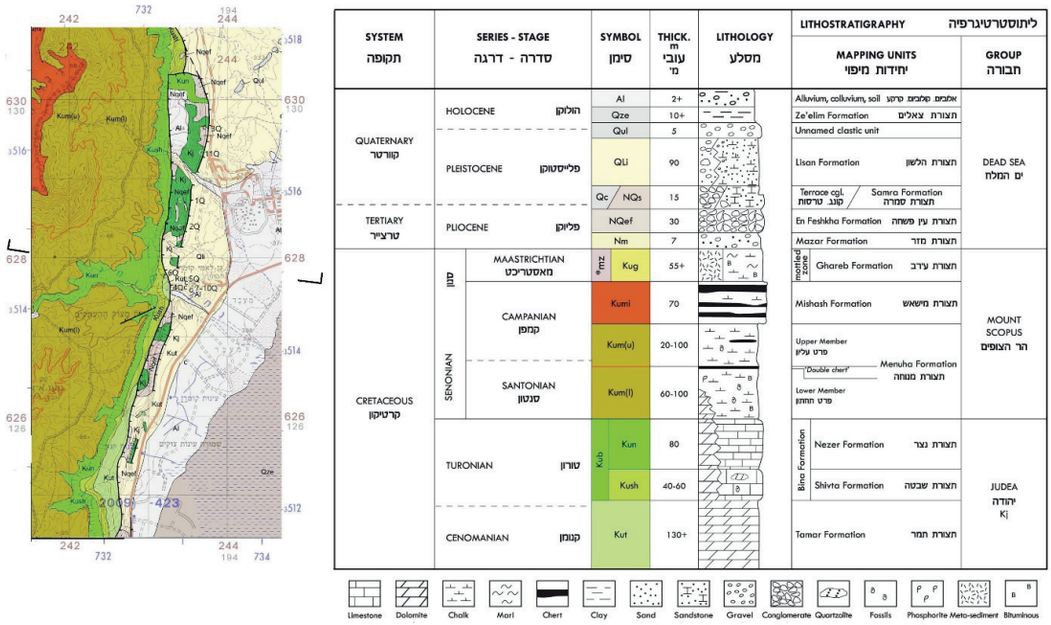

Figure 1: *Qumran scroll caves (1Q–11Q) on a geological map with a columnar section of the Qumran area. Modified after Israel Roth, Avihu Burg, and Amihai Sneh, "Geological Map of Israel in 1:50,000 Scale," Qalya Sheet 12–I, II (Jerusalem: Geological Survey of Israel, 2008).*

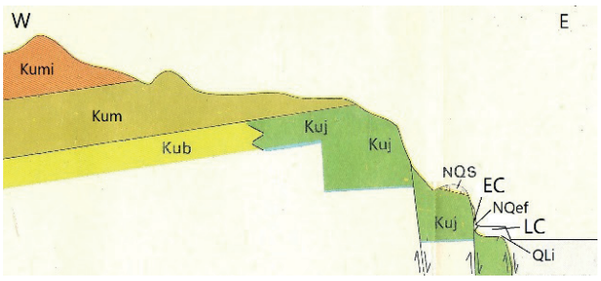

Figure 2: *Schematic geological section of the Qumran region. For location and legend see Figure 1. Modified after: Israel Roth, "Geological Map of Israel in 1:50,000 Scale," Wadi el-Qilt Sheet 12–I (Jerusalem: Geological Survey of Israel, 1971).*

The Judean Desert in eastern Israel consists of a late Cretaceous epicontinental carbonate terrain that was formed at the interface between the Neotethys Ocean and the Gondwanian African-Arabian plate. Various rock types were deposited through fluctuations between marine and continental environments due to ingressions and regressions. Orogenic folding of the Syrian Arc fold system occurred between the late Cretaceous and the Neogene. The folds formed a barrier for deep flowing groundwater, which upwelled along the SE flank of the folds. Possibly mixing with local confined circulation, the hypogene flow created maze caves at the top of the late Cretaceous limestone, under the confinement of thick chalk and marl successions

During the Pliocene (?) a talus apron was deposited along the exposed steep escarpment. The talus breccia solidified by lake- and spring-carbonates, creating the En-Feshkha Formation, which drapes the lower escarpment in places. Repeated dissolution and precipitation of carbonates rendered the outer surface of the formation more indurated than the inner parts, promoting weathering of the inner breccia, forming additional shallow caves.

The caves are mostly dry, with rare speleothems. Further erosion and tectonics continued to shape the caves and create new, rather small, voids. The late Pleistocene Lake Lisan has deposited lacustrine laminated carbonates and detritus which form a terrace at the archaeological site of Qumran.

Our field work shows that the Dead Sea Scrolls caves can be classified into two main types according to their geology and formation processes (Frumkin 2025).

The Dead Sea Scrolls cave can be divided inti 2 main groups :

1. Natural caves in hard rocks of the Dead Sea escarpment (Fig. 3a). These caves are developed mostly in Turonian dolostones and younger breccias, up to two km north of the Qumran site (3Q is the northern-most scroll cave).

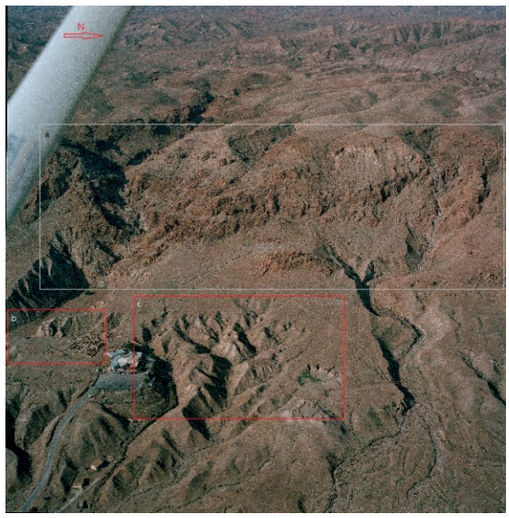

Figure 3: *Oblique air photo of the Qumran area, looking westward. (a) The Dead Sea escarpment with natural caves; (b) The area southwest of the Qumran site, with artificial caves in the Lisan terrace; (c) The area north of the Qumran site, with artificial and natural piping caves in the Lisan terrace.*

Figure 4: *Cave 1Q, developed around a strike-slip fault demonstrated by horizontal slickensides (left wall).*

Most of the caves developed originally in dolostones, while En Feshkha Formation breccias comprise the roof and walls of several caves (e.g. 3Q and 11Q), mainly north of Wadi Jofet Zeben. South of this wadi, caves 1Q and 2Q are entirely within dolomitic bedrock. Most caves have formed initially by hypogenic karst dissolution under the water table prior to the latest subsidence of the Dead Sea basin (FRUMKIN 2017b). However, the original dissolution morphology is obscured by tectonic fracturing and weathering. The tectonic domination is clear in Cave 1Q which developed around a strike-slip fault demonstrated by horizontal slickensides.

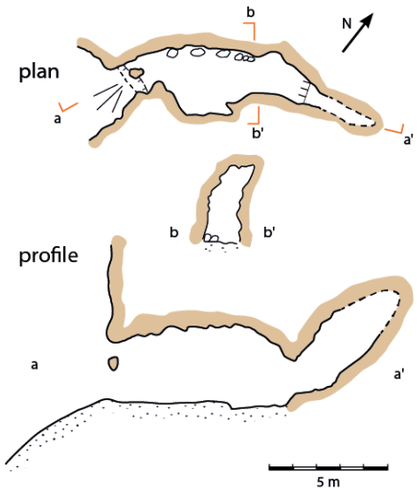

Figure 5: *Cave 1Q, surveyed by Shemesh Yaaran, ICRC.*

The original cave-formation age is probably Oligocene to early Miocene (FRUMKIN 2017a). At the northern caves, where En Feshkha Formation covers parts of the escarpment, the matrix of the inner breccias was decomposed by weathering, promoting the development of additional sub-breccia voids. Since the initial formation of the caves, they have been modified by collapse, shattering (due to tectonic stress, salt weathering and temperature variation), sediment deposition, lake water, as well as faunal and human activity. This group includes small voids as well as larger ones, such as the largest scrolls cave, 11Q (Fidanzio 2025). Other caves north of Wadi Qumran are generally smaller voids. Of these small caves, Cave 49 (recently numbered A4-002), on the northern wall of Wadi Qumran is longer than its neighbors, and is developed entirely within dolomitic bedrock.

Burial dating of sediments in associated caves by cosmogenic isotopes (Al-26, Be-10) indicate that deposition within the Cave of the Letters (Nahal Hever) and Masada 2008 Cave started prior to 3 million years ago, associated with early stages of the Dead Sea topographic low (Matmon et al. 2014). Within Qumran caves, Th-U dates of stromatolites show inundation of the caves by Lake Lisan ~70-15,000 years ago (Lisker et al. 2009). Later, ^{14}C dates of organic material shows that the lake has receded from the caves prior to 12,000 years ago, followed by human use since the Neolithic period (Gopher et al. 2013). The relative stability of the dry climate during the late Holocene provided shelter for some of the best-preserved scrolls. Remains of scrolls were found within caves 1Q, 2Q, 3Q, 6Q, and 11Q of this group. Among others, the escarpment caves include the first scrolls discovery on 1947 CE within 1Q Cave, the copper scroll at 3Q, and the latest important scroll find at 11Q (on 1956 CE).

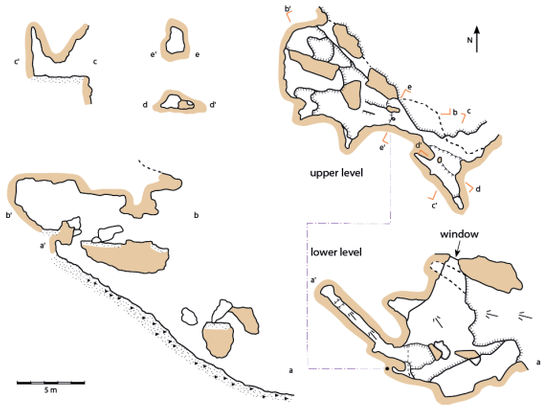

Figure 6: *Cave 2Q, surveyed by Boaz Langford, Uri Davidovich, and Micka Ullman, ICRC.*

2. The Lisan terrace caves are artificial and relatively unstable due to the less-cohesive sediments comprising the Lisan Formation, close to the built site of Qumran. Scrolls in some of these caves (particularly 4Q) were numerous but highly damaged. Caves 5Q, 7Q, 8Q, 9Q, 10Q, also belong to this group. Most of these caves have been highly damaged since being hewn by the Qumran people, and they have not reached long-term stability yet, due to stream entrenchment, slope retreat and collapse. They are located to the west and south-west of Qumran site. The relatively good preservation of 4Q is associated with the thicker and more cohesive layer comprising the roof of the void. Additional artificial caves are located within the Lisan terrace to the north of Qumran Site (Fig. 3c).

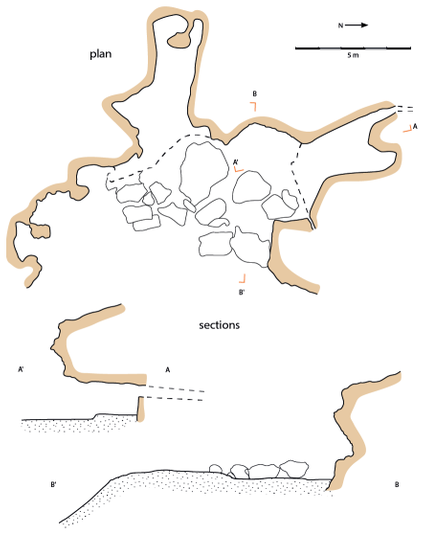

Figure 7: *Cave 3Q. Modified after FRUMKIN (2015).*

Figure 8: *The entrance of Cave 11Q (center, encircled), Qumran escarpment. Ein Feshkha Formation breccias dominate the slope above the cave, although the cave is mostly within Cretaceous dolostone. (Photo: Boaz Langford).*

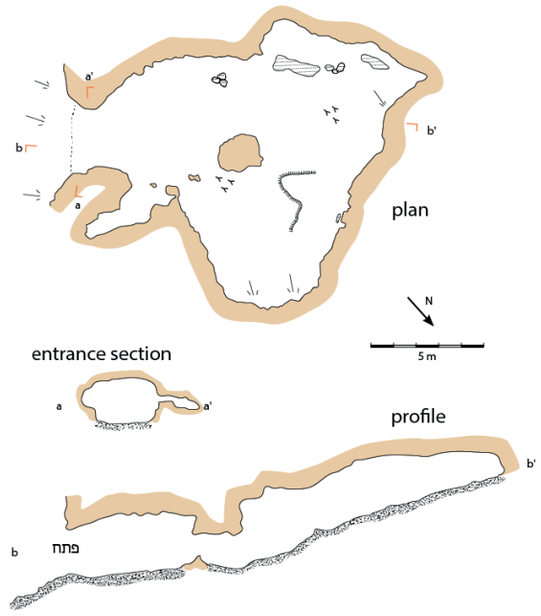

Figure 9: *Cave 11Q , surveyed by Boaz Langford, ICRC.*

Figure 10: *Cave 3Q, showing the overlying Ein Feshkha Formation breccias.*

Figure 11: *Cave 4Q in the Lisan terrace. The cave is entirely artificial, quarried within the soft, layered sediments. (Photo: Amos Frumkin).*

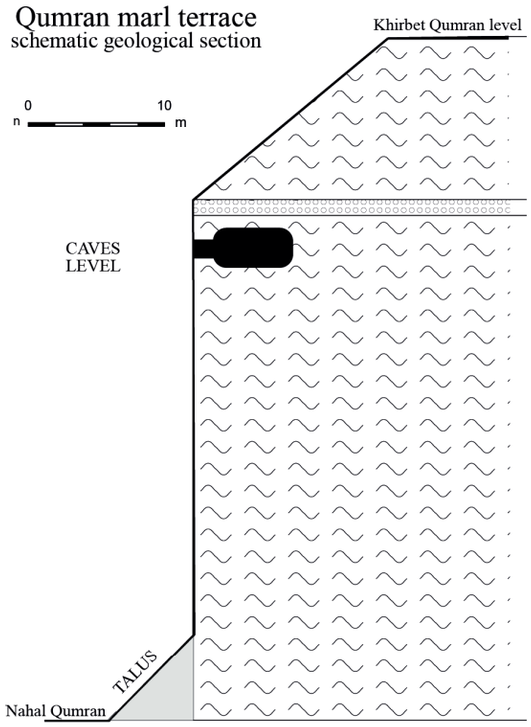

Figure 12: *Schematic section of the artificial caves location in the northern marly bank of Nahal (Wadi) Qumran.*

In addition, natural piping caves are observed in the Lisan terrace. Following the late Pleistocene recession of Lake Lisan and further down--faulting of the Dead Sea basin escarpments, small ephemeral streams have carved caves in the Lisan terrace. This cave formation process, termed piping, has disintegrated the unconsolidated sediments by physical erosion and dissolution, creating subsurface channels. These were later used by humans, associated with Qumran site. Caves C and F studied by BROSHI AND ESHEL (1999) seem to fall into this category, although human modification of the caves was apparent too. The original cave formation is attributed to piping due to their morphology (observed by me during Broshi and Eshel's excavation), and the relatively large catchment area flowing into them. The flow of ephemeral runoff through these caves has damaged the archaeological remains, leaving mainly domestic ceramics. This flash-flood runoff has caused a recent collapse of caves C and F.

Some piping caves have initiated at artificial caves or terraces, eventually collapsing and focusing runoff water which formed small

subsurface channels during the last 2000 years (Fig. 13). An example is a small cave at site A3-013 excavated by Haim Cohen (2021). The cave seems to have developed due to local runoff concentration caused by stream running into this cave. Thus the cave must be younger than ~2000 years. In general, there are many Lisan caves north of Qumran, whose morphology indicates both natural and man-made features. Deciphering which process occurred earlier is not always easy. In some humans enlarged existing piping caves, and in others the piping followed the artificial excavation. All Lisan caves are continuously and rapidly modified by fluvial, colluvial and collapse processes.

Figure 13: *Artificial and piping caves dominate the stream-cut valleys and hills of the Lisan terrace, north of the Qumran site. The holes in the center are stream sinks and collapsed cavities leading to piping caves that drain eastward, to the left. (Photo by Amos Frumkin).*

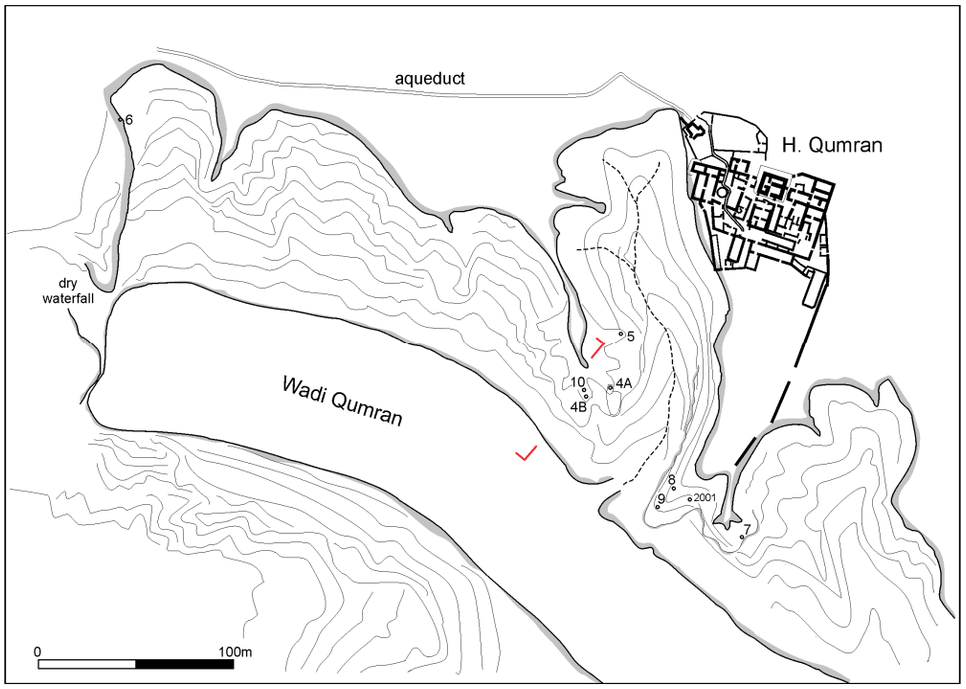

Figure 14: *Location of artificial caves between Wadi Qumran and the site of Qumran. Note the location of Fig. 10 section.*

4. Conclusions

The escarpment caves of Qumran are generally natural, within indurated rocks of Cretaceous-Pliocene age. They do not show any clear evidence of anthropogenic enlargement, although some artificial modification cannot be ruled out. The caves are widely dispersed along few km length of the dolomitic Dead Sea escarpment. Some of them were used by humans since Neolithic times. The Lisan terrace caves are mainly concentrated near Qumran site, and are therefore evidently associated with the settlement. They include artificial small voids, some of which were used for habitation. Scrolls were deposited in the caves closest to Qumran site. They indicate the need of the Qumran people for underground space, promoting artificial excavation within the soft sediments at optimal locations close to the site. This need is also demonstrated by the usage of some natural piping caves, in spite of unfavorable conditions due to occasional flash-floods.

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The monoxyle coffin caves of Nagaland (India) and South East Asia

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Abstract

The discovery of monoxylous coffins in two caves in the Indian state of Nagaland, 1000 km distant from those located in Myanmar and Thailand, is very remarkable and opens up new avenues of research – this is especially true since the tradition of burials in Naga Clan Caves have persisted until recently (in many remote rural areas, Christianity was only established in the 1950's and 1960's). Therefore, Ethnology may be able to help answer archaeological Questions. Furthermore, the finds in Nagaland are adding evidence to the existence of Neolithic migration from South East Asia to North East India.

Résumé

Les grottes à cercueils monoxyles du Nagaland (Inde)et de l'Asie du Sud-Est. La découverte de cercueils monoxyles dans deux grottes de l'État indien du Nagaland, à 1000 km de celles situées au Myanmar et en Thaïlande, est très remarquable et ouvre de nouvelles voies de recherche. Cela est d'autant plus vrai que la tradition des enterrements dans les grottes des clans Naga s'est maintenue jusqu'à récemment (dans de nombreuses zones rurales reculées, le christianisme n'a été instauré que dans les années 1950 et 1960). L'ethnologie peut donc aider à répondre aux questions archéologiques. En outre, les découvertes faites dans le Nagaland apportent des preuves supplémentaires de l'existence d'une migration néolithique de l'Asie du Sud-Est vers le Nord-Est de l'Inde.

Resumen

Las cuevas de ataúdes monóxilas de Nagaland (India) y el sudeste asiático.

El descubrimiento de ataúdes monóxilos en dos cuevas del estado indio de Nagaland, a 1000 km de distancia de las situadas en Mynmar y Tailandia, es muy notable y abre nuevas vías de investigación, sobre todo porque la tradición de los enterramientos en cuevas del clan Naga ha persistido hasta hace poco (en muchas zonas rurales remotas, el cristianismo no se instauró hasta los años 50 y 60). Por lo tanto, la etnología puede ayudar a responder a las preguntas arqueológicas. Además, los hallazgos de Nagaland añaden pruebas a la existencia de migraciones neolíticas desde el sudeste asiático hasta el noreste de la India.

1. Introduction

During Speleological Expeditions in Thailand and Myanmar between 2008 and 2017 it was possible to document several caves containing round log monoxylous coffins. Until recently this type of burial rite was not known further West than the state of Kayah on the Thailand/ Myanmar border. It's in the north East of Thailand where the largest concentration of these burial caves is situated, and the most in-depth studies have been conducted.

Monoxylous coffins, resembling those found in Thailand have been found throughout Southeast Asia, from southern China and Vietnam, western Thailand, Borneo and the Phillippines.

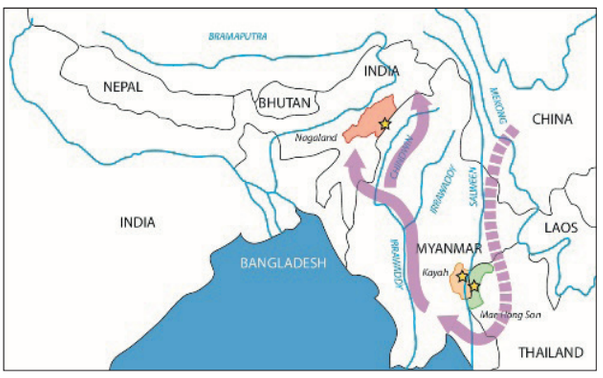

Figure 1: *Location map to show the coffin cave areas within Thailand, Myanmar and Nagaland and the possible migration Neolithic routes.*

2. Mae Hong Song, North West Thailand

Round log monoxylous coffins are characteristic for numerous overhang rock shelters and cave entrances in northwest Thailand. The largest concentration of these remarkable objects is located in Pang Ma Pha, near Mae Hong Song and close to the Myanmar border. To date, more than 80 sites have been recorded in this area. A smaller number of monoxylous coffin sites have also been discovered in the districts of Pai, Chiang Dao and Mae Sariang (SIDISUNTHORN GARDNER SMART 2006).

Samples from nine coffins from Pang Ma Pha have been dated between 2200 BP and 1200 BP. Most of the coffins were made from teak wood. The logs vary in size from one to nine meters in length and resemble hollowe-

d-out log canoes, which they were mistaken for by early explorers. Each individual coffin consists of two parts, a base and a lid. Most of the Pang Ma Pha coffins are carved at both ends with distinctive patterns. More than 30 types of carvings ranging from simple geometric motifs to animal heads are documented. There is no apparent relationship between the style and age of the coffins. In Pang Ma Pha, most of the coffins are neither buried nor placed on the ground, but are elevated on pillars and beams. Many of these support structures are extremely well made with mortise and tenon joints and beams notched to match the shape of the coffin base.

The foundations for some of the columns were prepared by digging one-meter-deep holes and filling them with large stones. Various funerary goods such as pottery, beads, and iron tools have been found in the coffins. In the Nam Lang Cliff cave, over 1,700 pottery fragments were recovered near a single coffin. In some sites, these artifacts are still inside the coffins, but in most cases, they are scattered on the cave floor, and their association with the coffins is not certain.

Fragments of human bones and teeth have also been found with the artifacts, both inside the coffins and on the cave floor. In some cases, the remains of several different people have been found in the same coffin.

The monoxylous coffin sites in northwest Thailand have been studied by various Thai researchers, but there is still no general consensus on their interpretation. Although most researchers agree that the coffins were probably associated with funerary rites, doubt remains as to whether the caves were primary or secondary burial sites. In primary burial sites, the body is placed directly in the coffin, while in secondary burials, the bodies undergo a decomposition phase by being buried underground or by other means. Only after all flesh has decomposed are the bones transferred to the coffins, which then serve as large funerary urns.

Which peoples made these coffins, and what became of them? Did they live in nomadic groups of hunter-gatherers or in sedentary agricultural communities? What beliefs did they hold, and what types of funerary rituals were associated with the coffins? None of these questions has been conclusively answered (ZEITOUN FORESTIER NAKBUNLUNG 2008).

Figure 1: *Monoxylous coffins in the caves of Mae Hong Song, West Thailand (Photos M.Björkman).*

3. Kayah Northwest Myanmar

Monoxylous coffins have been found in two caves in the Kayah state during the 2015 Myanmar Cave Documentation Project expedition. Before the discoveries made in Kyet Cave and Coffin Ridge Cave, no monoxylous coffin cavities had been reported in Myanmar. These two coffin caves were thus the most westernly known, and their discovery indicated a new area of expansion for this funerary practice (DREYBRODT ETTER HAPKA 2015).

Kyet Cave (Loikaw) and Coffin Ridge Cave (Demoso)

With 2.2 km of surveyed galleries, the Kyet Cave located near the Loikaw plain represents the third-longest cavity in Myanmar. It is made up of a well-developed upper gallery with numerous concretions. The lower part is occupied by a river that sometimes floods the entire gallery. The remains of at least 20 to 30 monoxylous coffins have been found in the upper gallery, sometimes perched on ledges more than 10 meters high. Some coffins reach four to five meters in length, and the stylistic similarities with those of Thailand are striking.

Figure 2: *Monoxyle coffins in the upper passage of Kyet Cave, Kayah/ Myanmar (Photo C. Densham).*

4. Mimi, Nagaland (Northeast India)

Before the Nagaland expedition at the end of 2022, very little was known about the presence of archaeology in the cavities of this mountainous state located in the far northeast of India, on the border with Myanmar.

In 2009, Naga archaeologist, Tiatoshi Jamir, studied a few caves in the karstic zone near the village of Mimi in the Kiphire district. Only one cave, Raneak Khün (also described as Cave 2), located at low altitude on the escarpment of a deep valley, revealed the presence of ancient artifacts. The excavated layers were dated between 6400 BP and 4500 BP, which corresponds to the Neolithic in northeast India (TIATOSHI 2014).

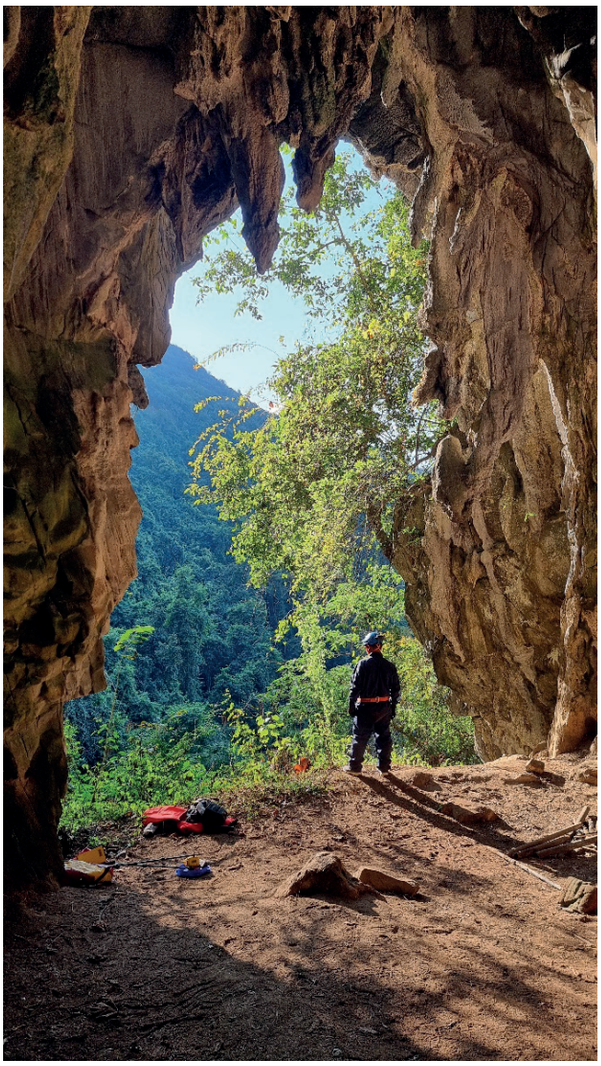

Figure 3: *Entrance of Raneak Khün, overlooking the densely overgrown Lapkhin Valley (Photo R. Hapka).*

During our survey excursion in December 2022 we found no evidence monoxylous coffins in Raneak Khun. However, in his 2009 Documentation9 Jamir reports the find of an earth grave with a rock lid, containing the remains of a young male adult. This is a primary burial place and would correspond with the funerary rites of the Yimkhiungrü tribe of primary- and secondary burials, but why the grave was not emptied for the latter, remains an unanswered question – even more because we found a broken clay urn containing human bones on a high ledge on the site.

The surprise came from two other caves located higher up on the Mimi Range: During our stay, the Chairman of Mimi Village Council showed us a short video sequence showing the extraction of a wooden coffin, evidently monoxylous, from a cave. This intervention would again be the work of Tiatoshi Jamir in December 2021 – and this is obviously a major discovery: The first evidence of the extension of the tradition of round log monoxylous coffin burials into India.

Our interest spurred, we asked the villagers to take us to this cave called Longtok Khun - eventually the visit was arranged for 31st December 2022. However, the two guides who accompanied us that day first lead us to a different cave (subsequently named Longtok 2) near (Jamir's) Longtok Khun (Longtok 1), which we accessed later.

Longtok Khün 2 (Longtok 2)

This is an alcove cave situated at an altitude of 1400m, high up in a large rock pinnacle accessible only by climbing the exposed rock face. A bleached fragment of a human skull was found on a rock ledge near the base of the climb. The alcove contained a number of small coffin--like hollow logs, presumably containing bones. Due to the exposed location and the flaky, lose rock on the last 2 to 3 meters, the cave was only accessed by one member of the team and just briefly inspected.

Longtok Khün 1 (Longtok 1)

This is a straight rift passage situated at the base of another cliff near Longtok 2, at an altitude of 1390m. In the cave we found three small round log monoxylous coffins, about 100cm long by 25cm wide, containing fragments of human skulls and bones. The coffins are positioned on large rocks and were discovered at a distance of 12m inside the cave. At the back of the cave there were the remains of a small rock wall and beyond this a few pot shards, a broken clay pipe and a small intact pot were found.

Figure 4: *Monoxylous coffins in Longtok Khün 1 (Photo R. Hapka).*

The Monoxylous coffins we detected in Longtok 1 and 2 are significantly smaller and shorter than the ones known from Myanmar and Thailand. We could not imagine that a person (neither child nor grown-up) could have been buried in such a small container. The puzzle was later resolved during the extended interview with the village elders when it became evident that round log coffins and (at a later stage) clay urns were traditionally used for the secondary burials where the remains of the dead are put to their permanent rest: The bodies were first buried in earth graves and let to decompose for one year. Then the remains were exhumed and the bones were placed in the small monoxylous coffins or urns. They were then ceremoniously brought to the clan burial caves and left there to rest in the company of their ancestors (HAPKA ARBENZ 2023).

5. Clan Caves of the Yimkhungrü Tribe

The Yimkhiungrü tribe inhabits the Eastern part of Nagaland and is one of the major recognized tribes of Nagaland. The Nagas migrated from South-East Asia through the mountains and basins of China and Thailand to their present location through Burma along the Irrawady and Chindwin rivers. Crossing the Patakai Range, the Yimkhiungrü settled down in the Saramati Area.

In Mimi, the original name is Long Tsürong Khong, the Clans present are Whourr, Merr and Bomrr. The tribe was the first to commence war upon the Indian Army in 1955 and has a rich history of freedom fighting for Naga Independence. As a consequence, the Yimkhiungrü were the last to give-up head hunting, which lasted till the early 1960's.

During the late part of the 1950's Christianity was established in the Yimkhiungrü area by Missionaries from the Sumi and Ao tribes. The religious communities are mainly Baptists (TIATOSHI TRESTO VENUH 2017).

Around Mini, various caves serve as secondary burial sites for the three represented clans clans. Large ceramic funerary urns were used to collect the remains of the deceased, similar to the practice of monoxylous coffins in Thailand and Myanmar. The only difference is that this tradition has been abandoned only relatively recently in Nagaland, during the campaign of the Christian Revival Movement 60 to 70 years ago.

Despite Christianity some of the animistic and pantheist rites and customs are living-on and clan members regularly visit their caves. For example, the practice of calling back the souls of the ancestors in times of need, illness or misfortune is still occasionally present, and respect for the souls in the caves is always due: when we were allowed to explore and survey the Whourr-Merr Clan Cave, our guide first greeted the ancestors and asked permission to enter the cave with us.

Figure 5: *Secondary burial urns in a Whourr-Merr Clan Cave (Photo T. Arbenz).*

6. Conclusion

The persistence of a tradition of cave burials in the Mimi region until relatively recent times represents an unparalleled opportunity to attempt to understand this use of the subterranean world. Whether in ancient monoxylous coffins or more recently large urns, the method of burial is similar. Moreover, these customs still are present in the mind of the inhabitants of Mimi, who are well aware of the locations of the caves of each of the different clans. In-depth ethnological research could potentially provide a better understanding of what was happening 2000 years ago and over 1000 km distant from the north-eastern border of India in the burial caves of Myanmar and Thailand.

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Ações de educação patrimonial em prol da conservação de sítios arqueológicos com pinturas ruprestes na Escarpa Devoniana (PR)

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Resumo

Este trabalho tem o objetivo de divulgar as ações do Grupo Universitário de Pesquisas Espeleológicas (GUPE) em prol da promoção e conservação de sítios arqueológicos situados na área da Escarpa Devoniana no estado do Paraná, em especial, aqueles com pinturas rupestres. Além disso, deixa em evidência os projetos de pesquisa desenvolvidos pelo GUPE ao longo dos últimos cinco anos, as conquistas e desafios das atividades praticadas e as parcerias estabelecidas para o desenvolvimento das ações. Conclui salientando que a educação patrimonial permite a divulgação do conhecimento e a valorização da riqueza local, além de possibilitar a reflexão e despertar o sentimento de pertencimento e identidade na sociedade com relação ao patrimônio natural e cultural.

Abstract

This work aims to promote the actions of the University Speleological Research Group (GUPE) in favor of the promotion and conservation of archaeological sites located in the Devonian Escarpment area in the Paraná state, especially those with rock paintings. Furthermore, it highlights the research projects developed by GUPE over the past five years, the achievements and challenges of the activities carried out, and the partnerships established for the development of these actions. It concludes by emphasizing that heritage education enables the dissemination of knowledge and the appreciation of local wealth, while also fostering reflection and awakening a sense of belonging and identity in society regarding natural and cultural heritage.

Resumen

Este trabajo tiene como objetivo divulgar las acciones del Grupo Universitario de Investigaciones Espeleológicas (GUPE) en favor de la promoción y conservación de sitios arqueológicos situados en el área de la Escarpa Devónica en el estado de Paraná, especialmente aquellos con pinturas rupestres. Además, pone en evidencia los proyectos de investigación desarrollados por el GUPE a lo largo de los últimos cinco años, los logros y desafíos de las actividades realizadas y las alianzas establecidas para el desarrollo de dichas acciones. Concluye resaltando que la educación patrimonial permite la difusión del conocimiento y la valorización de la riqueza local, además de posibilitar la reflexión y despertar el sentimiento de pertenencia e identidad en la sociedad con respecto al patrimonio natural y cultural..

1. Introdução

A región da Escarpa Devoniana, o degrau topográfico que separa o primeiro e o segundo Planalto Paranaense (Souza e Souza, 2002), é considerada um hotspot da espeleologia e arqueologia nacional, pois ali são conhecidas centenas de cavernas e sítios arqueológicos (sobretudo com pinturas rupestres) e com amplo potencial para novas descobertas.

Em estudos recentes nos municípios de Ponta Grossa, Tibagi, Castro e Piraí do Sul (Paraná), desenvolvidos pelo Grupo Universitário de Pesquisas Espeleológicas (GUPE), nos anos de 2021 a 2025, identificaram nesta área 68 novos sítios arqueológicos, incluindo o primeiro registro de pinturas rupestres de araucárias e 248 cavidades naturais subterrâneas (PONTES e MASSUQUETO, 2023; PONTES et al., 2024).

Um dos focos principais nos últimos anos, a partir de novas descobertas, tem sido o inventário, catalogação, divulgação e proteção desses ambientes, incluindo atenção especial para aqueles com patrimônio cultural material, como as pinturas rupestres. Essas pesquisas do GUPE se alinham com as premissas presentes na Constituição Federal Brasileira de 1988, especificamente ao inciso X do artigo 20, onde se salienta que as cavidades naturais subterrâneas e os sítios arqueológicos e pré-his-

tóricos são considerados bens da União, e seu artigo 216, que considera os sítios de valor histórico, paisagístico, arqueológico, paleontológico, ecológico e científico como patrimônio cultural brasileiro, incluindo as cavidades naturais subterrâneas. Dessa forma, se coloca que proteger o patrimônio arqueológico é urgente e necessário e uma das melhores formas é investir na educação patrimonial, a qual visa valorizar e preservar patrimônios culturais e históricos, a partir de atividades pedagógicas e sociais, voltadas para toda a comunidade.

Com o objetivo de ampliar as ações de educação patrimonial, o GUPE estabeleceu parceria contínua com o Projeto Arqueotrekking – Roteiros Arqueológicos e o Laboratório de Turismo em Áreas Naturais (LABTAN) da Universidade Estadual de Ponta Grossa (UEPG). Estas parcerias tem permitido a união de esforços, focando principalmente na captação de recursos via editais de instituições públicas e na soma de experiências para o desenvolvimento de trabalhos cada vez mais técnicos e capacitados metodologicamente.

Dessa forma, o objetivo principal deste trabalho é mostrar ações em prol da promoção e conservação de sítios arqueológicos situados na área da Escarpa Devoniana na região dos Campos Gerais do Paraná, em especial aqueles com presença de pinturas rupestres.

2. Materiais e Métodos

Desde o ano de 2021, o Grupo Universitário de Pesquisas Espeleológicas (GUPE) está à frente de projetos de pesquisas (dois já finalizados e outros dois em andamento), nos quais a busca por novos sítios arqueológicos e novas pinturas rupestres em sítios já conhecidos, está entre os objetivos centrais. Tais projetos aconteceram em quatro distintos municípios do Paraná, sendo: Ponta Grossa, com o projeto 'PGRupestre : *sítios arqueológicos da Área de Proteção Ambiental (APA) da Escarpa Devoniana em Ponta Grossa: inventário e educação patrimonial'*, nos anos de 2021 e 2023, em Tibagi, com o projeto *'Tibagi Rupestre: patrimônio arqueológico da APA da Escarpa Devoniana em Tibagi (PR)'*, o qual iniciou em 2024 e com previsão de finalização em 2026 e em Piraí do Sul, o projeto *'PiraíRupestre: descobrindo novos sítios arqueológicos com pinturas rupestres em Piraí do Sul (PR)'*, com início em 2024 e término previsto para o segundo semestre de 2025 e o *'Projeto EspeleoPiraí: patrimônio espeleológico arenítico da Escarpa Devoniana em Piraí da Serra/PR'* desenvolvido nos anos de 2021 a 2023 nos municípios de Piraí do Sul, Castro e Tibagi.

Estes projetos permitiram (e permitem) ampliar de maneira significativa a realização de:

1. Prospecção arqueológica contínua em locais pouco amostrados e de potencial para ocorrência de sítios arqueológicos;
2. Inventário e caracterização de novos sítios arqueológicos ou aqueles já conhecidos, mas que ainda não foram caracterizados;
3. Ampliação do acervo fotográfico (imagético) das pinturas rupestres da área da Escarpa Devoniana;
4. Cadastro dos sítios arqueológicos no SICG/IPHAN;
5. Mapeamento dos sítios arqueológicos, com localização georreferenciada das pinturas rupestres e demais vestígios dos abrigos e;
6. Publicação de trabalhos científicos em periódicos e eventos da área ambiental e cultural.

Mas além dos resultados científicos, com novas descobertas e ocorrências de grande valor científico, estes projetos têm trazido resultados positivos no âmbito educativo e didático.

Esta ampliação do conhecimento sobre a arqueologia da Escarpa Devoniana, somada a parceria estabelecida entre o GUPE, Arqueotrekking e LABTAN/UEPG tem permitido o desenvolvimento de ações contínuas de educação patrimonial, conforme descritas a seguir.

3. Resultados

Com a ampliação do conhecimento sobre os sítios arqueológicos da Escarpa Devoniana, obtidas a partir de projetos de pesquisas coordenados pelo GUPE, é possível desenvolver uma série de ações de educação patrimonial que tem como público alvo, crianças, jovens e adultos.

Nestes últimos 5 anos, o GUPE realizou inúmeras palestras e cursos de capacitação com servidores públicos, professores e estudantes (Figura 1). Além disso, publicou e distribuiu gratuitamente dois livretos infantis: *"As aventuras arqueológicas de Ema"*, que trata sobre a arqueologia com foco na educação patrimonial para o público infantil de escolas públicas e particulares e o *"Guia para conhecer o mundo das cavernas"*, material que descreve as cavernas da Escarpa Devoniana e seus aspectos naturais e culturais (Figuras 2 e 3).

Como ação adicional, o grupo realizou oficinas de produção de pinturas rupestres com crianças do ensino fundamental, momentos que permitiram a divulgação sobre a ciência arqueológica e o estímulo da criatividade dos alunos (Figuras 4).

Figura 1: *oficina de capacitação com professoras (es) da rede de ensino público de Ponta Grossa.*

Figura 2: *crianças da rede pública de ensino de Ponta Grossa com o livreto "As aventuras arqueológicas de Ema", durante oficina de produção de pinturas rupestres.*

Figura 3: *crianças da rede pública de ensino com o livreto "Guia para conhecer o mundo das cavernas", durante aula em escola de Piraí do Sul.*

Figura 4: *oficina de produção de pinturas rupestres com crianças do ensino fundamental em Ponta Grossa.*

O GUPE também produziu uma série de quatro microdocumentários sobre os resultados do Projeto EspeleoPiraí, que teve como objetivo trazer para a sociedade os estudos desenvolvidos, as belezas e riquezas das cavernas e sítios arqueológicos dos municípios de Piraí do Sul, Castro e Tibagi (Figura 5).

Figura 5: *série de microdocumentários sobre o Projeto EspeleoPiraí disponibilizados canal do YouTube do GUPE (https://www.youtube.com/@gupecavernas3781).*

Dois projetos de extensão do GUPE estão em desenvolvimento, ambos com o objetivo de produção e publicação de curtas metragens, para serem utilizados como ferramentas de educação por professores do ensino básico, médio e superior. O primeiro, denominado *"As pinturas rupestres de Ponta Grossa"*, tem como objetivo mostrar de maneira didática os resultados do Projeto PGRupestre, os aspectos da arqueologia local e a paisagem de campos em Ponta Grossa. O segundo curta, denominado *"Os campos nativos que aqui existiam"*, apresentará a destruição dos campos nativos de Ponta Grossa por diferentes atividades humanas, através da comparação de imagens antigas e atuais de diferentes locais do município. Ambos os projetos contam com recursos da Lei Paulo Gustavo, Secretaria de Cultura de Ponta Grossa (PR).

Há também o projeto *"Pinturas rupestres, turismo e uso público: ferramentas de monitoramento"*, uma iniciativa coordenada pelo LABTAN em parceria com a West Virginia University e com recursos do Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). Dentre o principal produto de educação patrimonial desenvolvido neste projeto está o site www.pinturarupestre.com.br, uma página inédita para o estado do Paraná que divulga a ciência arqueológica, reúne e disponibiliza gratuitamente trabalhos científicos, livros, relatórios de pesquisas, vídeos, fotos e informações gerais sobre os sítios arqueológicos do Paraná (Figura 6).

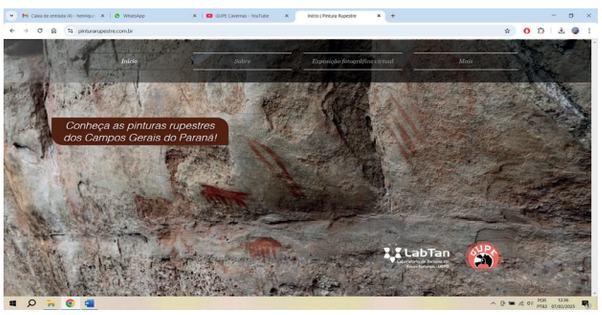

Figura 6: *página da internet focada na divulgação científica e educação patrimonial (www.pinturarupestre.com.br).*

4. Discussão

O Grupo Universitário de Pesquisas Espeleológicas (GUPE) chega aos seus 40 anos com inúmeros projetos de pesquisas e várias ações de educação patrimonial. Os estudos possibilitaram a criação de um repertório de informações suficientes para a promoção do patrimônio natural e cultural, e produção de conteúdos e materiais de caráter técnico, educativo e didático, ideais para a sensibilização e divulgação do conhecimento para a comunidade em geral. Este trabalho educativo alcançou crianças, jovens e adultos, rompendo uma barreira que, geralmente, impõe muitos desafios, a de fazer chegar à sociedade os resultados das pesquisas e destacar a importância do patrimônio espeleológico e arqueológico.

Mas estas conquistas do GUPE só foi possível graças às parcerias com coletivos que se somaram às ações de pesquisa e educação patrimonial. O Projeto Arqueotrekking – Roteiros Arqueológicos, é uma iniciativa pioneira desenvolvida na região dos Campos Gerais do Paraná, ao desenvolver o Turismo Arqueológico, unindo arqueologia com caminhadas e educação patrimonial e ambiental. O Laboratório de Turismo em Áreas Naturais (LABTAN) é uma iniciativa de professores e professoras do Departamento de Turismo da Universidade Estadual de Ponta Grossa (UEPG), e tem como objetivo realizar pesquisas e dar suporte a projetos que sejam relativos ao turismo realizado em áreas naturais. É graças a esta união de esforços, entre GUPE, Projeto Arqueotrekking e LABTAN, que tem sido possível o desenvolvimento de diferentes ações de educação patrimonial na região dos Campos Gerais do Paraná.

Cabe destacar que a região dos Campos Gerais, especificamente as áreas situadas no contexto da Escarpa Devoniana, o degrau topográfico que separa o primeiro do segundo Planalto Paranaense, tem sofrido ampla descaracterização por atividades humanas, sobretudo com a monocultura de soja e plantio comercial de espécies exóticas (principalmente o pinus). O impacto primário destas atividades envolve a destruição dos campos nativos, e com a supressão dessa vegetação aumenta-se o risco de degradação do patrimônio espeleológico e arqueológico.

É notável a presença de uma descaracterização da informação sobre a destruição dos campos nativos para apagamento da memória coletiva, um discurso e tratamento errôneo de que o campo não seria uma vegetação nativa protegida por Lei, mas sim áreas de uso consolidado, passíveis de serem alteradas sem qualquer cuidado. É neste contexto que as ações de educação patrimonial mostradas nos resultados desse resumo, tornam-se relevantes, pois cumprem um papel de resgate da importância dos campos, de sua proteção e de toda a paisagem onde se desenvolvem, pois foi nestas paisagens que as comunidades pretéritas se desenvolveram. Estes impactos negativos tem causado perdas irreparáveis ao patrimônio natural e cultural dos Campos Gerais, assim, a divulgação científica e educação patrimonial são fundamentais, servindo de contraponto e possibilitando a adesão de mais pessoas na luta pela proteção das cavernas, sítios arqueológicos e suas paisagens correlatas.

5. Conclusão

As ações de educação patrimonial são fundamentais por vários aspectos. Este trabalho mostrou que não se trata apenas de um instrumento de divulgação científica e educação de crianças, jovens e adultos, mas também uma ferramenta em prol da conservação de sítios arqueológicos com pinturas rupestres na Escarpa Devoniana (PR).

Ao trabalhar com sítios arqueológicos é possível incluir vários outros temas (e patrimônios), como o espeleológico, biológico, geológico. É possível unir os aspectos naturais e culturais, e trabalhar o ensino de forma integrada e como um instrumento de luta e de militância política, com foco na proteção da natureza e do patrimônio cultural brasileiro. A educação patrimonial permite, além de múltiplas formas de divulgação do conhecimento e da riqueza de determinada área, criar reflexão na sociedade e despertar o sentimento de pertencimento e identidade. É desta forma que se busca uma sociedade mais justa e, verdadeiramente, um meio ambiente mais equilibrado.

A união de esforços é fundamental para o pleno desenvolvimento da educação patrimonial, pois busca-se com isso agregar diferentes expertises e somar contribuições de distintos especialistas, para atingir o máximo possível de pessoas e da melhor forma possível.

Cabe destacar que este trabalho visa estimular ações de educação patrimonial nos grupos de espeleologia brasileiros, na busca do fortalecimento de ideais conservacionistas e de uma sociedade mais justa, com identidade fortalecida e com o sentimento de valorização do patrimônio natural e cultural sempre presente. Somente desta forma será possível cobrar e exigir políticas públicas de proteção da natureza, fiscalização constante e eficiente e punição e pagamento de compensação/restauro em situações que envolvam a destruição de bens brasileiros de valores naturais e culturais.

Agradecimentos

A todos os órgãos, instituições e empresas que financiaram e apoiaram os projetos mencionados neste trabalho, especificamente: Termo de Compromisso de Compensação Espeleológica – TCCE nº 01/2021 entre Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) e Margem Mineração (Secil Cimentos); Programa Municipal de Incentivo Fiscal à Cultura (PROMIFIC), da Prefeitura Municipal de Ponta Grossa, Secretaria Municipal de Cultura e Conselho Municipal de Política Cultural - patrocinadores AP Winner e Águia Florestal - apoiadores do projeto: Planalto Arqueologia e Patrimônio, ABC Projetos Culturais e Parque de Natureza Buraco do Padre; Programa Estadual de Fomento e Incentivo à Cultura (PROFICE) da Secretaria de Estado da Cultura e do Governo do Estado do Paraná - empresas Continental e Copel; Secretaria de Estado da Cultura - Governo do Paraná, com recursos da Lei Paulo Gustavo, Ministério da Cultura - Governo Federal; ao Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq pelo suporte financeiro ao projeto «Pinturas Rupestres, turismo e uso público: ferramentas de monitoramento» (Chamada CNPq/MCTI Nº 10/2023 - Faixa A).

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Sedimentation in caves and archaeologic lithic raw materials from the Peruaçu River Basin and adjacencies / Brazil

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Abstract

This text discusses the main sediments formed in caves and their surroundings, from the point of view of their usefulness as lithic raw material for the prehistoric peoples who frequented the region of the Peruaçu Caves National Park and surrounding areas, from the Pleistocene-Holocene boundary. We also describe the latest sediments before the human occupations inside the shelters, as well as hypotheses about the geological origins of the different types of silexite, quartz and silicified sandstone, materials commonly found in archaeological artifacts of this region.

Résumé

Ce texte présente les principaux sédiments formés dans les grottes et leurs environs, ainsi que les matières premières lithiques utilisées par les peuples préhistoriques qui fréquentaient la région du Parc National des Grottes de Peruaçu depuis la limite entre le Pléistocène et l` Holocène. On présente également les sédiments immédiatement antérieurs à l'occupations humaines à l'intérieur des abris et des hypothèses sur les origines géologiques des différents types de silex, quartz et grès silicifiés rencontrés durant les fouilles archéologiques.

Resumen

Este texto aborda los principales sedimentos formados en cuevas y sus alrededores, asi como las materia prima líticas usadas por los pueblos prehistóricos que frecuentaban la región del Parque Nacional de las Cavernas de Peruaçu y alrededores, desde el limite Pleistoceno-Holoceno. También se presentan los últimos sedimentos anteriores a las ocupaciones humanas al interior de los abrigos asi como hipótesis sobre los orígenes geológicos de los diferentes tipos de sílex cuarzo y arenisca silicificada, materiales comúnmente encontrados en los artefactos arqueológicos en esta región.

1. Introdução

O Parque Nacional Cavernas do Peruaçu (PNCP), criado em 2001 e sob atual responsabilidade do ICMBio, contém mais de 80 sítios arqueológicos e espeleológicos ; está situado nos municípios de Januária e Itacarambi, norte de Minas Gerais (Fig. 1). Geologicamente, constitui-se de rochas carbonáticas ediacariano-cambrianas do Grupo Bambuí, recobertas por arenitos cretáceos do Grupo Urucuia. A erosão parcial destas unidades levou ao desenvolvimento de formas de relevo cárstico de notável importância espeleológica, geológica, paleontológica, arqueológica, ambiental, patrimonial e turística. Os trabalhos pioneiros de arqueologia e geomorfologia e espeleologia iniciaram-se nos anos de 1980, com pesquisadores do Setor de Arqueologia da Universidade Federal de Minas Gerais-UFMG (PROUS et al. 1984, PILÓ 1989, RODET et al. 2009), de sociedades espeleológicas e, mais recentemente, do Museu de Arqueologia e Etnologia da Universidade de São Paulo (MAE-USP). As ocupações humanas mais antigas na região remontam ao limite Pleistoceno-Holoceno (PROUS & SCHLOBACH, 1997), cujos vestígios líticos, ósseos, alimentares e rupestres são conhecidos em sítios arqueológicos abrigados e, em menor número, a céu aberto. Entre as diversas matérias-primas usadas por essas populações, destacam-se numericamente as variedades de sílex e o arenito silicificado, seguidas por calcários e, raramente, seixos fluviais de quartzo ; além desses, encontram-se rochas básicas exógenas ao Parque trazidas pelos humanos. Serão abordados brevemente rochas e sedimentos utilizados pelos antigos frequentadores da região, notadamente os formados em abrigos calcários e imediações. Buscando entender as proveniência das variedades de sílex e do arenito silicificado, muitas vezes lascados nos próprios abrigos, serão apresentadas hipóteses de origens geológicas para essas litologias.

2. Materiais e métodos

Foram efetuados levantamentos estratigráficos de detalhe e petrografia em dois paredões calcários geologicamente representativos (Arco do André e Torre do Gongolo); caminhamentos geológicos em sítios a céu aberto (ex. Judas, Terra Brava) e abrigados (ex., Cascudos, Lapa do Rezar, Lapa do Cabo) ; estudos macroscópicos de sedimentos e rochas nas imediações de vários sítios ; estudos arqueológicos e litológicos de artefatos líticos disponíveis na Reserva Técnica do Museu de História Natural e Jardim Botânico da UFMG (sítios Lapa do Boquete externo

e Abrigo do Malhador). Não serão abordados aqui os sedimentos detríticos das granulometrias grânulo e inferiores contidos nas camadas arqueológicas, estudo que pode ser consultado em Moura (1997). Serão enfatizadas as variedades de sílex e o arenito silicificado.

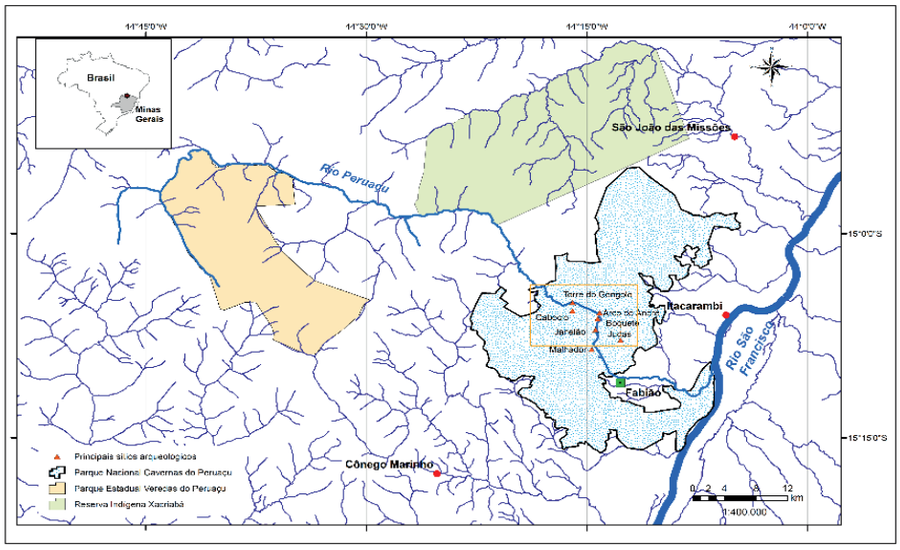

Figura 1: *Mapa de situação da bacia do Rio Peruaçu e do PNCP (em azul), que corresponde à porção cárstica, onde se concentra a maioria dos sítios arqueológicos. Geologicamente, predominam calcários do Grupo Bambuí. Fonte : SEMAD, PNCV-Instituto Chico Mendes de Conservação e Biodiversidade, FUNAI e IBGE.*

3. Resultados

Os três tipos de depósitos sedimentares clásticos mais frequentes nos abrigos calcários do PNCP são brechas dos cones de dejeção, matacões individuais desabados e conglomerados de rios endocársticos. As brechas associam-se a colapsos de teto, formam corpos com geometria muito irregular, com clastos angulosos a subangulosos em trama caótica, de dimensões milimétricas a métricas (Fig. 4), em geral coesos por um cimento carbonático e/ou argiloso rico em óxidos. Tais clastos são em sua maioria de calcários da Formação Sete Lagoas (unidade basal do Grupo Bambuí) de formatos variados e cores em tons de cinza, e muito subordinadamente, de sílex de coloração variada e de arenitos silicificados avermelhados do Grupo Urucuia (Fig. 4). Os conglomerados são constituídos principalmente por clastos de calcário em formatos placoidal, discoide e globular de arredondamento mediano a elevado, com dimensões ora mili-centimétricas, ora subdecimétrico-decimétricos, organizados em tramas produzidas por fluxo hídrico (eixos maiores concordantes a subconcordantes com o acamamento incipiente), como no Mirante de Itacarambi e na Lapa do Boquete, Fig. 5). Outra categoria de sedimentos clásticos oriundos de desabamentos são os matacões em formatos poliédrico ou placoidal do interior dos abrigos que se desprendem do teto e paredes (Fig. 6), e as denominadas concreções, que quando se desprendem da porção frontal dos paredões devido à erosão remontante dos maciços calcários, constituem matacões. Os blocos desabados do teto e parede por vezes contêm pinturas e incisões rupestres, e aqueles que são fragmentos de estalactites, colunas ou cortinas foram, em alguns casos, trabalhados pelas populações antigas, que deixaram pequenas depressões picoteadas (Lapa do Boquete, do Índio, Desenhos, do Boi), as denominadas cupules. Há ainda nos abrigos sedimentos de natureza química, como as tufas (em geral nas porções internas) e as películas de carbonatos reprecipitados em paredes. Estas últimas consistem de superfícies esbranquiçadas de carbonatos produzidas por exsudação, observados em praticamente todos os sítios e que causam uma perda de visibilidade, ou mesmo a ocultação, de vários conjuntos rupestres (Fig. 7). Outro tipo de exsudação, menos comum, possui coloração rosada e é provavelmente constituído por minerais do grupo dos fosfatos (Lapa do Rezar). Quanto ao sílex, suas gêneses podem ser sumariamente agrupadas em três tipos. O sílex de origem mais antiga é representado por nódulos discoidais inseridos em camadas de calcilutitos neoproterozoicos da Formação Sete Lagoas. Eles são brilhantes, negros a cinza escuro, fraturados, variando em diâmetro de poucos centímetros a 2 m (Fig. 3, Lapa do Rezar, Torre do Gongolo, Arco do André, Cascudos). Ainda formados possivelmente no Neoproterozoico são os silexitos brancos e cinzas (Fig. 2) que constituem corpos discordantes encaixados em calcários na zona das cabeceiras do rio Peruaçu, expostos na mina inativa de manganês de Olhos d'Água (SILVA & MARTINS 1987). O terceiro tipo genético possui colorações cinza e branca e origem exclusivamente supergênica, constituindo corpos irregulares no contato da base dos arenitos Urucuia com o topo de siltitos carbonáticos do Grupo Bambuí (PENHA et al. 2024, sítio a céu aberto do Judas, Fig. 2).

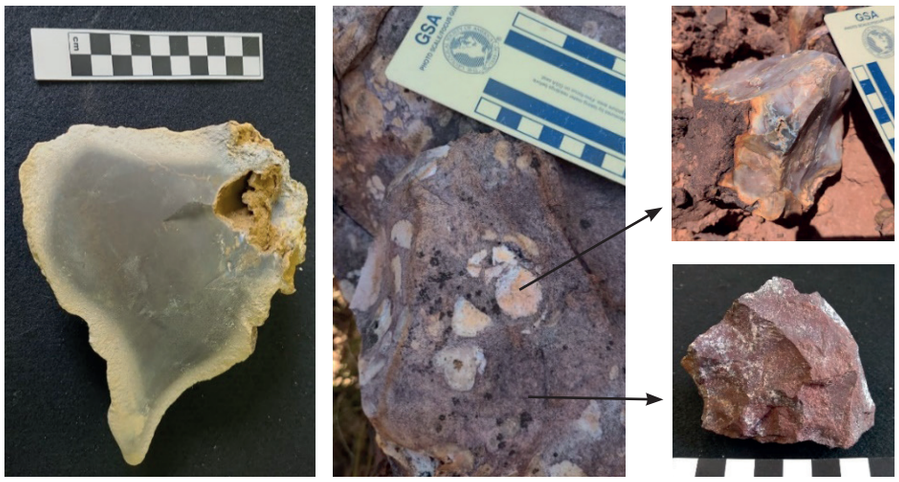

Figura 2: *Alguns exemplos de materiais silicosos utilizados pelas populações pré-históricas e de seus artefatos líticos. À esquerda, sílex de origem hidrotermal da Mina Olhos d'Água. Ao meio, matacão de arenito silicificado com nódulos de sílex branco do Grupo Urucuia, ambos de origem supergênica (sítio do Judas). À direita superior, peça arqueológica de sílex cinza (sítio do Judas). À direita inferior, peça arqueológica em arenito silicificado (sítio Lapa do Boquete).*

4. Discussão

Os depósitos conglomeráticos (que incluem clastos plaquetoides de sílex) encontrados no interior de vários abrigos, naturalmente expostos ou exumados pelas escavações arqueológicas, situam-se abaixo das primeiras camadas ocupacionais pré-históricas, não sendo conhecidos até o presente vestígios arqueológicos abaixo deles. Contudo, podiam ser explorados pelos indígenas como fonte de matéria-prima.

A hipótese de uma origem por fluidos hidrotermais dos matacões de sílex na área da mina Olhos d'Água se sustenta pelo seu conteúdo em Mn (de até 33%, e teores elevados em Ba). Estes núcleos silicosos vêm sendo lixiviados (possivelmente desde o início do Neógeno), o que reduz o seu conteúdo original de Mn e altera sua coloração negra para tonalidades cinza e branca; este processo também deu origem ao minério de Mn na forma de pirolusita e psilomelano. Blocos e matacões desta variedade de sílex formam depósitos secundários ao longo de vários quilômetros do leito do Peruaçu em suas cabeceiras.

Figura 3: *Alternância de calcarenitos beges e calcilutitos cinzas, este contendo nódulos de sílex preto. Arco do André.*

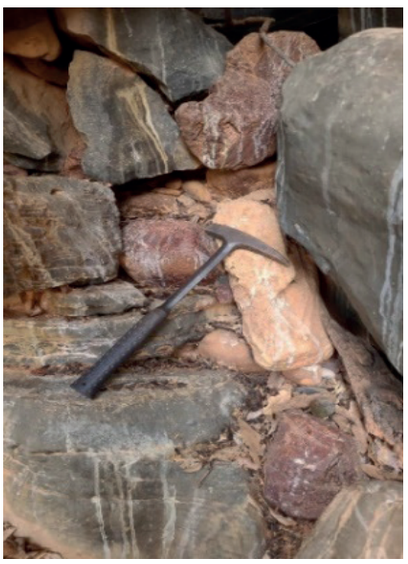

Figura 4: *Brecha de colapso com matacões de calcário cinza e de arenito silicificado avermelhado (Lapa do Jorge).*

Figura 5: *Camada conglomerática (salientada pelos traços pretos) da Lapa do Boquete.*

Figura 6: *Bloco de calcário com 1,5 m de largura desprendido do teto contendo incisões rupestres. Escavação arqueológica central da Lapa do Boquete.*

Figura 7: *Escorrimento de carbonatos recobrindo pinturas rupestres. Notar cavidade de canal fluvial endocárstico (diâmetro de 15 cm). Abrigo do Malhador.*

5. Conclusão

As brechas de colapso podem apresentar forte coesão e cimentação de seus clastos (as mais antigas ?), ao passo que outras contêm matriz arenosa, porosa e avermelhada e cimentação menor. A presença de brechas com clastos angulosos de calcário com comprimento superior a 1 m (Lapa dos Cavalos) permite associá-las a episódios de elevada pluviosidade durante a evolução cárstica do PNCP. A concentração dos clastos em duas classes de granulometria (mili-centimétricos no Mirante do Itacarambi e subdecimétrico-decimétricos em Boquete) dos conglomerados endocársticos indica fluxos de menor e maior energia do sistema hídrico endocárstico. A sua matriz grânulo-arenosa e o cimento de óxidos, observados tanto nas brechas quanto nos conglomerados, sugerem uma pedogênese com participação expressiva do intemperismo dos arenitos Urucuia, ricos em películas oxidadas contornando seus grãos.

O interesse da arqueologia nos maiores clastos desprendidos dos tetos e paredes é a eventual presença de figuras rupestres em suas superfícies, a partir das quais estabelecer idades relativas, datando carvões de fogueiras humanas obtidas nos sedimentos arqueológicos que os recobrem. Os menores clastos silicosos e calcários podendo ser utilizados para fabricação de instrumentos líticos.

Três gêneses geológicas são propostas para as variedades estudadas de sílex : (i) sinsedimentar, associada à diagênese dos sedimentos carbonáticos marinhos da Formação Sete Lagoas (Torre do Gongolo, Arco do André, Lapa do Rezar, Cascudos) ; (ii) hidrotermal, constituindo veios de sílex manganesífero nos calcários da Formação Sete Lagoas, relativamente enriquecidos em sílica pela lixiviação supergênica do seu conteúdo em manganês por águas meteóricas (mina de Olhos d'Água) ; e (iii) supergênico, formado ao longo da barreira físico-química que ocorre entre o topo dos pelitos pouco permeáveis do Grupo Bambuí e a base dos arenitos porosos do Grupo Urucuia (Judas e Guarapari), ao longo do Neógeno, simultaneamente à gênese do arenito silicificado vermelho, ao qual se associa.

Quanto aos calcários dos abrigos, foram utilizados como bigorna tanto em lascamentos de sílex como para quebrar vegetais. E ainda, para a obtenção de cal para proteger depósitos alimentares. Algumas concreções carbonáticas (provavelmente estalactites) foram transformadas em adornos (Lapa dos Bichos) e pigmento branco.

O quartzo forneceu algumas lascas cortantes. As rochas básicas de origem distante serviram de matéria-prima para elaboração das lâminas de machado.

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Novas descobertas arqueológicas na região dos Campos Gerais do Paraná (Sul do Brasil)

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Resumo

Este trabalho apresenta os resultados preliminares dos projetos de pesquisa realizados pelo Grupo Universitário de Pesquisas Espeleológicas (GUPE) na região dos Campos Gerais do Paraná, o Tibagi Rupestre e o Piraí Rupestre. Ambos os projetos contam com financiamento à partir de incentivo fiscais para ações culturais, situação que facilita o desenvolvimento dos estudos. Até o momento, foram realizadas quatro expedições, totalizando 10 dias de trabalhos de campo. Ao todo, já foram percorridos 94 quilômetros a pé e identificados 11 novos sítios arqueológicos com pinturas rupestres e 36 novas cavidades naturais subterrâneas (a maioria do tipo abrigo). Além dos sítios arqueológicos com grafismos, outros seis sítios com muros de taipa foram cadastrados e diversas cavidades naturais subterrâneas estão sendo catalogadas. Após a finalização da etapa de prospecção e inventário arqueológico, ações de educação patrimonial serão desenvolvidas com estudantes, professores, servidores públicos e a comunidade em geral.

Abstract

This work presents the preliminary results of research projects carried out by the University Speleological Research Group (GUPE) in the Campos Gerais do Paraná region, specifically the Tibagi Rupestre and Piraí Rupestre projects. Both projects projects have tax incentive programs for cultural initiatives, which facilitate the development of the studies. So far, four expeditions have been conducted, totaling 10 days of fieldwork. In total, 94 kilometers have been covered by walking, leading to the identification of 11 new archaeological sites with rock paintings and 36 new natural underground cavities (most of them classified as shelters). In addition to the archaeological sites with rock art, six other sites featuring taipa (wall produced by stacked rocks) have been registered, and various natural underground cavities are being cataloged. After completing the prospecting and archaeological inventory phase, heritage education activities will be carried out with students, teachers, public officials, and the community.

Resumen

Este trabajo presenta los resultados preliminares de proyectos de investigación realizados por el Grupo Universitario de Investigaciones Espeleológicas (GUPE) en la región de Campos Gerais, Paraná, Tibagi Rupestre y Piraí Rupestre. Ambos proyectos se financian a partir de incentivos fiscales a acciones culturales, situación que facilita el desarrollo de estudios. Hasta la fecha se han realizado cuatro expediciones que suman 10 días de trabajo de campo. En total, ya se han recorrido a pie 94 kilómetros y se han identificado 11 nuevos yacimientos arqueológicos con pinturas rupestres y 36 nuevas cavidades naturales subterráneas (la mayoría de tipo refugio). Además de los sitios arqueológicos con gráfica, se registraron otros seis sitios con muros de tapial y se están catalogando varias cavidades naturales subterráneas. Una vez finalizada la etapa de prospección e inventario arqueológico, se desarrollarán acciones de educación patrimonial con estudiantes, docentes, servidores públicos y comunidad en general.

1. Introdução

A região dos Campos Gerais do Paraná, sobretudo no contexto da Escarpa Devoniana e seu entorno (o degrau topográfico que separa o Primeiro do Segundo Planalto Paranaense), constitui um importante patrimônio natural entremeado por diferentes elementos culturais, a exemplo da ocorrência de sítios arqueológicos, tanto do período pré-colonial como histórico (Parellada, 2007). O patrimônio arqueológico desta região reúne centenas de sítios com vestígios cerâmicos, materiais líticos, gravuras e pinturas rupestres. Nos grafismos dos Campos Gerais, presentes em lapas e abrigos desenvolvidos principalmente em rochas areníticas da Formação Furnas (Siluriano/Devoniano da Bacia do Paraná), há representações de linhas, pontilhados, formas geométricas, zoomorfos, fitomorfos, antropomorfos, formas híbridas e representações enigmáticas (Silva, Melo e Parellada, 2006; Silva, Parellada e Melo, 2007; Gomes, 2011; Oliveira, 2014, Oliveira et al., 2015; Parellada, 2015; Parellada, 2016).

Devido a esta riqueza arqueológica, ainda pouco explorada e estudada, ao longo das duas últimas décadas, o Grupo Universitário de Pesquisas Espeleológicas (GUPE) tem explorado, identificado e estudado inúmeras novas cavidades subterrâneas na região dos Campos Gerais do Paraná, especificamente no contexto da Escarpa Devoniana.

Durante este tempo, com a descoberta de centenas de cavernas, vários sítios arqueológicos foram encontrados e, por este motivo, o GUPE, em parceria com o Projeto Arqueotrekking Roteiros Arqueológicos, desenvolveu o Programa Campos Gerais Rupestre, uma iniciativa

que teve início no ano de 2021 e configura um conjunto de projetos de pesquisa e extensão focados no inventário do patrimônio arqueológico e na educação patrimonial.

Este programa foca na realização de prospecção detalhada, a qual visa identificar novos sítios arqueológicos no território da Área de Proteção Ambiental (APA) da Escarpa Devoniana. Atualmente, este programa já conta com um projeto finalizado, o "PGRupestre - Sítios arqueológicos da Área de Proteção Ambiental (APA) da Escarpa Devoniana em Ponta Grossa: inventário e educação patrimonial" e dois projetos em andamento, um no município de Piraí do Sul, denominado "Piraí Rupestre: descobrindo novos sítios arqueológicos com pinturas rupestres em Piraí do Sul (PR)" e outro em Tibagi, chamado "Tibagi Rupestre: patrimônio arqueológico da APA da Escarpa Devoniana em Tibagi (PR)".

Estes dois projetos, ainda em andamento, possuem recursos de leis de incentivo à cultura do Estado do Paraná, o que tem permitido o desenvolvimento de estudos nesta área e a descoberta de novos sítios arqueológicos, conforme será mostrado adiante.

2. Materiais e Métodos

Os projetos Tibagi Rupestre e Piraí Rupestre envolvem o inventário de sítios arqueológicos. Para isso estão sendo realizados trabalhos de campo para o desenvolvimento de prospecções, com o objetivo de identificar e cadastrar novos sítios arqueológicos e recadastrar (quando necessário) os locais já conhecidos. O foco principal é o registro do grafismo rupestre (pinturas e gravuras), mas a ocorrência de outros vestígios em superfície (situações afloradas, sem o uso de escavação) também são registradas.

Para a identificação e caracterização dos grafismos está sendo utilizado um método de realce das pinturas em fotografias obtidas com máquina fotográfica com a aplicação de filtros DStretch, uma extensão utilizada a partir do programa ImageJ. Este realce possibilita a identificação de registros imperceptíveis a olho nu, devido ao desvanecimento da tinta pelas ações de intempéries. Também é realizada a descrição detalhada dos grafismos e do seu contexto arqueológico superficial, de forma digital e indireta, sem nenhum contato físico com as pinturas, gravuras e a rocha.

Os resultados obtidos junto ao projeto PGRupestre, desenvolvido em Ponta Grossa/PR, evidenciaram que a utilização desta técnica de realce fotográfico é de fundamental importância durante os trabalhos de prospecção, pois dezenas de novos sítios foram identificados dessa forma no referido município.

Os sítios arqueológicos de maior destaque e relevância (abundância de pinturas/gravuras, diversidade da estilística, raridade do conteúdo representado, estado de conservação dos registros etc.) estão sendo mapeados com uso de técnicas de topografai espeleológica e os painéis com ocorrência de pinturas rupestres e demais registros arqueológicos são geoespacializados.

Após a fase de prospecção, inventário e cadastramento, será desenvolvida a etapa de educação patrimonial, envolvendo estudantes de escolas públicas e privadas, professores (as) e servidores públicos que atuam na gestão do patrimônio natural/cultural.

3. Resultados

Os resultados dos projetos Tibagi Rupestre e Piraí Rupestre ainda são preliminares, uma vez que tiveram seu início em julho de 2024 e dezembro de 2024, respectivamente. No contexto dos dois projetos já foram realizadas quatro expedições, totalizando 10 dias de trabalhos de campo. Ao todo, já foram percorridos 94 quilômetros a pé e identificados 11 novos sítios arqueológicos com pinturas rupestres e 36 novas cavidades naturais subterrâneas (a maioria do tipo abrigo). Além dos sítios arqueológicos com grafismos, outros seis sítios com muros de taipa foram cadastrados (figura 1).

Dentre os registros realizados pelo GUPE, chama a atenção a ocorrência no Abrigo do Cervídeo Gordo, localizado no Parque Estadual do Guartelá, município de Tibagi. Apresentando cerca de 30 metros quadrados de área, esta pequena cavidade possui três painéis pintados e em um deles há o registro de um grande cervídeo galhado (figura 2).

Este motivo é retratado na cor vermelha, apresenta preenchimento com traços produzidos na vertical e distribuído de forma aleatória, com linhas grossas de bordas que chegam a medir até 2 centímetros de espessura em alguns pontos. O cervídeo possui cerca de 1 metro de largura e 60 centímetros de altura. Esta representação encontra-se muito bem preservada, distinguindo-se das demais pinturas rupestres da região que, em sua maioria, estão desbotadas ou destruídas por conta da fragmentação natural da rocha arenítica.

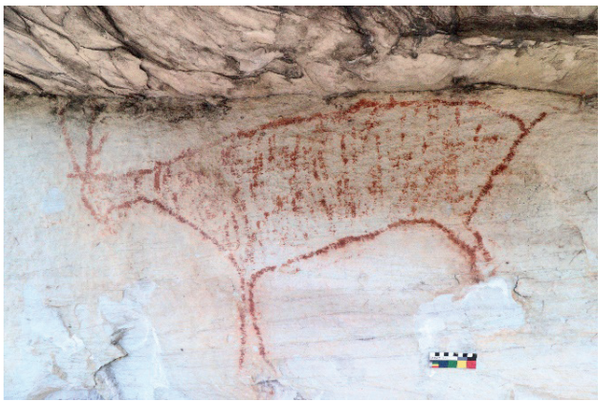

Figura 2: *cervídeo galhado representado em parede do Abrigo do Cervídeo Gordo.*

Outro achado de destaque é o Abrigo da Jararaca, no município de Piraí do Sul. O local foi identificado por um morador parceiro dos projetos do GUPE e no seu interior há vários painéis com grafismos. Contudo, um deles apresenta um conjunto de pinturas bastante desbotadas, mas que, a partir da aplicação de filtros DStretch, foi possível desvendar várias figuras, incluindo possíveis cenas envolvendo cervídeos, aves, antropomorfos e estruturas (figuras 3 e 4).

Além dos novos achados, o GUPE tem revisitado sítios arqueológicos já conhecidos e cadastrados, a fim de realizar novas descobertas e o recadastramento (quando for o caso) destas novas ocorrências de pinturas em sítios já estudados.

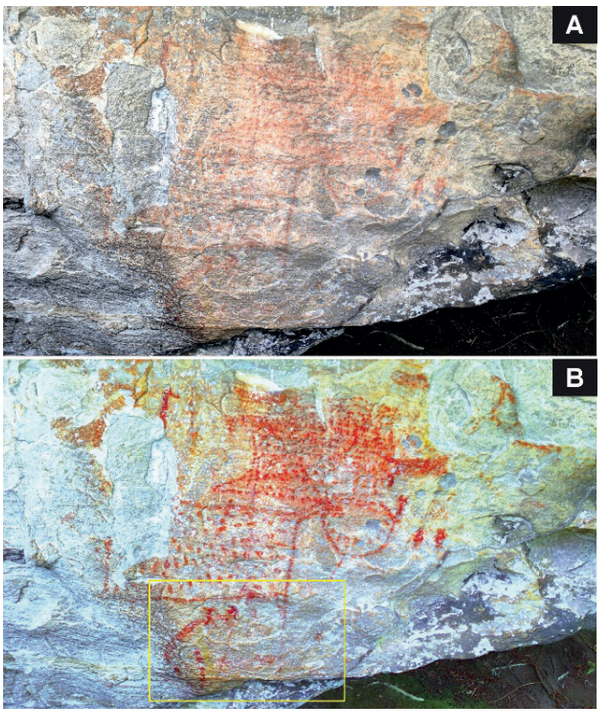

Figura 3: *painel contendo cenas sobrepostas. Imagem original (A) e após uso de filtro YRD do DStretch. O quadrado em amarelo indica a área detalhada na figura 3.*

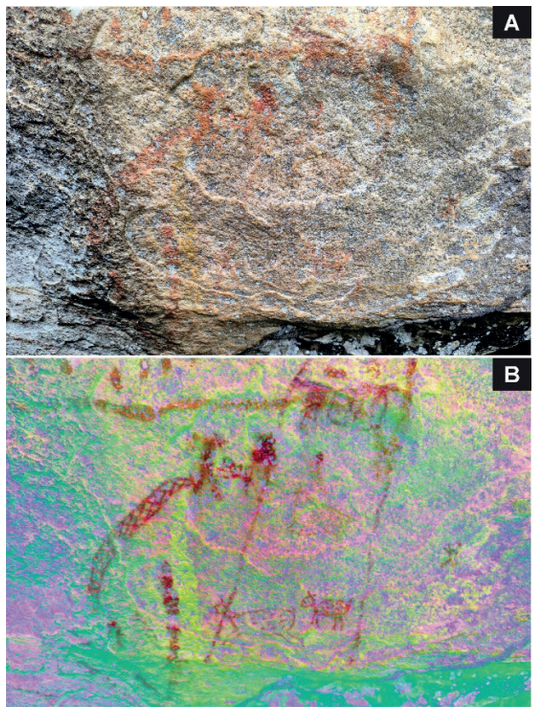

Figura 4: *detalhe da área indicada pelo quadrado em amarelo apresentado na figura 2. Notar a presença de estruturas e figuras antropomórficas, constituindo uma possível cena. Imagem original (A) e após uso de filtro CRGB do DStretch.*

4. Discussão

O uso de filtros DStretch tem sido uma tecnologia primordial para a identificação de novas pinturas rupestres que se encontram imperceptíveis a olho nu, devido ao desvanecimento da tinta pelas ações das intempéries. A utilização desta técnica de realce fotográfico é de fundamental importância durante os trabalhos de prospecção, pois dezenas de novos sítios já foram identificados pelo GUPE ao longo dos últimos anos, sendo 11 novos sítios arqueológicos apenas no âmbito dos projetos Tibagi Rupestre e Piraí Rupestre, ainda em suas fases iniciais, o que mostra o potencial para novas descobertas.

Áreas protegidas foram criadas na região dos Campos Gerais ao longo dos anos, mas não surtiram real efeito na proteção efetiva dos sítios arqueológicos e cavernas da área da Escarpa Devoniana, pois diferentes usos do solo, como a conversão dos campos nativos para plantio, principalmente de soja e pinus, vêm cada vez mais colocando em risco este importante patrimônio. Além dos impactos negativos a que estes sítios estão submetidos, o conhecimento acerca deste patrimônio arqueológico não é aprofundado e uniforme. Esta lacuna de dados, associada à incipiência na educação patrimonial e na divulgação científica para a sociedade, colocam esse patrimônio em risco. Assim, como muitos sítios arqueológicos e cavidades ainda não são conhecidas e cadastradas, a realização de projetos de pesquisa com prospecção e inventário são de fundamental importância. Somente assim é possível ter informação básica para ações de gestão e manejo dos diferentes usos do solo, de seus recursos e patrimônio.

É neste sentido que os editais e programas de fomentos à cultura têm sido um caminho alternativo para a captação de recursos financeiro para o desenvolvimento de pesquisas de caráter científico em cavernas e sítios arqueológicos. Leis a nível Federal como o Programa Nacional de Apoio à Cultura (PRONAC), Política Nacional Aldir Blanc (PNAB) e a Lei Paulo Gustavo (LPG), além de iniciativas a nível de estado do Paraná, como o Programa Estadual de Fomento e Incentivo à Cultura do Paraná (PROFICE), e na esfera do município de Ponta Grossa (PR), como o Programa Municipal de Incentivo Fiscal à Cultura (PROMIFIC), têm contribuído de modo significativo no desenvolvimento dos programas e projetos do GUPE.

5. Conclusão

Os projetos Tibagi Rupestre e Piraí Rupestre estão mostrando bons resultados, mesmo com pouco tempo desde o início dos estudos. A expectativa do GUPE é de que dezenas de novos sítios arqueológicos (e consequentemente cavidades subterrâneas) sejam identificados até o final das pesquisas.

Mas não apenas de pesquisa científica estes projetos são constituídos. Há várias contrapartidas sociais alicerçadas em ações de educação patrimonial, que inclui a distribuição gratuita para escolas municipais e estaduais e outros espaços de realização e promoção de educação patrimonial/ambiental, de um livreto infantil sobre a arqueologia da APA da Escarpa Devoniana. Este livreto será disponibilizado para que estudantes possam ter acesso ao conteúdo acerca do patrimônio cultural local/regional. Para garantir a acessibilidade serão produzidos o audiolivro e a audiodescrição da obra, o que permitirá às pessoas com deficiência visual conhecer com autonomia o conteúdo pedagógico do material.

Como caráter descentralizador, o GUPE tornará as informações e produtos gerados acessíveis para agentes culturais da cidade, como servidores públicos, representantes do poder executivo, de conselhos municipais e legisladores. Também serão realizadas oficinas para docentes da rede pública de ensino, principalmente das áreas de ciências, história e geografia, com o objetivo de capacitar multiplicadores que terão papel fundamental na divulgação e educação patrimonial.

Ainda, o GUPE realizará capacitação de servidores de órgãos públicos da área de meio ambiente e cultura, tendo como foco a disseminação de conhecimento e informações visando à gestão do patrimônio arqueológico. Da mesma forma, serão ministradas palestras para a comunidade, direcionada principalmente aos produtores rurais para promover a educação patrimonial com proprietários de áreas com ocorrência de sítios arqueológicos.

Além disso, para o Projeto Tibagi Rupestre será produzido um livro sobre a arqueologia da área estudada, obra que também será distribuída gratuitamente.

Como continuidade destes projetos estão previstas as seguintes ações: a) atualização sistemática de banco de dados do patrimônio arqueológico da APA da Escarpa Devoniana e disponibilização dos dados para órgãos responsáveis pela fiscalização e gestão do patrimônio cultural; b) execução de cursos de capacitação de servidores públicos; c) apresentação dos resultados e produtos do projeto para proprietários e comunidade do entorno de sítios arqueológicos; d) publicações e comunicações científicas dos dados, resultados e experiências levantados ao longo do projeto em periódicos e eventos da área ambiental e cultural e; e) continuidade do Programa Campos Gerais Rupestre em outros municípios da APA da Escarpa Devoniana.

Agradecimentos

Agradecemos ao Programa Estadual de Fomento e Incentivo à Cultura | PROFICE da Secretaria de Estado da Cultura | Governo do Estado do Paraná, às empresas Continental e Copel pelo fomento financeiro ao Projeto Tibagi Rupestre. Também estendemos nossos agradecimentos à Secretaria de Estado da Cultura - Governo do Paraná, com recursos da Lei Paulo Gustavo, Ministério da Cultura - Governo Federal pelo fomento financeiro ao Projeto Piraí Rupestre

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The ancient statues of Laos caves

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1. Introduction

One evening in April 2004, Boun Nong a peasant from Ban Na Khang Xang village (Khammouane Province) went to bats hunting. Unfortunately, in Laos, bats are considered culinary delicacies. Boun Nong saw a small entrance suspended in a cliff at 15 m heights, a possible place where many bats could shelter. With the help of lianas, Boun Nong did a risky climbing on the vertical wall. After the small entrance was a larger room, but instead of bats, perfectly aligned inside rimstone dams, were 229 statues of Budha, up to 1.5 m tall, mostly bronze, but also 15 built-in massive gold! It was the most important archaeological find in the last 100 years in Laos (MOURET 2022, MOURET & GHOMMIDT, 2004, VALE-

NAS 2019a). Tham Pha Fa cave became almost immediately a great tourist attraction, but also a permanent pilgrimage place for the Laotian Buddhists. Archaeologists, as well as the speleologists, quickly came to a unanimous conclusion, but false. Considering the extreme difficulty of reaching this cave, no doubt it was a rescue action at the last moment of the precious statues undertaken by the Buddhist monks several centuries ago. Hidding the statues in the cave would have protected them from the invasion of a foreign army. Just over a few years, at about 20 km away from Tham Pha Fa C ave, in a small tunnel cave, Tham Pha Bang (Tham Pha Noi), hidden in a niche suspended at 4 m height, perfectly aligned, another 80 old statues of Buddha it discovered (MOURET 2022, MOURET et al. 2014, VALENAS 2019a). This time they had been stored in bronze trays. Who would have hidden them and for what purpose?

Figure 1: *Bronze statue of Buddha from the Tham Pha Bang (Tham Pha Noi) Cave (photo Liviu Valenas).*

Figure 2: *Tham Pha Fa, the first cave in which it found ancient statues of Buddha (photo Charles Ghommidh).*

Figure 3: *The bronze statues from the Tham Pha Bang Cave (photo Liviu Valenas).*

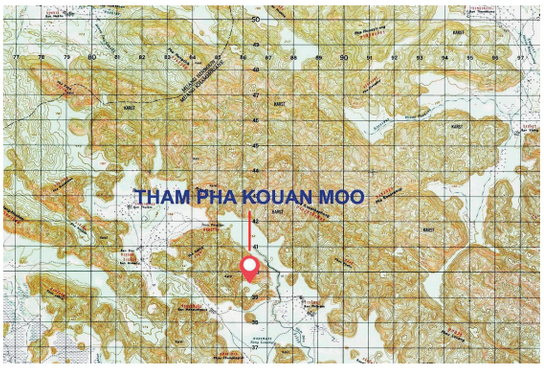

Figure 4: *The location of Tham Pha Kouan Moo cave in the karst area at the north of Thakhek.*

Figure 5: *The statuary group from Tham Pha Kouan Moo Cave (photo Liviu Valenas).*

2. Materials and metods

Tham Pha Kouan Moo Cave was surveyed and mapped with Suunto compass, Disto D2 and inclinometer. The cave entranc- es were positioned with GPS, Garmin 62s. The topographical maps of the area were US military maps from 1965, later made public by the University of Florida, US. The statues were photographed with a Nikon D 5200 camera, Tamron lens, 18-270 mm, UV filter.

3. Results

In March 2018, Mehdi Boukhal and Liviu Valenas, as part of the international speleological expedition SPELEO LAOS 2018, resumed the Tham Pha Kouan Moo Cave exploration. In a niche suspended 15 old statues of Buddha 3 carved in stone and the rest in gilded wood it discovered. Statues were small, only 8-35 cm tall. Tham Pha Kouan Moo is also a suspended cave at 20 m above the valley in the south cliffs of Pha Soung Mountain but in the same area as the caves mentioned before. The age of the statues is still unknown. The style in which they carved and especially cast, invariably takes us to the Laotian kingdom under the King Setthatirath (1548-1571). The discovery from the Tham Pha Kouan Moo Cave, especially the wooden statues could help in finding out the statues age. For more in-depth research, in our future expeditions in Laos, we invite any team of archaeologists to join us. One thing is certain, especially considering the latest discovery from Tham Pha Kouan Moo cave: the ancient Buddhist sanctuaries- hidden in the caves of Laos, will be rediscovered (VALENAS 2019a, 2019b, 2019 c).

If the Buddhist monks knew only the entrance, the first spe- leological exploration of the cave took place in 2016, being undertaken by Liviu Vălenaş, Khamlex Khomxayxana and Son- say Xayavongsa. With a total length of 1,040.5 m, Tham Pha Kouan Moo cave is one of the relatively large caves in Laos (VALENAS 2017, VALENAS 2018, VALENAS 2019a). The net-

work develops in the southern slope of Pha Soung Mountain, at 70 m distance by the great maze cave Pha Soung (21,190 m total length/2024). Until today there is not a junction between the two caves. Tham Pha Kouan Moo Cave has two distinct sectors. The lower cave has 223.4 m length and 7 entrances, of which three have big openings. This sector includes a small underground water stream and a deep sump lake. Through a vertical squeeze (an opening passable with effort) of 15 m high, a junction to the upper cave has made in the 2016 year and, later the statues of Buddha discovered there in 2018.

Figure 6: *Detail from a statue in Tham Pha Kouan Moo Cave (photo Liviu Valenas).*

Figure 7: *Small statue in Tham Pha Kouan Moo Cave (photo Liviu Valenas).*

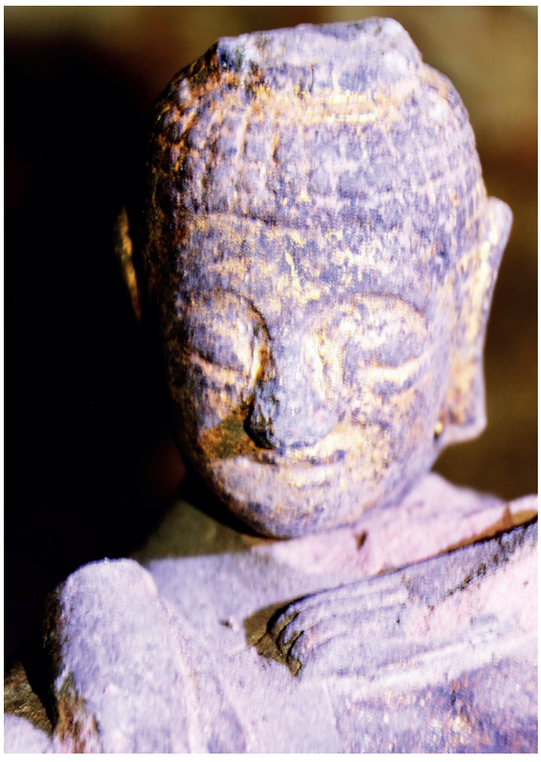

Figure 8: *Detail from a statue in Tham Pha Kouan Moo Cave (photo Liviu Valenas).*

Figure 9: *Detail from a statue in Tham Pha Kouan Moo Cave (photo Liviu Valenas).*

Figure 10: *Small statue in Tham Pha Kouan Moo Cave (photo Liviu Valenas).*

The upper cave has several entrances, of which a large portal. Excepting for a maze in the first third, the upper cave is devel- oped on a very corroded main gallery with an average section of 6 m by 9 m. Tham Pha Kouan Moo ends surprisingly: after a negative step of 5.5 m follows a deep pit of 20 m who ends to the phreatic table. After this deep pit, a superior gallery wasn't yet explored. The lack of any air flow, the aged look of the main gallery, does not support the idea of a possible junction to the Pha Soung System.

Figure 11: *Detail from a statue in Tham Pha Kouan Moo Cave (photo Mehdi Boukhal).*

Figure 12: *Detail from a statue in Tham Pha Kouan Moo Cave (photo Mehdi Boukhal).*

4. Discussion

According to this discovery, the thesis that statues were de- posited in caves in a rescue operation because of an imminent invasion have to abandoned. Nothing proves it. Accepting that these statues are 450-500 years old, we are going back to the sixteenth century when in Laos was great prosperity and tranquillity under the reigns of two kings: Photisarath (1520-1548) and his son, the legendary King Setthatirath (1548-1571). Setthatirath waged more wars, especially against the Burmese armies and against the Cambodians. All the battles took place in the north of kingdom- in the central part of today Thailand and, in the south of actual Laos, near the current border with Cambodia. The central province Khammouane has not been a theatre of war and no invasion in the XVI century on its territory had been present and Buddhist chronicles do not mention about something different. For these reasons, we consider as false the thesis that the statues only sheltered in these caves. There is no document in this regard (VALENAS 2019a, 2019b, 2019 c).

During the great prosperity of the Laotian kingdom under the King Setthatirath, countless Buddhist temples were built, inclusively in the current Khammouane province. Caves have always considered by Buddhist monks, but also by population, as sacred places, a Buddha's creation. That is why we are sure that these three caves, where the Buddha statues have been perfectly conserved, in reality, are subterrene Buddhist sanctuaries. The perfect cave location and the precise alignment of the statues prove it. If the statues have hidden in a desperate rescue, probably other valuable, profane goods might have been found. But they are missing in reality. Of course, choosing the caves has not been done at random it has looked for those caves with difficult access and, it has assured the protection against to potential thieves or vandals. Undoubtedly, these underground temples were also places of pilgrimage. But with the catastrophic defeat of the Laotian armies against Siam in 1828 at Udon Thani, it followed nearly 100 years of invasion and anarchy and, these underground sanctuaries have been completely forgotten and, they have been rediscovered barely over two hundred years.

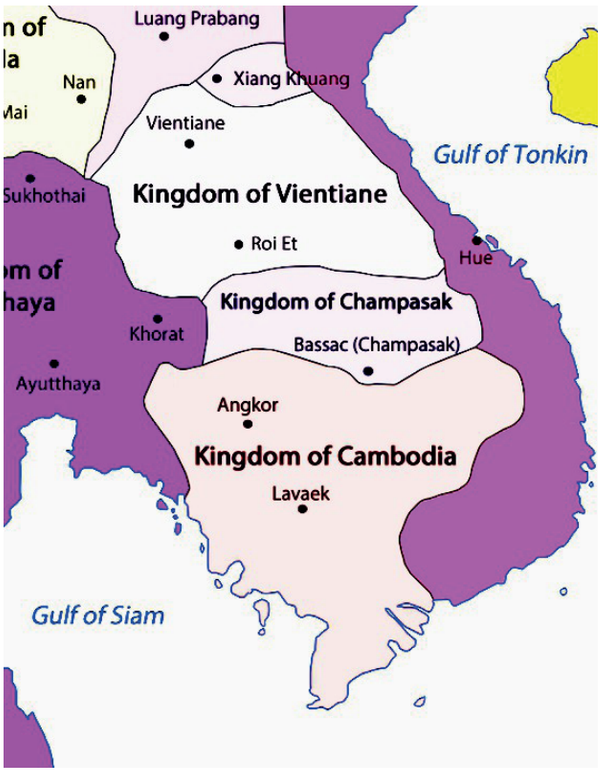

Figure 13: *Map of Laos around 1750.*

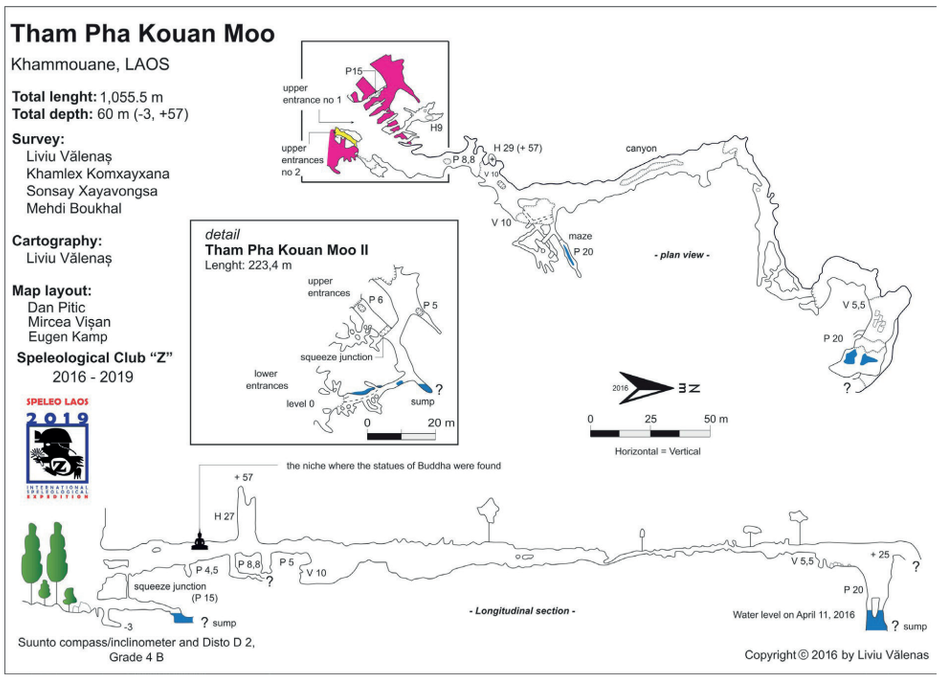

Figure 14: *Tham Pha Kouan Moo Cave, plan und longitudinal section (cartography by Liviu Valenas)*

5. Conclusion

All the statues discovered in the three caves have great stylistic similarities between them having influences from Vietnamese and Cambodian Buddhism. The elegance of the style betrays the influence of a great artist. Statues probably come from a large manufactory where the anonymous artist had had his disciples. The large size and differences between the material of statues in the three caves are believed to be due only to the different financial power of the local Buddhist communities who created, administered and protected these underground temples (VALENAS 2019a, 2019b, 2019 c).

Acknowledgements

I would like to thank Mehdi Boukhal, †Gheorghe Popescu, Georgeta Maria Vinay, Mircea Vişan, Khamlex Khomxayxana, Sonsay Xayavongsa, Claude Mouret, Jean-François Vacquié,

†Charles Ghommidh, Dan Pitic, for helping me with their generous expertise.

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Peintures pariétales en nord-est de la Thaïlande

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Abstract

Cave paintings in northeastern Thailand. In Thailand, cave paintings that are several thousand years old are distributed almost everywhere in Thailand, particularly in the northeast- ern provinces of Thailand in what is called Isan, but also in the rest of the country (Kanchanaburi, Uthai Thani, Mae Hong Son, Lampang, Chiang Mai, Phang Nga, Krabi, etc.). This study is not an exhaustive work, but aims to present in more detail three important sites in Isan, namely the sites of Pha Taem National Park, Phu Sa Dok Bua and Phu Phrabat. The authors of the work came to another interpretation of the meanings of the parietal paintings and question the relatively recent age indicated by the Thai researchers.

1. Introduction

En Thaïlande, des peintures pariétales vieilles de plusieurs milliers d’années sont réparties pratiquement partout en Thaïlande et notamment dans les provinces du nord-est de la Thaïlande dans ce qu’on appelle l’Isan, mais aussi dans le reste du pays (Kanchanaburi, Uthai Thani, Mae Hong Son, Lampang, Chiang Mai, Phang Nga, Krabi, etc.) La présente étude n’est pas un ouvrage exhaustif, mais vise à présenter plus en détail trois sites importants de l’Isan, à savoir les sites du parc national Pha Taem, Phu Sa Dok Bua et Phu Phrabat.

2. Matériels et méthodes

Les grottes de Tham Phataem a été cartographiées à l’aide d’une boussole Suunto, d’un Disto D2, d’un inclinomètre et d’une règle en fibre de verre. L’entrée de la grotte était posi- tionnée à l’aide d’un GPS Garmin 62s. Les peintures pariétales ont été photographiées avec un appareil photo Nikon D 5200 un objectif Tamron 18-270 mm et un filtre UV. Plus tard, avec un programme ACD Systems 2024 le contraste a été augmenté dans chaque cliché, afin de mieux montrer les peintures.

3. Résultats

Pha Taem. Les peintures pariétales les plus intéressantes de toute la Thaïlande se trouvent sur la falaise de Pha Taem, dans le parc national du même nom, dans la province limitrophe du Laos, Ubon Ratchathani. À Pha Taem il y a en tout 300 picto- grammes, disposés sur une longueur de 300 m, la plus longue fresque préhistorique du monde ! Cependant, l’immense fresque n’a été découverte qu’en 1981. Pha Taem est sans aucun doute la « Chapelle Sixtine » des peintures pariétales de toute la Thaïlande. La falaise est constituée de grès quartz- itiques et domine de plus de 200 m le fleuve Mékong qui coule devant l’imposant rocher. Bien que l’administration du parc national de Pha Taem décrivent cette falaise comme une grotte-abri, nos recherches ont clairement prouvé qu’il ne s’agit pas du tout d’une grotte, ni même d’un abri, mais simplement d’une paroi verticale légèrement en surplomb. Cette morphologie a conduit ceux qui ont peint ces fresques à choisir ce lieu. Plus le fait qu’il domine le fleuve Mékong. Il y a deux fresques principales sur la falaise de Pha Taem, les pein- tures sont réalisées à l’ocre rouge. La plus importante fresque,

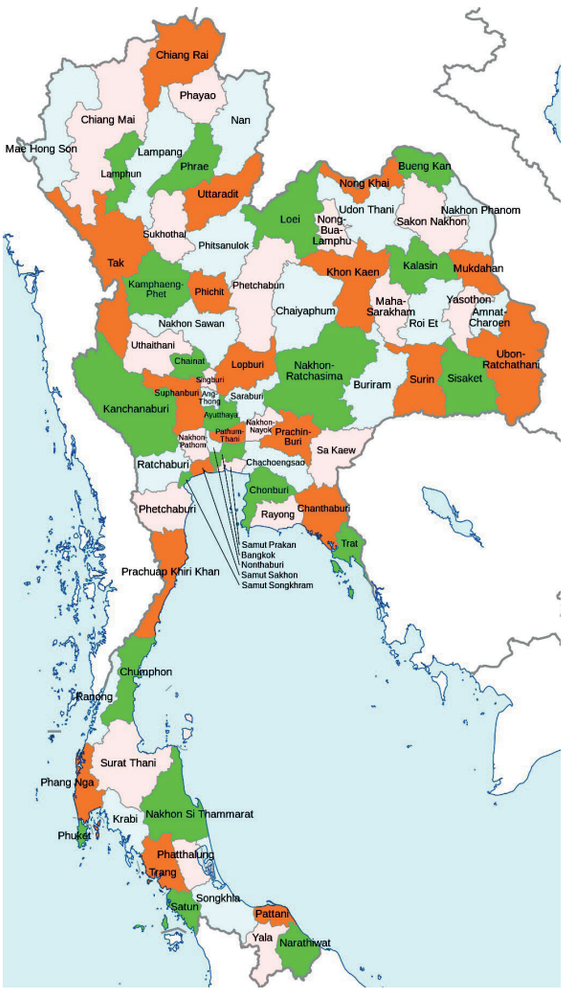

Figure 1: *Carte administrative de la Thaïlande. Les provinces d’Ubon Ratchathani, Mukdahan et Udon Thani sont situées au nord-est du pays.*

développée horizontalement, est très complexe. La partie animale, située au sommet, est exclusivement représentée par des animaux aquatiques. Il y a trois énormes poissons. Les chercheurs thaïlandais ont pensé qu'ils représentaient des baleines (?!), mais la mer ou l'océan le plus proche se trouve à plus de 1 000 km ! À une étude attentive de la représentation graphique de ces animaux aquatiques, on constate qu'ils ont plus de nageoires et que la nageoire caudale est verticale ce qui démontre à notre avis que ces animaux ne représentent en aucun cas des baleines, mais des poissons. Il faut mentionner que le plus gros poisson d'eau douce du monde vit dans le Mékong, un poisson-chat géant (Pangarianodon gigas), un spécimen capturé il y a quelques années du côté thaïlandais du Mékong pesait 293 kg. Il est possible qu'il y ait d'autres espèces dans les représentations de ces poissons, le fleuve Mékong compte toujours le plus grand nombre d'espèces de poissons d'eau douce au monde, dépassant clairement même l'Amazonie. il y a aussi un autre animal aquatique représenté aux côtés du poisson, une tortue.

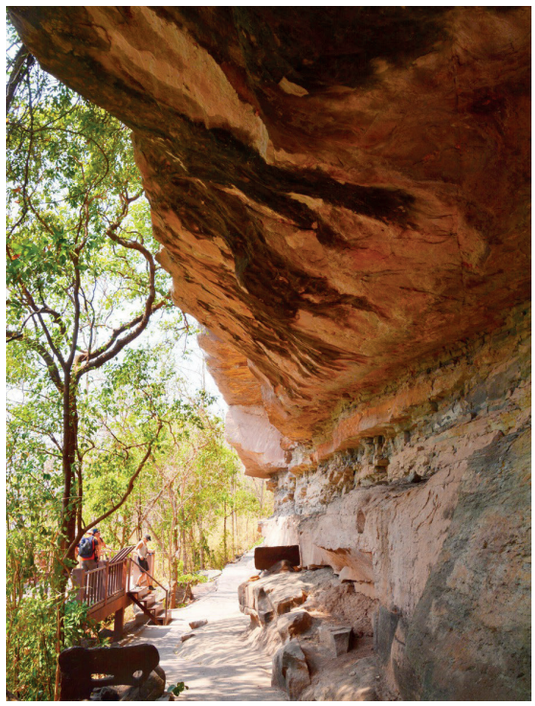

Figure 2: *La falaise en grès quartzitiques où se trouvent les peintures pariétales de Pha Taem (photo Liviu Valenas).*

Figure 3: *La fresque principale de Pha Taem (photo Liviu Valenas).*

Au bas de cette étonnante fresque se trouvent plusieurs fig- ures humaines. Si les figures animales sont présentées de manière très réaliste, les figures humaines sont peintes de manière schématique et symbolique. Les figures humanoïdes sont alignées comme dans une procession sacrée. La tête de ces personnages est peinte de manière purement symbol- ique, représentée par un triangle avec la pointe vers le bas. Au-dessus du groupe humain se trouve une représentation graphique qui semble suggérer des vagues, mais, à notre avis, il s'agit d'un filet pour attraper du poisson. Debout, à gauche du groupe, se trouve un autre groupe de personnes, présenté de manière beaucoup plus schématique, uniquement par des contours relativement élégants, les gens sont courbés. Le premier homme à droite semble tenir un harpon ou une lance, évidemment également pour la pêche. Fait intéressant, et c'est aussi la clé de la fresque mystérieuse, le groupe de per- sonnes commence par un poisson, qui a tendance à s'enfoncer encore plus profondément. Il faut également mentionner une représentation plus petite, au milieu de la fresque, d'un mammifère, qui ressemble à un mouton, mais nous doutons qu'il y a 2 500 à 3 000 ans la population locale ait connu et domestiqué cet animal. Ou le petit mammifère représente- t-il un chien ? Cette fresque est « signée » par au moins 11 empreintes palmaires. Il est intéressant de noter que même au Paléolithique européen, l'artiste qui peignait les scènes d'ani- maux dans les grottes signait généralement de cette manière. Mais généralement à travers une seule empreinte palmaire. Le fait que nous avons ici au moins 11 empreintes de mains pourrait indiquer que plusieurs artistes-peintres ont participé à la réalisation de cette imposante fresque. Une hypothèse. La grande fresque à gauche de la paroi verticale représente un éléphant. Et pas un éléphant assis ou qui marche, mais un éléphant qui nage ! Plus qu'intéressant, il y a un poisson sur le dos de l'éléphant et un autre poisson est peint entre la trompe et les pattes avant de l'éléphant. Actuellement, les éléphants sauvages d'Asie ont disparu du parc national de Pha Taem, mais il y a plusieurs milliers d'années, il était certainement répandu dans cette région, et le fleuve Mékong était un lieu de baignade quotidien favori de ces éléphants.

La question clé à propos de ces fresques est de savoir qui les a peintes il y a 2 500 à 3 000 ans ? Il est évident que les peintures appartiennent à une population éteinte ou as- similée plus tard, sans lien avec le peuple thaïlandais actuel, qui s'est installé dans la Thaïlande actuelle et au Laos voisin seulement à partir du 9ème siècle après JC. Les représen- tations de poissons, d'une tortue et d'un éléphant nageant parmi les poissons sont selon nous l'œuvre d'une population dont l'activité principale était la pêche dans le Mékong. Les poissons représentés ont un caractère sacré, ils étaient vénérés. La population des pêcheurs avait certainement une foi, une foi animiste. Au Laos voisin, 30 % de la population a encore

cette croyance et dans tout le nord-est de la Thaïlande (qui appartenait au Laos jusqu'en 1828), il existe des réminiscences de cette croyance. Des chercheurs thaïlandais ont creusé une petite grotte de seulement 6 m de long au pied de la falaise. Nous n'avons aucune information de ce qu'ils ont découvert, s'ils ont découvert quoi que ce soit. Il est certain que dans les publications thaïlandaises spécialisées, presque toutes les peintures pariétales de Thaïlande sont estimées comme datant de seulement 2 500 à 3 000 ans, c'est-à-dire lorsque la civilisation grecque existait dans la région méditerranéenne et que la civilisation égyptienne était à son apogée. Nous ne savons pas sur quoi se basent ces chiffres concernant l'âge des peintures. Malheureusement, aucune précision n'a été donnée à ce sujet. Enfin, on ne peut préciser si la population à laquelle appartiennent ces fresques était une population nomade ou sédentaire. L'absence de vestiges d'anciennes habitations humaines à Pha Taem appuierait cependant la première hypothèse.

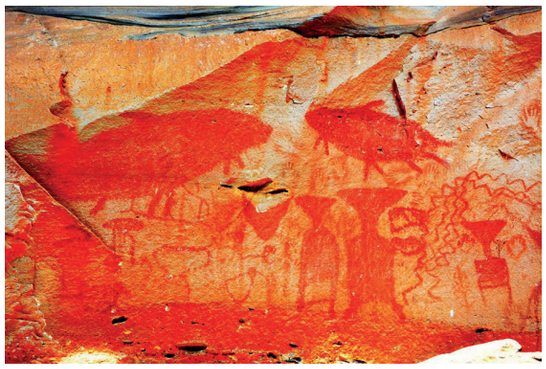

Figure 4: *La fresque principale de Pha Taem, détail avec des poissons et des figures humaines (photo Liviu Valenas).*

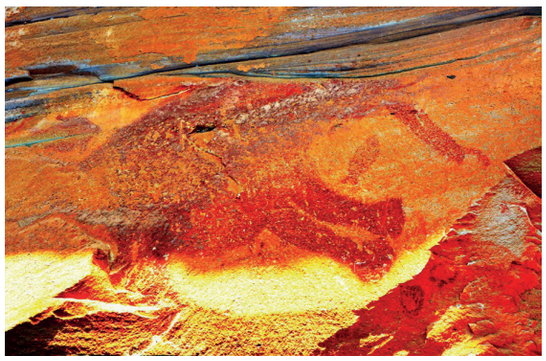

Figure 5: *La fresque principale de Pha Taem, détail avec un éléphant nageant parmi les poissons. (photo Liviu Valenas).*

Figure 6: *L´abri de Tham Pathaem (photo Liviu Valenas).*

Tham Phataem. Un peu plus au nord de la province d'Ubon Ratchathani, dans la province de Mukdahan, dans le parc national de Phu Sa Dok Bua, d'autres pictogrammes rupestres apparaissent. Cette fois, ils sont abrités par un abri, Tham Pha- them (VALENAS 2020a, 2020b), lui-même développé au pied d'une imposante falaise en surplomb qui domine le paysage environnant. Les peintures de Phu Sa Dok Bua ne ressemblent en rien à celles de Pha Taem. S'agit-il de symboles plutôt énigmatiques, représentent-ils une écriture ancienne, aujo- urd'hui disparue ? Il est certain qu'au milieu de ces symboles, peints horizontalement, il y a la «signature» du peintre, le dessin d'une empreinte palmaire, représentée par cette date graphique. Et l'administration du parc estime que ces symbole peints ont entre 2 500 et 3 000 ans.

Phu Phrabat. Au nord-est de la Thaïlande, dans la province d'Udon Thani, se trouve le parc historique national de Phu Phrabat (KINGMANEE 2018). Il s´agit toujours aussi d´un parc naturel, qui comprend un très grand nombre de formes d'éro- sion dans les grès quartzitiques, appelées «champignons de pierre». Beaucoup d'entre eux ont été érigés au fil du temps comme temples ou refuges pour les ermites. Deux époques historiques classiques se sont succédées sur ce petit terri- toire. D'abord les cultures indiennes Dvaravati et Lopburi, apportées par la civilisation khmère, avant le XIIIe siècle, lorsque le royaume khmer possédait sur son territoire la to- talité de la Thaïlande actuelle. Cependant, à partir du XIIIe siècle, l'influence bouddhiste apportée du Laos à travers la culture Lanxang commence à se faire sentir, à travers plusieurs temples et de nombreuses statues de Bouddha situés dans ce parc historique. L'influence laotienne persista jusqu'en 1828, date à laquelle le Laos perdit tout son territoire occidental, incorporé de force au Siam.

Mais avant l'hindouisme et le bouddhisme, une population locale a laissé de nombreuses peintures rupestres. Au to- tal, ce parc historique compte 54 fresques, pictogrammes et symboles (KINGMANEE 2018). Et on estime qu'ils ont entre 2 500 et 3 000 ans. Deux fresques, également peintes à l'ocre rouge, sont très intéressantes. D'abord une belle fresque animalière, avec de nombreux bovidés sauvages (qui vivent encore aujourd'hui en Thaïlande), mais aussi des cervidés et même un oiseau plus grand. Sous les animaux, une figure humaine semble lancer un lasso. Il est bien clair que, contrai- rement à Pha Taem, ceux qui ont peint cette scène étaient des chasseurs et non des pêcheurs. Un fait qui s'explique par le fait qu'il n'y a pas de rivière majeure à proximité. La fresque a probablement aussi un caractère rituale, celui de vénération de ces animaux. La deuxième fresque, également disposée horizontalement, représente un groupe de personnes qui sem- blent aller chasser ensemble. Ou représente-t-elle une céré- monie chamanique ? Comme pour Pha Taem, on ne sait pas quelle population a peint ces fresques et ces pictogrammes, ainsi qu'un certain nombre de symboles, impossibles à déchif- frer aujourd'hui. Selon nous, plusieurs générations de peintres se sont succédé ici pendant au moins 500 ans.

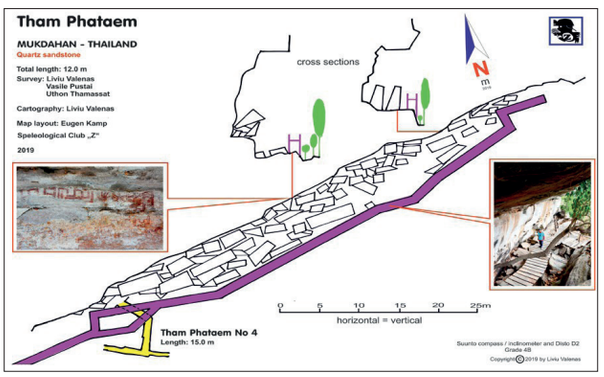

Figure 7: *L´abri de Tham Pathaem, plan et sections trans- versale (cartography Liviu Valenas).*

Figure 8: *L'abri de Tham Pathaem, des symboles peints, ou une écriture encore non déchiffrée (photo Liviu Valenas).*

4. Discussions

Les peintures pariétales de Thaïlande soulèvent de nombreus- es questions. Tout d'abord, il n'y a aucune ressemblance avec les célèbres peintures rupestres d'Europe, qui datent du Paléo- lithique et dont l'âge est estimé à environ 30 000 ans. De plus, les peintures rupestres d'Europe dénotent une technique et un raffinement exceptionnels qui n'ont jamais été égalés auparavant, ce qui n'est pas le cas des peintures pariétales de Thaïlande. Au Paléolithique européen, il est évident que les peintures rupestres étaient l'œuvre d'artistes professionnels et non d'amateurs. En Thaïlande une chose est particulièrement claire : les peintures n'ont pas été réalisées par des profes- sionnels, mais par des populations locales de chasseurs, de pêcheurs ou encore d'éleveurs. C'est pour cette raison qu'ils ont un caractère plutôt primitif. Il est assez étrange qu'à 20 000 km de là, dans le parc national de Bryce-Canyon, dans l'état de l'Utah, aux États-Unis, on trouve des dessins très semblables à ceux de Thaïlande, gravés dans les pierres. Convergence des formes... Et les gravures de l'Utah sont estimées à 2 000 ans. Elles ressemblent aussi un peu aux peintures rupestres du Tassili dans le Sahara algérien ou à celles réalisées par les aborigènes australiens. Mais il y a un problème : les célèbres peintures du Tassili ont 16 000 ans, et celles d'Australie sont à peu près aussi vieilles, voire même plus anciennes (certaines d'entre elles). Quelque chose de similaire a été découvert il y a trois ans en In- donésie, donc non loin de la Thaïlande, et les analyses au radiocarbone ont prouvé qu'elles sont les plus

anciennes du monde : 51 500 ans ! Et là, on entre dans le vif du sujet : quel âge peuvent avoir les peintures rupestres de Thaïlande ? Une peinture rupestre de l'ouest de la Thaïlande était datés U/Th et datait entre 1856 ± 16 et 1728 ± 41 ans, correspondant à la dynastie des Han de l'Est (entre 25 et 230 après J.-C.) en Chine voisine (SHAO et al. 2017). Durant cette période, la Chine a connu une période d'épanouissement et l'art chinois de cette époque était extrêmement raffiné. Ainsi, la théorie selon laquelle les personnes qui auraient peint les dessins rupestres et les fresques en Thaïlande se- raient originaires de Chine s'est avérée complètement fausse (SCOTT & KANJANAJUTORN 2023). Les auteurs de ces pein- tures pariétales en Thaïlande étaient les populations locales, constituées de personnes très simples.

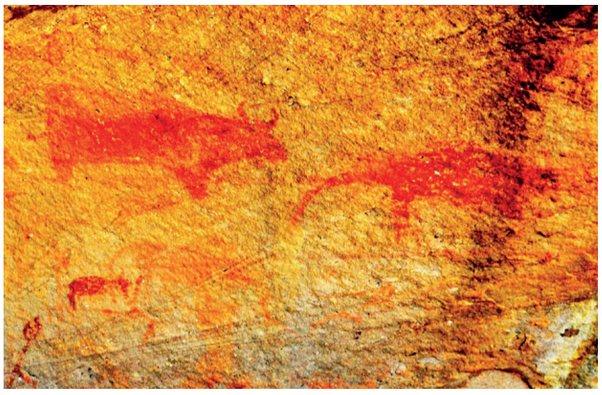

Figure 9: *La fresque principale de Phu Phrabat avec des bovidés (photo Liviu Valenas).*

Figure 10: *La fresque principale de Phu Phrabat avec des personnages humains dans une procession rituelle (photo Liviu Valenas).*

5. Conclusions

Les peintures pariétales de Thaïlande soulèvent encore de nombreuses questions quant à leur ancienneté. À notre avis, elles sont d'âges différents et si beaucoup d'entre elles avaient été datés au radiocarbone, ils auraient probablement été beaucoup plus âgées que 1 800 à 4 000 ans. À notre avis également, elles peuvent appartenir à différentes périodes historiques. Il existe une autre différence entre les peintures paléolithiques d'Europe et celles de Thaïlande. Celles d'Europe étaient presque toutes peintes à l'intérieur des grottes, et celles de Thaïlande uniquement sur des parois verticales ou dans certains abris. Une exception, mais sans rapport avec notre sujet, sont les dessins beaucoup plus récents, représentants des navires européens, trouvés dans les grottes des îles Phi Phi, dans la province de Krabi. Ces dessins ne sont pas non plus datés avec précision, ils sont supposés avoir seulement entre 400 et 100 ans.

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Session 03

CAVE PALEONTOLOGY

Preliminary insights into fossil findings at Al-Hammam well sinkhole in Nineveh, Iraq

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Abstract

The Alou Antar sinkhole, also known as Al-Hammam Well, is located five kilometers northwest of Talafar, in the Nineveh governorate of Iraq. This sinkhole was used by the "Islamic State of Iraq and Syria" (ISIS) in 2014 as a mass grave disposing the bodies of its victims. In May 2024, a specialized Iraqi team from "Mass Graves Protection Directorate" in Baghdad, collaborated with the "United Nations Investigative Team to Promote Accountability for Crimes Committed by Da'esh/ISIL" and initiated excavations at the site to identify the remains of victims. During these excavation works, a variety of fossils were discovered, including vertebrates, invertebrates, and plants.

1. Introduction

The fossil record of Iraq is limited, not due to the absence of deposits bearing them, but primarily because of the lack of paleontological excavations and research, a situation common to many southwestern Asian countries.

In May 2024, the first author participated in an investigation led by the "Iraq Mass Graves Protection Directorate" in collaboration with the "United Nations Investigative Team to Promote Accountability for Crimes Committed by Da'esh/ISIL" (UNITAD), aimed to identify bodies disposed of by ISIS in the Alou Antar sinkhole, also known as Al-Hammam Well (Fig. 1). This karstic sinkhole is located approximately five kilometers northwest of Talafar (coordinates: 36.430181° N, 42.446841° E) in the Nineveh Governorate of Iraq (Fig. 2). Talafar is situated about sixty kilometers west of Mosul. It is well known throughout history that sinkholes are used as either burial grounds or places where bodies are disposed of from Mayans in southern America to WWII in Europe to recent conflicts in Lebanon and southwestern Asia.

The Al-Hammam Well is a karstic sinkhole one of many presents in northern Iraq (Jassim et al. 1997). During the investigation, a rock measuring approximately 35×30 cm was discovered, containing several vertebrae and other bone fragments and two small rock pieces containing teeth. Additionally, exceptionally well-preserved plants and invertebrate fossils were found.

Figure 1: *Al-Hammam Well sinkhole as seen in May 2024.*

Figure 2: *Google earth map of Al-Hammam Well location.*

2. Materials and methods

An agreement has been established between Mr. Husham Khirullah Abdulzahra, an Iraqi herpetologist and teacher in Basra Education Directorate and discoverer of the fossils, and an international team of researchers from Syria, Brazil, Chile, and Lebanon to study and identify the fossils and improve the geological understanding of Al-Hammam Well sinkhole. What Started as a forensic investigation of human remains in a sinkhole resulted in discovering a major paleontological site in the sinkhole. The team includes several specialists, namely: Dr. Daniel Sedorko a paleontologist from the National Museum of Rio de Janeiro, Brazil; Dr. Joseline Manfroi, a paleobotanist from the Research and Advancement Corporation for Atacama's Paleontology and Natural History (CIAHN Atacama) in Chile; Dr. Issam Bou Joude, a professional geologist and cave and karst specialist based in Canada; and vertebrate paleontologists Dr. Max Cardoso Langer and Dr. Wafa Adel Alhalabi from the Paleontology Laboratory of the University of São Paulo, Ribeirão Preto, Brazil.

The block containing vertebrate fossils was CT-scanned at a private clinic in Basra, but the resulting images did not provide useful information. Consequently, the first author will undergo training in manual preparation techniques to extract the vertebrate fossils. In parallel, images of the invertebrate and plant fossils have been shared with specialists for preliminary analyses.

A comprehensive geological study of the sinkhole will be conducted in situ, whereas sediment samples from the site will be sent to the Paleontology Laboratory, in Ribeirão Preto. Possible microfossils present in the samples will help determine the age of the rocks.

3. Results

Karstified Middle Miocene sediments are widely exposed in northern Iraq, particularly around the city of Mosul. Jassim et al. (1997) mapped karstic features in an area of about 1.600 square kilometers surrounding Mosul, which includes several small highs/anticlines (considered as mountains locally): Ishkfat, Sasan, Zambar, Sheikh Ibrahim, among others. Al-Hammam Well sinkhole, located in Sasan mountain, is one of 4.000 karstic sinkholes (dolines) of the area, developed in gypsum strata and manifested by the collapse of the overlying limestone (Jassim et al. 1997). Two karstic systems have been identified, an active system developed over anticlinal structures and an older (Pleistocene) fossil karst system, which includes the Al-Hammam Well, among others (Jassim et al. 1997). The studied sinkhole is located in an area mapped as exposing the Middle Miocene Fatha Formation, which is one of the most regionally widespread stratigraphic units in Iraq (Al-Juboury et al. 2001). It is mainly evaporitic, consisting of numerous shallowing-upward cycles of alternating mudrocks, limestones, gypsum, anhydrite, and halite (Al-Jaboury and McCann 2008). The rocks in the core of the Al-Hammam Well and the other sinkholes in the area were not described by Jassim et al. (1997). Yet, it is possible that they may include Paleogene, or even Cretaceous deposits, as recorded in the cores of similar anticlinal structures northeast of the Mosul area (Jassim et al. 1997). The walls of Al Hammam Well have not yet been studied in detail, but a section of another sinkhole of the Sasan mountain, the closest to Al Hammam Well, exposes the upper and lower members of the Fatha Formation. This section includes a sequence of limestone, marl, gypsum, claystone/mudstone, and sandstone of Middle Miocene (Al-Jaboury and McCann, 2008).

The rocks sampled from the Al-Hammam Well include some plant-looking pseudofossils, corresponding to mineral encrustations (likely manganese oxide) forming dendrites. The actual fossil plants recovered to date from the site are characterized by fragmentary fossil branches (Fig. 3).

Figure 3: *Plant fossils. Scale bar: 2 cm.*

Vertebrate fossils are not yet fully identified. The several vertebrae preserved in the main block, as well as the two isolated teeth, are still undergoing identification (Fig. 4). Bivalve, predominantly pectinids, and gastropod mollusks are the dominant "invertebrate" fossils (Fig. 5).

Figure 4: *Vertebrate fossils. Scale bar: 2 cm.*

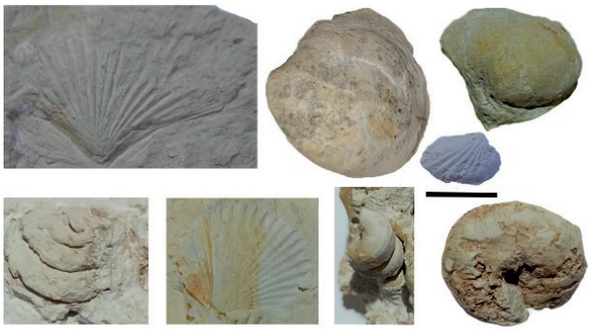

Figure 5: *Invertebrate fossils, including pectinid bivalves and gastropods. Scale bar: 2 cm.*

4. Discussion

While awaiting permission to conduct a geological survey of the sinkhole and obtain sediment samples to look for microfossils and perhaps estimate the age of the rocks, preliminary ideas were raised about the the invertebrates and plants fossils. These initial insights, along with future analysis of the vertebrate fossils, will be further refined and expanded upon in future research.

The carbonate layers are characterized by the occurrence of bivalves, predominantly pectinids. These fossils have a discoidal shell morphology, with well-defined radial ribs, including secondary ribs, and a distinctly triangular resilifer, accompanied by a prominent pallial line preserved as molds. The bivalves are primarily found in a horizontal orientation in relation to the bedding plane, although the presence of some articulated specimens suggests apparent preservation in life position. Trace fossils were not yet observed within the carbonate deposits.

The fossil plants recovered to date are characterized by fragmentary branches, with low-angle bifurcation and morphology associated with humid/aquatic environments. Due to the fragmentary condition of the fossil plants and the absence of diagnostic structures such as leaves and reproductive structures, it was still not possible to associate them with a specific taxonomic group. However, future analyses using scanning electron microscopy will be carried out and will likely reveal more details of the specimens. The impression-comprehension preservation type sometimes reveals 3D structures, which may also provide taphonomic information for the fossil assemblage.

The fossils were publicly exhibited on December 1, 2024, by the first author, under the patronage of the "Basra Education Directorate" and the "Mass Graves Protection Directorate" (Fig. 6). The fossils will be housed and cataloged at Basra Museum, so to be available for research by the international paleontological community.

Figure 6: *Photo from the fossil exhibition presented by the first author in Basra, December 2024.*

5. Conclusion

The new fossil discoveries, particularly of plants that are very rarely found in the Arabian Plate and invertebrates that were not studied in Iraq before, hold significant importance for understanding the environmental history and ancient ecosystems of the area.

The potential for fossil discoveries in Iraq is promising and more extensive exploration will surely yield more significant finds, contributing to the understanding of the Middle East ancient life.

Acknowledgments

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Research on taphonomy and ichnology in Brazilian caves: a scientometric analysis

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Resumo

Desde o trabalho pioneiro de Peter Wilhelm Lund no início do século XIX, as cavernas têm se tornado cada vez mais significativas para a pesquisa paleontológica no Brasil. Nesta perspectiva, conduzimos um estudo cienciométrico para investigar as pesquisas em tafonomia e icnologia dentro de cavernas brasileiras. Os dados foram coletados das bases de dados Scopus, Web of Science e Google Scholar, e gráficos foram gerados para descrever quantitativamente os dados. Também realizamos uma análise exploratória utilizando nuvens de palavras. Um conjunto de dados de 43 publicações de 2002 a 2024 foi compilado e analisado. A pesquisa tafonômica, predominantemente publicada em inglês, está geograficamente dispersa por nove estados brasileiros, com uma notável concentração na Bahia. O "Journal of South American Earth Sciences" foi identificado como o principal veículo de publicação para estudos de tafonomia e icnologia. A pesquisa icnológica, exclusivamente em inglês, também demonstra uma ampla distribuição geográfica, abrangendo oito estados brasileiros, embora a Bahia continue sendo um foco significativo das investigações icnológicas. Este estudo fornece uma visão geral abrangente da produção científica em paleontologia de cavernas no Brasil, permitindo o mapeamento de características-chave, lacunas e tendências neste campo de pesquisa.

Abstract

Since the pioneering work of Peter Wilhelm Lund in the early 19th century, caves have become significant repositories for paleontological research in Brazil. In this context, we conducted a scientometric study to investigate research in taphonomy and ichnology within Brazilian caves. Data were collected from the Scopus, Web of Science, and Google Scholar databases, and graphs were generated to quantitatively describe the data. We also performed an exploratory analysis using word clouds. A dataset of 43 publications from 2002 to 2024 was compiled and analyzed. Taphonomic research, predominantly published in English, is geographically dispersed across nine Brazilian states, with a notable concentration in Bahia. The "Journal of South American Earth Sciences" is identified as the primary publication venue for taphonomic and ichnology studies. Ichnological research, exclusively in English, also demonstrates a broad geographic distribution, spanning eight Brazilian states, though Bahia remains a significant focus of ichnological investigations. This study provides a comprehensive overview of scientific production in cave paleontology in Brazil, underlining the key characteristics, gaps, and trends in this research field.

Resumen

Depuis les travaux pionniers de Peter Wilhelm Lund au début du XIXe siècle, les grottes sont devenues des lieux de dépôt importants pour la recherche paléontologique au Brésil. Dans ce contexte, nous avons mené une étude scientométrique pour examiner la recherche en taphonomie et ichnologie au sein des grottes brésiliennes. Les données ont été collectées à partir des bases de données Scopus, Web of Science et Google Scholar, et des graphiques ont été générés pour décrire quantitativement les données. Nous avons également effectué une analyse exploratoire à l'aide de nuages de mots. Un ensemble de données de 43 publications de 2002 à 2024 a été compilé et analysé. La recherche taphonomique, principalement publiée en anglais, est géographiquement dispersée dans neuf États brésiliens, avec une concentration notable à Bahia. Le "Journal of South American Earth Sciences" est identifié comme le principal lieu de publication pour les études de taphonomie et d'ichnologie. La recherche ichnologique, exclusivement en anglais, démontre également une large distribution géographique, couvrant huit États brésiliens, bien que Bahia reste un axe important des investigations ichnologiques. Cette étude fournit un aperçu complet de la production scientifique en paléontologie des grottes au Brésil, permettant de cartographier les principales caractéristiques, lacunes et tendances dans ce domaine de recherche.

1. Introduction

The study of fossil deposits provides a comprehensive understanding of various aspects related to past organisms, including burial processes and the modifications undergone by organic remains from the moment of death to their discovery and collection (BEHRENSMEYER & KIDWELL, 1985; LYMAN, 1994). So, taphonomy and ichnology constitute distinct yet complementary fields of study that serve as essential tools for investi-

gating these transformative processes. Additionally, they are crucial for interpreting the paleoecological significance of fossil accumulations and reconstructing ancient ecosystems (BEHRENSMEYER & KIDWELL, 1985; ARAÚJO JÚNIOR & BISSARO-JÚNIOR, 2017; PAES-NETO & FRANCISCHINI, 2020). When considering Quaternary fossil deposits in Brazil, caves stand out as sites that preserve a large quantity of well-preserved fossils from this geological period (e.g., LUND, 1839 ; PAULA COUTO, 1959; CARTELLE & FONSECA, 1982 ; LESSA et al., 1998; PUJOS et al., 2023).

Since the early 19th century, cave deposits have played a pivotal role in Brazilian paleontological research, largely due to the pioneering studies conducted by the naturalist Peter Wilhelm Lund. His decade-long investigations in Brazilian limestone caves laid the foundation for subsequent research, fostering a long-standing scientific interest in these deposits (HOLTEN & STERLL, 2011). Over the following centuries, numerous researchers have continued to explore these environments, significantly advancing knowledge on Quaternary paleofauna (e.g., CARTELLE & MAHECHA, 1984; CARTELLE et al., 2008; HUBBE et al., 2011).

Despite the growing interest in cave paleontology, there has been a lack of comprehensive analyses assessing the research trends, focal areas, and gaps in the fields of taphonomy and ichnology in Brazilian caves.

Scientometric approaches offer a powerful tool for mapping scientific production, identifying key contributions, and guiding future investigations by highlighting knowledge gaps and emerging research directions.

From this perspective, the aim of this research was to conduct a descriptive and exploratory analysis of scientific publications in the field of taphonomy and ichnology in Brazilian caves using the scientometric method. Providing an overview and insights that can support future research initiatives, contributing to the advancement of knowledge in these scientific domains.

2. Materials and Methods

To analyze the publications on “taphonomy and ichnology in caves”, we collected the articles from the Scopus, Web of Science, and Google Scholar databases. Data from Scopus and Web of Science were extracted directly from their interfaces, accessed through the CAPES (Coordination for the Improvement of Higher Education Personnel) Portal.

On the other hand, we obtained data from Google Scholar using the web scraping technique, an approach that allows the automated extraction of information from the World Wide Web (WWW), which was then stored in file systems or databases for analysis (KUMARESAN & RAMANUJAM 2016).

To search for articles in these databases, we used the following combination of descriptors: “(cave OR karst OR toca OR gruta OR lapa) AND (taphonom? OR ichnology)” in the title, abstract, and keyword fields, focusing on Brazil, without any temporal restrictions.

After completing the data collection, cleaning, and organization procedures, we obtained a CSV file containing the following variables: title, journal, Brazilian state of the studied caves, year of publication, area of paleontology addressed in the article, and language.

For the automated data retrieval through web scraping, the Python libraries Selenium and BeautifulSoup were employed. We conducted the exploratory analysis step using the Pandas, NumPy, Matplotlib, Seaborn, Geopandas, and WordCloud libraries in Python, version 3.8.16.

3. Results

The final dataset includes 43 records, featuring articles published from 2002 to 2024. Out of these, 33 articles exclusively focused on taphonomic analyses, seven included only ichnological analyses, and two studies covered both types.

3.1. Taphonomic research

We observed that there was a substantial increase in scientific output related to taphonomy in 2020 and 2022 (Figure 1).

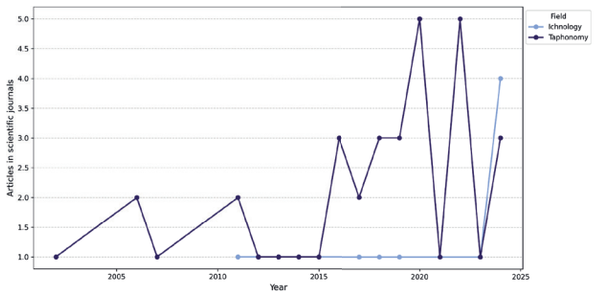

Figure 1: *Chronological development of the scientific research on taphonomy and ichnology in Brazilian caves per year.*

Regarding the language, researchers published 72.2% of the taphonomy studies in English, 25.0% in Portuguese, and only 2.8% in Spanish.

In relation to the geographical distribution of the deposits, taphonomy studies were carried out across nine Brazilian states (Figure 2). The majority of the investigations into taphonomy were concentrated in Bahia State. Minas Gerais was the second most common state observed in the studies.

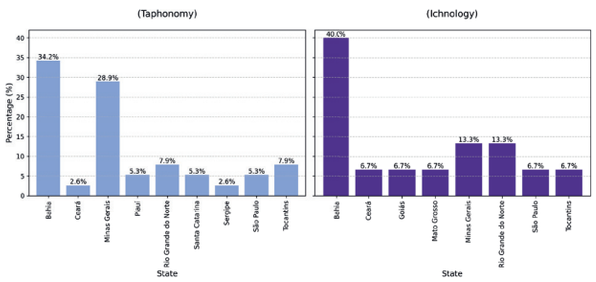

Figure 2: *Relative percentage frequency of the number of studies in taphonomy for Brazilian states.*

The study of the most common keywords in taphonomy articles showed that terms like «Taphonomy,» «Quaternary,» and «Brazil/Brasil» appear frequently (Figure 3).

In terms of journals, the «Journal of South American Earth Sciences» and «Palaeogeography, Palaeoclimatology, Palaeoecology» are the primary venues for taphonomy research, each representing approximately 14.0% of the publications. The «Revista Brasileira de Paleontologia» follows with approximately 8.0%.

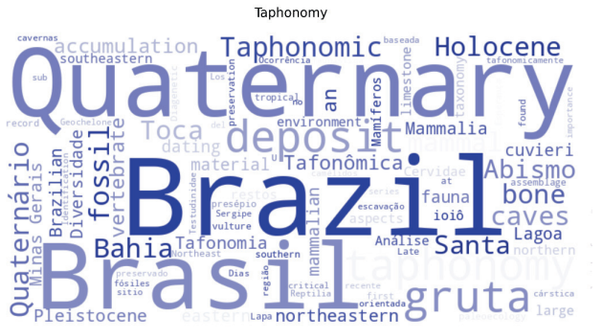

Figure 3: Word cloud of the most frequent words in the titles of taphonomy articles.

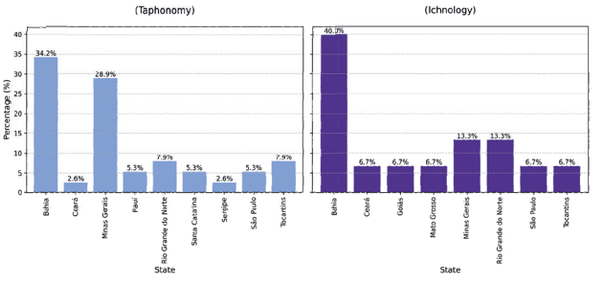

Figure 4: Relative percentage frequency of the number of studies in ichnology for Brazilian states.

Figure 5: Word cloud of the most frequent words in the titles of ichnology articles.

In terms of language, all published studies were in English. The analysis of the titles with the most recurrent keywords revealed the prevalence of terms such as «Brasil,» «Brazilian,» «Pleistocene,» and «Quaternary» in ichnology articles (Figure 5).

Considering the journal of publication, the "Journal of South American Earth Sciences" also had the highest number of articles (approximately 11.00%).

4. Discussion

Regarding the caves, while these environments contain a significant fossil record, there is a noticeable scarcity of investigations focused on understanding the preservational processes that have affected fossils within these deposits. Considering that there are currently over 20,000 known and cataloged caves in Brazil in the Geospatial Database of Caves of Brazil (ICMBio, 2023), studies integrating fossil data with their depositional context in these environments are relatively recent and remain infrequent in the scientific literature. The majority of research is directed towards other lines of investigation, such as taxonomy and paleoecology (e.g., CARTELLE & HARTWIG, 1996; ARAÚJO et al., 2016; CARTELLE et al., 2008; DANTAS et al., 2021; ALVES-SILVA et al., 2023; LIMA et al., 2023). Considering the ichnological research, there is an even greater scarcity of studies on fossils from karst environments, limiting not only the understanding of potential traces and their ecological contexts but also aspects of systematic ichnology, which are essential for the identification and differentiation of traces.

The highest number of publications in English may reflect an attempt to internationalize the research. English gained acceptance as the *lingua franca* in science (BORDONS & GÓMEZ, 2004). A text written in English has the potential to reach a broader audience (DI BITETTI & FERRERAS, 2017), thereby integrating Brazilian research more effectively into the international community. Furthermore, the articles published in English have a higher number of citations than those published in other languages (DI BITETTI & FERRERAS, 2017).

In relation to the states with the highest number of studied deposits, a notable element contributing to the prevalence of cave-related studies in Minas Gerais and Bahia is the substantial quantity of deposits present in these states. In Brazilian karst environments, the states of Minas Gerais and Bahia out for their abundance of caves, ranking as the first and third Brazilian states with the highest number of cataloged caves, respectively (ICMBIO, 2023).

The presence of the Quaternary as one of the most frequent terms in the word clouds of taphonomy studies is justified by the fact that, when considering Brazil's Quaternary fossil deposits, caves and natural tanks stand out as sites that preserve a large quantity of fossils from this geological period.

5. Conclusion

Studies on the contexts and preservation states of fossils in caves remain scarce, and this gap becomes even more evident when considering ichnology.

The absence of thorough investigations into the taphonomic processes in these environments compromises the comprehension of fossil deposit formation and may result in limited interpretations of the paleontological record. From this perspective, it is essential to develop new studies that address both the cave-specific taphonomic mechanisms and ichnology, thereby expanding knowledge on paleoecological interactions and fossilization processes in these subterranean systems.

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Record of Teiidae (Squamata) in Toca da Trincheira, Bahia: implications for the quaternary herpetofauna

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Resumo

A Toca da Trincheira, localizada na Bahia, abriga um registro fóssil de Teiidae (Squamata) datado do Quaternário. O material analisado consiste em um fragmento de dentário direito, atribuído ao gênero Salvator (Tupinambis) com base em características dentárias, como a presença de dentes posteriores rombudos e molariformes, indicativos de hábitos alimentares especializados. A caverna está inserida em um ambiente semiárido da Caatinga, caracterizado por formações carbonáticas da Formação Caatinga. O registro fósil amplia o conhecimento sobre a distribuição dos Teiidae no Brasil e reforça a importância dos depósitos cavernícolas para estudos paleontológicos. Comparações morfológicas com representantes atuais e fósseis permitiram a identificação do espécime, embora uma determinação específica não tenha sido possível devido à fragmentação do material. A presença desse fóssil sugere um ambiente pleistocênico diversificado e contribui para a reconstituição paleoambiental da região. Os resultados corroboram a relevância das cavernas como locais de preservação da herpetofauna extinta, evidenciando sua contribuição para o entendimento da evolução e biogeografia dos Teiidae na América do Sul.

Abstract

The Toca da Trincheira, located in Bahia, preserves a Quaternary fossil record of Teiidae (Squamata). The analyzed material consists of a fragment of a right dentary, attributed to the genus Salvator (Tupinambis) based on dental characteristics, such as the presence of robust, molariform posterior teeth, indicative of specialized feeding habits. The cave is situated in the semi-arid Caatinga environment, characterized by carbonate formations of the Caatinga Formation. This fossil record expands the knowledge of Teiidae distribution in Brazil and reinforces the importance of cave deposits for paleontological studies. Morphological comparisons with both extant and fossil representatives enabled the identification of the specimen, although a specific determination was not possible due to the fragmentation of the material. The presence of this fossil suggests a diverse Pleistocene environment and contributes to the paleoenvironmental reconstruction of the region. The results corroborate the relevance of caves as preservation sites for extinct herpetofauna, highlighting their contribution to understanding the evolution and biogeography of Teiidae in South America.

Resumen

La Toca da Trincheira, située en Bahia, abrite un registre fossile de Teiidae (Squamata) datant du Quaternaire. Le matériel analysé se compose d'un fragment de dentaire droit, attribué au genre Salvator (Tupinambis) sur la base de caractéristiques dentaires, telles que la présence de dents postérieures robustes et molariformes, indicatrices d'habitudes alimentaires spécialisées. La grotte est située dans un environnement semi-aride de la Caatinga, caractérisé par des formations carbonatées de la Formation Caatinga. Ce registre fossile enrichit les connaissances sur la répartition des Teiidae au Brésil et renforce l'importance des dépôts cavernicoles pour les études paléontologiques. Des comparaisons morphologiques avec des représentants actuels et fossiles ont permis l'identification du spécimen, bien qu'une détermination spécifique n'ait pas été possible en raison de la fragmentation du matériel. La présence de ce fossile suggère un environnement pléistocène diversifié et contribue à la reconstitution paléoenvironnementale de la région. Les résultats confirment la pertinence des grottes en tant que sites de préservation de l'herpétofaune éteinte, mettant en évidence leur contribution à la compréhension de l'évolution et de la biogéographie des Teiidae en Amérique du Sud.

1. Introduction

The Quaternary record of lizards is predominantly composed of disarticulated fragments and exhibits significant taxonomic diversity. In South America, including Brazil, fossil records of representatives from the families Iguanidae, Liolaemidae, Teiidae, Leiosauridae, and Gekkonidae have been documented (RUSCONI, 1937; HOFFSTETTER, 1970; VAN DEVENDER, 1977; ESTES, 1983; DONADIO, 1984; DE LA FUENTE, 1999; ALBINO, 2005). In Brazilian territory, this record is particularly diverse, encompassing fossils of Tropiduridae, Teiidae, Leiosauridae,

Polychrotidae, Gekkonidae, and Anguidae. Among these families, Teiidae is the most frequently recorded, with multiple findings in Pleistocene sites (HSIOU, 2007; CAMOLEZ & ZAHER, 2010; HSIOU et al., 2012, 2016).

This study aims to report the occurrence of Teiidae in a cave in Bahia, contributing to the understanding of the composition and distribution of the herpetofauna throughout the Quaternary.

2. Materials and Methods

The specimen consists of a fragment of a right dentary (LIFE 002), which is housed in the fossil collection of the Instituto Federal de Educação, Ciência e Tecnologia do Sertão Pernambucano, Petrolina, Pernambuco. The material was collected from a limestone cave known as Toca da Trincheira. The osteological nomenclature follows PRESCH (1974), ESTES (1983), NYDAM & CIFELLI (2002), and BRIZUELA & ALBINO (2010). The systematic organization follows VENCZEL & CODREA (2015).

Toca da Trincheira (WGS84-UTM 292494 m E 881988 m N) is a limestone cave located at the border between the municipalities of Mirangaba and Ourolândia, in the northern region of the state of Bahia (see, ARAUJO et al., 2019). Situated within the Salitre River Basin, a sub-basin of the São Francisco River (SILVA, 2006), the area surrounding the cave is characterized by predominantly sparse, shrubby vegetation, typical of the Caatinga biome. The climate is semi-arid, with an average annual precipitation of approximately 490 mm, concentrated between February and May, and an average temperature of around 30 °C (AULER et al., 2009).

The cave (Figure 2) is embedded in carbonate rocks of the Caatinga Formation, which consists of Cenozoic-age limestones (AULER & SMART, 2001). Its morphology includes a main conduit measuring 140 m in length and 20 m in width, as well as two points where water emerges in shallow pools, forming a lentic environment.

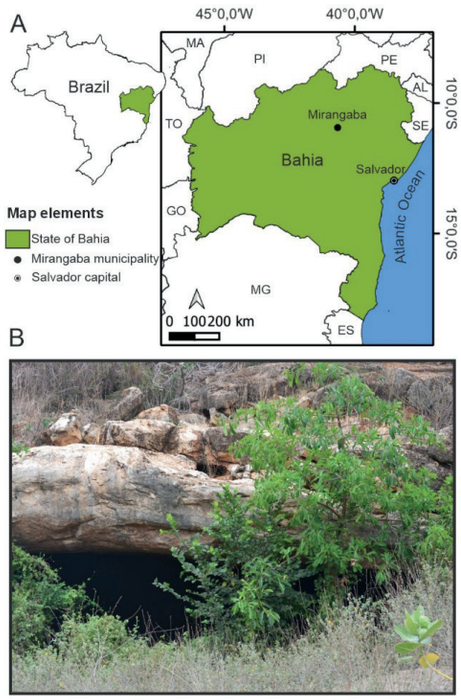

Figure 1: *Location map of Toca da Trincheira. A, location of the municipality of Mirangaba, Bahia; B, entrance to Toca da Trincheira.*

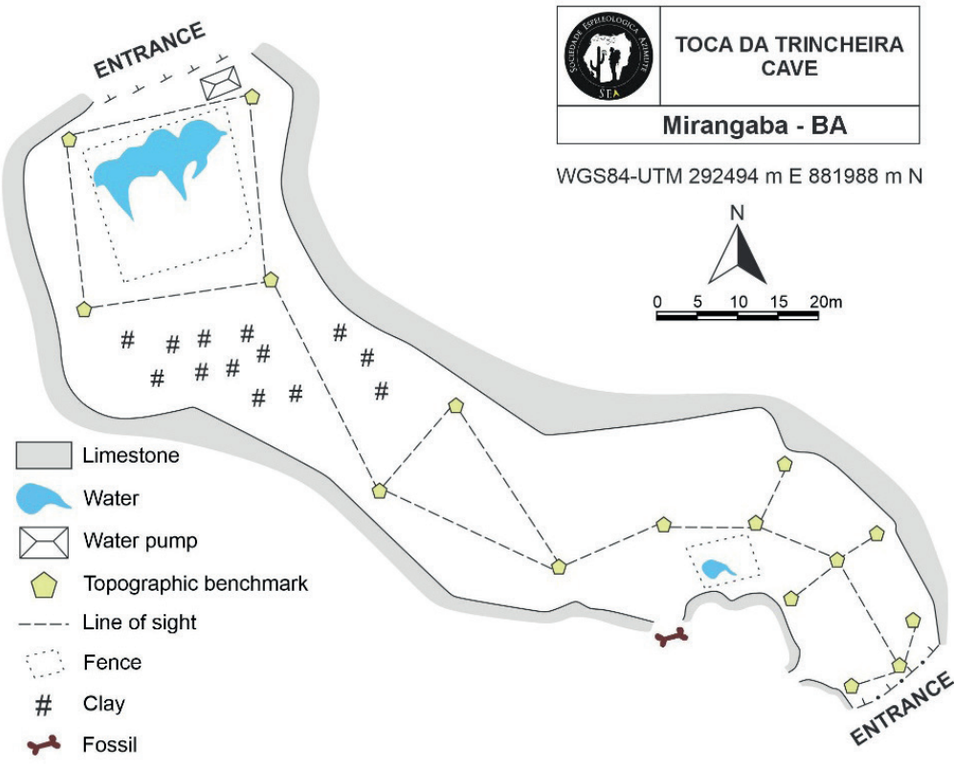

Figure 2: *Topographic map of Toca da Trincheira, Mirangaba, Bahia. Adapted from Araújo et al., 2019.*

3. Resultados e Discussão

Order SQUAMATA Oppel, 1811
Suborder SCLEROGLOSSA Estes et al., 1988
Infraorder SCINCOMORPHA Camp, 1923
Superfamily TEIOIDEA Estes et al., 1988
Family TEIIDAE Gray, 1827
Subfamily TUPINAMBINAE Bonaparte, 1831
Genus Tupinambis Daudin, 1802
Salvator (Tupinambis)
(Figure 3)

Referred specimen. LIFE 002, fragment of a right dentary.

Locality. Toca da Trincheira, located between the municipalities of Mirangaba and Ourolândia, Bahia, Brazil (WGS84-UTM 292494 m E 881988 m N).

Description. The right dentary fragment (LIFE 002) is well preserved, displaying both the buccal and lingual surfaces, the latter featuring a subdental shelf. The specimen has nine dental alveoli, with the first lacking preserved dentition, while the others show enamel wear, particularly in the occlusal region. The curvature of the alveolar region increases distally, becoming more pronounced from the fifth alveolus onward.

According to BRIZUELA & ALBINO (2010), the four anterior teeth exhibit a tricuspid morphology, with a blunt central cusp, and are robust and large, with the first three showing a slight distal inclination. In contrast, the four posterior teeth are smaller, with reduced occlusal height and narrower buccolingual dimensions. These morphological characteristics allow for the interpretation of these teeth as molariform.

Comments. The specimen LIFE 002 exhibits dental characteristics consistent with Teiidae, including heterodont dentition, with variation along the dental row, and the development of flattened molariform teeth (PRESCH, 1974; ESTES, 1983; HSIOU et al., 2016). Within Tupinambinae, it presents subpleurodont dentition, basal attachment with extensive cement deposits, and a well-developed sulcus dentalis (NYDAM et al., 2007; HSIOU et al., 2016).

The fossil specimen is distinguishable from Crocodilurus and Callopistes, in which the lower jaw teeth are isodont, strongly recurved, and pointed (PRESCH, 1974; EVERS-JUNIOR & SOARES, 2007; HSIOU et al., 2016), contrasting with the blunt and nearly vertical teeth observed in the described specimen. Dracaena exhibits a distinct dental pattern within the group, with blunt and isodont anterior teeth, while the posterior ones show anteroposterior expansion, forming «crushing plates» (PRESCH, 1974; HSIOU et al., 2016).

In adult individuals of Tupinambis, the anterior teeth are typically isodont and recurved, while the posterior teeth are blunt and isodont (PRESCH, 1974; BRIZUELA & ALBINO, 2010), a pattern observed in the specimen analyzed in this study.

Due to the great diversity within the genus and the lack of detailed studies, we chose not to propose a more precise identification for the specimen, which is identified only at the genus level.

Figure 3: *Salvator (Tupinambis), LIFE 002, fragment of the right dentary; A, lateral view; B, medial view; C, occlusal view. Scale: 10 mm.*

4. Conclusion

Fossil records of Teiidae in South America are well represented throughout the Cenozoic, although the fragmentation of materials often hinders precise taxonomic identification. In this study, the specimen from Toca da Trincheira was assigned to Tupinambis based on dental and mandibular characteristics, particularly the presence of robust molariform posterior teeth, which indicate predatory habits adapted for crushing hard prey.

The presence of this fossil suggests a diverse Quaternary environment and contributes to expanding the record of Teiidae in South America.

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Fossil record of platyrrhine primates in brazilian caves: new report of *Alouatta* sp.

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Abstract

Platyrrhine remains are occasionally found in Quaternary paleontological and archaeological contexts in the Neotropics, but these remains typically belong to extant species. The only known exceptions come from two geographical regions—the Greater Antilles and eastern and northeastern Brazil—where extinct platyrrhines from the late Quaternary have been discovered. In nearly all cases, these remains were found in cave deposits, emphasizing the crucial role of speleological sites in preserving Neotropical fossils and enhancing our understanding of platyrrhine diversity and evolution. In this paper, we describe a cranial fragment from the late Pleistocene site of Toca Fria in southwestern Bahia, Brazil. Morphological and metric traits allow us to conclude that this specimen closely resembles the howler monkey (*Alouatta* sp.).

1. Introduction

Primate fossils are rare in the fossil record, yet they provide valuable insights into recent climatic and environmental changes. The presence of Neotropical primate fossils from the Quaternary has been known since the early 19th century, beginning with Peter Wilhelm Lund's (1840) reports on the Pleistocene fauna of caves in eastern Brazil. Notably, the first correctly identified and named primate fossils were discovered in July 1836 by Lund at Lapa de Periperi, a cave system in Lagoa Santa, Brazil. Based on these remains, a left proximal femur and a right distal humerus—Lund described *Protopithecus brasiliensis* in a letter dated November 16, 1837. His findings were first published in 1838 and later republished in several European journals (LUND, 1840).

After long periods without new discoveries, significant fossil material has since been collected, shedding light on the origin, evolutionary history, and paleobiogeography of platyrrhines, particularly since the 1990s (RIVERO & ARREDONDO, 1991; MACPHEE & FLEAGLE, 1991; MACPHEE et al., 1995). In 1993, Castor Cartelle announced the discovery of two nearly complete skeletons, found by Grupo Bambuí de Pesquisas Espeleológicas in 1992 in Toca da Boa Vista, a large cave in Bahia, Brazil. HARTWIG & CARTELLE (1996) attributed one of these skeletons to *Protopithecus brasiliensis*. The second skeleton belonged to a previously unknown large-bodied ateline (approximately 20 kg), which CARTELLE & HARTWIG (1996) named *Caipora bambuiorum*. The genus name "Caipora" means "dweller in the wood" and references an Amerindian legend about a large monkey inhabiting the Brazilian highlands (LUND, 1840).

Further investigations of these two skeletons revealed that the material initially attributed to *Protopithecus* differed significantly from the fossils originally described by Lund in 1836. As a result, a new genus and species, *Cartelles coimbrafilhoi*, was proposed to accommodate the material found in 1992 (HALENAR & ROSENBERGER, 2013; COOKE et al., 2016).

In addition to these extinct taxa, fossils of extant primate species have also been recorded. Lund documented several primate fossils from caves in Lagoa Santa, Minas Gerais, including *Alouatta caraya* (Humboldt, 1812), *Cebus apella* (Linnaeus, 1758), *Callithrix penicillata* (É. Geoffroy, 1812), and *Callicebus personatus* (É. Geoffroy, 1812) (CARTELLE, 2012). More recent discoveries of extant primate fossils in Brazilian caves include:

2. A fossilized capuchin monkey (*Cebidae*) skull from a limestone cave in Ubajara National Park, Ceará (XIMENES & MACHADO, 2004).
3. *Alouatta mauroi*, an extinct howler monkey species from the Pleistocene of Bahia, found in Lapa dos Brejões (TEJEDOR et al., 2008).
4. A skull and right femur belonging to a female of *Alouatta* sp. found in Clóvis Saback I cave, located in Tiquara, Campo Formoso, Bahia (ARAÚJO et al., 2016).
5. A fragment of a left jaw of *Alouatta* sp. and a skull of *Cebus* sp. from Lapa do Bode cave, Ituaçu, Bahia (LEONI et al., 2023).

The present study aims to contribute to the growing record of platyrrhine fossils by documenting new skeletal material from Brazilian speleological sites, providing further insights into the region's primate paleobiology.

2. Materials and Methods

The partial cranium (LEG 3356, Figure 1) which is housed in the fossil collection of the Laboratório de Ecologia e Geociências (LEG) in the Universidade Federal da Bahia, campus Anísio Texeira, Vitória da Conquista, Bahia. Was found at the Toca Fria in the karst region of Iuiú, located in the municipalities of Iuiú, state of Bahia, Brazil (Figure 2). This karstic region is situated at the hydrographic right of Sao Francisco River between the coordinates 14°28'2.41" S and 43°34'31.38" W at 794 m above sea level (CARDOSO et al., 2021). It is inserted in the sub-region of Sao Francisco, in the biogeographic domain of Caatinga under BSh climate Koppen category (semi-arid) (ALVARES et al. 2013). Serra de Iuiu presents vegetation composed of deciduous and semideciduous forests, besides limestone outcrops vegetation (APGAUA et al. 2014).

Figure 1: partial cranium LEG 3356 in superior view.

The taxa were categorized according to taxonomic classifications from RYLANDS & MITTERMEIER (2009). To make a comparison, the cranial measurements follow those presented by GREGORIN, 2006 and WRIGHT et al., 2015. Orbital width (OW), Bi-orbital width (BOW), Inter-orbital width (IOW) and Post-orbital constriction (POC). Linear measurements of the cranium were taken by A.V.A. using Stratovan Checkpoint software on surface scans. The surfaces are scanned with a Revopoint handheld scanner by A.V.A. The 3D surface files from living primates used here were shared by Dr. Lauren Halenar-Price, Dr. Sergio Almécija, Dr. Ashley Hammond, Dr. Jeffrey Spear and downloaded from Morphosource (BOYER et al., 2016).

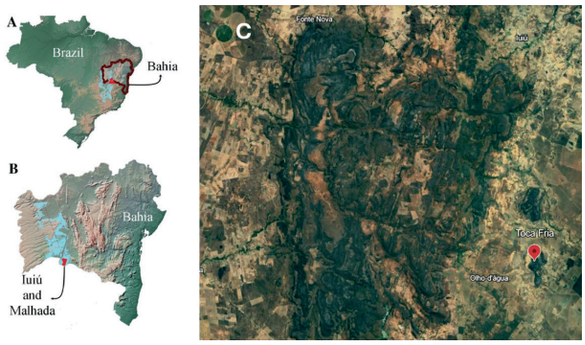

Figure 2: Location map of the Toca Fria.

3. Results

Systematic palaeontology

Primates Linneaus, 1758.
Haplorhini Pocock, 1918.
Platyrrhini Geoffroy, 1812.
Atelidae Gray, 1825
Subfamily Alouattinae Elliot, 1904
Genus Alouatta Lacépede, 1799

Referred specimen. LEG 3356, fragment of cranium.
Locality. Toca Fria, located the municipalities of Iuiú, state of Bahia, Brazil (WGS84- UTM 645 260 S 8,397 588 E).

Description. A partial cranium preserved the upper orbits with part of nasion and anterior part of frontal and parietal bones.

Comments. The specimen is a platyrrhine primate with size in range of the largest Cebids and Atelids. The inter-obital area is extremely different between the genera of Cebidae and Atelidae. Among all the genera *Alouatta* and *Brachyteles* are those with the broad inter-orbital area (table 1). The fossil specimen is distinguishable from *Brachyteles* in size related to the width of the orbits and due a more pronounced post-orbital constriction.

Taxon	sex	n	OW			BOW			IOW			POC		
			Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
LEG 3356	U	1		**18**			**51.3**			**11**			**39.5**	
Alouatta belzebul	M	2	21.2	20.4-22	1.13	62.45	61.9-63	0.77	12.1	11.3-13	1.2	34.7	33.4-36	1.83
	F	3	19.3	18.8-20	0.62	53.4	52.3-55.1	1.45	10.3	8.7-11.2	1.38	39.4	38.5-40.3	0.9
Alouatta caraya	M	4	19.7	18-21.3	1.35	56.5	54-59	2.04	11	10.7-11.3	0.38	33.5	30.9-37	2.68
	F	2	18.7	18.1-19.4	0.91	49.5	48.1-50.9	1.97	9.55	8.9-10.2	0.91	33,6	33.5-33.8	0.21
Alouatta guariba	M	2	22	21.4-22.7	0.91	54.8	54.3-55.3	0.70	9.95	9.2-10.7	1.06	36.7	33.1-40.7	5.1
	F	2	18.6	17.2-20.1	2	49.9	47.8-52	2.9	8.9	8.3-9.5	0.84	35.8	35.1-36.6	0.98
Alouatta ululata	U	5	22.4	18.8-29.8	4.3	59	51.4-63.9	5	11.9	8.7-14.8	2.2	38.7	33.5-40.5	2.9
Ateles geoffroyii	M	3	19.4	19-20.2	0.6	53.6	51.4-55.1	1.98	8.5	7.8-9.1	0.6	43.2	42.5-44.7	1.24
	F	3	19.5	18.5-20.2	0.92	55.1	51.4-58.8	3.7	8	6.7-9.5	1.41	44.9	41.9-47.8	2.95
Lagothrix lagotrhica	M	3	19.4	16.8-21.4	2.37	57.8	55-62.7	4.25	7.53	7.3-7.8	0.25	39.4	37.4-41	1.84
	F	3	19.6	16.8-22	2.64	55.2	55-55.8	0.52	6.9	5.8-7.5	0.98	39.4	34.8-43.6	4.41
Brachyteles arachnoides	M	3	20.6	20.3-21	0.35	59.2	56.8-61	2.1	11	8.9-11	1.15	44	42.1-46.4	2.18
	F	3	19.8	19.6-20.1	0.25	58,5	56,4-61	2.3	10.4	9.5-11.8	1.22	42.4	40.2-45.3	2.62
Sapajus apella	M	8	15.8	15.2-17.4	0.87	45.4	40.9-47.8	2.7	6.08	4.4-8	1.14	37.3	34.6-39.7	1.65
	F	5	15.3	13.6-17.4	1.92	45.7	43.1-53.3	4.2	7.1	6.3-8.1	0.71	38.4	36.8-40.3	1.42
Sapajus libidinosus	M	5	16.5	14-17.8	1.47	47	40-55	5.6	5.5	4-7.7	1.34	35.9	34.3-40	2.3
	F	3	15.8	14.3-17.2	1.48	44.1	39.7-48.3	4.3	5.1	4.6-5.5	0.21	33.9	32.1-34.6	1.64
Cebus sp.	M	4	17.2	16.2-17.8	0.44	45.7	42.4-48.6	2.2	5.45	5.1-6.7	0.83	40.5	39.4-42.2	1.25
	F	3	14.7	13.1-16	1.49	39.1	36.5-42.2	2.86	5.1	3.3-6.4	1.6	37.2	35.1-38.5	1.88

Table 1: Measurements (in mm) describing the size of the orbits of selected platyrrine primates species.

4. Discussion

The size and morphologie of LEG 3356 closely resemble those of the genus *Alouatta* mainly in the inter-orbital area. Acoording to BRUNER et al., (2004) the inter-orbital area represents a very important source of information because of its role in relationship between face and vault in the skull of *Alouatta*. This spatial relationship of the face in relation to the neurocranium could be responsible for the howlers' bone arrangement at the infratemporal fossa and interorbital area, which is different from common platyrrhine schemes (WALLNER, & RÖHRER-ERTL, 2005). Accor-

ding to GREGORIN (2006) the current distribution of Alouatta closest to the area of the present study includes: *A. caraya*; *A. belzebul*; *A. guariba* and *A. ululata*. The material presented here is considered insufficient for safe specific attribution. Therefore, it was preferred to maintain its classification only at genus level.

5. Conclusão

Absolute dating has not yet been carried out on this material, and a more precise chronostratigraphic position is not currently possible. With this information, we will know whether the specimen presented here lived at the same time as the great extinct primates already known from the region, such as *Cartelles coimbrafilhoi, Caipora bambuiorum* and *Alouatta mauroi*. Furthermore, the dating of this material, and the other taxa found in association in this speleological site, may help us to infer what the vegetation physiognomy of the environment in which they lived was like, and allow us comparisons with current conditions.

Finally, we will classify this material as belonging to the late Pleistocene - Holocene, considering that the temporal resolution found in caves is very low, as fossils with ages ranging from 300 thousand years to 10 thousand years can be found in association in the same cavity.

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Late pleistocene giant sloths from brazilian intertropical region: adaptation to aquatic lifestyle?

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Abstract

In recent years, efforts have been made to generate new information to elucidate the paleoecology of giant sloths inhabiting historically stable areas of the Brazilian Intertropical Region. Radiocarbon data suggest their occurrence until the Late Pleistocene, whereas stable carbon isotopes and morphological indices indicate niche differentiation among the nine extinct giant sloth taxa. This study aimed to evaluate the compactness of the ribs and humeri of the species *Nothrotherium maquinense*, *Ahytherium aureum*, *Valgipes bucklandi*, *Catonyx cuvieri*, and *Eremotherium laurillardi* to assess potential adaptations to an aquatic lifestyle. These results suggest that none of these species has adapted to an aquatic lifestyle.

1. Introduction

Currently, nine species of extinct giant sloths are recognized in the historically stable area of the Brazilian Intertropical Region (BIR sensu Dantas et al., 2024a): *Nothrotherium maquinense* (average body mass - bm = 134 kg), *Ahytherium aureum* (bm = 214 kg), *Australonyx aquae* (bm = 296 kg), *Valgipes bucklandi* (bm = 703 kg), *Catonyx cuvieri* (bm = 901 kg), *Glossotherium phoenesis* (bm = 936 kg), *Ocnotherium giganteum* (bm = 1188 kg), *Mylodonopsis ibseni* (bm = 1,621 kg), and *Eremotherium laurillardi* (bm = 3,144 kg) (Cartelle and Fonseca, 1983; Cartelle, 1991; 1992; Cartelle and De Iuliis, 1995; 2006; Cartelle et al., 2008; 2009; De Iuliis et al., 2009; Cartelle et al., 2019; Dantas et al., 2024b).

In recent years, there has been increasing effort to generate new information to elucidate the paleoecology of giant sloths inhabiting the BIR. All available radiocarbon data suggest their occurrence until the Late Pleistocene (42 ka to 12 ka; Dantas and Cherkinsky, 2023), whereas carbon stable isotopes (e.g. Omena et al., 2021 and references therein) and morphological indices (Santos et al., 2024) indicate niche differentiation between extinct giant sloth taxa.

In low-density forest habitats, *N. maquinense*, *A. aureum*, and *Au. aquae* resided, all of which exhibited a browser diet with substantial consumption of C3 plants ($pi C_3 > 80\%$) and climber habits. In arboreal savanna habitats, *Catonyx cuvieri*, *Ocnotherium giganteum*, and *Valgipes bucklandi* were present, all with a mixed feeder diet, consuming more C_3 plants ($pi C_3 > pi C_4$); however, only *C. cuvieri* and *O. giganteum* were potentially capable of exploring roots. Finally, in the ecotone of arboreal to open savanna habitats, *Glossotherium phoenesis*, *Mylodonopis ibseni*, and *Eremotherium laurillardi* were found, with a mixed-feeder diet rich in C_4 grass ($pi C_3 < pi C_4$), with only *G. phoenesis* and *M. ibseni* capable of exploring the roots.

While efforts have been made to elucidate the paleoecology of giant sloths, the potential for adaptation to an aquatic lifestyle has not been evaluated until now. Adaptation to aquatic life induces several bone modifications. In tetrapods, these changes are observed in the internal and histological architecture, demonstrating an increase in density and mass resulting from greater compaction of the internal bone architecture (osteosclerosis) (Buffrénil et al., 2010). This phenomenon is attributed to excessive deposits of secondary lamellar bone during intense remodeling, which occurs predominantly in the medullary region of the long bones and ribs (Houssaye, 2012). Osteosclerosis is evident in the bone skeletons of several groups of fossil and extant aquatic animals such as Mesozoic reptiles (Houssaye, 2012). Among avian species, divers exhibit a high degree of osteosclerosis (Medonza and Tambussi, 2015). Sirenians also exhibit this condition (Buffrénil et al., 2010). Buffrénil et al. (2010) posited that such modifications serve hydrostatic functions and contribute to the regulation of buoyancy and body balance in aquatic environments.

Therefore, this study aims to evaluate whether certain extinct giant sloth taxa potentially exhibited adaptations to an aquatic lifestyle.

2. Materials and methods

2.1. Material

Fractured ribs and humeri, recovered from five caves and one tank of Bahia state (Figure 1), of the following taxa were analyzed for this study: four specimens of *Nothrotherium maquinense* (specimen 1, rib LEG 1325 and humerus LEG 1359; specimen 2, humerus LEG 2497; specimen 3, rib LEG 0528; specimen 4, rib LEG 1233); one specimen of *Ahytherium aureum* (rib LEG 2279 and humerus LEG 1494); one specimen of *Valgipes bucklandi* (rib LEG 1710 and humerus LEG 1870), one specimen of *Catonyx cuvieri* (rib LEG 2936); two specimens of *Eremotherium laurillardi* (specimen 1, rib LEG s/n; specimen 2, humerus LEG 1871). All specimens are housed in the Scientific Collection of the Laboratório de Ecologia & Geociências of the Universidade Federal da Bahia, campus Anísio Teixeira (Vitória da Conquista, Bahia).

2.2. Bone compaction analysis

Histological sections of the fractured ribs and humerus, which facilitate examination of the microstructure and histology of the osseous tissue, were photographed, digitally processed, and subsequently

converted to bitmap format utilizing Corel Draw X6® (Figure 1). For the ribs, it is not possible to ensure that the observed fractures occurred at the midlength of the bone. In the humerus, the fracture occurred (considering the proximal epiphysis) at ~31% in *A. aureum*, ~39% in *V. bucklandi*, ~68% in *N. maquinense*, and ~57% in *E. laurillardi*.

To evaluate whether the studied taxa exhibited adaptations to aquatic life, considering that this habitat induces skeletal modifications, such as increased density and mass, resulting in greater bone compaction (osteosclerosis), the bone profileR program (Girodont and Laurin, 2013) was utilized to assess bone compaction. Canoville and Laurin (2010) suggest that terrestrial mammals had a mean value of observed compactness for ribs and humerus of 0.566, while Amson et al. (2014) propose a value above 0.850 for the aquatic sloth *Thalassocnus spp.* (unique giant sloth taxa adapted to an aquatic lifestyle), which will be used to interpret whether the extinct giant sloth taxa from the BIR could be adapted to an aquatic lifestyle.

3. Results and discussion

The The bone compactness observed in the ribs (0.479±0.177) was significantly higher than that observed in humeri (0.393±0.118) across all studied taxa. It was noted that Nothrotherium maquinense (rib = 0.611; humerus = 0.378; Figure 1) and Eremotherium laurillardi (rib = 0.714; humerus = 0.554; Figure 1), both classified as members of the Megatheriidae family, exhibited the highest values, followed by members of the Scelidotheriidae family, Catonyx cuvieri (rib = 0.421; Figure 1) and Valgipes bucklandi (rib = 0.344; humerus = 0.369; Figure 1). Megalonychiidae Ahytherium aureum (rib = 0.304; humerus = 0.269; Figure 1) had the lowest values.

Taxa/locality	Observed compacity			
	rib	sample	humerus	sample
Nothrotherium maquinense				
Gruta da Marota, Andaraí/BA	0.648	LEG 1325	0.414	LEG 1359
Toca da Barriguda, Campo Formoso/BA	-	-	0.343	LEG 2497
Toca da Barriguda, Campo Formoso/BA	0.696	LEG 0528	-	-
Toca da Barriguda, Campo Formoso/BA	0.488	LEG 1233	-	-
Ahytherium aureum				
Gruta do Engrunado, Nova Redenção/BA	0.304	LEG 2279	0.269	LEG 1494
Valgipes bucklandi				
Gruta do Engrunado, Nova Redenção/BA	0.344	LEG 1710	0.369	LEG 1870
Catonyx cuvieri				
Gruta da Aventureira, Campo Formoso/BA	0.421	LEG 2936	-	-
Eremotherium laurillardi				
Tanque, Campo Formoso/BA	-	-	0.554	LEG 1871
Toca Fria, Iuiu/BA	0.714	LEG s/n	-	-

Figure 1: *Observed compacity in ribs and humerus for five extinct giant sloth taxa from six localities in Bahia, Brazil.*

The observed compactness in the members of the families Scelidotheriidae and Megalonychiidae is below the mean values observed in terrestrial mammals (rib/humerus = 0.566) by Canoville and Laurin (2010), suggesting that all these taxa were adapted to a terrestrial lifestyle.

Although members of the Megatheriidae family presented values higher than the mean values for terrestrial mammals, these values were lower than those observed for the aquatic sloth species of Thalassocnus spp. (rib/humerus = 0.850), indicating that these taxa also adapted to a terrestrial lifestyle. These higher values corroborate the observation made by Amson et al. (2014) that the elevated values observed in some clades could be a preexisting condition, not related to adaptation to an aquatic lifestyle.

4. Conclusion

The bone compactness observed in the ribs and humeri of the extinct giant sloths Nothrotherium maquinense, Ahytherium aureum, Valgipes bucklandi, Catonyx cuvieri, and Eremotherium laurillardi suggests that none of these taxa adapted to an aquatic lifestyle, contributing to a better understanding of the ecological niche of these species and their differentiation to avoid competition during the Late Pleistocene in the BIR.

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Body Mass Estimates from Skeletal Remains of *Conepatus* cf. *amazonicus* (Carnivora, Mephitidae) Preserved in Poço Azul de Milú, Nova Redenção, BA

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Resumo

Fósseis de *Conepatus* cf. *amazonicus* (Mephitidae) foram coletados em cavernas da Bahia, Brasil. No presente estudo, foram feitas estimativas de massa corporal a partir desses elementos fósseis, com o objetivo de comparar essas massas com as estimadas de espécimes atuais, utilizando o método de regressão linear a partir de diferentes elementos ósseos (crânios, molares, fêmures e úmeros). Os resultados mostraram uma diferença significativa entre as massas estimadas dos fósseis e dos viventes, foi calculada uma massa média de 3.675 kg para os fósseis, a qual foi maior que a média das massas dos viventes (2,52 kg). Esses resultados indicam uma possível redução no tamanho corporal do grupo desde o final do Pleistoceno, seguindo uma tendência já demonstrada para outros grupos, na literatura.

Abstract

Fossils of *Conepatus* cf. *amazonicus* (Mephitidae) were collected in caves in Bahia, Brazil. In the present study, body mass estimates were made from these fossil elements with the aim of comparing these masses with those estimated for extant specimens, using the linear regression method based on different bone elements (skulls, molars, femora, and humeri). The results showed a significant difference between the estimated masses of the fossils and the living specimens, with an average mass of 3.675 kg calculated for the fossils, which was greater than the average mass of the living specimens (2.52 kg). These results indicate a possible reduction in body size of the group since the end of the Pleistocene, following a trend already demonstrated for other groups in the literature.

Résumé

Des fossiles de *Conepatus* cf. *amazonicus* (Mephitidae) ont été collectés dans des grottes en Bahia, Brésil. Dans la présente étude, des estimations de masse corporelle ont été faites à partir de ces éléments fossiles dans le but de comparer ces masses avec celles estimées pour les spécimens actuels, en utilisant la méthode de régression linéaire à partir de différents éléments osseux (crânes, molaires, fémurs et humérus). Les résultats ont montré une différence significative entre les masses estimées des fossiles et des spécimens vivants, une masse moyenne de 3,675 kg ayant été calculée pour les fossiles, ce qui était supérieur à la masse moyenne des spécimens vivants (2,52 kg). Ces résultats indiquent une possible réduction de la taille corporelle de le groupe depuis la fin du Pléistocène, suivant une tendance déjà démontrée pour d'autres groupes, dans la littérature.

1. Introduction

The genus *Conepatus* is a diverse but scarcely studied group, occurring throughout the American continent in various habitats, such as grasslands, forests, fields, and suburban areas (MACHADO et al., 2024). These animals have a set of synapomorphies such as the absence of the carnassial notch in P4 and a reduced dental formula. They also have anal scent glands, similar to mustelids (WANG & CARRANZA-CASTAÑEDA, 2007; MACHADO et al., 2024). This taxon is current classified within the family Mephitidae, which was previously considered a subfamily of Mustelidae but was reclassified due to its synapomorphies and significant karyotypic differences from weasels, which are mustelids. This classification is supported by chromosomal data obtained through fluorescence *in situ* hybridization (DRAGOO, 2009). Additionally, they have a larger olfactory bulb and a less expanded neocortex than mustelids (RADINSKY, 1973).

The family Mephitidae includes both, extant and extinct species distributed across the Americas, Europe, and Asia, with four living genera (*Spilogale*, *Mydaus*, *Mephitis*, and *Conepatus*) and nine extinct genera (*Palaeomephitis*, *Promephitis*, *Osmotherium*, *Brachyprotoma*, *Martinogale*, *Pliogale*, *Buisnictis*, *Miomephitis*, and *Brachyopsigale*) (PBDB, 2025). Possibly originating in Mexico, the genus Conepatus was among the many that diversified during the Great American Biotic Interchange (GABI), probably between the late Miocene and early Pliocene, being the only genus of Mephitidae in South America (RODRIGUES, 2013). Twelve fossil species of the genus have been found throughout the Americas, seven of which are extinct. There are few Miocene records from Mexico, but the majority of fossil records are from the Pleistocene (PBDB, 2025).

A large number of fossil skeletal elements, possibly from the Pleistocene-Holocene transition, were found and collected in 2005 at Poço Azul de Milú, Nova Redenção - BA, and Toca da Boa Vista, Campo Formoso - BA (CARTELLE, 1998). Among these elements, bones of subfossil *Conepatus* cf. *amazonicus* were present (CARVALHO, 2019). This material was used in this study to estimate the body masses of this Conepatus population and compare them with the masses of extant individuals.

It is hypothesized that, during much of the Quaternary, the average body mass of mammals in the American continent was significantly different when compared to mammalian masses in Eurasia and Australia (SMITH et al., 2018). The reduction in mammalian body mass averages occurred later in the Americas, at the end of the Pleistocene. The influence of hominid dispersal on this reduction remains a debated and controversial topic (SMITH et al., 2018; ZUO et al., 2013). However, the arrival of hominids in different continents coincides with the selective extinction of certain megafaunal species in each region, reducing the local mammalian average body mass—a trend that persists to this day (SMITH et al., 2018). In this study, analyses were conducted to determine whether there is a difference between the body masses of fossil and extant *Conepatus* cf. *amazonicus* populations.

Determining the body size of a species' population is crucial for understanding its physiology and ecology. Therefore, body mass estimation methods are widely used in paleobiological studies, aiding in the inference of evolutionary and ecological patterns (CAMPIONE & EVANS, 2012). One method for estimating the mass of a fossil is through linear regression (ENGELMANN, 2022). In this method, measurements related to the body mass of various animals are collected and used to establish a linear regression equation, which describes the relationship between the measured variable and the body mass of the group. This method was chosen for its applicability to fossilized skeletal elements, since it can be applied to isolated bones, given that complete skeletons are barely found.

2. Material and Methods

Measurements of 138 fossil elements and 17 extant elements of *Conepatus* cf. *amazonicus* from the Museu de Ciências Naturais da PUC Minas collection were taken, as described by Anyonge (1993), Campione & Evans (2012), Van Valkenburg (1990), and Engelmann (2022) (Tab. 1). Regarding the fossil elements, 133 were from the Poço Azul de Milú location, and 5 were from the Toca da Boa Vista. The elements of the Toca da Boa Vista location were found in articulation, representing a single specimen. Elements of the extant specimens represent 7 individuals and are from different municipalities of the state of Minas Gerais, Brazil (i.e., Serra do Salitre, Minas Novas, Pains, Pedro Leopoldo, Uberaba, and Grão Mogol).

The bony elements used in this research consisted of femora, humeri, skulls, and lower molars. Linear measurements were taken with a digital caliper, and circumferences with a tape measure. Lengths and circumferences were measured in the femora and humeri. For the skulls, the total length, the orbital-occipital length, and the occipital width were measured. Circumferences of long bones were taken at the midshaft of the diaphyses. Most skeletal elements consist of isolated bones and were treated as different individuals. In this case, each bone led to one individual mass estimate. When antimere bones were identified or different bones known to be of the same individual were measured, the average value of the body mass estimates was considered to represent the mass of one individual. Average estimates of body mass were also taken when more than one estimated value could be calculated using only one bone, such as a complete skull, for example.

Body masses estimates were calculated using the linear regression equations of Anyonge (1993), Campione & Evans (2012), Van Valkenburg (1990), and Engelmann (2022) (Tab. 1). In addition to the estimated body masses of fossils and recent bones physically assessed and measured, we used the data of *Conepatus amazonicus* (Lichtenstein, 1838) body masses available in the literature (MACHADO et al., 2024) in our comparisons. In the aforementioned work, the average female body mass is equal to 1.955 kg (N = 11, SD = 0.362), and the average male body mass is equal to 2.507 kg (N = 28, SD = 0.439). A combined weighted average and standard error were calculated to obtain a representative body mass average for the species as a whole, regarding the literature data.

Graph plots and statistical analysis were carried out using the software Paleontological Statistics (PAST) version 4.03 (HAMMER et al., 2001). Statistical analysis included summary statistics; a normality test to decide whether parametric or non-parametric tests should be applied; and univariate, several-sample tests, to compare statistical significance between fossil, measured extant, and literature average body mass estimates and to compare average body mass estimates of each equation.

Measured variable (abbreviation)	Equation	Statistical parameters	Studied taxon	Reference
Total skull length from posterior surface of occipital condyles to anterior of premaxilla (SKL)	log(mass_kg) = 3.39 x log(SKL_mm) - 6.03	N = 37; r = 0.95; SE = 0.199; %SEE = 58; %PE = 40	Mustelidae	VAN VALKENBURGH, 1990, p. 187, Tab. 10.2
Occiput-to-orbit length, measured from occipital condyles to anterior edge of orbit (OOL)	log(mass_kg) = 3.29 x log(OOL_mm) - 5.53	N = 37; r = 0.93; SE = 0.220; %SEE = 66; %PE = 47	Mustelidae	VAN VALKENBURGH, 1990, p. 187, Tab. 10.2
Total length of lower first molar, measured at alveolar margin (M1L)	log(mass_kg) = 3.48 x log(SKL_mm) - 3.04;	N = 37; r = 0.93; SE = 0.220; %SEE = 66; %PE = 45	Mustelidae	VAN VALKENBURGH, 1990, p. 187, Tab. 10.2
Femur maximum proximodistal length between articulating surfaces (FL)	log(mass_kg) = 2.92 x log(FL_mm) - 5.27	N = 28; r = 0.95; SE = 0.201; %SEE = 46; %PE = 25	Carnivora	ANYONGE, 1992, p. 343, Tab. 2
Femur circumference at the midshaft (FC)	log(mass_kg) = 2.88 x log(FC_mm) - 3.4	N = 28; r = 0.98; SE = 0.131; %SEE = 30; %PE = 22	Carnivora	ANYONGE, 1992, p. 343, Tab. 2
Humerus maximum proximodistal length between articulating surfaces (HL)	log(mass_kg) = 2.93 x log(HL_mm) - 5.11	N = 28; r = 0.94; SE = 0.214; %SEE = 51; %PE = 30	Carnivora	ANYONGE, 1992, p. 343, Tab. 2
Femoral circumference (FC)	log(mass_g) = 2.79 x log(FC_mm) - 0.29;	N = 48; R2= 0.97	Carnivora	CAMPIONE 7 EVANS, 2012, p. 6, Tab. 1
Humeral circumference (HC)	log(mass_kg) = 2.6 x log(HC_mm) - 0.001	N = 48; R2= 0.98	Carnivora	CAMPIONE 7 EVANS, 2012, p. 6, Tab. 1
Occipital condylar width (OCW)	ln(body mass) = 8.5852 × ln(OCW)2/3 − 10.2696	N = 81; r2adj = 0.97; %PE = 22.6; CF = 1.03; %PEcf= 21.96; %SEE = 34.62	Carnivora	ENGELMANN, 2022, p. 11, Tab. 4

Table 1: *Equations used to estimate body masses of Conepatus individuals. Abbreviations: r, correlation coefficient;* ***SE****, standard error of estimate;* ***%SEE****, percent standard error of estimate;* ***%PE****, percent prediction error;* ***R2****, coefficient of determination;* ***r2adj****, adjusted r2 value;* ***CF****, averaged correction factor;* ***%PEcf****, percent prediction error after applying correction factor.*

3. Results

The average estimate of the body mass of the 124 individuals of the fossil population is equal to 3.675 kg, with a standard deviation equal to 1.086. In contrast, the average body mass estimates of the 7 recent individuals of an extant population is equal to 2.686 kg (SD = 0.380), and the weighted average and standard error representative of the literature data is equal to 2.351 kg (SD = 0.485) (Fig. 1).

Estimates for the fossil population do not have a normal distribution (Shapiro-Wilk W = 0.958; p-value < 0.05), but estimates for the extant population (Shapiro-Wilk W = 0.893; p-value = 0.29) and the literature data (MACHADO et al., 2024) have a normal distribution. The Mann-Whitney pairwise test indicated a statistically significant difference between the body mass estimates of the fossil population when compared to both extant populations (measured individuals and literature data, with Bonferroni corrected p-value < 0.05), while the average of both extant populations did not differ significantly (Bonferroni-corrected p-value = 0.50).

Each applied equation led to highly variable body mass estimates of fossil and extant populations (Fig. 2). Estimates for the fossil population based on the humerus circumference equation proposed by CAMPIONE & EVANS (2012) have a median value of 5.84 kg, with maximum and minimum values of 8.72 kg and 3.81 kg, respectively. On the other hand, estimates for the fossil population, based on the equation using the total skull length of VAN VALKENBURG (1990), returned a median value of 2.67 kg, with a maximum estimate of 3.28 kg and a minimum estimate of 2.21 kg (Fig. 2). Nevertheless, body mass estimates from the extant population are consistently lower than body mass estimates from the fossil population. Comparing with the same equations applied to the fossil population mentioned above, estimates based on humerus circumference yielded a median of 3.15 kg (max. = 3.63, min. = 2.68). and those based on total skull length returned a median value of 2.39 kg (max. = 3.16 kg, min. = 1.54 kg) (Fig. 2).

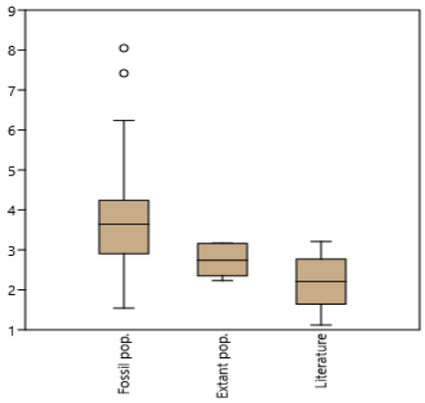

Figure 1: *Boxplot of estimated body masses of the extinct population of Conepatus cf. amazonicus (N = 124), extant population (N = 7) and the literature data (N = 39). Two estimates of the fossil population are indicated as outliers (circles). Y-axis represents body mass in kg.*

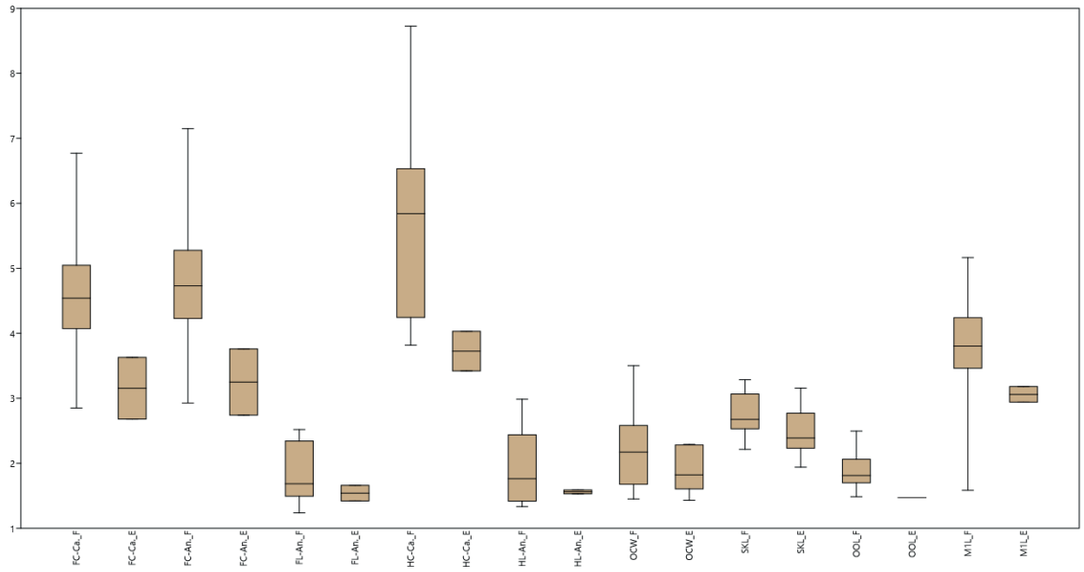

Figure 2: *Boxplot of equation used to estimate body masses of the fossil (F) and extant (E) populations of Conepatus amazonicus. Abbreviations:* ***FC-Ca_F****, masses from fossil femoral circumference using the Campione and Evans (2012) equation;* ***FC-Ca_E****, masses from extant femoral circumference using the Campione and Evans (2012) equation;* ***FC-An_F****, masses from fossil femoral circumference using the Anyonge (1992) equation;* ***FC-An_E****, masses from extant femoral circumference using the Anyonge (1992) equation;* ***FL-An_F****, masses from fossil femoral length using the Anyonge (1992) equation;* ***FL-An_E****, masses from extant femoral length using the Anyonge (1992) equation;* ***HC-Ca_F****, masses from fossil humeral circumference using the Campione and Evans (2012) equation;* ***HC-Ca_E****, masses from extant humeral circumference using the Campione and Evans (2012) equation;* ***HL-An_F****, masses from fossil humeral length using the Anyonge (1992) equation;* ***HL-An_E****, masses from extant humeral length using the Anyonge (1992) equation;* ***OCW_F****, masses from fossil occipital condyle width;* ***OCW_E****, masses from extant occipital condyle width;* ***SKL_F****, masses from fossil skull length;* ***SKL_E****, masses from extant skull length;* ***OOL_F****, masses from fossil orbit-occipital length;* ***OOL_E****, masses from extant orbit-occipital length;* ***M1L_F****, masses from fossil first molar length;* ***M1L_E****, masses from extant first molar length.*

4. Discussion

Considering the equations studied individually, each estimates significantly different body masses, even for the same skeletal element (compare, for example, equations using femoral circumference and femoral length, or humeral circumference and humeral length in Fig. 2). Thereby, we opted to consider, in addition to the general average body mass estimates, the most accurate ones based on the Percent Prediction Error (%PE) and the Percent Standard Error of the Estimate (%SEE). Estimates based on the circumference of the femur, proposed by ANYONGE (1992), presented the lowest values of %PE and %SEE, respectively, 30% and 22% (Tab. 1). Estimates based on this equation yield higher mass estimates for both fossil and extant individuals than the other methods used (Fossil: average = 4.66 kg, max. = 7.15, min. = 2.93; Extant: average = 3.25 kg, max. = 3.76, min. = 2.74), but estimates comparing fossil and extant individuals remained consistently different. Therefore, our results suggest that the fossil population of *Conepatus* cf. *amazonicus* individuals preserved in the Poço Azul was effectively larger than the living specimens.

The results presented in this study help corroborate the pattern observed by Smith et al. (2018), where the average body mass of American fauna decreased at the end of the Pleistocene. This reduction may be associated with anthropogenic interference, either directly or indirectly, or with climatic changes that occurred during this geological epoch.

Cascade effects were hypothesized, where the alteration of fauna interfered with the body size of carnivores due to indirect human action in Eurasia (SZUMA & GERMONPRÉ, 2019). Similarly, this effect may have occurred with the studied group, in which ecological changes, such as in the food niche, influence the body size of populations.

Isotopic analysis and radiometric dating evidence from caves and bones shows that the region where the fossils studied here were collected underwent climatic changes during the Quaternary. The environment at that time was wetter and probably had more abundant vegetation compared to the present day (AULER & SMART, 1999).

5. Conclusion

Based on the collected data and the statistical analyses performed, it is concluded that there is a significant difference between the body masses of the fossil population of Conepatus cf. amazonicus and the studied living specimens.

As the literature presents few studies on mass estimation in Conepatus amazonicus, collecting more data from recent specimens can be highly valuable for expanding the sample and increasing the robustness of comparisons with the ancient population. Additionally, the same study can be conducted with fossils from other regions to determine whether this pattern holds true in other ancient populations.

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Revisitando a Loca do Angá: novos achados paleontológicos

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Resumo

Este artigo busca identificar as principais rotas do fluxo subterrâneo atual e pretérito da Loca do Angá, que tenham permitido o transporte de bioclastos e a natureza dos mecanismos de preservação desse material, permitindo assim descrever novos registros fósseis na cavidade onde foram achados os restos ósseos de um Mastodonte no final da década de 1990 pelo Espeleogrupo EPA, e cadastrada no Cadastro Nacional de Informações espeleológicas (CANIE/CECAV/ICMBio) como Gruta do Mastodonte (Guano Espeleo, 1998). Dois padrões foram identificados de deposição bioclástica, (i) restos ósseos de maior densidade, transportados por drenagem do tipo enxurrada, distribuídos ao longo do desenvolvimento superior da cavidade, antigo nível de base e, (ii) restos ósseos menos densos carreados via drenagem subterrânea de fluxo lento que os descarregou em câmara interna no desenvolvimento mais inferior da cavidade.

Abstract

Revisiting the Loca do Angá: New Paleontological Records

This article sought to identify the main routes of the current and past underground flow of Loca do Angá, which allowed the transport of bone remains. The mechanisms of preservation of this material according to the clastic nature of the surrounding substrate found, thus allowing the description of new fossil records in the cavity where the bone remains of a Mastodon was found in the late 1990s by the EPA Spelogroup and registered in the National Registry of Speleological Information (CANIE/CECAV/ICMBio) as Gruta do Mastodonte (Guano Espeleo, 1998). Two patterns of bioclastic deposition were identified: (i) higher-density bone remains, transported by flood-type drainage, distributed along the upper development of the cavity, former base level, and (ii) less dense bone remains carried via slow-flow underground drainage that discharged them into an internal chamber in the lower development of the cave.

1. Introdução

A caverna, objeto deste estudo, se localiza no município de Pains, pertencente à região conhecida como Província Cárstica do Alto do Rio São Francisco (CASF), inserida no Cráton São Francisco, podendo ser considerada como um dos registros mais completos dos eventos que ocorreram após as glaciações. (ALKMIN & MARTINS-NETO 2001, 2012 ; WARREN et al. 2013; REIS & SUSS, 2016; UHLEIN et al 2019). Geologicamente, a área cárstica de Pains, situa-se na porção sudoeste do Cráton São Francisco, composta por uma sucessão de depósitos predominantemente terrígenos do Grupo Macaúbas, recobertos por pelitos e carbonatos neoproterozoicos do Grupo Bambuí compondo o Supergrupo São Francisco (ALKMIN & MARTINS-NETO, 2012).

Na região cárstica de Pains ocorre a sucessão sedimentar de rochas carbonáticas da Formação Sete Lagoas, composta por espessa sequência de calcários e dolomitos, com margas e siltitos subordinados, de ambiente marinho raso a litorâneo (MEYER; RUDNITZKI; CARVALHO, 2022).

Na região tem-se o registro de mais de 2.500 cavernas, sendo considerada a região com o maior número de cavernas carbonáticas conhecidas do país (ICMBio, 2023).

O Bloco São Miguel, posicionado a leste, é o menos deformado, devido a seu maior distanciamento da Faixa de Dobramentos Brasília. É representado por extensos e contínuos maciços calcários marcados por diferentes tipos de lapiás (*karren*) (TRAVASSOS, 2019; COELHO & CALLUX, 2022), drenagem predominantemente subterrânea com a presença de sumidouros, ressurgências, cânions, dolinas de abatimento e dissolução, uvalas e torres. De acordo com TIMO et al. (2022), o Bloco São Miguel possui a maior concentração de cavernas, com porcentagem estimada em 80% do total da região.

Timo (2019) realizou inventariamento no Domínio do Planalto cárstico do leste do rio São Miguel, identificando geossítios com interesse para a preservação da geodiversidade da região cárstica de Pains, para utilização científica, educacional e turística, totalizando 35 sítios. Dentre os pontos inventariados, a Loca do Angá é o geossítio 12 (Fig.1)

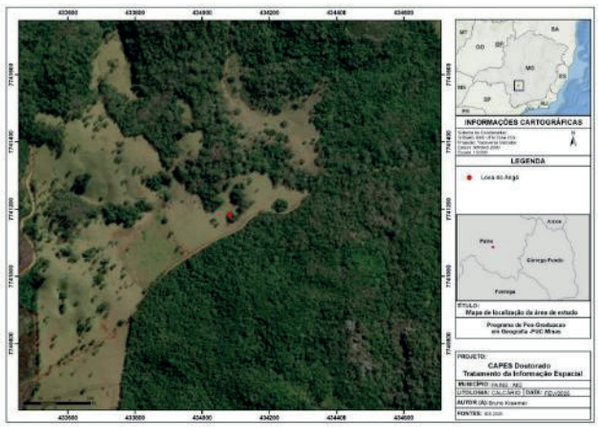

Figura 1: *Mapa de localização da Loca do Angá, município de Pains, MG, Brasil.*

A caverna apresenta um padrão planimétrico curvilíneo ramificado (*branchwork*), com forte controle por fraturas NW-SE. Possui duas entradas com sumidouros, ambas no fundo de dolinas: o Sumidouro 1 a montante (Fig.2), e o outro, a jusante, o sumidouro 2 (Fig.3).

Figura 2: *Sumidouro 1 (sentido SE), que dá acesso ao nível de base da drenagem. Sua drenagem é perene, variando o nível negativamente na estação seca e permanecendo inundada nos meses chuvosos.*

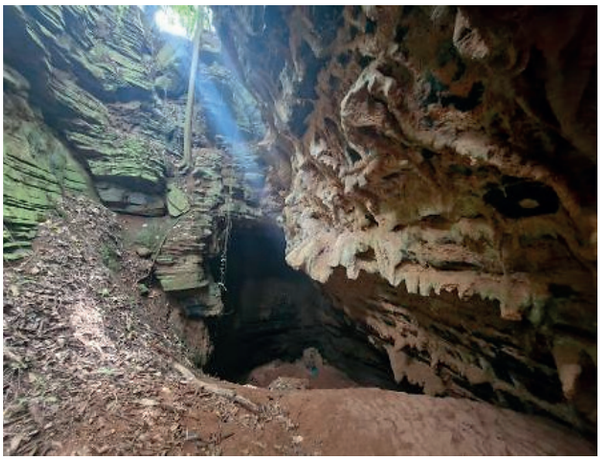

Figura 3: *Sumidouro 2 (sentido NW) encontra-se ao fundo de uma dolina de abatimento profunda, estreita e alongada.*

A Loca do Angá, foi descoberta pelo Espeleogrupo EPA, de Pains, no ano de 1997, sendo renomeada posteriormente por Gruta do Mastodonte, em 1998, quando nativos da região encontraram os restos fósseis de um mastodonte sul-americano (*Notiomastodon platensis* Ameghino, 1888). Tal achado se deu no conduto superior (LAn1), onde passava paleo canal, muito acima do nível de base local atual, com desenvolvimento, sendo predominantemente seca.

Uma equipe interinstitucional, coordenada pelo Setor de Paleontologia do Museu de Ciências Naturais da PUC Minas em parceria com os membros dos grupos de espeleologia EPA e Guano Speleo deram andamento à escavação no ano de 1998, com a primeira campanha, e a segunda no ano seguinte, quando da retirada de alguns ossos dos pós-crânio.

O achado paleontológico consistia em um crânio com a face esquerda incompleta e desprovido das presas, coletado no mesmo ano de sua descoberta. Posteriormente, em 1999, foram também encontrados os restos ósseos do pós-crânio (tíbia direita, rádio esquerdo, ulna esquerda fragmentada; e cinco ossos carpais do membro torácico esquerdo) (ALBERDI; PRADO; CARTELLE, 2002; HUBBE, 2022).

O mastodonte da extinta família Gomphotheriidae, foi a única família de proboscídeos que colonizou a América do Sul, cuja linhagem ancestral já habitava a américa do Norte. Os registros de *Notiomastodon platenses* estão distribuídos do Ensenadense (início do Pleistoceno) ao início do Holoceno e ocorrem em todo o continente sul-americano com mais de 140 localidades, mas não há registros na Bolívia, Guiana, Guiana Francesa e Suriname (PRADO et al., 2005; AVILLA et al., 2013; DANTAS et al., 2013; MOTHÉ & AVILLA, 2015).

No Brasil intertropical, esses mamíferos possivelmente ocupavam planícies com manchas de matas ciliares, habitat semelhante ao atual Cerrado, onde desenvolveu uma dieta mista, tendo por base o estrato graminóceo e complementaria com vegetação arbórea (CARTELLE, 2012).

O achado surpreendeu à época, dado que não se tinha conhecimento de megafauna pleistocênica para a região cárstica de Pains, restringindo os achados à ossadas atuais e subfósseis de mamíferos e aves de pequeno porte, tais como, roedores hystricomorfos, quirópteros e psitacídeos, ou ainda, mamíferos de médio porte, dentre esses, ossos de porcos tayassuídeos, macacos atelídeos, felinos e canídeos, silvestres e domésticos, cervídeos, e bovídeos domésticos.

Segundo Sasowsky (2007), cavernas podem persistir no relevo por até 10 milhões de anos, sendo seus sedimentos retratos do pleistoceno e parte do Neógeno. Processos como precipitação química, entrada e remoção de sedimentos, estão intimamente relacionados com as condições paleoclimáticas/hidrológicas do passado formando complexos sedimentares que podem ser objeto de estudo na compreensão do paleoambiental.

Além disso, são importante fontes de pesquisa, sendo utilizados para determinar ambientes deposicionais, gênese dos sedimentos, grau de desenvolvimento de cavernas ou paisagens e investigações paleontológicas (SPRINGER, 2005; AULER et al., 2009; CAMPAÑA et al., 2017).

Sendo assim, a pesquisa tem como objetivo principal a confirmação da importância espeleológica e paleontológica da Gruta em relação à novos achados da megafauna pleistocênica.

2. Materiais e Métodos

O material analisado foi coletado em depósitos localizados nos três níveis de desenvolvimentos da Gruta, recebendo o acrônimo LAn, referindo-se ao nível do desenvolvimento observado para a Loca do Angá (LAn). Assim, tem-se o Nível LAn1, conduto superior direito, de nível vadoso, sentido NW, cujo piso é trecho de paleocanal; Nível LAn2, conduto inferior direito, de nível epifreático, sentido SE, marcado por águas estagnadas e drenagens ativas e Nível LAn3, conduto inferior de nível epifreático, abaixo do LAn2, pertencente ao sistema lótico de cavernas Narigudo-Loca Feia-Loca do Angá. Este nível é acessado por mergulho ou quando o nível do córrego está abaixo do nível de vazão média, permitindo passar pelo sifão que dá acesso à câmara semialagada.

A prospecção no conduto superior LAn1 teve como objetivo identificar registros fósseis em níveis superficial e subsuperficial. Para isso, foi aplicada a técnica de busca ativa, que consistiu na remoção manual de blocos e matacões utilizando alavanca, ponteira, talhadeira, pincéis, lupas etc. (Fig. 4 e 5). O piso desse conduto apresenta cimentação em brecha com alto grau de retrabalhamento, sem planos de acamamento, o que se deve ao paleofluxo de entrada.

Figura 4: *Prospecção paleontológica no Conduto superior LAn1, com uso de ferramentas manuais na tentativa de isolamento de fósseis cimentados ao paleopiso.*

A ausência de fácies sequenciais pode estar associada às variações constantes da vazão da drenagem, que erodiam e redistribuíam os sedimentos durante eventos pluviométricos intensos, tornando a leitura estratigráfica e cronológica mais complexa.

A litificação do sedimento, especialmente nas áreas onde passava o paleocanal, resultou na formação de uma crosta calcítica que recobre o material raso. A dureza do paleopiso e a presença de lajedos imbricados impediram o aprofundamento dos níveis inferiores com as ferramentas disponíveis, inviabilizando a escavação convencional. Essa limitação restringiu a prospecção à superfície, buscando isolar fósseis cimentados ao substrato e identificar possíveis evidências de preservação.

Figura 5: *Técnica de busca ativa, onde são varridos nichos, brechas interclásticas, canalículos, planos de acamamento das paredes e pisos dos condutos, além de calha de drenagem.*

Nos condutos LAn2 e LAn3 da Gruta do Angá, situados em níveis freáticos profundos, a prospecção exigiu abordagens diferenciadas devido às características hidrológicas e sedimentológicas do ambiente. Esses condutos correspondem ao nível de base local e apresentam fluxo de água perene de baixa vazão, que se intensifica durante o período chuvoso. A sedimentação nesses trechos não favorece a formação de fácies bem estratificadas, pois a constante ação do fluxo hídrico provoca a redistribuição dos depósitos, resultando em camadas mal selecionadas e de estrutura irregular.

A inviabilidade de escavação nesses níveis decorre da elevada dureza dos sedimentos e da disposição dos blocos, que dificultam a remoção manual. Diante dessas condições, a busca ativa foi a principal técnica utilizada, com inspeção detalhada de nichos, brechas interclásticas, canalículos, planos de acamamento das paredes e pisos, além das fácies de canal. Esse método permitiu a identificação de fósseis incrustados e desagregados, alguns apresentando mineralização parcial. A observação direta foi fundamental para reconhecer padrões de preservação e deposição nesses ambientes subterrâneos, ampliando a compreensão sobre o contexto geológico e paleoambiental da caverna.

3. Resultados

Os achados paleontológicos registrados para a Loca do Angá podem ser categorizados segundo duas naturezas: (i) registros de fósseis incrustados no paleopiso do conduto superior LAn1, de difícil remoção e, (ii) fósseis que estiveram cimentados a brechas que foram erodidas, se desagregando e retrabalhados ao longo do curso do conduto LAn1; e (iii) fósseis desagregados e mineralizados associados aos depósitos de clastos densos e "lavados", em calha de drenagem, no conduto inferior LAn3, levados por fluxos de entrada via sumidouro.

O material fóssil coletado se encontrava sob diferentes contextos, como cimentado em brechas ou desagregado de qualquer sedimento (sobre o piso). Dentre as alterações nos ossos coletados na Gruta, estão, alto grau de fragmentação, desarticulação, polimento e abrasão, indicando que os restos esqueletais foram carreados para os condutos por meio de transporte hidráulico.

3.1. Registros fósseis no conduto LAn1

Para o conduto superior LAn1 foram resgatados alguns fragmentos fósseis com padrões estruturais: (i) fragmentos fósseis altamente friáveis, em superfície, com fissuras relacionadas à longa exposição às intempéries, assim como abrasão relacionada ao transporte dos bioclastos (Fig.6A; (ii) fragmentos fósseis, em subsuperfície, altamente perminera-lizados, cuja percolação calcítica, preencheu todo o espaço interno, restando resquícios da do canal medular ósseo (Fig.6B).

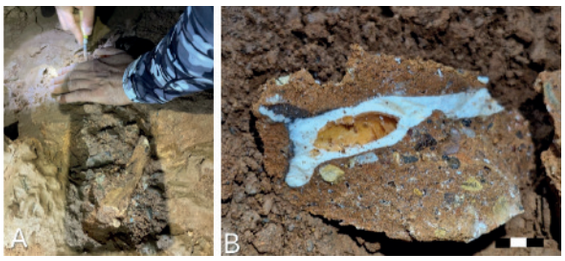

Figura 6: *Registro fóssil no conduto superior LAn1(A) corte em plano paralelo superficial da brecha intraclástica; (B) Fóssil permineralizado com alta dureza mineral e totalmente incorporado à rocha. Escala: 6 cm.*

Pode-se inferir que a brecha intraclástica que cobre o depósito do conduto superior LAn1, formou-se em regimes de vazões diferenciadas, o que explica a distribuição caótica de fragmentos ósseos na matriz, sendo concluído que essas características apontam que o depósito sofreu sucessivos fluxos de entrada e retrabalhamentos do depósito.

Um achado relevante para o conduto LAn1, consiste no registro de fragmento de epífise de outra espécie extinta pertencente à chamada "megafauna pleistocênica", ou seja, uma preguiça terrícola pertencente à subfamília Scelidotheriinae (Ameghino, 1904) e denominada por Lund, no ano de 1839, como *Catonyx Cuvieri*.

A peça fóssil encontrava-se presa entre os blocos abatidos presentes na entrada principal (sentido SE). Provavelmente desgarrara-se da brecha calcítica em que estava incluso, sofrendo retrabalhamento gravitacional e hídrico. Ainda apresentando restos de sedimento endurecido em seu corpo (Fig.7).

Figura 7: *Epífise proximal de úmero direito de Catonyx cuvieri (Pilosa, Scelidotheriinae), encontrada na entrada principal da Loca do Angá. Notar que esteve incrustado parcialmente a alguma brecha, mas foi retrabalhado e solto.*

3.2. Registros fósseis nos condutos LAn2-LAn3

Para o conduto LAn2-LAn3 foram registradas dezenas de ossos isolados e distribuídos ao longo da calha das drenagens perenes que transcorrem os dois condutos inferiores. Os fósseis coletados apresentam distintas colorações que sugerem diferentes condições de fossilização, indo de cores mais esbranquiçadas a dores mais escuras, tendendo do marrom claro a escuro.

As peças mais claras são tem menor densidade e as escuras maior, permitindo inferir que as mais claras estão preservadas quanto à sua constituição biomineralizada e as escuras estão parcialmente mineralizadas em diferentes graus, dependo da exposição das peças ao meio circundante (Fig.8).

Figura 8 : *Conjunto de ossos coletados no conduto inferior LAn3.*

As marcas de abrasão são feições de desgaste geradas pelo impacto dos sedimentos na superfície óssea (SHIPMAN, 1981) e incluem todos os tipos de arredondamento ou polimento observáveis nos ossos, seja como resultado de transporte. Porém o grau de abrasão varia em função do tipo de sedimento e, principalmente, das condições orgânicas e/ou mineralógicas em que o osso se encontra, se está preservado estado de umidade, se está seco, intemperizado ou fossilizado.

Os elementos esqueléticos são pertinentes a diferentes táxons de mamíferos da fauna atual. Os restos foram atribuídos a pecarídeos (porcos-do mato) e suídeos (porcos-domésticos), cervídeos (veados), equídeos (cavalos), canídeos (cachorro-do-mato), mustelídeos (jaratataca), bovídeos (adultos e joviais), roedores strycomorfos (pacas e roedores menores), dentre outros táxons representativos da fauna silvestre e doméstica.

Um detalhamento mais apurado dos aspetos morfológicos, tafonômicos e taxonômicos serão contemplados em publicações posteriores e decorrentes deste trabalho.

4. Discussão

Os processos sedimentológicos em cavernas são semelhantes aos superficiais (como deposição, transporte e sedimentação). No entanto, fatores específicos do ambiente subterrâneo comprometem a eficácia dos estudos, como intensidade do fluxo nos condutos, destruição de sequências sedimentares e inversões estratigráficas.

A arquitetura deposicional bem como a natureza geológica dos sedimentos permitiram estabelecer correlações com a energia do fluxo hidráulico e resultando na identificação do estado tafonômico das peças encontradas.

A representatividade óssea refere-se ao estado de completude ou fragmentação dos ossos, que varia conforme a velocidade com que foram soterrados (SHIPMAN, 1981). Isto deve ser levado em conta na análise de restos fósseis no contexto da dinâmica sedimentar em uma caverna. A completude individual dos fósseis, bem como o grau de articulação, são indicadores úteis para avaliar a ocorrência de perturbações após a deposição e se os animais adentraram na caverna de forma ativa ou passiva (*pós-mortem*) (AULER et al., 2006).

O fragmento de úmero direito de *Catonyx cuvieri*, preguiça extinta encontrada no conduto LAn1, pertence ao mesmo contexto de sedimentação do mastodonte Notiomastodon waringhi, encontrado no ano de 1998. Representando assim, a principal peça descoberta, apresentando características idênticas a de outros úmeros encontrados em outras regiões do Brasil atribuídos a *Catonyx cuvieri*, como o entepicôndilo alongado e a ausência do foramen entepicondilóide, características diagnósticas deste animal (PAULA COUTO, 1979; CARTELLE, DE IULLIS & FERREIRA, 2009).

O maior número de trabalhos envolve mamíferos, destacando os grupos dos artiodáctilos, ungulados, perissodáctilos e roedores.

5. Conclusão

O presente estudo evidencia a importância dos ambientes endocársticos na preservação de depósitos sedimentares de grande valor científico, fazendo-se necessária a preservação destes ambientes para que futuros estudos e aplicações de métodos mais detalhados possam fornecer informações mais precisas sobre a evolução climática do passado na região cárstica de Pains.

Este estudo visou comunicar os novos achados paleontológicos na loca do Angá, de forma a associá-los à natureza dos depósitos sedimentares e à dinâmica do fluxo de entrada no sistema. Análises tafonômicas, faciológicas e granulométricas serão tratados durante a elaboração de tese de doutorado do autor principal.

As informações apresentadas constituem novos e raros dados sobre o registro de megafauna pleistocênica para a região após a ocorrência do icônico « Mastodonte de Pains » no ano de 1998, corroborando para a possibilidade de novos achados ocorrerem, ou que já tenham sido notificados em estudos de licenciamento ambiental, mas não comunicados aos órgãos deliberativos ou autoridades fiscalizatórias.

Agradecimentos

Nossos agradecimentos sinceros ao Espeleogrupo EPA, guardião do patrimônio espeleológico da região cárstica de Arcos-Pains, que comunicou o achado da Gruta, como também do achado do mastodonte de Pains, na figura do Agenor Nativo, que nos acompanhou em todo os trabalhos de prospecção paleontológica, juntamente com o espeleólogo técnico Reginaldo, que foi de grande utilidade para levantar pesados matacões e lajes. Outro agradecimento ´é direcionado ao Diretor do Museu de Ciências Naturais PUC Minas, na figura de seu Diretor Henrique PAPROCKI e ao Prof. Cástor CARTELLE, paleontólogo que concederam a carta de endosso para tombamento do material paleontológico resgatado. Também gostaríamos de agradecer ao Espeleo Mergulho Brasil (EMB) pela assessoria, informações e comunicação de achados no nível freático da Loca do Angá, principalmente na figura do Lukas Castro que nos acompanhou na travessia para alcançar o conduto inferior LAn3. Agradecemos, também, à CAPES e ao CNPq pelas bolsas de estudo e pesquisa.

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Gruta João Lemos: um novo marco paleontológico para a região de Pains, Minas Gerais, Brasil.

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Resumo

A Gruta João Lemos ou do Borel, é uma cavidade natural localizada no Carste do Alto são Francisco, no município de Pains,

O escopo do trabalho foi descrever o achado e resgate de três espécimes fósseis: *Catonyx cuvieri* (Lund, 1839), *Nothrotherium maquinense* (Lund, 1839) e *Cuniculus paca* (Linnaeus, 1766), investigando os restos ósseos exumados sob duas perspectivas: 1) a de elementos esqueléticos, através da análise anatômica e taxonômica e 2) a de bioclastos, através da análise tafonômica, ambas considerando algum aspecto da distribuição dos fósseis. A metodologia consistiu na plotagem de todos os elementos fósseis e identificando sua posição geografia no locus, para posterior coleta e encaminhamento a coleção de referência. Os resultados corroboram que entradas alóctones bióticas no meio cavernícola, sejam a principal fonte de incorporação dos restos ósseos aos pacotes de sedimentos presentes na Gruta João Lemos. Estudos de cunho tafonômico, sedimentológico e faciológico serão apresentados a posteriore sobre o material coletado.

Abstract

João Lemos Cave: a new paleontological landmark for the Pains region, Minas Gerais, Brazil.

The João Lemos or Borel Cave is a natural cavity located in the Alto São Francisco Karst, in the municipality of Pains. The scope of the work was to describe the discovery and rescue of three fossil specimens: *Catonyx cuvieri* (Lund, 1839), *Nothrotherium maquinense* (Lund, 1839) and *Cuniculus paca* (Linnaeus, 1766), investigating the exhumed bone remains from two perspectives: 1) that of skeletal elements, through anatomical and taxonomic analysis and 2) that of bioclasts, through taphonomic analysis, both considering some aspects of the distribution of the fossils. The results corroborate that allochthonous biotic entries into the cave environment are the main source of incorporation of bone remains into the sediment packages present in the João Lemos Cave. Taphonomic, sedimentological and facies studies will be presented later.

1. Introdução

Grande parte das informações paleontológicas do Quaternário no Brasil vem de depósitos em cavernas (PAULA COUTO, 1953, 1979; LINO et al., 1979; CARTELLE, 1999; 1994; 2012 ; HUBBE, 2008; AULER et al., 2006; VASCONCELOS et al., 2018).

Depósitos sedimentares em cavernas localizadas em carste carbonático são locais viáveis ao registro de fósseis Quaternários, potencializando pesquisas investigativas promissoras no campo da taxonomia, tafonomia, cronologia, paleoecologia, sedimentologia e estratigrafia, possibilitando interpretações ambientais (CARTELLE, 1999; HUBBE et al., 2011; 2013a; NEVES, HUBBE & KARMANN, 2017).

Os fósseis de vertebrados são os mais comuns em cavernas porque seus ossos e dentes biomineralizados, especialmente de grandes mamíferos, são resistentes ao intemperismo (PAULA COUTO, 1979 ; CARTELLE, 1992; HUBBE, 2008; VASCONCELOS & BITTENCOURT, 2019).

As pesquisas analisam, de modo geral, apenas aspectos anatômicos ou taxonômicos dos fósseis, ainda que fundamentais na compreensão da mastofauna intertropical brasileira (PAULA COUTO, 1979 ; CARTELLE & BOHORQUEZ, 1982 ; CARTELLE, 1992; CARTELLE, IULIIS & FERREIRA, 2009; CARTELLE et al., 2019).

Estudos de enfoque tafonômico, cronológico e palecológico surgiram a pouco mais de duas décadas atrás em território nacional (NEVES & PILÓ, 2003; DE VIVO & CARMIGNOTTO, 2004; HUBBE, 2008; MAYER, 2011 ; HUBBE et al., 2013a; HUBBE et al., 2013b; HUBBE, 2018; DANTAS et al., 2017; 2019).

No entanto, poucos foram realizados com controle estratigráfico devido à natureza complexa dos processos de acumulação sedimentar em cavernas (NEVES & PILÓ, 2003; AULER et al., 2006 , 2009 ; HUBBE, 2008 ; HUBBE et al., 2011). Diversos outros destacam os processos *post mortem* que influenciam bioclastos recentes e fósseis em diferentes condições biológicas, hidráulicas e químicas. Porém, há poucos estudos sobre como esses processos afetam a distribuição de fósseis (KIDWELL, 1985, 1986).

Considerando que os processos responsáveis pela acumulação de ossos em um determinado sítio podem resultar em padrões característicos de distribuição desses bioclastos entre os sedimentos, a análise desses padrões tem grande potencial para compreender os eventos que levaram à formação de um depósito fossilífero (SHIPMAN, 1981; KIDWELL, 1985; 1986; LYMAN, 1994).

Um aspecto tafonômico de interesse particular é o processo de acumulação óssea em cavernas. Restos de vertebrados são registrados em cavidades naturais, por diferentes vias: acidentalmente (quedas em fendas ou clarabóias), ou decorrente da busca ativa por recursos (habitação, abrigo e nutrição), ou por transporte físico (fluxo hídrico e/ou gravitacional) ou biológico (carreamento por predadores) (LUND, 1837).

Peculiares são os casos em que depósitos fossilíferos têm uma forte tendência ao acúmulo selecionado de espécies (WHITE et al., 1984). Como exemplo de estudo nacional, HUBBE & AULER (2012) destacaram significativa acumulação de restos de Cervidae em um dos condutos de uma caverna, podendo estar associada a quedas acidentais desses animais, cuja interpretação tafonômica contribuiu para o entendimento dos processos tafonômicos específicos inerentes a cada espécie que ocorre dentro das cavernas, oferecendo uma oportunidade para avaliar os mecanismos de controle que influenciam a acumulação óssea.

A área de interesse do estudo está inserida no Carste de Pains, na região do Planalto Cárstico do Leste do Rio São Miguel, inserido no Domínio do Alto São Francisco, dentro dos limites do município de Pains, no centro-oeste do Estado de Minas Gerais e pertencente à Província Espeleológica de Bambuí (MAGALHÃES, 1989; TEIXEIRA-SILVA et al., 2013; TIMO, 2019; 2022).

Atualmente a região cárstica de Pains apresenta o maior número de cavernas carbonáticas cadastradas no Brasil (ICMBio, 2023). Em contraposição, poucos fósseis foram encontrados nas cavernas da região, cerca de uma dezena de fósseis que foram coletados e tombados no Museu de Ciências Naturais da PUC Minas

Destaca-se o achado do crânio de um mastodonte associado a alguns ossos apendiculares, *Notiomastodon platensis* Owen, 1840 (ALBERDI; PRADO & CARTELLE, 2002; GUTIERRÉZ; ALBERDI & PRADO, 2005; MOTHÉ; AVILLA; COZZUOL, 2013). Além desses materiais, foram registrados, mas não coletados, alguns fósseis pertinentes à fauna terrestre regional, tais como Didelphimorpha, Cuniculidae, Cervidae, Tayasuidade, Canidae, Felidae, Procyonidae, Mustelidae, Myrmecophagidae, Dasypodidae e Atelidae (ESCHWEGE, 2011; MORATO; BAPTISTA; FARIA, 2003;; KRAEMER, 2011).

Registros de megafauna, além do «mastodonte de Pains» são considerados raros para a região, sendo avistado crânio de *Nothrotherium maquinense* Lund, 1839, pequena preguiça terrícola extinta (MORATO, BAPTISTA & FARIA , 2003).

Porém é sabido, mas pouco comentado, que existem registros de dois esqueletos de duas preguiças extintas Scelidotheriinae inclusas em paleoteto calcítico de uma determinada caverna, assim como suposto abismo com restos de ossos gigantes em seu fundo. Contudo tais descobertas são guardadas a «sete chaves», dado serem achados decorrentes de trabalhos de prospecção com fins de licenciamento ambiental, não sendo registrados nos órgãos regulamentadores, portanto, falseando o real potencial paleontológico para a região, considerado como « baixo ».

2. A Gruta João Lemos

A Gruta João Lemos localiza-se ao fundo de grande dolina de abatimento, na base de maciço (Fig. 1). Sua entrada de 3,44m de altura localiza-se na vertente nordeste, em cota altimétrica de 854m, com 422,94m de desenvolvimento linear, que apresenta planta baixa linear ramificada volumosa conforme Fig. 2 (TIMO, 2019).

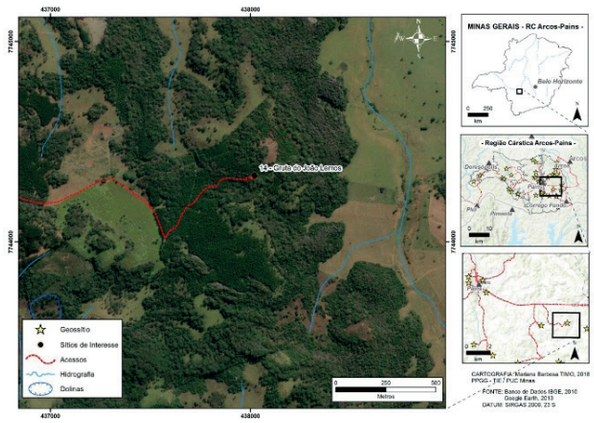

Figura 1: *Mapa da localização da Gruta João Lemos, Geossítio 14, Pains, MG. Fonte: TIMO (2019).*

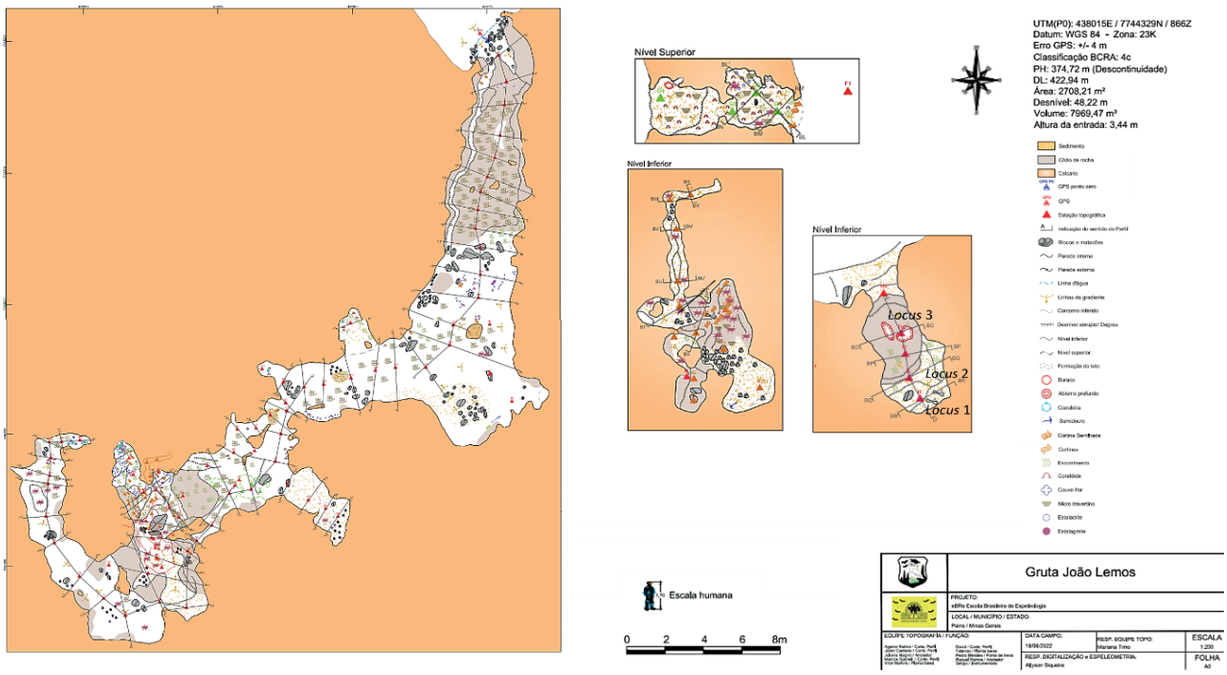

Figura 2: *Mapa topográfico da Gruta João Lemos, Pains, MG. Adaptado de Escola Brasileira de Espeleologia/eBRe,2022.*

A gruta é volumosa e compartimentalizada em um conduto principal superior que se ramifica em dois amplos salões, onde foram observados depósitos significativos, indicativos de fluxos atuais e antigos. Observa-se uma grande quantidade de sedimentos finos inconsolidados que adentram os sistemas de condutos através das fraturas da rocha ou através de dreno vertical, se acumulando em configuração de rampa de proporções métricas (Fig. 3).

Figura 3: *Rampa de sedimentos finos vermelhos de origem predominantemente alóctone, com aproximadamente 8m de espessura.*

Diversos autores denominaram este tipo de sedimento de "peneirados", referindo ao efeito de seleção exercido na porosidade secundária do epicarste (WHITE, 2007; LAUREANO & KARMANN, 2013). Foram também observadas brechas-matriz suportadas, mal selecionadas (silte a cascalho) que ocorrem no interior do conduto superior, preservando-se como depósitos reliquiares de regimes torrenciais pretéritos (Fig. 4).

Figura 4: *Detalhe de patamar plano paralelo parcialmente preservado, composto por interfaces de diamicton alternado com piso estalagmítico, localizado em porção parental no conduto principal da Gruta João Lemos, evidenciando sucessivos estágios de preenchimento e erosão do depósito. Foto Kraemer, 2025.*

Estes sedimentos são produtos de movimentos de massa (fluxos de lama) transportadas das bacias de captação durante regime de chuvas de alta intensidade (GILLIESON, 1986, 1996). BOSH & WHITE, 2007 adotaram a denominação genérica de fácies diamicton para qualificar depósitos gravitacionais encontrados no interior de condutos. LAUREANO (1998) descreveu brechas de matriz argilosa com clastos intraformacionais correspondente a fluxos de lama que retrabalharam sedimentos pré-existentes na Lapa Doce (BA).

O salão de interesse paleontológico é o "Salão do Abrupto" com desnível de aproximadamente 15m ao final do conduto principal, sendo necessárias técnicas verticais para acessá-lo (Fig. 5).

Figura 5: *Uso de técnica vertical para descida e acesso ao Salão do Abrupto. Foto: Kraemer, 2024.*

Ao alcançar o piso deste salão, à sua direita ao fundo, visualiza-se o denominado "Abismo da Preguiça", que dá acesso à pequena câmara (Fig. 6).

Figura 6: *Acesso em vertical à câmara com pacote fossilífero. Foto: Kraemer, 2022.*

Ao adentrá-la, visualiza-se trincheira ao fundo, com aproximados 2,5m de altura (Fig. 6), onde foram registrados elementos ósseos isolados, parcialmente inclusos em matriz composta por argilas e siltes transportados pelos condutos como carga em suspensão (LAUREANO & KARMANN, 2013).

A manutenção constante da umidade na câmara, favorece dilatação dos interstícios que exercem pressão sobre os elementos fósseis, conferindo-lhes alto grau de friabilidade, sendo difícil seu isolamento, retirada e resgate da matriz.

No nível mais alto da trincheira, é encontrada grande área coberta por brecha carbonática com esqueleto parcialmente completo de fóssil de megafauna Quaternária (Fig.7).

Figura7: *Brecha do teto da câmara, onde encontra-se esqueleto parcialmente completo e articulado de preguiça Catonyx cuvieri (Xenarthra, Scelidotheriinae). Nos círculos estão demarcados registros fósseis. Foto: Kraemer, 2022.*

No lado direito da câmara ocorre uma passagem estreita, o "Conduto da Paca", que consiste em uma passagem com desnível de aproximados 3m negativos. Tal passagem dá acesso ao nível mais inferior da cavidade, o "Conduto da Paca", onde foi encontrado outro registro fóssil (Fig.8; Fig. 9).

Figura 8: *Descida em vertical rumo ao "Conduto da paca". Foto: Kraemer, 2024.*

3. Materiais e Métodos

3.1. Material

O material analisado compreende os fragmentos ósseos e ossos íntegros, diagnosticáveis taxonomicamente, entre os grupos de mamíferos viventes e extintos. Consiste em 49 ossos e fragmentos ósseos de *Catonyx cuvieri*, 1 crânio parcialmente completo de *Nothrotherium maquinense* Lund, 1839, e 174 ossos de Cuniculus paca.

Os depósitos paleontológicos consistem em três tipos de substrato sedimentares. *Locus 1*: solo carbonatado e cimentado a paleoteto (brecha); *Locus 2*: trincheira colmatada de matriz sito-argilosa inconsolidada; *Locus 3*: piso de conduto vadoso.

Especificamente, no *Locus 1*, a escavação por decapagem não foi viável, dada a limitação espacial da câmara, decorrente do afunilamento da área a ser explorada, como também pela ocorrência de sedimentos altamente cimentados e desornado dos elementos clásticos, e pela alta dureza mineralógica incorporada aos elementos fósseis.

Brechas, no sentido mais amplo, são rochas de aspecto fragmentário, constituídas de clastos angulosos e não arredondados, imersos

e cimentados em uma matriz mais fina, assemelhando-se aos conglomerados, com pouca posibilidade de análise que oferecem devido ao assentamento caótico dos ossos na matriz (RODRIGUEZ-HERNANDEZ et al., 2009). Brechas com ossos inclusos são compostas por uma matriz de ossos esfarelados e sedimento carbonatado, contendo ossos pouco fragmentados ou íntegros (HUBBE, 2008).

Geologicamente, são pacotes sedimentares sem horizontes estratigráficos definidos, de alta dureza e resistência, onde não se pode fazer qualquer tipo de leitura de fácies, dada a

natureza caótica em que os elementos constituintes podem se encontrar (Fig. 9)

Figura 9: *Brecha clástica contendo ossos o esternebras, articulação radio-umeral de Catonyx cuvieri (Xenarthra, Scelidotheriinae). Abismo da Preguiça, Gruta João Lemos. Pains, MG. Foto: Kraemer, 2022.*

Outro tipo de registro fóssil, consistiu-se em elementos ósseos distribuídos aleatoriamente na trincheira de matriz silto-argilosa colmatada e localizada abaixo da brecha de ossos (*locus 2*). Nela foram encontrados ossos que, dada a alta adesão ao substrato circundante e ao alto grau de friabilidade, só foi possível a coleta dos elementos parcialmente expostos (Fig. 10).

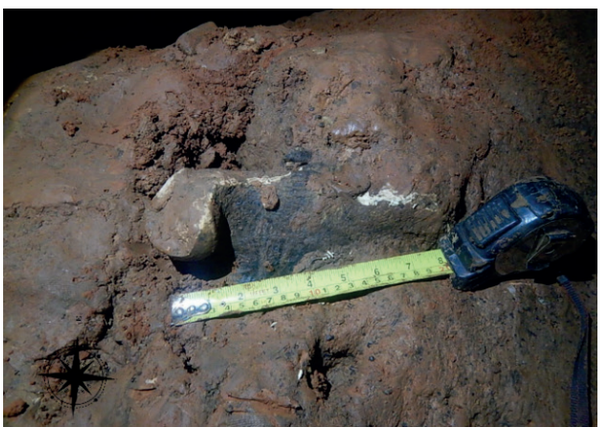

Figura 10: *Porção médio-distal de fêmur direito de Catonyx cuvieri parcialmente aflorada na trincheira. Escala 8cm. Foto: Kraemer, 2022.*

Para esse jazigo, denominado locus 2, não foi possível aplicar controle estratigráfico, visto que, uma vez no interior dos condutos, principalmente aqueles associados ao nível d'água, os sedimentos são retrabalhados em ciclos sucessivos de erosão e deposição entre as entradas e as ressurgências do sistema de condutos (Gillieson, 1996; Bosh e White, 2007).

Para o *locus 3*, denominado "Conduto da Paca", também não foi possível o uso de técnicas de controle estratigráfico pelo reduzido espaço para aplicar a técnica, como também pela natureza da deposição do fóssil, que se encontra acomodado superficialmente sobre fina camada de sedimento carbonatado misto associado a seixos em menor quantidade, que se assenta diretamente na rocha matriz, não viabilizando leituras estratigráfica por ausência de planos de acamamento (Fig. 11).

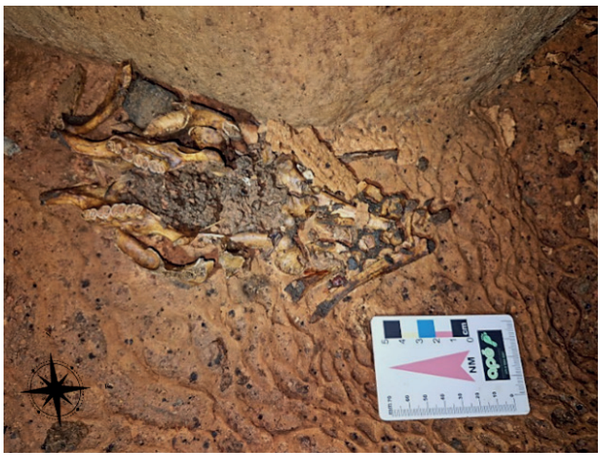

Figura 11: *Esqueleto preservado de Cuniculus paca (Rodentia, Cuniculidae) parcialmente incluso em fina capa calcítica no piso do conduto. Escala 5cm. Foto: Nativo, 2022.*

O material fóssil foi coletado com a anuência das licenças SISBIO/ICMBIO/MMA Nº 87973-1 e COPAL/ANM Nº 028/2023,

3.2. Métodos

A escolha do método a ser aplicado a certo depósito depende de uma série de fatores como o seu conteúdo mineralógico, sua antiguidade e mesmo os recursos financeiros disponíveis. Para o presente estudo não foi possível realizar escavação com controle estratigráfico, dado o risco e ausência de horizontes estratigráficos nos sítios visitados, dificultando assim analisar questões que extrapolem o material fóssil abordado, como análise sedimentológica, faciológica e bioestratigráfica, devido à natureza dos *loci* fossilíferos analisados. Se atendo, portanto, a análise de aspectos taxonômicos e tafonômicos. Possíveis análises faciológicas serão feitas a posteriore, nos pacotes clásticos reliquiares, a fim de compreender a dinâmica sedimentar da caverna.

A coleta adotou critérios tafonômicos adaptados de Holz & Barberena (1989), Almeida (2000) e Holz & Simões (2002).

O método de coleta foi aplicado em três substratos diferenciados; *Locus 1*: solo carbonatado e cimentado a paleoteto (brecha); *Locus 2*: trincheira colmatada de matriz sito-argilosa inconsolidada; *Locus 3*: piso de conduto vadoso.

3.2.1. Resgate fóssil

Locus 1: Como medidas essenciais para um trabalho preciso de extração fóssil em brecha, foram plotados todos os ossos aflorados e parcialmente inclusos na matriz cimentada, sendo utilizado o acrônimo GJL para designar a cavidade (Gruta João Lemos) seguido por sequências numéricas (e.g., GJL001). Seguida da diagnose morfológica do elemento fóssil. Foram utilizados instrumentos de atrito para extração mecânica, entre eles, o uso de marreta, cinzéis, ponteiras e marteletes para fragmentar a matriz cimentada do entorno das peças fósseis.

Locus 2 : foram utilizados estiletes, espátulas e bisturis para extração detalhada dos fósseis inclusos na matriz argilosa úmida. As peças resgatadas também foram identificadas seguindo a ordem sequencial utilizada na brecha. O pacote não apresenta planos de fácies.

Locus 3: para a retirada do esqueleto do "Conduto da Paca", foram

utilizados estiletes e pinças para captura de pequenos elementos ósseos que foram acondicionados em frascos forrados com algodão hidrófilo. Cada porte recebeu um número de identificação e discriminados os ossos contidos no seu interior.

Os elementos fósseis foram embalados com uso de rolo de papel térmico multibanco dim. 57x40x11mm, sendo acrescido plástico bolha de 1,30x100m e vedados por fita silver, rolo 48mmx50m para amortecimento de choques mecânicos. Tais pacotes contendo os fósseis, foram inseridos em caixote baú de madeira preso a cordas e içados por força braçal, para o nível superior do abismo pela equipe de resgate fóssil (Espeleogrupo de Pains/EPA, Programa de Pós-graduação de Geografia/PUC Minas e Escola Brasileira de Espeleologia eBRe/SBE).

3.2.2. Curadoria do material

Antes de qualquer análise, fez-se necessário curar o material paleontológico, passando por cura mecânica, retirando os sedimentos atacados aos elementos fósseis. As peças que se apresentavam recobertas por concreçoes carbonáticas que obliterassem caracteres diagnósticos de cunho taxonômico foram selecionadas para triagem mecânica e química, segundo protocolo adotado pela equipe da Coleção de Paleontologia do Museu de Ciências Naturais PUC Minas.

A primeira delas concentrou-se na remoção mecânica dos conglomerados carbonáticos e foi efetuada com o auxílio de um conjunto de instrumentos tais como martelos, alicates ponteiras, caneta pneumática e centrífuga elétrica. A remoçao mecânica foi preponderante por eliminar grandes volumes de concreções em tempo relativamente curto quando comparado ao tratamento químico. Tal procedimento foi adotado apenas quando grandes volumes de concreção estavam a uma distância segura das superfícies do elementos fósseis que permita sofrer choques mecânicos sem causar danos.

As concreções desprendidas dos fósseis foram reservadas para análises futuras. A curadoria focou na identificação anatômica e taxonômica do material. A diagnose taxonômica do material foi realizada por comparação direta com os acervos valorosos depositados nas Coleções de Paleontologia e Mastozoologia do Museu de Ciências Naturais PUC Minas.

A descrição anatômica dos ossos seguiu as especificações da Nomina Anatomica Veterinaria (International Committee on Veterinary Gross Anatomical Nomenclature, 1983).

4. Resultados

Os resultados apresentados dão enfoque aos aspectos taxonômicos e tafonômicos. Análises morfológicas, faciológicas, paleoecológicas e sedimentares comporão os capítulos de dois estudos de caso de Tese *stricto sensu* já em andamento, com apoio financeiro da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES/MEC).

4.2.1. Locus 1

Neste local foram encontrados os restos esqueléticos incrustados em brecha carbonática da preguiça terrícola *Catonyx cuvieri* Lund, 1839, somando 49 elementos ósseos (Fig. 12)

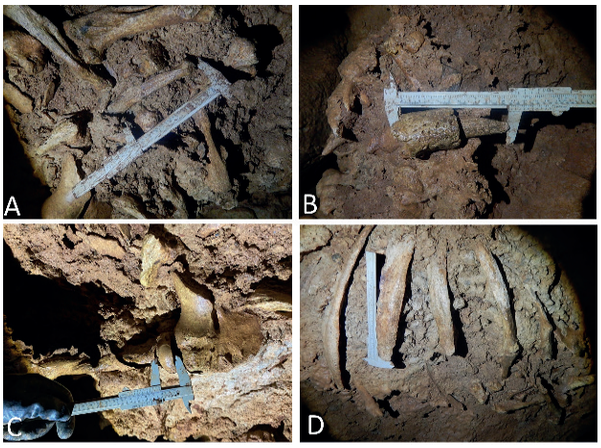

Figura 12: *Regiões anatômicas diagnosticadas na brecha do locus 1. (A) vértebras e costelas esternais ; (B) Falange distal III, esquerda. (C) articulação rádio-umeral direita. (D) série de costelas torácicas. Fotos : Kraemer, 2022.*

Coluna vertebral e cintura pélvica, encontram-se, ou inclusas, ou não se depositarão no locus 1, permitindo o resgate apenas de ossos longos (úmeros e rádios, fíbula esquerda, esternébras, costelas torácicas e esternais, autopodiais. O estado de conservação dos elementos ósseos de *C. cuvieri* retirados da brecha carbonática é satisfatório (Fig.13C), permitindo realizar um diagnóstico morfológico preciso, dado vários elementos ósseos estarem mantidos articulados.

Constata-se a densidade friável dos elementos fósseis aflorados nas brechas, enquanto outros, inclusos na matriz clástica silto-argilosa, apresentavam-se compactos e permineralizados. Pela distribuição dos elementos na brecha e sua interface com o *locus 2*, se infere que os dois *loci* foram contíguos, sofrendo a *posteriore* perturbação hídrica e gravitacional.

O material osteológico encontrado no “Abismo da Preguiça” pode ser atribuído a um único indivíduo adulto de *C. cuvieri*, baseado nos caracteres anatomo-morfológicos, como o entepicôndilo alongado e a ausência do foramen entepicondilóide, assim como o fusionamento visível das epífises umerais e radiais (CARTELLE et al., 2009).

4.2.2. Locus 2

Os fósseis coletados no pacote silto-argilo abaixo da brecha, incluindo o crânio de *N. maquinense*, uma pequena preguiça terrícola, descoberta cujo protótipo foi coletado na Gruta de Maquiné, Cordisburgo, Minas Gerais (CARTELLE, 1994; 2012; MARCHESOTTI, 2005), além da porção distal de fêmur direito de *C. cuvieri* e outros fragmentos não identificáveis dado alto grau de fragmentação óssea. Os fósseis apresentavam-se em estado friável, permitindo inferior que ao estarem imersos na trincheira que se apresenta constantemente úmida dado sua proximidade com a zona epifreática, os fósseis também sofreram tensão superficial, tornando-se úmidos e friáveis (Fig. 13).

Figura 13: *Vista palatal de crânio de Nothrotherium maquinense parcialmente incompleto e com deformação compressional lateral esquerda. Foto: Kraemer, 2024.*

4.2.3. Locus 3

No sumidouro intercomunicante entre os dois níveis inferiores da cavidade, foi encontrado o esqueleto completo e fossilizado de Cuniculus paca Linnaeus, 1766, um roedor Hystricomorpha representante da família Cuniculidae Miller & Gidley, 1918, cujo congênere vivente é Cuniculus taczanowski (WILSON & RIDER, 2005).

A espécie vivente C. paca foi registrada em depósitos quaternários do território intertropical brasileiro (MAYER, 2011).

Lund, em 1837, descreveu duas espécies extintas para a família Cuniculidae: Cuniculus laticeps e Cuniculus major, enfatizando a grande semelhança entre a morfologia dos ossos pós cranianos das duas espécies extintas com C. paca. A diferença está na forma do crânio, sendo mais largo em C. laticeps. C. major apresentava proporções ósseas de 20 30% maiores que C. paca, apresentando proporcionalidades mais próximas entre C. paca, C. taczanowski e C. laticeps (PAULA COUTO, 1953; MAYER, 2021).

Figura 14: *Crânio invertido de Cuniculus paca (Rodentia, Cuniculidae), registrado no locus 3. Escala: 3cm.*

5. Discussão

A análise do processo de incorporação do material fóssil registrado no pacote sedimentar do locus 1 permite avaliar que o processo de inserção dos ossos teria se dado por transporte alóctone biótico, podendo haver três possibilidades: (i) entrada e extravio do animal nos condutos da caverna, com posterior queda em abismos ou poços que o impeçam de encontrar a saída, (ii) queda acidental do animal em claraboias presentes no epicarste, e (iii) relacionados aos processos de enchentes e de alta energia, escorregamentos de sedimentos e colapsos de nível (SIMPSON, 1994; HUBBE 2008).

A explicação mais plausível é a de que pode ter sido uma via de entrada mista, com transporte ativo e passivo, com entrada e extravio do animal (HOLZ & SIMÕES, 2002).

Quanto ao *locus 1*, o pacote em brecha teria sofrido percolação em contato com o teto, formando brecha parental em seu terço superior. O restante do depósito permaneceu inconsolidado sendo retrabalhado por erosões sucessivas nos períodos cíclicos de novas entradas de enchentes.

GHILARDI et al. (2011) afirmam que sedimentos em cavernas são constantemente retrabalhados por inundações que destroem o empilhamento estratigráfico misturando-os aos sedimentos fósseis, geralmente relacionados aos períodos de maiores chuvas com aumento na drenagem superficial.

Sinais de transporte e retrabalhamento são muito claros nos materiais do *locus 2*, dentre eles, o mais significativo, o crânio de *N. maquinense*, apresentando sinais evidentes de fragmentação decorrente de acúmulos altamente transportados, retrabalhados e concentrados ao longo de um grande período temporal (HOLZ & SIMÕES, 2002).

Diante do exposto, a aplicação de controle estratigráfico parece ser inviável para a brecha (*locus 1*), para a trincheira (*locus 2*) e para o conduto inferior ao abismo (*locus 3*).

Segundo Laureano (1998), os depósitos sedimentares remobilizados e misturados no interior das cavernas, decorrem principalmente devido a processos fluviais, o que diminui a confiabilidade certa da proveniência dos registros fósseis, enfraquecendo uma classificação de origem.

Em trabalho posterior, o autor adverte que em algum momento durante a deposição sedimentar poderá ocorrer contribuições autóctones e alóctones tornando o critério de proveniência um parâmetro insuficiente para classificação (LAUREANO & KARMANN, 2013).

6. Conclusão e recomendação

O achado paleontológico no “Abismo da Preguiça”, revelou fósseis de *Catonyx cuvieri* e *Nothrotherium maquinense*, duas espécies de Pilosa além do esqueleto fossilizado de Cuniculus paca. Esses registros reforçam a relevância da Gruta João Lemos e o carste em que se insere, para a paleontologia do Quaternário, ampliando o conhecimento sobre a o quaternário da região. Diante dos achados e da importância científica da caverna, recomenda-se a implementação de estratégias de conservação e gestão do sítio, considerando seu potencial para pesquisas e educação ambiental. O reconhecimento da Gruta João Lemos como um geossítio de relevância para a geodiversidade e o patrimônio espeleológico reforça a necessidade de sua proteção, garantindo a preservação dos registros geológicos e paleontológicos para as futuras gerações.

O excelente estado de preservação dos fósseis, especialmente de *C. cuvieri*, permitirá a realização de diagnósticos morfológicos detalhados, contribuindo para estudos de anatomia comparada, tafonomia, sistemática, assim como possíveis inferências paleoambientais que comporão Tese do autor principal deste artigo.

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Expanding the paleontological record in the Cabachuelas Nature Reserve, Morovis, Puerto Rico.

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Abstract

Caves are used by various animals as shelter and a source of food. However, animals can sometimes become trapped or lost due to the complex geomorphology and darkness of these environments. These characteristics make caves ideal settings for the accumulation of fauna, both current and extinct. This study aims to identify and document extinct and extant species native or endemic to Puerto Rico found in cave deposits. The research was conducted in Estancita Cave at the Cabachuelas Natural Reserve, located in Morovis, Puerto Rico. The reserve lies within the Lares Limestone, formed during the late Oligocene, between 26.5 and 24.7 million years ago. The study site was selected through exploration and inspection of the caves, focusing on areas where sediments had accumulated and served as natural or anthropogenic deposits. In each study area, loose sediments were collected and sieved using different mesh sizes to recover bones, macro and microfossils. The recovered specimens were photographed and documented. Preliminary findings include remains of vertebrates and invertebrates, including *Elasmodontomys obliquus* (a partial molar), a partial humerus of *Peltophryne lemur*, and a shell of *Macleania darlingtoni*. These discoveries contribute to understanding the island's past and present biodiversity.

1. Introduction

Paleontological studies in Puerto Rico began at the start of the 20th century in great part as a result of the New York Academy of Sciences scientific survey of the island, marking the beginning of fossil discoveries. Caves which provided some of the first discoveries in the island can be rich in paleontological material. Some of these cave deposits accumulate over time as animals can sometimes become trapped or lost due to the complex geomorphology and darkness of these environments. In other instances, caves are used as shelter by different species of birds of prey (particularly owls), resulting in abundant accumulations of pellets filled with the bones of their prey [DODSON & WEXLAR (1979), KUSMER (1990), COMAY & DAYAN (2018)]. Some of the first collections of fossil vertebrates from cave deposits in Puerto Rico were made by the American paleontologist Harold E. Anthony, who conducted extensive work in 1916. Anthony collected a significant number of fossil mammals, which were found in sediment deposits located inside caves in three main study sites; Catedral Cave, Clara Cave, and San Miguel Cave, all located in the municipality of Morovis [ANTHONY (1918)]. The Morovis area is considered one of the richest regions for paleontological studies in Puerto Rico due to its exceptional productivity in fossil preservation [WETMORE (1922) and MCFARLANE (1999)]. Additional work in that region was conducted in 1957, by paleontologist James W. Bee from the University of Kansas [WOODS (1996)]. During his visit to Clara Cave in Morovis, Bee identified a specimen of *Macrotus waterhousii waterhousii* Gray, a bat species that had been declared extinct, thus contributing to the knowledge of the island's past biodiversity [CHOATE & BIRNEY (1968)]. Paleontological studies of cave deposits on the island have continued over time, with works focused on the avifauna [e.g. OLSON (1976); OLSON & MCKITRICK (1981); OLSON (2015)], reptiles and amphibians [PREGILL (1981); VELEZ-JUARBE & MILLER (2007)] and mammals [e.g. CHOATE & BIRNEY (1968); MCFARLANE (1999a, b); TURVEY (2006)]. Recent analyses conducted by the authors has identified the caves of Morovis as some of the sites of greatest importance for paleontological research. For this study, the selected caves are located within the Las Cabachuelas Natural Reserve, which belongs to the geomorphological province of the Northern Karst Belt [MONROE (1980)] which provided an ideal habitat for various species. The reserve lies within the Lares Limestone, deposited during the Late Oligocene, specifically between 26.5 to 24.7 million years [ORTEGA-ARIZA (2015)]. The cave being studied for this project is Estancita Cave which was first recognized as a paleontological locality during the 1976 Smithsonian Expedition [PREGIL (1981)] and [OLSON (1985)]. In our karst fauna, we can find a variety of species, but most importantly, it serves as a refuge for endangered species, such as the Puerto Rican Nightjar (*Caprimulgus noctitherus*), Puerto Rican Crested Toad (*Peltophryne lemur*), Coquí Llanero (*Eleutherodactylus juanariveroi*), Puerto Rican Parrot (*Amazona vittata*), and the Puerto Rican Boa (*Chilabothrus inornatus*) amongst others. The primary objective of our research is to increase the species database for this region to reconstruct past biodiversity, establish connections between extinct and existing species, and analyze the evolutionary relationships that link them. This work is crucial for a deeper understanding of our biological and ecological history, providing a solid foundation for future advancements in the field.

2. Methods and Materials

In this study, a variety of materials were used both in the field and in the laboratory, each selected for its specific function in different stages of the research. During fieldwork, tools such as shovels, spatulas, brushes, measuring tapes, rulers, tweezers, scales, flashlights, gloves,

and sampling bags were used. This equipment was essential for carefully collecting fossils, bones, and sediment. In the laboratory, we utilized a digital microscope, gloves, a desiccator, aluminum trays, sieves, scales, brushes, and sampling bags. These tools facilitated the cleaning, sorting, and analysis processes, enabling the precise separation of organic material from the fossils and bones. The meticulous use of these materials ensured the collection of reliable samples and the preservation of the integrity of the specimens gathered and the cave. The sampling area was divided into four sites. After the area was selected, we proceeded to collect samples starting from the surface to near-surface depths. Visible fossils in the loose sediments were collected initially. The specimens we collected were cleaned with a brush and placed in sample bags, each carefully labeled according to its area. After the initial collection, we gathered two bags of loose sediment for each area. Throughout the process, we documented the locations of the areas and their findings with photographs and notes. In the laboratory, the sediments samples were wet sifted through meshes of different sizes (125 µm, 2µm, and 0.250 µm) to collect the bones and fossils. After this process, the material trapped in the meshes was transferred to sample trays and placed in a desiccator for about a week to make sure everything was completely dry. After drying, we examined the subsamples under a digital microscope, sorting bones, fossils, and shells into separate collection bags. Then, the specimens were photographed and identified.

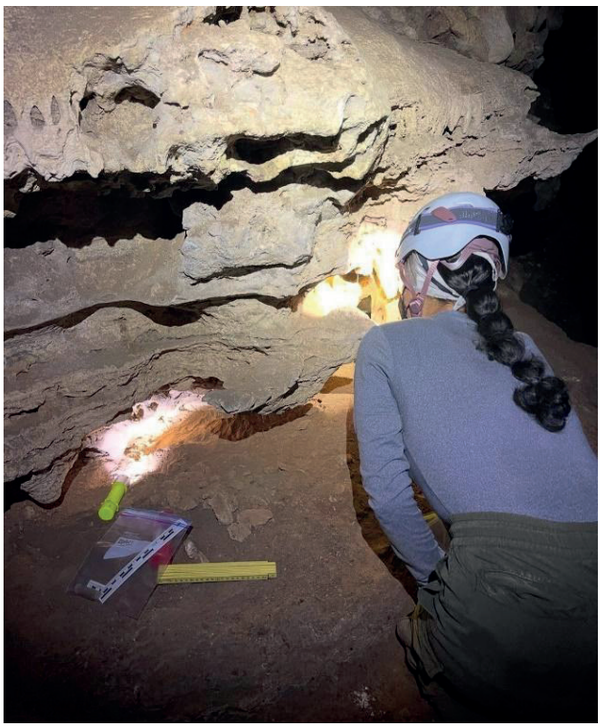

Figure 1: *In this image of Sydnie Vazquez collecting fossils from the loose sediments in the Estancita cave.*

3. Results

The results obtained in this study provide key evidence of the paleontological richness of Puerto Rico. Estancita Cave revealing species of great importance to our island within its deposits (Fig.1). Some of the fossils collected include *Elasmodontomys obliquus* (extinct giant hutia) shown in Fig. 2, *Macleania darlingtoni* (Sierra snail) shown in Fig. 4 and *Peltophryne lemur* (Puerto Rican crested toad) presented in Fig. 6. These species are found exclusively in the karst regions of Puerto Rico and are, or were, fundamental to maintaining local ecosystems. *Peltophryne lemur*, commonly known as the Puerto Rican crested toad, is an endemic and critically endangered species, currently restricted to a small area within the southern karst belt. Our discovery is the second specimen recovered from Estancita Cave (see Pregill, 1981) and represents a significant contribution to further understanding its past distribution and highlights the importance of this area as a refuge for local biodiversity. Other findings included the *Brachyphylla cavernarum* (Fig. 3), known as the Antillean fruit-eating bat, *Stenoderma rufum* (Fig. 5), known as the red fruit bat native to Puerto Rico, and the endemic teiid lizard *Pholidoscelis exsul* (Fig.7). The most abundant remains were chiropterans (bats). Figure 8 present the list of know taxa for the Estancita cave and what new taxa was documented in this study, expanding the paleontological record for this cave.

Taxon	Element
Elasmodontomys obliquus	Partial molar
Peltophryne lémur	Partial humerus
Stenoderma rufum	Mandible
Brachyphylla cavermarum	Mandible
Macleania darlingtoni	Shell
Pholidoscelis exsul	Femur

Figure 1: *List of taxa and elements collected from Estancita Cave during this project.*

Figure 2: *Elasmodontomys obliquus.*

Figure 3: *Brachyphylla cavernarum.*

Figure 4: *Mcleania darlingtonia.*

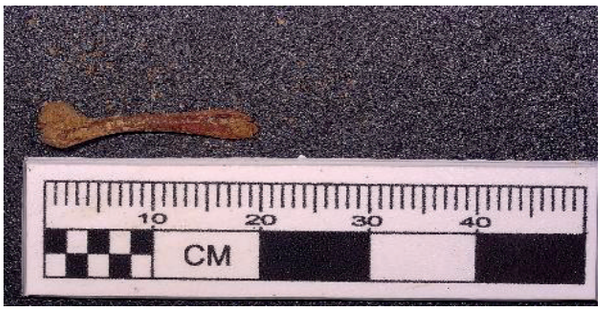

Figure 5: *Peltophryne lemur.*

Figure 6: *Pholidoscelis exsul.*

Figure 7: *Steboderma rufun.*

Taxon	Source
Mcleania darlingtonia	This work
Peltophryne lemur	Pregill,1981; this work
Leptpdactylus albilabris	Pregill ,1981
Anolis cuvieri	Pregill, 1981
Anolis cristatellus	Pregill,1981
Pholidoscelis exsul	Pregill, 1981; this work
Cyclura pinguis	Pregill, 1981
Diploglossus pleii	Pregill,1981
Chilabothrus inornatus	Pregill,1981
Borikenphis portoricensis	Pregill,1981
Magliophis stahli	Pregill,1981
Nesotrochis debooyi	JVJ,pers.obs.
Psittacara maugei	Olson,2015
Pedinorthis stripsarcana	Olson & McKitrick, 1981
Brachyphylla cavernarum	This work
Stenoderma rufum	This work
Nesophontes edithae	Pregill, 1981, pers.obs.
Elasmodontomys obliquus	This work

Figure 8: *List of Pleistocene-Holocene taxa known from Estancita Cave, Morovis, Puerto Rico.*

4. Discussion

The results of this study underscore the importance of conserving and continuing to study both existing and extinct species in Puerto Rico. The discovery of key species such as *Elasmodontomys obliquus, Peltophryne lemur*, and *Macleania darlingtoni* in Estancita Cave reinforces the idea that the island's karst regions have served as essential ecological refuges over time. Specimens of *Elasmodontomys obliquus* were first described by H. E. Anthony in 1916 based on specimens collected the prior year in Utuado, with additional material collected in later expeditions [ANTHONY (1918)]. This species, endemic to Puerto Rico, became extinct approximately 2,400 years ago [TURVEY (2007)]. Other non-volant mammals known from this cave include the island-shrew, Nesophontes edithae, whose last appearance date is around 990 years ago [PREGILL (1981)]. Furthermore, the discovery of the bats *Brachyphylla cavernarum* and *Stenoderma rufum* provides valuable insights into the biodiversity within the cave systems. These bats require high temperatures for survival and reproduction, making their presence significant for understanding the cave's environmental conditions. Although known from other caves in the area [ANTHONY (1918) and McFarlane (1999b)], this is the first report of E. obliquus, B. cavernarum and S. rufum from Estancita Cave. Considering previously documented mammals, birds, reptiles and amphibians, our preliminary results are

the first to report on additional mammals and invertebrates within the Pleistocene-Holocene fauna of Estancita Cave. These findings not only corroborate previous studies on Puerto Rico's historical biodiversity but also expand our understanding of the distribution of endemic and endangered species, such as the Puerto Rican crested toad (*Peltophryne lemur*). Across the Greater Antilles, Puerto Rico is the only island to have lost all its endemic non-volant endemic mammals as well as several endemic or native birds and lizards [PREGILL & OLSON (1981); MACPHEE & FLEMMING (1999)]. The specific drivers of these extinctions are not precisely known; however, it is likely that both, natural and anthropogenic environmental changes and habitat modification are the likely culprits as some of these extinctions took place after the arrival of humans to the island.

5. Conclusion

Research conducted in Estancita Cave has enabled significant strides toward a better understanding of Puerto Rico's natural history. The fossils collected so far underscore the importance of continuing paleontological research in Puerto Rico. This project aims not only to identify fossil remains but also to highlight the significance of caves as repositories of our natural past. As we continue to explore more caves and expand our analysis and identification of specimens, we hope to contribute valuable knowledge that benefits our island and the Caribbean region. Future work aimed at collecting additional material and carbon-dating of specimens may lead to additional insights into the timing of extinction and raise important questions about the ecological and climatic changes that may have influenced the composition of fauna in these regions. Paleontology provides us with a window into our past, helping us to comprehend our present and prepare for our future.

Acknowledgments

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Reassessment of *Trigodonops lopesi* Roxo,1921 based on identification and dental analysis of Toxodontinae material from caves in Brazil

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Resumo

O trabalho aborda a subfamília Toxodontinae, cujo registro geológico vai do Paleoceno Inferior ao Pleistoceno Final, com ampla distribuição nas Américas. O estudo se concentrou nas mandíbulas de 12 espécimes de Toxodontinae, coletados nas cavernas Toca dos Ossos e Gruta do Labirinto do *Toxodon*, na Bahia, Brasil. Os materiais analisados revelaram variações na linha de esmalte e na formação dos sulcos dentários, sobretudo em molares e pré-molares, com diferenças ontogenéticas entre espécimes juvenis e adultos. Em *Toxodon platensis* e *Mixotoxodon larensis*, a presença de esmalte foi considerada característica juvenil. Diagnósticos anteriormente atribuídos a *Trigodonops lopesi*, como o esmalte lingual espesso no P4 e sulcos dentários distintos, foram também observados em outras espécies. O estudo destaca a importância das variações ontogenéticas nos diagnósticos de Toxodontinae.

Abstract

The study, which focuses on the Toxodontinae subfamily, presents significant findings that contribute to our understanding of the geological record of this species. The research examined 12 mandibular specimens of Toxodontinae collected from Toca dos Ossos Cave and Gruta do Labirinto do *Toxodon* in Bahia, Brazil. The analysed materials revealed variations in enamel lines and dental groove formation, particularly in molars and premolars, with ontogenetic differences between juvenile and adult specimens. In *Toxodon platensis* and *Mixotoxodon larensis*, the presence of enamel was considered a juvenile trait. Previously attributed diagnoses for *Trigodonops lopesi*, such as thick lingual enamel on P4 and distinct dental grooves, were also observed in other species, leading to synonymy between T. lopesi and M. larensis. The study emphasises the importance of ontogenetic variations in the diagnoses of Toxodontinae, providing a significant contribution to the field.

1. Introduction

The Early Paleocene to the Late Pleistocene is the temporal range of the Toxodontidae. Initially documented the *Perutherium altiplanense* Grambast et al. (1967), which was discovered in Laguna Umayo, Peru (MARSHALL et al., 1983; SIGÉ et al., 2004; BRAUNN & RIBEIRO, 2017). In Uruguay, Charles Darwin discovered the first Toxodontidae in Pleistocene-aged strata in 1833 (FERNICOLA, 2009). In 1837, Owen recognised the specimen as *Toxodon platensis*, and it is now kept in the Museum of London. However, according to Paula-Couto (1979) and Cartelle (1992), Peter Wilhelm Lund was the first Toxodontidae specimen collector in Brazil who worked in Lagoa Santa, Minas Gerais. Winge later identified these in 1906. However, the genus's presence in Brazil was first noted by paleontologist Cope (1886).

Between Argentina and the southern United States, the Toxodontidae family is widely distributed, occurring in Bolivia, Brazil, Colombia, Ecuador, El Salvador, Honduras, Peru, Uruguay, and Venezuela. From the Miocene to the Late Pleistocene, fossils can be found in strata (NASIF et al., 2000; BOND et al., 2006; LUNDELIUS et al., 2013). Hypsodonty and lophodonty, traits of the Toxodontidae family, cause differences in the layers of enamel, alternating areas of presence and absence, and unique morphological characteristics within and between genera. There is minimal differentiation between their high crowns' intra- and extra-alveolar portions (BERGQVIST et al., 2000; MENDONSA, 2007). The family currently consists of two subfamilies: Toxodontinae and Nesodontinae. Only members of the Toxodontinae subfamily have been found in Brazil. With a weight of 1,000–1,200 kg, *T.platensis* is the largest member of the Toxodontidae (NELSON et al., 2023). According to COSTAMAGNA et al. (2024), this species exhibits size and dental angulation variability across populations, which may indicate variations in local habitat and diet.

Three additional species have been identified in Brazil: *Piauhytherium capivarae* Guérin & Faure, 2013 from Lagoa dos Porcos (BA), represented by cranial and postcranial material; *Mixotoxodon larensis* Van Frank, 1957, a Pan-American species and the only Toxodontidae found in Central and North America, with its holotype also juvenile and originating from Venezuela; and *Trigodonops lopesi* Roxo, 1921 found exclusively in Brazil from the upper Juruá region (AC), based on a juvenile type specimen. SILVA (2019) disproved the species even though some later research still recognises it. In this perspective, the objective of this study is to present a reassessment of *Trigodonops lopesi* Roxo, 1921, based on the identification and dental analysis of *Toxodon platensis* and *Mixotoxodon larensis* material from caves in Bahia, Brazil.

2. Materials and Methods

The mandibular materials of *Toxodon platensis* and *Mixotoxodon larensis* examined in this study were gathered from the Toca dos Ossos, and Gruta Labirinto do *Toxodon* caves in the 1980s by Cástor Cartelle Guerra, the curator of the Paleontology Laboratory at PUC Minas, and his colleagues (Fig. 1). This meticulous collection procedure guarantees the accuracy and dependability of our findings.

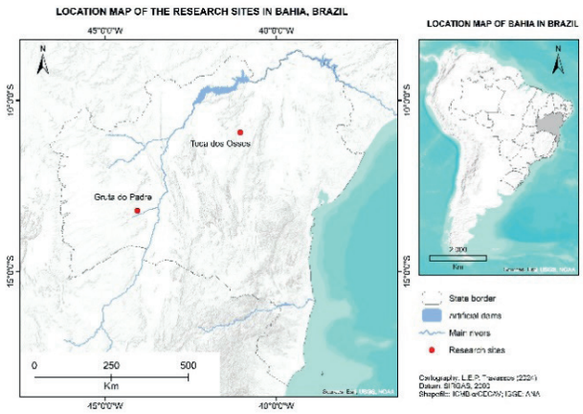

Figure 1: *Location of explored caves.*

The analyzed material consists of 12 Toxodontinae specimens, each has distinct characteristics that shed light on the species. Only specimens with mandibles attached to multiple teeth were chosen to facilitate intraspecific ontogenetic analysis and dental comparisons (Figs. 2, and 3).

The Toca dos Ossos Cave (10° 55′ 52′′ S and 41° 3′ 24′′ W) is in the northern part of the Chapada Diamantina, in the municipality of Ourolândia, northeastern Bahia, within the Salitre River Basin. It is part of the Miocene-dated limestone massif of the Caatinga Formation (Branner, 1911). The cave is 60 meters above sea level (Cartelle, 1992); it has labyrinthine chambers and passages, and the predominant limestone is white-pink to greyish-white in color (Motoki et al., 2005) (Cartelle, 1992). It is noteworthy for its length and depth, with a mapped horizontal extension of 14,200 meters (Rubbioli et al., 2019). During the rainy season, water is still present in the lower levels but does not flow in the upper levels (Auler, 2006).

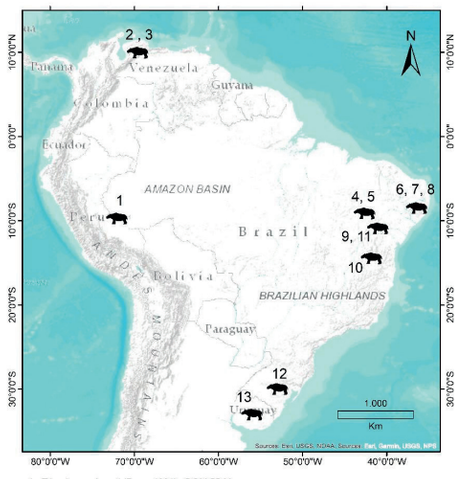

Figure 2: *Drawing of dental material of T. platensis (A: MCL4.383 B: MCL4.387 C: MCL4.390 D: MCL4.403/02 E: MCL5.257).*

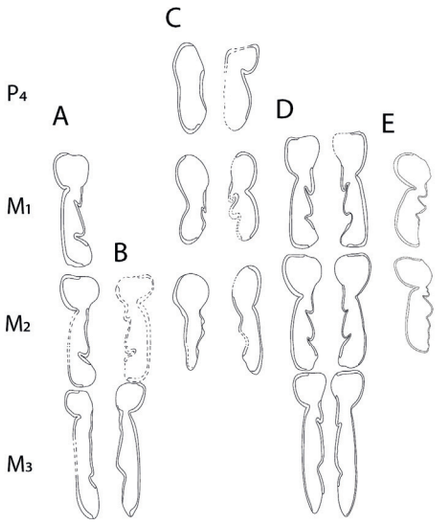

Figure 3: *Drawing of dental material of M. larensis (A: MCL4.385/2 B: MCL4.386 C: MCL4.391 D: MCL4.393 E: MCL4.395 F: MCL4.396 G: MCL4.397 H: MCL5.229).*

Only one specimen (MCL 4403/02) in this analysis was collected in the Labirinto do Toxodon Cave (14° 28′ 53′′ S and 41° 48′ 31′′ W). This material is characterised by two white-coloured mandibular rami that lack the symphyseal region. This cave is part of the Gruta do Padre complex in Santana, BA. In Brazil, it is the third-largest cave complex. Lastly, the material under study was located and sketched for comparison with published Brazilian material, type specimens, and other examples.

3. Results and Discussion

There is an enamel line pattern that is visible in each analyzed dentary. The enamel line and the groove formation pattern within the same mandible were inconsistent, like Mendonsa (2007). Both the molars and premolars of the two species (*T. platensis* and *M. larensis*) exhibited this trait. The dental arch is altered in both species due to the delayed growth of the third and final molars. Its growth seems earlier in the *T. lopesi* material under study, though this finding cannot be extrapolated to the entire species. The taxonomy and ontogenetic variations of Toxodontinae are better-understood thanks to these findings, especially when considering dental analysis and enamel line patterns. To sum up, our research emphasises how crucial it is to consider ontogenetic differences when diagnosing Toxodontinae (e.g., figure 5).

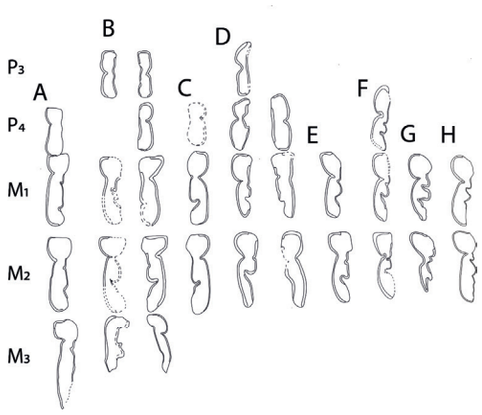

Figure 4: *Photos comparing the mandibular variation between (A, B) T. platensis, (C, D) M. larensis, (B, D) juvenile specimens.*

The lack of enamel covering on M1's metaconid, as noted by Laurito (1993), was not found in *M. larensis*. Two grooves and an enamel line were found on the lingual part of the tooth in a juvenile specimen from *M. larensis* (MCL 4396). Other individuals, all of whom have juvenile morphotypes, also showed enamel on their third and fourth premolars.

The left fourth premolar of the juvenile specimen MCL 4390 of *T. platensis* had an enamel line (Fig. 6). No structural dental difference between the two species could be determined a priori. However, wear and the tooth's location in the mandible cause dental variation between juvenile and adult members of the same species.

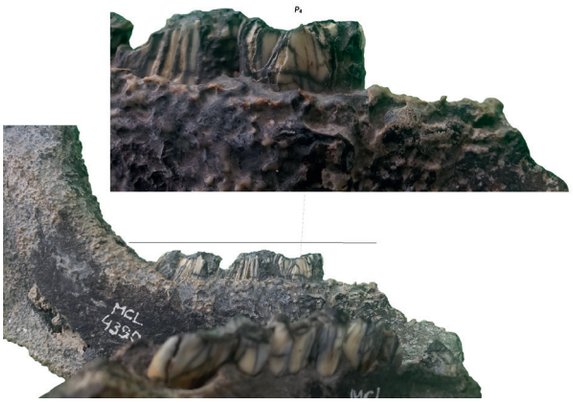

Figure 5: *Photo of Toxodon platensis MCL4.390 with tooth enamel on P4, with 10cm scale.*

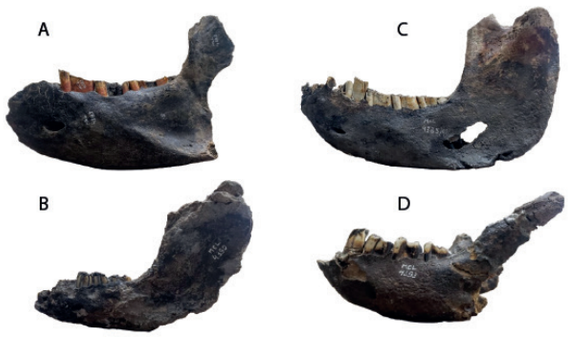

Figure 6: *Proportion of groove and number of teeth from Toxodon platensis in PUCMinas collection.*

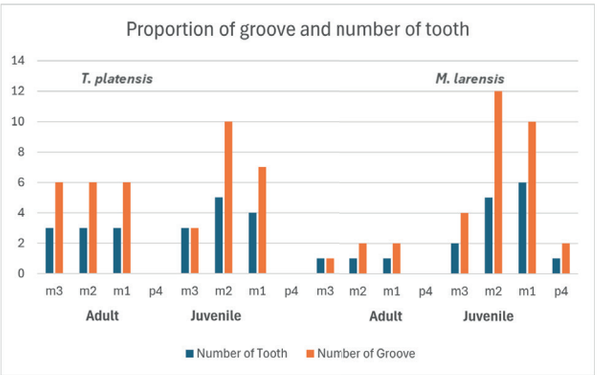

Figure 7: *Proportion of groove and number of teeth from Mixotoxodon larensis in PUC Minas collection.*

4. Conclusion

The diagnostic characteristics of *Trigodonops lopesi*, such as its P4 having a thick enamel layer on the lingual surface and a distinct groove on the external or vestibular face, as well as M1-2, presenting only a well-defined ento-hypocolunid groove and a subtle undulation replacing the meta-entoconid groove (more pronounced in M2), were also observed in *Toxodon platensis* and *Mixotoxodon larensis*. The enamel line on P4 was considered a juvenile trait in Toxodontinae. Regarding the grooves, they reflect individual ontogenetic processes without precise diagnostic significance.

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Meso-megamammals from the late plesitocene of Toca Fria Cave, Iuiú, Bahia, Brazil

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Abstract

Caves are important sites for the study of Late Quaternary mammalian fossils, providing diverse records of both extant and extinct species, thus contributing to the understanding of the region's past biodiversity, paleocommunity structure, and paleoenvironment. Toca Fria Cave is situated in Serra do Iuiú, on the border between the municipalities of Iuiú and Malhada, both in Bahia, Brazil. In 2013, Dantas et al. presented the taxonomic identification of fossils of eight taxa collected at this site. New field activities were conducted in this cavity between 2023 and 2024, resulting in the collection of several new mammalian specimens. Therefore, the objective of this communication is to present an expansion and update of the taxonomic composition of the Pleistocene mesomegamammal fauna collected at Toca Fria Cave. The material comprises cranial and postcranial bones attributed to 11 distinct taxa, belonging to the orders Carnivora (*Arctotherium wingei* and *Cerdocyon thous*), Folivora (*Nothrotherium maquinense*, *Valgipes bucklandi*, *Catonyx cuvieri*, *Glossotherium phoenesis*, *Eremotherium laurillardi*), Cingulata (*Pampatheridae*), Proboscidea (*Notiomastodon platensis*), Notoungulata (*Toxodon platensis*) and Artiodactyla (*Mazama sp.*). The expansion of information regarding the fauna represents a crucial step towards understanding the environmental conditions of the Iuiú/BA region during the Late Pleistocene.

1. Introduction

Fossils discovered in caves constitute one of the primary sources of study material for the Paleomastozoology of the Brazilian Quaternary. Initial research in this field commenced in the 19th century, conducted by Peter Wilhelm Lund in the caves of Lagoa Santa, Minas Gerais (AULER et al., 2003). Numerous cave systems are recognized in the Northeast and Southeast regions of Brazil, where extensive karst areas developed in rocks belonging to the Bambuí and Una Groups occur (AULER & FARRANT, 1996). The state of Bahia ranks third in the number of registered caves (ICMBio, 2023). Among the caves in Bahia, several possess high paleontological significance, such as Toca dos Ossos (Ourolândia, Bahia) and Poço Azul (Nova Redenção, Bahia). Studies on mammal fossils recovered from these caves have contributed substantially to the understanding of the fauna, not only of the region but of all of South America.

The objective of this study is to expand knowledge regarding the taxonomic composition of the fauna found in Toca Fria (municipality of Iuiú, Bahia), where eight taxa dated between 32 and 15 ka have already been recorded (DANTAS et al., 2013; 2020), thus contributing to the knowledge and characterization of the paleocommunity and paleoenvironmental aspects of the region.

2. Material and methods

The material was collected from the Toca Fria cave, situated in the Serra do Iuiú, on the border between the municipalities of Iuiú and Malhada, Bahia (Figure 1). The Geology of the region is characterized by the São Francisco Supergroup, comprising the Sete Lagoas Formation, which belongs to the Bambuí Group (BARBOSA et al., 2012).

Fossils were exposed on the surface of the cave conduits and chambers, obviating the need for sediment excavation during collection. The acquisition of the material was authorized through SISBIO license no. 51438 issued to the author «M.A.T.D.», and duly communicated to the Agência Nacional de Mineração.

All collected specimens were housed in the scientific collection of the Laboratório de Ecologia & Geociências (LEG) of the Instituto Multidisciplinar em Saúde of the Universidade Federal da Bahia (IMS/CAT-UFBA; Vitória da Conquista, Bahia, Brazil).

The recovered material underwent a screening process to eliminate specimens lacking diagnostic characteristics and to select skeletal elements exclusively belonging to meso-megamammals and small mammals such as canids and cervids, while excluding micromammals (rodents and marsupials) and primates.

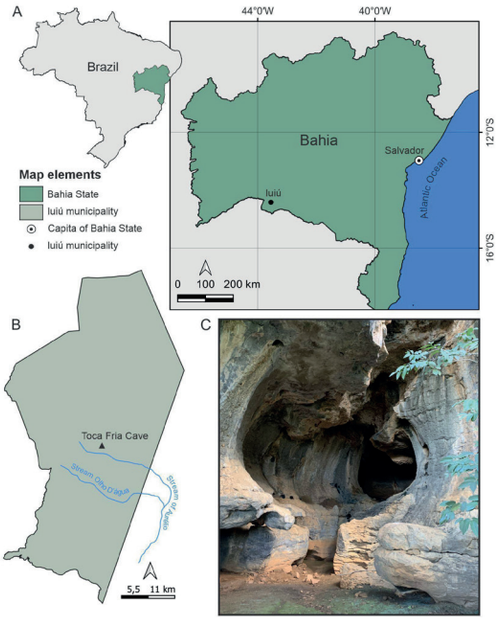

Figure 1: *Location map of the study area. A, Map of the location of the cave; B, municipality of Iuiú/BA; C, Toca Fria cave.*

3. Results

Arctotherium wingei **(Ameghino, 1902)**

Material: Right humerus (LEG 2937); right femur (LEG 2938).

Description and comments: The analyzed materials are incomplete, with only the distal portion present and available for comparison in both specimens. The humerus (LEG 2937) exhibits a distal epiphysis with a deep olecranon fossa, which widens towards the lateral epicondyle. The femur (LEG 2938) possesses a rectangular and flattened body, a distinctive characteristic of ursids (TREVISAN et al., 2023), in addition to a widened lower extremity.

For the Pleistocene in South America, only the genus *Arctotherium* has been documented (SOIBELZON, 2002), which comprises five species, with *Arctotherium wingei* being the sole species recorded in Brazil. Consequently, we hypothesized that the present material belongs to *A. wingei*.

Cerdocyon thous **Linnaeus, 1766**

Material: Cervical vertebra (LEG 3351).

Description and comments: Specimen LEG 3351 comprised a complete cervical vertebra. The morphology and dimensions of the specimen indicated its probable attribution to a small canid.

Morphological comparisons were conducted using five small canid species: *Cerdocyon thous, Lycalopex gymnocercus, Lycalopex vetulus, Speothos venaticus*, and *Speothos pacivorus*. The specimen exhibits morphological and dimensional similarities to *C. thous*, as evidenced by its subtriangular shape in the dorsal view, which narrows proximally to the cranial articular surface and exhibits a recess at the caudal extremity and anterior to the cranial articular surface.

Eremotherium laurillardi **(Lund, 1842)**

Material: Skull fragments (LEG 3208, 3210, 3211); maxilla fragments (LEG 3212-3213); dentary fragments (LEG 3209 and LEG 3214-3219); isolated molariforms (LEG 3221-3222); vertebrae (LEG 3266-3270, LEG 3276-3277, LEG 3279-3291); haemal arches (LEG 3292-3296); manubria (LEG 3297-3298); humerus fragment (LEG 3302); ulna fragment (LEG 3303); carpals (LEG 3308-3314); metacarpals III (LEG 3020-3022); metacarpals IV (LEG 3323-3325); metacarpals V (LEG 3327-3329); phalanges of the hand (LEG 3330-3334, LEG 3340 and LEG 3342); patella (LEG 3307); fragments of fibulae (LEG 3304-3306); tarsals (LEG 3314-3319, LEG 3335-3336, LEG 3338-3339); metatarsals V (LEG 3337 and LEG 3341); and phalanges of the foot (LEG 3340 and LEG 3342).

Description and comments: The molariforms (LEGs 3221 and LEG 3222) exhibited a prismatic morphology, characterized by robustness and an absence of enamel coverage (Figure 2 A and E). LEG 3221 corresponds to the morphology and dimensions of the fourth upper molar, while LEG 3222 corresponds to the third lower molar, exhibiting more pronounced wear than LEG 3221. Both the specimens were fragmented into the inferior portion. Most of the remaining materials were fragmented.

The presence of materials, such as prismatic and quadrangular molariforms, in addition to mandibular fragments, facilitates the attribution of this material to the Megatheriidae family (CARTELLE, 1992; CARTELLE & DE IULIIS, 2006). The sole valid large species of Megatheriini present in intertropical Brazil is *Eremotherium laurillardi* (CARTELLE & DE IULLIS, 1995; CARTELLE, 2014). Consequently, we ascribe the discovered material to this taxon.

Nothrotherium maquinense **(Lund, 1839)**

Material: Second upper molar (LEG 2939).

Description and comments: Specimen LEG 2939 represents a second upper molar exhibiting fragmentation in the lingual portion. The specimen possesses an approximately quadrangular and prismatic morphology, which are characteristic features of Megatheriidae (Figure 2 D and H). The molar exhibited a mesial groove, which is indicative of the degree of occlusal wear. The dimensions of this specimen are comparable to those attributed to *Nothrotherium maquinense* by CARTELLE & FONSECA (1983), and its morphology aligns with that described by PUJOS et al. (2023).

Valgipes bucklandi **(Lund, 1839)**

Material: Palate (LEG 2943); fourth upper molar (LEG 2944); fragment of dentary (LEG 2945); left clavicle (LEG 2946); vertebrae (LEG 2965-2976); distal epiphyses of humerus (LEG 2947 and LEG 2948); fragment of right radius (LEG 2949); fragment of radius (LEG 2950); fragments of ulna (LEG 2951-2953); left scaphoid (LEG 2954); right metacarpal III (LEG 2955); left metacarpal III (LEG 2956); proximomedial phalanx (LEG 2957); fragments

of right femurs (LEG 2959 and LEG 2961); medial condyle of the femur (LEG 2960); calcaneus (LEG 2962); left metatarsal III (2977) and proximal phalanx of the foot (LEG 2963).

Description and comments: The palate (LEG 2943) is fragmented, preserving only the portion corresponding to the dental alveolus of the fourth molar, which exhibits a highly pronounced bilobate structure, a characteristic anticipated in specimens of Valgipes bucklandi. The fourth upper left molar (LEG 2944) displays, in lingual view, a deep indentation and bilobate structure, which is less prominent in the dentition of *Catonyx cuvieri* (Figure 2 C and G). The morphology of the specimen aligns with that described by WINGE (1915) for *Valgipes bucklandi* (=*Catonyx giganteus*) and CARTELLE (2009). Moreover, the measurements correspond to those reported for V. bucklandi by CARTELLE (2009).

***Catonyx cuvieri* (Lund, 1839)**

Material: Tibia (LEG 3262) ; right calcaneus (LEG 3263) ; and phalanx of toe V (LEG 3264).

Description: The distal articulation surface of the tibia (LEG 3262) exhibits a prominent medial malleolus. In the right calcaneus (LEG 3263), only the calcaneal tuberosity is present, presenting a flattened and highly curved morphology. This morphology is distinct from other species, such as *Ahytherium aureum, V. bucklandi, Glossotherium phoenesis*, and *E. laurillardi*, which possess a less curved calcaneal tuberosity, with the latter three species exhibiting a more robust structure. The distal phalanx of digit V of the left foot (LEG 3264) is complete and demonstrates a morphology identical to that described for *C. cuvieri* by CARTELLE (2009).

***Glossotherium phoenesis* Cartelle et al., 2019**

Material: Fragments of the maxilla (LEG 3241); third upper molar (LEG 3240); fragment of dentary (LEG 3242); fragment of humerus (LEG 3243); tibial shaft (LEG 3244); and ectocuneiform (LEG 3353).

Description and comments: The maxillary fragment (LEG 3241) exhibits the presence of the fourth upper molar (Mf4), which possesses an elongated morphology resembling the numeral «8» with a larger distal lobe. The third upper molar (LEG 3240) demonstrated a subtriangular configuration, with a wider lingual portion that gradually narrowed (Figure 2 B and F). The lingual surface displays a prominent apicobasal groove. The dentary fragment (LEG 3242) preserved a portion of the alveolus of the first molar and exhibited a pronounced bilobate structure.

The specimens presented herein were attributed to *G. phoenesis*, based on the presence of a well-defined apicobasal groove on the lingual surface of the third upper molar (Mf3), which is absent in *G. robustum*.

Pampatheriidae indet.

Material: Ungueal phalanx (LEG 3354).

Description and comments: The ungueal phalanx (LEG 3354) is complete and well preserved. Based on its elongated dimensions and morphology, it is hypothesized to belong to the third digit of the manus of a Pampatheriidae specimen. However, this isolated element did not provide sufficient evidence for a definitive taxonomic attribution.

***Notiomastodon platensis* (Ameghino, 1888)**

Material: Occipital condyle (LEG 3011); fragments of incisor growth rings (LEG 3009 and LEG 3010); fragments of molariforms (LEG 3012-3013); cervical vertebrae (LEG 3014); thoracic vertebrae (LEG 3015); caudal vertebrae (LEG 3016-3018); magnum (LEG 3019); metatarsal IV (LEG 3020-3021); and phalanx (LEG 3022).

Description and comments: The occipital condyle (LEG 3011) exhibits substantial robustness and is characterized by a height exceeding its width, demonstrating morphological and dimensional similarities to Gomphotheriidae. Isolated molar fragments were recovered (LEG 3012 and LEG 3013). LEG 3012 presents a thick enamel layer devoid of wear indicators and displays a cloverleaf morphology characteristic of the group (Figure 2 K and L). The tusk fragments (LEG 3009 and LEG 3010) possess a circular cross-sectional shape, exhibit curvature, and lack enamel coverage. These specimens revealed observable Schreger patterns, a distinctive feature of proboscidean tusks (ASEVEDO et al., 2021).

According to MOTHÉ et al. (2012), *Notiomastodon platensis* was hypothesized to be the sole gomphotherid inhabiting the lowlands of South America. Consequently, we propose that the specimens described herein can be attributed to *N. platensis*.

***Toxodon platensis* (Owen, 1840)**

Material: Left occipital condyle (LEG 2996); maxillary fragments (LEG 2994-LEG 2995); teeth (LEG 2998-3000); humerus fragment (LEG 3003); magnum (LEG 3001); right scaphoid (LEG 3002); right calcaneus (LEG 3004); left calcaneus (LEG 3005); metatarsal III (LEG 3006); and phalanges (LEG 3007-3008).

Description and comments: Several tooth fragments were recovered (LEG 2998-3000); however, only the second upper incisor (LEG 2999) was sufficiently preserved for comparative analysis. It exhibited a slightly flattened morphology, downward curvature, and the presence of enamel in the labial and mesial portions (Fig. 2 M and N). In the vestibular portion, a longitudinal groove was observed almost mesially.

Two species of Pleistocene toxodontids have been recognized in Brazil: *Toxodon platensis* and *Trigodonops lopesi*. This material is attributed to *T. platensis* based on the morphology of the upper incisors, which are distinctly different between the two species. *Trigodonops lopesi* possesses triangular incisors, whereas *T. platensis* is flat and wide, which is consistent with the characteristics described herein.

***Mazama* sp.**

Material: Right dentary (LEG 3343); left dentary (LEG 3344); tibia (LEG 3345-3346); fibula (LEG 3347); metatarsus (LEG 3348); and phalanx of digit IV (LEG 3349).

Description and comments: The left dentary (LEG 3344) is represented by a fragment containing only the first two premolars, which exhibits a rectangular and flattened morphology with minimally discernible lobes. The right dentary (LEG 3343) presents a preserved dental series comprising selenodont teeth that are trilobed and feature «V»-shaped lobes (Figure 2 I and J). These characteristics are consistent with those observed in cervid dentition (OLIVEIRA et al., 2014; BUCHMANN et al., 2017).

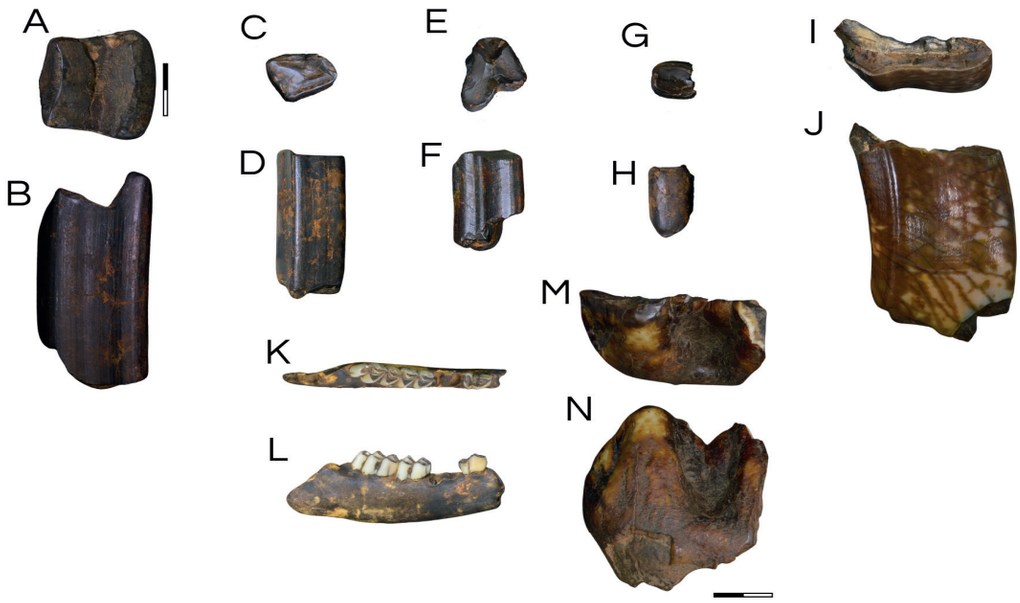

Figure 2: *Dentition of seven taxa recovered from Toca Fria in the occlusal and lateral views. A and B, Eremotherium laurillardi; C and D, Glossotherium phoenesis; E and F, Valgipes bucklandi; G and H, Nothrotherium maquinense; I and J, Toxodon platensis; K and L, Mazama sp.; M and N, Notiomastodon platensis. Scale bar: 20 mm.*

4. Discussion

The fossils collected at Toca Fria exhibit significant fragmentation, with the majority of specimens displaying a dark brown coloration and some presenting a brownish hue. These characteristics can be attributed to hydrological processes, as the cave is subjected to water flows during periods of precipitation. Furthermore, all the material was located at a considerable distance from the cave entrance and was concentrated within a single conduit, suggesting that these fossils were potentially transported by water currents.

Based on isotopic data, DANTAS et al. (2020) proposed that the Final Pleistocene environment of Iuiú was analogous to a savannah characterized predominantly by grasses, shrubs, and sparse trees. The taxa identified in this study corroborate this paleoenvironmental reconstruction, considering that *A. wingei, N. maquinense, C. cuvieri, T. platensis*, and *V. bucklandi* serve as indicators of low-density forest habitats. Concurrently, *E. laurillardi, N. platensis,* and *Pampatherium indet*. are known to inhabit arboreal savannah environments (DANTAS et al., 2020; OMENA et al., 2021).

The paleoecology of the extinct taxa discovered in Toca Fria bear resemblance to the current environmental conditions of the Iuiú region, where a Cerrado biome predominates, comprising tree and shrub species from deciduous and semi-deciduous forests.

5. Conclusion

This work contributes to the knowledge of the Pleistocene fauna of southwestern Bahia, expanding the record of nine more taxa (*Arctotherium wingei, Cerdocyon thous, Nothrotherium maquinense, Valgipes bucklandi, Catonyx cuvieri, Glossotherium phoenesis, Eremotherium laurillardi, Pampatheridae*, and *Notiomastodon platensis*) for Toca Fria (Iuiú, Bahia). These new fossil discoveries highlight the importance of Bahia caves for Quaternary Paleomastozoology.

Acknownledgments

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Studies in the Cuchillo Curá cave system: new paleontological and geological interpretations

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Abstract

In the Cuchillo Curá Protected Natural Area (ANPCC) lies the homonymous cave system developed in Mesozoic carbonate rocks of the La Manga formation. As part of the International Bioespeleosud 2023 campaign, geological and paleontological surveys were conducted, continuing studies that began at the site 42 years ago by the Grupo Espeleológico Argentino (GEA). The outcrops previously attributed to the Lotena Formation in earlier studies, as well as the overlying limestones in the southern sector of the area, were analyzed, concluding that they belong to the La Manga Formation, thus proposing a new stratigraphic profile. This allowed for a new interpretation of the stratigraphy and structure of the area. A survey of marine fossils found in the deposits of the La Manga Formation, recognized both on the surface and within the caves, was also conducted, leading to a paleoenvironmental reconstruction. This work provides new interpretations of the studies conducted in the area, contributing to the knowledge and enhancement of the geological and paleontological heritage of the ANPCC. It highlights the geodiversity present at the site and justifies its conservation.

Résumé

Dans l'aire Naturelle Protégée Cuchillo Curá, où se trouve le système système de grottes homonyme, un relevé géologique et paléontologique a été réalisé dans le cadre de la campagne internationale Bioespeleosud 2023. Il s'inscrit dans la continuité des études qui ont commencé sur le site il y a 42 ans par le Grupo Espeleológico Argentino (GEA). Les affleurements attribués, dans des études antérieures, à la formation Lotena, ainsi que les calcaires sus-jacents dans le secteur sud de la zone, ont été analysés, concluant qu'ils appartiennent à la formation La Manga, ce qui propose un nouveau profil stratigraphique. Cela a permis une nouvelle interprétation de la stratigraphie et de la structure de la zone. Un relevé des fossiles marins trouvés dans les dépôts de la formation La Manga, pouvant être reconnus à la fois en surface et à l'intérieur des grottes, a également été fait, générant une reconstruction paléoenvironnementale. Ce travail apporte de nouvelles interprétations aux études réalisées jusqu'à présent dans la région, contribuant à la connaissance et à la valorisation du patrimoine géologique et paléontologique de l'ANCC. Il met en évidence la géodiversité du site et justifie sa conservation

Resumen

El Área Natural Protegida Cuchillo Curá (ANPCC), alberga el Sistema Cavernario homónimo que se desarrolla en rocas carbonáticas mesozoicas de la formación La Manga. En el marco de la campaña Internacional Bioespeleosud 2023 se realizó un relevamiento geológico y paleontológico que da continuidad a estudios que comenzaron en el sitio hace 42 años, llevados a cabo por el Grupo Espeleológico Argentino (GEA). Se analizaron los afloramientos atribuidos, en estudios anteriores, a la Formación Lotena y en las calizas suprayacentes en el sector sur del área, concluyendo que los mismos pertenecen a la Formación La Manga, por lo que se propone un nuevo perfil estratigráfico. Esto permitió una nueva interpretación de la estratigrafía y la estructura del área. Se realizó, también, un relevamiento de los fósiles marinos que se encuentran en los depósitos de la Formación La Manga y que pueden reconocerse tanto en superficie como dentro de las cavernas. Generándose una reconstrucción paleoambiental. Este trabajo aporta nuevas interpretaciones a los estudios hasta ahora realizados en la zona, contribuyendo al conocimiento y puesta en valor del patrimonio geológico y paleontológico del ANPCC que dan cuenta de la geodiversidad que alberga el sitio y justifican su conservación.

1. Introduction

The ANPCC is located in the Picunches Department, Province of Neuquén, Argentina, about 13 km S of the town of Las Lajas. This area houses the Cuchillo Curá Cave System (SCCC), which consists of four caves aligned in an E-W direction, called Cabritos, Templo, Gendarme, and Arenal. The total length of the surveyed galleries to date is 5,160 meters, making it the largest karst system in Argentina. Access to the area is via National Route 40, taking a dirt road W for approximately 2 km that crosses the Estancia La Porteña (Fig. 1).

Figure 1: *Location of the ANPCC.*

The ANPCC covers 386.25 hectares and was established in 2003 through provincial decree No. 161/2003, based on speleological studies conducted primarily by the GEA. Its purpose is to conserve the provincial biostratigraphic units and the geological, cultural, archaeological, biological, paleontological, scenic, and speleological heritage in both epigean and hypogean environments.

The ANPCC is located within the Neuquén Basin, a sedimentary basin whose evolution extends from the Late Triassic to the Tertiary. The main Mesozoic sedimentary rocks exposed in the area correspond to deposits from the La Manga Formation, limestone where the SCCC develops. Although this unit has been documented at various sites within the Neuquén Basin, from San Juan to Neuquén, detailed sedimentological, paleontological, and structural studies had not been conducted in the SCCC area until now. These are very important for interpreting the speleogenesis of the SCCC.

The Mesozoic sedimentary rocks are surrounded by a basaltic structural plateau, resulting from Pliocene lava flows that form the olivine facies of the Zapala Formation, which are in paraconcordance with the limestones. It is noteworthy that these basalts are eroded in the study area. In the northern lowland, where the entrance to the Arenal cave is located (Fig. 2), basalt and limestone outcrops can be observed among modern regolith deposits (Catinari et al, 2022).

Quaternary deposits cover the previous units and accumulate in low or depressed areas. There are deposits of lowlands, mallines and lagoons, which are often occupied by temporary waters and contain abundant accumulations of silts, clays, and salts.

In the Northern Lowland, fluvial-lacustrine deposits develop where lagoons were previously located. This sector represents an endorheic basin that used to host the Cuchillo Curá lagoon and a smaller one to the W, called El Álamo, both of which are currently dry. The water level of the lagoons is highly variable, and when it rises, the water floods part of the cave system (Catinari et al, 2022).

The regional structures that influenced the sedimentation evolution in this sector of the Neuquén Basin correspond to the Huincul Ridge and the Agrio Folded and Thrust Belt. The Huincul system is a structural feature that crosses the central-southern part of the Neuquén Basin from E to W. It has a width of 120 km in the W and decreases to 60 km in the E. The Agrio Folded and Thrust Belt is located in the center-W of Neuquén province and corresponds to a series of folds associated with faults that expose Mesozoic outcrops from sequences accumulated during the retroarc basin stage.

The study area is located in the internal sector of the Agrio Folded and Thrust Belt and is part of the anticlinal structure of the Sierra de la Vaca Muerta (Lambert, 1956), with the Cuchillo Curá and Curymil ridges representing the NW and SE expressions of this structure (Catinari et al., 2022).

Barredo et al. (2013) suggest the presence of a subordinate folding, oriented E-W, within the ANPCC, in the southern lowland, near the southern basalts. In this work, this structure is redefined and located further N, given its importance in controlling the evolution of the caves.

2. Materials and methods

During the visit to the ANPCC, surveys were conducted both inside the El Arenal and El Gendarme caves and on the surface, with a special focus on recognizing the fossil material that constitutes a large part of the exposed rocks in the area. A sedimentary profile and its corresponding facies analysis were carried out. The lithofacies were described according to the Dunham (1962) classification modified by Embry and Klovan (1971).

The facies analysis followed the principles of Flügel (2005).

Transects were conducted perpendicular to the direction of stratification to generate a more accurate structural section of the study area.

The La Montura Hill, located to the E of the ANPCC, where the limestones of the La Manga Formation also outcrop, was surveyed.

Specific sectors were surveyed, including the area where rocks were assigned by Elzeard (1987) to the Lotena Formation outcrop, as well as the limestones in the southern ledge of the area.

For the paleontological survey, only field recognition and photographic recording were carried out, as permits for material extraction were not obtained.

3. Results

Geological and structural analysis

A N-S transect was conducted within the ANPCC to traverse the complete outcropping stratigraphic sequence, observing the present lithological and facies variations.

This transect was carried out from point A to point B (Fig. 2), traversing the different outcropping Mesozoic limestone layers and areas with modern fluvial and eolian sedimentation in the southern lowland.

During this traverse, the repetition of yellow-toned limestones with similar characteristics was observed in zones A and C (Fig. 3). Subsequently, the repetition of the gray limestones, overlying the yellow ones and outcropping in zone A further N, is also observed at point B. These are the rounded and occasional outcrops that are in contact with the overlying basalt in the southern ledge of the area.

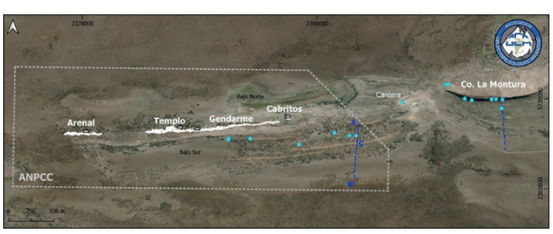

Figure 2: *Surface sectors surveyed (blue dotted line) and points of interest recorded (light blue points).*

It is inferred, then, that there is a structure between points A and C, which would consist of an anticlinal axis oriented E-W. The erosive characteristics of the outcrops that constitute the southern flank did not allow for dip measurements to be taken; these beds tend to be very rounded (gray limestones in contact with the basalts at point B) or are situated at ground level among the Quaternary sediments (areas between points A and C) (Fig. 3).

Figure 3: *Limestones of the La Manga Formation a) Yellow limestone (weathering), b) Gray limestones outcropping between points A and C, c) Rounded limestones due to erosion in contact with the Zapala basalt in the southern sector of the area.*

This structure is linked to the dynamics of the caves, since the development of major ducts and galleries coincides with the E-W folding

axis, while the numerous sets of joints, which vary from N15°E to N10°W, would have controlled the installation of the minor galleries that are thus arranged in a predominantly southern direction (Barredo et al., 2013).

A survey was also carried out on the southern slope of La Montura Hill, located 1.2 km E of the ANPCC. This hill is higher than the ANPCC, thus exposing more clearly the complete stratigraphic sequence of the limestones of the La Manga Formation. The sequence there has a thickness of between 30 and 35 m, while in the ANPCC the outcrops do not exceed 5 m.

In this area, banks similar lithologically and in their fossil content to those in the study area were identified, being the continuation of the carbonate platform with its respective lateral changes in facies, passing from areas of deposition of greater depth The presence of this anticlinal would correspond to the structural characteristics and lithological repetitions observed, the northern flank exhibits a steeper inclination than the southern flank, which would explain why the repetitions to the S are more isolatedand lower energy to the W (ANPCC), to areas of shallower deposition towards the E.

The La Montura Hill presents more inclination than the ANPCC and is interpreted as two structural blocks separated by a fault.

Based on the information collected in the field, the geological map of the area was updated (Fig. 4), modifying the assignment of the outcrops identified in the central-E area, now classified as the La Manga Fm, previously assigned to the Lotena Fm (Elzeard, 1987). In addition, the axis of the inferred structure in the southern lowland was modified, assigning it the character of an anticline and placing it between the outcrops of the La Manga Fm, and the dips of the banks were identified, to the N and to the S with respect to the axis of the anticline. Isolated calcareous outcrops were also identified, found in the area close to the axis of the anticline, also assigned to the La Manga Fm.

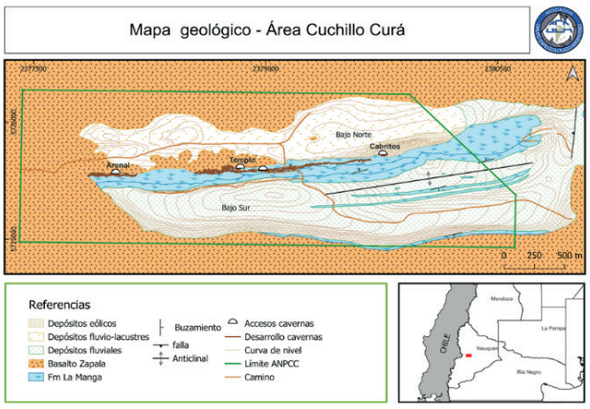

Figure 4: *Updated geological map.*

Paleontological survey

Sampling was carried out by taking photographs in epigeic and hypogeic environments to lithologically characterize the banks, propose a paleoenvironmental reconstruction of the studied sediments, and generate a biostratigraphic framework.

From the study of the field material and the analysis of its photographs, at least two genera of fossil scleractinian corals were recognized, with the most abundant being the genus Stelidioseris (Fig. 5) and, subordinately in the form of rolled fragments within the outcrops, the genus Australoseris appears. The coral specimens are found both in a living position and reworked. As a detail of the hypogeal fossils, it can be mentioned that the three-dimensional morphology of the colonies is preserved and exposed due to preferential dissolution processes, although it is only a very fragile preservation «ghost», the shape of the colonies is perfectly preserved within a micritic envelope (microcrystalline calcite with a low magnesium content). From the premise that the morphology of some colonial sessile organisms can be considered a phenotypic eco-adaptation to a given environment, the paleoenvironmental conditions in which these organisms developed can be inferred (i.e. paleoenvironmental and paleoecological reconstructions) (Chappel, 1980; Todd, 2008 among others).

Finally, amalgamated stromatolitic limestone deposits, 80 cm thick, could be observed, which shows that the deposits of the La Manga Formation in the study area also record high cyanobacterial activity for the Late Jurassic.

Figure 5: *Laminar colonies with columnar or dendroid projections of the genus Stelidioseris sp. Note the proximity between them, this indicates that they are part of a bioconstruction.*

On the other hand, turritellid and gnathicid gastropods, cidaroid echinoderms (?Balanocidaris) (Fig. 6), bivalves such as: Ctenostreon, Aetostreon, Trichites, Lithophaga and Pinna, among others, which could not be assigned due to the impossibility of taking samples, were recognized. In turn, serpulids, foraminifera, rhodhoficean algae and dasycladaceas (e.g. Acicularia) were recognized.

Figure 6: *Specimens of cidaroid sea urchins (?Balanocidaris) from the hypogeal environment (a) and from the surface (b).*

Stratigraphy and paleoenvironment

Based on the data collected in the caves (El Templo and El Arenal) and on the surface, both in the ANPCC and in Cerro La Montura, a stratigraphic profile (Fig. 7) was made that represents the rocks included in the La Manga Formation in the study area and their contact with rocks that could be attributed to the Lotena Formation.

The profile begins with deposits of a sandstone with calcareous cement enriched with fragments of bivalve shells; these banks could be beach bars belonging to the transitional deposits of the Lotena Formation (Mb. El Vado de Veiga et al., 2011). Then there are several meters covered by Holocene regoliths and typical steppe vegetation.

The sequence continues with an intercalation of limestones ranging from bioclastic packstones to pure oobioclastic and oolitic grainstones.

This stratigraphic sequence allows us to observe, in the stacking pattern and in the sequence of lithologies, a tendency towards shallowing in the depositional environment, which could indicate a forced regression in the context of a carbonate ramp, where facial changes occur from medium ramp deposits to lagoon facies.

Based on this analysis, a paleoenvironmental reconstruction was generated (Fig. 8). A transect was made in a SW-NE direction, where the moment of shallowing is represented, considering the basin center towards the SW and the decrease in sea level (SNM 1 to SNM 2). As a consequence of this event, a lagoon was generated in the NW sector, which would be represented by the algal limestones found on the W side of Co. La Montura.

On the other hand, it should be noted that the subsequent exposure of some sectors as the paleocoastline retreated would have generated a karst, represented by the gaps in the profile. This karstic surface was the consequence of subaerial exposure that was probably accompanied by one or more carbonate recementation processes associated with flooding episodes.

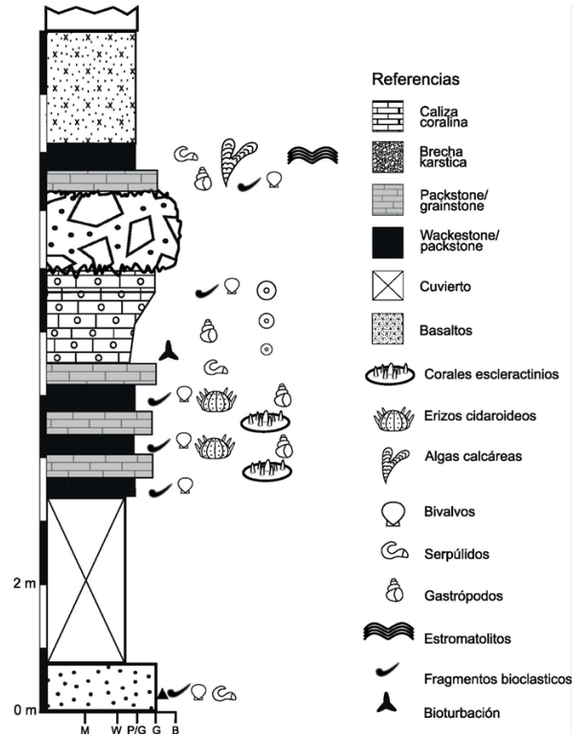

Figure 7: *Stratigraphic profile. Note that the size of the oolites increases from base to top, indicating a decrease in bathymetry and an increase in water agitation.*

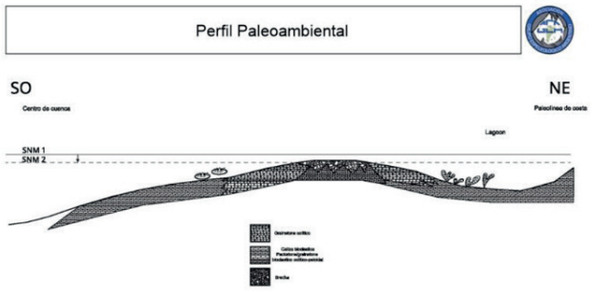

Figure 8: *Paleoenvironmental profile.*

4. Discussion

Based on new observations made along the transect and other surface surveys, the outcrops previously mapped as the Lotena Formation by Elzeard (1987) were identified. According to the new interpretations, these limestones are actually part of the La Manga Formation, coinciding lithologically and in their fossil content with the limestones recognized at the base of the La Montura hill profile.

In the structural analysis, Barredo et al (2013) proposed a structure that they could not identify, but whose axis, in an E-W direction, was located in the southern lowland near the basalt wall. In this work, based on the surface surveys and the surveyed transect, evidence is provided of the existence of an anticline with an E-W axis located between the limestone outcrops identified with points A and C in Figure 2, which have dips to the North and to the South, respectively, and can be seen represented in the updated geological map (Fig. 4).

On the other hand, the recognition of the fossil components present in the outcrops of La Manga in this locality is in itself an important advance, although the taxonomic analysis was not sufficiently exhaustive because, prior to the campaign, the collection of macroscopic samples of fossil corals was planned when they could be removed from the outcrops without the need to destroy them, however the necessary permits to do so were not obtained. Therefore, the studies to determine the species level in the fossil material could not be carried out, with the genus level being, in many cases with doubts, the least inclusive taxonomic level reached. Regarding the damage of not having been able to sample macrofossils, it can be said that this was much greater than that which could have been inflicted on the area, since in this type of deposits (carbonate of bioclastic origin) the abundance of component fossils is high, including scleractinian corals. This particularity makes the impact of sampling minimal.

5. Conclusion

Regarding the structural geology of the area, the presence of an anticlinal fold with an axis in the sector located between the main limestone front that houses the caves in the North and the elevated area in the center of the ANPCC was determined. A first sedimentary profile of the La Manga Formation in this sector is proposed.

The GEA has carried out multiple campaigns at the ANPCC from 1982 to the present. The one in January 2023 was the first in which an exhaustive paleontological survey was carried out, regarding the fossiliferous content of the La Manga Formation. The rocks that constitute this formation were deposited, during the middle to late Oxfordian, in a carbonate ramp environment with warm and clear waters and their development. In them, bioconstructions of scleractinian corals and calcareous algae could be recognized; the former are small bulges generated by the growth of several flat colonies with columnar projections; the latter were meadows of calcareous algae in very shallow waters. These bioconstructions presented a varied and relatively diverse accompanying macrofauna.

The presented results add value to the geodiversity of the ANPCC and contribute to a more comprehensive understanding of the cave system and its surroundings.

Acknowledgments

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Exposições estromatolíticas em caverna: contribuição ao patrimônio geoespeleológico da Gruta do Tamboril, Unaí (MG)

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Abstract

Stromatolites are laminated microbial structures indicators of early life and environmental conditions. In the Tamboril Cave, located in Unaí, Minas Gerais, Brazil, Proterozoic stromatolites are preserved within dolomitic rocks of the Sete Lagoas Formation (Bambuí Group). This study documents their morphological diversity, stratigraphic distribution, emphasizing their scientific and patrimonial significance. Were identified three distinct stromatolite morphologies. Diagenetic processes, including dolomitization and silicification, contributed to the preservation of laminae and intercolumnar spaces. The cave's unique setting allows for observations free from surface weathering, enhancing its value as a natural archive. These occurance contributes to the importance of conserving Tamboril Cave as a repository of geological history.

Résumé

Les stromatolithes sont des structures microbiennes laminées, indicateurs de la vie primitive et des conditions environnementales. Dans la Grotte de Tamboril, située à Unaí, Minas Gerais, Brésil, des stromatolithes d'âge protérozoïque sont préservés au sein des roches dolomitiques de la Formation Sete Lagoas (Groupe Bambuí). Cette étude documente leur diversité morphologique et leur distribution stratigraphique, en mettant en avant leur importance scientifique et patrimoniale. Trois morphologies distinctes de stromatolithes ont été identifiées. Les processus diagénétiques, incluant la dolomitisation et la silicification, ont contribué à la préservation des lamines et des espaces intercolonnaires. Le cadre unique de la grotte permet des observations exemptes d'altération de surface, renforçant sa valeur en tant qu'archive naturelle. Cette occurrence souligne l'importance de conserver la Grotte de Tamboril en tant que dépôt de l'histoire géologique.

Resumen

Los estromatolitos son estructuras microbianas laminadas, indicadores de la vida temprana y de las condiciones ambientales. En la Cueva de Tamboril, ubicada en Unaí, Minas Gerais, Brasil, se preservan estromatolitos del Proterozoico dentro de rocas dolomíticas de la Formación Sete Lagoas (Grupo Bambuí). Este estudio documenta su diversidad morfológica y distribución estratigráfica, destacando su importancia científica y patrimonial. Se identificaron tres morfologías distintas de estromatolitos. Los procesos diagenéticos, incluyendo la dolomitización y la silicificación, contribuyeron a la preservación de las laminaciones y de los espacios intercolumnarios. El entorno único de la cueva permite observaciones libres de alteración superficial, aumentando su valor como archivo natural. Esta ocurrencia contribuí a la importancia de conservar la Cueva de Tamboril como un repositorio de la historia geológica.

1. Introdução

Os estromatólitos são estruturas microbiais autigênicas laminadas, frequentemente com morfologia dômica ou colunar, que se formam na interface entre água e sedimento em ambientes de água doce, marinhos ou evaporíticos (REITNER et al., 2011). Esses depósitos fósseis estão presentes no registro geológico desde o Arqueano e possuem ampla relevância científica, abrangendo áreas como paleobiologia, sedimentologia e estratigrafia (RIDING, 1999). Representam, ainda, a principal evidência de vida no planeta durante o Eon Pré-Cambriano (RIDING, 2000). Dada sua importância científica e patrimonial, torna-se essencial documentar continuamente a distribuição desses carbonatos microbiais em escala global.

Na região do Distrito Federal e seu entorno ocorrem estromatólitos de idade Proterozoica, registrados nas unidades carbonáticas dos grupos Paranoá, Vazante e Bambuí. Esses carbonatos microbiais passaram por processos de carstificação, resultando na formação de cavidades naturais subterrâneas. Entretanto, a evolução das cavernas e o preenchimento com sedimentos químicos secundários (espeleotemas) frequentemente dificultam a observação direta das paredes rochosas originais. Em contraste, quando expostos, afloramentos no interior de cavernas, por estarem protegidos de intempéries, oferecem condições favoráveis para estudos geológicos, comparativamente a afloramentos de superfície. Dessa forma, o interior de cavernas pode ser excelente para observação de afloramentos geológicos.

Nesse contexto, este trabalho descreve exposições estromatolíticas do interior da Gruta do Tamboril, localizada no noroeste de Minas Gerais. Ressalta-se que o morro em que a caverna está inserida apresenta es-

tromatólitos expostos na superfície externa. Contudo, o acesso a esses afloramentos é dificultado pela declividade do terreno, ausência de trilhas, densa cobertura vegetal e dispersão das ocorrências. Além disso, os afloramentos superficiais encontram-se intemperisados, prejudicando a observação das estruturas. Já os estromatólitos preservados no interior da caverna permitem análises sob diferentes perspectivas (longitudinal e transversal), dependendo do plano de interseção entre as paredes da cavidade e o acamamento sedimentar da rocha.

2. Materiais e métodos

2.1. Localização e aspectos gerais

A Gruta do Tamboril localiza-se no município de Unaí, 150km à sudeste de Brasília via BR-251 (Fig. 1). A região é caracterizada por clima tropical. A sazonalidade é definida por duas estações principais, sendo a estação de chuva abrangendo os meses de outubro a abril e a estação seca abrangendo os meses de maio a setembro (INMET, 2019). O principal bioma é caracterizado por Cerrado, contudo em áreas cársticas ocorre preferencialmente a fitofisionomia decídua mata seca.

A caverna está inserida em rochas dolomíticas, com intercalações de pelitos e margas da Formação Sete Lagoas, base do Grupo Bambuí (RIBEIRO, 2019). Em dimensão, apresenta aproximadamente 950 m de desenvolvimento linear, largura e altura máximas de 55 m e 30 m, respectivamente (SILVA et al., 2001).

2.2. Metodologia

Durante visitas de campo anteriores à Gruta do Tamboril foi identificado o local da seção de interesse, que apresentava uma sequência contínua com exposição dos estromatólitos. Posteriormente, uma segunda campanha de campo foi realizada em novembro de 2018, envolvendo integrantes do GREGEO, para a descrição detalhada da seção.

O levantamento estratigráfico foi realizado com o uso de trena de fita, ao longo do salão da caverna, acompanhando o caimento das camadas sedimentares. Foi coletada uma amostra destinada à confecção de lâmina delgada na área externa da caverna, próximo a uma pedreira desativada no mesmo morro.

O mapeamento mineralógico e composicional foi realizado por meio da técnica de QEMSCAN, no laboratório QEMLAB da Universidade de Brasília.

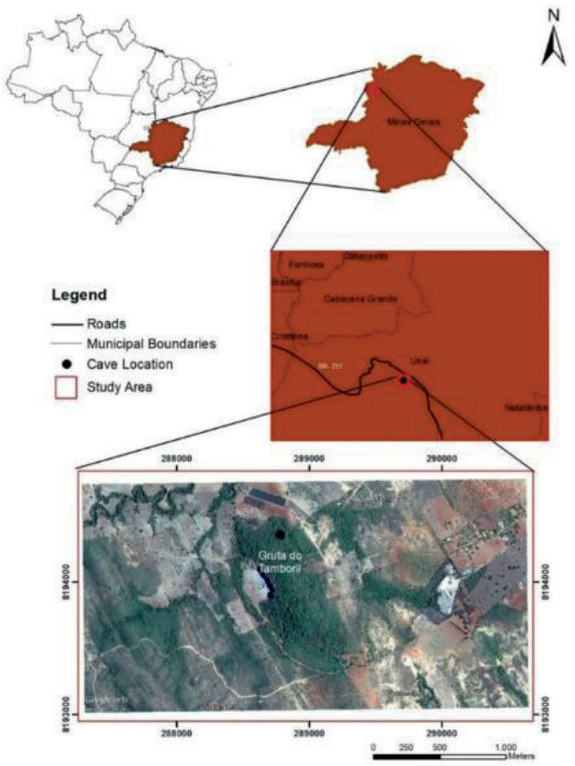

Figura 1 : *Mapa de localização da Gruta do Tamboril. De RIBEIRO (2019).*

3. Resultados

Dentro da cavidade, os estromatólitos podem ser observados em diferentes perspectivas, dependendo da variação estrutural do acamamento rochoso. Na porção inicial da gruta, próxima à entrada, as camadas de rocha apresentam-se verticalizadas. Em contraste, na porção distal da caverna, após o lago, o acamamento torna-se relativamente horizontalizado (RIBEIRO, 2019). Essa mudança permite, na porção distal, a observação de cortes longitudinais ao longo do eixo de crescimento dos estromatólitos nas paredes da cavidade.

Apesar da atitude verticalizada das camadas, o teto alto e às paredes recobertas por grandes escorrimentos calcíticos na porção inicial da gruta não favorecerem a visualização direta, ainda assim, é possível identificar estromatólitos em grandes blocos colapsados, desprendidos do teto da cavidade. O desmoronamento desses blocos ocorre naturalmente ao longo de planos de fraqueza da rocha, geralmente representados pela interseção de fraturas com o plano de acamamento sedimentar original. Esse processo expõe, as seções transversais dos estromatólitos, permitindo sua observação e documentação (Fig. 2).

A rocha encaixante é composta por dolomito de coloração cinza claro, intercalado com camadas de marga marrom ocre e níveis de silexito que variam de cinza escuro a preto. Localmente, também ocorrem camadas de siltito.

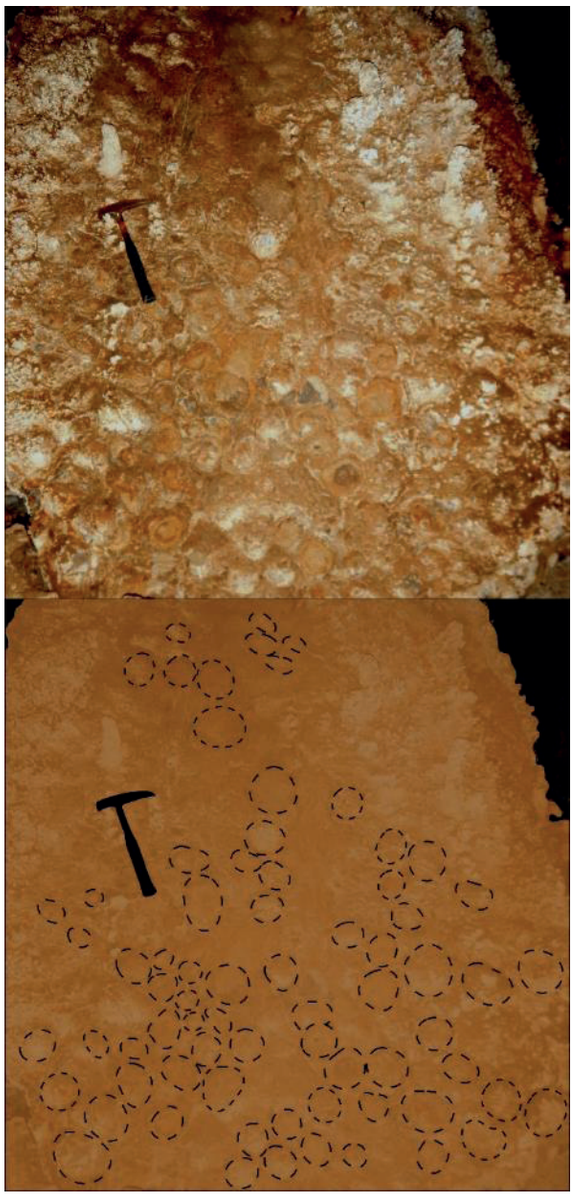

Figura 2 : *Bloco caído (aprox. 3x2m) com exposição em planta do topo dos domos estromatolíticos. A superfície do bloco preserva a rugosidade das convexidades da estrutura externa dos estromatólitos. Martelo de escala (41 cm).*

Embora todo o pacote rochoso do morro esteja tectonizado, os afloramentos estudados preservam as estruturas sedimentares, que apresentam apenas leve deformação. A Figura 3 ilustra a seção estratigráfica do afloramento estudado, destacando os níveis com os estromatólitos.

3.1. Descrição morfológica macroscópica

Os estromatólitos da Gruta do Tamboril são predominantemente colunares, laminados e ocorrem em um horizonte específico. Suas dimensões variam com o tipo. Foram identificadas três morfologias distintas, classificadas como tipo 1, tipo 2 e tipo 3. A base da seção estratigráfica estudada é marcada por uma superfície irregular ondulada, que separa uma camada inferior de marga e sílex, de coloração ocre-amarronzada, de uma camada superior composta por carbonato cinza claro contendo os estromatólitos.

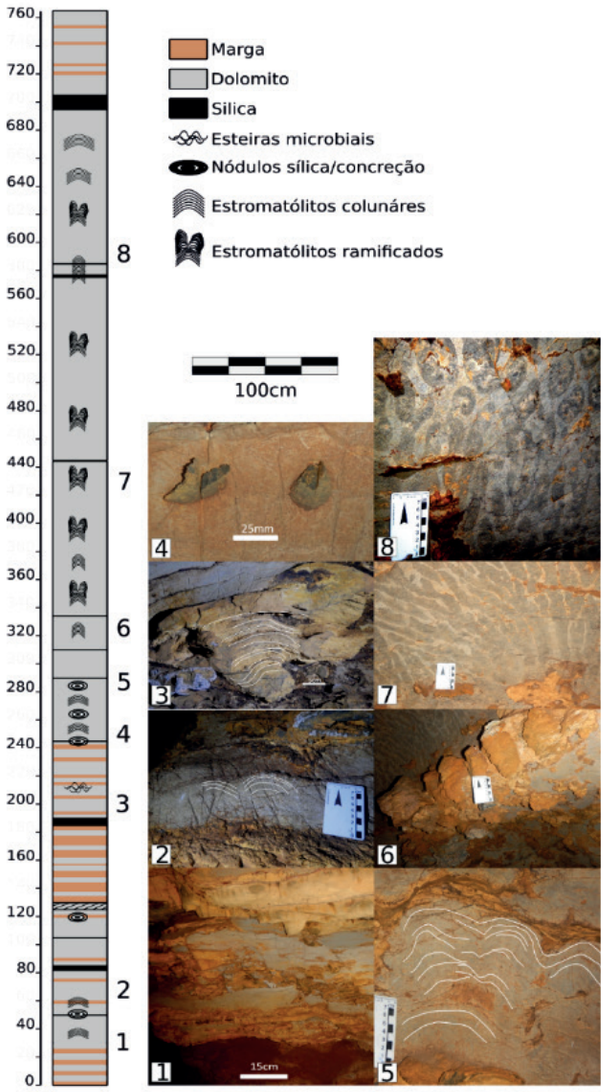

Figure 3 : *Coluna estratigráfica da seção estromatolítica descrita na Gruta do Tamboril. Escala em centímetros.*

Os estromatólitos da porção inferior da seção (tipo 1) apresentam colunas de 5-10 cm de comprimento, que se alargam em direção ao topo, frequentemente com desenvolvimento de ramificações no topo. A laminação, visível macroscopicamente, é caracterizada pelo contraste entre níveis cinzas e marrom-esbranquiçadas. Essa laminação apresenta forma convexa, com curvatura de baixo ângulo, sendo heterogênea, descontínua e de difícil identificação em algumas porções. As colunas são independentes, sem contato direto entre si, com preenchimento intercolunar de coloração variando de cinza a creme claro. Esse material intercolunar possui textura fina e aparência micro-esparítica, sem porosidade primárias, grãos ou clastos visíveis macroscopicamente. Destaca-se que no interior da coluna, há laminas preenchidas pelo material intercolunar (cor creme).

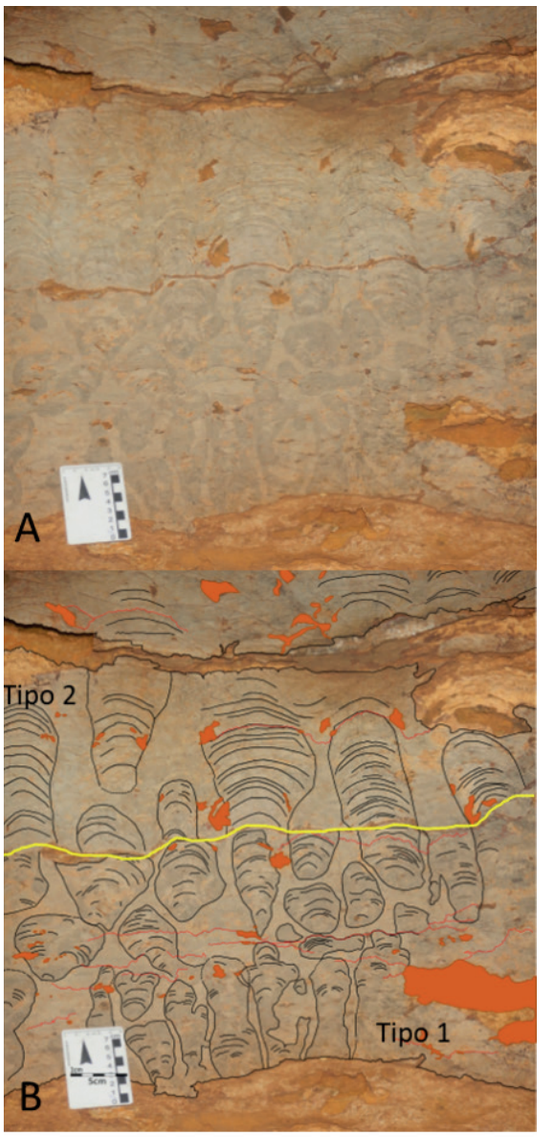

Figura. 4 : *Estromatólitos do tipo 1 (base) e 2 (topo). Nota-se os limites dos níveis estromatolíticos (linha amarela). Em laranja: porções silicificadas. Linhas vermelhas: Estilólitos Linhas pretas: contornos e laminações estromatolíticas. A: Foto original. B: Foto com destaque das feições.*

Camadas contínuas de silexito ocorrem intercaladas ao acamamento sedimentar. Essas camadas podem atingir espessuras de até 10 cm. Bolsões de contorno irregular de sílex também estão dispersos na rocha. A sílica muitas vezes preenche fraturas, estilólitos, e as colunas estromatolíticas, destacando laminações internas em algumas áreas.

Este estromatólito está representado nas fotos 2 e 3 da seção estratigráfica (Fig. 3), ocorrendo nos primeiros 240 cm basais da exposição.

O segundo tipo morfológico (tipo 2) foi identificado na porção central do afloramento, entre 200 e 400 cm, e são representados pelas fotos 5 e 6 da seção estratigráfica (Fig. 3). As colunas tornam-se mais homogêneas, apresentando formato cilíndrico, laterais regulares e vetores de crescimento lineares. As laminações convexas são bem definidas, mais persistentes e apresentam curvatura suave.

Esta morfologia é separada do tipo 1 por uma fina lâmina ondulada de sílex, que segue o horizonte de topo dos estromatólitos da porção inferior (Fig. 4). Algumas colunas do tipo 1 são abruptamente truncadas por este nível de sílica, e não tem continuidade na camada superior. Da mesma forma, as bases das colunas do tipo 2, que sobrepõem o nível de sílex, não coincidem com os limites das colunas subjacentes.

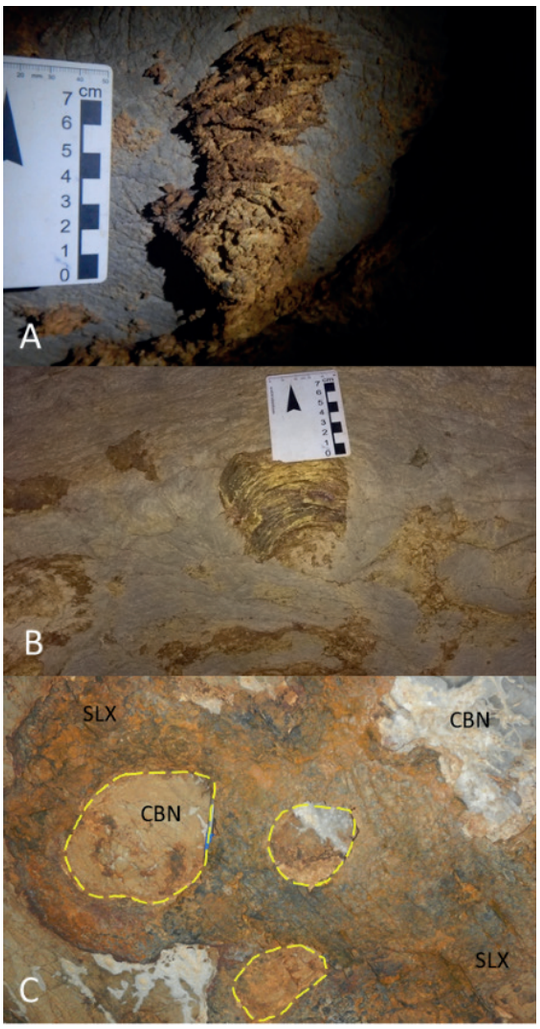

Figura 5: *Exemplo de estromatólitos silicificados (A e B), e espaço intercolunar silicificado (C).*

Observado em vários pontos da caverna, alguns estromatólitos encontram-se total ou parcialmente substituídos por sílex, preservando em alto-relevo as laminações originais (Fig. 5). Em muitos casos, o carbonato entre as lâminas e entre colunas foi totalmente dissolvido, restando somente a laminação silicificada preservada nas paredes da cavidade. O sílex também preenche o espaço intercolunar, feição registrada em crostas de sílex no teto da cavidade, paralelas ao acamamento sedimentar, em formatos circulares (Fig. 5).

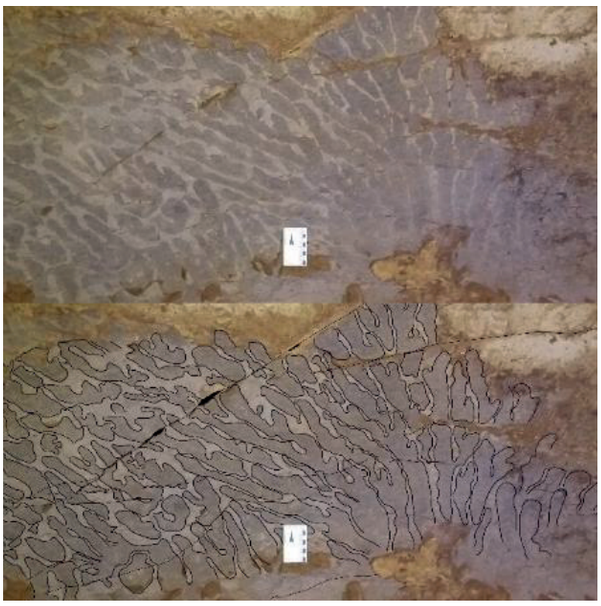

Figura 6 : *Estromatólitos do tipo 3.*

Na porção mais alta do salão, identifica-se uma terceira morfologia (tipo 3), caracterizada por colunas estreitas, com cerca de 5 cm de largura. Essas colunas possuem contornos bem delineados e preservados, permitindo a identificação clara dos limites individuais. Os vetores de crescimento são divergentes na base e apresentam inclinações mais acentuadas em relação aos tipos 1 e 2. Além disso, as colunas exibem coloração mais escura, o que facilita a diferenciação em relação à rocha encaixante. As laminações macroscópicas do tipo 3 são marcadas pela intercalação de finas camadas cinza escuro e cinza-esbranquiçadas. O material intercolunar apresenta coloração cinza claro, e contém fragmentos intraclásticos, possivelmente derivados do retrabalhamento do próprio estromatólito. As colunas alongadas do tipo 3 apresentam uma relação largura/comprimento de 1:10, contrastando com os tipos 1 e 2, cuja relação é cerca de 1:3.

Este afloramento mostra várias superfícies de truncamento, que interrompem, as vezes bruscamente, as estruturas primárias organo-sedimentares (Fig. 6).

3.2. Descrição morfológica microscópica

Microscopicamente, as laminações dos estromatólitos são micrométricas e de difícil identificação, uma vez que todo o material da estrutura é composto por dolomita (Fig. 7). A textura é microcristalina, caracterizando um dolomicroesparito.

Níveis de estilólitos acompanham a convexidade das laminações, auxiliando na identificação e visualização da estrutura das colunas. A laminação é destacada por variações no teor de magnésio (Mg), que oscila entre 0% e 25%. A sílica em pontos, uniformemente dispersa por toda a área da coluna, representa uma contribuição clástica na sedimentação.

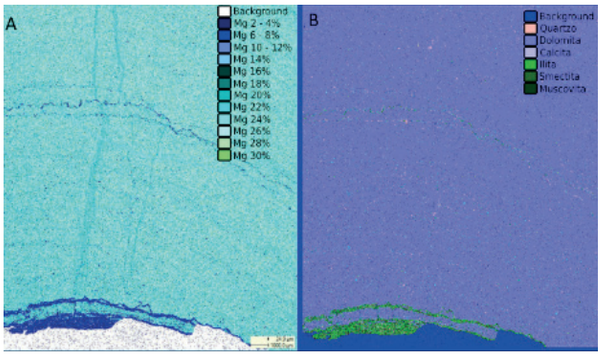

Figura 7: *Mapa composicional de magnésio (A) e mapa mineralógico (B) para os estromatólitos da Gruta Tamboril.*

4. Discussão

As exposições dos estromatólitos na Gruta do Tamboril é influenciada pela variação na atitude do acamamento rochoso, verticalizado na entrada e horizontalizado na porção distal da cavidade. Essa variação estrutural afeta diretamente as possibilidades de observação dos estromatólitos, permitindo cortes longitudinais e/ou transversais.

A superfície ondulada na base da seção marca o contato entre marga + silex (base da seção) e o carbonato dolomítico que hospeda os estromatólitos. Esse horizonte sugere uma mudança nas condições paleoambientais, como variação no aporte sedimentar, favorecendo o desenvolvimento das colônias microbiais. Enquanto a presença de marga indica maior aporte de sedimentos terrígenos, colônias estromatolíticas requerem águas límpidas, geralmente quentes e rasas, para o seu crescimento.

Dada a abundante presença de estromatólitos, o calcário dolomítico pode ser, ao menos localmente, classificado como *boundstone* (Dunhan, 1962), no qual os componentes originais foram unidos durante a deposição.

As colunas do tipo 1, de menores dimensões e com ramificações no topo, sugerem um crescimento em condições de menor estabilidade ambiental ou em um substrato irregular. O preenchimento intercolunar com material fino e cristalino, sem porosidade aparente, pode apontar para uma silicificação pós-deposicional precoce, associada a processos diagenéticos. De acordo com RIDING (2011), o tipo 1 pode ser clssificado como trombolito (trama coagulada) transicionando para estromatólito (colunas laminadas).

As colunas do tipo 2 exibem maior homogeneidade, com laterais regulares e crescimento linear. Essas características, combinadas com laminações persistentes e bem definidas, indicam um ambiente mais estável, favorável ao crescimento uniforme das colunas. A camada de sílex que separa os tipos 1 e 2, e que trunca abruptamente as colunas do tipo 1, sugere que a silicificação ocorreu aproveitando uma superfície de descontinuidade deposicional significativa, possivelmente associada a variação do nível d'água, com exposição e erosão de parte da rocha. Devido ao aspecto colunar a dômico e laminação interna homogênea, as feições do tipo 2 podem ser classificadas como estromatólitos propriamente ditos (RIDING, 2011).

Já a terceira morfologia, caracterizada por colunas alongadas (relação largura/comprimento de 1:10) e divergências de crescimento na base, sugere condições de sedimentação mais profundas ou influenciadas por fluxos turbulentos, onde as esteiras microbiais se adaptaram às variações locais no substrato. A ocorrência de intraclastos sugere retrabalhamento das colunas durante ou após a deposição, sugerindo um ambiente de maior energia. Algumas das fições dendríticas isoladas na terceira tipologia podem ser classificadas como dendrolitos, ao passo que as feições coagulares são classificadas como trombolitos (RIDING, 2011).

A silicificação é um processo amplamente conhecido para os carbonatos do Grupo Bambuí. Níveis e nódulos de sílex são abundantes em meio a sequências carbonáticas. No caso da Gruta do Tamboril, a silicificação é observada na forma de nódulos e camadas, ao longo de toda a cavidade. Na seção descrita, a substituição pela sílica preservou

detalhes estruturais, como laminações interna dos estromatólitos, destacando estas feições em alto-relevo, promovendo a preservação da estrutura mesmo após a dissolução parcial do carbonato.

A silicificação também ocorre nos espaços entre as colunas, sem penetrar nas laminações internas. Essas diferenças indicam complexidade no processo de silicificação, com multiplas rotas de fluxos devido à heterogeneidade da rocha. De forma geral, a silicificação ocorre concordante com o acamamento sedimentar, sendo este provavelmente a principal rota de fluxo para os fluidos percolantes.

A textura de dolomicroesparito, a presença de estilólitos e de sílex sugerem recristalização dolomítica em resposta à compactação e processos diagenéticos tardios. Esses fatores destacam a complexa interação entre sedimentação primária e processos pós-deposicionais.

A presença de estromatólitos na Gruta do Tamboril adiciona um componente único ao patrimônio geológico da caverna, destacando-a como uma cavidade com afloramentos rochosos de interesse científico. A exposição pode ser utilizada como um recurso educativo, tanto para a comunidade científica quanto para o público em geral.

A exposição pode ser utilizada para comparar outros registros estromatolíticos em cavernas ou afloramentos, enriquecendo o conhecimento sobre as condições paleoambientais em diferentes locais dos mares pré-cambrianos.

Exposições contínuas e bem preservadas de estromatólitos em cavernas são raras. Esse exemplo reforça a necessidade de proteger e documentar essas formações como parte do patrimônio geoespeleológico e paleontológico brasileiro. A promoção do valor científico e patrimonial da Gruta do Tamboril pode fortalecer os esforços de conservação e fomentar a conscientização sobre a importância das cavernas como ambientes únicos.

5. Conclusão

Os estromatólitos da Gruta do Tamboril destacam-se pela sua diversidade morfológica, boa preservação e interação com processos diagenéticos de silicificação e recristalização dolomítica. As três morfologias identificadas refletem variações nas condições paleoambientais e no regime sedimentar, desde ambientes instáveis e rasos até condições mais profundas e turbulentas. A silicificação, amplamente observada, preservou detalhes estruturais e contribuiu para a conservação dessas formações, evidenciando a complexidade dos processos pós-deposicionais no Grupo Bambuí.

Essa exposição representa um registro da vida microbiana primordial e um recurso científico de alto valor para estudos estratigráficos, paleoambientais e diagenéticos. A Gruta do Tamboril é um arquivo natural da história da Terra e as exposições estromatolíticas agregam ainda mais valor ao patrimônio geoespeleológico da cavidade.

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Identification of vertebrate remais in karst sediments in Minas Gerais, Brazil

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Abstract

According to previous studies, carbonate Karst terrains cover a portion of Brazil, with estimates varying between 2.2% and 7% of the country's area. These areas, mainly located in the São Francisco Craton and the Bambuí Speleological Province, are vital for understanding geological and biological processes. Rich in carbonate and dolomitic lithologies, Brazilian karst support exceptional biodiversity and serve as important sites for paleontological discoveries, particularly in caves that favour fossil preservation. Small mammals, especially rodents, are essential bioindicators in these environments, reflecting past climatic and ecological changes. Studies have shown that while many small mammal species survived the Pleistocene-Holocene transition, significant shifts occurred in their communities due to environmental changes. Fossil deposits in Brazilian caves, such as in Rio Grande do Sul and Serra da Bodoquena, reveal adaptations of small mammals to diverse habitats, offering insights into past climates and ecosystems. This research focuses on microfauna in karst sediments, employing fieldwork and laboratory analysis. Methods include dissolving breccias, sieving sediments, and comparing fossil remains with reference collections. These findings may contribute to understanding ecological dynamics, species evolution, and the importance of conserving karst ecosystems as biological and geological history repositories.

Resumo

De acordo com estudos anteriores, os terrenos cársticos carbonáticos cobrem uma parte do Brasil, com estimativas variando entre 2,2% e 7% da área do país. Essas áreas, localizadas principalmente no Cráton do São Francisco e na Província Espeleológica do Bambuí, são fundamentais para a compreensão dos processos geológicos e biológicos. Ricas em litologias carbonáticas e dolomíticas, as regiões cársticas brasileiras sustentam uma biodiversidade excepcional e servem como importantes locais de descobertas paleontológicas, especialmente em cavernas que favorecem a preservação de fósseis. Os pequenos mamíferos, especialmente os roedores, são bioindicadores essenciais nesses ambientes, refletindo mudanças climáticas e ecológicas do passado. Pesquisas mostram que, embora muitas espécies de pequenos mamíferos tenham sobrevivido à transição Pleistoceno-Holoceno, ocorreram mudanças significativas em suas comunidades devido a transformações ambientais. Depósitos fósseis em cavernas brasileiras, como as do Rio Grande do Sul e da Serra da Bodoquena, revelam adaptações de pequenos mamíferos a diversos habitats, fornecendo informações sobre climas e ecossistemas do passado. Este estudo foca na microfauna presente nos sedimentos cársticos, utilizando trabalho de campo e análises laboratoriais. Os métodos incluem a dissolução de brechas, peneiramento de sedimentos e comparação de restos fósseis com coleções de referência. Esses achados podem contribuir para a compreensão das dinâmicas ecológicas, da evolução das espécies e da importância de conservar os ecossistemas cársticos como repositórios da história biológica e geológica.

Resumen

Según estudios previos, los terrenos kársticos carbonatados cubren una parte de Brasil, con estimaciones que varían entre el 2,2 % y el 7 % del área del país. Estas áreas, ubicadas principalmente en el Cratón de São Francisco y en la Provincia Espeleológica de Bambuí, son fundamentales para comprender los procesos geológicos y biológicos. Ricas en litologías carbonatadas y dolomíticas, las regiones kársticas brasileñas sostienen una biodiversidad excepcional y sirven como importantes sitios de descubrimientos paleontológicos, particularmente en cuevas que favorecen la preservación de fósiles. Los pequeños mamíferos, especialmente los roedores, son bioindicadores esenciales en estos entornos, reflejando cambios climáticos y ecológicos del pasado. Las investigaciones han demostrado que, si bien muchas especies de pequeños mamíferos sobrevivieron a la transición Pleistoceno-Holoceno, se produjeron cambios significativos en sus comunidades debido a las transformaciones ambientales. Los depósitos fósiles en las cuevas brasileñas, como los de Rio Grande do Sul y la Serra da Bodoquena, revelan adaptaciones de pequeños mamíferos a diversos hábitats, ofreciendo información sobre climas y ecosistemas del pasado. Este estudio se

centra en la microfauna de los sedimentos kársticos, utilizando trabajo de campo y análisis de laboratorio. Los métodos incluyen la disolución de brechas, el tamizado de sedimentos y la comparación de restos fósiles con colecciones de referencia. Estos hallazgos pueden contribuir a comprender las dinámicas ecológicas, la evolución de especies y la importancia de conservar los ecosistemas kársticos como depósitos de historia biológica y geológica.

1. Introduction

Of the Brazilian continental area, which spans approximately 8.5 million km², KARMANN (1994) estimated that about 5 to 7% consists of carbonate karst terrains. However, AULER (2002) stated that approximately 2.2% of Brazil's territory features exposed carbonates. More recently, Karmann and SALUM FILHO (2007) estimated the total to be 2.8%. Such areas should generally be considered the main geological units favourable for developing endogenous and exogenous karst features. The primary units are in the São Francisco Craton, comprising Minas Gerais, Goiás, and Bahia, on upper Proterozoic carbonate and dolomitic lithologies (TRAVASSOS, 2010; 2019).

According to ROLDAN, WAHNFRIED, and KLEIN (2003), the main speleological provinces of Brazil include the Vale do Ribeira Speleological Province, the Unã Speleological Province, the Serra da Bodoquena Speleological Province, and the Bambuí Speleological Province. The latter, located in Minas Gerais, stands out for its significant carbonate occurrences and extensive traditional karst areas. Beyond the cultural importance of karst, it is fundamental to highlight its role as a basis for extraordinary biodiversity both above and below the surface.

Caves in Brazil's intertropical region have been important sources for discovering Quaternary vertebrate fossils. The environmental conditions within caves, such as low exposure to chemical and physical agents, promote the preservation of organic material, such as bones and teeth. As a result, the fossiliferous deposits found in these caves offer unique opportunities for paleontological and taphonomic studies.

According to DE IULIIS et al. (2016), the study of taphonomy in small mammals and megafauna in Brazilian caves has its roots in the works of Lund and Winge. Their initial research in the Lagoa Santa region advanced the understanding of Brazil's Xenarthra (WINGE, 1915; Lund, 1846). Subsequent taxonomic revisions conducted by HOFFSTETTER (1954) introduced new classifications for some of these species, demonstrating the taxonomic complexity of Brazil's Pleistocene fauna.

Moreover, studies on the accumulation of skeletal remains by predator activity provide a solid theoretical basis for analysing the ecology of these animals. Through the regurgitation of pellets, owls preserve small mammals in caves, creating a highly faithful ecological record that allows robust comparisons between death assemblages and living communities. This type of preservation is significant for accessing ecological data with a temporal depth far beyond the scope of modern ecological studies (TERRY, 2010).

According to BORONI et al. (2015), the study of micromammals, especially rodents and marsupials, has gained relevance in various fields, from palaeontology to ecology. These small mammals are important bioindicators due to their sensitivity to environmental changes and wide geographic distribution. They facilitate data collection for paleoenvironmental reconstructions and contemporary and historical diversity and biogeography studies. Furthermore, these studies provide insights into the evolutionary patterns of small mammal species in karst areas, offering a clearer understanding of the occupation of Brazilian karst regions over different geological periods.

The primary goal of this research is to investigate the traces of microfauna associated with karst sediments, a relatively underexplored area in the country and the state. CAMINHA and LEITE (2015) proposed that microfossils vary from a few thousandths of a millimetre to a few centimetres, depending on the group studied. Thus, the term microvertebrate defines the group of small organisms that lived in the past.

In karst areas, fractures and fissures in rocks and the bottoms of dolines serve as natural "traps" for sediments. The researchers involved aim to collect material from these spaces to identify traces of microfauna associated with karst sediments to expand knowledge of the region's geological and biological history, demonstrating the importance of a Conservation Unit in a traditional karst area.

2. Materials and methods

The methodology employed in this study was divided into three main phases: bibliographic research, fieldwork with *in situ* collection, and laboratory work. The fieldwork was conducted in a Conservation Unit in Minas Gerais (Gruta Rei do Mato Natural Monument), focusing on collecting bone remains from small vertebrates found in cave sediments. According to CHEREM et al. (2018), the collection allows for obtaining representative samples of skulls, mandibles, and teeth.

After collection, the bones undergo a detailed analysis. The taxonomic identification of micromammals is based on cranial and dental characteristics, often compared to reference collections of recent and ancient specimens (HADLER & FERIGOLO, 2004). In many cases, comparing fossil material with zoological collections assists in identifying both extinct and extant species, which is particularly important when studying morphologically similar genera (e.g., *Akodon and Oligoryzomys*), whose differentiation from fragmented remains can be challenging (HADLER et al., 2016).

In addition to morphological analysis, the study may include a taphonomic approach that investigates the preservation conditions of the bones and fossils, considering factors such as predation marks, fractures, weathering, and encrustations (HASHEMI et al., 2006). This taphonomic analysis is essential to determine whether the remains were naturally accumulated or resulted from predatory activity, as in the case of birds of prey. BORONI, PARDIÑAS & LESSA (2018) assert that samples can be divided into surface and stratified categories. Surface samples are from fresh owl pellets (not used in this research), while stratified samples are small excavations prioritised for this research.

Laboratory work followed rigorous steps. First, the collected sediments were given water and hydrogen peroxide (H_2O_2) to disaggregate the material, particularly when found in breccias (Figure 1). Then, the sediments were sieved using sieves of different diameters, and after drying, the bones were carefully separated and analysed with stereoscopic magnifying glasses. Identifying remains involves comparisons with reference collections and specialised literature, as GHILARDI et al. (2011) exemplified.

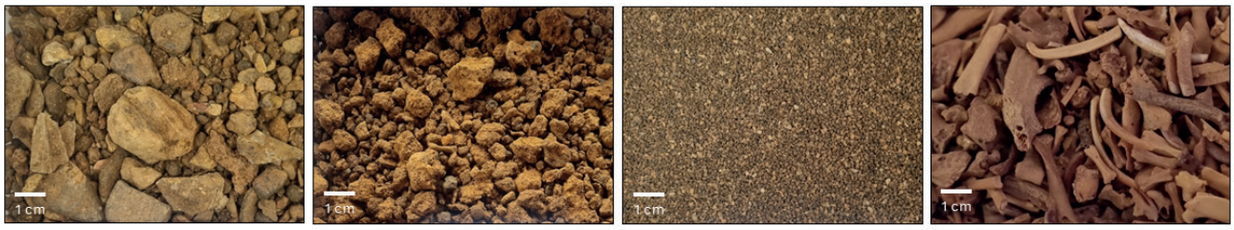

Figure 1: *Karst sediment fractions from Gruta Rei do Mato State Natural Monument. From left to right: (1) Coarse fraction: angular to sub-angular gravel and small rocks (>1 cm); (2) Medium fraction: mixed sediments primarily composed of sand and small gravel (<1 cm); (3) Fine fraction: silt and clay particles (<1 mm); (4) Fossiliferous fraction: microfaunal remains, including small vertebrate bones and fragments, notably rodent bones (scale bar: 1 cm).*

3. Results

The Gruta Rei do Mato Natural Monument is one of the important Conservation Units in Minas Gerais, Sete Lagoas. Covering a total area of 160 hectares, it was established in 1984 through Law No. 8,670, which designated the region as a special protection area due to its natural and geological significance. In 2009, Law No. 18,348 reclassified the area as a State Natural Monument, highlighting its importance for preserving unique karst formations, associated ecosystems, and valuable paleontological evidence.

The area is home to karst formations and caves that serve as natural reservoirs of biodiversity and fossils. In the monument's surroundings, a region known as "Britador" revealed a natural underground cavity where promising fossil fragments of small vertebrates were discovered. These materials include bones, jaws, and teeth, providing valuable data for understanding ancient ecosystems and environmental conditions in the region during past geological periods.

Among the most significant finds are bone fragments from amphibians, such as those belonging to the order Anura (Fig.2).

Figure 2: *Anuran bone fragment, showing preservation details, with a scale bar indicating 10 mm.*

The small size of these bones suggests they come from smaller species, known for their high sensitivity to ecological changes. These remains are essential in paleoenvironmental reconstruction, indicating climatic and ecological variations.

Other materials include well-preserved dentitions (Fig.3), which can provide detailed information about the diet of these animals and, consequently, about the vegetation and climate of the time. Fossilised long bone fragments (Fig.4), possibly belonging to small mammals or reptiles, were found in good condition, suggesting that these cavities may have functioned as natural traps that effectively preserved rem ains.

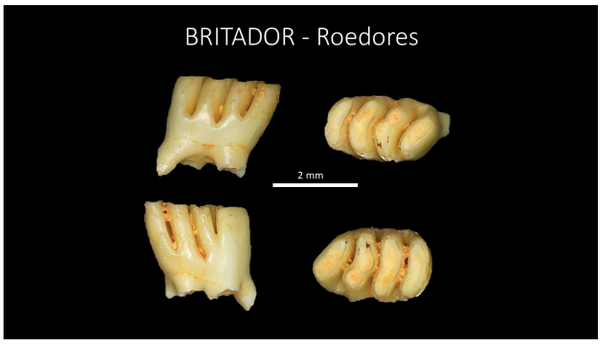

Figure 3: *Rodent dental fragments displaying preserved morphological features, with a scale bar indicating 2 mm.*

Figure 4: *Bone fragment presenting signs of preservation.*

Fossilised jaws of rodents from the subfamily Sigmodontinae (Fig. 5) were identified, indicating the presence of species such as Oecomys, which are key to studying past habitats. These fossils help reconstruct the local ecosystems, revealing a fauna that adapted to varying environmental conditions. Additionally, bone fragments attributed to the Caviidae family (Fig. 6) suggest the presence of larger rodents, typically associated with open and dry environments, reinforcing the hypothesis that the region experienced arid climatic periods.

Within the Gruta Rei do Mato itself, deer bone fragments, including phalanges, dental fragments, and a possible astragalus, were identified. These fragments expand our understanding of the diversity of vertebrates that once inhabited the area, providing insights into the past interaction between fauna and the environment that led the remains to the underground.

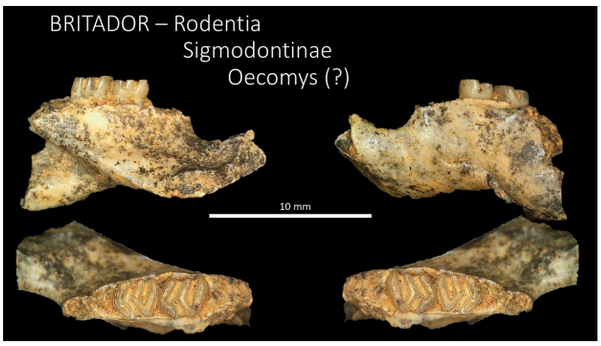

Figure 5: *Mandible of a rodent, tentatively identified as Oecomys. It shows well-preserved molar rows and distinctive dental patterns. The scale bar indicates 10 mm.*

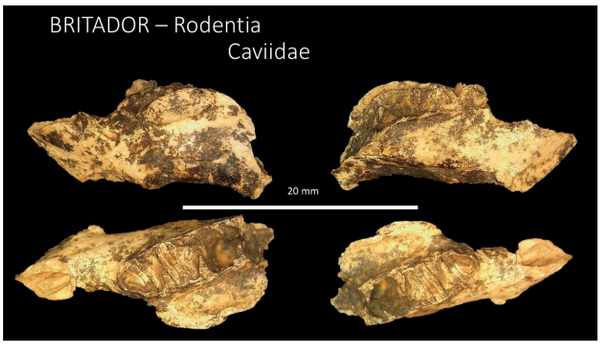

Figure 6: *Fossilized rodent mandible showing well-preserved molars with intricate occlusal patterns and cusp morphology, indicative of dietary adaptations. The scale bar is 20 mm.*

4. Discussion

The research was developed based on the concepts and methodologies proposed by LEVINSON (1982), AGUILAR et al. (1998, 2001), and TOŠKAN (2009), as well as those of Ivan HORÁČEK et al. (2007), BOGIĆEVIĆ & NENADIĆ (2008), and Boroni (2012). These studies employed the technique of dissolving karst breccias in the laboratory to recover the remains of small vertebrates.

The paleontological literature has extensively documented small mammals' response to climate changes at the end of the Pleistocene. According to FLANNERY (1999) and HASHEMI et al. (2006), small mammals, especially rodents and lagomorphs, are important bioindicators due to their sensitivity to environmental changes. In many caves, remains of small mammals are often found in owl pellets, reflecting the fauna available during sediment deposition. Thus, they provide a valuable source for paleoecology and archaeozoology.

Studies also demonstrate that significant changes in community composition occurred while many small mammal species survived the extinction event that affected megafauna. BLOIS et al. (2010) affirm that the transition from the Pleistocene to the Holocene was marked by a loss of diversity and a reorganisation of communities, particularly in regions like California, where species richness and even local extirpation were observed.

Small mammal communities are sensitive to environmental variations due to their direct dependence on local resources and rapid life cycles. However, an important characteristic of these animals is their resilience; despite shifts in geographic distribution, many species did not experience global extinctions but rather local and regional changes (TERRY, 2009). These mammals play vital roles in ecosystems as soil aerators, seed dispersers, and prey for predators, making their study essential for understanding past and future ecological dynamics.

Fieldwork and laboratory analyses are ongoing, and sedimentary material collected from various areas is still being processed. The potential for further discoveries in the region is vast, and the expected results will not only enhance knowledge of the local geological and biological history but also underscore the need to conserve this unique natural heritage.

Combining environmental preservation with high-relevance scientific research, the Gruta Rei do Mato State Natural Monument reaffirms its importance as a valuable space for science, education, and sustainable tourism. The discoveries made so far enrich the region's paleontological knowledge and emphasise the necessity of public policies to protect karst areas and their associated ecosystems.

According to LAUDET & SELVA (2005), studies on the accumulation of small mammal remains, particularly in paleontological and archaeological sites, have revealed the role of different birds and mammalian predators as accumulating agents. Among the known predators, corvids such as the raven (*Corvus corax* - Linnaeus, 1758) and nocturnal birds of prey like owls are frequent accumulators of bones.

The preservation of fossils in caves occurs in environments that protect materials from destructive factors. Studies such as ANDREWS (1990) show cave environments, with constant humidity and temperature, contribute to the minimal decomposition of remains. SIMMS (1994) and CARTELLE (1999) state that caves function as natural traps where animals may become confined, facilitating the formation of fossil deposits.

In Brazil, paleontological studies conducted in Rio Grande do Sul have revealed the presence of various Pleistocene rodent species, such as *Myocastor coypus* (MOLINA 1782) and *Reithrodon auritus* (G. FISCHER, 1814). These rodents, associated with open and semi-arid environments, indicate the predominance of a colder and drier climate during the Pleistocene. The morphology of their teeth and skulls suggests specific adaptations to the vegetation and soil of the time, such as hypsodont and brachyodont teeth, typical of rodents inhabiting sparse vegetation areas with low humidity (RODRIGUES & FERIGOLO, 2004).

According to BORONI et al. (2019), fossils of rodents from the subfamily Sigmodontinae have been found in Serra da Bodoquena, Mato Grosso do Sul. This reinforces the importance of these small mammals in understanding climatic and ecological changes during the Quaternary. The analyses suggest that, in addition to morphological adaptations, the geographic dispersion patterns of these rodents were strongly related to the climatic oscillations of the period.

These studies also provide insights for broader paleoenvironmental

interpretations. The presence of rodents in deposits from different regions of Brazil enables comparisons between contemporary environments, such as the coastal region of Rio Grande do Sul and the semi-arid interior of Bahia, where fossils of *M. coypus* were found (CARTELLE & LESSA, 1989). These findings confirm Pleistocene rodents' ability to occupy various ecological niches, adapting to coastal and inland environments.

As rodents are widely recognised as excellent bioindicators due to their rapid evolution rates and adaptation to different environmental conditions, these small mammals are particularly useful for dating Quaternary deposits and providing information about the climate and vegetation of the time (HADLER & FERIGOLO, 2004). The presence of M. coypus and R. auritus species in Pleistocene sediments indicates a colder and drier climate, consistent with global climatic patterns of that period. Studies on Pleistocene fauna in Brazil have revealed the coexistence of large herbivores, such as the extinct Xenarthra and Notoungulata, with small rodents adapted to open and semi-arid habitats (RODRIGUES & FERIGOLO, 2004). The coastal plain of Rio Grande do Sul has been a significant research focus due to its rich fossil deposits. Rodent fossils from this region have enabled a detailed reconstruction of environmental and evolutionary conditions during the late Pleistocene.

In addition to small rodents, the analysis of small marsupial fossil remains can reveal spatial and temporal distribution patterns, aiding in understanding the dynamics of extinction and species survival during the Pleistocene (AGUILAR et al., 1998). Rodents are particularly important for biostratigraphy, as their high evolution rates allow them to serve as precise temporal markers. The geographic distribution of Pleistocene rodents also provides clues about this period's climatic and environmental changes.

Studies of vertebrate fossils associated with cave sediments, particularly in Slovenia's Classical Karst and Brazil's intertropical region, have brought valuable discoveries about the Pliocene and Pleistocene periods. Analyses of megafauna fossils, such as Pleistocene ground sloths, have revealed critical information about the paleoecology and adaptation of these animals to significant environmental changes (MIHEVC et al., 2007; DANTAS et al., 2022).

Vertebrate fossils found in caves can provide valuable information about paleoclimatic environments and the evolutionary phases of these geological formations. In the study by MIHEVC et al. (2007), the use of paleomagnetic techniques in cave sediments in Slovenia allowed precise dating of cave evolution phases and their correlation with the global geomagnetic polarity time scale (GPTS). Additionally, biostratigraphy based on small mammals, such as rodents and shrews, helped identify specific periods of the Pliocene and Pleistocene, clarifying paleoenvironmental changes in the Classical Karst.

According to CASTRO and LANGER (2011), fossil deposits in caves are essential for preserving the remains of small animals, which are often underrepresented in other sedimentary contexts. The analysis of vertebrate fossils has mainly focused on dental enamel fragments from small mammals, such as rodents and shrews, identified based on taxonomic characteristics and comparisons with previous fossil records.

The absence of arvicolines with rootless teeth and the composition of mammal fauna suggested a Pliocene age for the deposits studied at the Črnotiče II site (MIHEVC et al., 2007). Studies such as CHAHUD et al. (2022) highlight the importance of specimens from sites like Gruta Cuvieri in Brazil, which house remains of extinct megafauna and contemporary small vertebrates. The preservation of these paleontological and archaeological records provides valuable data on the ecology and evolution of mammals during the Holocene and late Pleistocene. SEERSHOLM et al. (2021) emphasise that using DNA preserved in small bone fragments facilitates understanding migration patterns and ecological changes over time, particularly when associated with historical collections.

Although remains of small animals are harder to find, taphonomic studies of fossils collected in caves allow for a detailed understanding of the interactions between geological and biological processes that affect the preservation of skeletal remains. According to BEHRENSMEYER (1991), taphonomy involves analysing post-mortem modifications of organisms, such as fragmentation, tooth marks, abrasion, and hydraulic deposition. These factors were observed by CHAHUD et al. (2022) at Gruta Cuvieri, where fossils of megafauna, such as *Catonyx cuvieri* (LUND, 1839), an early Holocene ground sloth, were highlighted.

The exploration of karst regions in Brazil, particularly within conservation units such as the Gruta Rei do Mato Natural Monument, underscores the significance of caves as reservoirs of geological, paleontological, and ecological data. These environments preserve information about past climates, ecosystems, and faunal dynamics, highlighting their importance for understanding biodiversity and environmental changes over geological timescales.

The preliminary findings demonstrate the relevance of potentially integrating taxonomic, taphonomic, and paleoecological analyses to reconstruct past ecosystems and reveal faunal distribution patterns and resilience. Additionally, the continued investigation of fossil deposits in karst formations enriches the understanding of evolutionary processes and reinforces the necessity of preserving these unique geological features. This research contributes to the scientific community and supports the development of public policies that protect and promote the sustainable use of Brazil's karst regions.

5. Conclusion

The Gruta Rei do Mato Natural Monument is distinguished by its karstic nature and the conspicuous presence of vertebrate fossil remains, emphasising micromammals. These are predominantly composed of representatives of the Order Rodentia, although some remains of Amphibia and Aves are also represented in smaller numbers. This rich and abundant presence of organisms sensitive to paleoclimatic and paleoenvironmental changes, as observed in rodents, which are typical of the Pleistocene/Holocene boundary, highlights the importance of research in this and other karstic units within the region and across other states. These fossils can provide valuable information about the climatic and environmental conditions of the region in the past, as well as the dynamic faunal successions that occurred during this interval.

These fossil accumulations can also be subjected to taphonomic studies to understand these remains' formation, sedimentation, and preservation, enabling inferences about the depositional dynamics in each cave environment. Additionally, this research underscores the importance of preserving karstic environments, as they represent unique and highly informative ecosystems, requiring public policies focused on sustainable conservation and exploration.

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Session 04

CAVE MINERALOGY AND SEDIMENTS

Speleothems of Puerto Vallemí, Eastern Paraguay: preliminary results

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Abstract

The morphological, mineralogical, and chemical characteristics of the speleothems observed in three cave systems in the northwestern region of Eastern Paraguay are described here: Santa Caverna, Caverna 14 de Julio, and Caverna 54. These endokarstic systems developed in the Neoproterozoic carbonate succession of the Itapucumí Group. The main speleothems morphologies observed in Santa Caverna and 14 de Julio include Flowstones, Stalactites, Stalagmites, Stalactite draperies, Popcorn, Coraline, Mushrooms, Pearls, Flowstones and Helictites. In contrast, only millimeter-scale siliceous speleothems were identified in Caverna 54. X-ray diffraction (XRD) analyses reveal similar mineralogical and chemical compositions between Santa Caverna and Caverna 14 de Julio, with dominant mineral phases of calcite, dolomite, and quartz, occasionally accompanied by gypsum and clay minerals (e.g., illite). Fourier-transformed infrared (FTIR) spectrometry results reveal carbonate ion (CO_3^{2-}) vibrational modes. Scanning electron microscopy (SEM) imaging shows the presence of microorganisms (bacteria, spores, and fungal hyphae) in speleothems. These results strongly contrast with the stone structures of Caverna 54, which are composed of quartz, hematite, and siderite, with a total absence of carbonate speleothems.

Resumen

Se describen las características morfológicas, mineralógicas y químicas de los espeleotemas observados en tres sistemas de cuevas en la región noroeste del Paraguay Oriental: Santa Caverna, Caverna 14 de Julio y Caverna 54. Estos sistemas endokársticos se desarrollaron en las unidades carbonáticas neoproterozoicas del Grupo Itapucumí. Las principales morfologías de espeleotemas observadas en Santa Caverna y Caverna 14 de Julio incluyen *Flowstones*, Estalactitas, Estalagmitas, Cortinas de estalactitas, *Popcorns*, *Coralines*, Hongos, Perlas, *Flowstones* y Helictitas. En contraste, en la Caverna 54 solo se identificaron espeleotemas silíceos a escala milimétrica. Los análisis de difracción de rayos X (XRD) revelan composiciones mineralógicas y químicas similares entre Santa Caverna y Caverna 14 de Julio, con fases minerales dominantes de calcita, dolomita y cuarzo, ocasionalmente acompañadas de yeso y minerales de arcilla (por ejemplo, illita). Los resultados de la espectrometría infrarroja con transformada de Fourier (FTIR) revelan modos vibracionales del ion carbonato (CO_3^{2-}). Las imágenes de microscopía electrónica de barrido (SEM) muestran la presencia de microorganismos (bacterias, esporas e hifas fúngicas) en los espeleotemas. Estos resultados contrastan fuertemente con las estructuras pétreas de Caverna 54, las cuales están compuestas por cuarzo, hematita y siderita, con una ausencia total de espeleotemas carbonatados.

1. Introduction

Speleothems are secondary deposits of mineral precipitation formed inside carbonate, siliceous, and ferriferous caves (Fairchild and Baker, 2012).

Several underground karst systems were developed in carbonates rocks in the northwest of the Eastern Paraguay, in the localities of Puerto Vallemí and San Lázaro of Concepción Department (Figure 1). The outcrops comprising siliciclastic and volcanic rocks of the Vallemí Formation at the base, which are followed by limestones and dolostones of the Camba Jhopo and Tagatiya Guazu formations, and capped by marls, limestones and siliciclastic mudstones of the Cerro Curuzu Formation from the Itapucumí Group. The ages for these rocks are typical of the end of the Ediacaran Period, reinforced by the presence of Claudina guide-fossil, between 550 and 542 Ma (Warren et al., 2019).

Among the most notable karst systems are the *Cantera 54* Cave, *Cantera 30* Cave, the *Camba Jhopo* Cave, and the *Tres Cerros* Cave (Dejean and Perea, 1985), the *Santa Caverna* Cave, *14 de Julio* Cave, *Morado* Cave, and *Risso* Cave. Quaternary clay was deposited in some of these caves, in which well-preserved fossil remains of *C. cuvieri* (Sanabria et al., 2024) have been found and described within their galleries, along with a significant number of small mammals remains from the Late

Pleistocene (Torres et al., 2013).

Some of these caves have been designated protected areas under the Natural Monument category (Law No. 4577).

This study describes the morphological, mineralogical, and chemical characteristics of the speleothems observed in three cave systems: Santa Caverna, 14 de Julio and 54.

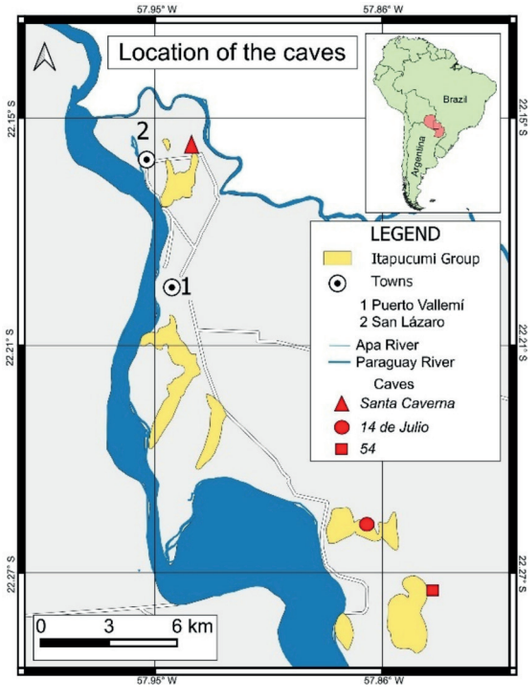

Figure 1: *Map of the location of the carbonate outcrops of the Itapucumí Group and the studied caves: Santa Caverna, 14 de Julio, and 54 Caves.*

2. Methodology

The applied methodology was based on observing, describing, and comparing speleothems and on mineralogical and chemical analysis for their morphogenetic evaluation.

Compositional analyses were performed using X-ray diffraction (XRD) to identify minerals. The samples analysed using the total rock method were ground with an agate mortar until a fine powder was obtained and placed on a stainless steel sample holder. The analyses used a Panalytical AERIS diffractometer with Cu radiation and a Ni filter. The measurement conditions were 40 kV and 15 mA. Sample readings were carried out at a scan speed of 0.2° theta/s over a 5 to 85° 2-theta range. The HighScore 5.1 software, under an academic license, was used for result interpretation and graph generation. The analyses were conducted at the División de Mineraología, Petrología y Sedimentología del Museo de La Plata (Buenos Aires, Argentina).

Infrared (IR) absorption was evaluated using Fourier-transform infrared (FTIR) spectroscopy in attenuated total reflection (ATR) mode, with a Thermo Fisher Summit X model. The spectrum acquisition conditions consisted of 128 scans with a resolution of 4 cm ^{1}. Spectragryph software was used to process Raman and FTIR vibrational spectra, including baseline correction, smoothing, and band identification.

The fitting and deconvolution of Raman and IR spectra were carried out using a model of N coupled oscillators with independent Gaussian responses. In this approach, each Raman- or IR-active band represents the contribution of a Gaussian curve. The determination of band positions was based on a comparison between the theoretically expected values, calculated using Density Functional Theory, and the position of the minima in the second derivative. The deconvolution was performed using the open-source software Fityk.

For this study, scanning electron microscopy (SEM) operated at a voltage of 15 kV to optimize imaging conditions. The carbonate samples were mounted on carbon tape and then coated with a thin carbon layer, deposited at 4V for 8 seconds using the Agar Auto Carbon Coater system.

3. Results

X-ray diffraction analyses performed on samples from Santa Caverna (E1 - Mushroom – SC, E3 - Estalactita – SC, E4 - Coralina – SC, E5 - Estalactita – SC and M2E2 - Colada Estalagmítica - SC) and 14 de Julio cave (E2 - Mushroom - C14J) reveal very similar mineralogical compositions, with the presence of mineral phases of calcite (R040070.1), dolomite (R050370.1), gypsum (R040029.1), quartz (R060604.1), and occasionally, neo-minerals from the illite group (00-002-0050). In contrast, the samples from 54 cave (E6 – espeleotema férrico - C54 and E7 – espeleotema férrico - C54) exhibit a very different mineralogical composition, dominated by quartz phases (R040031.1), with minor phases of hematite (R050300.1) and siderite (R040034.1).

Regarding the morphology of calcium carbonate speleothems, in Santa Caverna and 14 de Julio caves, they form spectacular structures, contrasting notably with the structures of 54 cave, where they are completely absent. Instead, only small lithic structures of less than 1 cm are observed. Among the identified morphologies, the main ones include flowstones, gours, and stalagmitic flowstones; cylindrical forms such as stalactites, stalagmites, popcorn, mushrooms, coraline, and helictites; and concentric forms like cave pearls and peloidal speleothems.

Flow morphologies cover the surface of the rock and develop on the floor, walls, and sloping surfaces, giving rise to stalagmitic flowstones. Cylindrical forms, including stalactites, curtains, and stalagmites, grow perpendicular to the ceiling and the floor, respectively, with 0.6 to 3.3 meters lengths.

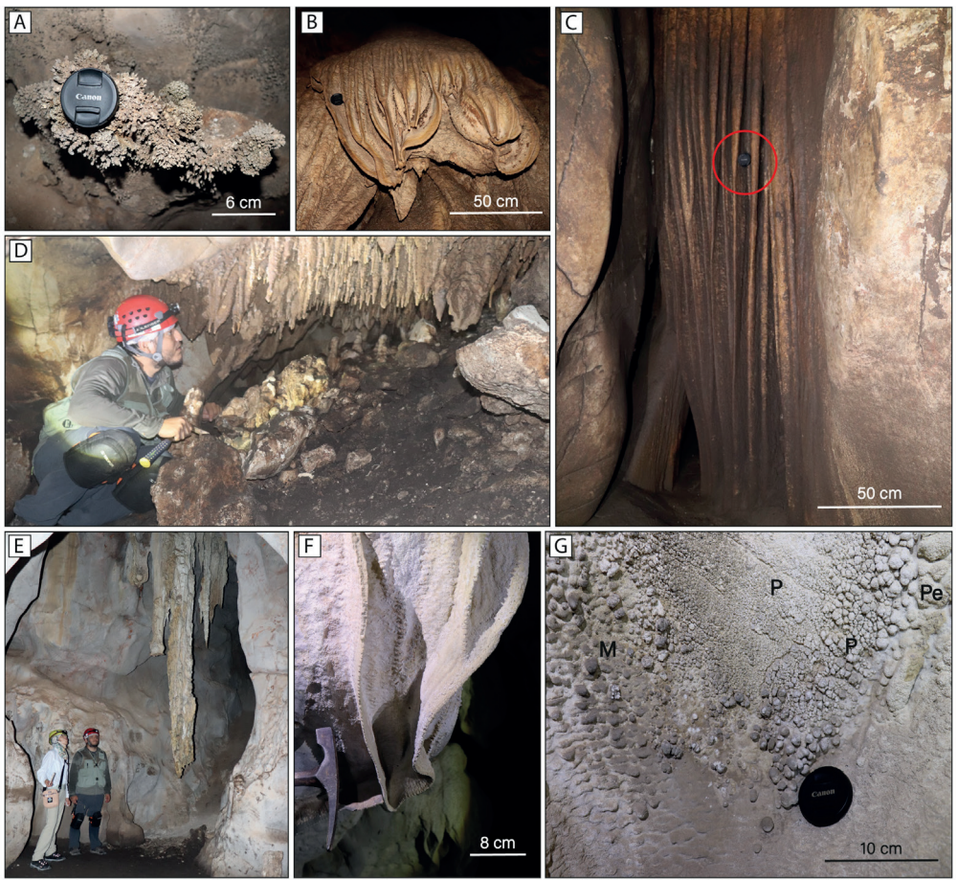

Figure 2: *Calcareous speleothems. Morphologies: A) Coralines. B and C) Curtains. D) Soda straw-type stalactites. E) Stalactites. F) Fish-tail. G) Cylindrical speleothems, including Mushrooms (M), Coralines (C), Popcorns (P), and Peloidals speleothems (Pe).*

Other structures, such as mushrooms (Aubrecht et al. 2018), coraline and popcorns, are formed on the surface of stalactites and walls, with thicknesses of less than one centimeter and diameters smaller than 2 cm. Coraline formations arranged in clusters resemble a cauliflower, while popcorn resembles a bunch of grapes. The helictites are delicate and thin cylindrical forms with erratic growth associated with stalactites, joints, and other types of fractures. “Fish-tail” type speleothems develop from the ceiling. Cave pearls are found on the floor and gently sloping walls, unlike peloidal speleothems, which have an elongated hemispherical morphology and develop on the walls and on the surface of stalactites and stalagmites.

The karst forms exhibit colors ranging from whitish and grayish to yellow, brown, and reddish tones, with a generally opaque appearance. However, helictites are white, shiny, and sometimes translucent, with water droplets at their free ends.

On the other hand, among the dissolution morphologies typical of underground karts, plunge pools and pendants (ceiling pillars) were recognized (Bretz 1942 in Gutiérrez Elorza, 2008). Marmites are located on the ceiling and walls, while pendants are found only on the ceiling.

Regarding the FTIR analyses, the samples show spectral responses typical of carbonates, a condition expected due to the type of rock. This highlights the main absorption bands associated with the characteristic vibrational modes.

Spectrometry deconvolution analyses are being carried out in the regions of interest, allowing for better differentiation of the spectral contributions. Among the main bands identified are: 1412 cm^{-1}, corresponding to the symmetric mode of the CO_3 group, as well as to N-H and C-N vibrations; 872 cm^{-1}, associated with the out-of-plane bending of the CO_3 group; and 713 cm^{-1}, which also corresponds to an out-of-plane reflection mode of the CO_3 group (Reig et al., 2002; Dos Santos et al., 2021; Limeira et al., 2023).

In the images obtained by SEM, the presence of microorganisms (on the surface of the speleothems) was recorded, based on their characteristic shapes, such as cocci, chains of cocci, and spirilla (bacteria), spores, and fungal hyphae.

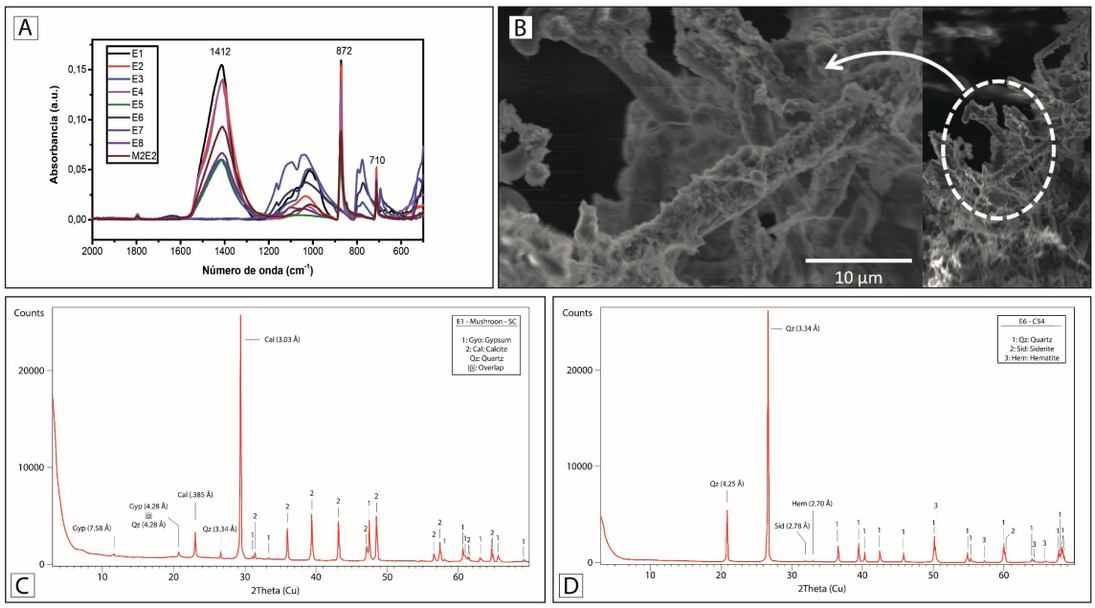

Figure 3: *A) Comparison of FTIR spectrograms. B) SEM image, where elongated (bacilli) forms, associated with bacteria, as well as circular and tubular structures, interpreted as fungal spores and hyphae, are recognized. C) X-ray diffractogram of sample E1-Mushroom-SC. D) X-ray diffractogram of sample E6-54.*

4. Discussion

The processes involved in forming calcareous speleothems are primarily dissolution and precipitation. The images acquired by SEM revealed signs of biological activity. However, the extent of its involvement in secondary precipitation and in the diversity of morphologies, as seen in silica-based speleothems, remains unknown (Sauro *et al.*, 2013).

Dissolution occurs due to the action of water with high concentrations of carbon dioxide, which gives it enough acidity to alter the structure of carbonates (Fairchild, 2006; Gutiérrez Elorza, 2008). Secondary precipitation is due to the supersaturation of the aqueous solution and the degassing of CO_2 (Fairchild, 2006), and the microenvironmental conditions of the cave (temperature, relative humidity, CO_2 pressure, and evaporation), along with hydrogeological processes such as flow, capillarity, dripping, condensation, and water spray (Hill and Forti, 1995).

The vibrational modes obtained by FTIR complement the mineralogical information obtained by XRD, revealing the presence of inorganic compounds associated with the carbonate ion (CO_3^{2-}), typical of the mineral phases of calcite and dolomite.

The presence of mineral phases such as quartz, hematite, and siderite in the siliceous speleothems, like millimeter-centimeter-sized stone structures (Aubrecht *et al*., 2018) in 54 Cave, observed in the fracture zones of host rock, suggests a possible relationship with meteoric fluids enriched in silica and allochthonous iron.

These fluids, when migrating laterally and leaching through fractures in the carbonate rocks from the surface, could have precipitated within the subsurface.

karst system. A similar process was described by Alexandrowicz and Pawlikowski (1982), who explained that exposed rocks react with rainwater, forming ferruginous sulfate solutions due to the decomposition of alkaline minerals, which are then leached from a source area.

Bourman *et al*. (2022) pointed out that compounds transported in solution can precipitate far from the source area that enriched the fluids, reinforcing the plausibility of this hypothesis. In this context, it is not unreasonable to consider the position of the carbonate deposits on the western margin of the Eastern Region of Paraguay, along the river of the same name and in association with the Río Apa Craton. Sarubbi *et al*. (2019) observed geomorphological indicators of deep chemical weathering on the eastern margin of northern Eastern Paraguay. This process affected Upper Jurassic sedimentary rocks and Lower Cretaceous volcanic rocks during the Late Cretaceous.

Since, in our case, the carbonate deposits are associated with the Río Apa Craton, it would be pertinent to evaluate a similar genesis, considering the processes of deep chemical weathering that may have acted on the cratonic area.

5. Final remarks

Considering that the initial precipitation of a siliceous solution under Earth's surface conditions results in the non-crystalline form opal-A (Wray, 1999), the presence of quartz in Caverna 54 suggests a higher degree of crystallinity and a prolonged precipitation period, likely predating the calcareous morphogenesis or representing microfragments of the host rock.

On the other hand, the presence of water in the speleothems of Santa Caverna indicates that speleothem formation processes are still active. Additionally, the absence of large speleothems may be attributed to a two-stage cave evolution process: initial expansion in both longitudinal and vertical directions, followed by mineral deposition. In this context, Caverna 54 could be in an early developmental stage or may lack the mineralogical and environmental conditions necessary for the formation of calcareous speleothems.

Acknowledgments

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Análise de Material Particulado e Recuperação de Cavidades Naturais: Soluções para Preservação de Ecossistemas Subterrâneos

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Resumo

Este estudo avaliou a deposição de material particulado e a eficácia da limpeza em uma cavidade natural sob influência de atividades de mineração. A poeira foi monitorada com placas coletoras, mostrando maior acúmulo na região proximal e menor na medial, possivelmente devido à geomorfologia e à presença de uma claraboia. A limpeza foi eficaz, removendo particulados e aumentando a fauna local, beneficiando a biodiversidade. Os resultados indicam que a cavidade não recebe carga excessiva de partículas, provavelmente devido a condições ambientais estáveis e à proteção da vegetação à frente do maciço, que reduz a entrada de material externo. Conclui-se que a metodologia foi eficiente, mas estudos de longo prazo e monitoramento contínuo são necessários para entender a dinâmica dos depósitos e preservar esses ecossistemas sensíveis.

Abstract

This study evaluated the deposition of particulate matter and the effectiveness of cleaning in a natural cave under the influence of mining activities. Dust was monitored using collector plates, showing greater accumulation in the proximal region and less in the medial region, likely due to the cave's geomorphology and the presence of a skylight. The cleaning was effective, removing particulates and increasing local fauna, benefiting biodiversity. The results indicate that the cave is not receiving an excessive load of particles, likely due to stable environmental conditions and the protection provided by vegetation in front of the massif, which reduces the entry of external material. It is concluded that the methodology was efficient, but long-term studies and continuous monitoring are necessary to understand the dynamics of deposits and preserve these sensitive ecosystems.

1. Introdução

As cavernas são ambientes sensíveis, especialmente próximas a atividades humanas intensas, como a mineração. Os principais impactos incluem a contaminação das águas e a poluição do ar, com a dispersão de partículas que alteram a composição natural, prejudicando ecossistemas subterrâneos e a qualidade ambiental (AULER, 2006; PALMER, 2007). A presença de material particulado é um fenômeno natural no Brasil, mas atividades como a mineração intensificam esse processo, afetando a qualidade do ar, a umidade e os substratos, o que impacta a fauna de invertebrados (FARIAS & EUGENIO, 2002; MOZART, 2021; FERNANDES et al., 2022). Embora esses impactos sejam reversíveis, é importante realizar análises e monitoramentos contínuos para mitigar os efeitos.

Souza et al. (2022) destacam que a limpeza de cavidades naturais é uma prática pouco explorada no Brasil, embora seja bem estabelecida em países como os Estados Unidos, onde há diversos trabalhos publicados e grupos dedicados a essa atividade, como no Parque Nacional Mammoth Cave, no Kentucky. No Brasil, essa metodologia ainda é escassa e pouco difundida, com poucos estudos e praticantes. A maioria das ações de limpeza é realizada por empresas de consultoria, geralmente vinculadas a grandes empreendimentos que buscam cumprir a legislação ambiental devido aos impactos de suas atividades. Essa lacuna evidencia a necessidade de maior discussão e aplicação de práticas de conservação e limpeza de cavidades naturais no país (Horrocks e Ohms, 2006; Hildreth-Werker e Werker, 2006).

A limpeza de poeira em cavidades, segundo Horrocks e Ohms (2006), deve ser realizada com uma análise contextualizada para escolher o método mais adequado, considerando as particularidades de cada cavidade. Souza et al. (2022) destacam que, no Brasil, a empresa Casrte foi pioneira na aplicação de técnicas de limpeza no Complexo Germano, da Samarco, mostrando a importância de adaptar práticas de restauração para garantir a conservação desses ecossistemas sensíveis. Além disso, Souza et al. (2022) ressaltam que o entendimento sobre o patrimônio espeleológico é limitado, já que ele se adapta a mudanças no entorno, o que torna esses ecossistemas vulneráveis. Projetos que visam a recuperação de cavidades são essenciais para a conservação e o avanço científico na área.

Este trabalho tem como objetivo apresentar os resultados da análise

de partículas aéreas e da limpeza realizadas em uma cavidade natural localizada na APA Carste Lagoa Santa, em uma área de mineração. As atividades foram conduzidas por uma empresa especializada em 2023, com o propósito de avaliar e mitigar os impactos ambientais nesse ecossistema cavernícola.

2. Materiais e Métodos

A área de estudo está situada na APA Carste Lagoa Santa, na região metropolitana de Belo Horizonte, uma região conhecida por sua relevância espeleológica e ambiental, abrigando diversas cavidades naturais de grande importância ecológica e científica. A metodologia empregada incluiu dois eixos principais: a análise dos particulados depositados em placas, com identificação e quantificação dos componentes, e a limpeza da cavidade após a coleta e interpretação dos dados.

Análise de particulas aéreas

Este trabalho descreve a análise de poeira em uma cavidade em Pedro Leopoldo/MG, utilizando placas coletoras para medir a deposição de partículas em três zonas da cavidade (proximal, medial e distal). As placas de vidro (90 x 15 mm) foram instaladas estrategicamente e identificadas conforme sua localização. O objetivo era capturar a poeira sedimentar durante um período controlado, fornecendo dados sobre a distribuição e concentração de partículas.

O material coletado foi analisado em laboratório, incluindo pesagem dos particulados, análise granulométrica e mineralógica, conduzidas pela empresa Ecoar Monitoramento Ambiental LTDA. A pesagem foi realizada com balança de precisão, e a granulometria foi feita com espalhamento de luz laser (Método Malvern), enquanto a análise mineralógica utilizou espectrômetro de fluorescência de raios X. Ambas as análises exigem uma amostra mínima de 30 gramas. Essas metodologias, adaptadas de Toomey (2009), permitiram uma avaliação detalhada da deposição de partículas, essencial para o monitoramento ambiental.

Limpeza da Cavidade

Após a análise das partículas nas placas, foi realizada a limpeza controlada da cavidade com base nos dados das análises granulométricas e mineralógicas, visando minimizar os impactos ambientais. Um novo monitoramento de material particulado foi feito para comparar os resultados antes e depois da limpeza.

A metodologia adotada segue referências como Hildreth-Werker e Werker (2006) e Horrocks e Ohms (2006) e consiste em algumas etapas: Inventário e Planejamento: Diagnóstico da cavidade, analisando a ocorrência de material particulado, fatores que dificultam a limpeza e a fragilidade ambiental. Registro fotográfico: Documentação visual do ambiente para comparação antes e após a limpeza. Aquisição de materiais: Obtenção dos materiais necessários para a limpeza. Limpeza das cavernas: Execução da limpeza propriamente dita.

Para a limpeza, foi utilizada uma metodologia de limpeza a seco, adotando materiais específicos para diferentes áreas da cavidade. Foram usadas trinchas para locais mais robustos, pincéis com cerdas macias para áreas mais sensíveis, como espeleotemas e estruturas menores, lona para proteger o chão da cavidade e também para recolher particulados caídos, baldes para armazenar o sedimento retirado e escadas para alcançar locais mais altos. Todo o processo foi realizado com o devido cuidado para não interferir nos processos orgânicos naturais da cavidade.

3. Resultados

Diagnóstico prévio da cavidade

A cavidade está situada próxima ao topo de um maciço rochoso mais estreito, apresentando inflexões e irregularidades com grau médio de alteração da rocha matriz. Ela se desenvolve na direção NE, com padrão morfológico linear em planta e perfil longitudinal horizontal, sendo escavada em calcário homogêneo de coloração cinza escuro e textura micrítica. A caverna é amplamente recoberta por sedimentos químicos, e o acamamento é sub-horizontalizado, com fraturas de pequena continuidade e ausência de estruturas de controle morfológico significativo.

A cavidade pode ser dividida em dois setores principais:

Setor Inicial: Com duas entradas separadas por um pilar, acessos restritos e teto baixo, conduzindo a um conduto retilíneo com teto alto, paredes irregulares e piso plano. Existem evidências de canais de teto, possivelmente formados durante uma fase de entupimento.

Setor Final: Apresenta um desnível abrupto de cerca de 2 metros de altura, com conduto retilíneo, piso estalagmítico e teto mais baixo na porção distal. Este setor é marcado pela abundância de espeleotemas.

Apesar da entrada estreita, a cavidade possui uma claraboia que permite a entrada de material particulado do ambiente externo. Durante o estudo, foi observada a presença de poeira em toda a cavidade, indicando a influência de atividades externas, como mineração, no ecossistema cavernícola.

A figura 01 mostra a entrada e um depósito químico da cavidade.

Figura 01: *Entrada da cavidade e depósito químico com presença de particulados aéreos. Fonte: Geodo Meio Ambiente, 2023.*

Análise de partículas

As placas foram distribuídas nas cavidades naturais subterrâneas em 06/01/2023, após o diagnóstico prévio das cavidades, e retiradas em 06/06/2023, totalizando um semestre de coleta de material particulado.

As placas de Petri foram estrategicamente instaladas em áreas de maior fluxo de ar na cavidade, a fim de garantir a coleta de material particulado representativo. Para evitar contaminação, foram posicionadas longe de umidade e goteiras, e niveladas para assegurar a homogeneidade das amostras. As placas foram fixadas com cola adesivo termofixo para garantir estabilidade. Após a coleta, cada placa foi embalada para transporte seguro ao laboratório Ecoar Monitoramento Ambiental para análise. A Figura 02 ilustra uma tabela com os resultados obtidos.

Identificação da Amostra	*Data*	*LQ*	*Massa depositada na placa de petri (g)*
PONTO 1 - ZONA PROXIMAL	06/01/23 a 06/06/2023	0,001	**0,114**
PONTO 2 - ZONA MEDIAL	06/01/23 a 06/06/2023	0,001	**0,0176**
PONTO 3 - ZONA DISTAL	06/01/23 a 06/06/2023	0,001	**0,0265**

Figura 02: Valores da pesagem do material particulado presente nas placas de petri. Fonte: Geodo Meio Ambiente, adaptado de Ecoar Monitoramento Ambiental LTDA, 2023. ***LQ**= Limite de Quantificação.*

Após a pesagem, as seis placas de Petri apresentaram uma deposição inferior a 0,12 gramas, o que foi insuficiente para realizar os ensaios de fluorescência de raios X (FRX) e granulometria por espalhamento de laser de baixo ângulo, que exigem no mínimo 30 g de amostra. Isso limitou a análise detalhada da composição e distribuição do material particulado.

Limpeza da cavidade

Após o levantamento inicial e a inspeção detalhada na cavidade, foram identificados diversos pontos de fragilidade que exigem cuidado durante o processo de limpeza. Entre esses pontos estão os aportes orgânicos, como folhas, ossos, galhos, fezes e outros detritos vegetais e animais, guano de morcegos e depósitos químicos, incluindo espeleotemas, conforme mostra a imagem 03. Esses elementos precisam ser preservados ou manuseados com precaução para evitar impactos negativos ao ecossistema cavernícola. Todos os pontos de fragilidade identificados foram registrados e mapeados, incluindo a localização exata, descrição detalhada da condição e avaliação do nível de fragilidade. Esses dados foram utilizados como base para orientar a execução da limpeza da cavidade.

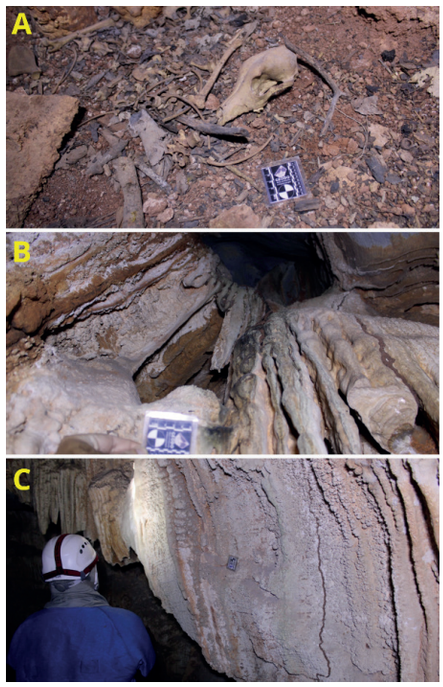

Figura 03: *(A) Detritos vegetal e animal (carcaça); (B) Guano seco; (C) Depósito químicos. Fonte: Geodo Meio Ambiente, 2023.*

A limpeza da cavidade ocorreu no dia 01/07/2023, com foco na remoção de particulados das paredes e teto, e comparar os dados antes e posterior a limpeza. Os sedimentos coletados foram armazenados em sacos plásticos e enviados ao laboratório da ECOAR Monitoramento Ambiental para pesagem, além de análises granulométricas e mineralógicas.

A Figura 04 demonstra o processo de limpeza da cavidade, ilustrando as etapas realizadas para a remoção dos particulados das paredes e teto.

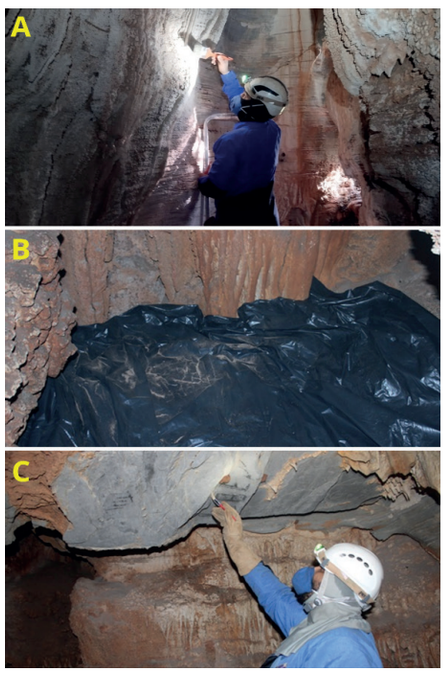

Figura 04: *(A-C): Retirada do material particulado; (B) Armazenamento do material em lona. Fonte: Geodo Meio Ambiente, 2023.*

Após a conclusão do processo de limpeza, observou-se um aumento significativo no número de indivíduos identificados, além de um aumen-

to na diversidade e quantidade de espécies. Especificamente entre os invertebrados, a fauna observada tornou-se mais abundante, com um incremento no número de espécimes registrados.

Após análise química do sedimento coletado, os compostos químicos mais prevalentes foram o CaO (óxido de cálcio, também conhecido como cal virgem), SiO^2 (dióxido de silício, popularmente conhecido como sílica) e Al^2O^3 (óxido de alumínio, principal componente da bauxita). Esses resultados indicam que a composição química do sedimento após a limpeza estava dentro do esperado, uma vez que CaO e SiO^2 são compostos típicos encontrados em cavernas calcárias, fazendo parte de sua composição natural. A presença de Al^2O^3 pode estar relacionada à entrada de partículas do ambiente externo, já que a bauxita é um mineral comum, sendo o principal componente desse óxido. Os demais componentes não apresentaram valores particularmente significativos.

Após a análise granulométrica, observou-se uma distribuição mais concentrada em partículas maiores, o que sugere uma deposição mais rápida. O gráfico de Distribuição de Tamanho de Partículas, apresentado na Figura 05, ilustra essa tendência, mostrando a predominância de partículas de maior tamanho na amostra coletada.

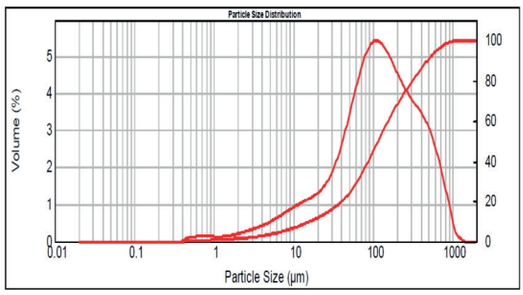

Figura 05: *Gráfico de distribuição "curva granulométrica" de particulados da limpeza da cavidade. Fonte: Geodo Meio Ambiente, 2023.*

4. Discussão

O baixo volume de material particulado encontrado nas cavidades sugere que elas não estão recebendo uma carga excessiva de partículas no momento. Isso pode ser resultado de condições ambientais estáveis, como fluxo de ar controlado, proteção natural ou ausência de fontes próximas de poluição. Fatores sazonais e climáticos também podem influenciar, apontando a necessidade de estudos mais longos para compreender melhor a dinâmica desses depósitos. No entanto, é importante considerar que a metodologia adotada pode ter influenciado os resultados, uma vez que esse tipo de estudo é escasso e a abordagem utilizada ainda carece de maior refinamento e validação em cenários semelhantes.

Na cavidade em questão, observou-se maior acúmulo de material na zona proximal, menor na medial e intermediário na distal, possivelmente devido à sua geomorfologia, com uma entrada pequena e baixa. Duas hipóteses principais foram levantadas para explicar o menor volume na zona medial: (1) a presença de uma claraboia pode ter direcionado o fluxo de ar e partículas para a zona distal, e (2) uma colônia de morcegos na zona distal pode ter contribuído para o maior acúmulo nessa região. Além disso, a vegetação nativa próxima à entrada pode estar atuando como uma barreira natural, reduzindo a entrada de material particulado. Essa hipótese merece investigação futura para avaliar o papel da vegetação na proteção das cavidades.

Em relação à limpeza, os resultados apresentados foram os esperados para este tipo de cavidade, com a remoção eficaz dos particulados das superfícies. Os dados obtidos indicam que os impactos provenientes dos empreendimentos próximos não interferem significativamente na quantidade de material particulado dentro da cavidade, sugerindo que a influência externa na qualidade do ambiente subterrâneo é limitada, pelo menos no que diz respeito aos particulados.

A metodologia adotada, após observação da fauna da cavidade, se mostrou eficaz, pois resultou em um aumento significativo no número de animais. Esse incremento na fauna indica que a limpeza e o monitoramento realizados contribuíram positivamente para a preservação e estímulo à biodiversidade local. No entanto, há a necessidade de mais monitoramentos contínuos e estudos mais aprofundados para avaliar os impactos de longo prazo e garantir a manutenção da saúde do ecossistema subterrâneo.

5. Conclusão

Em conclusão, o estudo realizado na cavidade demonstrou a eficácia da metodologia adotada para a remoção de material particulado e monitoramento da fauna local, resultando em um aumento significativo no número de animais observados. Os resultados indicaram que a cavidade não está recebendo uma carga excessiva de partículas, o que pode ser atribuído a condições ambientais estáveis, como fluxo de ar controlado e proteção natural, além de fatores sazonais e climáticos. No entanto, a escassez de estudos similares e a necessidade de um refinamento nas metodologias utilizadas sugerem que mais monitoramentos e pesquisas são necessários para uma compreensão mais profunda da dinâmica dos depósitos de material particulado e dos impactos ambientais nas cavernas. A continuidade desses estudos será fundamental para garantir a preservação do ecossistema subterrâneo e melhorar as práticas de manejo ambiental em cavernas.

Agradecimentos

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More exotic tufa deposits on the island of Lismore, Argyll, Scotland

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Abstract

Although tufa deposits are uncommon in Scotland, 79 sites with tufa and speleothem deposits were previously reported on the calcareous island of Lismore in Loch Linnhe, Argyllshire. This paper summarises the finding of 76 additional exotic cool freshwater deposits. Mainly these occur beside the raised beach of the Main Rock Platform on the western coast, with a few on the eastern coast and a few inland. The deposits at coastal cliff sites are commonly associated with dykes and with cliff indentations, fissures and short littoral caves. The bulk of surface tufa deposits probably formed in the Holocene, but speleothems within any cave passages that survived the Devensian glaciation could be as old as the MIS5e Eemian Interglacial.

1. Introduction

The 16km-long and 1.6km-wide metalimestone island of Lismore is aligned within Loch Linnhe, a sea loch SW of Fort William in the Grampian Highlands of Scotland, UK, just east of the Great Glen Fault (Figure 1). About 80 sites with surface tufa and cave speleothem deposits were found there and reported by members of the Grampian Speleological Group in June 2018 (FAULKNER & CRAE, 2018; 2022). This work built on a report of speleothems in littoral cave entrances by GRAY & IVANOVICH (1988). During another visit to Lismore in June 2022 (FAULKNER, 2023), another 76 sites with tufa and speleothem deposits were located. The 2022 team included speleologists studying tufa and caves (FAULKNER, 2025) and entomologists studying moths and flies. Such inter-disciplinary collaboration is useful, because tufa is a preferred habitat for caddis, soldier and crane flies, for which caves can also provide a temporary refugium. During the 2022 visit, the locations and photographs of additional tufa exposures were obtained during walks averaging 6km on each of six days. This article summarises the new tufa sites, whilst making some observations in a global context and discussing the possible ages of the tufa and speleothem deposits. For an introduction to the calcareous geology, geomorphology, Quaternary glacial history, karst and hydrogeology of Lismore, and the types of tufa and speleothem found more widely, refer to FAULKNER & CRAE (2018; 2022).

2. The additional tufa sites on Lismore

The 76 additional individual tufa sites found in 2022 were listed by FAULKNER (2023: Tables 2–4), and herein (Table 1) are quantified by type alongside the original 79 found in 2018. Classifications used are based on existing definitions, with some new sub-divisions to accommodate intermediate varieties found on Lismore, which can merge into each other. Morphological tufa Types A, B, G, H and I of the PENTECOST (1995) classification remain unobserved on Lismore. Altitude ranges for the bases of all the various recorded types are little-changed from those reported by FAULKNER & CRAE (2018; 2022), with none for coastal tufa being higher than 25m above sea level (asl). Table 1 shows that the known tufa sites predominate on the western coast (117) rather than on the eastern coast (26) or inland (12).

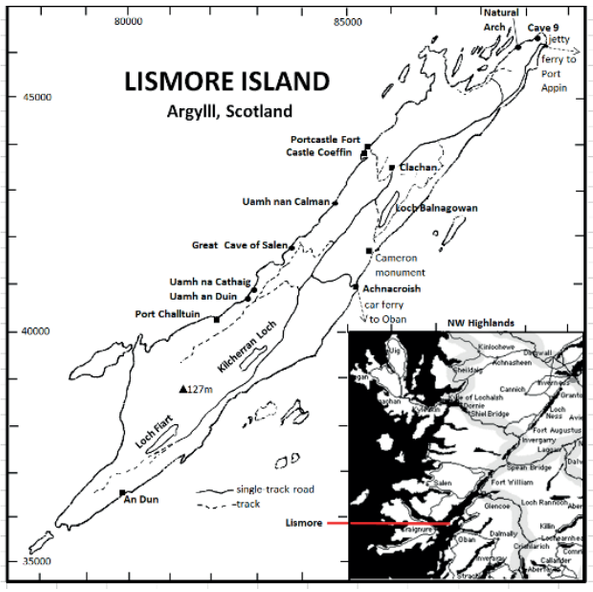

Figure 1: *Location of Lismore Island, showing selected place names.*

	Names	Notes	References CHAFETZ & FOLK (1984) PENTECOST (1995) PEDLEY et al. (2003)	2018 No.	2022 No.	Base alt. range m asl
A	Perched springline; Spring mound	Instantaneous precipitation at spring orifices. They are fan shaped in plan, cone- or wedge-shaped downwards in profile, and can contain mounds.	PEDLEY (1990).	0 0 0	0 0 0	
A1	Thin cliff deposit	A thin calcitic crust on a near-vertical coastal cliff. Assumed active by its bright white colour and to be formed by evaporation of sea spray. Can also form on non-karstic rocks. Not white lichen, which also grows on marble.	FAULKNER & CRAE (2018) STUBBS et al. (2024)	9 0 0	15 1 0	10–25 8
A2	Springline 'speleothem'	Stalactites and stalagmites below overhanging perched springline.	FAULKNER & CRAE (2018)	0 1 0	1 0 0	4 4
A3	Cliff 'speleothem'	Stalactites, stalagmites, flowstones and pillars just outside a cave entrance or in cliff indentations / undercuts / overhangs.	FAULKNER & CRAE (2018) TABOROSI et al. (2006) discussed stalactitic tufa on tropical cliffs.	34 5 0	2 0 0	3–25 11–25
C	Cascade; Screen	On steep (>10°) slopes and waterfalls. They are fast-forming and can overhang to produce caves , some with tufa stalactites and stalagmites.	FORD (1989) PENTECOST (1993)	2 7 0	12 1 2	0–25 0–9 32–33
D	Non-tidal dam; Barrage; Terraced mound; Pool	Full-width rimstone dams / crests / curtains, which can be buttressed and vegetated, to create upstream pools. [c.f. cave gours]	PENTECOST (1981) PEDLEY (1987) PEDLEY (1993)	0 0 1	0 0 0	 30
D1	Tidal dam	Small tufaceous dams just above sea level, fed by small springs. Commonly coloured green by vegetation	FAULKNER & CRAE (2018)	2 1 0	12 1 0	0–8 0–3
E	Fluviatile crust	Cream or brown sheet deposits and terraces in low gradient stream channels; can contain 1–5cm diameter oncoids.	PEDLEY (1990)	1 3 3	14 2 3	0–10 0–10 10–50
F	Lacustrine crust; Krustenstein: 5mm layer	Around broad shallow lake margins, perhaps with oncoids (grains coated with carbonate and microbial mats).	PENTECOST (1981) PEDLEY (1990)	0 0 1	0 0 2	 20–28
S	Internal cave speleothem	Stalactites, stalagmites, flowstones and pillars in or near the daylight zone of a cave.	FAULKNER & CRAE (2018). See also FORD & PEDLEY (1996).	8 1 0	3 1 0	1–25 10–15
	Not identified			0 0 0	2 2 0	0–10 10–13
	Totals	Western coast Eastern coast Inland		56 18 5	61 8 7	0–25 4–25 20–50
	Grand totals			**79**	**76**	**0–50**

Table 1: *Morphological types of calcareous deposits recorded on Lismore by FAULKNER & CRAE (2018) and FAULKNER (2023). The numbers of sites given are in the order: western coast, eastern coast, inland.*

Type A1 thin cliff deposits occur almost uniquely on the western coast; 15 additional sites were found, with bases ≥10m asl, where the cliffs meet the inclined raised beaches (Figure 2). A solitary example from a narrow ravine is now reported on the eastern coast. These are assumed to be formed by evaporation of sea spray, as occurs on non-carbonate rocks farther NW in Scotland (Stubbs et al., 2024). A second series of Type A2 springline 'speleothems' was observed on the western coast, just above the sea, creating tiny constructional 'caves' (Figure 3). It looks similar to the original example on the eastern coast (FAULKNER & CRAE, 2022: Fig. 4). Two more Type A3 cliff 'speleothems' that occur at various altitudes are located on the western coast. Figures 4 and 5 illustrate examples previously recorded by FAULKNER & CRAE (2018). SHTOBER-ZISU et al. (2015) discussed long inland notches at high altitudes in Israel, some containing tufa or speleothems that resemble Lismore Types A1 and A3.

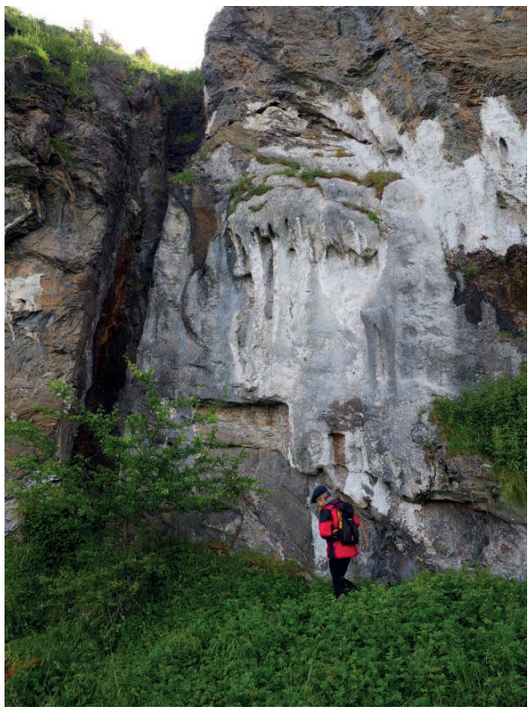

Figure 2: *Type A1 cliff tufa on both sides of an eroded dyke. Photo by Alan Marshall.*

Figure 3: *Type A2 tufa flowstones near Port nan Gallan, 4m above the sea. Photo by Alan Marshall.*

Figure 4: *Type A3 tufa columns within Uamh an Duin. Photo by Alan Marshall.*

Figure 5: *Type A3 massive tufa column outside Tufa Column Cave. Photo by Trevor Faulkner.*

Twelve additional Type C cascade deposits were reported on the western coast (Figures 6 and 7) and one more on the eastern coast. Two are now known inland; one is quite small, whereas the other, on the west side of Loch Balnagowan, is substantial and covered by moss. No extra Type D non-tidal dams were recorded. However, 12 extra Type D1 vegetated tidal dams were observed on the western coast (Figure 8), and one on the eastern coast. These remarkable dams resemble the previous example seen on the eastern coast (FAULKNER & CRAE, 2022: Fig. 9). Fourteen extra Type E fluviatile crust deposits were reported on the western coast (Figure 9), with two more on the eastern coast and three inland. It was observed that the association of vegetation with Types C, D1 and E tended to cause the tufa colours to change from brown to yellow to green as the sea was approached. Tufa within the tidal range commonly provides a habitat for ***Ulva lactuca*** (sea lettuce) and ***Fucus vesiculosus*** (bladder wrack seaweed).

Figure 6: *Type C narrow vegetated tufa cascade. Photo by Alan Marshall .*

Figure 7: *Type C yellow-green tufa cascade above a pool near sea level. Photo by Trevor Faulkner.*

Figure 8: *Three tiers of Type D1 green gour pools. Photo by Alan Marshall.*

Possible Type F lacustrine crusts occur inland in Loch Fiart, from observed possible calcite rafts (Figure 10). Coring in an isolation basin NE of Loch Balnagowan provided evidence of 18m of CaCO3 sediment accumulation in fully marine conditions for a time after deglaciation at the start of the Lateglacial at 14.7ka BP (MATTHEWS et al., 2021). Because such crusts were previously reported in Kilcheran Loch, this shows that all three large freshwater lochs on Lismore are commonly super-saturated with calcite. This suggests that they have low flow rates, with little underground drainage. Indeed, there are no reports that they demonstrate turlough behaviour, by draining away in dry weather. Three more Type S internal cave speleothems were reported on the western coast (Figure 11) and one on the eastern coast (Figure 12). Open-air examples of a deposit of calcite pearls and of a spread of hundreds of oncoids were also reported by FAULKNER & CRAE (2018). Two more inland sites with oncoids were listed by FAULKNER (2023: Table 4).

Figure 9: *Type E yellow-green fluviatile tufa on coastal slope to sea level. Photo by Alan Marshall.*

Figure 10: *Inland Type F possible calcite deposit in the east side of Loch Fiart. Photo by Noel Williams.*

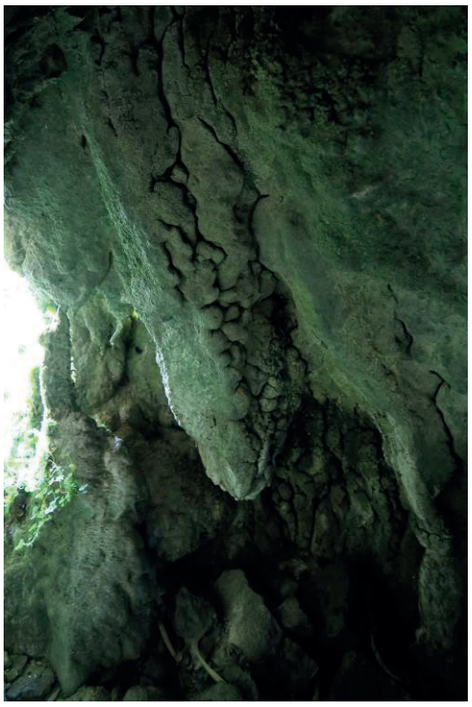

Figure 11: *Type S large coralloid stalactite in the John's Cave daylight zone. Photo by Noel Williams.*

Figure 12: *Type S flowstone column in the entrance to Uamh Dhun Fraoin. Photo by Derek Whiteley.*

3. Discussion

FAULKNER & CRAE (2018) showed that many coastal tufa deposits on Lismore are commonly associated with littoral caves and indentations in the cliffs above the raised beaches or with one of the many vertical igneous dykes that intrude the metacarbonate outcrop orthogonally. This report confirms those findings and that tufa deposits predominate on the western coast rather than on the more sheltered eastern coast or inland. This might be explained if moist westerly winds, charged with dissolved calcium carbonate from calcite-saturated sea water, supplement the tufa-forming processes by evaporating on the western cliffs, especially as Type A1, as suggested occurs in NW Scotland (STUBBS et al., 2024). Evidence of calcite deposition by evaporation rather than by CO2 degassing is provided by the large, 1m-long, coralloid stalactite with popcorn morphology in John's Cave (Figure 11). Most calcite deposits on Lismore are regarded as soft, non-thermal, biologically-assisted, tufa. Increased understanding of the geobiological controls in the formation of tufa and some speleothems was provided in the book edited by PEDLEY & ROGERSON (2010). According to MARTIN-PEREZ (2020), tufa and most speleothems, which commonly form in layers, can be distinguished from moonmilk, which is fibrous, although also biologically-assisted. Although the occurrence of tufa on coastal sedimentary limestone outcrops might be more common globally, it had only rarely been reported, according to FORD & PEDLEY (1996). However, it is apparently also common on the low-lying grassy coasts of the Outer Hebrides of Scotland, presumably associated with Lewisian marbles (FAULKNER, 2023), and on tropical islands (TABOROSI et al., 2006). The need for an integrated terminology for tufa on rocky coasts was reviewed by GARNER et al. (2024).

The rates at which tufa grows on Lismore remain unknown. However, rates are potentially much faster than for underground speleothems, considering that MARIC et al. (2020) measured mean rates >5mm/year in Croatia, with rates up to 19mm/year in turbulent water near mosses. That result agreed with PEDLEY & ROGERSON (2010), that tufa precipitation is greatest in fast flows from high, presumably calcite-saturated, water tables. RICKETTS et al. (2019) also reported from a global study that tufa ages peak during the wetter climates of deglaciations and interglacials. DABKOWSKI (2020) and DABKOWSKI & BEAUMONT (2024) reviewed the evidence for a 'late Holocene tufa decline' in a study of European sites. They concluded that fluvial tufas declined from c. 5ka BP, probably caused by human deforestation. However, no significant trend was observed in the number of lacustrine and spring tufas.

4. Conclusions

Known sites of tufa deposits on Lismore now number 155, after perhaps 45% of the coastline has been investigated, mainly along the Main Rock Platform at c. 10m asl. There has been little systematic study on the higher raised beaches or inland. Visits to otherwise inaccessible littoral caves and tufa deposits in the present tidal range by canoe and kayak have only just started. It is therefore clear that there are probably several hundred tufa deposits of various types on Lismore, making this island quite exceptional in the British Isles and perhaps more widely. Because the coastal cliffs and inland landscape were glacially eroded at the Last Glacial Maximum, all surface tufa must be younger than the c. 14.7ka age of Lismore deglaciation. It seems possible that tufa could have formed during the warm Lateglacial Interstadial from 14.7–12.9ka BP, but less likely that it would have survived the harsh periglacial conditions of the Younger Dryas Stadial from 12.9–11.7ka BP. Thus, it seems probable that the bulk of the surface tufa on Lismore has developed during the Holocene, as proposed by GRAY & IVANOVICH (1988). However, underground speleothems in littoral caves could be older, and perhaps of MIS5e age, if their host passages survived glaciation, as suggested applied in some caves by FAULKNER & CRAE (2018) and FAULKNER (2025).

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New frontiers in speleothems studies

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Abstract

At the end of the last millennium, it was commonly believed that the achieved knowledge on the genesis and development of speleothems was optimal, at least at theoretical level.

The speleothem shape was simply referred to the type of water flowing over them. Therefore, they were often theoretically represented as perfect solids: the stalactites as inverted cones, the soda straws as cylinders and so on.

However, any caver can confirm that this vision is simplistic, since it overlooked many factors, which, although theoretically secondary (like feeding regimen, flow speed, crystallization processes, etc.) may often become fundamental in shaping the different speleothems.

Another often overlooked aspect was the role played by the substrate, especially when it was plastic or porous and, consequently, progressively changed not only its hydrodynamic and/or mechanical characteristics but also its chemistry

Finally, in recent years, the role that living organisms play in the development of peculiar forms of a speleothem and/or in the minerogenetic mechanisms has been increasingly highlighted.

These few examples make evident that the study of speleothems is in reality still far from being exhaustive and therefore the future will hold great satisfaction for those who wish to dedicate themselves to this important field of investigation.

1. Introduction

In 1997, when the volume Cave Minerals of the World was printed (HILL & FORTI, 1997), regarded until now as the fundamental text in this field for almost 30 years, it was believed that the knowledge achieved was optimal and that very little could change in the future, at least in theoretical level. The following 25 years, however, have shown that this belief was decidedly wrong: in fact, from then to today, many things have changed in the world of cave formations and cave minerals. In fact, at that time it was believed that the speleothem morphology was practically only the result of the type of flow of water flowing over them. Therefore, perfect solids may, at least theoretically, represented all of them (Fig. 1): stalactites as inverted cones, soda straws as cylinders like stalagmites, which however also had a convex top, cave pearls were spheres, while the flowstones and shelfstones were respectively horizontal or vertical planar surfaces. However, in reality, any person who has frequented the cave environment can confirm that this vision was simplistic, since it overlooked many factors, which, although theoretically secondary, in practice often meant that the various cave formations exhibit very different shapes from the one predicted theoretically. The assumption of stationary homogeneous flow conditions were at the base of these models, but most of the real speleothems evidence complex morphological patterns developed in unsteady and/or heterogeneous flow conditions: therefore, most of these forms, still are unexplained from the genetic point of view.

Exemplary cases of this behavior are those of the ribbed drapery in the Puerto Princesa Underground River (BADINO et al, 2016) or the squared stalactites in the Dry Cave (USA), (FORTI & SPRINGER, 2020).

Figure 1: *Simple solids commonly used to describe the shape of the main speleothem's types.*

In the last decade, a few speleothems were specifically analyzed and studied in detail (BADINO et al. 2019, CALAFORRA & FORTI 2019, COLUMBU et al. 2022). Thus, some different mechanisms, that time by time may supervise the development of the different speleothem's types where understood.

By sure, the speleothem that, at least actually, shows the greatest morphological variability is the flowstone, which can even present very different shapes within a single speleothem (Fig. 2).

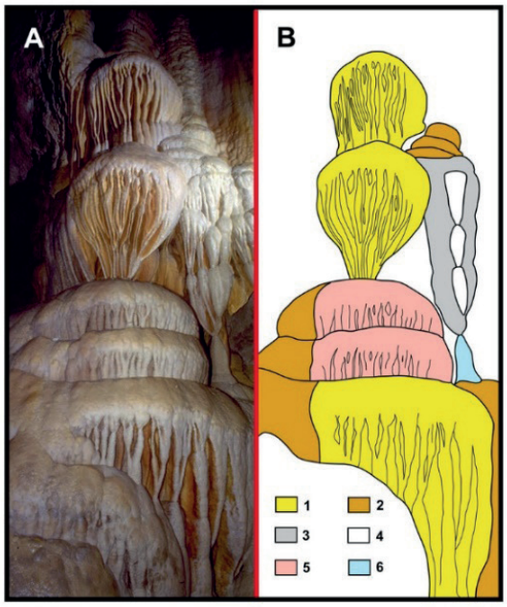

Figure 2: *Re Tiberio gypsum cave (Italy): a big complex flowstone with very different shapes within a single speleothem (Photo by Carlo Azzali); B: graphic restitution of its principal characteristics: 1: "octopus"; 2: big steps; 3: upside-down conical drapery; 4: sequence of upside-down cones; 5: "organ pipes"; 6: stalagmite (after BADINO et al. 2017).*

In the absence of evaporation, two are the main parameters that control the flowstone's shape: 1) the feeding water's flow rate and 2) the steepness of the substrate on which they develop.

Low flow speed (laminar flow), planar flowstones normally develop regardless of the steepness of the rocky substrate, while in presence of a higher speed (turbulent flow) the shape of the flowstone can range from basins of various shapes and sizes to ribbed flowstones.

But, if unsteady and or heterogeneous flow conditions occurs many other parameters (as degassing ratio, energy

For instance: with a steepness between 30 and 70°, a very low supersauration together with a feeding water characterized by sudden and violent impulses, but which do not involve the transition to turbulent motion, regular waved flowstones can develop (COLUMBU et al 2022).

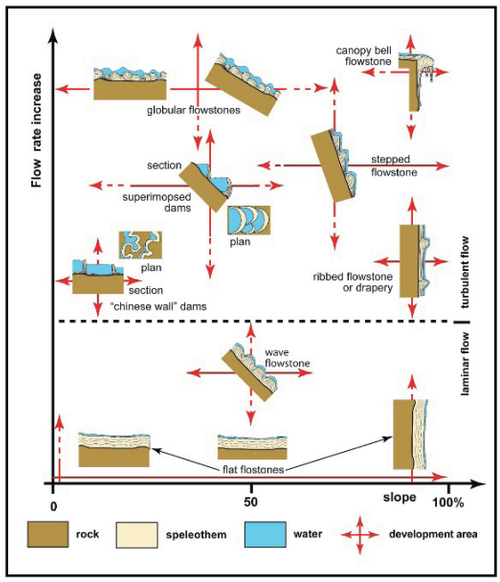

Figure 3: *Sketch summarizing the different actually known flowstone's shapes as a function of the feeding water, flow rate and the substrate steepness.*

2. The role of substratum

Another partially overlooked aspect was the role played by the substrate, especially when it was plastic and could be shaped over time or porous and, consequently, progressively changed its hydrodynamic and/or mineralogical characteristics.

Until the end of the second millennium, in fact, the conulites, the Coral Pipes and the so called septaria - in reality a peculiar subtype of boxwork (HILL & FORTI 1997) - were unique speleothems whose shape was evidently conditioned by the presence of a very particular substrate (HILL & FORTI 1997). Of these three, however, only the Coral Pipes were actually the only one in which the substrate contributed in a fundamental way to the formation of its growing layers.

Only very recently, after it became evident that many other factors could be important in influencing the development of speleothems, a greater attention was given to what could happen on soft and/or inconsistent substrates.

Consequently, some complex speleothems have been discovered and described, in which the deposition of calcium carbonate did not occur uniformly over an unaffected substrate, but the latter contributed - sometimes in a preponderant way - to the final composition and shape of the speleothem that was developing (FORTI et al. 2022).

The first of these complex speleothems (DE WAELE & FORTI 2020) was observed in a Philippine cave: it consists of the coalescence of small basins (created by dripping over the mud during the wet periods) grouped in such a way as to closely resemble the cells of a beehive, and therefore called «honeycomb pavement» (Fig. 4). The presence of a few centimeters thick layer of mud, progressively and partially washed away during the flood periods and renewed at the end of the same, then solidifying during the long dry intervals induced the development. The walls of each cells consist of thin superimposed layers of calcite which on turn trap inside their structure a high amount of the original mud.

A few years later, two other speleothems were observed in which the mud of the substratum was fundamental for their development: the Cave Mussels of the Lacca della Seggiovia in Liguria (Fig. 5A) and the «septaria» of the del'INpero Cave in Veneto (Fig. 5B).

Figure 4: *The honeycomb pavement of the Puerto Princesa Underground River (Philippines) (Photo by Vittorio Crobu, La Venta Exploring Team).*

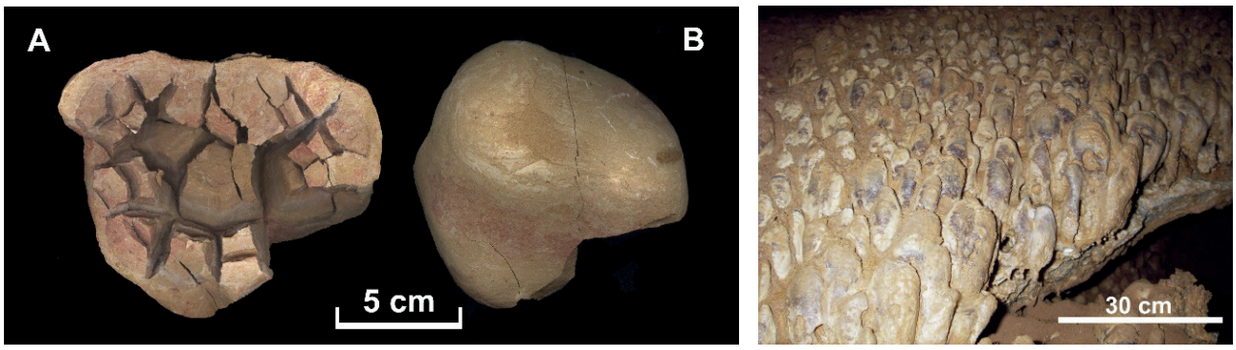

Figure 5: On the left: Partial view of the "Cave Mussels colony"; on the right one of the septaria recovered and opened to highlight its internal structure characterized by various septa separated by large contraction fractures (A). Inside them practically no other mineral has been deposited, while the external part is smooth and globular (B) (After Rossi et al. 2024).

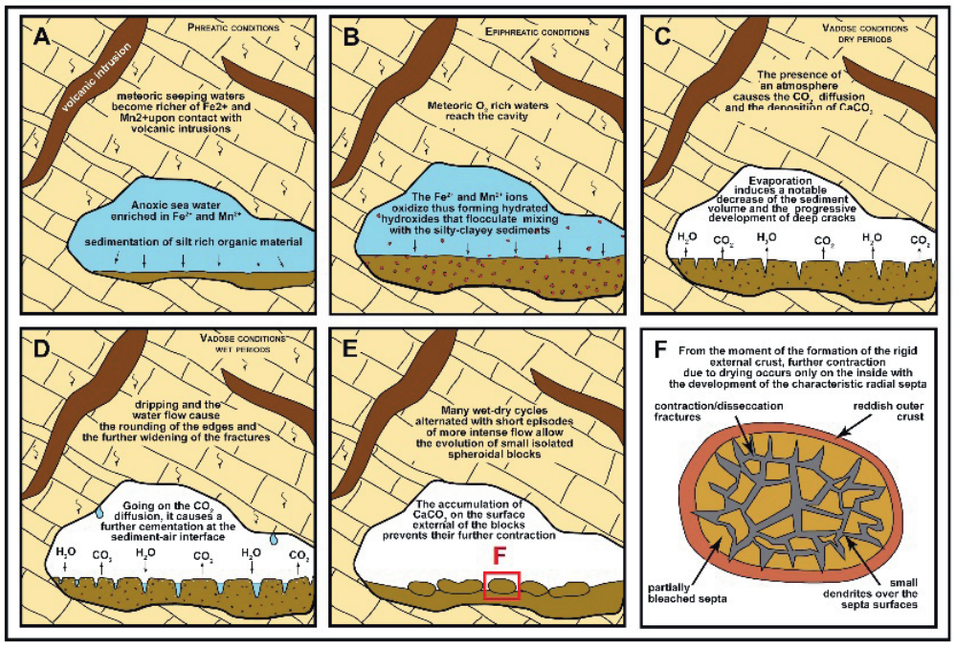

Figure 6: Sketch of the main steps, which characterized the development of the septaria within the INpero cave (After Rossi et al. 2022 modified).

The morphological and genetic study of the «Mussels» (De Waele et al. 2024) has made it possible to demonstrate that they are actually real speleothems that develop in a similar way to the coral pipes (Hill & Forti 1997).

But their development was much more complex, being controlled not only by the local hydrodynamics, which cyclically varies from turbulent flow to dripping to capillary uplift, but also by the lithology of the host rock, its structural setting and calcite recrystallization processes with the consequent segregation of mineral impurities.

The septaria, however, turned out to be a completely new type of speleothem, completely different from the one described by Hill & Forti (1997), which was actually a subtype of boxwork.

This is the very first discovery of real septaria developed inside the sediment of a cave. Their growth totally occurred within this cavity and their genetic mechanism differs substantially from that commonly accepted for normal septaria (Fig. 6, previous page)

Their genesis certainly took a very long time and was controlled by the surrounding conditions on fact they varied over time, going from submersion in marine waters to epiphreatic marine conditions and then becoming, at least in some periods, vadose in a continental conte

3. The role of living organisms

In recent years the role that living organisms play in the development of peculiar forms of a speleothem has been increasingly highlighted. A theory that was very popular in the 18th century - when cave formations were supposed to be real «stony plants»- had been soon completely discarded at the beginning of the 19th and only from the last two decades of the last century it was, at least partially reconsidered. Anyway, at the end of second millennium (Hill & Forti 1997) the role played by biogenic reactions in shaping cave speleothems was still underestimated. In fact, the biological interference was normally referred as a passive action: it was normal to believe that living organisms (mainly roots) gave just a preferential surface for the deposition of calcite to form rootsicles. In reality, today we know that in some cases even roots can play an active, and not just passive, role in the development of very peculiar calcite speleothems, as in the case of the Hairy Stalagmites (Fig. 7 left) discovered in a cave in Botswana (DU PREEZ G. et al. 2015).

Some first examples of direct biochemical control on speleothem

development start to be referred in the last decade of 1900 century, just in the Grave Grubbo gypsum cave (Forti & Lombardo 1998) were breathing activity of some larvae of a troglophile insect (Trichoptera wormaldia) induced the deposition of a thick calcite flowstone (Fig. 7 right).

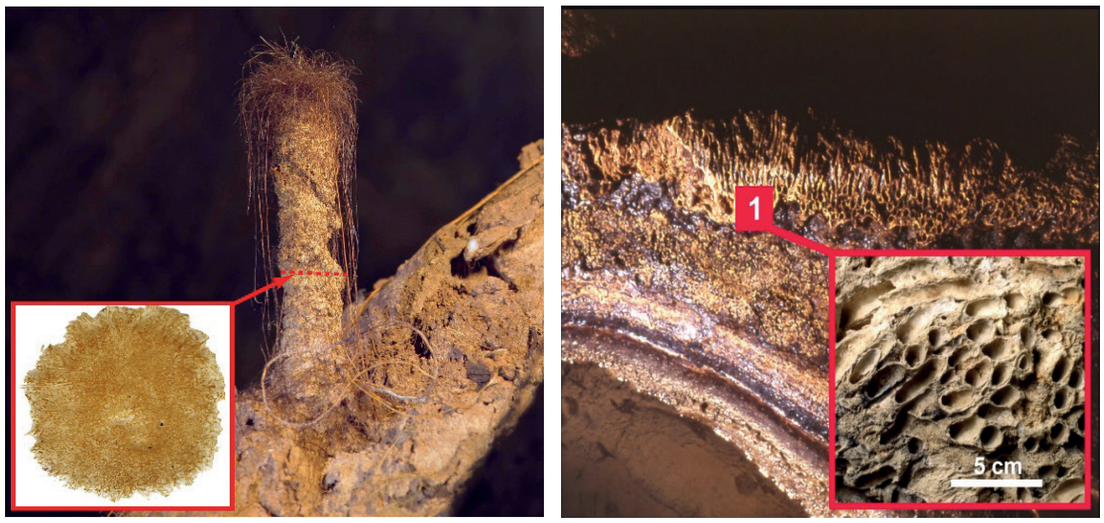

Figure 7: *On the left: roots associated with an active Hairy Stalagmite. The roots create a nest at the top of the speleothem which captures the water from the drip (Photo by Anton Jacobs), while the body of the stalagmite consist of calcite tubes grown over the roots. On the right: the calcite flowstone of the Grave Grubbo cave (Calabria) consisting of a network of equidimensional tubes the genesis of which was induced by the breathing activities of the larvae of a troglophiles insect Tricoptera vormaldia. When the calcite layer became too thick, the larvae had no more possibility to breathe and abandoned the tube, which stop its development; 1- particular to highlight the tube structures inside the flowstone. (After Calaforra & Forti 2021).*

More recently, it was then demonstrated that the oxidation of Fe^{2+} and Mn^{2+} ions - and therefore also their deposition in caves in the form of more or less hydrated oxides/hydroxides - was always a process triggered by specific microorganisms and therefore all iron and/or manganese speleothems in whatever cave they were formed are biogenic deposits (Kotula et al. 2019).

Nowadays the idea that living organism play a fundamental role in speleothem's formation is starting to gain ground and a good part of speleothems could have developed only thanks to biogenic mechanisms. Moreover, in some extreme cases, it is even incorrect, from a genetic point of view, to consider them cave formations.

It is the case of the famous stromatolites of the Jenolan Cave in Australia (Fig. 8 left or the iron and manganese helictites of the Zoloushka gypsum cave in Ukraine (Fig. 8 right), because they should instead be genetically defined as true fossils (Calaforra & Forti 2021).

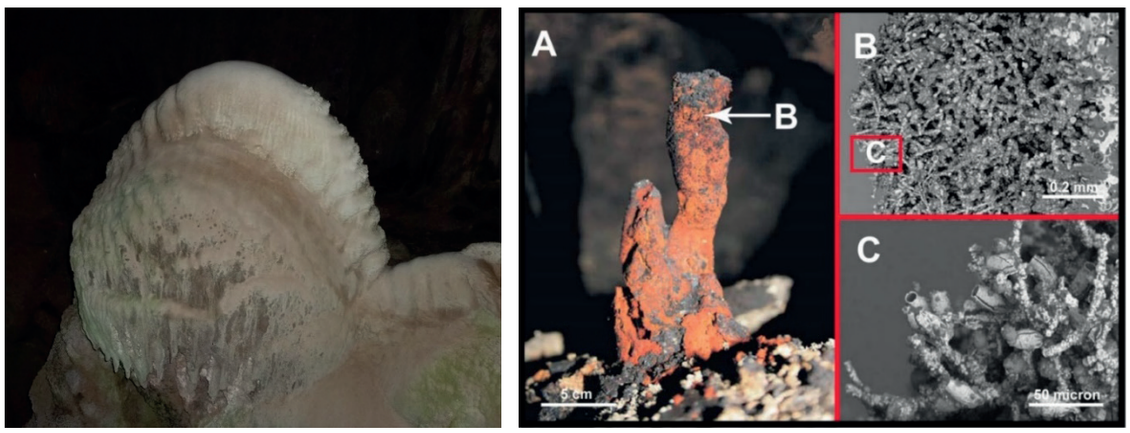

Figure 8: *On the left: one of the giant stromatolitic formations inside the Jenonan Caves in Australia (Photo by Paolo Forti). On the right: Zoloushka Cave, Ukraine: A) pseudo-stalagmite totally formed by iron oxides grown on a colony of fungiform bacteria (Photo: Viacheslav Andreytchouk); B) electron microscope image of a cross section of the pseudo-stalagmite which highlights its totally biogenic structure; C) enlargement of B to highlight the biological structures fossilized by iron oxides (After CALAFORRA & FORTI 2021).*

Finally, during the last few couples of years the great development of speleological explorations performed in caves developed in rocks different from limestone and gypsum ones made it possible to observe speleothems totally developed thanks to biogenic processes. In particular, this is true for the giant opal formations recently discovered and studied within the quartzite caves of the Tepui in Venezuela and Brazil (Fig. 9). In fact, the study of those, often giant, opal speleothems evidenced that always the process of their deposition is to be referred to biogenic processes controlled by specific microorganisms (SAURO & CAPPELLETTI 2023).

Figure 9: *Big globular opal stromatolitic formations inside the quartzite cave of Imawari Yeuta in Venezuela (Photo by Vittorio Crobu, La Venta exploring team).*

4. Conclusion

The few examples shortly described above make evident that the study of speleothems is still far from being exhaustive. Moreover, papers recently printed on speleothems, whose genesis is controlled by many different factors, will make it necessary to revisit this problem in depth. In fact it will be necessary to address any genetical problem with a multi-disciplinary approach that takes into account not only all the possible inorganic environmental parameters (geological, mineralogical, hydrogeological and climatological).

Moreover -and perhaps above all - it will be fundamental to consider the real contributions offered by microbiological

ecosystems, which influence the evolution of many, if not the totality, of cave formations.

At the same time, it will be very important that all those who, for pleasure or study, frequent the environment of natural cavities carefully consider the presence of peculiar or otherwise strange speleothems that can be seen during their explorations. There is the possibility, which we now know is not remote, that these speleothems will result new for science (Fig. 10).

Figure 10: *Pozzalagua cave (Spain) a macrocrystalline calcite speleothem (Photo Jabier Less) with a peculiar crystal orientation, the evolution of which is still under study (Photo by Jabier Les).*

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The taranakite – francoanellite dehydration reaction: new data and possible implications for minerogenetic processes in cave environments

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Abstract

Taranakite ($K_3Al_5(PO_3OH)_6(PO_4)_2 \cdot 18H_2O$, *trigonal*, *R3C*) is a hydrated phosphate occurring in caves as a reaction product between bat guano and detrital silicates. Its presence has been documented widely throughout the world (HILL & FORTI, 1997). Previous experimental work has determined its high sensitivity to temperature change, which can lead to the loss of part of its structural water and the formation of the lower hydrate form francoanellite. The latter has also been proven to form in nature by BALENZANO et al. (1976), transforming taranakite into francoanellite ($K_3Al_5(PO_3OH)_6(PO_4)_2 \cdot 12H_2O$, *trigonal*, *R3C*). The name derives from Franco Anelli, former Italian karstologist and discoverer of the Castellana Caves (Apulia, Italy), where the first occurrence of the mineral was documented. With this contribution, we present a new occurrence of taranakite from the Pollera Cave (Liguria, Italy) and new experimental data regarding its thermally induced dehydration and consequent formation of francoanellite. Hence, we discuss a possible genetic mechanism for this rare and seldom investigated cave mineral both in natural (wild) caves and in show caves (such as in Castellana Cave, where the mineral was first discovered).

1. Introduction

The generally simple chemical systems which characterize the majority of known karst hypogean environments can be greatly complicated by the introduction of bat guano. Bat guano is very rich in P, S and N, which are released in the fluids and gases liberated by the degradation of organic matter driven by microbial activity. This triggers intense variations in the physico-chemical conditions of guano-influenced environments, such as pH values as low as 3, increase in CO2 partial pressure and increase in temperature. Therefore, the presence of bats and of their metabolic products leads to the onset of biocorrosion processes (DANDURAND et al., 2019) and to the formation of a rich variety of phosphate and sulphate minerals (HILL & FORTI, 1997; AUDRA et al., 2019).

The mineral assemblage is influenced by the nature of the material interacting with guano-derived fluids; where detrital or paragenetic siliciclastic deposits are involved, K-Al-Fe hydrated phosphates are the most common reaction products. In this context, taranakite is one of the most commonly observed phases and can form powdery surface aggregates, nodules and veinlets crosscutting sediments admixed with guano. On the other hand, the occurrence of francoanellite has been reported from a very limited number of sites (BALENZANO et al., 1976, 1979; CANCIAN, 1985; CHIORBOLI, 1985; DELL'ANNA et al., 1989; ONAC & VEREŞ, 2003).

The first to observe that the prolonged exposure of taranakite to a temperature of 95°C led to its degradation and the formation of a lower hydrate, characterized by a strong X-ray diffraction line at 13.8 Å, were SMITH & BROWN (1959). Further work was directed at studying the thermal behaviour of taranakite using thermogravimetric analysis and X-ray diffraction on the quench products after prolonged heating (ARLIDGE et al., 1963; SAKAE & SUDO, 1975; FIORE & LAVIANO, 1991).

It was only at the end of last century that DICK et al. (1997) and DICK & ZEISKE (1998) conducted single crystal X-ray diffraction and neutron powder scattering analyses on taranakite and francoanellite to solve their crystal structures.

2. Site description

The taranakite samples used for this study were collected in the Pollera Cave (Liguria, Italy). The cavity is hosted in the Pietra di Finale Fm. (Miocene), and actively controls part of the water runoff in the area with a subsurface stream (Rio Montesordo) which comes to light at the Arma del Buio resurgence and forming a tributary to the Aquila Stream (Figure 1). It is also a site of significant archaeological interest, due to the discovery of a plethora of artifacts attributed to the Bronze Age (DEL LUCCHESE & STARNINI, 2013) and of skeletal remains dated to the Neolithic, which were object of palaeopathological investigations (SPARACELLO et al., 2017). In its overall extension of more than 2 km, the cave also includes fossil passages characterized by collapse deposits and morphologies. One of the collapse rooms (Saloni Bensa) hosts a subfossil guano deposit, whose degradation has generated a varied phosphate-sulphate assemblage, which was the object of this study.

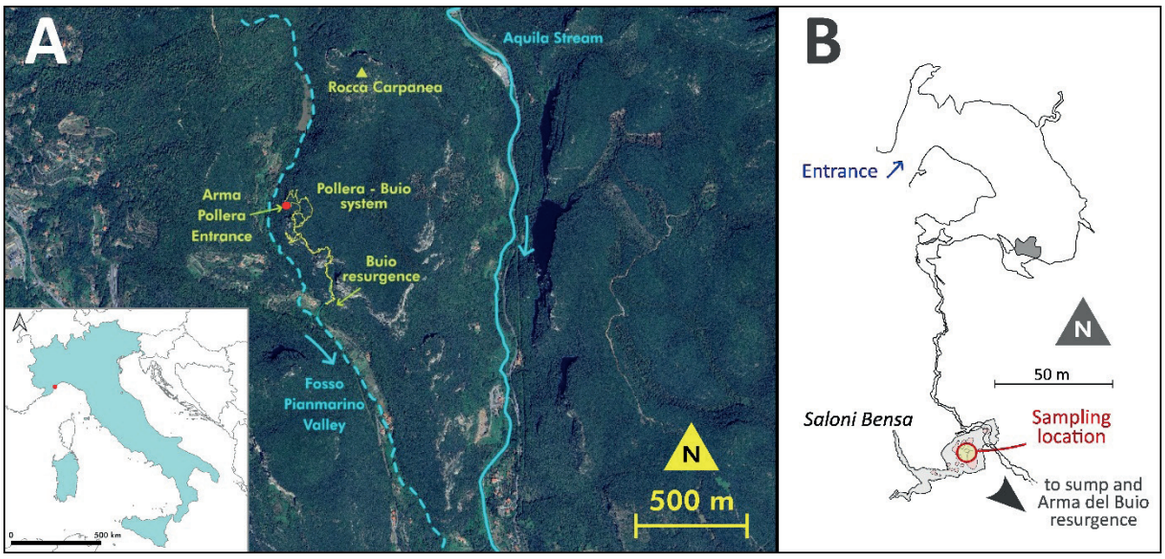

Figure 1: (A) Location of the Pollera Cave on Google Earth imagery. The yellow lines show the plain view of the Pollera – Buio system survey, acquired from the regional speleological database and developed by the members of Progetto Carpeneam. The inset shows the location of the cave in Italy. (B) Simplified map of the Pollera Cave, with the sampling location highlighted by a red circle.

3. Methods

Sampling for mineralogical investigation was conducted while trying to respect cave conservation criteria; it did not involve complex speleothems but was limited to rock surfaces and loose aggregates. Samples for mineral identification were collected in small quantities (~ 5 mg) and stored in Eppendorf - type flasks and in sealed plastic bags, to preserve the natural state of humidity until the day of examination.

The taranakite sample was checked for purity under a stereoscopic microscope and lightly ground in an agate mortar. After a preliminary analysis at ambient conditions, the powder was then subdivided into 5 aliquots and heated at different temperatures for different periods of time, cooled to room temperature and subjected to X-ray diffraction analysis.

Powder X-ray diffraction (PXRD) measurements were performed at the Department of Earth, Environmental and Life sciences of the University of Genoa. Data collection was carried out using a Philips PW 3710 diffractometer equipped with a Co anode and a point detector at 40 KV and 20 mA, using 0-background Si-crystal sample holders, in the angular range 3-40 °2θ, with a step size of 0.02 °2θ and a scan time per step of 1 s; PXRD data interpretation was carried out with X'pert High Score and Profex. Thermogravimetric – Differential Thermal Analysis (TG-DTA) was performed at the Department of Chemistry and Industrial Chemistry of the University of Genoa using a LabsysEvo 1600–Setaram. The sample (untreated taranakite) was placed in a closed alumina crucible and heated in a dry atmosphere (60 mL min–1) from 30°C to 250°C, with a heating rate of 10°C/min.

4. Results and Discussion

During preliminary investigations, combined PXRD, SEM-EDS, Raman and FTIR analyses confirmed that (i) apatite, ardealite, brushite and gypsum constitute the reaction products on top of the surfaces of collapsed limestone blocks while (ii) taranakite and leucophosphite have formed at the contact between guano and a ***terra rossa*** deposit (Figure 2). Here, taranakite appears as white powdery nodules and veins that cut through the clay deposit, while leucophosphite forms purplish-brown crusts and botryoidal aggregates.

The results of thermogravimetric analysis on taranakite (displayed in Figure 3), in line with previous work (e.g., FIORE & LAVIANO, 1991; MARINCEA & DUMITRAŞ, 2003) demonstrated that, at a heating rate of 10°C/min, the mass loss starts at T ≈ 95°C. The weight of the sample shows a steady decrease up to about 160°C, where an inflection in the TG curve suggests that pretty much all of the taranakite has now dehydrated to form francoanellite.

Figure 2: The subfossil guano deposit and associated mineralisation. The surfaces of collapsed limestone blocks are altered in a Ca-phosphate assemblage; in the position marked by the yellow arrow, the terra rossa deposit is evidently transformed into a K-Al-Fe phosphate assemblage.

The mass loss of 7.38 % is close to the 8.05% expected for the loss of ~ 6 H2O molecules from the theoretical formula of taranakite. This corresponds to the loss of interlayer water from the structure. The relative DTA endothermic peak is centred at ~ 152°C. The next dehydration step observed in the inspected T range, marked by the endothermic peak in the DTA curve at ~ 187°C, is due to the complete loss of structural water and amorphization of the material, which is completed at T > 250°C.

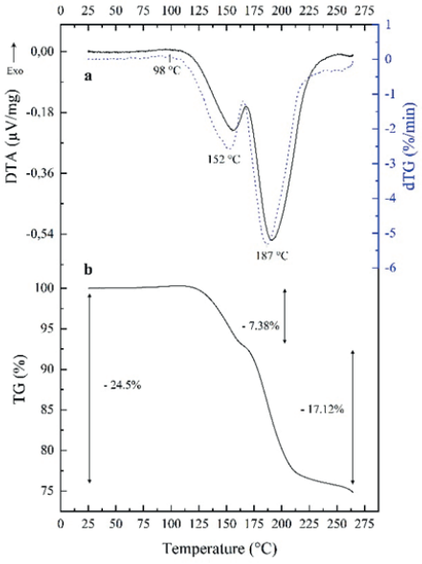

Figure 3: *Results of the thermogravimetric analysis conducted on the Pollera Cave taranakite. In the upper part of the graph (a), differential thermal analysis (DTA – black solid line) and the first derivative of the thermogravimetric curve (dTG – blue dotted line) are reported. In the lower part of the graph (b), the thermogravimetric curve (TG) is reported.*

However, heating taranakite ex-situ in isothermal conditions using a static oven results in quite different temperatures for the onset of the dehydration. As can be seen in Figure 4, signs of taranakite degradation and consequent formation of francoanellite start to be evident at temperatures as low as 55°C, if this condition is maintained for 68 hours. If taranakite is left at 60°C for 76 hours, francoanellite becomes the predominant phase, and the same result is achieved at 65°C for 65 hours, and at 85°C for as short as 8 hours. It is also worth mentioning that the heating of taranakite in isothermal conditions at temperatures between 55 and 65°C for prolonged periods generates powders with a characteristic diffraction peak at ~ 14.7 Å, about halfway between the distinctive peaks of taranakite (at 15.7 Å) and francoanellite (at 13.8 Å), which hints at the possible presence of a phase with intermediate state of hydration in the sample.

As evidenced in this set of measurements, the temperature for the onset of the taranakite – francoanellite dehydration reaction resulting from thermogravimetric experiments conducted at a constant heating rate, be it moderately high (as in our case) or slow (e.g. FIORE & LAVIANO, 1991), is definitely higher than the one that can be achieved in case of isothermal heating. With the timespans available in normal laboratory settings (i.e., some tens of hours at a time), it was possible to trigger the start of taranakite dehydration at temperatures as low as 55°C.

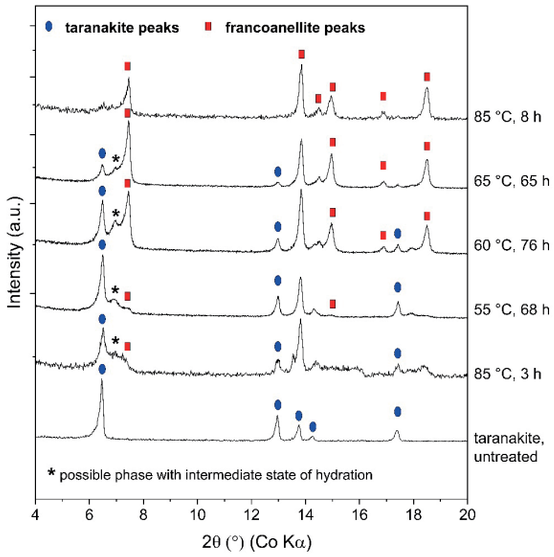

Figure 4: *PXRD data of taranakite treated at different temperatures and for different times; h : hours spent at given temperature. The peaks are assigned after ICDD-00-029-0980 (francoanellite) and ICDD-00-029-0981 (taranakite).*

The question that would naturally arise after observing these data, is whether these conditions are achievable in nature, and if the heating of taranakite could be considered a viable mechanism for the formation of francoanellite in cave environments. It is also important to consider that there is one more condition regarding the maximum temperature, which should not exceed ~ 150°C, so as not to trigger complete dehydration. For this reason, we should discard guano-combustion events (ONAC & FORTI, 2011). However, by taking into account that the degradation of organic matter by microbial action happens predominantly through exothermic reactions, it is possible to hypothesize that, in a limited number of cases, the temperatures reached inside guano deposits experiencing bacterial decay, or the temperature reached during the diagenesis of sediments admixed with guano, might be sufficiently high to cause the dehydration of taranakite, but not as high as to cause the amorphization of newly formed francoanellite.

5. Conclusion

Taranakite, a hydrated K-Al phosphate typical of cave sediments altered by fluids generated from bat guano degradation in damp conditions, is present in the phosphate-sulphate mineral assemblage of the Pollera Cave in proximity to a subfossil guano deposit. Thermogravimetric data, in accordance to the available literature, suggest that its thermal degradation should start at ~ 95°C. However, probably due to the slow kinetics of this dehydration reaction, experiments conducted in isothermal conditions confirmed that the destabilization of taranakite and consequent gradual formation of francoanellite can take place at temperatures much lower than previously thought. At present, it is difficult to assess whether the mild heating provided by the decay of organic matter in actively degrading guano deposits could provide the necessary conditions for the formation of francoanellite. This would explain most of the natural occurrences of francoanellite in wild caves. In Castellana Cave, high temperatures might have occurred close to powerful spotlights. Further mineralogical, geomorphological and microbiological observations in these contexts might aid in better understanding the processes regulating the thermal evolution of degrading guano deposits and the transformation taking place in their surroundings.

Acknowledgments

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First insights into the geomorphology, mineralogy and microclimate of *Cueva Grande del Arco* (Cieza, Region of Murcia, SE Spain)

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Abstract

The archaeological excavations in *Cueva del Arco* cave (Cieza, Region of Murcia, SE Spain) have enable the discovery of a large cavity. A preliminary scientific survey was conducted to investigate its geomorphology, mineralogy, and underground atmosphere. Cupolas several meters in diameter can be seen on the cave ceilings, as well as dissolution surfaces and corrosion features, typically related to hypogenic speleogenesis. The presence of gypsum on the cave walls and ceilings may indicate also sulfuric acid speleogenesis. The guano deposits in the deepest cave parts reveal the paleo-activity of bats, which may have also influenced the cave morphology. Phosphate speleothems have been identified, including hydroxylapatite, fluorapatite, and crandallite, related to the alteration of guano deposits. The concentration of CO2 in the cave atmosphere ranged from 1300 to 1850 ppm, and its relatively low δ13C values (-19.5 to -21.4‰) suggest significant contributions of CO2 from overlaying soil or/and in-cave microbial degradation of the guano. The concentration of CH4 is lower in the inner galleries, and its δ13C values (<-65‰) are lower than outside (~-50‰), because of methanogenic and methanotrophic bacterial activity associated with the guano. These preliminary results will be used to establish a medium- and long-term research plan in this cave, with special focus on protection.

1. Introduction

The speleological explorations over the last decades in the Region of Murcia (southeast of the Iberian Peninsula) have enabled the discovery of over 20 caves whose morphologies suggest a hypogenic origin, often related to hydrothermal processes (Gázquez et al., 2017). The formation mechanisms of these caves implied the corrosive action of slightly acidic waters containing CO2 and/or H2S of deep origin. The underground features generated by hypogenic speleogenesis often include dissolution morphologies with a marked vertical component, resulting from the upward movement of hydrothermal water flows, as well as large domes, among others (Klimchouk, 2009). The interaction between water and the host rock can lead to characteristic surface alterations, and in the case of sulfuric acid-bearing waters, minerals such as gypsum (CaSO4·2H2O) and alunite ($KAl_3(SO_4)_2(OH)_6$) can form, among others (Hill & Forti, 1997).

In the *Calasparra* syncline area, located in the northern part of the region, two caves of distinctly hypogenic origin exist: *Cueva del Puerto* cave, to the north of the syncline, and *Sima del Pulpo* (Gázquez et al., 2017), to its south (Fig. 1). These caves have been known for decades, with *Cueva del Puerto* being adapted as a show cave in recent years. Meanwhile, archaeological excavations conducted in *Cueva del Arco* (Martín-Lerma et al., 2023), south of the same syncline and just 1.5 km from *Sima del Pulpo*, have led to the discovery of a large cavity that has begun to be studied from a multidisciplinary perspective.

In this work we present the first results of this research, including geomorphological observations, mineralogical analyses, and assessments of its underground atmosphere. The goal was to generate an initial genetic model of the cavity, evaluate its mineralogical richness, and characterize its underground atmosphere. These results will serve as a guideline for future scientific investigations in this cave.

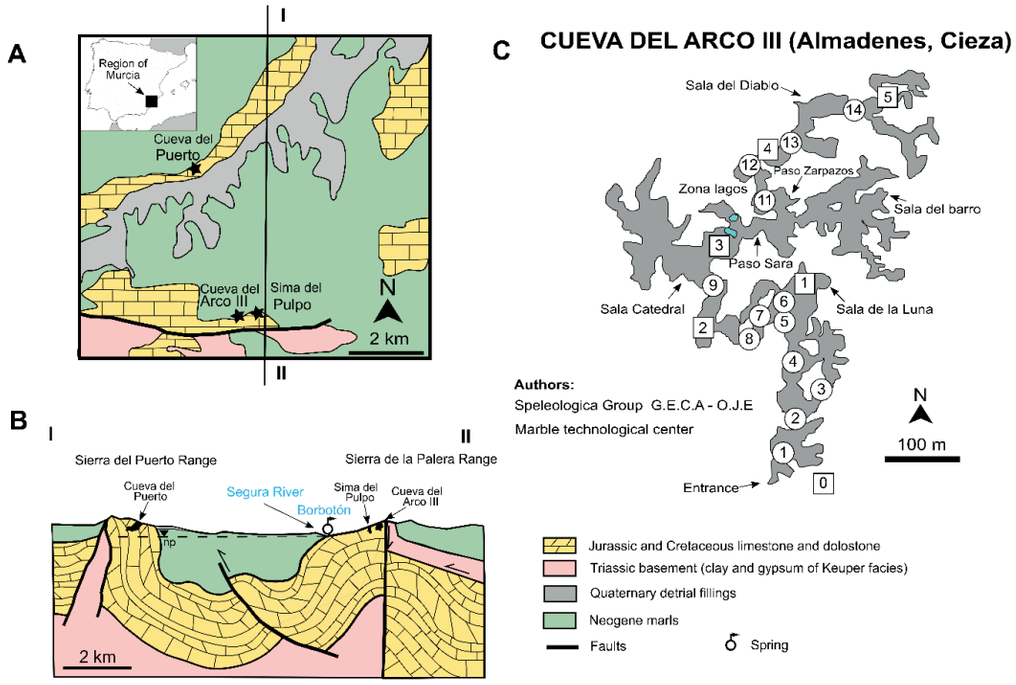

Figure 1: *A. Location of the Cueva Grande del Arco (also known as Cueva del Arco III) and other nearby hypogenic cavities associated with the Calasparra syncline: Cueva del Puerto and Sima del Pulpo caves. Geological map modified from MAGNA 1:50,000 (Jerez-Mir et al., 1972). B. Geological cross-section of the Calasparra syncline and the location of the mentioned caves, modified from the Geological Map of Spain (Jerez-Mir et al., 1972). C. Plan of the Cueva Grande del Arco showing the sampling locations. Circles denote mineral samples, while squares indicate air sampling points.*

2. Geological setting and cave description

The *Cueva Grande del Arco* cave, also known as *Cueva del Arco III*, is located in the municipality of Cieza, Region of Murcia (Spain), at an approximate altitude of 350 m a.s.l. (Fig. 1), on the left side of the *Barranco de la Tabaquera*, which drains into the Segura River. Archaeological work conducted since 2015 outside the cavity (Martín-Lerma et al., 2023) led to the discovery of its natural entrance. The climate is typically Mediterranean, with an average annual temperature of 16.7°C, precipitation of 328 mm/yr, and dry summers during which maximum temperatures can reach 40°C. Vegetation above the cave is sparse, dominated by Mediterranean scrub, primarily *esparto* grass (*Stipa tenacissima*).

The cave entrance is on a small plateau located between the *Almadenes Canyon* to the north and the *Sierra de la Palera* (654 m a.s.l.) to the south. The cave develops within Cretaceous carbonate rocks belonging to the internal Prebetic domain (Jerez-Mir et al., 1972), at the boundary between whitish massive limestones of the Coniacian, which outcrop east of the cave, and massive dolomites of the Turonian, located to the west (Fig. 1).

The cavity has a known development of 1,360 m and a depth of 28 m, with the entrance area being located at the highest altitude. Labyrinthine galleries appear, particularly around the *Sala de la Luna* and before reaching the *Sala de la Catedral* (Fig. 1). In general, the galleries and chambers are spacious, with heights exceeding 2 m. Dissolution morphologies are abundant throughout the cavity, especially in the upper levels, where metric-sized domes occasionally occur. Ceiling tubes and other dissolution features, similar to those identified in the nearby *Cueva del Puerto* and *Sima del Pulpo* (Gázquez et al., 2017), has been identified.

Conventional speleothems, such as stalactites and stalagmites, are relatively scarce in the large chambers and are limited to an area near small, perched lakes located in the central section of the cavity. Here, soda straws nearly 2 m long have been documented. Less conventional mineralizations also appear on the walls and ceilings, forming crusts, some with a microcrystalline texture and others as thin layers covering the domes on the cave ceilings.

In the area farthest from the entrance, beyond the section known as the *Paso de los Zarpazos*, abundant bat guano deposits with varying degrees of mineralization are observed. Particularly notable is the guano accumulation in the *Sala Colmatada*, where the deposit reaches a height of approximately 1.5 m, exhibiting a less mineralized appearance compared to other sectors.

3. Materials and methods

Sampling of minerals and gases

In September 2021, a sampling campaign was conducted, collecting 13 mineral samples from various cave sites (Figure 1). The samples included microcrystalline crusts from walls and ceilings (ARC-01, ARC-02, ARC-03, ARC-05, ARC-08, ARC-14C); white powdery sediments from the floors (ARC-04); fillings in rock fractures (ARC-06); rock surfaces with black mm-sized dots (ARC-07); thin crusts on the rock, mostly found on ceilings and inside domes (ARC-09); bluish laminated speleothems observed on bat guano deposits (ARC-11A); reddish, crystalline-looking speleothems of millimeter size (ARC-11B); and whitish, powdery minerals also found on guano (ARC-12).

Five air samples were collected using 1 L Ritter® bags with a manual pump to study the isotopic composition of carbon in CO2 and CH4, aiming to determine their origin and the degree of gas exchange with

the exterior (Fig. 1). Environmental parameters were also measured in situ using XP100 and XP200 portable sensors (Lufft), equipped with an external temperature probe (PT100 1/10 DIN-B) and an NDIR probe for CO2 concentration (EE871, E+E Elektronik), range of 0-10,000 ppm and an accuracy of ±5%.

Isotopic analysis of CO_2 and CH_4

In the laboratory, the air bags were analyzed to determine the concentrations of CO_2 and CH_4 and their $\delta^{13}C$ values, using a CRDS system (Picarro G2201-i Analyzer, USA) at the Stable Isotopes Laboratory of the University of Almería. Three internal standards with certified gas mixtures and known CO_2 concentrations (7000 ppm, 400 ppm, and zero CO_2) and CH_4 (1.8 ppm, 0.5 ppm, and zero CH_4) supplied by Abello Linde-Spain were used to calibrate the CO_2 concentration values in the air samples. The stable carbon isotopic compositions of both gases (CO_2 and CH_4) were expressed as $\delta^{13}C$ relative to the Vienna Pee Dee Belemnite (VPDB) standard. CO_2 content measurements achieved a precision of 200 ppb and better than 0.15‰ for $\delta^{13}C$-CO_2. For CH_4, the precision was 5 ppb ($^{12}CH_4$) and 1 ppb ($^{13}CH_4$), resulting in a precision better than 1.15‰ for $\delta^{13}C$-CH_4.

Mineralogical and compositional analyses

X-ray diffraction (XRD) analyses were conducted using a powder D8 ADVANCE DAVINCI X-ray diffractometer with a Cu anode (CuKα, λ = 0.154 nm) and a graphite monochromator. The voltage and current were set at 40 kV and 30 mA, respectively, for all analyses. The 2θ scan method was used, with 0.400 seconds per step, within angular limits of 5° to 80°. Mineralogical identification was performed using the PDF-2 (Powder Diffraction Files) database. The microscopic structure of the minerals was further examined using a field-emission scanning electron microscope (FESEM), Zeiss Sigma 300 VP. Chemical composition was determined using an X-ray probe coupled with the FESEM, enabling precise analysis of specific points on the samples at a microscopic scale. Both the mineralogical and geochemical analyses were conducted at the Central Technical Services of the University of Almería.

Figure 2: *Morphologies and minerals in the Cueva Grande del Arco. A. Domes on ceilings, occasionally covered with thin brown crusts (B) from which sample ARC-9 (hydroxyapatite) was collected; C. Signs of corrosion of the host rock; D. Gypsum crusts, sometimes appearing as hollow balls or "blisters" (sample ARC-02); E. Mineralized guano deposits in the Sala del Diablo (ARC-11A) (fluorapatite, quartz, and carnallite); F. Reddish speleothems in the form of small spheres, ranging in size from centimeters to millimeters (ARC-11B) (fluorapatite, quartz, and crandallite).*

4. Results

Isotopic composition and concentration of CO_2 and CH_4 in cave air

The results from our preliminary survey conducted in early September, during high external temperatures (33ºC), revealed marked thermal stability and a highly homogeneous gaseous composition in the cave atmosphere. Air temperature dropped to 20.2ºC within the first 250 m from the entrance. As the gallery elevation decreased, the temperature stabilized between 19.6 and 19.7ºC in the sector containing water masses (referred to as the "Lakes Zone," Fig. 1). In the most distal galleries from the entrance, at depths of -22 to -24 m relative to the surface (*Sala del Diablo* sector, Fig. 1), the temperature stabilized around 20.03±0.01ºC.

The average CO_2 concentration was relatively high (1659 ppm), suggesting limited gas exchange with the exterior during the sampling period. Spatial variation in CO_2 concentration ranged from 1298 ppm at station 5 (closest to the entrance) to nearly 1900 ppm in the deepest zones (~-24 m). The average $\delta^{13}C$-CO_2 value was -20.7‰, with a narrow range of variation from -19.5‰ to -21.5‰ across all explored galleries (Fig. 4A). The mean CH_4 concentration ranged from 0.2-0.3 ppm in the most distal areas to 0.9 ppm closer to the exterior (Fig. 4B).

Chemical and mineralogical composition of speleothems

The analyzed speleothem samples exhibited significant mineralogical diversity, including sulfates, phosphates, carbonates, oxides, and silicates. Gypsum ($CaSO_4 \cdot 2H_2O$) was predominantly found near the cave entrance, forming crusts on the walls and floors (samples ARC-01, ARC-02, and ARC-03). Minor quantities of quartz (SiO_2), calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), and goethite (FeOOH) were also identified. Microanalysis confirmed the presence of these minerals (Fig, 3). Gypsum was also found in loosely consolidated materials on the floor of the *Sala de la Luna* (ARC-04), forming conulite-like structures. Here gypsum displayed an uncommon crystalline habit resembling an "accordion" (Fig 3B).

Sample ARC-09, a ~1 mm crust on the cave ceiling in a dome, consisted of hydroxyapatite ($Ca_5(PO_4)_3(OH)$). A floor sample (ARC-11A) collected below these dome mainly contained fluorapatite ($Ca_5(PO_4)_3F$), another phosphate typical of guano deposits in caves. Sample ARC-12, taken from black, paste-like deposits on the cave floor, had an poorly-defined mineralogy, showing only quartz (SiO_2) and muscovite ($KAl_2(AlSi_3O_{10})(OH)_2$), suggesting that the guano deposits may be relatively recent and not yet mineralized. In some locations with guano deposits, crandallite ($CaAl_3(PO_4)(PO_3OH)(OH)_6$) was identified (sample ARC-11B), another calcium-aluminum phosphate typically associated with guano in caves (Fig. 3D and E). Gypsum was also identified in some guano-related samples (ARC-12).

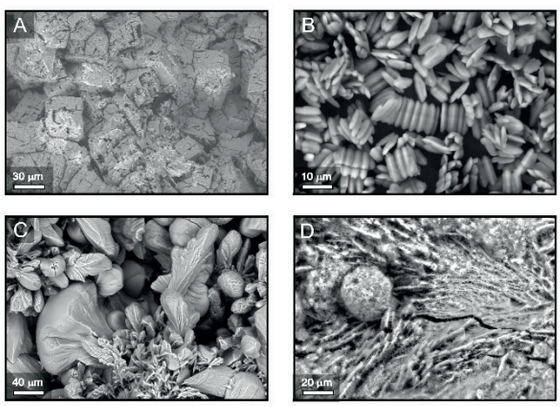

Figure 3: *FESEM photographs of samples ARC-07 (A) (corroded calcite and goethite), ARC-04 (B) (gypsum), ARC-11 and ARC-14 (C and D) (crandallite).*

5. Discussion

Characteristics and isotopic composition of the underground atmosphere

The Keeling plot (Fig. 4A), which models the CO_2 mixing between cave atmosphere and outside, confirms that the cave CO_2 originates from the degradation of organic matter and root respiration in external soils, dominated by C_3-type vegetation (with $\delta^{13}C\text{-}CO_2$ around -25‰). Additionally, there is a likely contribution of CO_2 from the rock fissures and pores above the cavity, generated through the degassing of slowly infiltrating water.

The elevated and spatially homogeneous CO_2 concentration in the cave and relatively low $\delta^{13}C\text{-}CO_2$ values indicate limited gas exchange with the external atmosphere. This relative isolation becomes particularly evident beyond 250 m from the entrance, with marked spatial homogenization in CO_2 concentration (>1600 ppm) and $\delta^{13}C\text{-}CO_2$ values (<-20‰). Long-term monitoring will help determine whether this degree of isolation persists or if seasonal changes occur due to external meteorological conditions.

The concentration of methane decreases with distance from the entrance (Fig. 4B), suggesting that it is almost entirely consumed by methanotrophic microorganisms present in the walls and sediments of the cave. Some bacterial colonies are visible near the entrance, although their presence may be more widespread and would require specific microbiological sampling and analysis. Bioluminescence assays (ATP measurements) could quantify microbial biomass in sediments and surfaces of the cavity as a preliminary step to evaluate the degree of microbiological colonization by sectors of the cave and its relationship with the spatial gradient in CH_4 consumption.

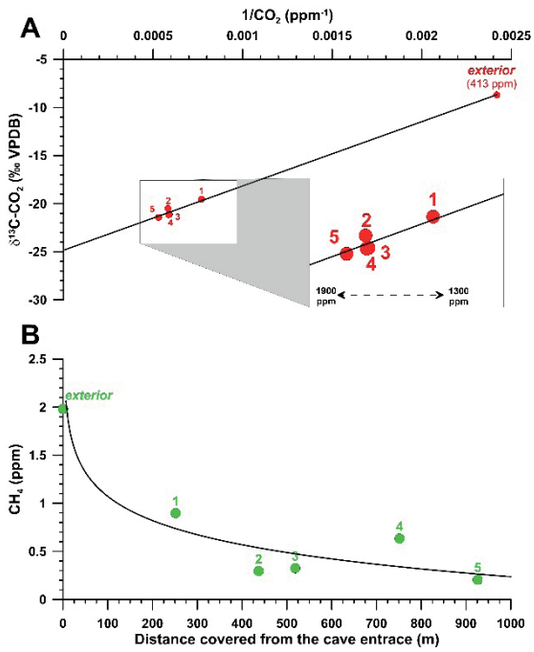

Figure 4: *A: Keeling diagram for CO_2 ($1/CO_2$ vs. $\delta^{13}C\text{-}CO_2$). B: Spatial variation gradient of CH_4 concentration in the underground atmosphere of Cueva Grande del Arco. The labels on each point indicate the location of the air samples (Fig. 1).*

The values of $\delta^{13}CH_4$ are highly variable. However, values significantly lower than the $\delta^{13}CH_4$ of the external atmosphere (~-50‰) may indicate residual CH_4 generated by methanogenic bacterial activity associated with the numerous bat guano deposits in the cavity, such as near point 4, where a spatial anomaly in CH_4 consumption is detected (Fig. 4B). This biogenic CH_4 would subsequently be oxidized by methanotrophic microorganisms to concentrations below atmospheric CH_4 levels (1.98 ppm outside). However, it is worth noting that the CRDS analyzer's precision for $\delta^{13}C\text{-}CH_4$ decreases with methane gas concentrations (<0.5 ppm). Thus, these results should be interpreted cautiously, and further data are required to identify a more robust spatiotemporal pattern in CH_4 consumption processes.

Preliminary geomorphological interpretations and mineralogy of the *Cueva Grande del Arco*

The *Cueva Grande del Arco* exhibits signs of a primary origin related to hypogenic processes, as indicated by typical geomorphological and mineralogical features. The rounded surfaces on walls and ceilings (Fig. 2A), areas with labyrinthine passages (Fig. 1C), corroded surfaces (Figure 2C), and the complete absence of fluviokarstic sediments suggest the cave was flooded by water under relatively stable conditions in the past, completely isolated from the surface, likely in a confined aquifer. The relative scarcity of conventional dripstone speleothems, such as stalagmites or stalactites, in most of the chambers indicates, on the one hand, a poorly developed epikarst and limited rainwater infiltration. On the other hand, it suggests that the cave may have been under water until geologically recent times. Otherwise, sufficient time likely would have allowed for the development of epikarst and a more significant presence of subaerial speleothems, which have only been observed in a few sites. No water level marks or speleothems typical of CO2 degassing zones under epiphreatic conditions, such as cave pearls, folia, cave clouds, or raft-calcite cones (Audra et al., 2009; Gázquez & Calaforra, 2013), are observed. This may indicate that the cave emerged rapidly, transitioning from phreatic to vadose conditions in a short period. This sudden change did not provide the necessary stability for the formation of such speleothems, as has been suggested for the *Cueva del Puerto* cave (Gázquez et al., 2017).

The presence of large domes, particularly in the *Sala de la Luna*, is remarkable. In cases, these features are linked to thermal water processes and deep hypogenic flows (Audra et al., 2009; Klimchouk, 2009), which require further investigation, as dome formations in caves have also been associated with bat activity (Barriquand et al., 2021). The significant abundance of ancient guano deposits in various chambers of the cavity is striking. However, no bat colonies are currently present in the cave, indicating their disappearance long ago, possibly due to a natural closure of the original entrance entrance. Nearby caves, such as the *Cueva del Puerto* and the *Sima del Pulpo* caves, exhibit very similar geomorphological features (Gázquez et al., 2017), suggesting a shared origin along both flanks of the Calasparra syncline due to a confined regional water mass. Therefore, a combined study of these cavities could shed light on regional hydrothermal processes and their chronology.

Gypsum is especially abundant in *Cueva Grande del Arco*, primarily found in the upper parts of the cavity. Its origin could be subaqueous, resulting from the replacement of carbonate rock by sulfate-rich acidic waters. This process occurs mainly in the more oxygenated superficial parts of the aquifer, while deeper zones would have more anoxic conditions with sulfur in its reduced form as sulfide ions. This gypsum likely formed due to the reaction of limestone with sulfuric acid derived from sulfur gases (H_2S and H_2SO4) during the hypogenic phase of the aquifer (e.g. Onac et al., 2009). This process may have also occurred under subaerial conditions due to sulfurous gases and condensation processes on the host rock. Slightly acidic sulfate-rich condensation waters from H_2S oxidation could replace carbonate with calcium sulfate. The "blister" structures observed near the entrance (Fig. 2) may be related to this subaerial process. Gypsum also appears in the nearby *Cueva del Puerto* and *Sima del Pulpo* caves (Gázquez et al., 2017), indicating that these cavities share not only geomorphological processes but also a common hydrogeochemical history leading to certain mineralogical similarities. Notably, some pulverulent gypsum deposits on the floor of the Sala de la Luna seem to have detached from the ceiling. These may have resulted from rock alteration due to gases emitted by extensive

guano deposits, as sulfates like gypsum, along with phosphates and nitrates, are common secondary minerals associated with bat activity. A detailed geochemical study, such as isotopic analysis of this gypsum, is necessary to draw more solid conclusions.

In addition to gypsum, the presence of less conventional minerals such as phosphates stands out. These appear both in relation to the maturation of guano deposits in the deeper areas of the cavity and through interactions between bat urine and the surface of the ceilings within cupolas. These minerals have been found in other caves worldwide, most often associated with bat guano, including various types of apatite and less common minerals such as crandallite (Hill & Forti, 1997). It is worth noting that the cavity lacked an accessible entrance until its discovery, and it is likely that bats accessed it in the past through other entrances now blocked. Particularly noteworthy is the accumulation of guano in the room furthest from the current entrance to the cavity. The ceiling of this room forms a large dome developed in detrital sediments that do not seem related to the stratigraphic sequence of Jurassic and Cretaceous limestones and dolomites but instead appear to be more recent materials. It is possible that access to the cavity occurred in the past through this room, now sealed. Dating the sediments using luminescence techniques such as OSL (Optically Stimulated Luminescence) could help determine when this potential entrance was blocked. Additionally, dating the guano deposits using radiocarbon (^{14}C) would establish when the cave ceased to host bats and how long they inhabited it. Another possible line of investigation could involve studying the guano deposits to infer past climate conditions in the region, as has been done in caves elsewhere (Onac et al., 2015).

Finally, the presence of manganese oxides as inclusions in the carbonate rock at several sites within the cavity is remarkable (Fig. 3A). These minerals contain metallic elements that, when oxidized, generate protons that acidify the environment and contribute to dissolving the limestone. This process has been observed in other cavities in the Murcia Region, such as *Sima de la Higuera* cave (Gázquez et al., 2012). In fact, part of the cave speleogenesis may be related to this process, along with dissolution under phreatic conditions, subsequent acidic dissolution under vadose conditions due to condensation-corrosion processes, and the biogenic activity of bats.

6. Conclusions

The recently discovered *Cueva Grande del Arco* cave exhibits unique geomorphological characteristics, distinct from most Spanish caves but similar to others in the Murcia Region. These features, including large domes and corrosion forms, are typical of hypogenic processes caused by deep-origin waters in confined aquifers. The presence of significant amounts of gypsum suggests that speleogenesis likely involved sulfuric acid. Phosphate minerals associated with the activity of bat colonies that inhabited the cavity in the past have been identified. Observations during the visit suggest a poorly ventilated underground atmosphere with significant CO_2 contributions from the soil above the cave or, more likely, from the degradation of abundant bat guano deposits by microorganisms. The decreasing CH_4 concentration trend towards the interior of the cavity indicates consumption of this gas by methanotrophic microorganisms. However, the residual methane concentrations, depleted in ^{13}C, suggest minimal external CH_4 contribution and instead possible *in situ* production associated with guano degradation. Given the excellent state of conservation of *Cueva Grande del Arco* and the numerous elements of scientific interest, it is urgent to develop a structured research plan for the coming years, prioritizing the conservation and protection of this cavity.

Acknowledgments

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Geochemical and mineralogical analysis of speleothems in iron formations of Southern Espinhaço Range, Brazil

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Abstract

This study, carried out in iron formation caves of the Brazilian Southern Espinhaço Range, focused on the mineralogical and geochemical characterization of speleothems from 75 caves targeted for speleological salvage between 2018 and 2021. A total of 188 samples were collected and analyzed, classified into five speleothem types: coralloids, crusts, flowstones, pendants, and speleothems developed over termite mounds. Mineralogical analysis identified five primary mineral groups: oxide-hydroxides (62%), silicates (30%), phosphates (5%), sulfates (2%), and carbonates (2%). Goethite and hematite were the most common minerals among oxides, while quartz and amorphous silica dominated the silicates. Oxide-hydroxides, predominantly goethite, were linked to the high iron content of the region's rocks, particularly itabirite and canga. Hematite frequently co-occurred with phosphates, sulfates, and silicates. Phosphate minerals, including spheniscidite and strengite, were likely influenced by guano deposits, whereas sulfate minerals like jarosite were often associated with oxides. Additionally, silica-rich lithologies contributed to the formation of quartz and amorphous silica, reflecting diverse geological processes. This study underscores the significant mineralogical diversity of these caves, highlighting the influence of iron-rich lithologies on speleothem formation. The findings provide insights into mineral formation processes and the interactions between geological and biological factors in iron cave ecosystems.

1. Introduction

Speleothems are secondary chemical deposits that form in caves. While they are most commonly associated with carbonate caves, they can also develop in other lithologies, including iron and siliciclastic rocks (ALBUQUERQUE et al. 2018).

Research on speleothems in iron formation caves remains relatively scarce. The earliest records originating from Brazil's Iron Quadrangle, which focused on describing stalactites and crusts in such caves (PISSIS 1842, HENWOOD 1871). In the Carajás region (northern Brazil), MAURITY & KOTSCHOUBEY (1995) conducted the first mineralogical study of speleothems on the N1 Plateau of Serra Norte. They observed variations in speleothem abundance among caves, with most occuring on floors, walls, and collapsed blocks, but rarely on ceilings. Three main types were identified: oxide-hydroxide, phosphate, and aluminum/iron sulfate speleothems, occasionally containing calcium and potassium. These studies underscore the diverse mineralogy and formation contexts of speleothems in iron-rich caves. Speleothems in iron formation caves exhibit a wide range of mineral compositions and formation processes (MAURITY & KOTSCHOUBEY 1995, ALBUQUERQUE et al. 2018, FIGUEIRA et al. 2019, AULER et al. 2022). In the False Cave, centimeter- thick goethite-hematite crusts develop on surfaces exposed to water runoff and erosion (MAURITY & KOTSCHOUBEY 1995). These crusts feature botryoidal and framboidal textures on their surfaces, with finely laminated cross- sections indicating a polyphase formation history. Pale- yellow, friable, microtravertine-like gibbsite layers have also been observed, formed through slow dissolution of oxides- hydroxides, which mobilize iron and aluminum as colloids. Limited water runoff leads to flocculation, forming gels that dehydrate and crystallize into speleothems. This process continues in certain N1 Plateau caves, where percolating water leaves gelatinous aluminous or ferruginous layers (HILL & FORTI 1986). Phosphate minerals are abundant in the N1 and Guarita caves, coating surfaces, filling cracks, or replacing laterite through phosphatization. Predominant minerals include strengite, phosphosiderite, and leucophosphite, often associated with iron oxides- hydroxides. These speleothems exhibit diverse textures, ranging from porcelain-like surfaces to spherulitic and cellular patterns. Laminations and gradual transitions from laterite to phosphate-rich zones indicate progressive replacement processes (MAURITY & KOTSCHOUBEY 1995). Fragments of ferruginous crusts embedded within phosphate matrices in some areas suggest the transformation of lateritic material under cold metamorphic conditions. Aluminum and calcium sulfate speleothems, including gypsum, alunite, basaluminite, and meta- aluminite, have been reported in the Guarita, N1, and Fenda caves (MAURITY & KOTSCHOUBEY 1995). Gypsum forms thin white layers or translucent crystals, often found alongside alunite. Basaluminite appears as plastic masses or powdery coatings, while meta-aluminite forms milky-white, cauliflower-like deposits in dry corridors. These formations illustrate the unique geochemical and mineralogical processes shaping iron-rich cave systems.

Studies of speleothems and lithologies in the Carajás region reveal significant mineralogical diversity (ALBUQUERQUE et al. 2018, FIGUEIRA et al. 2019, AULER et al. 2022), whereas data from the Southern Espinhaço Range remain limited. For instance, ALBUQUERQUE et al. (2018) described phosphate mineral formation processes through geochemical

and petrographic analysis, X-ray powder diffraction (XRD), differential scanning calorimetry coupled with thermogravimetry (DSC-TG), Fourier-transform infrared (FTIR), and scanning electron microscopy (SEM). Their geochemical analysis revealed enrichment in P2O5, Zn, Ni, and Rb in both speleothems and phosphatized laterite, suggesting bat guano as a primary source of these element. FIGUEIRA et al. (2019) investigated the mineral, crystallographic, and chemical properties of sulfate and phosphate speleothems, along with the physicochemical conditions influencing their formation, in caves within banded iron formations and lateritic duricrusts in eastern Amazonia, Brazil. Their findings identified aluminite, felsobanyaite, jarosite, spheniscidite, phosphosiderite, and amorphous phosphatic material in coralloid speleothems, while spheniscidite, phosphosiderite, and strengite were present in stalactitic forms. These minerals result from chemical interactions between bat guano (rich in K+, Na+, Ca2+, Mg2+, NH4+) and iron and aluminum from the cave's lateritic walls, ceilings and floors, producing sulfate and phosphate assemblages. These findings enhance the understanding of speleothem mineralogy in iron formation caves, emphasizing their scientific and ecological significance.

This study aimed to characterize the geochemical composition of iron speleothems in 75 caves subjected to speleological salvage in Southern Espinhaço Range, Minas Gerais, southeastern Brazil.

2. Materials and methods

This study was conducted in 75 iron formation caves designated for speleothem salvage, located within the intervention area of the Sapo Mine Extension, in the municipalities of Alvorada de Minas and Conceição do Mato Dentro, along Sapo Ridge in the Southern Espinhaço Range, Minas Gerais, Brazil. The full-scale speleothem extraction began in 2018 with 65 caves. As the project expanded, addiotional caves were incorporated into the compensation process: two (2) in 2019, seven (7) in 2020 and one (1) in 2021.

The research process began with a bibliographic review of the geochemistry of iron-rich lithologies and the mineralogy of speleothems in iron caves. This provided a theoretical foundation and comparative data for analysis. Additionally, a review of existing speleological documentation from the region guided sample selection. Speleothem and lithotype sampling took place between 2018 and 2021. Samples were extracted using a petrographic hammer, while highly crystallized specimens were removed with chisels of varying sizes. Each sample was identified, described and photographed during collection, and securely bagged. A total of 188 speleothem samples were collected. In total,

188 speleothem samples were collected. The only exceptions were the two cavities studied in 2019, where no speleothem formations were present.

Speleothem samples collected in 2018 were analyzed at the X-ray Laboratory of the Professor Manoel Teixeira da Costa Research Center (CPMTC) at Federal University of Minas Gerais (UFMG). Samples from 2020 and 2021 were sent to the Technological Characterization Laboratory of the Polytechnic School at the University of São Paulo, for mineralogical analysis using X-ray Diffraction (XRD). The analyses were performed using the powder diffraction method with a PANalytical X'Pert PRO diffractometer equipped with an X'Celerator detector. Crystalline phases identification was achieved by comparing sample diffractogram with reference databases, including PDF2 from the International Centre for Diffraction Data (ICDD) and PAN-ICSD from PANanalytical's Inorganic Crystal Structure Database.

3. Results

A total of 188 samples were classified into five types of speleothems: coralloids (N = 107), crusts (N = 67), flowstones (N = 11), pendants (N = 2), and speleothems developed over termite mounds (N = 1). Chemical analysis confirmed the presence of five mineral groups: oxide- hydroxides, silicates, phosphates, sulfates, and carbonates. Among the oxides, goethite (33%) and hematite (32%) were the most abundant minerals, while quartz (21%) and amorphous silica (14%) dominated the silicate group. Other identified minerals included phosphates (5%), gibbsite (2%), carbonates (2%), and sulfates (2%), along with isolated occurrences of magnetite, muscovite and kaolinite (1%). The predominance of goethite among the oxide-hydroxides is directly linked to the geochemical composition of the iron- rich rocks hosting most of the studied caves.

Coralloids: A total of 107 coralloid samples were recovered from 40 cavies (Figure 1). Their mineralogical composition revealed 10 distinct minerals, with hematite (28%), goethite (25%), amorphous silica (22%) and quartz (19%) being the most prevalent (Figure 1). Oxide-hydroxides were present in 54% of the samples, with hematite frequently occurring alongside goethite. Silicates and hydrated silicates, including quartz, kaolinite and amorphous silica, were found in 42% of the samples. Carbonates, phosphates and sulfates were identified in isolated cases. Quartz and amorphous silica appeared in 41 and 48 samples, respectively. Kaolinite, typically associated with the weathering of siliciclastic minerals in acidic environments, may have a residual origin in the caves. Kaolinite was identified in only one speleothem sample (E-02) in cave CSS-0017.

Figure 1: *Coralloids: ASS-0010.E-02 composed of amorphous silica (A); ASS-0006.E-04 consisting of hematite (B); CSS- 0005.E-03 with goethitic mineralogy (C); CSS-0006.E-02 composed of quartz (70.4%) and hematite (24.5%) (D).*

Crusts: A total of 67 crust samples were collected from 33 caves during the speleothem removal process. This speleothem type contained four phosphate minerals: strengite, spheniscidite, sodium phosphate, and phosphosiderite; along with four oxide-hydroxides: hematite, goethite, gibbsite and magnetite; five sulfate mineral species: felsobanyaite, jarosite, alunite, ammonium sulfate and alum-(Na) sulfate; and three types of silicate minerals: quartz, muscovite and amorphous silica. Regarding the mineralogical composition of the crusts, chemical analysis identified 17 different minerals, with goethite (33%) and hematite (31%) being the most abundant among oxide-hydroxides. Quartz was the predominant

silicate, present in 18% of the samples (Figure 2). The remaining minerals sppeared in smaller proportions, occurring in five samples or fewer. Noteworthy occurrences include a high concentration of strengite in sample CSS- 0084.E-04 (92.7%), felsobanyaite associated with ammonium sulfate in sample CSS-0027.E-09, and spheniscidite phosphate in samples E-04 and E-05 from cave CSS-0019, both associated with hematite.

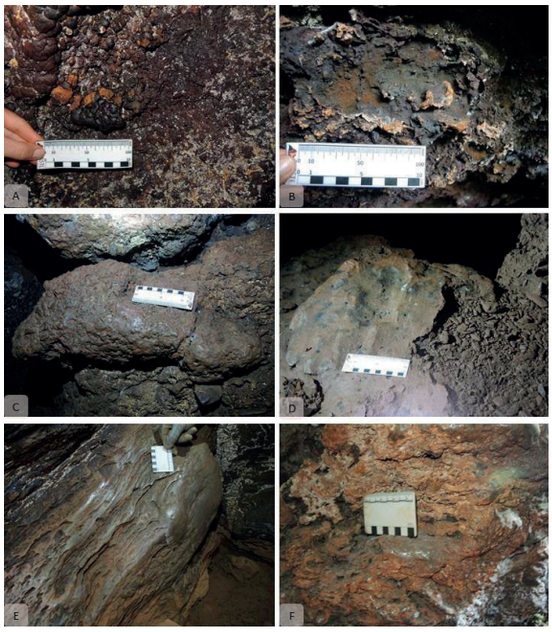

Figure 2: *Crusts: CSS-0016.E-01 formed exclusively of goethite (A); CSS--0008.E-03 composed of hematite and goethite (B); CSS-0089.E-01 sample (C); CSS-0005.E-05 composed of quartz, hematite and goethite (D); CSS--0068.E- 033 sample (E); CSS-0068.E-04 sample (F).*

Flowstone: Eleven samples of flowstone were recovered from eight caves, containing five different minerals, from oxide-hydroxide and silicate groups (Figure 3). Oxide- hydroxides represent 76% of the analyzed flowstone samples, while the remaining samples consisted of siliciclastic minerals, primarily quartz and amorphous silica.

Figure 3: *Flowstone in cave CSS-0005.E-06 consisting of goethite (A) and FSS-0043.E-01 composed of goethite and quartz (B).*

Pendants: Two pendant samples were collected: CSS-0006- E-03, composed solely of goethite, and CSS-0096.E-03, which contained quartz, goethite, hematite, and lepidolite (Figure 4).

Figure 4: *Pendant identified in cave CSS-0006 (A); and in cave CSS-0096.E-03 (B).*

Speleothems developed over termite mounds: A single speleothem specimen formed over termite mounds was collected from cave CSS-0024 (Figure 5). Mineralogical analysis revealed the presence of goethite (oxide-hydroxide) and quartz (silicate).

Figure 5: *Speleothem formed over termite mounds identified in cave CSS-0024.*

Mineralogy: Oxide-hydroxides were the predominant mineral group, accounting for 62% of the analyzed samples, followed by silicates at 30%. Phosphates, sulfates, and carbonates were present in smaller proportion (Figure 6). While the chemical analysis provided quantitative values for crystalline minerals, amorphous silica, due to its lack of a defined structure, was analyzed only for presence or absence. To better understand their characteristics and specificities, mineral occurrences were examined separately by group.

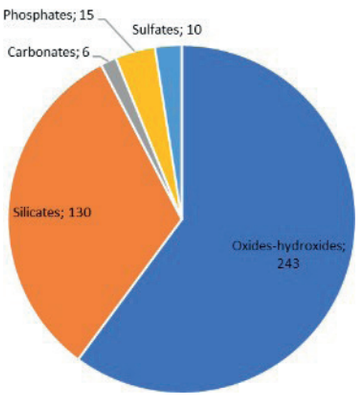

Figure 6: *Frequency of mineral groups verified in the mineralogical analysis of speleothems.*

Oxides-hydroxides: Among the studied caves, 96% of the oxide-hydroxide speleothems were composed of goethite and hematite, with the remaining 4% consisting of gibbsite, lepidocrocite, and magnetite (Figure 7). The distribution was as follows: goethite was present in 119 speleothem samples; hematite was identified in 114 speleothem samples; gibbsite was found in eight speleothem samples; lepidocrocite and magnetite were identified in a single speleothem sample each.

Phosphates: The phosphate minerals identified in the analyzed speleothems included spheniscidite, strengite, sodium phosphate, and phosphosiderite (Figure 8).

Silicates: Quartz was the most abundant silicate, occurring in 58% of the samples, followed by amorphous silica, which appeared in 39% of the specimens. Muscovite, kaolinite, and phlogopite were each identified in approximately 1% of the samples (Figure 9).

Carbonates: Only two carbonate minerals were identified in the caves: calcite and dolomite. Given that these caves developed in iron and siliciclastic rocks, carbonate occurrences were relatively rare (Figure 10).

Sulfates: Sulfate minerals were relatively common in the studied caves. The identified sulfates included felsobanyaite, ammonium sulfate, alunite, Alum-(Na), and jarosite, with jarosite being the most frequently occurring sulfate in speleothems (Figure 11).

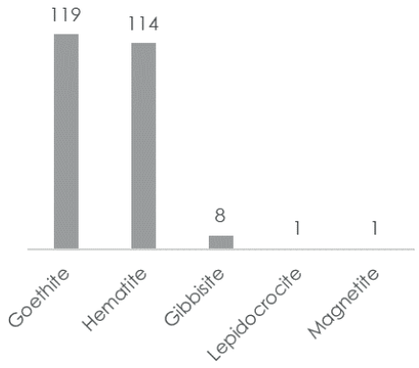

Figure 7: *Frequency of oxides-hydroxides in the analyzed samples.*

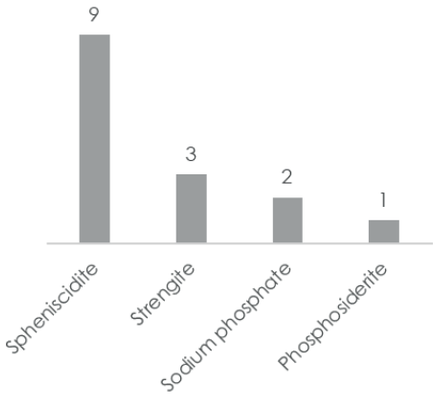

Figure 8: *Frequency of phosphates in the analyzed samples.*

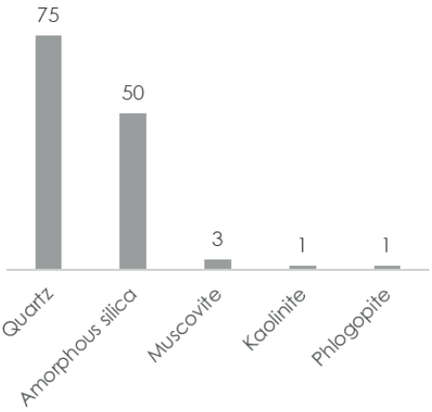

Figure 9: *Frequency of silicates in the analyzed samples.*

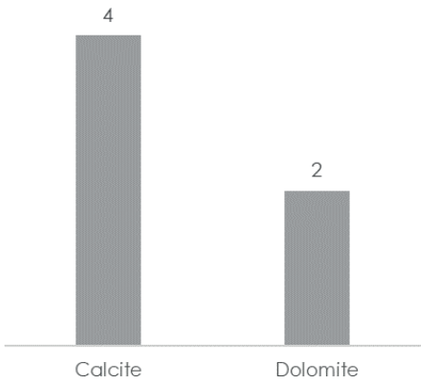

Figure 10: *Frequency of carbonates in the analyzed samples.*

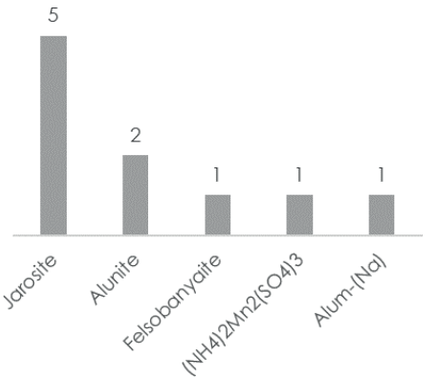

Figure 11: *Frequency of sulfates in the analyzed samples.*

4. Discussion

The formation of speleothems depends on rock characteristics such as lithology, structure, and environmental conditions. According to AULER et al. (2022), there is a typological gradation of speleothems depending on the amount of light and airflow. More pronounced air currents lead to the development of pointed and smaller coralloids, whereas the distal portions of caves, characterized by greater atmospheric stability and higher air humidity, favor the formation of ferruginous crusts and rounded coralloids (AULER et al., 2022).

Coralloids are small, nodular, or coral-like speleothems formed through capillary action and hydrological processes, including percolation, water films, splashes, and condensation (HILL & FORTI, 1997; ALBUQUERQUE et al. 2018; FIGUEIRA et al., 2019). In caves with multiple entrances and increased air circulation, their formation is driven by evaporation. These speleothems primarily consist of iron and aluminum oxides-hydroxides, sulfates, and phosphates, which originate from the host rock and guano. Crusts form as millimetric to centimetric layers on cave walls, ceilings, and floors. While sulfate minerals typically compose wall and ceiling crusts, carbonate minerals dominate floor crusts (HILL & FORTI, 1997). Their diverse shapes and colors reflect the mineralogical variations present, though no strict correlation exists between speleothem type and mineral composition. Flowstone, common in carbonate and iron caves, result from solution flows along fractures and rock planes, often forming laminated structure resembling travertine curtains. Pendants, ferruginous formations resembling stalactites but lacking a focal water

source or flow marks, may be hollow and deposit material at their base as terrigenous elements leach from the core. Thin veins of crystallized iron ore are interspersed with limonitic material.

Speleothems formed over termite mounds are rare cave formations that resemble termite constructions. They arise from mineral residues left by the insects' biological activity. These formations develop when termites modify subterranean conditions during colony construction, facilitating the precipitation of carbonates and sulfates. They represent a unique interaction between termite activity and the cave's geological environment.

Regarding mineralogy, oxides-hydroxides are minerals formed by cations combined with oxygen, with hydroxides incorporating hydrogen in the form of hydroxyl groups or hydration water. Goethite forms under oxidizing conditions through the weathering of iron minerals and is commonly found in caves and iron rocks. Hematite, which may indicate past hydrothermal activity or the transformation of goethite at low temperatures, and gibbsite, which results from aluminum dissolution under acidic conditions, are also present. Lepidocrocite, a polymorph of goethite, forms on oxidized iron and sulfide ores, while magnetite, distinguished by its strong magnetism and black streak, develops through bacterial reduction of Fe^{3-} under reducing conditions (HILL & FORTI, 1997; KLEIN & DUTROW, 2009; AULER et al. 2022).

Phosphate minerals, characterized by the tetrahedral (PO4)3- structure, are commonly found in caves and are often associated with host rock composition and bat guano. Microbial activity in guano releases acids that react with rock and sediments, leading to the formation of over 100 secondary minerals. Phosphates occur as nodules within guano deposits or as coatings on rock surfaces. While generally insoluble, they can dissolve in the presence of carbon dioxide and organic compounds. Spheniscidite, a monoclinic phosphate, forms through the interaction of guano-derived solutions with micaceous minerals and chlorides. Strengite, associated with guano and dolomite dissolution, is found globally, including in Brazil's Serra dos Carajás. Phosphosiderite, identified in crust-type speleothems, is linked to spheniscidite, strengite, silicates, and hematite (MAURITY & KOTSCHOUBEY, 1995; HILL & FORTI, 1997; ALBUQUERQUE et al., 2018, FIGUEIRA et al., 2019).

Silicate minerals, dominated by the SiO4 tetrahedral group, constitute 95% of Earth's crust but are rare in caves. Quartz was identified in 76 speleothem samples as crusts, flowstones, and coralloids, forming under high temperatures, through opal recrystallization, or from oversaturated silica solutions. Amorphous silica, present in 50 samples, lacks a crystalline structure and is more soluble than quartz, precipitating when pH decreases in silica-rich water. Kaolinite, a triclinic mineral that results from silicate weathering under mildly acidic conditions, was found in one sample. Muscovite, identified in three samples, is an aluminous phyllosilicate often associated with quartz. Phlogopite, linked to metamorphic processes (HILL & FORTI, 1997), was detected in one crust sample.

Carbonate minerals are rare in iron-rich caves due to the dominance of iron-bearing lithologies such as itabirite and canga. However, calcite and dolomite were identified in four samples, suggesting specific geochemical formation processes. Calcite, a trigonal mineral, occurs in crusts and flowstones, likely forming through interactions between carbonate-rich solutions and ferruginous materials. Dolomite, also trigonal, was found in crusts and coralloids, often appearing as fine granular deposits, possibly forming trough the alteration of minerals such as aragonite or huntite, or via direct precipitation under localized geochemical conditions (HILL & FORTI, 1997 ; KLEIN & DUTROW, 2009 ; AULER et al. 2022).

Sulfates are minerals contaning the anionic group $(SO_4)^{2-}$, with jarosite being the most common, accounting half of the sulfate minerals occurences. In Brazil, jarosite is frequently found in crusts and coralloids, typically alongside hematite and, in some cases, phosphates. Alunite was identified in two speleothems, mainly as a crust in sandstone caves where potassium is sourced from guano. Felsobanyaite, a rare mineral derived from marcasite oxidation, is commonly associated with aluminum oxide. Ammonium sulfate and Alum-(Na) were each found in one crust sample, highlighting their rarity in the cave mineral assemblage (MAURITY & KOTSCHOUBEY 199, ALBUQUERQUE et al. 2018). In the

Carajás region, speleothems form through interaction between sulfates and phosphates derived from bat guano, urine, and decomposed bone material with banded iron formation (BIF) and lateritic duricrusts on cave walls and floors (FIGUEIRA et al. 2019).

5. Conclusion

The study of speleothems revealed five types of chemical deposits: coralloids, crusts, flowstones, pendants, and those over termite mounds. The predominant mineralogy cosisted of oxides-hydroxides, followed by silicates, phosphates, sulfates, and carbonates. Goethite was the most common mineral, idetified in 17 samples, primarily in crusts and flowstones, and ranked second in coralloids after hematite. Hematite frequently appeared alongside phosphates, sulfates, and quartz, often in association with goethite. Gibbsite, mainly found with goethite and hematite, likely resulted from acidic dissolution, soil leaching, and guano deposits. Magnetite, a less frequent oxide-hydroxide, was identified in a single sample along with other iron oxides. The mineralogical composition of the speleothems strongly reflects the surrounding iron formations, such as itabirite and canga, which are rich in iron oxides. Silicates, primarily amorphous silica and quartz, constituted the second most abundant group, with silica-rich itabirite deposits occurring near quartzite areas. Carbonate, phosphate, and sulfate minerals were less common. Among sulfates, jarosite was the most frequently occurring, typically found in association with goethite, hematite, and quartz. Regarding phosphate minerals, spheniscidite was the most common, often co- occurring with hematite, goethite, and quartz. Strengite was found in association with goethite, dolomite, and hematite. Among sulfates, felsobanyaite and ammonium sulfate were the rarest, each identified in only one sample.

This study highlights the complexity of speleothem formation in iron-rich caves, emphasizing the interplay between lithology, geochemical conditions, and external influences such as guano deposition. The findings contribute to a broader understanding of mineralogical diversity in speleothems and their environmental implications.

Acknowledgments

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Speleological rescue: mineralogy of speleothems in iron caves, southeastern Brazil

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Abstract

The suppression of legally protected caves in Brazil for mineral resource exploration requires geospeleological rescues to preserve geological and biological elements. These rescues, conducted as part of environmental licensing, involve documenting and collecting representative geological materials to mitigate the irreversible impacts of cave suppression. This study reports on the geological rescue of 11 iron caves in the Tico-Tico Mine area of Minas Gerais, located within the geologically significant Iron Quadrangle, southeastern Brazil. The caves, formed primarily in Cauê Formation itabirites of the Minas Supergroup, were sampled once between September 2020 and August 2023. The rescue included photographic documentation, bibliographic reviews, and collection of rocks, speleothems, and clastic sediments. Speleothems were categorized by color, morphology, and cave location, while clastic deposits underwent granulometric and geochemical analyses using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and X-Ray Diffraction (XRD). Findings revealed that cave rocks were predominantly hematite (44–97%) and quartz (1–55%), with secondary elements like diphosphorus pentoxide and aluminum oxide. Speleothems primarily consisted of quartz and hematite, with some influenced by bat guano acidification. These rescues preserve key geological data, highlighting the need for comprehensive documentation of caves impacted by mining activities.

1. Introduction

Mineral resource exploration may require the suppression of legally protected caves in Brazil (IBAMA 2017, BRASIL 2022). Legally protected caves impacted by activities like mining require thorough environmental licensing, which mandates the geospeleological and biospeleological rescue of unique geological and biological elements (IBAMA 2017, BRASIL 2022). These efforts aim to document and preserve the irreplaceable scientific and conservation value of caves before their suppression. The collected specimens, such as minerals, speleothems, and fauna, are transported to scientific collections, ensuring their availability for research and education (IBAMA 2017). Cave rescues and environmental licensing processes are critical for balancing resource extraction with environmental preservation.

Iron caves, especially those in regions like Brazil's Iron Quadrangle, are notable for their unique mineralogical features (AULER et al. 2019). Formed primarily in iron-rich formations like itabirites, these caves predominantly comprise hematite and quartz, with secondary elements such as phosphorus and aluminum oxides (AULER et al. 2022). Iron caves in Brazil are unique ecosystems of significant geological, biological, and cultural value (FERREIRA et al. 2022). They host diverse subterranean species, including troglobitic organisms, and exhibit rare mineral formations, making them critical for biodiversity and scientific research (AULER et al. 2019, FRAGA et al. 2023). However, these caves face threats from mining activities due to their location within high-value iron ore deposits. Legal protections prioritize the preservation of caves classified as «maximum relevance» (BRASIL 2022), but others may be suppressed if deemed less critical (IBAMA 2017, FERREIRA et al. 2022), with environmental licensing requiring the rescue of biological and geological elements. Conservation efforts focus on advanced research techniques, public awareness, and sustainable practices to balance mining interests with environmental protection, ensuring the preservation of these irreplaceable natural resources.

The study of cave geological structures has evolved from early visual surveys and manual mapping to advanced technological methods. Early techniques focused on qualitative observations and basic geological sampling, while the mid-20th century introduced thin-section microscopy and radiometric dating for precise analysis (WHITE 2006, CHIARADIA 2023). Modern advancements include non-invasive geophysical surveys, X-ray diffraction, isotope geochemistry, and high-resolution imaging technologies like LIDAR and photogrammetry, which enable detailed 3D mapping and geochemical characterization (SPOLADORE et al. 2015, ALI et al. 2022, KAHN et al. 2022). These advancements have shifted research towards understanding the processes that shape cave mineralogy.

Phosphatization and sulfurization are prominent processes in iron caves, driven by the interaction of biological activity and environmental conditions (ALBUQUERQUE et al. 2018, FIGUEIRA et al. 2019). Phosphatization occurs when organic matter, such as bat guano, breaks down and releases phosphoric acid, leading to the formation of phosphate minerals (ALBUQUERQUE et al. 2018). Sulfurization involves sulfur compounds reacting with cave substrates, often through microbial activity, resulting in secondary minerals like gypsum or jarosite (COSMODIS et al. 2019, FIGUEIRA et al. 2019). These processes highlight the complex interplay between geology, biology, and hydrology, offering insights into past environmental conditions and the dynamic nature of cave ecosystems.

Specificaly, the geological rescue includes the collection, transport, and preservation of geological and biological elements in scientific collections due to the irreversible impact on these natural formations (IBAMA 2017). Before cave suppression, geospeleological rescues are conducted as part of environmental licensing, involving photographic documentation, inventory, and the collection of geological elements representative of the subterranean ecosystem (IBAMA 2017, BRASIL 2022).

In this study, we present the results of the geological rescue conducted in iron caves before cave suppression in Minas Gerais, Brazil. We also evaluate the chemical composition of the rescued elements to better understand the processes of cave formation.

2. Materials and methods

The 11 iron caves sampled were in the Tico-Tico Mine area, municipalities of Brumadinho, Igarapé, and São Joaquim de Bicas, Minas Gerais, southeastern Brazil (Figure 1). This region encompasses the Iron Quadrangle at the southern end of the São Francisco Craton. Geomorphologically, the caves are in Serra Azul, the western extension of Serra do Curral beyond the Paraopeba River. Structurally, Serra do Curral forms a large hogback, representing the inverted flank of a syncline with predominantly NNW vergence. At the northwest end of the Iron Quadrangle, Serra Azul is supported by metasedimentary rocks of the Minas Supergroup, especially Cauê Formation itabirites on the ridge. The region also includes the Basement Complex and the Rio das Velhas Supergroup.

Cave	Lat	Long	Elevation	pH	Slope	Area	Volume	Relevance
SAZ-0068	574915	7776087	1237	14.3	4	26.1	19	High
SAZ-0001	574928	7776093	1244	72.2	6.5	226	213	High
SAZ-0008	575011	7776210	1245	53.3	5.2	104	84	High
SAZ-0009	575023	7776213	1241	51.8	3.6	151	161	High
SAZ-0026	575975	7776052	1211	17.5	3.9	28.3	24	High
SAZ-0028	576052	7776078	1192	28.5	7.5	88.6	92	High
SAZ-0030	576045	7775923	1258	43.4	5.9	110	175	High
SAZ-0042	576221	7775821	1241	10.3	6.6	54.6	88	High
SAZ-0045	576292	7775920	1195	22.4	3.2	105.9	55	High
SAZ-0056	576009	7775345	1266	41.1	5.1	123	73	High
SAZ-0076	574588	7775480	1164	23.1	4.7	75.1	59	High

Figure 1: *Coordinates, speleometric data and relevance of the target caves for rescue. Datum SIRGAS 2000 23S.*

The speleological rescue methodology was based on the Speleological Rescue Plan (BIOESPELEO 2019). The rescue included a bibliographic review, photographic records (Figure 2), collection, and analysis of speleothems and rocks. We collected samples of rock, speleothems, and clastic sediments representative of the caves.

For the chemical deposit samples, all types of speleothems seen inside the cave were collected. The speleothems were described in terms of color, morphology, dimensions, and cave location. Clastic sedimentary deposits were assessed by opening trenches at selected locations within the cave (Figure 3). The granulometric test was carried out using the dry method on meshes with different dimensions.

Figure 2: *Photographic records in the cave SAZ-0028.*

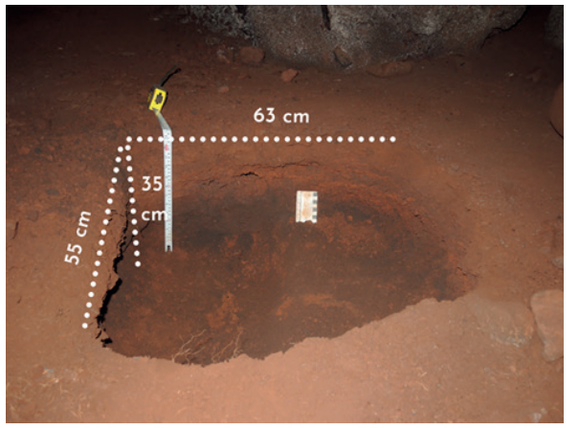

Figure 3: *Trench showing the different layers found in the cave floor.*

The rescue was carried out once per cave between September 2020 and August 2023. Geochemical analyses were performed using the Inductively Coupled Optical Emission Spectrometer (ICP-OES) and X-Ray Diffraction (XRD) techniques. The ICP-OES is an analytical technique that quantifies chemical elements (metals, semi-metals, and rare material), while the XRD method is the interaction between an incident beam of X-rays and the electrons of the component atoms of a material.

The rescue operations were conducted for each cave on a single occasion between September 2020 and August 2023, prioritizing a comprehensive geochemical analysis of the samples collected. Two advanced analytical techniques, Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) and X-Ray Diffraction (XRD), were employed to characterize the composition of the geological and chemical materials.

ICP-OES is a highly sensitive technique used to quantify a wide range of chemical elements, including metals, semi-metals, and rare materials. This method involves exciting atoms and ions in a plasma, causing them to emit light at characteristic wavelengths, which are then measured to determine element concentrations with remarkable precision (ALI et al. 2022). XRD, on the other hand, focuses on identifying the crystalline structure of materials by analyzing the interaction between incident X-rays and the electrons of the material's atoms. This interaction produces a diffraction pattern unique to each mineral or compound, enabling the identification of mineral phases present in the samples (KHAN et al. 2022). By combining these complementary techniques, the study provided detailed insights into the mineralogical and chemical composition of the cave materials, contributing valuable data on the geological processes and environmental conditions shaping these unique subterranean systems.

3. Results

Mostly rock caves were predominantly formed by hematite (Fe2O3; range 44–97%) and secondarily by quartz (SiO_2; range 1–55%) (Figure 4). Some rock caves had diphosphorus pentoxide (P_2O_5) or aluminum oxide (Al_2O_3) as secondary main element. Speleothems (crust and coralloid) (Figure 5) were predominantly formed by quartz and hematite. Others identified mineral specimens appear to be genetically related to the speleothem's type, since the crusts diffractograms resemble each other, unlike the diffractogramas associated with coralloids. Coralloids exhibit chemical composition with a predominance of silica, followed by iron, aluminum and phosphorus. The beginning of their diffractogram presents a small protuberance (Figure 5), without any defined peak, characteristic of the presence of amorphous mineral phases and with insufficient crystalline plane to be detected by X-ray without adequate treatment, possibly being related to poorly crystalline phosphate mineral phases, as well as amorphous phases of secondary products of the weathering of jarosites ($K(Fe_3(SO_4)_2(OH)_6$). Regarding the crusts, the high percentage of Fe stands out, followed by P, Al and Si. The higher concentration of phosphorus allows the diversification of the phosphate assembly, with minerals such as spheninscidite ($(NH_4)Fe_2(PO_4)_2(OH)$ $2H_2O$)), leucophosphite ($KFe_2(PO_4)_2(OH)$ $2H_2O$), strengite ($Fe(PO_4)(H_2O)_2$) and phosphosiderite ($Fe(PO_4)(H_2O)_2$) being identified.

Cave	Al_2O_3	BaO	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	P_2O_5	SiO_2	TiO_2	MnO	V_2O_5	LOI	Ba	Nb	Sr	Zn	Zr	V
SAZ-0001	1.25	0.02	0.02	<0.01	85	0.03	<0.1	<0.1	5.72	1.99	0.13		0.02	6.54						
SAZ-0008	0.57	0.03	0.02	<0.01	95	<0.01	<0.1	<0.1	0.42	2.05	0.24		0.02	2.13						
SAZ-0026	0.78	<0.01	<0.01	<0.01	96.5	<0.01	<0.1	0.12	0.31	1.24	0.2		<0.01	1.41						
SAZ-0028	0.62		0.01	<0.01	>75	0.04	<0.01	<0.01	0.2	2.31	0.28	0.01		1.29	10	<10	<10	<5	51	112
SAZ-0030	0.24	<0.01	0.08	<0.01	62.7	0.01	<0.1	<0.1	0.29	35.7	0.02		<0.01	0.28						
SAZ-0045	0.24		0.04	<0.01	44.48	0.05	<0.01	<0.01	0.16	55.24	<0.01	0.01		0.48	46	<10	20	<5	<10	<5
SAZ-0056	1.17	<0.01	0.03	<0.01	94.9	<0.01	<0.1	<0.1	0.21	0.82	0.48		<0.01	1.57						
SAZ-0056	1.07	0.02	0.03	0.01	94.5	<0.01	<0.1	<0.1	0.19	0.71	0.28		<0.01	1.75						
SAZ-0068	1.64	<0.01	0.03	0.01	85.8	0.04	<0.1	<0.1	4.61	2.28	0.45		<0.01	4.24						

Figure 4: *Result of rock compositional analysis.*

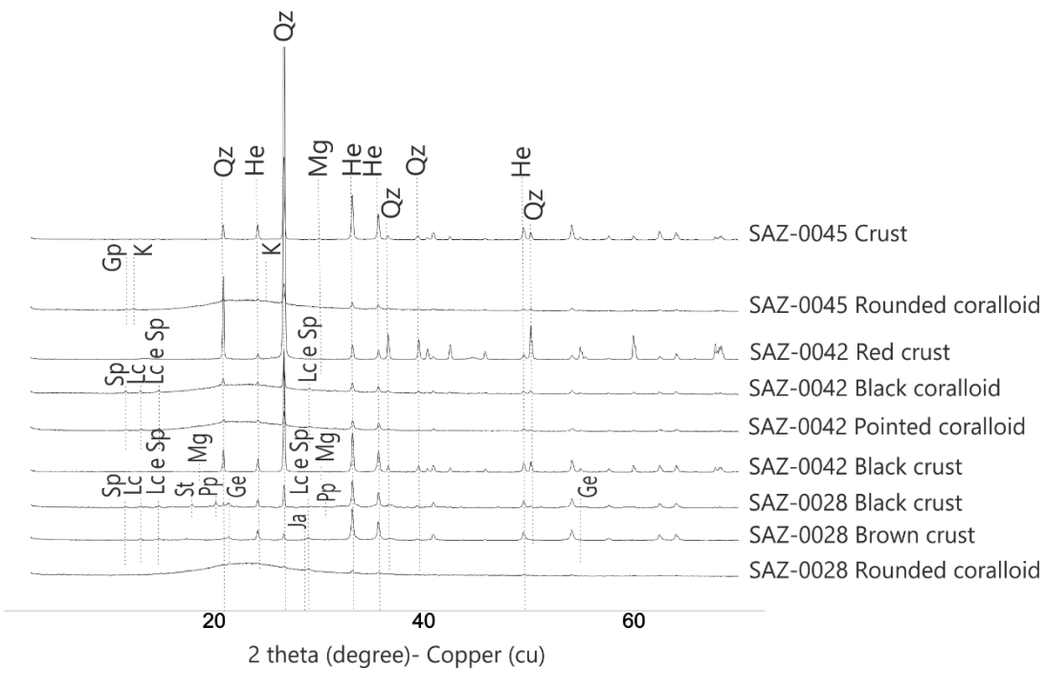

Figure 5: *Representative XRD diffractogram patterns pf coralloid and crust-type speleothems. Ja: Jarosite ; Ge: Goethite; Gp: Gypsum; K: Kaolinite; Lc: leucofosfita; Mg: magnetita; Qz: quartzo; Sp: sphenicidita ; St: Sphenicidite; St: Strangite.*

Cave/Sample	Sample	Al_2O_3	BaO	CaO	Cr2O3	Fe_2O_3	K_2O	MgO	Na_2O	P_2O_5	SiO_2	TiO2	V_2O_5	MnO	LOI	Ba	Nb	Sr	Zn	Zr	V
SAZ-0001	Coralloid	2.28	0.08	0.37	<0.01	31.7	0.14	0.11	<0.1	0.19	54	0.17	<0.01	-	8.98	-	-	-	-	-	-
SAZ-0001	Coraloid	3.97	0.06	0.27	<0.01	25.7	0.36	<0.1	<0.1	0.45	54.7	0.15	<0.01	-	14.57	-	-	-	-	-	-
SAZ-0001	Coraloid	3.08	0.07	0.3	<0.01	23.6	0.93	<0.1	<0.1	0.7	57.8	0.14	<0.01	-	12.79	-	-	-	-	-	-
SAZ-0001	Crust	1.7	0.03	0.07	0.01	58.6	0.66	<0.1	<0.1	12.08	18.1	0.41	0.01	-	8.18	-	-	-	-	-	-
SAZ-0008	Coralloid	3.81	0.07	0.2	0.01	19.6	0.25	<0.1	<0.1	0.5	64.7	0.1	<0.01	-	9.21	-	-	-	-	-	-
SAZ-0008	Crust	3.18	0.03	0.06	0.01	74.5	0.09	<0.1	<0.1	2.49	12.8	0.42	0.02	-	6.29	-	-	-	-	-	-
SAZ-0009	Crust	3.71	0.05	0.05	0.02	62.4	0.15	<0.1	<0.1	3.7	21.7	0.5	0.03	-	7.38	-	-	-	-	-	-
SAZ-0028	Rounded coralloid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAZ-0028	Pointed coralloid	1.79	-	0.26	<0.01	9.65	0.1	0.1	0.06	1.09	79.95	0.11	-	0.01	8.27	319	<10	60	14	11	<5
SAZ-0028	Brown crust	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAZ-0028	Black crust	2.37	-	0.03	<0.01	>75	0.36	0.01	<0.01	6.87	2.1	0.65	-	0.02	6.98	35	21	<10	111	137	107
SAZ-0028	Trench 1 (0-5 cm)	2.03	-	<0.01	0.01	>75	<0.01	<0.01	0.17	2.91	4.13	0.83	-	0.02	5.6	13	<10	<10	<5	149	232
SAZ-0028	Trench 1 (5-50+ cm)	1.71	-	<0.01	<0.01	>75	<0.01	0.01	0.19	1.07	3.58	0.66	-	0.02	4.3	<10	<10	<10	<5	124	175
SAZ-0028	Trench 2 (0-3 cm)	2.52	-	0.04	<0.01	73.47	<0.01	0.02	0.24	0.34	21.18	0.44	-	0.02	4.34	26	<10	14	<5	91	145
SAZ-0028	Trench 2 (3-15 cm)	2.52	-	<0.01	<0.01	>75	<0.01	0.01	0.23	0.5	5.46	0.75	-	0.02	4.34	12	<10	<10	<5	127	201
SAZ-0028	Trench 2 (15-43+ cm)	2.1	-	0.03	<0.01	>75	<0.01	0.03	0.015	0.39	2.84	0.59	-	0.02	3.45	11	11	<10	34	109	251
SAZ-0030	Coralloid	0.92	0.09	0.65	<0.01	4.35	0.11	0.11	<0.1	2.76	81.6	0.08	<0.01	-	8.13	-	-	-	-	-	-
SAZ-0042E01	Red crust	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAZ-0042E02	Black crust	0.26	-	0.04	<0.01	51.8	0.01	0.02	<0.01	0.24	47.08	0.02	-	0.02	0.14	82	<10	12	<5	13	42
SAZ-0042E03	Pointed coralloid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAZ-0042E04	Large coralloid	3.04	-	0.23	<0.01	18.9	0.36	0.1	0.03	3.01	66.82	0.13	-	0.04	9.76	1529	10	192	25	32	23
SAZ-0042E05	Black coralloid	2.92	-	0.26	<0.01	11.13	0.2	0.07	0.05	2.93	70.07	0.08	-	0.02	11.8	796	<10	114	25	17	42
SAZ-0042T1S01(0-35)	Trench 1 (0-35 cm)	1.2	-	0.02	<0.01	71.17	<0.01	0.03	0.16	0.12	25.42	0.19	-	0.02	3.32	15	<10	<10	<5	56	125
SAZ-0042T1S02(35-60)	Trench 1 (35-60 cm)	1.34	-	0.01	<0.01	68.36	<0.01	0.03	0.23	0.13	26.67	0.2	-	0.02	2.47	12	<10	<10	<5	47	83
SAZ-0042T2S01(0-25)	Trench 2 (0-25 cm)	1.54	-	<0.01	<0.01	67.15	<0.01	0.03	0.22	0.17	24.28	0.21	-	0.02	2.75	12	<10	<10	<5	39	88
SAZ-0042T2S02(25-60)	Trench 2 (25-60 cm)	1.34	-	<0.01	<0.01	>75	<0.01	0.02	0.18	0.27	23.14	0.21	-	0.02	1.96	12	<10	<10	<5	43	104
SAZ-0045E01	Coralloid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAZ-0045E02	Crust	0.41	-	0.03	<0.01	65.26	0.06	0.02	<0.01	0.35	35.31	0.05	-	0.02	0.71	46	<10	16	5	19	31
SAZ-0045S01	Trench 1 (0-55 cm)	4.56	-	<0.01	<0.01	63	0.06	0.08	0.16	0.06	29.62	0.8	-	0.08	2.98	59	11	<10	<5	135	159
SAZ-0056	Coralloid	8.55	<0.01	0.2	<0.01	11.1	0.03	<0.1	<0.1	0.31	67.7	0.22	<0.01	-	10.95	-	-	-	-	-	-
SAZ-0068	Coralloid	2.69	0.06	0.16	<0.1	16.8	2.18	<0.1	<0.1	1.02	62.2	0.07	<0.1	-	15.48	-	-	-	-	-	-
SAZ-0068	Coralloid	2.5	0.1	0.2	<0.1	15.5	0.19	0.13	<0.1	0.69	71.4	0.07	<0.1	-	8.94	-	-	-	-	-	-

Figure 6: *Result of the compositional analysis of coralloids, crusts and trenches recovered from the caves.*

Cave	Cave sample	Mineral	Formula	Observation	Sample
SAZ-0001	SAZ-0001E02	Hematite	Fe_2O_3	-	Coralloid
SAZ-0001	SAZ-0001E02	Goethite	FeO(OH)	-	Coralloid
SAZ-0001	SAZ-0001E02	Gypsum	$Ca(SO_4)(H_2O)_2$	Possible presence	Coralloid
SAZ-0001	SAZ-0001E02	Quartz	SiO_2	Possible presence	Coralloid
SAZ-0001	SAZ-0001E06	Hematite	Fe_2O_3	-	Crust
SAZ-0001	SAZ-0001E06	Quartz	SiO_2	-	Crust
SAZ-0001	SAZ-0001E06	Spheniscidite	$(NH_4)Fe_2(PO_4)_2(OH)$ $2H_2O$	-	Crust
SAZ-0001	SAZ-0001E06	Jarosite	$K(Fe_3(SO_4)_2(OH)6)$	-	Crust
SAZ-0001	SAZ-0001E06	Goethite	FeO(OH)	Possible presence	Crust
SAZ-0001	SAZ-0001E06	Strengite	$Fe(Po_4)(H_2O)_2$	Possible presence	Crust
SAZ-0008	SAZ-0008E02	Hematite	Fe_2O_3	-	Coralloid
SAZ-0008	SAZ-0008E02	Goethite	FeO(OH)	-	Coralloid
SAZ-0008	SAZ-0008E02	Quartz	SiO_2	Possible presence	Coralloid
SAZ-0009	SAZ-0009E01	Hematite	Fe_2O_3	-	Coralloid
SAZ-0009	SAZ-0009E01	Quartz	SiO_2	-	Coralloid
SAZ-0009	SAZ-0009E01	Goethite	FeO(OH)	-	Coralloid
SAZ-0026	SAZ-0026E01	Hematite	Fe_3O_4	-	Coralloid
SAZ-0026	SAZ-0026E01	Goethite	FeO(OH)	Possible presence	Coralloid
SAZ-0026	SAZ-0026E01	Quartz	SiO_2	Possible presence	Coralloid
SAZ-0026	SAZ-0026E02	Hematite	Fe_3O_4	-	Coralloid
SAZ-0026	SAZ-0026E02	Goethite	FeO(OH)	-	Coralloid
SAZ-0026	SAZ-0026E02	Quartz	SiO_2	Possible presence	Coralloid
SAZ-0026	SAZ-0026E03	Hematite	Fe_3O_4	-	Crust
SAZ-0026	SAZ-0026E03	Goethite	FeO(OH)	Possible presence	Crust
SAZ-0026	SAZ-0026E03	Quartz	SiO_2	Possible presence	Crust
SAZ-0030	SAZ-0030E04	Amorphous phase	-	-	Coralloid
SAZ-0030	SAZ-0030E04	Quartz	SiO_2	-	Coralloid
SAZ-0030	SAZ-0030E04	Hematite	Fe_3O_4	Possible presence	Coralloid
SAZ-0030	SAZ-0030E04	Gypsum	$Ca(SO_4)(H_2O)_2$	Possible presence	Coralloid
SAZ-0030	SAZ-0030E01	Hematite	Fe_3O_4	-	Crust
SAZ-0030	SAZ-0030E01	Quartz	SiO_2	-	Crust
SAZ-0030	SAZ-0030E02	Amorphous phase	-	-	White crust
SAZ-0030	SAZ-0030E02	Quartz	SiO_2	Possible presence	White crust
SAZ-0056	SAZ-0056R02B	Hematite	Fe_2O_3	-	Rock
SAZ-0056	SAZ-0056R02B	Quartz	SiO_2	-	Rock
SAZ-0056	SAZ-0056R02B	Magnetite	Fe_3O_4	Possible presence	Rock
SAZ-0056	SAZ-0056E02	Hematite	Fe_2O_3	-	Crust
SAZ-0056	SAZ-0056E02	Goethite	FeO(OH)	-	Crust
SAZ-0056	SAZ-0056E02	Quartz	SiO_2	Possible presence	Crust
SAZ-0056	SAZ-0056E02	Magnetite	Fe_3O_4	Possible presence	Crust
SAZ-0068	SAZ-0068E04	Hematite	Fe_3O_4	-	Coralloid
SAZ-0069	SAZ-0068E04	Goethite	FeO(OH)	Possible presence	Coralloid
SAZ-0070	SAZ-0068E04	Quartz	SiO_2	Possible presence	Coralloid
SAZ-0071	SAZ-0068E04	Gypsum	$Ca(SO_4)(H_2O)_2$	Possible presence	Coralloid
SAZ-0072	SAZ-0068E03	Hematite	Fe_3O_4	-	Crust
SAZ-0073	SAZ-0068E03	Goethite	FeO(OH)	Possible presence	Crust
SAZ-0074	SAZ-0068E03	Quartz	SiO_2	Possible presence	Crust

Figure 7*: Identification of the main minerals found in the caves.*

4. Discussion

The findings on the mineralogical composition of iron caves provide valuable insights into their formation processes and environmental dynamics. Hematite (Fe_2O_3) and quartz (SiO_2) dominate both rock formations and speleothems, with hematite comprising up to 97% of the composition in some caves. This dominance underscores the significant influence of the iron-rich geology in these subterranean systems (DORR 1969). Known for representing the main constituents of the sand and silt fraction (DREES 1989), the chemical and structural characteristics of quartz provide efficient resistance to authigenic and crystallographic transformations. These same characteristics are also responsible for promoting high-intensity peaks in the diffractograms, such as those observed in the samples.

The specificities of the diffractograms are shown from two perspectives. The first concerns the comparison between the types of speleothems sampled. The diffractograms of the crusts are smoother and linear, while those of the coralloids show noise and a small hill at the beginning, a configuration that marks the presence of amorphous mineral phases, possibly related to poorly crystalline phosphate mineral phases. The presence of such phosphate minerals is the second aspect of note. The geochemistry of the rocks analyzed shows insignificant amounts of phosphorus, which is only supplied to these environments by guano from bat colonizations (past or present). The relationship between guano, solution and materials makes it possible for a series of geochemical reactions to take place, based on precipitation, dissolution, interaction with basic or acidic solutions, dehydration and hydration, oxy-redox reactions (ONAC and FORTI 2011) which produce distinct and diverse mineralogical assemblages, resulting in the authigenic precipitation of more complex and diverse minerals, such as leucophosphite iron phosphates, sphenicidite, strengite and phosphosiderite. The role of nesting bats is important not only in mineralogical diversification but also in making up for the nutritional poverty of the parental material, and is essential in maintaining resources for cave micro- and mesofauna. This ecological service earns bats the nickname of ecosystem engineers in caves (PILÓ et al. 2023), modifying the distribution of matter and energy based on the geochemical and physical transformations provided by the colonies.

Moreover, secondary elements such as diphosphorus pentoxide (P_2O_5) and aluminum oxide (Al_2O_3) in certain caves reflect localized geochemical variations (CALUX et al. 2019, SPIER et al. 2019). These could arise from interactions between environmental factors like bat guano deposits, microbial activity, and the acidification of drip water. Acidic solutions from guano decomposition and microbial activity are capable of corrode cave floors and walls, leading to structural enlargement (PILÓ et al. 2023). Such processes introduce heterogeneity into the caves, influencing their mineralogical profiles and providing evidence of biological and chemical interplay over time (AULER et al. 2019).

The clastic deposits found in the caves are predominantly autogenic consisting of hematite clasts originating from the banded iron formations, canga, and sometimes altered mafic rocks (AULER et al. 2022). These stratifications provide insights into the depositional history and environmental changes within the caves. They may act as natural archives, documenting the sedimentary and hydrological conditions that have prevailed over time.

These results have implications for the conservation and study of iron caves. By understanding their mineralogical and geochemical complexity, researchers and conservationists can better appreciate their ecological and geological significance. This knowledge is particularly critical in regions where mining activities pose threats to these unique environments, informing strategies for preservation and sustainable management (FERREIRA et al. 2022).

5. Conclusion

The mineral formations observed in the rescued caves are likely influenced by the acidification of drip water interacting with bat guano, which accumulates in the cave microenvironment from past or ongoing bat colonizations. By employing advanced analytical techniques such as Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and X-Ray Diffraction (XRD), critical geological and geochemical characteristics of the suppressed iron caves were effectively documented and preserved.

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Textura dos solos e sedimentos das cavernas do Legado Verdes do Cerrado, Goiás

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Resumo

Solos e sedimentos recobrem o carste e sua textura influencia diretamente na porosidade, aeração e infiltração de água. Esse trabalho objetivou comparar a textura dos solos e sedimentos nas cavernas do Tarzan, Timor e Val, em Goiás. A análise granulométrica pelo método da pipeta revelou diferentes proporções de areia, silte e argila, posteriormente mapas topográficos foram vetorizados no QGIS e foi realizada interpolação estatística pelo método IDW. A areia predominou em todas as cavernas, com valores acima de 50%. A argila oscilou entre 30 e 42% nas cavernas do Tarzan e do Val, sendo expressivamente reduzida na caverna do Timor, entre 11 e 19%. O silte apresentou menor proporção, entre 8 e 11% nas cavernas Tarzan e Val, elevando-se sensivelmente na caverna do Timor, para 25 a 31%. A diversidade de tamanho de partículas encontradas nos solos e sedimentos estudados reflete a ampla variação granulométrica associada às rochas do grupo Paranoá, como quartzito, filito e ardósia do material de origem. Evidencia-se que, em cada uma das três cavernas, fluxos hídricos ocorrem com intensidades diferentes refletindo nos processos de sedimentação onde partículas com diferentes tamanhos podem ser depositadas, em diferentes posições das cavidades, de acordo com o relevo interno do piso.

Abstract

Soils and sediments cover the karst and their texture directly influences porosity, aeration and water infiltration. This work aimed to compare the texture of soils and sediments in the caves of Tarzan, Timor and Val, in Goiás. Granulometric analysis using the pipette method revealed different proportions of sand, silt and clay, subsequently topographic maps were vectorized in QGIS and interpolation was performed using statistics IDW method. Sand predominated in all caves, with values above 50%. Clay fluctuated between 30 and 42% in the Tarzan and Val caves, being significantly reduced in the Timor cave, between 11 and 19%. Silt presented a lower proportion, between 8 and 11% in the Tarzan and Val caves, rising significantly in the Timor cave, to 25 to 31%. The diversity of particle sizes found in the soils and sediments studied reflects the wide granulometric variation associated with the rocks of the Paranoá group, such as quartzite, phyllite and slate of the source material. It is evident that, in each of the three caves, water flows occur with different intensities, reflecting the sedimentation processes where particles with different sizes can be deposited, in different positions of the cavities, according to the internal relief of the floor.

1. Introdução

O solo e sedimentos apresentam características de permeabilidade que podem afetar, em diferentes magnitudes, os processos deposicionais, a dinâmica ambiental e as interações entre fatores geológicos, hidrológicos e climáticos nas cavernas e entorno (ROSÁRIO, 2021). Por sua vez, a permeabilidade do substrato terroso em ambientes cársticos e em geral, depende de aspectos físicos como textura, espessura, porosidade e mineralogia.

A textura dos solos e sedimentos é um dos critérios fundamentais para caracterizar um ambiente deposicional e avaliar as propriedades físicas dos substratos. É um reflexo do material de origem e/ou das condições de transporte e deposição, fornece, inclusive, subsídios para interpretar a história evolutiva e paleoambiental das cavidades subterrâneas (VASCONCELOS; BITTENCOURT, 2018).

A composição granulométrica dos solos e sedimentos (Terra fina Seca ao Ar – TFSA) é definida pelas proporções de areia, silte e argila, de acordo com a EMBRAPA (2018).

A fração areia contém as partículas maiores, com diâmetro entre 0,05 mm e 2mm e confere características como alta porosidade e baixa capacidade de retenção de água. A fração silte, de tamanho intermediário (entre 0,002 mm e 0,05 mm), contribui para a retenção de água, mas oferece pouca coesão. A fração argila é composta por partículas muito finas (menores a 0,002 mm), e confere ao substrato alta capacidade de retenção de água e nutrientes, além de uma maior compactação e menor permeabilidade.

Depósitos de granulometria fina, como silte e argila, indicam ambientes calmos e estáveis, favoráveis à preservação de restos orgânicos e fósseis delicados, como pequenos ossos e conchas (VASCONCELOS; BITTENCOURT 2018). Já granulometrias maiores, como a areia, indicam ambientes com maior atividade, associados a fluxos de energia moderada que podem transportar materiais maiores, mas que também podem impactar a preservação de registros paleontológicos.

Este trabalho teve como objetivo identificar e mapear a distribuição granulométrica (textura) dos solos e sedimentos das camadas superficiais presentes no interior das cavernas Tarzan, Timor e Val, em Niquelândia, Goiás.

2. Materiais e Métodos

As cavernas Timor, Tarzan e Val estão localizadas na Reserva Privada de Produção Sustentável Legado Verdes do Cerrado (LVC), em Niquelândia, Goiás (fig.1). A região possui clima tropical chuvoso (Aw), com verões úmidos, invernos secos, pluviosidade média anual de 1787 mm e temperaturas entre 17°C e 34°C e vegetação típica do bioma cerrado, com diversas fitofisionomias (REZENDE; ALVES, 2017).

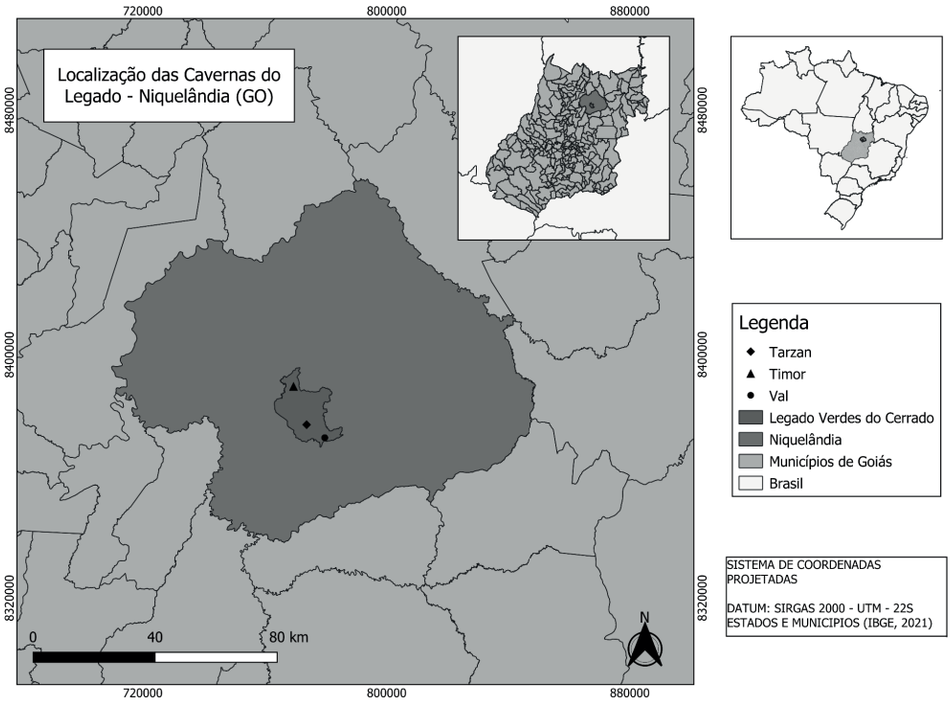

Figura 1: *Mapa de localização das cavernas Tarzan, Timor e Val, no Legado Verdes do Cerrado, Niquelândia, Goiás.*

A área está inserida no Grupo Paranoá, composto por metassedimentos como quartzitos, filitos, ardósias, calcários, dolomitos e mármores, formados em ambientes marinhos no Mesoproterozóico e Neoproterozóico. A paisagem local, caracterizada por relevo acidentado, inclui serras, montanhas e depressões intermontanas, da Chapada do Alto Rio Maranhão (900-1100 m) e da Depressão do Alto Tocantins (700-800 m) (ZANCOPÉ et al., 2023).

Na região, Latossolos são observados nas áreas aplainadas, Cambissolos nas encostas levemente inclinadas e Neossolos Litólicos nas encostas fortemente inclinadas (BRANDÃO et al., 2022). No carste carbonático do LVC ocorrem os Neossolos Litólicos eutróficos (MIRANDA et al., 2022). Apesar de rasos, esses solos possuem características físico-químicas favoráveis de boa porosidade e permeabilidade e elevados pH, Soma de bases (SB) e Saturação por bases (V%) que os tornam capazes de sustentar densa vegetação arbórea no bioma Cerrado.

Os dados sobre textura dos solos e sedimentos aqui avaliados fazem parte do projeto de pesquisa « Espeleologia e biodiversidade no Legado Verdes do Cerrado» (FAPEG n°202310267000407) e são resultantes de amostras coletadas em campo, na camada 0-5 cm, e analisadas em laboratório previamente, entre janeiro e julho de 2024.

A composição granulométrica dos solos e sedimentos foi obtida utilizando o método da pipeta, conforme o Manual de Métodos de Análise do Solo (EMBRAPA, 2017).

A partir de planilhas eletrônicas, foram elaborados gráficos de barras acumuladas horizontais para expressar os percentuais de areia, silte e argila em cada posição dentro de cada uma das 3 cavernas. Na caverna do Tarzan (70 m de desenvolvimento linear - DL) foram coletadas 4 amostras em posições diferentes, sendo TP1 na parte externa. A caverna do Timor, por sua pequena extensão (DL=13m), ofereceu apenas dois pontos amostrais, sendo F1, o ponto externo. A caverna do Val (DL=54m) teve 5 locais amostrados, 4 internos e um externo – VP1.

Expedições anteriores do Pequi Espeleogrupo de Pesquisa e Extensão foram responsáveis pela elaboração de levantamentos e mapeamentos topográficos, grau BCRA4 (ASSUNÇÃO; BRAGANTE-FILHO, 2015) com azimutes, distâncias e inclinações obtidos com bússola modelo Tandem da marca Suunto, que possui clinômetro acoplado e trena a laser Leica. Os pontos externos georreferenciados para amarração com pontos internos às cavernas foram obtidos com GPS marca Garmin, modelo CSx60.

Tais mapeamentos anteriores serviram de base para o traçado do perímetro, limites das paredes obtidos previamente em campo e posterior elaboração dos mapas de distribuição espacial dos solos e sedimentos nas cavernas, com a vetorização no programa QGIS e conversão para arquivos no formato shapefiles. Em seguida, os dados foram interpolados pelo método IDW gerando mapas de distribuição de areia, silte e de argila (%) da camada 0-5 cm de profundidade das cavidades.

3. Resultados

A análise granulométrica dos solos e sedimentos das cavernas Tarzan, Timor e Val revelou diferenças expressivas na composição e distribuição das frações de areia, silte e argila, evidenciando padrões distintos de transporte e deposição sedimentar. Sendo que, de forma geral, a fração areia predominou em todas as cavernas e em todos os pontos avaliados.

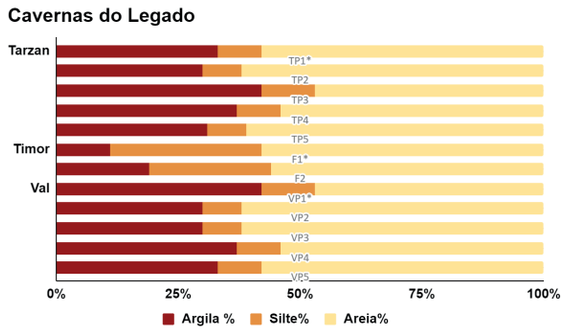

Figura 2: Granulometria comparativa dos solos/sedimentos nos pontos internos e externos das cavernas do Tarzan, do Timor e do Val.

Na Caverna Tarzan, a areia foi predominante em todas as amostras analisadas, seguida de proporções intermediárias de argila e baixos teores de silte. Essa distribuição sugere a predominância de um ambiente com alta energia de transporte, favorecendo a deposição de partículas maiores, tamanho areia.

Na Caverna Timor, observou-se um aumento expressivo na proporção de silte nas amostras. A argila apresentou baixa concentração, enquanto a areia permaneceu como a fração dominante. Esse padrão pode indicar condições mais estáveis para a deposição de partículas médias, com intensidade moderada nos fluxos hídricos.

A Caverna do Val apresentou distribuição granulométrica semelhante à do Tarzan, com predomínio da fração areia, exceto no ponto externo VP1, onde a fração argila teve maior concentração em comparação às outras cavernas. A fração silte apresentou proporções semelhantes à caverna do Tarzan, sugerindo um ambiente com baixa turbulência, maior possibilidade de retenção de partículas finas e, provavelmente, menor contribuição de rochas metapelíticas como siltitos e filitos.

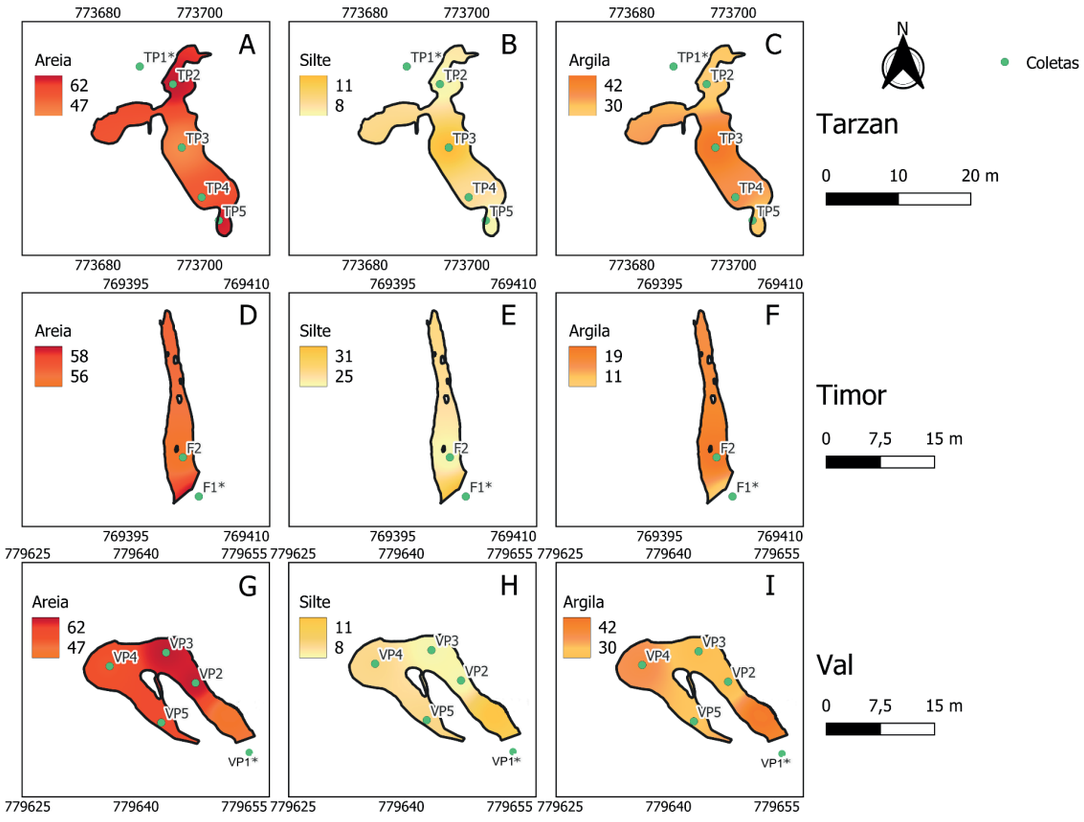

Figura 3: Distribuição espacial das frações granulométricas areia (A, D e G), silte (B, E e H) e argila (C, F e I) nas cavernas do Tarzan (A,B e C), do Timor (E, F e G) e do Val (G,H e I), cores mais intensas refletem valores maiores e vice-versa.

Os mapas de distribuição espacial revelaram que os maiores teores de areia, silte e argila se alternam quanto às suas posições avaliadas, não havendo posição preferencial de acúmulo, quanto à proximidade ou distanciamento da entrada e/ou das fontes de iluminação. Ao observar os mapas de areia (Fig. 3A, D e G), nota-se cores intensas nas 3 cavernas, variando de laranja a vermelho escuro em posições diversas em cada cavidade, indicando que a fração areia predomina em todas as posições em cada uma das 3 cavernas. Na caverna do Tarzan, os teores de argila e silte se elevam em um pequeno trecho da porção central (Fig. 3B,C). Na caverna do Timor, os baixos teores de argila se concentram próximos à entrada. Na caverna do Val, os maiores valores de argila se concentram no ponto externo à entrada da cavidade. Provavelmente, devido à maior concentração de matéria orgânica (M.O.) proveniente da vegetação da parte externa da caverna e/ou maior atividade da fauna, visto que a M.O. corresponde ao tamanho argila.

Como a argila tende a se concentrar em áreas de menor fluxo, o

silte se acumula em regiões intermediárias e a areia predomina onde os fluxos são mais intensos, foi possível captar diferenças que refletem as condições locais de transporte sedimentar e a dinâmica hídrica de cada caverna avaliada.

Os resultados confirmam que a granulometria dos sedimentos está diretamente relacionada às características geomorfológicas, hidrológicas e ambientais das cavernas analisadas, fornecendo uma base sólida para compreender os processos deposicionais em sistemas cársticos do Cerrado.

4. Discussão

Estudo realizado por BENTES (2019) em duas cavernas no carste carbonático da Formação Araxá, em Vila Propício, Goiás, município vizinho à Niquelândia, revelou a ocorrência de um padrão semelhante de predomínio da fração areia. Entretanto, este estudo apontou valores de silte maiores e argila menores do que os observados nas cavernas do LVC.

Como a fração silte representa um estágio transitório na degradação dos minerais rumo à fração argila, duas hipóteses podem explicar: i) as rochas do LVC contém poucos minerais originalmente no tamanho silte, ou ii) as condições hidrológicas e topográficas resultam em fluxos superficiais de menor intensidade, capazes de transportar e promover a deposição de partículas finas como a fração argila. Como é comum a presença de rochas como filito do LVC, ricas em silte, é mais provável haver condições hídricas diversas.

A análise dos sedimentos nas cavernas Tarzan, Timor e Val revelou padrões granulométricos distintos que refletem as condições deposicionais e dinâmicas ambientais específicas de cada caverna. O predomínio de areia em todas as cavernas sugere fluxos hídricos de média a alta energia, responsáveis pelo transporte e deposição de partículas maiores. No entanto, as diferenças na proporção de silte e argila destacam a influência de fatores locais, como microclima, declividade e topografia interna.

A Caverna Timor, por exemplo, apresentou maior proporção de silte, o que pode indicar fluxos de menor intensidade ou condições mais estáveis para a deposição de partículas médias. Já a Caverna Val, com maior concentração de argila na parte externa, aponta para ambientes de baixa turbulência, favoráveis à sedimentação de partículas finas. Então, podemos assumir de acordo com o estudo de RODRIGUES (2014) no qual observou que em regiões com maiores declividades, a energia do fluxo hídrico é mais elevada, favorecendo o transporte e a deposição de partículas de maior granulometria, como areia. Para a deposição de frações mais finas, como silte e argila, é necessário um ambiente com menor energia hidráulica e turbulência, condições típicas de áreas com relevo suavizado ou planícies. Nesses locais, a redução da velocidade do fluxo permite a sedimentação dessas partículas de menor tamanho, que, em condições de maior energia, seriam transportadas e não depositadas. Assim, como observado no estudo de BRANDÃO et al. (2022), a Caverna Tarzan também exibiu maior homogeneidade, com predomínio de areia em todas as amostras, sugerindo maior uniformidade nas condições de transporte e deposição.

Essas variações reforçam a importância da interação entre fatores geológicos, climáticos e hidrológicos na definição dos padrões granulométricos em ambientes cársticos. Além disso, a caracterização granulométrica contribui para a compreensão dos processos erosivos e deposicionais, sendo uma ferramenta valiosa para estudos ambientais e de conservação em cavernas do Cerrado.

5. Conclusão

Nas três cavernas analisadas, é possível observar que a porcentagem de areia é predominante em todas. A presença de materiais mais arenosos em todas as cavernas indica que esses ambientes podem estar sujeitos a influência de fluxos hídricos intensos com processos de sedimentação onde a areia é mais facilmente depositada, devido à alta competência dos fluxos.

A textura do solo pode contribuir para o entendimento e reconhecimento dos processos físico-hídricos nos terrenos cársticos, além de fornecer informações sobre a dinâmica dos sistemas e as interações entre o solo e outros elementos naturais.

A análise granulométrica é útil para avaliar a estabilidade geotécnica de terrenos, o potencial de infiltração de água e a distribuição de nutrientes no solo. Contribuindo, inclusive, para a reconstrução de cenários paleoambientais e para o entendimento da dinâmica dos ecossistemas que existiram em diferentes períodos geológicos.

Agradecimentos

Agradecemos à Fundação de Amparo à Pesquisa do Estado de Goiás (FAPEG) e à Reserva Legado Verdes do Cerrado (CBA/Votorantim) pelo suporte financeiro ao Projeto Espeleologia e Biodiversidade (Chamada Pública 10/2022, n. 202310267000407), ao Laboratório de Geomorfologia, Pedologia e Geografia Física (Labogef-IESA/UFG) e ao Pequi Espeleogrupo de Pesquisa e Extensão pelo apoio logístico e instrumental e à equipe gestora do Legado Verdes do Cerrado pela colaboração em atividades de campo.

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Holocene environmental shifts in East-Central Europe: A Romanian cave sediment record

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Abstract

This study presents a reconstruction of environmental changes in East-Central Europe during the Middle to Late Holocene, based on sediment cores from Ciur Izbuc Cave in northwestern Romania. Through a multi-proxy approach, including lithological, geochemical, magnetic susceptibility, organic matter, and charcoal analyses, the study provides insights into past climatic conditions, vegetation shifts and human impact on the landscape. Since caves respond sensitively to hydrological processes, including sediment transport influenced by variations in external climatic conditions, the findings reveal key climatic events and highlight the significant role of human activities, particularly fire, in shaping the region's environment. This study offers valuable contributions to understanding the interplay between natural climate variability and human influence during this period.

Résumé

Cette étude présente une reconstitution des changements environnementaux en Europe centro-orientale au cours de l'Holocène moyen à tardif, basée sur des carottes sédimentaires prélevées dans une grotte du nord-ouest de la Roumanie. Grâce à une approche multiproxy incluant des analyses lithologiques, géochimiques, de susceptibilité magnétique, de matière organique et de charbon de bois, cette recherche apporte des éclairages sur les conditions climatiques passées, les modifications de la végétation et l'impact humain sur le paysage. Les résultats révèlent des événements climatiques clés et soulignent le rôle significatif des activités humaines, en particulier l'utilisation du feu, dans la transformation de l'environnement régional. Cette étude constitue une contribution précieuse à la compréhension des interactions entre la variabilité climatique naturelle et l'influence humaine au cours de cette période.

Resumen

Este estudio presenta una reconstrucción de los cambios ambientales en Europa centro-oriental durante el Holoceno Medio y Tardío, basada en núcleos de sedimentos extraídos de una cueva en el noroeste de Rumanía. A través de un enfoque multiproxy, que incluye análisis litológicos, geoquímicos, de susceptibilidad magnética, materia orgánica y carbón vegetal, la investigación proporciona información sobre las condiciones climáticas pasadas, los cambios en la vegetación y el impacto humano en el paisaje. Los resultados revelan eventos climáticos clave y destacan el papel significativo de las actividades humanas, en particular el uso del fuego, en la configuración del medio ambiente de la región. Este estudio ofrece contribuciones valiosas para comprender la interacción entre la variabilidad climática natural y la influencia humana durante este período.

1. Introduction

The Middle to Late Holocene (approximately 6000 to 4000 years ago) was a period marked by significant climatic and environmental transformations across East-Central Europe (PERȘOIU et al., 2019). These changes were driven by natural climate variability, as well as the influence of human activities, including early agricultural practices. Understanding the dynamics of this period is critical for reconstructing past environmental conditions and evaluating their impact on regional ecosystems and societies. This study investigates the environmental history of the Middle to Late Holocene using sediment samples from Ciur Izbuc Cave, located in the Pădurea Craiului Mountains of northwestern Romania. The site holds particular significance due to the discovery of over 400 human footprints in its upper passages (RUSU et al., 1969). By employing a multi-proxy approach, integrating lithological, geochemical, magnetic susceptibility, organic matter and microfossil analyses, the study reconstructs past climatic conditions and ecological dynamics, providing valuable insights into the region's environmental evolution.

2. Materials and methods

Sediment samples were collected at 2-cm intervals from a 128 cm deep trench excavated in the cave's sediment sequence (Fig. 1). The cave sediments were chosen for their exceptional stratigraphy and their potential to provide a high-resolution environmental record. The samples were analyzed using a combination of complementary proxies, each contributing a distinct perspective on the past environment:

Figure 1: *The investigated sediment sequence in Ciur Izbuc Cave, with a measuring tape for scale (55 cm).*

- **Lithological analysis:** The sedimentary layers were studied to identify variations in sediment types and structures, providing insights into changes in depositional environments over time. These shifts are reflected by the sediment input, quantified through the sediment accumulation rate (Fig. 2a).
- **Geochemical analysis:** Elemental concentrations were measured to assess changes in the chemical composition of the sediments, allowing for the identification of key climatic shifts, such as periods of increased moisture or drought (erosion levels derived from Titanium (Ti) concentration in the cave sediments; see Fig. 2b).
- **Magnetic susceptibility:** The magnetic properties of the sediments were analyzed to infer variations in moisture levels and sedimentation rates, which are often influenced by changes in rainfall and temperature.
- **Organic matter analysis:** The composition of organic material in the sediment cores was examined to trace shifts in vegetation and determine the sources of organic matter, which could reflect changes in climate and ecosystem dynamics (see organic matter (C%) in Fig. 2c).
- **Non-pollen palynomorphs (NPPs):** Microfossils, such as fungal spores, were studied to reconstruct past ecological conditions, complementing the pollen data and offering additional insights into vegetation and climate.
- **Charcoal analysis:** The presence of charcoal in the sediment layers was used to identify fire events, providing valuable information on human activity and its environmental impact during the Holocene (Fig. 2d).

The chronology of the sediment sequence is based on an age-depth model constructed using six radiocarbon dates obtained from charcoal and macroplant remains. Therefore, these analyses were conducted with high temporal resolution, allowing for the detection of fine-scale environmental changes throughout the Holocene.

3. Results and discussions

The sediment cores revealed several important findings regarding environmental changes in East-Central Europe during the Middle to Late Holocene (ONAC et al., 2025). From 6500 to 3500 calibrated years BP (cal BP), the data indicate a dynamic system with consistent surface-to-subsurface connections, generally wetter conditions, moderate-to-high erosion, and moderate sediment accumulation rates, with the exception of a brief period of drier conditions approximately 4500 cal BP. The interval between 3500 and 2000 cal BP is marked by low accumulation under reduced water flow, reflecting a stable late mid-Holocene climate. From 2000 to 100 cal BP, hydroclimate conditions became more complex, with an initial phase showing an abrupt transition to wetter conditions, characterized by minerogenic sediments derived from runoff (Fig. 2a). This was followed by sporadic intense erosion events driven by short-term climatic fluctuations (Fig. 2b). These findings highlight the following:

Climatic variability: Geochemical and magnetic susceptibility data revealed a series of climatic shifts, including phases of increased moisture and periods of aridity (Fig. 2a). The data suggest that the study region was sensitive to these larger-scale climatic changes, with impacts on vegetation and fire regimes.

Organic matter sources: Organic matter analysis indicated significant changes in the composition of organic material in the sediments over time. Variations in the source and quality of organic matter suggest shifts in vegetation types and climate. For example, changes in the composition of organic matter at certain points in time may correspond to shifts in regional climate, such as periods of drought or cooling (Fig. 2c).

Vegetation shifts: NPPs data revealed distinct shifts in vegetation over the study period, reflecting changes in climate and land use. The record suggests transitions between forested landscapes and more open, herbaceous environments, with the latter indicating periods of drought or human-induced deforestation. These shifts provide evidence of both natural climate fluctuations and anthropogenic activities, such as early agriculture and land clearing.

Fire activity: Charcoal analysis revealed a close correlation between fire events and periods of human settlement, highlighting the role of human activities in altering the landscape. Fire events were identified around 6200 and 5200 cal BP, possibly associated with land clearance for agriculture. Over the past 1800 years, fire frequency increased significantly (Fig. 2d). This finding underscores the anthropogenic impact on the environment and suggests that early human populations were actively modifying their surroundings.

The findings from this study offer valuable insights into the environmental history of East-Central Europe during the Middle to Late Holocene. The data suggest that the region experienced significant climatic fluctuations, influenced by both natural and anthropogenic factors. The detection of vegetation shifts, and fire events further supports the idea that both climate and human activity played key roles in shaping the regional environment. The increased frequency of fire events during certain periods is particularly noteworthy, as it points to the significant impact of early human populations on the landscape, especially in the context of agricultural expansion and land use.

The study also highlights the effectiveness of a multi-proxy approach in reconstructing past environmental conditions. By combining data from multiple sources—such as pollen, geochemistry, magnetic susceptibility, and charcoal analysis—the study provides a comprehensive picture of

the region's environmental history. This approach not only enhances our understanding of climatic and ecological changes during the Holocene but also allows for a more nuanced interpretation of the interplay between natural and anthropogenic forces.

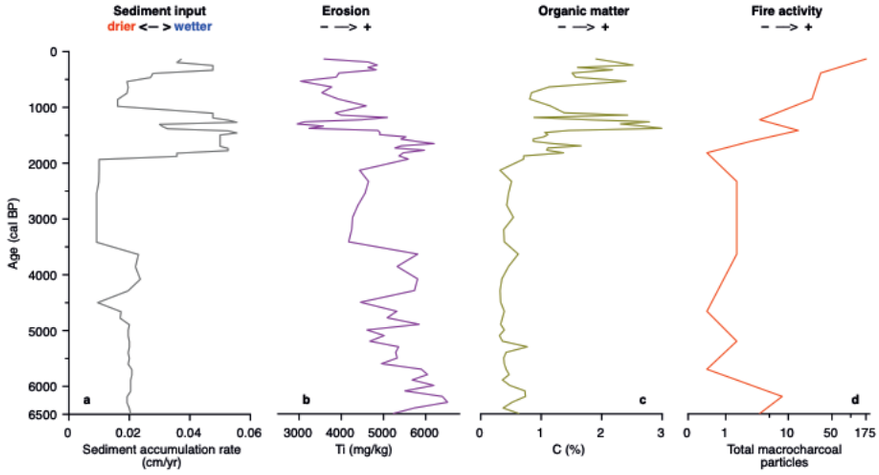

Figure 2: *Environmental changes inferred from sediment input (a), erosion (b), organic matter (c), and fire activity records preserved in the Ciur Izbuc Cave sediments.*

4. Conclusion

This study provides a detailed reconstruction of environmental changes in East-Central Europe from the Middle to Late Holocene, contributing valuable information to our understanding of past climate variability and human-environment interactions. The findings underscore the complexity of the region's environmental history, shaped by both natural climatic events and the evolving influence of human activity. The multi-proxy analysis employed in this study proves to be an effective method for reconstructing past climates and ecosystems, offering new insights into the ways in which human populations adapted to and modified their environments. As the region continues to experience environmental change, understanding its past provides essential context for future ecological and climate-related research.

Acknowledgments

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Expanding the cave mineral database: 53 new additions

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Abstract

This note presents a list of 53 new minerals discovered in various cave environments between 2011 and the present. Of these, 23 are sulfates, followed by silicates and phosphates, comprising eight and seven minerals, respectively. Additionally, the list includes five oxides/hydroxides, five carbonates, two halogenides, and three cryogenic borate minerals. With these new additions, the total number of minerals described from caves worldwide now reaches 372 species.

Résumé

Cette note présente une liste de 53 nouveaux minéraux découverts dans divers environnements de grottes entre 2011 et aujourd'hui. Parmi eux, vingt-trois sont des sulfates, suivis par les silicates et les phosphates, comprenant respectivement huit et sept minéraux. En outre, la liste inclut cinq oxydes/hydroxydes, cinq carbonates, deux halogénures et trois minéraux boratés cryogéniques. Avec ces nouvelles découvertes, le nombre total de minéraux décrits dans les grottes à travers le monde atteint désormais 372 espèces.

Resumen

Esta nota presenta una lista de 53 nuevos minerales descubiertos en diversos entornos de cuevas entre 2011 y el presente. De estos, 23 son sulfatos, seguidos por los silicatos y fosfatos, que comprenden 8 y 7 minerales, respectivamente. Además, la lista incluye 5 óxidos/hidróxidos, 5 carbonatos, 2 halogenuros y 3 minerales de boratos criogénicos. Con estas nuevas incorporaciones, el número total de minerales descritos en cuevas de todo el mundo alcanza ahora las 372 especies.

1. Introduction

Speleothems, with their unique morphology and color, have always intrigued both cavers and scientists. For cavers, the fascination lies in *how* speleothems can take on such peculiar shapes and *what* causes changes in their color. For scientists, speleothems exhibiting exotic colors often conceal unique mineral assemblages, which they strive to identify and understand, particularly in terms of whether their precipitation is an inorganic or biologically mediated process. Additionally, speleothems found in volcanic caves, lava tubes, sulfuric acid cavities, and even the seemingly unremarkable earthy masses around or within guano deposits, provide promising locations for discovering new cave minerals.

At the International Congress of Speleology in La Chaux-de-Fonds, Switzerland, Carol A. HILL and Paolo FORTI (1997) released the second edition of *Cave minerals of the world*, a comprehensive resource that catalogs 255 mineral species—an increase of 82 species from the first edition (HILL & FORTI, 1986). Since then, the pace of documenting previously undiscovered minerals in cave environments worldwide has remained remarkably rapid. By 2011, ONAC and FORTI (2011) had compiled a list of 319 cave minerals, to which I now add 53 new species, described in 20 papers.

The newly identified minerals below belong to seven chemical classes: oxides & hydroxides, halogenides, carbonates, borates, sulfates, phosphates, and silicates. Notably, the largest number (23) is represented by sulfates, with 13 of these species described from Cueva Los Minerales in Costa Rica by ULLOA et al. (2013, 2018). A notable development in the past decade of cave mineral research has been the identification of three cryogenic borates in the Kungur Ice Cave, Russia (ANDREYCHOUK et al., 2013).

2. Results

OXIDES & HYDROXIDES

Buserite – $Na_4Mn_{14}O_{27}\cdot 21H_2O$ (?); Zoloushka Cave, Ukraine (Andreychouk & Klimchouk, 2001)

Jacobsite – $Mn^{2+}Fe^{3+}{}_2O_4$; Aixa Cave, Spain (?) (Galán et al., 2011); Cova des Pas de Vallgornera, Mallorca Spain (Onac et al., 2014)

Janggunite – $(Mn^{4+},Mn^{2+},Fe^{3+})_6O_8(OH)_6$; Puerto Princesa Cave, Palawan, Philippines (De Vivo et al., 2013)

Népouite – $Ni_3Si_2O_5(OH)_4$; Aven du Marcou, France (Vlieghe et al., 2023)

Vernadite – $(Mn,Fe,Ca,Na)(O,OH)_2\cdot nH_2O$; Shopov's cave system, Bulgaria (?)/ Grotta del Cervo, Italy (Bernardini et al., 2021)

HALOGENIDES

Antarcticite – $CaCl_2\cdot 6H_2O$; Arco de la Paciencia Cave, Atacama, Chile (De Waele et al., 2017)

Tolbachite – $CuCl_2$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2018)

CARBONATES

Dundasite – $PbAl_2(CO_3)_2(OH)_4\cdot H_2O$; Monte Giusi Cave, Sardinia, Italy (Moldovan et al., 2013)

Gaylussite – $Na_2Ca(CO_3)_2\cdot 5H_2O$; Kungur Ice Cave, Russia (Tchaikovskiy et al., 2015)

Hydrotalcite – $Mg_6Al_2(CO_3)(OH)_{16}(H_2O)_4$; Monte Cucco Cave, Italy (D'Angeli et al., 2018)

Pyroaurite – $Mg_6Fe^{3+}_2(CO_3)(OH)_{16}{\cdot}4H_2O$; Monte Kronio cave system, Sicily, Italy (Audra et al., 2025)

Zaccagnaite – $Zn_4Al_2(OH)_{12}(CO_3){\cdot}3H_2O$; El Soplao Cave, Spain (Lozano et al., 2012)

BORATES

Inyoite – $CaB_3O_3(OH)_5{\cdot}4H_2O$; Kungur Ice Cave, Russia (Andreychouk et al., 2013)

Inderite – $Mg[B_3O_3(OH)_5](H_2O)_4{\cdot}H_2O$; Kungur Ice Cave, Russia (Andreychouk et al., 2013)

Ulexite – $NaCaB_5O_6(OH)_6{\cdot}5H_2O$; Kungur Ice Cave, Russia (Andreychouk et al., 2013)

SULFATES

Aplowite – $Co(SO_4){\cdot}4H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2013)

Bieberite – $Co(SO_4){\cdot}7H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2018)

Boyleite – $Zn(SO_4){\cdot}4H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2013)

Cyanochroite – $K_2Cu(SO_4)_2{\cdot}6H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2018)

Dietrichite – $ZnAl_2(SO_4)_4{\cdot}22H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2018)

Eugsterite – $Na_4Ca(SO_4)_3{\cdot}2H_2O$; Acqua Fitusa Cave, Sicily, Italy (D'Angeli et al., 2018)

Ferricopiapite – $Fe^{3+}_{0.67}Fe^{3+}_4(SO_4)_6(OH)_2{\cdot}20H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2018)

Ferrinatrite – $Na_3Fe^{3+}(SO_4)_3{\cdot}3H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2013)

Glaucocerinite – $(Zn_{1-x}Al_x)(SO_4)_{x/2}(OH)_2{\cdot}nH_2O$ (x < 0.5, n > 3x/2); Su Zurfuru Mine, Sardinia, Italy (Gázquez et al., 2013)

Görgeyite – $K_2Ca_5(SO_4)_6{\cdot}H_2O$; Liliecilor Cave, Romania (Puşcaş et al., 2014)

Grandviewite – $Cu_3Al_2(SO_4)(OH)_{10}{\cdot}H_2O$; Grandview Mine, AZ, USA (Colchester et al., 2008)

Lausenite – $Fe^{3+}_2(SO_4)_3{\cdot}5H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2018)

Lishizhenite – $ZnFe^{3+}_2(SO_4)_4{\cdot}14H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2018)

Magnesiocopiapite – $MgFe^{3+}_4(SO_4)_6(OH)_2{\cdot}20H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2013)

Omongwaite – $Na_2Ca_5(SO_4)_6{\cdot}3H_2O$; Fagrdalsfjall Lava Tube F10, Iceland (Sauro et al., in prep.)

Osarizawaite – $Pb(Al2Cu^{2+})(SO_4)_2(OH)_6$; Grandview Mine, AZ, USA (Mathis, 2012)

Parawulffite – $K_5Na_3Cu_8O_4(SO_4)_8$; Fagrdalsfjall Lava Tube F10, Iceland (Sauro et al., in prep.)

Pentahydrite – $Mg(SO_4)_3{\cdot}5H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2018)

Pseudomalachite – $Cu_5(PO_4)_2(OH)_4$; Cave 4, Eldhraun lava field, Iceland (Kopacz et al., 2022)

Uklonskovite – $NaMg(SO_4)F{\cdot}2H_2O$; Fagrdalsfjall Lava Tube F10, Iceland (Sauro et al., in prep.)

Walthierite – $Ba_{0.5}Al_3(SO_4)_2(OH)_6$; Corona'e Sa Craba, Sardinia, Italy (Sauro et al., 2014)

Wulffite – $K_3NaCu_4O_2(SO_4)_4$; Fagrdalsfjall Lava Tube F10, Iceland (Sauro et al., in prep.)

Wupatkiite – $CoAl_2(SO_4)_4{\cdot}22H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2013)

PHOSPHATES

Goyazite – $SrAl_3(PO_4)(PO_3OH)(OH)_6$; Monte Cucco Cave, Italy (D'Angeli et al., 2018)

Philipsbornite – $PbAl_3(AsO_4)(AsO_3OH)(OH)_6$; Grandview Mine, AZ, USA (Mathis, 2012)

Robertsite – $Ca_2Mn^{3+}_3O_2(PO_4)_3{\cdot}3H_2O$; Puerto Princesa Cave, Palawan, Philippines (De Vivo et al., 2013)

Rossiantonite – $Al_3(PO_4)(SO_4)_2(OH)_2(H_2O)_{10}{\cdot}4H_2O$; Akopan-Dal Cin cave system, Venezuela (Galli et al., 2013)

Serrabrancaite – $Mn(PO_4){\cdot}H_2O$; Puerto Princesa Cave, Palawan, Philippines (De Vivo et al., 2013)

Sphenisciditе – $(NH_4)Fe^{3+}_2(PO_4)_2(OH){\cdot}2H_2O$; Corona'e Sa Craba, Sardinia, Italy (Sauro et al., 2014)

Svanbergite – $SrAl_3(SO_4)(PO_4)(OH)_6$; Spider & Lechuguilla caves, NM, USA (Spilde et al., 2005)

SILICATES

Chamosite –$(Fe^{2+},Mg,Al,Fe^{3+})_6(Si,Al)_4O_{10}(OH,O)_8$; Cova des Pas de Vallgornera, Mallorca, Spain (Onac et al., 2014)

Greenalite – $(Fe^{2+},Fe^{3+})_{2-3}Si_2O_5(OH)_4$; Grotta che Parla, Sicily, Italy (D'Angeli et al., 2018)

Lizardite – $Mg_3Si_2O_5(OH)_4$; Corona'e Sa Craba, Sardinia, Italy (Sauro et al., 2014)

Marinellite – $Na_{42}Ca_6Al_{36}Si_{36}O_{144}(SO_4)_8Cl_2{\cdot}6H_2O$; Cueva Los Minerales, Costa Rica (Ulloa et al., 2018)

Plancheite – $Cu_8(Si_4O_{11})(OH)_4{\cdot}H_2O$; Monte Guisi Cave, Sardinia, Italy (Moldovan et al., 2013)

Pumpellyite - (Mg) – $Ca_2(MgAl_2)(Si_2O_7)(SiO_4)(OH)_2{\cdot}H_2O$; Fagrdalsfjall Lava Tube F4, Iceland (Sauro et al., in prep.)

Titanite – $CaTi(SiO_4)O$; Monte Cucco Cave. Italy (D'Angeli et al., 2018)

Trattnerite – $Fe^{3+}_2(Mg_3Si_{12})O_30$; Lava tube 29, El Malpais, NM, USA (Onac et al., in prep.

3. Conclusion

The growing interest in characterizing mineral phases within lava tubes and sulfuric acid caves holds the potential to catalyze the discovery of novel cave minerals. Notably, the likelihood that secondary minerals could preserve biosignatures presents a compelling incentive for investigating lava tubes that serve as Earth analogues of subsurface Martian or Moon environments. Consequently, I anticipate a surge in research endeavors and the identification of novel minerals within these cavities within the next decade.

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Paleokarst cave breccia (Istria, NW Croatia)

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Abstract

Along the entire southeastern coast of the Ubac peninsula (Istria; NW Croatia) the remains of a large, probably halocline, paleokrast cave occur. The cave was formed in the Paleogene at the flank of the peripheral bulge. The breccias in question represent evidence of the evolution of the mature and especially the last phases of the cave, or its gradual filling and disintegration. Sediments typical of cave environments are interwoven with surface karst sediments, or residuals and products of carbonate pedogenesis.

Résumé

Sur toute la côte sud-est de la péninsule d'Ubac (Istrie; nord-ouest de la Croatie), on trouve les vestiges d'une grande grotte paléokarstique, probablement halocline. La grotte s'est formée au Paléogène sur le flanc du renflement périphérique. Les brèches en question témoignent de l'évolution des phases matures et surtout finales de la grotte, ainsi que de son remplissage et de sa désintégration progressifs. Les sédiments typiques des environnements de grottes sont entrelacés avec des sédiments karstiques de surface, des résidus, et des produits de la pédogenèse carbonatée.

Resumen

A lo largo de toda la costa sudoriental de la península de Ubac (Istria; noroeste de Croacia) se encuentran los restos de una gran cueva paleocárstica, probablemente haloclina, formada en el Paleógeno en el flanco del abultamiento periférico. Las brechas en cuestión representan evidencia de la evolución de las fases maduras y, especialmente, de las últimas de la cueva, así como de su llenado y desintegración gradual. Los sedimentos típicos de los entornos cavernarios se entremezclan con sedimentos kársticos superficiales, residuos y productos de la pedogénesis carbonatada.

1. Introduction

Certain karst surface features, such as elongated dolines, dry valleys, and trenches, may represent denuded remnants of former phreatic caves. Identifying these roofless caves can significantly enhance understanding of the speleological, geomorphological, hydrological, and tectonic evolution of karst regions (Mihevc, 2001). In SW Slovenia and Istria, a major Late Cretaceous-Paleogene unconformity is often marked by infilled roofless phreatic caves preserved as elongated, lens-shaped clastic sediment bodies within continuous carbonate successions (Otoničar et al., 2003; Otoničar, 2007, 2021). These sediments commonly include breccias with clasts from cave walls and speleothems in a silty to sandy matrix composed of calcareous, clayey, and ferruginous/bauxitic components.

When cave-related features are extensively denuded or poorly exposed, remnants may appear as untypical lithologies within carbonate bedrock, potentially leading to misinterpretation as other clastic or residual deposits.

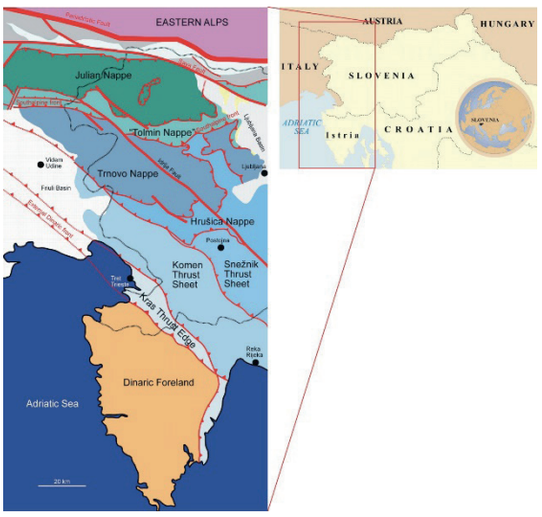

Figure 1: *Geographical position and simplified geological map of western Slovenia and Istria (modified after Placer, 1999).*

Studying the diagenetic history of these sediments and bedrock provides critical insights into paleohydrology and karstification. Exposed roofless cave features offer valuable opportunities to investigate the paleokarst evolution of a region and interpret paleokarst-related

unconformities, aiding in the understanding of ancient carbonate aquifers and landscapes.

The study focuses on the SE coast of the Ubac peninsula near Koromačno village on the Istrian peninsula, NW Croatia (Fig.1). The paleokarst cave and associated deposits mark the unconformity between Upper Santonian shallow marine carbonates and Lower Eocene paralic carbonates. This megasequence boundary separates the underlying passive margin carbonate succession from synorogenic carbonate platform deposits of the foreland basin periphery (Otoničar, 2007).

Tectonically, the area corresponds to the foreland of the Dinaric fold-thrust belt, part of the Cretaceous Adriatic Carbonate Platform and the Upper Cretaceous-Eocene synorogenic carbonate platform. During a prolonged subaerial exposure, various surface and subsurface paleokarst features developed and were subsequently infilled with breccias and other sediments. During the early Eocene transgression, carbonate facies were strongly influenced by the underlying karst topography, representing a «blue hole» phase of transgression.

The study aims to examine the evolution of the paleokarst cave and its overlying surface by interpreting cave sediments, with a particular focus on cave breccia.

2. Materials and methods

Detailed geological mapping was conducted in the field at scales ranging from 1:250 to 1:1000, with lithostratigraphic sections sampled at scales of 1:50 and 1:100. Special attention was given to paleokarst phenomena, using detailed sketches and photographs to document observations. The photographs were also used as a foundation for creating detailed sketches of lithological characteristics and marking sampling sites.

The study involved comprehensive petrographic analyses of sedimentary and diagenetic features in rocks associated with paleokarst cave. More than 50 rock samples were collected, from which plates averaging 50 cm^2 were prepared and examined under a binocular microscope. Almost 40 thin sections were prepared from selected samples for standard petrographic and cathodoluminescence studies.

Cathodoluminescence analyses were performed using a Technosyn® cold cathodoluminescence luminoscope (model CITL CL8200 MK4) with a 14 kV electron beam and an electron current of 350-400 µA, mounted on a Nikon Eclipse E600 petrographic microscope. Images in both transmitted and cathodoluminescent light were captured using a Nikon Coolpix 990 digital camera.

Qualitative and semi-quantitative mineral compositions of 5 selected cave-related samples were determined via powder X-ray diffraction (XRD). Analyses were performed using a Bruker D2 PHASER diffractometer at the Karst Research Institute ZRC SAZU. Recording conditions included a CuKα anode, 40 kV electron voltage, 30 mA current, Ni filter, proportional counter, and automatic divergence valve. Data were recorded continuously at a rate of 2° 2Θ/min, covering a range of 2Θ angles from 2° to 70°.

3. Results

The coarse-grained breccia bodies (Fig. 2A), as the main paleokarstic deposits, comprise chemical/biochemical and mechanical materials frequently overprinted by pedogenic modifications. Chemical deposits include in-situ and re-deposited speleothems, while mechanical deposits dominate, consisting of coarse-grained limestone breccias (Fig. 2) with calcareous/bauxitic matrix (Fig. 3) and intercalated calcareous/bauxitic sandstone and siltstone. Subaerial weathering of windborne non-carbonate material and in-situ weathering of carbonate bedrock contributed to soil material and bauxite formation. The bauxite, mainly parautochthonous, was transported into the cave environment and should therefore be considered as sedimentary rock.

The breccia cross-cuts shallow marine carbonates and is overlain by a paralic carbonate succession (see the uppermost part of Fig. 2A). The contact with the bedrock is sharp and irregular, characterized by dissolution-widened fractures and channels, frequently coated with flowstone and ferruginous crusts. Breccia bodies extend over hundreds of square meters, with thicknesses exceeding 6 meters. In contrast, adjacent breccia formations on the Ubac peninsula can reach thicknesses of up to 20 meters (Magaš, 1968).

Breccia Units

The breccia is divided into three units of varying thicknesses (Fig. 2A): (1) a lower unit, up to 4 meters thick; (2) a bit thinner middle unit (Fig. 2B); and (3) an upper unit, up to 1 meter thick (Fig. 2C). Calcareous siltstone and sandstone intercalations are scattered throughout, with the most prominent occurrences between the lower and middle units. Transitions between the units and intercalations are gradual. All three units are unstratified, with clasts chaotically oriented. The lower unit exhibits the most variable fabric and is predominantly framework-supported. The middle unit is clast-supported, while the upper unit is primarily matrix-supported.

Clast Characteristics

Clast sizes range from fine pebbles to boulders, with cobbles being the most common. Clast size decreases upward: the lower unit exhibits the widest size range, including boulders exceeding 1 meter, while the middle unit is more uniform. The upper unit predominantly contains pebbles. Clasts are subangular to angular, with roundness increasing upward. Limestone-derived clasts are dominant, though speleothem fragments, including stalagmites and stalactites, are locally abundant. Some clasts display joints filled with pedogenically modified sediment, and the uppermost breccia clasts feature weathered or biogenically altered rims.

Matrix Composition

The breccia matrix (Fig. 3), classified as calcareous/bauxitic sandstone, comprises sand- to pebble-sized particles, including disintegrated speleothems, aluminous and ferruginous oolites (Fig. 3b, i), peloids (Fig. 3b, g, h, i), and intraclasts (Fig. 3c, e). These components are embedded in a silty to clayey matrix (Fig. 3a–g). The calcite crystal grains are angular, the intraclasts sub-rounded, and the bauxitic particles rounded. In the upper breccia type (type 3), the matrix exhibits pedogenic modification and includes microcodium particles, clotted micrite, bedrock intraclasts, and terrestrial snail fragments. Porosity, likely resulting from rhizoliths, is infilled with non-luminescent spar (Fig. 3a) and clayey to silty material (Fig. 3d). Remaining voids and portions of the matrix contain kaolinite, identifiable by its violet-blue luminescence (Fig. 3f).

Figure 2: *A) Framework-supported block breccia forms the lower part of a disintegrated and collapsed paleokarstic phreatic cave (Type 1). Note the flowstone deposited on the blocks and as broken columns/stalagmites. B) Clast- to matrix-supported coarse stone/cobble breccia (Type 2 in Fig. 2A). Note the chaotic distribution of in-situ rounded stones/cobbles. C) Matrix- to clast-supported conglomerate/breccia forms the uppermost part of the described breccia body (Type 3 in Fig. 2A).*

Calcite Spar (Speleothem)

Speleothems occur both as in-situ precipitates and as clasts within the breccia. These include flowstones, stalagmites, stalactites, cave peloids (pearls), and calcite rafts, with flowstone being the most common type. While primarily considered in-situ precipitates, some calcite rafts and larger stalagmites appear only slightly displaced from their original positions. Larger clasts of flowstone and stalagmites are more abundant in the lower breccia section, appearing as macroscopic clasts up to 1 m^3 or as smaller calcite particles within the breccia matrix and sandstone intercalations (Fig. 3c). The outer edges of speleothems in contact with breccia matrix or sandstone intercalations often exhibit jagged surfaces, with crystalline particles dispersed into adjacent sediments. Laminations at these contacts may alternate with irregular patches of neomorphic calcite spar. Small calcareous crystals within the breccia matrix and sandstone intercalations likely originate from disintegrated calcite rafts. Notably, cave pearls or terrestrial pisolites within clast- to matrix-supported breccias often have bedrock particles, Microcodium rosettes, and ferruginous or bauxitic grains as nuclei (Fig. 3c).

Diagenesis of the Bedrock

The wall-rock of the breccia bodies exhibits a complex diagenetic history, including micritization, neomorphism, leaching, dissolution, cementation, and the precipitation of pyrite and gypsum. These diagenetic features are apparent at both macroscopic and microscopic scales. At the macroscopic level, reddish-stained horizons up to a meter thick, aligned parallel to stratification, are visible beneath the cavernous porosity associated with the breccia deposit. These horizons, particularly the uppermost one directly below the breccia, contrast sharply with the unstained parts of the rock, offering critical insights into the diagenetic conditions during the early stages of cave formation.

The diagenetic history can be divided into two main paragenetic stages:

- *Shallow Marine Synsedimentary Stage:* This stage encompasses the bioerosion of rudist skeletons, micritization of skeletal grains, and the cementation of intrafossil porosity with neomorphosed fibrous marine cement. These processes predate the collapse of rudist structures and the infiltration of internal sediments into intra-skeletal pores.
- *Near-Surface Early Diagenetic Stage:* Non-marine processes dominated this stage, influenced by the bedrock's proximity to the paleokarst surface and its diagenetic potential. Initially weakly altered marine carbonate successions underwent extensive meteoric diagenesis, including neomorphism, leaching, dissolution, and cementation. Beneath the paleokarst surface, evidence of pedogenic modification and calcrete formation is present.

The reddish-stained horizons exhibit distinctive diagenetic alterations, including staining, associated dissolution, neomorphic transformation, gypsum precipitation, and calcite cementation. The reddish staining results from oxidized pyrite, predominantly confined to clotted micrite (possibly neomorphosed). In contrast, greenish-grey and brownish mottles in the unstained limestone reflect disseminated pyrite, with greenish tones indicating unaltered pyrite and brownish tones indicating partial oxidation.

Secondary dissolution cavities and root-related fenestrae are common in these horizons, later infilled with equant sparry calcite. Kaolinite rosettes, which appear deep blue under cathodoluminescence (CL), are associated with reddish clotted micrite and cavities, likely forming as pseudomorphs after gypsum crystals. These kaolinite features predate calcite cementation.

In the upper section near the paleokarst surface, non-fabric-selective vugs and dissolution-enlarged fissures are abundant. These irregularly shaped cavities, often interconnected by thin fissures, reveal complex sedimentary histories, including sparry calcite rims and alternating phases of dissolution, deposition, and erosion.

Pedogenically induced calcretes are also observed, including rhizoliths, coated grains, blackened pebbles, and laminar calcretes. Calcrete microfabrics display features such as *Microcodium*, alveolar septal textures, peloids, and distorted needle-fiber calcite.

4. Discussion

Numerous petrographic characteristics indicate that the breccia body, situated between stratified shallow marine carbonate successions, is at least indirectly a product of karst-related processes. While clastic cave sediments often include a wide variety of terrestrial sediments of diverse origins, certain diagnostic features of cave deposition are identifiable. The chaotic framework-supported breccia in the lower part of the section was deposited after significant precipitation of speleothems. The wide size range of predominantly angular clasts, derived from adjacent host rock strata and speleothems, combined with the infiltrating nature of vertically alterating matrix, suggests collapse as the primary mechanism for breccia framework deposition. The presence of calcareous/bauxitic sandstone intercalations within the breccia (Fig. 3), deformed sandstone layers beneath breccia clasts, and in-situ flowstone deposits within the sandstone indicate that the breccia formation occurred through multiple collapse events. These were punctuated by periods of quiescence, during which sandy and silty sediments and flowstone were deposited.

In the middle and upper sections of the breccia body (Figs. 2B, C), features increasingly indicative of pedogenic origin and modification are observed (Figs. 3d – i). Alternating generations of dissolution, deposition, and cement precipitation are evident. Relatively well-rounded clasts in clast- to matrix-supported coarse stone/cobble breccia (Figs. 2B, C) suggest subcutaneous dissolution, a common process in many recent karst-related breccias. This section likely represents a cave entrance facies, where clasts primarily derived from the gradually collapsing cave ceiling. Over time, as widened joints in the cave ceiling and underlying passages were filled, the ceiling transformed into a clast- to matrix-supported breccia with subcutaneously rounded clasts and a predominantly soil-derived matrix. This breccia may also have been partially resedimented by slope processes, such as creeping and sliding.

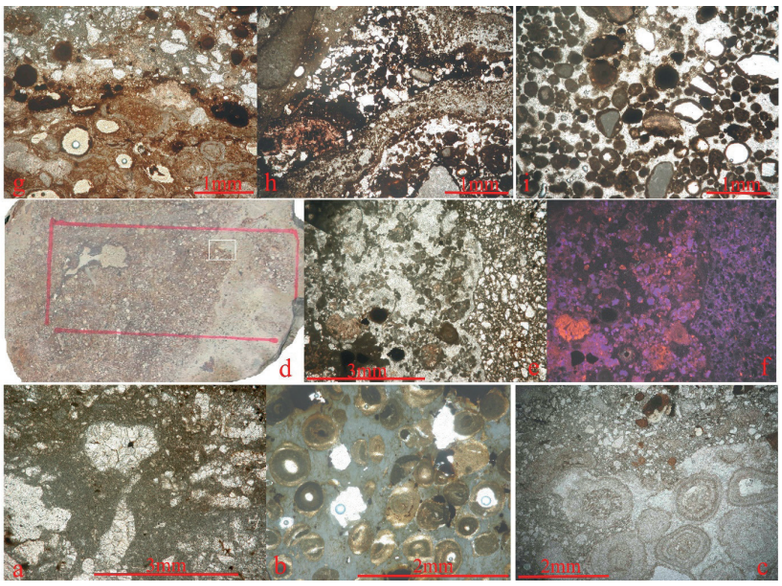

Figure 3: *Breccia matrix suggesting multiple generation of matrix deposition among the breccia clasts ; a, b, c: Matrix of the framework-supported block breccia (type 1 on fig. 2A); d, e, f : matrix of clast- to matrix-supported coarse stone/coble breccia (type 2 on fig. 2A and fig. 2B) ; Pedogenically altered matrix- to clast-supported pebble conglomerate/breccia (type 3 on fig. 2A and fig. 2C).*

The uppermost breccia section was subjected to continuous pedogenic modification until inundation during the transgression. While not exclusively karstic, the presence of bauxites within otherwise continuous carbonate successions indicates periods of subaerial exposure under humid tropical or subtropical climate.

Speleothems are key indicators of caves in paleokarst sections. Flowstones, stalagmites, and stalactites form in subaerial conditions within vadose zones, while calcite rafts and cave pearls are deposited in cave pools. Alternations of sparitic and micritic laminas reflect periodic environmental changes, likely introduced by percolating water. Microorganisms may have influenced micrite layer formation in stalactites and cave pearls (Jones, 1994). Brown coloration in speleothems results from humic acids derived from overlying soils, while white speleothems are associated with fulvic acids or aragonitic origins that resist humic substance uptake (Hill & Forti, 1997). Seasonal or climatic variations could explain stained laminas due to changes in plant material breakdown during different temperature and biological activity levels.

Speleothems were primarily deposited before significant clastic sedimentation. Only thin reddish-brown flowstone layers, occasionally associated with small cave pearls and rafts, formed during major depositional events. Weathering processes, likely in soil or sediment, caused the disintegration of crystalline speleothems, redistributing their particles into calcareous bauxitic sediments.

Reddish-stained horizons not directly attached to the paleokarstic surface might result from reduction-oxidation reactions in mixing-zone waters. Bacteria-mediated sulphate reduction in the presence of Fe oxides promotes pyrite precipitation, reducing carbonate dissolution and enhancing carbonate cementation (Stoessell, 1992). Back-oxidation of sulphides in oxygenated waters produces sulphuric acid and Fe oxides, leading to carbonate dissolution and reddish staining. Evidence includes gypsum precipitation from Ca-sulphate enriched water and later dissolution in the vadose zone, with voids subsequently filled by kaolinite from colloidal solutions. This interplay of diagenetic processes highlights the importance of mixing-zone and vadose environments in shaping the diagenetic evolution of paleokarst systems.

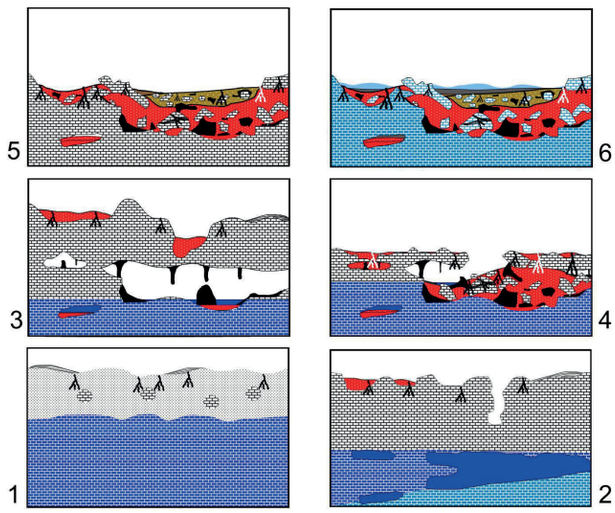

Figure 4: *Developmental phases of the cave and paleokarst surface in the area where the ceilings of halocline paleokarst caves were exposed due to denudation (unroofed caves). The phases of development are detailed in the text below.*

5. Conclusion

Caves without roofs in eogenetic karsts offer unique insights into relative sea-level changes before, during, and after subaerial exposure of a carbonate platform. In isolated carbonate platforms with no non--carbonate basement or hinterland, extensive cave development often correlates with freshwater lenses sitting atop denser marine water beneath subaerially exposed areas (Mylroie & Carew, 1995). Dissolution is most pronounced in the mixing zone between freshwater and marine phreatic or vadose zones, particularly along island flanks where these zones intersect (Mylroie & Carew, 1995).

At the Koromačno site, initial subaerial exposure occurred due to forebulge uplift (Otoničar, 2007). Freshwater lens development lithified the bedrock, leading to subsequent uplift, denudation, and secondary porosity formation. This evolution facilitated mixing-zone diagenesis and dissolution, most likely near the former coastline during a relative sea-level stillstand. Given the extent of the discussed paleokarst cave remains and the presumed duration and elevation of the subaerially exposed part of the peripheral bulge, caves of this type may have formed under similar conditions to the Quintana Roo-type caves on the Yucatan Peninsula in Mexico (see Smart et al., 2006).

Evolution of the Paleokarstic Cave and Surface (Fig. 4):

1. **Initial Uplift and Freshwater Lens Formation.** An initial uplift exposed diagenetically immature carbonate sediments above sea level, forming an extended freshwater lens within the meteoric phreatic zone. Uniform neomorphic alterations occurred, while heterogeneous dissolution and precipitation were influenced by local conditions in the vadose zone.
2. **Porosity Reduction and Cave Formation.** Continued hydrologic and diagenetic alterations reduced porosity and increased permeability in stabilized carbonate rocks. This enhanced dissolution, particularly at freshwater lens outflows, where flank margin or similar caves formed. Autogenic meteoric water became focused at point recharges, with roots and soil CO_2 enhancing vadose zone dissolution.
3. **Sea-Level Fall and Cave Infilling.** A relative sea-level fall placed phreatic caves in epiphreatic and vadose zones, leading to partial or complete infilling by speleothems and detrital sediments. Denudation of the paleokarst surface increased connectivity with phreatic caves, filling them with soil-derived material like clays, bauxite, and carbonate soil products (e.g., Microcodium, terrestrial oncoids). Some deeper cavities remained free of surface-derived material.
4. **Roof Collapse and Surface Infilling.** Oscillations in the water table and freshwater lens, coupled with thinning of cave roofs, led to roof disintegration. This caused intensive infilling of cavities and alteration of deposits by surface processes. On the surface, bauxite deposits accumulated and were periodically resedimented into vadose and phreatic cavities.
5. **Unroofed Caves and Surface Resedimentation.** Before transgression, unroofed caves formed closed depressions/elongated dolines, where deposits were resedimented by creeping/sliding.
6. **Transgression and "Blue-Hole Phase".** During the initial transgression over an irregular karstic surface, the rising water table inundated depressions, initiating a "blue-hole phase" of transgression. The lowermost carbonate sequences exhibit marginal marine and palustrine lithofacies with frequent pedogenic alterations. Continued subsidence led to open marine deposition of foraminiferal limestones.

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Heavy metals in karst soils in the Bohemian Massif (Czech Republic)

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Abstract

This study, which presents new data, deals with the basic geochemical comparison of the content of selected risk elements in soils of karst areas of the Bohemian Massif. The basic geochemical parameters of the soils within the karst were studied in detail in terms of their possible contamination due to risk elements. In order to objectively assess the level of risk, the newly generated data were compared with the globally accepted baselines data for the entire European continent and Czech Republic respectively: results of the GEMAS project.

1. Introductions

This work was carried out as part of the Rock Environment and Natural Resources project (RENS). The main objective of the project SS02030023 RENS is to research, monitor and evaluate the state of the rock environment, natural resources, geological risks and geological information throughout the Czech Republic and to provide new knowledge not only to the state administration, but also to the professional and lay public. The project is divided into four research themes: Mineral Resources, Groundwater in Karst Areas, Geologic Hazards-Ground Instabilities, and Geologic Hazards-Mine Subsidence Districts. One of the important works of the research topic Groundwater in Karst Areas is the research of the subsidy background outside karst areas, specifically the study of the distribution of trace elements and heavy metals at risk in the soils of the subsidy background. In this respect, a significant volume of groundwater in karst areas originates outside the karst areas themselves, on the surface of non-karst rocks.

2. Materials and Methods

The topsoil and rock samples were collected in the karst areas of the Chýnov, Javořič, Moravian and Hranice karst in 2022. A total of 64 topsoil samples and 47 rock samples were collected. All topsoil samples were air dried, sieved through a 2 mm nylon screen, milled to fineness under 0,063 µm, and analysed in the laboratory of the Czech Geological Survey, Czech Republic. Topsoil samples were leached by modified aqua regia digestion prior to analysis and then analysed (ICP-MS) for 53 elements (Ag, Al, As, Au, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, Hg, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Pd, Pt, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Y, Zn and Zr) The analytical data quality was guaranteed through the implementation of laboratory quality assurance and quality control methods, including the use of reference materials (METRANAL 31-RM, METRANAL 33-RM) operating procedures, calibration with standards, analysis of reagent blanks, recovery of spiked samples and analysis of replicates.

As there are no legislative limit values for the Czech Republic (heavy metals and trace elements contents in soils), the results of the international project “Geochemical Mapping of Agricultural Soils” (GEMAS) were used as limit values. The international project was carried out in 2009–2014 by the Geochemistry Expert Group EuroGeoSurvey and a number of other world geoscientific institutions. The results of this project are accepted background values for trace element and heavy metal contents in European soils.

The GEMAS project results present fully harmonised data about the chemical composition (more than 60 elements analysed by three different methods), and of parameters influencing the availability of the elements in 2108 samples of agricultural (ploughed, 0-20 cm) and 2024 samples of grazing land soil (land under permanent grass cover, 0-10 cm), collected at the European scale (33 European countries participated), (Reimann et al., 2014). In addition to these continent-wide data, data valid for the Bohemian Massif-66 samples collected in the Czech Republic were also used. These samples are a subset of all GEAMAS samples.

3. Results

At the current time, we have only partial, preliminary results, these being the content of the monitored risk elements in the topsoil of the individual karst areas.

For the purpose of this study As, Bi, Cd, Cu, Mo, Pb and Zn were selected. The contents of these metals in the soils of individual karst areas are shown in Table 1.

	N		As	Bi	Cd	Cu	Mo	Pb	Zn
H	7	Min	7,68	0,172	0,185	14,5	0,682	23,9	57,1
		Med	10,31	0,200	0,332	17,9	0,914	29,9	64,4
		Max	18,62	0,244	0,386	31,0	1,364	37,6	87,8
M	33	Min	8,68	0,184	0,153	11,8	0,441	23,9	58,1
		Med	11,73	0,249	0,271	17,0	0,691	31,5	75,9
		Max	45,86	1,413	0,670	45,1	1,538	48,4	128,9
J	12	Min	10,10	0,226	0,130	15,8	0,472	24,0	58,1
		Med	15,33	0,256	0,246	22,5	0,629	31,4	80,1
		Max	19,12	0,363	0,423	60,3	1,208	43,5	125,3
C	8	Min	10,30	0,125	0,210	14,6	0,575	18,8	55,9
		Med	14,29	0,257	0,341	36,5	0,626	31,7	115,1
		Max	36,25	0,285	0,438	44,5	0,766	41,4	124,6

Table 1: *The content levels (mg.kg^{-1}) of selected elements in topsoils in individual karst areas, where N: num. of samples; H (Hranice karst), M (Moravian Karst), J (Javoříč karst) and C (Chýnov karst).*

4. Discussion

In order to evaluate these data objectively, the amounts of these metals were compared with data acquired from arable soils in entire European continent and the Czech Republic studied within the Geochemical Mapping of Agricultural and Grazing land Soil of Europe (GEMAS) project (Reimann et al., 2014).

This comparison (Table 2, Picture 1) shows that, with the exception of the Hranice Karst, the concentrations of most elements in all study areas were significantly higher than the concentrations of these elements in the arable soils of the European continent (GEMAS data). This is most evident in the case of As and Pb, the median concentrations of both elements being up to twice as high in karst soils as in European arable soils. No significant enrichment of karst soils with heavy metals was observed.

The situation is very similar when comparing the contents of selected heavy metals in karst areas with the results of the GEMAAS project valid only for Bohemian Massif (Czech Republic). No significant differences are observed. On the contrary, the ratios of elements in karst soils and in agricultural soils of the Czech Republic are lower than the values valid for the whole European continent. The fact that the median contents of some elements differ from the continent-wide scale for individual countries on the European continent is a well-known fact that has been discussed many times. This is primarily due to the different geological composition of the different European countries, different anthropogenic loads, etc. Airborne particulate matter deposition is known to be an important source of trace elements in topsoil of the Bohemian Massif. This is shown by the results from the GEMAS project (Tarvainen et al., 2014), as well as by a series of monitored peat bogs at different places in the Czech Republic (Novák et al., 2003, Zuna et al., 2011). The trace elements deposited originate mainly from burning coal from the deposits in the north-west of the Czech Republic.

The results of Student's t-tests comparing the contents of selected heavy metals in soils with the contents of these metals in GEMAS soils are shown in Table 3.

For the first time, we compared the metal contents of all topsoil samples collected, without separating them by karst region. The results clearly show that, with the exception of Mo, the differences between karst soils and GEMAS arable soils are statistically insignificant (≥0,05). The results of the statistical comparison of the contents of individual studied metals in individual karst areas with the results of the GEMAS project valid for Central Europe (Czech Republic) show that with the exception of Bi in Moravian and Chýnov karst, the differences in the heavy metal contents of the studied sets are statistically insignificant.

	H	M	J	C	GEMAS EU	GEMAS CZ
As	10.3	11.7	15.3	14.3	5.5	9.1
Bi	0.200	0.249	0.256	0.257	0.160	0.236
Cd	0.332	0.271	0.246	0.341	0.180	0.282
Cu	17.9	17.0	22.5	36.5	14.5	21.8
Mo	0.914	0.691	0.629	0.626	0.416	0.379
Pb	29.9	31.5	31.4	31.7	15.7	25.5
Zn	64.4	75.9	80.1	115.1	45.0	62.9

Table 2: *The medians of contents (mg.kg^{-1}) of selected heavy metals in soils in Karst soils, compared with GEMAS data: entire European continent and data for Czech Republic, where H (Hranice karst), M (Moravian Karst), J (Javoříč karst) and C (Chýnov karst).*

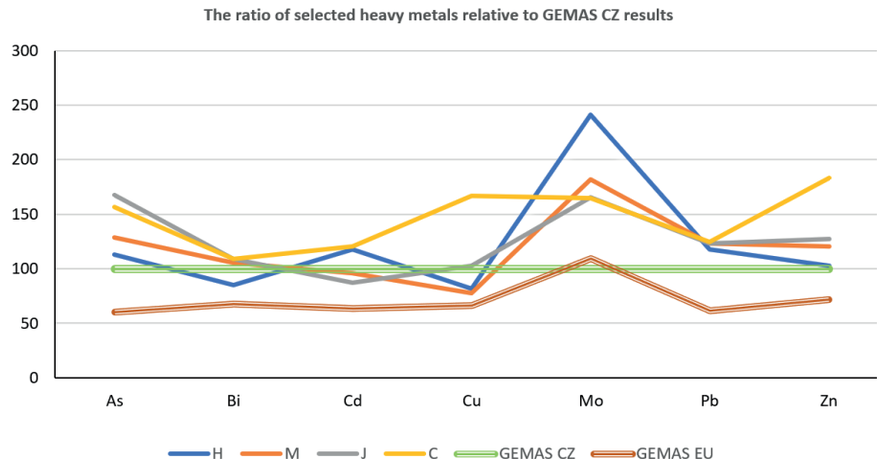

Figure 1: *The ratio of studied metals in Karst soils, compared with GEMAS CZ, where H (Hranice karst), M (Moravian Karst), J (Javoříč karst) and C (Chýnov karst).*

	As	Bi	Cu	Cd	Mo	Pb	Zn
SUMA	0,897	0,126	0,709	0,179	0,001	0,573	0,147
H	0,310	0,022	0,829	0,542	0,001	0,659	0,327
M	0,835	0,221	0,292	0,181	0,002	0,434	0,273
J	0,923	0,105	0,160	0,090	0,034	0,555	0,071
C	0,529	0,060	0,175	0,921	0,039	0,976	0,152

Table 3: *The probability values (critical value 0,05) of the t-tests of contents of selected heavy metals in soils in Karst soils, compared with GEMAS-CZ data, SUMA includes all topsoil samples (64), H (Hranice karst), M (Moravian Karst), J (Javoříč karst) and C (Chýnov karst).*

5. Conclusions

The results suggest that the soils of the monitored karst areas in the Bohemian Massif are not contaminated with the monitored heavy metals As, Bi, Cd, Cu, Pb and Zn respectively. The contents of these metals in soils in the studied karst areas correspond to the results of the GEMAS project valid for Central Europe (Czech Republic), but they seem to be influenced by global factors such as atmospheric deposition, geological substrate, or primary mineralization. Why there is a statistically significant difference between Mo contents in karst soils and GEMAS soils is not yet known.

In the next phase of the research we want to compare the contents of all 53 analysed elements with the results of the GEMAS project. In parallel, we are finalizing the analyses of the rock samples, and will be able to assess the influence of the parent rock on the content of the studied elements in karst soils. In the next steps we want to focus on the sequential analysis of the soils.

Acknowledgments

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Multidisciplinary study to unravel the genesis of the peculiar vermiculations in Puntali cave (Sicily, Italy)

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Abstract

Vermiculations are thin, irregular and discontinuous deposits of incoherent particles found on walls, ceiling and floors of both natural and man-made underground cavities. This study is focussed on vermiculations sampled inside the Puntali cave (Sicily, Italy) which is a small sub-horizontally cave about 290 m long. A multidisciplinary study was conducted by combining morphological, mineralogical, microbiological and geochemical studies with the aim to reconstruct the genetic evolution of these peculiar deposits, discriminating between the possible biotic or abiotic origin. The features of the cave, mainly characterized by a large colony of Chiroptera responsible for the abundance of guano, and the interdisciplinary approach testify the influence of the organic matter in promoting bacterial-mediated processes involved in the development of vermiculations. Collected data document an evolution from irregular, wet, poorly mineralized structures enriched in organic matter and trace elements to more regular, dry, mineralized frameworks depleted in organic matter and elements.

1. Introduction

Vermiculations are thin, irregular and discontinuous deposits of incoherent materials commonly found on the walls of caves and external surfaces and are a few centimetres in extent (BINI et al., 1978). Vermiculations have been documented worldwide in limestone, evaporitic and volcanic caves. Generally, they are mainly composed of calcite with the presence of quartz, clay minerals, metal oxides, and may contain organic matter in different amounts (ADDESSO et al., 2019 and reference therein). Various hypotheses have been proposed to explain their origin, including biological or physico-chemical processes (e.g.: BINI et al., 1978; JONES et al., 2008; ADDESSO et al., 2019; 2021). Vermiculations in SAS (sulphuric acid speleology) caves have been frequently described as the direct result of microbial growth and activity, and for this reason in some cases they have been even called “biovermiculations” (D’ANGELI et al., 2019).

In this work, a multidisciplinary study was conducted regarding the peculiar vermiculations present in Puntali cave (Sicily, Italy), with the aim to reconstruct the genetic and evolution processes of these deposits, discriminating between the possible biotic or abiotic origin.

Puntali Cave opens at about 100 m a.s.l in the north-western sector of the Palermo Mounts (north-western Sicily) and it is protected as a Regional Nature Reserve, managed by GRE-Sicilia Association. The cave is developed horizontally on two levels for about 290 m in Lower Cretaceous-Upper Jurassic forereef limestone and is made up of large galleries, decreasing in size towards the inner parts, reaching a depth of 21 m (Fig. 1). The floor is covered by breccia and fine brown sediments, in the innermost branches massive deposits of guano related to the presence of a large colony of Chiroptera are recognisable.

Dense networks of vermiculations characterized by different colours, morphologies and texture develop in many passages of the cave, mainly on the northern cave walls and in the areas close to guano piles.

The cave is currently devoid of water flow. Water circulation is limited to dripping that vary according to rainfall. Percolation and condensation processes moreover are active on the ceiling and cave walls. The average annual temperature is around 16 °C, while humidity progressively increases towards the innermost rooms, where it reaches 100%.

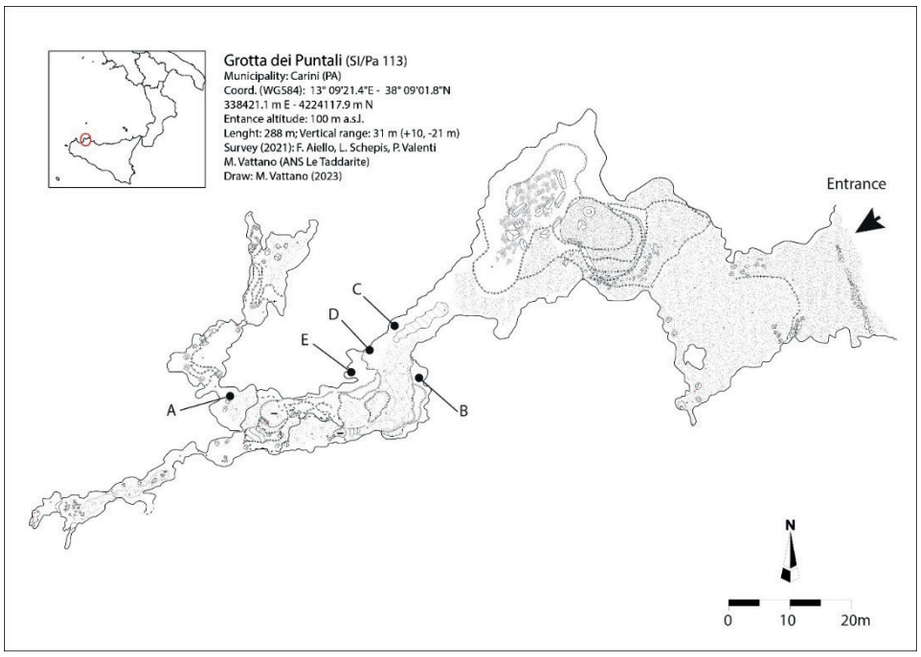

Figure 1: *Puntali cave map. A, B, C, D and E indicate the different sampling sites.*

2. Materials and methods

Fifteen vermiculation samples were collected from 5 sites in Puntali cave (Fig. 1). At each site 3-4 samples were taken on the basis of their colour and texture.

During the field survey for each sampled vermiculation, the morphology, colour, texture, substrate features (lithology, structure, slope, moisture), proximity to guano deposits, presence/absence of light were defined. For each sample, the minimum amount necessary for analysis was taken, trying to limit any impact on the surfaces (Fig. 2).

Sampling for microbiological analysis was carried from all the 5 sites within the cave by using sterile tools and wearing surgical masks to avoid contaminations. Vermiculation samples were stored into sterile tubes and brought to Molecular Environmental Microbiology Lab of University of Bologna for microbiological analysis. Microbial community composition was assessed through 16S rRNA gene sequencing. To this purpose, total DNA was extracted from each sample by using the DNeasy PowerLyzer PowerSoil Kit (QIAGEN) according to the manufacturer's protocol, and used as template to amplify the hypervariable region V3-V4 of 16S rRNA genes by using high fidelity ExTaq polymerase (TaKaRa) and universal primers 341F (5'-CCTACGGGNGGCWGCAG-3') and 805R (5'-GACTACHVGGGTATCTAATCC-3'). The PCR products were then sequenced by BMR genomics (Padova, Italy) through Illumina sequencing (Miseq Platform). Raw sequences were trimmed, filtered, denoised, merged, checked for chimeras and used to generate the Amplicon sequence variants (ASVs) by using Qiime2. Finally, taxonomy assignment of ASVs was carried out using SILVA database.

Microbial isolation strategies were applied and metabolic tests were conducted as previously described (GHEZZI et al., 2024).

To better identify the morphology of vermiculations, texture models were created by means of Adobe software, using the method described in ADDESSO et al. (2019). The morphologies were then defined according to Parenzan classification (1961).

The colour of vermiculations was defined in the laboratory by analysing the samples without being modified after the collection and after being processed as dry powdered samples using the Munsell Standard Soil Colour Chart, then converted in RGB codes.

Figure 2: *Vermiculation sampling in the Puntali cave.*

Mineralogical and geochemical analysis were carried out at the DiSTeM Labs (Palermo, Italy).

Bulk mineralogy was determined by powder X-ray diffraction (XRD) using a Philips PW14 1373 with a Cu-Kα radiation filtered by a monochromator crystal and a 2° 2θ/

minute scanning speed. Stable C and O isotope composition

was determined by a Thermo Scientific Delta V Advantage continuous flow mass spectrometer. CO_2 was obtained by classical H_3PO_4–$CaCO_3$ reaction method, at 50 °C, by an automated Carbonate Preparation Device (Thermo Scientific GasBench II).

Results are reported with typical delta (δ) notation relative to the

V-PDB standard. The relative precision for duplicate analyses improved to 0.1‰ for carbon and oxygen. Geochemical elemental analyses were performed by Perkin Elmer Optima8000 ICP-OES (Marine Ecology Lab) after a Microwave assisted acid digestion (USEPA 3051/2007 method). The detection limits were 0,003 ppm for all trace elements, 0.01% for Al, Fe and Si and 0,005% for P. Total Organic Carbon (TOC) and Total Nitrogen (Ntot) were performed by a Thermo Scientific FlashEA 1112 Elemental Analyzer (Marine Ecology Lab) following the DM 13/09/1999 (G.U. n° 248 del 21/10/99 Method VII.1) and the detection limit was 0.005% for both.

The obtained dataset was treated with multivariate techniques of Cluster Analysis (CA) using STATISTICA data analysis package. Application of Ward's linkage method and Euclidean distance produced significant clusters chosen considering 10 as threshold limit.

3. Results

All the sampled vermiculations were present in cave passages that were characterised by the absence of light and the presence of heavy guano piles on the cave pavement.

Vermiculations indiscriminately develop along vertical walls and in small niches at different heights above the cave floor, from about 0.3 m to 3 m. They involve bare rock (limestone), except for A2 sample which is set on a calcite crust. Some develop on smooth and non-fractured rock surfaces, others on slightly to intensely fractured substrates. During the sampling phases the rock was dry (A1, A2, A3/4a, A3/4b, B1, C1, C2, D1), slightly moist (D2, E1, E2, E3), or wet (D3, E5).

Heterogeneity in colour, consistency and morphology characterize the vermiculations under study (Fig. 3). They appear white, yellow, beige, grey, light grey, brown, dark brown and rust brown. Depending on their hydration state, they are muddy if very hydrated, moist, powdery if poorly hydrated, and hard in the absence of water. Vermiculation morphology is poorly diversified. According to the classification of PARENZAN (1961), most have a dendritic morphology, in places they are elongated along the maximum slope of the cave wall, assuming a stretched dendritic morphology, a few vermiculations have a hieroglyphic morphology instead.

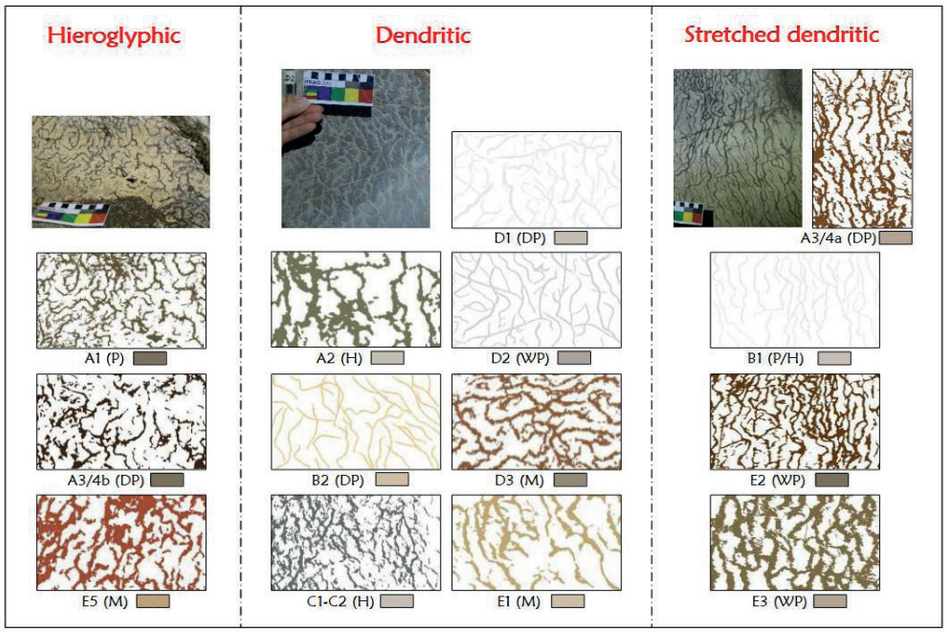

Figure 3: *Puntali cave vermiculations grouped on the basis of morphology with colours referring to the sample as received for analysis and (in the rectangles below) to the dry powdered samples. Textures are also reported: M=muddy; P=powdery; DP=dry powdery; WP=wet powdery; H=hard.*

Vermiculations from the Puntali cave are mainly constituted by calcite with percentages between 77 and 98%. Fluorapatite (4% in average), except in samples A2 and C1, and quartz with a main value of 2% in samples A3/4b, C2 and D3 and higher percentage in samples A1 and E5 (6 and 11%, respectively), are also detected. Moreover, a broad peak at about 15 °2θ, probably related to hydromagnesite, is documented in all samples with percentage ranging from 2 and 6%.

The stable carbon and oxygen isotopes are distributed in a wide range, with $\delta^{18}O$ ranging between -1 and -6‰ and $\delta^{13}C$ between +2 and -10‰. Isotope composition of the host rock was also determined, being $\delta^{18}O$ and $\delta^{13}C$ -1.34 and 2.37, respectively. The ratios are, among themselves, highly correlated (r=0.85; P=6*10-5) and the isotope composition is not related to the sampling site.

Same consideration can be made for the trace element, TOC and Ntot composition. For all these indicators the highest concentrations are recorded in samples A1, A3/4b, D2, E2, E3 and E5.

To better define the factors controlling the mineralogy and the isotope and element geochemical behaviour, CA was applied both with respect to cases (samples) and variables (data). As for the cases, three main clusters were defined: (i) samples A3/4a, A3/4b, B1, B2, D1, D2, D3, E1, E2, E3 (cluster S1) characterized by dendritic morphology, wet powdery texture and prevalent dark colour, (ii) samples A2, C1 and C2 (cluster S2) with dendritic morphology, hard texture light colour, and (iii) samples A1 and E5 (cluster S3) with hieroglyphic morphology, muddy and powdery texture and very dark colour. Regarding the CA processed on variables the three recognized clusters discriminate (Table 1): (i) cluster V1 grouping quartz, Si, Al, Fe, Ni, Pb, V, Cr and Co; (ii) cluster V2 grouping fluorapatite, P, Mn, Zn, Cu, Cd, TOC and Ntot, (iii) cluster V3 grouping calcite, hydromagnesite, $\delta^{18}O$ and $\delta^{13}C$.

First microbiological analyses indicated a correlation between the microbial diversity (alpha-diversity based on Shannon index) and the vermiculation colours (Fig. 4).

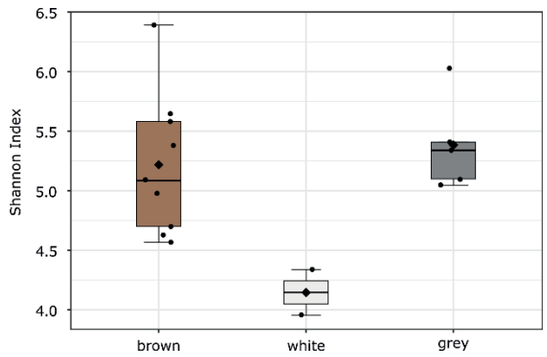

Figure 4: *Alpha-diversity within brown, white and grey vermiculations based on Shannon index.*

Specifically, microbial diversity was higher in brown and grey vermiculations compared to the white ones, indicating a higher heterogeneity in terms of microbial taxa (and therefore probably microbial functions) in wet and/or muddy dark vermiculations as compared to the dry and light-coloured ones.

Metabarcoding analyses showed that microbial communities in vermiculations were composed by members of the phyla Actinomycetota, Pseudomonadota, Firmicutes and Nitrospirota. Several bacteria known for chemolithotrophic activities (e.g. Nitrospira) have been found as well as heterotrophic bacteria indicating the development of complex communities in vermiculations established thanks to synergistic relationships. Within the Firmicutes and Actinomycetota phyla, diverse genera are known to solubilize and precipitate calcium carbonate. Among Firmicutes, members of the Bacillus and Paenibacillus were generally highly abundant in brown and grey vermiculations, and only in traces in the white ones. Other Firmicutes genera were dominant only in specific samples, like Paenisporosarcina in one grey vermiculation and Fictibacillus in a few brown vermiculations. Among Actinomycetota, Crossiella is known to biomineralize calcium carbonate and was highly abundant in the brown and grey vermiculations. Nocardioides and Pseudonocardia were dominant in two different white vermiculations.

A few microbial strains isolated in the lab from cave samples also showed the capacity to solubilize calcium carbonate on agar plates like indicated in Figure 5.

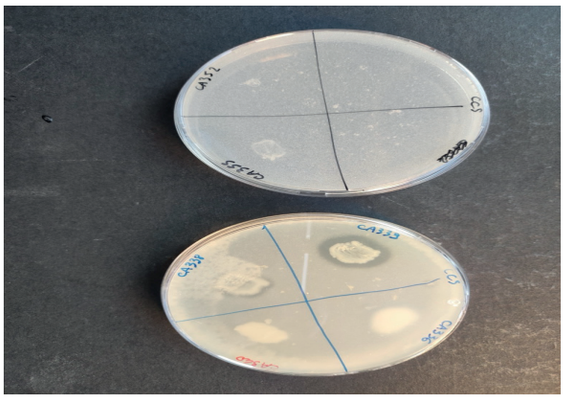

Figure 5: *Example of a microbial strain (the strain CA339) isolated from Puntali cave that showed the capacity to solubilize calcium carbonate on plate.*

Table 1: *Average value of the mineralogical and geochemical data as from CA applied both with respect to cases (samples; clusters S) and variables (data; clusters V). Qz=quartz; F-Ap=fluorapatite; Ca=calcite; Hy-Mag=hydromagnesite.*

	Cluster V1									Cluster V2								Cluster V3			
	Qz	Si	Al	Fe	Ni	Pb	V	Cr	Co	F-Ap	P	Mn	Zn	Cu	Cd	TOC	N_{tot}	Ca	Hy-Mag	$\delta^{18}O$	$\delta^{13}C$
	%	%	%	%	ppm	ppm	ppm	ppm	ppm	%	%	ppm	ppm	ppm	ppm	%	%	%	%	‰	‰
Cluster S1	0,49	0,31	0,09	0,11	2,82	1,39	5,82	2,66	0,98	4,49	0,43	50,88	46,08	9,18	0,07	1,86	0,60	90,29	4,73	-1,93	1,52
Cluster S2	0,58	0,32	0,13	0,04	1,80	0,45	2,29	0,86	0,34	0,78	0,16	9,50	22,82	5,75	0,02	0,59	0,20	95,13	3,52	-4,87	-7,91
Cluster S3	8,58	4,59	0,76	0,53	9,56	6,64	25,16	12,90	4,52	7,19	1,07	188,05	194,55	56,64	0,16	3,08	0,88	79,22	5,01	-3,97	-2,88

4. Discussion

Morphology and colour of the Puntali vermiculations seem to be independent by the features (slope, fractures, roughness) of substrate on which they develop. Only the texture is controlled by the water content. Independently by the biotic or abiotic origin of the vermiculations, their formation seems originate in presence of water with wet evolving towards dry and mineralized structures (BINI et al., 1978). As for the Puntali cave, the starting evidence are: 1) the mineralizations are represented by carbonate minerals; 2) on the base of isotope composition, considering the formation of vermiculations on the cave walls and according to BINI et al. (1978), the water involved in this process could be the condensation/percolation water; 3) consistently with recent researches (e.g. CAÑAVERAS et al., 1999; NORTHUP et al., 2001; JONES et al., 2008; ADDESSO et al., 2019; 2021) and first microbiologic results on the Puntali cave vermiculations, it is reasonable associate their origin to biotic processes. Indeed, we found in the different vermiculations complex microbial communities presenting both chemilithotrophic and heterotrophic bacteria that can establish synergistic relationships and can be involved in calcium carbonate solubilization and precipitation.

With these premises, and according to ENYEDI et al. (2020), it is here proposed a genetic scheme (Fig. 6) in which high amounts of organic matter (derived from guano) might have firstly triggered the development of complex microbial communities. The microbial activity could have modified the surrounding pH inducing dissolution of the host rock (BARTON & NORTHUP, 2007). At the same time the microbial cells produced and released exopolysaccharides (EPS) that are the main components of extracellular matrix of biofilm and are composed by negatively charged ions/polarized molecules (e.g. R-COOH, R-COO-, $H_nPO_4^{3-n}OH^-$). The dissolution induced the increase in Ca^{2+} ions and later of bicarbonate ions derived from the CO_2 production due to microbial organic matter oxidation. The increase of pH generated the conditions promoting the precipitation of chemical species mostly in the form of Amorphous Calcium Carbonate by using the EPS as nucleation site (ACC in Fig. 6). Subsequently, probably, the gradual disruption of the EPS, following the cell death, gave rise to the formation of calcite.

In the specific case of the Puntali cave the evolution can be summarized as followed:

1. Vermiculations of cluster S3 represent those formed in the early

stage. The hieroglyphic morphology and muddy/powdery texture with the highest TOC (and trace elements) were related to a proliferation of bacterial activity and an active EPS. High availability of P (derived from guano) produced the fluorapatite precipitation which removed Ca^{2+} ions producing increase in the Mg/Ca ratio and hydromagnesite precipitation (here considered as a form of ACC). The stable isotope composition of these samples would record the isotope signal of the first waters involved in mineral precipitation, namely the condensation/ percolation waters.

2. Vermiculations of cluster S1 document an intermediate stage in the mineralization. Actually, they are characterized by a more regular morphology (dendritic) and powdered texture intermediate between wet and dry. Intermediates are the content in TOC and trace elements, while fluorapatite and hydromagnesite decrease in favour of calcite. The isotope composition approach that of the host rock probably because, compatibly with the general model, the organic acids together with other enzymes, produced by bacterial metabolic activity, triggered a decrease in the EPS pH dissolving the host rock. This is confirmed by the presence of negative imprints in the host rock, under the vermiculations.

3. Vermiculations of cluster S2 can be considered those more evolved, as testified by the mostly hard texture, light colour and the lowest TOC and trace element concentrations. Calcite reaches the highest percentages with a decrease in both fluorapatite and hydromagnesite. Decrease in $\delta^{18}O$ may be related to a fast development of the vermiculation, after the degradation of the EPS, responsible of an enrichment in ^{16}O as consequence of a kinetic disequilibrium (JONES et al., 2008). At the same time, negative $\delta^{13}C$ are likely related to the availability of ^{12}C deriving by the complete microbial oxidation of the organic matter, as testified by the lowest TOC percentage.

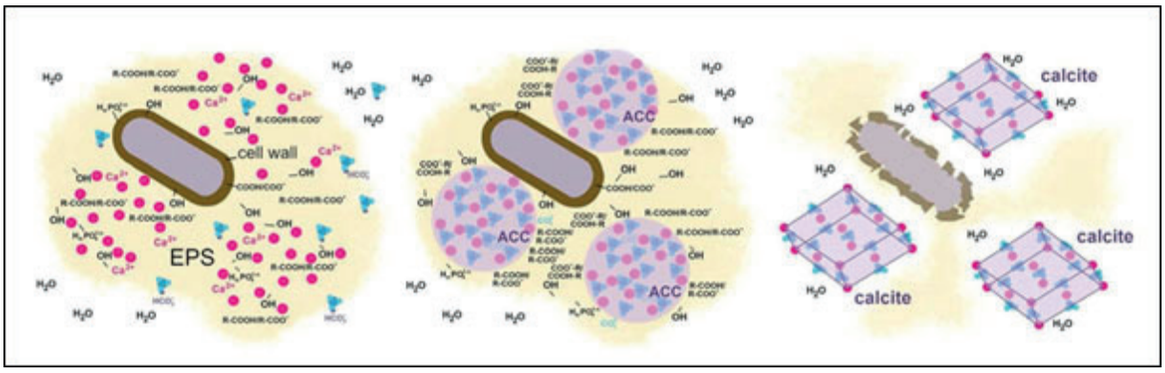

Figure 6: *Genetic scheme for the carbonate nucleation in the bacterial EPS (see text; modified from ENYEDI et al., 2020).*

5. Conclusion

Morphological, mineralogical, microbiological and geochemical study of the vermiculations in the Puntali cave allowed to reconstruct the genesis and evolution of these peculiar deposits. Vermiculations develop with different colour, texture and morphology on the cave wall. Collected data did not indicate an environmental control on the behaviour of the measured proxies possibly related to the different sampling site. Conversely, the application of multivariate analysis allowed to group the samples in three clusters, each related to different morphological features and different abundance of minerals, trace elements and isotopes. The three groups represented, in short, the stages of the vermiculation formation evolving from irregular, wet, poorly mineralized structures enriched in organic matter and trace elements to more regular, dry, mineralized frameworks depleted in organic matter and elements. The genetic process is interpreted as bacterial-mediated and triggered by the high amount of organic matter related to the abundance of guano in the Puntali cave. The water involved in the process origins from the percolation and condensation phenomena and carbonate is the result of mineralization, at least in part mediated by bacterial cells.

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The first occurrence of the biotic mineral guanine in Brazil, a nitrogen-bearing molecule found in a cavernicolous environment

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Abstract

Caves on Earth can be studied as analogous environments on Mars, like underground structures, including Martian lava tubes. On Earth, these environments can sustain large communities hidden from the Sun, thriving especially from chemolithoautotrophic metabolisms. Among the main elements for life as we know it (CHONPS), understanding the nitrogen cycle is of great importance. During sampling of caves for metagenomic studies in the region of Serro and Morro do Pilar, state of Minas Gerais, small deposits of a white/cream color organic material were found on the walls of a shelter. Using techniques like RAMAN and FTIR, it was possible to confirm that the substance found was guanine, a nitrogen-bearing mineral and nitrogen source. However, it has not yet been possible to perform sample diffraction (XRD) due to the low amount of material collected. It is proposed that guanine comes from the nitrogenous excreta of arthropods. This is the first record of mineral guanine in Brazil, with preservation similar to that of the mineral guanine from bat guano. This discovery can broaden our knowledge about minerals associated with caves in Brazil, expand the metabolic possibilities and ecological processes associated with cavernicolous environments, and bring new knowledge in an astrobiological context.

Résumé

Les grottes terrestres peuvent être étudiées comme des environnements analogues sur Mars, comme les structures souterraines, y compris les tubes de lave martiens. Sur Terre, ces environnements peuvent abriter de vastes communautés cachées du soleil, qui prospèrent notamment grâce à des métabolismes chimiolithoautotrophes. Parmi les principaux éléments de la vie telle que nous la connaissons (CHONPS), la compréhension du cycle de l'azote est d'une grande importance. Lors de l'échantillonnage de grottes pour des études métagénomiques dans la région de Serro et Morro do Pilar, dans l'État de Minas Gerais, de petits dépôts de matière organique de couleur blanche/crème ont été trouvés sur les parois d'un abri. En utilisant des techniques telles que RAMAN et FTIR, il a été possible de confirmer que la substance trouvée était de la guanine, un minéral azoté et une source d'azote. Cependant, il n'a pas encore été possible d'effectuer une diffraction d'échantillon (XRD) en raison de la faible quantité de matériel recueilli. Il est proposé que la guanine provienne des excréments azotés des arthropodes. Il s'agit du premier enregistrement de guanine minérale au Brésil, avec une préservation similaire à celle de la guanine provenant du guano de chauve-souris. Cette découverte peut élargir nos connaissances sur les minéraux associés aux grottes du Brésil, élargir les possibilités métaboliques et les processus écologiques associés aux environnements cavernicoles, et apporter de nouvelles connaissances dans un contexte astrobiologique.

1. Introduction

Although several studies have explored microbial communities in different subterranean ecosystems, little is known about the diversity of their metabolic processes and survival strategies. The mineralogy of caves is intimately linked with living beings that thrive in this environment, and recent studies have uncovered the potential relationships between microbial genomes and their ecological processes, like chemolithoautotrophic metabolisms (e.g. BENDIA et al. 2022). This provides support for discussing its implications for the search for life forms existing outside our planet, in environments rich in Fe, especially on Mars (e.g. SILVA et al., 2024).

The organisms in these caves and shelters have already been shown to have a high diversity of genes involved in different biogeochemical

cycles, including pathways reducing, and oxidative processes related to C, S, N and Fe. These metabolisms are closely linked to the availability of chemical species in caves and shelters, so local geochemistry and mineralogy are of great importance. Thus, the interpretation of the mineralogical mapping of the environment could reveal the metabolic potential and diversity in cave ecosystems, contributing to elucidate the potential metabolisms in analogous extraterrestrial oligotrophic systems, such as underground environments on Mars, such as lava tubes (LÉVEILLÉ & DATTA 2010; PUŞCAŞ et al. 2010; SAURO et al. 2020).

The presence of nitrogen-bearing minerals is common in caves and shelters, and it usually comes from the percolation of water receiving the contribution of organic matter or microorganisms that act to produce species like ammonium, nitrite and nitrate (such as *Nitrosomonas* and *Nitrobacter*) (ONAC & FORTI 2011; DE SOUZA et al. 2023). Other organic minerals can form from reactions of organic deposits, being the bat guano the most important, although bone breccias and the excrements of various animals may occasionally be the source. More than 100 secondary minerals are known as guano derivatives, while some organic compounds, like guanine and urea, segregate directly from the guano itself (ONAC & FORTI 2011).

Guanine, as a mineral occurrence, was recorded only in Peru (where it was discovered 1844), Australia, Chile, Mexico (2 different places) and South Africa (MINDAT 2025). To date, there are no reports of the observation of the mineral guanine in Brazil. Here, we describe the discovery of small deposits of a white organic material found on the walls of a shelter in the region of Serro and Morro do Pilar, state of Minas Gerais. This finding corresponds to the first discovery of guanine as a mineral in Brazil.

2. Materials and methods

Caves and shelters were visited in the region between Serro and Morro do Pilar, in the state of Minas Gerais, in July 2023. Samples of the wall and ceiling of a small shelter (-18.406673, -43.419928, 1315 m) containing mineral deposits (Fig.1) were initially collected during a prospecting for a genomic and geochemical study of the caves in the area.

The Raman measurements were carried out using a Renishaw InVia Reflex equipment coupled to a Leica DM2500M microscope, using a 785 nm (diode laser, Renishaw)-500 mW- with 5% of its power. Each individual spectrum was collected using 30 accumulations of 1 s each, with the removal of cosmic rays. The software Wire 4.4, Fityk 1.3.1, and OriginPro 8 were used to collect, analyze, and plot the data, respectively. Standards of adenine, cytosine, guanine, thymine, and uracil (Sigma Aldrich) were also measured and used as a comparison to help the identification of the mineral deposits.

Samples of the collected material and a commercial standard of guanine (Sigma Aldrich) were analyzed without prior treatment by infrared absorption spectroscopy (FTIR) in attenuated total reflectance (ATR) mode in a Bruker FTIR-ATR spectrometer, model ALPHA, equipped with a DTGS detector. The spectra were obtained with a resolution of 2 cm^{-1} and 128 accumulations.

Scanning Electron Microscopy (SEM) was performed at low pressure, on a Quanta 250 model equipment (FEI), with an Aztec EDS system, 82 mm^2 window, from Oxford Instruments Ltd, with 3 detectors - Secondary electron imaging (SEM), cathodoluminescence (CL) and backscattered electrons (DBS/BSE) for compositional characterization by EDS of various materials. Due to the size and shape of the whole samples, a small amount of the mineral had to be removed from the matrix and placed on a carbon tape for microscopy.

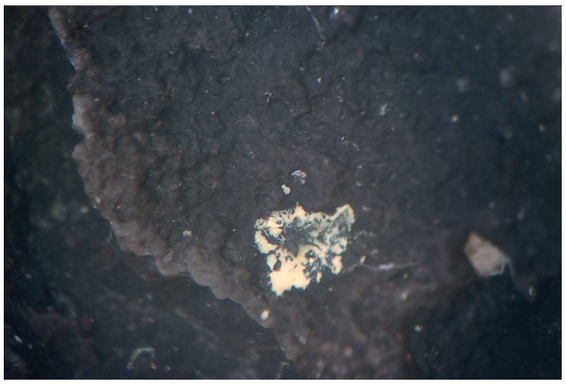

Figure 1: *Images displaying a large cream-colored deposit (~1 mm diameter) on the dark matrix (mag. ~40x).*

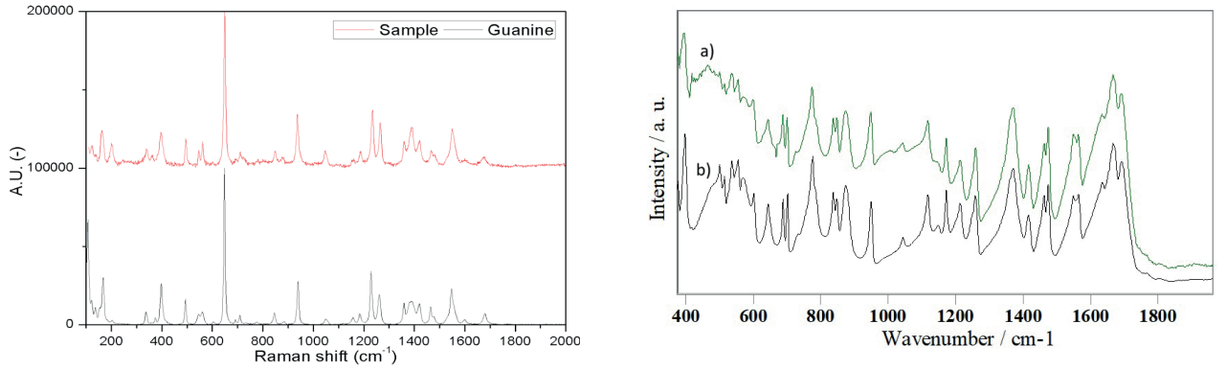

Figure 2: *(Left) Raman spectra of the material studied: the upper spectrum (Sample) corresponds to the mineral deposits collected in the quartzite shelter, and the lower spectrum (guanine) corresponds to the guanine standard. (Right) FTIR-ATR spectra (a) of the collected sample and (b) of the commercial guanine standard.*

3. Results

The expedition in the region between Serro and Morro do Pilar focused on collecting samples for a study to investigate the microbial communities that colonize iron-rich caves. However, during the prospecting, caves, and shelters in quartzite rocks were also located and visited. Although these sites were not the primary interest of the expedition, samples of those places were also collected and mineral characterizations were carried out. Wall and ceiling samples collected from one of those quartzite shelters showed small deposits of a white/cream color organic material on the matrix, a presence that was only recognized during the Raman characterization of the sample, days after the collection and return to the laboratory.

The deposits were present on a dark, almost black matrix. It is important to note that during sample collection, there was an interest in characterizing this black matrix rock from the shelter, generating a bias during the collection process. On the matrix, it is possible to find small white and transparent crystals identified by Raman as quartz, probably originating from the quartzite rock on which this dark matrix was formed. The mineral samples were also spread on the dark matrix, and have varied sizes and shapes, generally measuring around 1 mm in diameter.

Their coloration varies and can be described as ranging from a light cream color, almost white, to a yellowish color (Fig.1).

The Raman spectrum of the mineral sample was consistent with the guanine standard spectrum, showing peaks with similar shifts and relative intensities (Fig.2). The only two prominent differences between the spectra are the presence of a peak at 109 cm^{-1} in the guanine standard, absent in the mineral sample, and the presence of a much more intense peak at 202 cm^{-1} in the mineral sample than in the guanine standard.

The FTIR-ATR spectra recorded for the sample showed correspondence with the commercial standard of guanine in powdered solid form, with bands observed at 3312, 3167, 3110, 3060, 2988, 2903, 2844, 2783, 2689, 2639, 1693, 1667, 1651, 1634, 1563, 1548, 1474, 1461, 1415, 1370, 1360, 1258, 1213, 1172, 1148, 1117, 1044, 874, 848, 837, 776, 773, 726, 701, 688, 667, 644, 570, 555, 537, 514, 501, 419 and 397 cm^{-1} (Fig.2) (LOPES et al. 2012). The bands at 2379, 2349, and 2324 cm^{-1}, in turn, were observed exclusively for the investigated sample, related to the presence of carbon dioxide (CO_2) (CULP et al. 2010) probably adsorbed in the sample.

SEM showed the high purity of the sample, only demonstrating the presence of small amounts of Al and Si, probably originating from the matrix. In higher magnifications, it is possible to observe the crystalline structure of guanine on a small scale (Fig.3), similar to that observed in other guanine depositions of biological origin (HU et al. 2023).

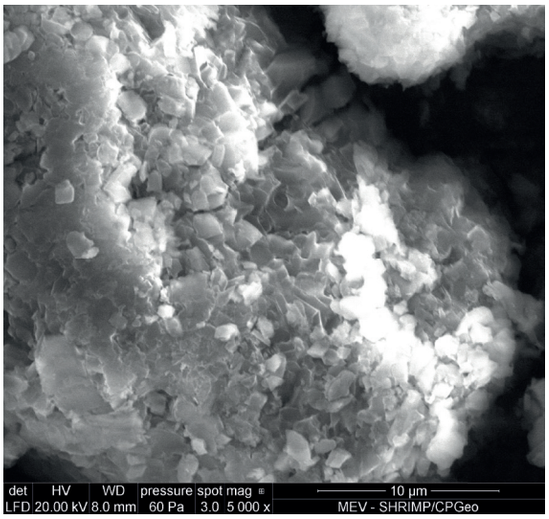

Figure 3: *SEM image of guanine crystals of the sample (mag. 5,000x).*

4. Discussion

With the aid of micro-Raman and FTIR spectroscopy, it was possible to confirm that the mineral sample that was collected was guanine. Guanine occurs mainly in three distinct forms or polymorphs: guanine monohydrate (GM), anhydrous guanine α form (AG α), and anhydrous guanine β form (AG β). Other three phases are also known: the dehydrated form of guanine monohydrate (synthesized at 150°C), the amorphous hydrated form of guanine, and the anhydrous guanine γ form (AG γ), sometimes interpreted as one type of twinning of AG β (HU et al. 2023). The most straightforward way to solve this doubt regarding the exact polymorph of these guanine deposits is using the X-ray diffraction technique (XRD), being fundamental for the description of the mineral.

Although not ideal for characterizing the type of guanine, Raman spectroscopy can provide some hints about the polymorph that was found. The absence of some intense peaks (e.g., 1474 cm^{-1}) and the presence of others (e.g., 1233, 1265, and 1552 cm-1) greatly reduces the likelihood that this sample is GM (PILÁTOVÁ et al. 2022). The Raman spectrum is in agreement with that expected for anhydrous guanine (LOPES et al. 2012), however, the presence of the peak at 202 cm^{-1}, associated with skeletal ring torsions of the molecule (LOPES et al. 2012), could be able to differentiate the AG α phase (without peak) from the AG β phase (with peak) (HU et al. 2023). Thus, the sample collected at the shelter would correspond to the AG β phase, while the standard guanine would be the AG α phase.

The FTIR-ATR spectra for the investigated sample and the analyzed commercial standard showed correspondence with FTIR spectra reported in the literature for the anhydrous form of guanine, in agreement with the FTIR spectrum expected for the tautomeric form 7H-ketoamine (LOPES et al. 2012). The distinction between the possible tautomeric forms of guanine is important to determine since they significantly influence the stability of the compound depending on the environment in which it is found (SHUKLA & LESZCZYNSKI 2006). The origin of the CO_2 adsorbed in the guanine sample investigated, in turn, may be related to decomposition processes still underway in the collected material, possibly resulting from microbiological activity. The decomposition of guanine by bacteria was demonstrated by RAKOSKY & BECK (1955), with the release of ammonia, CO_2, and acetic acid as final products. Taking this hypothesis into account, the non-observation of ammonia and acetic acid in the recorded spectra may be due to the low concentration of these species in relation to the guanine concentration.

Through SEM, it is possible to perceive the homogeneity and crystalline structure of guanine in the collected sample, which appears to have a high degree of purity. However, it is not possible to determine which crystalline phase is present, which is expected to be obtained in the future with XRD.

Studies indicate that guanine, as well as other nitrogenous compounds and organic materials, are associated with arthropod excreta in general (SOUZA et al., 2017; SANTOS & ANTUNES, 2018; CABEZAS-CRUZ, 2023). The products of such components contribute significantly to the ecology and diversity found in cave environments (TRAJANO, 2000; FERREIRA et al., 2007). Unfortunately, at the time of collection, no arthropods were observed on the walls of the shelter studied, nor were any signs (such as exuviae) that could suggest which arthropod produced the guanine deposit. However, the possibility of identifying the populations that produce such excreta opens doors for the conservation of species and preservation of cavities where they occur (AULER & PILÓ, 2014; NITZU et al., 2018).

5. Conclusion

This study characterized deposits found in a shelter in the region between Serro and Morro do Pilar, state of Minas Gerais. During the characterization, it was possible to demonstrate, thanks to similarities between the sample and a commercial standard observed during Raman spectroscopy and FTIR-ATR, that the material is a biomineralization of the substance guanine. This is the first description of the presence of this mineral in Brazil, only the sixth country in the world.

Guanine is found in three main phases, with the monohydrate phase being the least likely. Between the two anhydrous crystalline phases of guanine, the most likely one in this case would correspond to the AG β phase. However, only through XRD can the doubt be resolved, an analysis that has not yet been performed due to difficulties with the small quantity of the sample.

Due to the lack of light, the cave environment has a low capacity to maintain photosynthetic organisms, making the external supply of organic material and the internal production of excreta through their organisms essential in these environments (TRAJANO, 2013). In this sense, the microbial communities found in caves, often generated through guano (bat excreta) or other arthropod excreta, for example, are essential for the functioning and maintenance of cave communities (NORTHUP, 2011; TRAJANO, 2013; SAKOUI et al., 2020). Thus, in the present study, it was possible to observe samples of nitrogenous waste of arthropods, relating them to the presence of guanine. Thus, after excretion, guanine underwent a natural process of organization and crystallization, becoming a mineral originating from a biogenic substance.

Acknowledgments

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A Study on Cave Flower developed in the Paleozoic carbonate rocks of Southwest China

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Abstract

This study focuses on cave flowers developed in the Paleozoic carbonate strata of Southwest China. Through field investigations, mineralogical analysis, and sedimentary environment reconstruction, the formation mechanisms and mineralogical characteristics of these cave flowers are revealed. Cave flowers are primarily categorized into three types: aragonite flowers, calcite flowers, and gypsum flowers. Their distribution is controlled by the lithological combinations of Cambrian–Ordovician dolomite, limestone, and gypsum interlayers, as well as hydrogeochemical conditions. Aragonite flowers form through rapid crystallization in low-humidity environments, calcite flowers are associated with stable groundwater conditions, and gypsum flowers rely on sulfate-enriched solutions. The early Paleozoic evaporite lake sedimentary environment provided high solubility conditions conducive to cave flower formation, while hydrodynamic processes drove mineral differentiation. The findings deepen the understanding of Paleozoic karst geology and mineralogy while providing a scientific basis for cave conservation and sustainable utilization.

Résumé

Cette étude porte sur les anthodites de grotte développées dans les strates carbonatées paléozoïques du sud-ouest de la Chine. Grâce à des investigations de terrain, des analyses minéralogiques et une reconstruction de l'environnement sédimentaire, les mécanismes de formation et les caractéristiques minéralogiques de ces anthodites sont révélés. Les anthodites de grotte sont principalement classées en trois types : les anthodites en aragonite, en calcite et en gypse. Leur distribution est contrôlée par les associations lithologiques de dolomie, de calcaire et d'intercalations de gypse du Cambrien et de l'Ordovicien, ainsi que par les conditions hydro-géochimiques. Les anthodites en aragonite se forment par cristallisation rapide dans des environnements à faible humidité, celles en calcite sont associées à des conditions de nappe phréatique stable, tandis que les anthodites en gypse dépendent de solutions enrichies en sulfates. L'environnement sédimentaire des lacs évaporitiques du Paléozoïque inférieur a fourni des conditions de haute solubilité favorables à la formation des anthodites, tandis que les processus hydrodynamiques ont entraîné la différenciation minérale. Ces résultats approfondissent la compréhension de la géologie karstique et de la minéralogie du Paléozoïque tout en fournissant une base scientifique pour la conservation et l'utilisation durable des grottes.

Resumen

Este estudo concentra-se nas antoquitas de caverna desenvolvidas nos estratos carbonáticos do Paleozóico no sudoeste da China. Através de investigações de campo, análises mineralógicas e reconstrução do ambiente sedimentar, são revelados os mecanismos de formação e as características mineralógicas dessas antoquitas. As antoquitas de caverna são classificadas principalmente em três tipos: antoquitas de aragonita, de calcita e de gesso. Sua distribuição é controlada pelas combinações litológicas de dolomita, calcário e camadas intercaladas de gesso do Cambriano e Ordoviciano, bem como pelas condições hidrogeoquímicas. As antoquitas de aragonita formam-se por cristalização rápida em ambientes de baixa umidade, as de calcita estão associadas a condições de águas subterrâneas estáveis, enquanto as de gesso dependem de soluções ricas em sulfatos. O ambiente sedimentar dos lagos evaporíticos do início do Paleozóico forneceu condições de alta solubilidade favoráveis à formação das antoquitas, enquanto os processos hidrodinâmicos (gotejamento de água e ação capilar) impulsionaram a diferenciação mineral. Os resultados aprofundam a compreensão da geologia cárstica e da mineralogia do Paleozóico, ao mesmo tempo que fornecem uma base científica para a conservação e o uso sustentável das cavernas.

1. Introduction

Southwest China is one of the most well-developed karst regions in the world, covering a continuous area of approximately 500,000 square kilometers. The Paleozoic carbonate strata are widely distributed in this region (Huang, F. X. 2011), with over 75% of the caves in China (Zhang, Y. H., 2012). As speleothems, cave flowers serve as crucial indicators for studying hydrological and sedimentary environments due to their unique mineral morphology and formation mechanisms.

This study focuses on the Cambrian and Ordovician dolomite-limestone formations, systematically analyzing the mineral types, crystal characteristics, and controlling factors of cave flowers in the context of the regional geological background. The research aims to reveal the relationship between cave flower formation and the Paleozoic evaporite sedimentary environment (Huang, F. X. 2011), as well as hydrogeochemical conditions, providing new evidence for karst cave evolution and mineral deposition mechanisms.

2. Study area and methods

2.1. Study Area

The study area includes seven representative caves in southeastern Chongqing and western Guizhou, Southwest China (Figure 1), namely Shuanghe Cave, Wen'an Cave, Sanwang Cave, Furong Cave, Qianlong Cave, Shihua Cave, Jinfo Cave. Among them, six caves are developed within Cambrian–Ordovician strata, while Jinfo Cave is formed within Permian strata. The regional structure is relatively stable, controlled by the Paleozoic transgression-regression cycles of the Yangtze Plate. The presence of evaporite interlayers provides essential material conditions for the formation of cave flowers.

2.2. Research Methods

Field Investigation: Systematic surveys were conducted on the spatial distribution of cave flowers, host rock types, and hydrodynamic conditions.

Mineralogical Analysis: A handheld X-ray fluorescence (XRF) analyzer (X-MET8000) was used to rapidly analyze the elemental distribution in rocks and speleothems.

Crystal Morphology Analysis: The morphological characteristics of aragonite, calcite, and gypsum crystals were examined.

Sedimentary Environment Reconstruction: Based on stratigraphic sequences and paleogeographic data, the relationship between the ancient environment and cave flower formation was reconstructed.

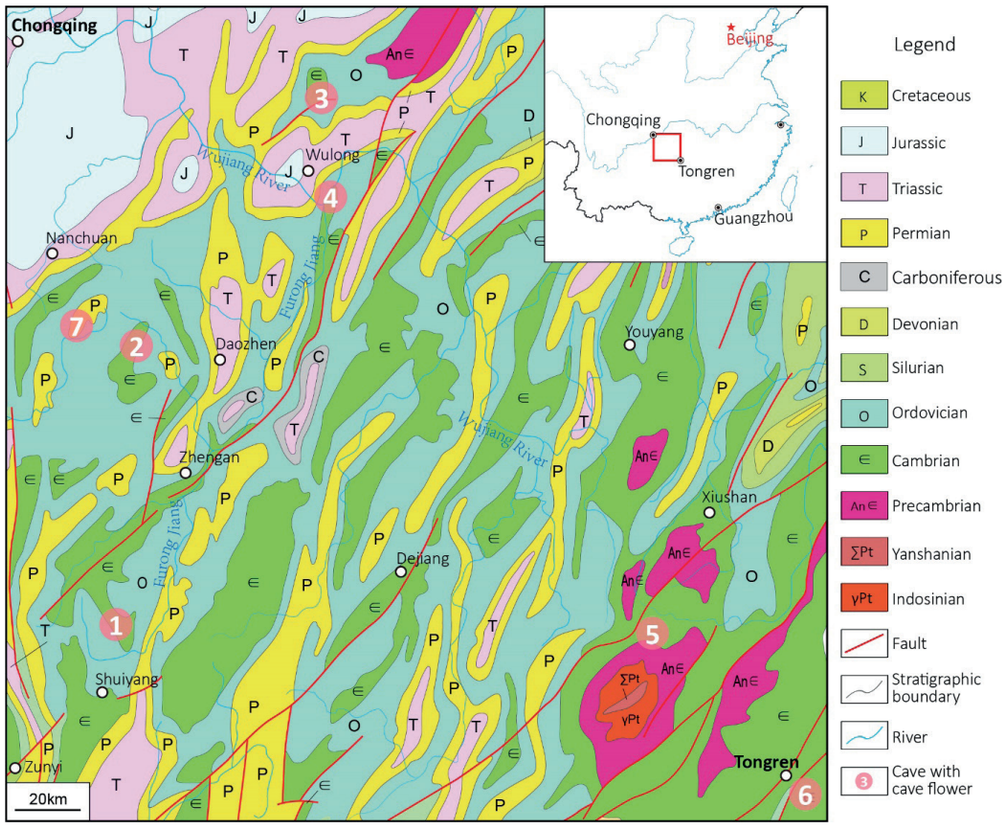

Figure 1: *The seven representative caves with cave flowers in Southeastern China.*

①Shuanghe Cave, ②Wen'an Cave, ③Sanwang Cave, ④Furong Cave, ⑤Qianlong Cave, ⑥Shihua Cave, ⑦Jinfo Cave

3. Results

Shuanghe Cave, with a total length of 437 km, is developed in the Middle Cambrian Loushanguan Group and the Lower Ordovician Tongzi Formation dolomite strata (Zhou, W. L., 2023). The Pixiao branch passage within the cave is densely populated with gypsum flowers, exhibiting petal-like crystals, with visible gypsum interlayers along the cave walls.

Wen'an Cave shares similar stratigraphic development with Shuanghe Cave, primarily featuring plate-like gypsum flowers distributed at the cave's terminal sections.

Sanwang Cave, with a length of 77 km, is formed within the Lower Ordovician Tongzi Formation dolomitic limestone and dolomite strata (Chen, W. H., 2006). Gypsum flowers are mainly distributed in the upper branch passages, displaying fibrous structures (Figure 2).

Figure 2: *The fibrous gypsum flower in Shuanghe Cave (by Zhang Y H).*

Furong Cave, developed in the Middle Cambrian dolomitic limestone and dolomite strata, extends 2.4 km in length (Chen, W. H., 2006). The first 1.5 km is dominated by calcite flowers and underwater crystalline deposits, while the latter half mainly contains aragonite flowers, characterized by needle-like structures (Figure 3), which are associated with high Mg^{2} / Ca^{2} ratio dripwater. A narrow passage connects the two sections, where petal-like gypsum flowers are found beneath large fractures in the rear section. These are influenced by secondary faults of the Furong River thrust fault and the downward percolation of solutions from overlying Cambrian evaporite nodules.

Qianlong Cave, developed within the Middle Cambrian Loushanguan Group dolomitic limestone-dolomite strata (Zhou, W. L., 2022), features a high density of stalactites and stalagmites but contains only calcite flowers, with no aragonite or gypsum flowers present.

Shihua Cave, formed in the Middle Cambrian Qingxudong Formation dolomitic limestone and argillaceous dolomite strata, exhibits widespread development of aragonite flowers, calcite flowers, and gypsum flowers.

Jinfo Cave, situated in the Late Paleozoic Permian limestone strata, is overlain by shale with coal-bearing interbeds (Zhang, R., 1998). Gypsum flowers in this cave exhibit petal-like crystal structures, originating from sulfate-rich solutions leached from the overlying coal-bearing interlayers.

Figure 3: *The needle-like aragnite flower in Furong Cave (by Zhang Y H).*

4. Discussion

The formation of cave flowers is controlled by three key factors:

5. (1) Lithological Composition: The dissolution of gypsum interlayers enhances the solubility of otherwise resistant dolomite, creating dissolution pathways conducive to flower formation.
6. (2) Hydrochemical Conditions: The dissolution of gypsum releases sulfate ions (SO_4^{2-}), driving the precipitation of gypsum flowers.
7. (3) Hydrodynamic Processes: Capillary action promotes the growth of fibrous aragonite, while dripping water facilitates the differentiation of calcite crystal clusters.

Further analysis reveals that the early Paleozoic evaporite lake environment provided a long-term source of sulfate enrichment, while regional tectonic uplift controlled the migration pathways of groundwater through fracture systems (Figure 4).

The morphological diversity of cave flowers, such as needle-like aragonite and petal-like gypsum formations, reflects the complex interplay of these factors. For instance, in low-humidity conditions, increased solution supersaturation may lead to rapid crystallization along specific crystal axes, resulting in the development of aragonite and calcite flowers. In contrast, gypsum precipitation is more likely to occur in sulfate-rich evaporative environments.

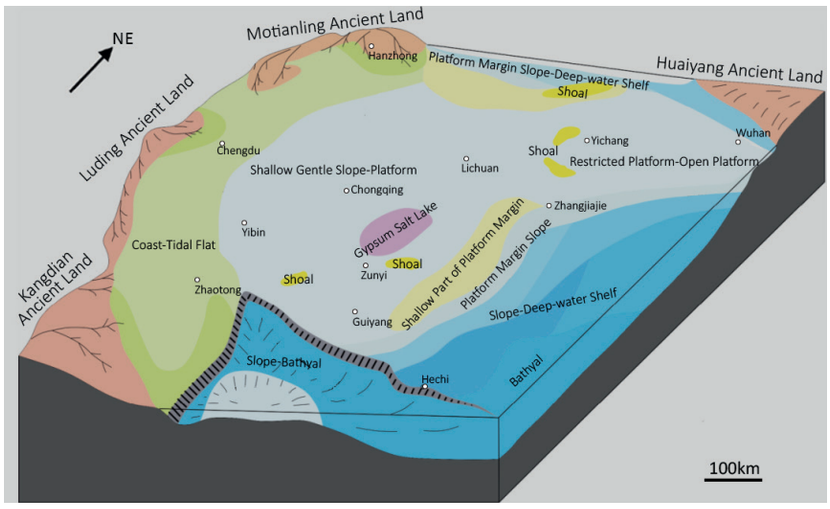

Figure 4: *Cambrian - Early Ordovician Sedimentary Model of the Upper-Middle Yangtze Craton Basin (Huang, F. X. 2011).*

5. Conclusion

The types of cave flowers are jointly controlled by stratigraphic lithology and paleohydrological conditions, with mineral differentiation reflecting groundwater geochemical equilibrium dynamics.

Gypsum interlayers serve as the primary material source for gypsum flower formation, with their distribution influenced by paleosedimentary environments and tectonic activity.

Future studies should integrate isotopic tracing and numerical simulations to quantify mineral precipitation rates and their response to climatic changes.

Session 05

GEOCHRONOLOGY, PALEOCLIMATOLOGY, AND CLIMATE CHANGE

Variação regional da precipitação na Bahia desde o último máximo glacial a partir da análise isotópica de espeleotemas

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Resumo

O território brasileiro representa uma boa oportunidade para o avanço de estudos de paleoclimatologia, devido a uma boa distribuição de terrenos cársticos. A análise de isótopos de oxigênio presentes em espeleotemas serve como base para entender o comportamento do clima no passado, e ajuda a revelar o impacto do movimento de diferentes fenômenos climáticos, como o Sistema de Monções da América do Sul (SMAS), a Zona de Convergência do Atlantico Sul (ZCAS) e a Zona de Convergência Intertropical (ZCIT). Esses fenômenos são influenciados por influenciados por eventos milenares, caracterizados por mudanças bruscas do clima. Sabendo disso, foram retiradas amostras da caverna Abelhão, no sudeste da Bahia, as quais foram datadas pelo método $^{230}U/^{234}Th$ e analisadas por espectrometria de massa, revelando idades do Holoceno (há aproximadamente 11,7 mil anos) e variações isotópicas de $\delta^{18}O$ (isótopo de oxigênio) e de $\delta^{13}C$ (isótopo de carbono) que se relacionam com a atividade dos eventos milenares, indicando oscilações de umidade. Esses resultados foram então comparados com dados de outras cavernas da região, além de outra na Chapada Diamantina, o que possibilita a obtenção de um melhor panorama da variação paleoclimática na Bahia, desde o ultimo maximo glacial ate os dias de hoje.

Abstract

The Brazilian territory represents a great opportunity for advancing paleoclimatology studies due to the widespread distribution of karst terrains. The analysis of oxygen isotopes in speleothems serves as a basis for understanding past climate behavior and helps reveal the impact of the movement of different climatic phenomena, such as the South American Monsoon System (SAMS), the South Atlantic Convergence Zone (SACZ), and the Intertropical Convergence Zone (ITCZ). These phenomena are influenced by millennial-scale events, characterized by abrupt climate changes. With this in mind, samples were collected from the Abelhão cave in southeastern Bahia, which were dated using the $^{230}U/^{234}Th$ method and analyzed by mass spectrometry. The results revealed Holocene ages (approximately 11,700 years ago) and isotopic variations in $\delta^{18}O$ (oxygen isotope) and $\delta^{13}C$ (carbon isotope) related to millennial-scale events, indicating fluctuations in humidity. These results were then compared with data from other caves in the region, as well as one in the Chapada Diamantina, providing a better overview of paleoclimatic variations in Bahia, from the last glacial maximum to the present day.

1. Introdução

Os espeleotemas fornecem informações valiosas sobre o clima do passado da Terra por meio da análise isotópica. Sua formação abrange diversos processos de escalas diferentes, desde a fotossíntese realizada por vegetação (no caso das análises de $\delta^{13}C$), até os movimentos de massas de ar que controlam as condições climáticas em nível local (no caso das análises de $\delta^{18}O$). Sabendo disso, foram amostras estalagmites da caverna Abelhão, localizada no sudeste da Bahia. Essas amostragens geraram resultados que então foram tratados, e analisados em conjunto com dados antigos de outros projetos, relacionando todas essas diferentes escalas de fenômenos naturais para melhor retratar o passado climático da região.

Neste trabalho, investigamos os processos formadores dos ambientes cársticos, o funcionamento do Sistema de Monção da América do Sul (SMAS) e sua relação com a atividade das convecções da Zona de Convergência Intertropical (ZCIT) e da Zona de Convergência do Atlântico Sul (ZCAS) na região sudeste da Bahia. Para tal, por meio análises de um espectrômetro de massa do tipo Magnetic Sector Multicolector - Inductively Coupled Plasma Mass Spectrometry (MC-ICPMS) foram obtidas as datações das amostras, e com um espectrômetro de massa de razão isotópica Thermo-Finnigan Delta Plus Advantage foram realizadas as analisadas de razões isotópicas de carbono e oxigênio. Trabalhos anteriores discutiram e analisaram a interação dos processos do SMAS com o retrato isotópico da região centro/norte do Brasil (Barreto, 2016; Strikis, 2015; Novello et al., 2017; Cruz et al., 2005) e, além de comparados e agregados com os dados novos, também foram relacionados com os eventos milenares conhecidos como Younger Dryas (YD), Bølling-Allerød (B-A) e Heinrich Stadial (HS) (Strikis, 2015).

2. Materiais e Métodos

As análises geocronológicas dos espeleotemas iniciam com a amostragem de carbonato utilizando uma microretífica. Em seguida, as amostras são preparadas e analisadas seguindo os padrões definidos por Shen et al. (2002). As análises geocronológicas são conduzidas

pelo método 230U/234Th utilizando um espectrômetro de massa do tipo Magnetic Sector Multicolector - Inductively Coupled Plasma Mass Spectrometry (MC-ICPMS). Essas análises são realizadas nos laboratórios de geocronologia da Universidade de Minnesota, nos Estados Unidos, e da Universidade Xi'an Jiaotong, na China, com a colaboração dos professores Larry Edwards e Hai Cheng.

Para a análise de isótopos, são amostrados aproximadamente 100 µg de calcita ao longo do eixo de crescimento das estalagmites. Essa amostragem é realizada usando um microamostrador modelo 5400 da Sherline ou um microamostrador de alta precisão, modelo MicroMill NW-100056 da New Wave Research. A escolha do equipamento parte da resolução temporal desejada para cada amostragem: o modelo 5400 permite uma resolução de até 0,4 mm, enquanto o modelo MicroMill alcança uma resolução de até 0,125 mm entre as amostras. 10 Com o carbonato extraído, ele é então preparado usando um sistema automatizado Thermo-Finnigan Gas Bench II, conectado a um espectrômetro de massa de razão isotópica Thermo-Finnigan Delta Plus Advantage no Laboratório de Isótopos Estáveis do Centro de Pesquisas Geocronológicas (LES-CPGEO) do IGc-USP. O espectrômetro de massa realiza a análise do CO2, gerado pela reação de hidrólise ácida do CaCO3 com H3PO4, possibilitando a medição das razões isotópicas.

Após a obtenção dos dados isotópicos, com o auxílio do Software R junto com o algoritmo de modelagem de idade de espeleotemas StalAge (Scholz & Hoffmann, 2011), serão obtidos os modelos geocronológicos para cada uma das estalagmites. Em sequência, também serão realizadas análises de séries temporais, como REDFIT e análise de ondaletas. Na análise de REDFIT (Schulz & Mudelsee, 2002) é possível verificar a frequência de determinados eventos ao longo do registro isotópico, e, com a análise de ondeletas, verificamos quando e com qual intensidade eles ocorrem no registro paleoclimático. Vale mencionar que, além dos obtidos para esse trabalho, dados de outros trabalhos (Barreto, 2016) e dados não publicados fornecidos pelo orientador, foram utilizados e passaram ou passarão pelo mesmo tratamento, com o intuito de serem comparados e agregados com os novos resultados.

3. Resultados

Utilizando o programa de confecção de gráficos Origin, foram gerados dois gráficos utilizando os resultados de isótopos de oxigênio e carbono obtidos da caverna Abelhão (ABE), além de resultados não publicados de espeleotemas de outras quatro cavernas e grutas do sudeste da Bahia, sendo elas a gruta do Deusdete (DEUS), a gruta São Gotardo (SG) e a caverna Nascente da Gruna (NGR), além de uma na região da Chapada Diamantina, chamada de caverna da Paixão (PX).

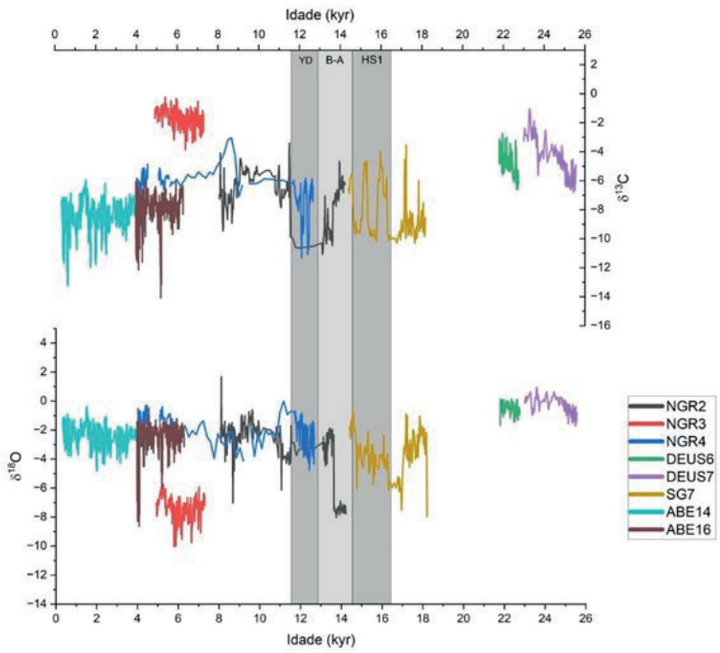

Figura 1: *Gráfico de razão isotópica de oxigênio ($\delta^{18}O$) e de carbono ($\delta^{13}C$) por idade (mil anos) de amostragens de espeleotemas do sudeste da Bahia. Estão incluídos também os eventos milenares Younger Dryas (YD), Bølling-Allerød (B-A) e Heinrich Stadial (HS).*

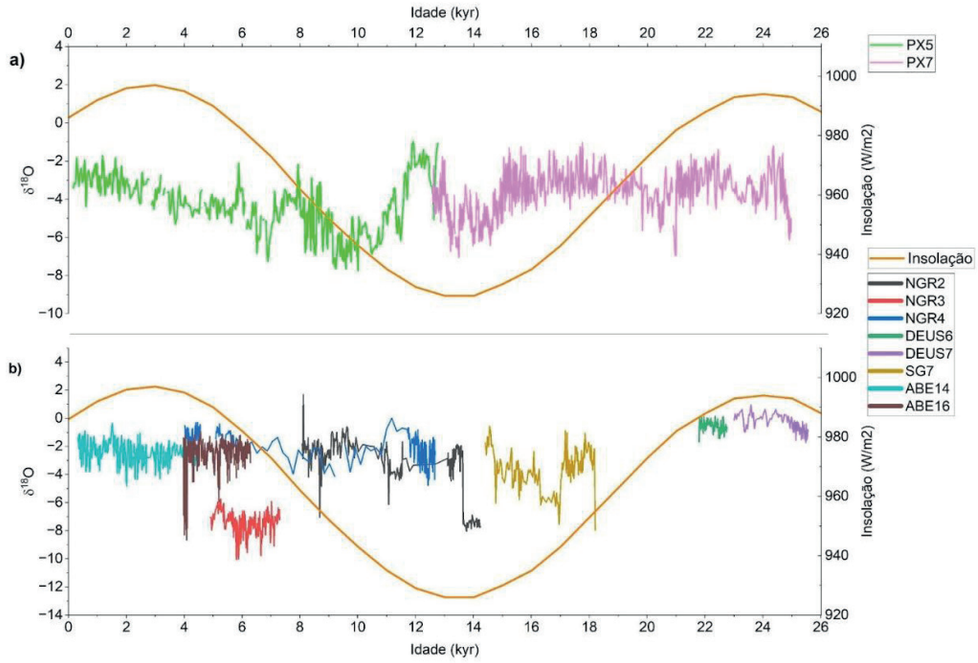

Figura 2: *a) Gráfico de razão isotópica de oxigênio ($\delta^{18}O$) por idade (kyr) x insolação (W/m^2) por idade (kyr) de amostragens de espeleotemas da Chapada Diamantina (Barreto, 2016); b) Gráfico de razão isotópica de oxigênio ($\delta^{18}O$) por idade (kyr) x insolação (W/m2) por idade (kyr) de amostragens de espeleotemas do sudeste da Bahia.*

4. Discussão

O primeiro gráfico (Fig. 1) revela que os resultados de isótopos de oxigênio e carbono seguem, no geral, um padrão desde o último máximo glacial (~25 mil anos), com exceção de um espeleotema da caverna Nascente da Gruna, o qual apresentou valores de $\delta^{13}C$ mais elevados e $\delta^{18}O$ mais reduzidos, o que naturalmente se deve a fatores próprios e locais dessa caverna que a deixaram mais úmida nesse intervalo de tempo. Além disso, os dados foram inseridos nos intervalos dos eventos milenares YD, B-A e HS1, revelando inicialmente uma oscilação considerável no HS1, com uma redução dos valores de $\delta^{18}O$, um período mais seco no B-A, evidenciado por um aumento nos valores de $\delta^{18}O$ e uma redução nos valores de $\delta^{13}C$, e por fim outra oscilação no YD. É importante deixar claro que, visto que os dados obtidos da caverna Abelhão para esse trabalho foram datados para uma época mais recente que estes eventos e permitem observar que, apesar da leve tendência de clima relativamente mais seco durante o Holoceno, seus valores não apresentam grande variações isotópicas para esse período.

Comparando os resultados da região da Chapada Diamantina com os do sudeste da Bahia (Fig. 2), podemos notar uma tendência de seca mais a norte no estado, demonstrada por um crescimento constante dos valores de $\delta^{18}O$ a partir do Holoceno (11,7 mil anos), o que indica menor umidade, enquanto ao sudeste, há uma relativa estabilização no valor isotópico.

Além disso, utilizando dados de insolação da região e comparando-os com os resultados, novamente temos duas interpretações distintas para cada região. Os dados isotópicos da caverna Paixão parecem ter uma relação com o comportamento da curva de insolação, principalmente no Holoceno, sendo que ao sudeste nota-se o oposto; com exceção dos dados mais antigos da Gruta do Deusdete, não aparenta haver uma correlação com o efeito da insolação.

5. Conclusão

A partir desses resultados preliminares pode-se obter um melhor entendimento em relação ao efeito que diferentes fenomenos climaticos possuem na oscilacão paleoclimatica desde o ultimo maximo glacial no nordeste brasileiro, mostrando correlações com dados adicionais alem do comportamento da insolação, e estabelecendo possiveis conexões com os eventos milenares discutidos no trabalho. Futuras analises e uma discussão mais profunda devem detalhar ou esclarecer essas interpretações.

Agradecimentos

Presto meus agradecimentos primeiramente ao meu orientador, Prof. Dr. Francisco William da Cruz Junior e minha coorientadora Nathalia Stadler, os quais serviram grande apoio e compreensao. Tambem sou grato aos meus familiares e amigos que estiveram me apoiando ao longo do meu curso e deste trabalho. Alem disso, estendo meus agradecimentos a toda a organizacao desse congresso.

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Examining the internal structure and geochemical properties of the lower disk of a palette speleothem

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Abstract

In dissolution caves, speleothems such as stalactites and stalagmites form through calcite deposition from water flow and dripping. One unique type, the palette (or shield), consists of two parallel travertine disks separated by a hairline fracture. Palettes exhibit concentric growth layers and can be found in various orientations on cave walls and ceilings. Despite their distinctive structure, their formation remains poorly understood due to inaccessibility and limited study. This research investigates a fragment of the lower disk of a palette from Endless Caverns (ECS) in Virginia, USA. The ECS specimen measures 22.3 cm in length, 23.1 cm in width, and 15 cm in height. A total of 71 samples were collected along the growth axis at 0.5 cm intervals to analyze isotopic trends and crystallographic structure, and to construct an age model using U/Th dating.

A key finding of this study is the reinterpretation of the palette structure. The flowstone, previously thought to be a separate component, is part of the lower disk. Additionally, stable isotope analysis revealed differences in $\delta^{18}O$ at 5.5 cm and 19.4 cm, suggesting shifts in environmental conditions, while low standard deviations indicate isotopic equilibrium during deposition. Hendy's test analysis shows that the $\delta^{18}O$ at the layer located at 5.5 cm from the base has an average value of -6.83, with a standard deviation of 0.01. At 19.4 cm, the δ18O average is -6.57, with a standard deviation of 0.02. These findings suggest that palettes could potentially serve as paleoenvironmental archives, providing insight into past climatic and environmental conditions.

Résumé

Dans les grottes de dissolution, des spéléothèmes tels que les stalactites et les stalagmites se forment par la déposition de calcite provenant de l'écoulement de l'eau et des gouttes. Un type unique, la palette (ou bouclier), consiste en deux disques parallèles de travertin séparés par une fine fissure. Les palettes présentent des couches de croissance concentriques et peuvent être trouvées dans diverses orientations sur les parois et les plafonds des grottes. Malgré leur structure distinctive, leur formation reste mal comprise en raison de leur inaccessibilité et de l'étude limitée dont elles ont fait l'objet. Cette recherche examine un fragment du disque inférieur d'une palette provenant des Endless Caverns (ECS) en Virginie, aux États-Unis. L'échantillon ECS mesure 22,3 cm de longueur, 23,1 cm de largeur et 15 cm de hauteur. Un total de 71 échantillons ont été prélevés le long de l'axe de croissance à des intervalles de 0,5 cm pour analyser les tendances isotopiques et la structure cristallographique, et pour établir un modèle d'âge à l'aide de la datation U/Th.

Une découverte clé de cette étude est la réinterprétation de la structure de la palette. Le flowstone, précédemment considéré comme un composant séparé, fait en réalité partie du disque inférieur. De plus, l'analyse des isotopes stables a révélé des différences dans le δ18O à 5,5 cm et 19,4 cm, suggérant des variations dans les conditions environnementales, tandis que les faibles écarts-types indiquent un équilibre isotopique lors de la déposition. L'analyse du test de Hendy montre que le $\delta^{18}O$ à la couche située à 5,5 cm de la base a une valeur moyenne de -6,83, avec un écart-type de 0,01. À 19,4 cm, la moyenne de $\delta^{18}O$ est de -6,57, avec un écart-type de 0,02. Ces résultats suggèrent que les palettes pourraient potentiellement servir d'archives paléoenvironnementales, fournissant des informations sur les conditions climatiques et environnementales passées. Cet abstract a été traduit avec Microsoft CoPilot.

Resumen

En las cuevas de disolución, se forman espeleotemas como estalactitas y estalagmitas por la deposición de calcita proveniente del flujo de agua y las gotas. Un espeleotema único, la paleta (alternamente conocido como escudo u orejones), consiste en dos discos paralelos de travertino separados por una fina fractura. Las paletas presentan capas de crecimiento concéntricas y pueden encontrarse en diversas orientaciones en las paredes y techos de las cuevas. A pesar de su estructura distintiva, su formación sigue siendo poco comprendida debido a su inaccesibilidad y al estudio limitado que se les ha realizado. Esta investigación examina un fragmento del disco inferior de una paleta de las Endless Caverns (ECS) en Virginia, EE.UU. El espécimen ECS mide 22.3 cm de largo, 23.1 cm de ancho y 15 cm de altura. Se recolectaron un total de 71 muestras a lo largo del eje de crecimiento a intervalos de 0.5 cm para analizar las tendencias isotópicas, observar la estructura y química cristalográfica, y para construir un modelo de edad utilizando la datación U/Th.

Un hallazgo clave de este estudio es la reinterpretación de la estructura de la paleta. La colada, previamente considerado un componente separado, en realidad forma parte del disco inferior. Además, el análisis de los isótopos estables reveló diferencias en el δ18O a 5.5 cm y 19.4 cm, lo que sugiere variaciones en las condiciones ambientales, mientras que los bajos valores de desviación estándar indican un equilibrio isotópico durante la deposición. El análisis de la prueba de Hendy muestra que el $\delta^{18}O$ en la capa situada a 5.5 cm de la base tiene un valor

promedio de -6.83, con una desviación estándar de 0.01. A 19.4 cm, el promedio de $\delta^{18}O$ es de -6.57, con una desviación estándar de 0.02. Estos resultados sugieren que las paletas podrían potencialmente servir como archivos paleoambientales, proporcionando información sobre las condiciones climáticas y ambientales pasadas.

1. Introduction

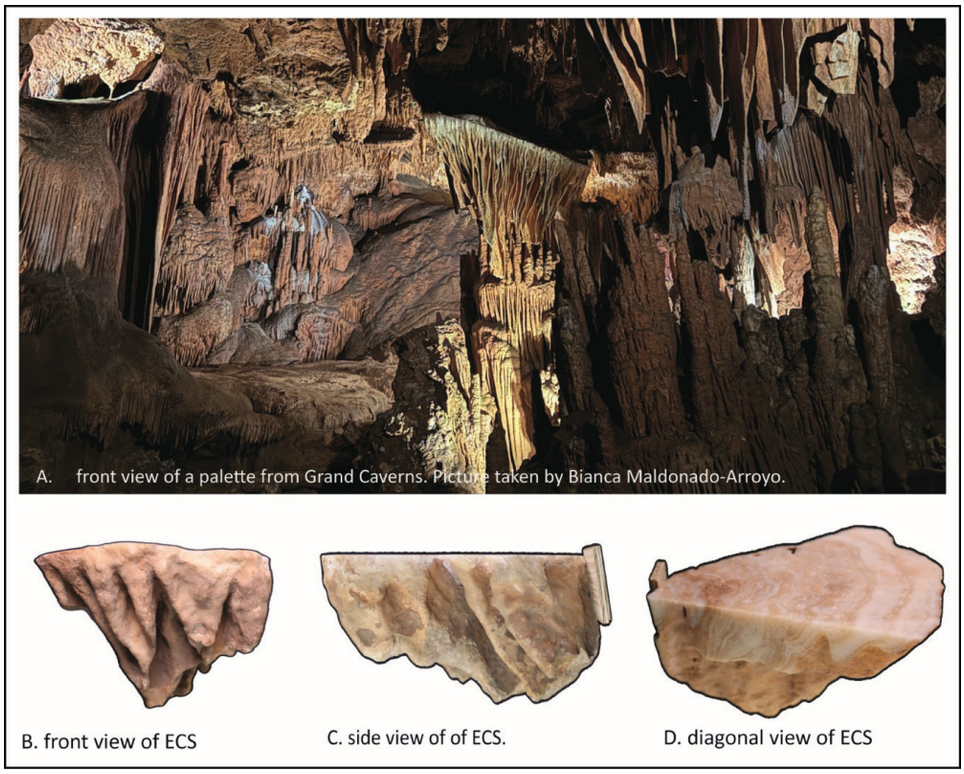

Figure 1: *Different views of a palette in situ compared with ECS from the front, side, and diagonal views.*

Speleothems are secondary mineral deposits found in solution caves that, in many cases, have the potential to enhance our understanding of past climates and environments in various parts of the world, as some of them act as archives. Palettes, a type of speleothem named after a painter's tool for organizing colors (see figure 1A), are considered rare compared to their more common counterparts, such as stalactites and stalagmites. Palettes, also known as shields in the United States of America (USA) MCGILL (1933); PALMER (2007), consist of two parallel oval disks divided by a hairline fracture. To this day, the origin of palettes is an enigma, but the current accepted explanation is that they form from the slow deposition of water containing Ca $(HCO_3)_2$ that emerges from cracks created by the intersection of joints or bedding plane surfaces within the cave (walls or ceilings) KUNDERT (1952).

Since the introduction of palettes in the literature, they have been described as three-component speleothem, composed of an upper disk, a lower disk, and as a variation when it has a flowstone accessory MCGILL (1933) that grows in the lower disk, also known as parachutes HILL & FORTI (1995).

One of the challenges in studying palettes is that they are not unique to a specific geographic context, geological setting, nor accessible. Caves with abundant palettes are reported to located in the Southwestern USA (e.g., Lehman Cave in Nevada; Crystal Cave in California), the Eastern USA (e.g., Grand Caverns and Endless Caverns in Virginia), the Caribbean (Bao Cave in Habana, Cuba), Europe (Cueva Nerja in Andalucía, Spain), and China (Shi Hua Cave). In caves with abundant specimens, palettes have been described in diverse sizes, without a preferential plane, angle, or plane surface for growth THOMAS & GARCIA (2022). Palettes, historically confused with welts, are travertine deposits that remain a mystery to the scientific community due to their inaccessibility to study further. In this paper, we share the preliminary findings from the geochemical characterization of a lower disk of a palette found in Endless Caverns, Virginia, USA, to reignite discussion about the origin, interpretation, and rarity of such speleothems. The results discussed here are the product of undergraduate research conducted over the summer of 2024 at the Research Experience for Undergraduates (REU) site: Undergraduate Research Opportunities in Cave and Karst Science (https://www.jmu.edu/geology/urocks/index.shtml).

2. Materials and methods

The lower disk of a palette (ECS or Endless Caverns Shield) acquired for this study was found in Endless Caverns, in New Market, Virginia, USA (see figure 2A). Endless Caverns is in the Shenandoah Valley at the base of the Massanutten Mountain range, within the New Market and Lincolnshire limestones of an anticlinal fold. Endless Caverns has been the center for studying speleogenesis features of phreatic, vadose caves, as well as megafauna of the north American continent HUBBARD & GRADY (1999).

The ECS sample dimensions are 22.3 cm in length, 23.1 cm in width, and 15 cm in height, including the excess flowstone growth. The plane where the upper and the lower disk meet did not present any remains

of the upper disk. The place surface was polished, and one of the sides was cut to better observe the relation between the flowstone accessory and the lower disk (see figure 2B). Once polished, the axis of growth was estimated to follow a sampling track of 25.4 cm through the concentric layers. A total of 71 subsamples were obtained following the axis of growth using a MicroMill with a tungsten carbide drill tip. The average subsample weight was 3.75 mg. These subsamples were divided for various analyses.

A total of 53 subsamples were collected to observe the trends of carbon and oxygen, similarly to how stalagmites are analyzed to observed paleoclimate archives. Samples were collected throughout the concentric layers following 4 sampling tracks at a resolution of 0.5 cm. Ten subsamples were used to perform the Hendy's test analysis to determine if stable isotopes were deposited in equilibrium during HENDY (1971) the formation of the palette. The subsampling collection was guided by 2 sampling tracks along two well-defined layers at 5.5 cm and 19.4 cm (see figure 2B).

Four subsamples were designated for Uranium-Thorium (U/Th) dating to determine the age of the palette and understand its formation timeline. Subsamples were taken at the beginning of the base for the axis of growth, and along the concentric layers at 4 cm, 19.8 cm, and 23.8 cm. We are not discussing the results of geochronological model in this paper.

Additional subsamples were collected for spectroscopy analysis, specifically Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray (EDX), to examine the microstructure and elemental composition of the samples.

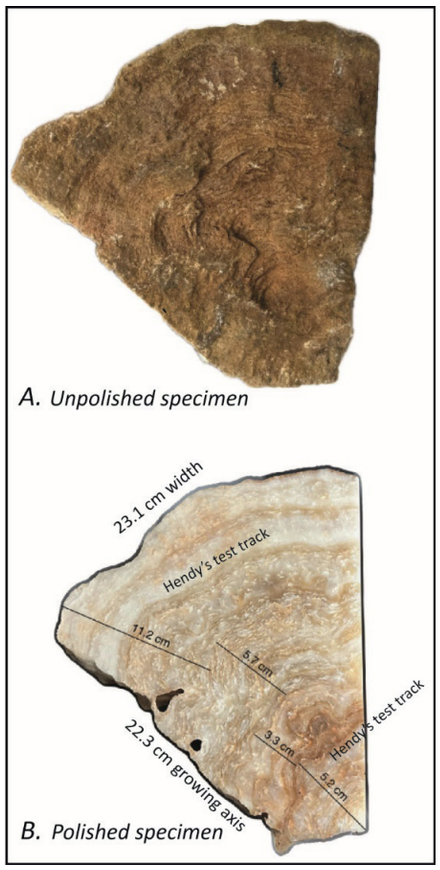

Figure 2: *ECS (Endless Caverns Shield) unpolished and polished to observe the internal structure and layering.*

3. Preliminary results

During the preparation of ECS to obtain subsamples for geochemical and radiometric analysis, we observed that our palette samples did not contain three distinct components as previously interpreted in the literature (see figure 1B-D). Specifically, what literature described as flowstone accessory to the lower disk is part of it. Sample ECS provides insight into the growth patterns of the layers, which extend outward from the growth plane, like the deposition observed in stalagmites. The layers also extend downward, creating a "flagging" pattern that could be misinterpreted as flowstone.

While these observations are primarily interpretative and qualitatively based, further research utilizing stable isotopes, trace elements, and U/Th dating will help determine the duration of palette formation and the distribution of trace elements and stable isotopes throughout the layers as they accumulate.

Hendy's test analysis shows that the $\delta^{18}O$ at the layer located at 5.5 cm from the base has an average value of -6.83, with a standard deviation of 0.01. At 19.4 cm, the $\delta^{18}O$ average is -6.57, with a standard deviation of 0.02 (see figure 3).

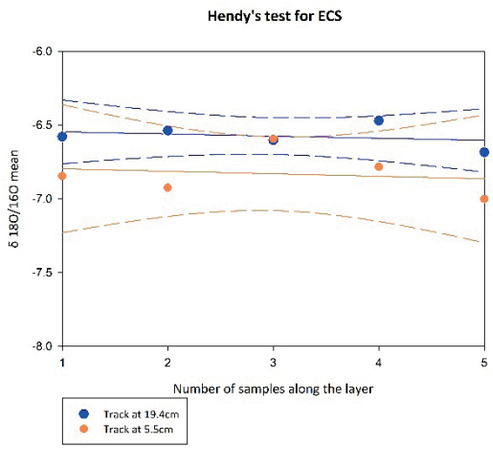

Figure 3: *Results for Hendy's test in two different tracks in ECS.*

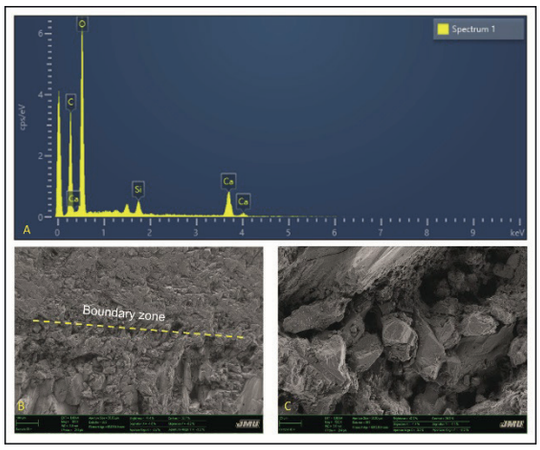

Figure 4: *EDX analysis and SEM observations of the internal structure and arrangement of a palette.*

4. Discussion

One of the major key observations with this study is the reinterpretation of the structure of the palette. By looking at ECS closely, the flowstone accessory is not separate but is, in fact, part of the lower disk itself. The original interpretations, which were based solely on external morphology, suggest that the depositional conditions could differ from previous understandings or that the initial models require revision. This may explain why shields have often been conceptualized like other speleothems, such as stalactites. The absence of a clear boundary between the flowstone and the disk could suggest that both formed under similar conditions (e.g., temperature, water chemistry, substrate).

The difference in oxygen isotope ratios ($\delta^{18}O$) at 5.5 cm and 19.4 cm could potentially suggest a shift in the isotopic composition of the water or environment in which palettes formed. However, the relatively low standard deviations (0.01-0.02) within each layer, suggests that the conditions were stable for oxygen to be deposited in equilibrium. Microscopic examination and EDX analysis reveal insights with potential relevance into the mineralogical and elemental composition of ECS. The elements detected—C, O, Ca, and Si—are consistent with a carbonate-rich system, but the presence of Si suggests the contribution of silica from a foreign external source (e.g., clay). The observed "transition zone" in the crystalline properties is especially interesting. The increase in Si abundance after the transition zone might suggest a shift in the local geochemistry.

The change in crystal morphology suggests a change in the rate of mineralization or the physical conditions of deposition (such as changes in temperature and/or supersaturation). The larger, more well-formed crystals may indicate a more stable or less dynamic environment.

5. Conclusion

Palettes have remained a longstanding puzzle in speleothem research for over 70 years, and these preliminary findings could significantly advance our understanding of how palettes function as archives of past environmental conditions.

The ECS sample, previously believed to consist of two separate components—a lower disk and a flowstone—it is observed to be a single, continuous unit. This reevaluation fundamentally changes our understanding of the structure of the palette and potentially its formation, updating the standing formation model. The revised interpretation of the ECS sample prompts a reflection to look into the mechanisms responsible for its formation, especially in relation to hydrological and sedimentological conditions.

Hendy's test analysis suggests that the conditions during formation were stable enough to allow for equilibrium in the deposition of oxygen. This stability implies that there may be potential to use this speleothem as an archive of past environmental conditions. However, further research is necessary to fully understand the specific type of archive it could represent, as well as the extent to which it can reliably record and preserve environmental signals over time.

Microscopic examination and EDX analysis offer further insights into the crystalline structure of the ECS sample, revealing a carbonate-rich system with an unexpected presence of silica (Si). This suggests the possible influence of an external source (e.g., clay), in the mineralization process. The presence of a boundary zone along the deposition of travertine is particularly noteworthy, as it may reflect a shift in the local geochemistry. Larger, more well-formed crystals could indicate a more stable or less dynamic environment.

A stable isotope analysis of the growing concentric layers is essential to test the hypothesis that these palettes are recording environmental or climatic changes. Additionally, a similar analysis is required to understand the equilibrium along the downward-growing layers, previously identified as flowstone. All findings presented in this manuscript should be contextualized using a geochronological model. However, the nature of the sample could mean that there is not enough radiometric material available for a geochronological model (e.g., U/Th).

These preliminary findings represent a significant step forward in understanding palettes as archives of past environmental conditions. While the revised interpretation of the ECS sample and Hendy's test analysis suggest potential for using this speleothem as a stable environmental archive, further research into the mineralogical composition, depositional processes, and hydrological conditions is needed to fully assess its reliability and the specific type of environmental record it can provide.

Acknowledgments

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Acknowledgments

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Tracking past relative sea-level changes using phreatic overgrowth on speleothems from Yucatan Peninsula, Mexico

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Abstract

This paleo-sea-level reconstruction is the first study to use phreatic overgrowths on speleothems (POS) for the Yucatan Peninsula, Mexico. POS form at the water table due to the degassing of CO_2 from brackish water. The process directly connects POS morphology to the elevation of past-sea level and indicates sea-level stability. Preliminary U-series ages from five POS record sea-stands from marine isotope stage (MIS) 9, 7, and 5. These results build upon previous reconstructions as well as introduce the first direct estimates of MIS 9 sea level from the area.

Résumé

Cette reconstruction paléo-niveau marin représente la première étude utilisant des croissances phréatiques sur spéléothèmes (POS) pour la péninsule du Yucatán, au Mexique. Les POS se forment au niveau de la nappe phréatique en raison du dégazage du CO_2 des eaux saumâtres. Ce processus relie directement la morphologie des POS à l'altitude des anciens niveaux marins, tout en indiquant une stabilité du niveau de la mer. Les âges préliminaires obtenus par séries uranium de cinq POS enregistrent des niveaux marins correspondants aux stades isotopiques marins (MIS) 9, 7 et 5. Ces résultats complètent les reconstructions précédentes et fournissent, pour la première fois, des estimations directes du niveaux marins pour le MIS 9 dans cette région.

1. Introduction

The study of past sea-level fluctuations has gained critical importance as the threat of anthropogenic-induced climate change continues to grow. Rising sea levels will impact more than one third of global populations living near the coast and pose significant risks to cultural and economic stability on a worldwide scale due to their interconnectedness (KOPP et al., 2023). To mitigate this risk, careful analysis of past sea-level is required to address the duration and amplitude of future sea-level rise.

Cave-based sea-level proxies provide both direct and indirect, independent records of past relative sea level (RSL). These records are influenced by both global (eustatic) and local effects, such as tectonic uplift and subsidence. Cave-derived sea-level reconstructions can be used to effectively address ice sheet vulnerability, with their utility varying based on the temporal resolution of the dataset (DUMITRU et al., 2019).

Marine isotope stage (MIS) 5, representing the peak of the last interglacial (126–116 kyr), serves as an important analogue for current climate conditions. During this time, atmospheric carbon dioxide levels and global temperatures were comparable to today, but approximately +1° to +1.5° C higher than preindustrial levels (i.e., 1850 CE) (HORTON et al., 2018). Additionally, other marine isotope stages document the waning and waxing of ice sheets, offering crucial context for understanding ice sheet vulnerability (DUTTON et al., 2009). Eustatic sea-level changes exhibit significant spatial variability, underscoring the importance of regional RSL reconstructions to complement global models. Such studies are essential for understanding localized impacts and refining predictions of future sea-level rise.

Phreatic overgrowths on speleothems (POS) are the most accurate cave-based sea-level indicator points (SLIP). They record the RSL within their morphology due to a unique hydrochemical process that triggers their formation inside littoral caves. POS precipitate at the air-water interface around preexisting vadose speleothems in caves partially flooded by marine water. This process is driven by CO_2 degassing from brackish water (BOOP et al., 2014). Their growth is confined to the tidal range (30 cm), resulting in a characteristic spindle shape, where the tapered top (bottom) represents high (low) tide, and the thickest middle part marks the position of mean sea level (Fig. 1). When the preexisting speleothem is shorter than tide range, POS take a knob morphology. These features offer unparallel accuracy in reconstructing past sea-level elevations, surpassing other proxies in reliability.

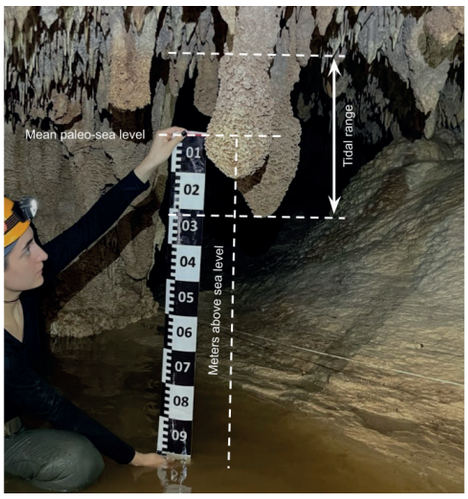

Figure 1: *POS MA-1 in Yucatan Peninsula cave. The widest part of the POS is representative of mean sea level, while the tapered end at the top of the encrustation corresponds to high tide. Low tide is inferred from the distance between those two points below the widest part.*

The Yucatan Peninsula is a low relief, eogenetic karst limestone platform characterized by extensive cave systems with both subaerial and submerged passages that extend tens of km inland from the coast. It is surrounded by the Gulf of Mexico to the north and west and the Caribbean Sea to the east. The sub-horizontal and mostly horizontal nature of the Paleogene to Quaternary limestones indicate little deformation has occurred since their deposition, indicating tectonic stability of the platform (RAMOS, 1975; SMART et al., 2006). The water table across the peninsula is nearly flat, lying approximately at sea level, with a very low hydraulic gradient ranging from 1 to 10 cm/km (BEDDOWS et al., 2007; BAUER-GOTTWEIN et al., 2011). The water table changes are controlled by tidal oscillations that have a strong effect due to the highly porous limestone (PERRY et al., 2002). The water table typically lies 10 and 20 m below the ground and is easily accessible through caves and cenotes (BEDDOWS et al., 2007; BAUER-GOTTWEIN et al., 2011).

Preliminary studies from the coastline and caves of the Yucatan Peninsula highlight the region's potential for high-resolution sea-level reconstructions (STEIDLE et al., 2021). The platform's low hydraulic gradient and tectonic stability simplify sea-level reconstructions. Existing proxy data from the peninsula has required minimal elevation corrections, apart from adjustments for glacial isostatic effects (STEIDLE et al., 2021). Previous studies have developed a sea-level record for the region using various proxies, including terrestrial limiting points from vadose speleothems and submerged vadose speleothems (MOSELEY et al., 2015; JENSON, 2019; STEIDLE et al., 2021), fossil corals (BLANCHON, 2009), and epiphreatic interface deposits (EID; JENSON, 2019). These efforts have constrained parts of the Holocene and Marine Isotope Stage (MIS) 5 while providing terrestrial limits for sea level between 250 to 150 kyr. However, due to the limited proxy data, many sea-stands remain undocumented.

The goal of this study is to extend the sea-level record using precisely dated POS of known elevation from caves in the Yucatan Peninsula.

2. Materials and methods

Nine POS samples were collected from five caves located within 10 km inland along the Yucatan Peninsula. The elevations of these samples range from 14 m below to 1 m above present sea level, suggesting different past sea-levels. Measurements of the widest part of each POS relative to present sea level were taken in-situ using a meterstick for subaerial samples or a dive computer for submerged ones (Fig. 1). Only POS with distinct morphology, allowing clear inference of mean sea level positions, were selected. Care was taken during sampling to minimize impact on the aesthetic and cultural significance of the caves.

Each POS was cut in half for crystal fabric analysis and geochemical sampling for U-series dating. Crystal fabric analysis was conducted prior to geochemical sampling to avoid porous or vuggy sections, which can introduce age uncertainties due to detrital thorium contamination. Well-crystalized carbonate speleothems typically incorporate measurable amounts of uranium into their crystal lattice while levels of initial thorium are usually low (Moseley et al., 2012). Aragonite is preferred for U-series dating over calcite due to its dense crystal structure and higher U concentration. Assessing the crystal fabric ensures high-quality geochemical data and reliable U-series age determinations.

Subsamples for analysis are generally 10 to 200 mg. Separation chemistry for the U-series method is described in ASMEROM et al. (2006). U and Th isotope ratios were measured on a Thermo Neptune multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS). This study employed improved radioactive half-lives for ^{230}Th and ^{234}U (CHENG et al., 2013).

3. Results and discussion

Currently five POS from four caves are being dated using the U-series method. The preliminary ages range from MIS 9 to MIS 5 (Fig. 2). Sample CK-1, dating to MIS 9 (~353 – ~290 kyr) was collected at a depth of 5 m below present sea level. Previously, the MIS 9 record from the Yucatan Peninsula has been indirectly inferred from the growth of stalactites (terrestrial limiting point) sampled at elevations between 4 and 8 m above present sea level (Fig. 2; JENSON, 2019). Our sample offers a better insight into sea-level conditions during MIS 9. However, we are working on additional samples to confirm the duration and extent of this sea stand.

Sample MA-1 sample is a ~40 cm long POS with its widest part situated 0.9 m above present sea level. The two U-series samples from MA-1 date to MIS 7 (~245 – ~200 kyr). In the current Yucatan Peninsula sea-level reconstruction, MIS 7 was analyzed by JENSON (2019) using vadose speleothems and EID. Vadose speleothems serve as terrestrial limiting points that form above sea level, whereas EID, though not well understood, are interpreted to form near the water table. POS MA-1 aligns well with these proxy data points. The lowest vadose speleothem elevation for MIS 7 reported by JENSON (2019) is about 3 m above sea level, having ages between ~240.96 and ~205.55 kyr. However, when plotted on the $\delta^{18}O$-based sea-level curve of SPRATT and LISIECKI (2015), these elevations are substantially above global estimates (Fig. 2).

POS TZ-2 and TZ-3, each ~15 cm in length, indicate that mean sea level during MIS 5d (~110 kyr) was ~14 m below present. This finding echoes the work of MOSELEY et al. (2013) and STEIDLE et al. (2021) who both documented this period using SVS. Their results suggest that between 109.2 ± 1.0 and 104 ± 0.58 kyr, sea level was ~11 m below present (Fig. 2).

POS TZ-1 (8 cm in length) was recovered from 4.9 m below present sea-level. One U-series sample from POS TZ-1 indicates an age of ~90 kyr, but with very large uncertainty. Additional U-series dates from POS TZ-1 may better constrain the duration of this sea-level stand.

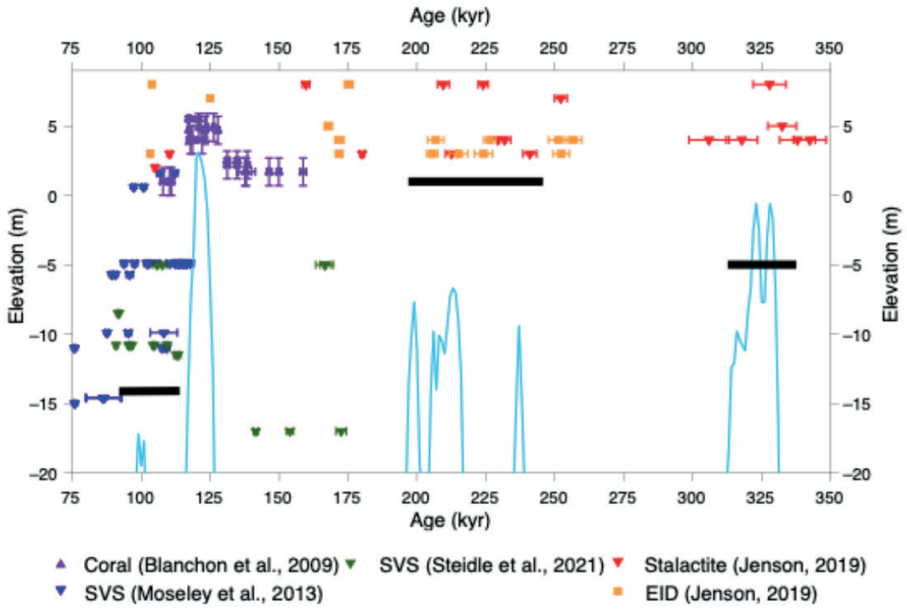

Figure 2: *Plot showing all available sea-level proxy data from the Yucatan Peninsula, compared to a global mean sea-level curve derived from $\delta^{18}O$ measurements of benthic foraminifera (blue line; SPRATT & LISIECKI, 2015). Black solid lines represent POS-based sea-level reconstructions from this study.*

4. Conclusion

This study provides the first POS proxy data from the Yucatan Peninsula, an important far-field site, demonstrating the potential of this type of research for high-precision sea-level reconstructions. These preliminary results highlight the advantages of using POS obtaining high-precision data. Future incorporation of additional U-series ages is expected to refine the sea-level reconstructions for the Yucatan Peninsula.

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Diving into the past: submerged coastal caves as archives of croatian environmental history

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Abstract

Submerged coastal caves in Croatia serve as valuable archives of past environmental and sea-level changes, providing insights into the region's Pleistocene and Holocene history. This study, conducted as part of the SEALeveL project, involved systematic exploration of over 20 caves along Croatian coast, focusing on speleothems as proxies for reconstructing relative sea-level history. Collected speleothem samples have demonstrated their potential for use in sea-level research. Among them, ML-12, SIP-1, and KRA-1 are among the oldest dated speleothems in Croatia. In Medvjeđa špilja Cave, the first Adriatic phreatic overgrowth on speleothem (POS) was identified. It formed at ca. 2800 years ago, at approximately −1.28 m below the current mean sea level (MSL). These records align with broader Mediterranean findings, supporting hypotheses of Holocene sea-level stability and climatic oscillations. Mineralogical analyses revealed distinctive characteristics, including hiatuses linked to sea-level oscillations during interglacial periods. These findings confirm the significance of submerged speleothems in refining regional sea-level curves and highlights the potential of scientific cave diving in paleoenvironmental studies. Future work will expand the exploration of caves, enhance dating precision, mineralogical analyses, and stable isotope measurements and leverage advanced technologies to further refine and enhance the accuracy of relative sea-level change reconstructions for the eastern Adriatic.

1. Introduction

In paleo sea-level research, a variety of indicators are employed, including sedimentological, geomorphological, archaeological, biological, and historical sources, with their selection depending on the time period under investigation and the availability of specific indicators at the surveyed location (FAIVRE & FOUACHE, 2003; FAIVRE et al., 2013; SHENNAN et al., 2015). In the context of environmental history, submerged coastal caves hold a unique role in preserving detailed records of past sea levels. For example, hiatuses in speleothem growth indicate transitions between vadose and phreatic conditions, a feature first documented by GASCOYNE et al. (1979) which can be used to reconstruct sea-level changes. Additionally, submerged speleothems with marine biogenic overgrowths and marine boring organisms, as studied by ALESSIO et al. (1992, 1994) and ANTONIOLI & OLIVERIO (1996), offer an important method for assessing past sea-level positions in littoral caves (ONAC et al., 2012; VAN HENGSTUM et al., 2015). Speleothems, provide accurate indicators of sea-level changes, as their formation is highly dependent on specific environmental conditions that reflect historical sea-level positions. For instance, phreatic overgrowths on speleothems (POS) can precisely pinpoint past sea levels, while submerged speleothems establish upper bounds for these levels (CHUTCHARAVAN & DUMITRU, 2025). Collecting these submerged speleothems, however, requires specialized techniques such as cave diving, an essential method for accessing these underwater formations. This technique allows researchers to gather valuable data from caves that were once above sea level and are now submerged due to sea-level rise (SLR).

The coastal region of Croatia, part of the external Dinaric Karst, features a broad spectrum of cave systems, ranging from dry, air-filled cavities to partially or fully submerged formations. These caves are essential archives of environmental history, recording evidence of climate changes (RUDZKA et al., 2012; LONČAR et al., 2017, 2019) and sea-level variations (SURIĆ et al., 2009; SURIĆ & JURAČIĆ, 2010; LONČAR et al., 2024) during the Pleistocene and Holocene epochs. By diving into these submerged coastal archives, scientists can piece together a clearer picture of Croatian environmental history and the broader patterns of climate change over millennia. Within the SEALeveL project (HRZZ-IP-2019-04-9445), supported by the Croatian Science Foundation, speleological and cave-diving investigations were conducted across the Kvarner, Zadar, Šibenik, and Dubrovnik regions. This research, part of the SEALeveL project, aimed to systematically explore and sample speleothems, focusing on phreatic overgrowths on speleothems, which serve as precise markers for stable sea-level periods.

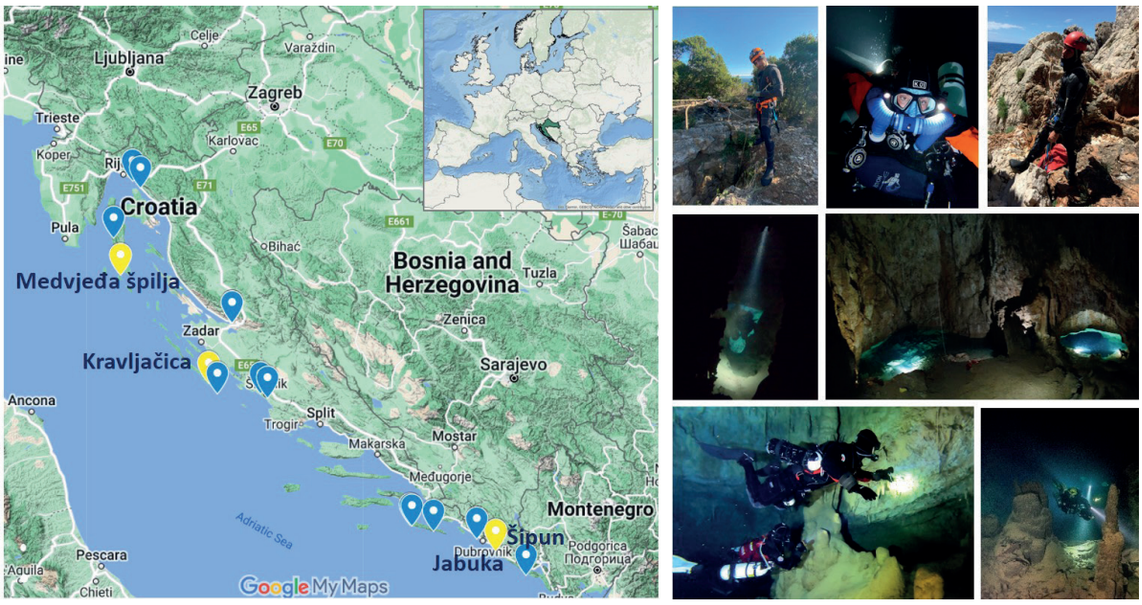

Figure 1: *Explored caves and sampling locations along Croatian coast.*

2. Materials and methods

Cave and cave-diving exploration were carried out systematically, part by part. Sampling depth was measured with the pressure depth--meter built in Sunto EON steel diving computer with the precision of 0.1 m. All depths presented here are the sum of the depth at which the sample was taken and length of the sample, referenced to the current MSL. Speleothem subsamples were dated by means of U-series disequilibrium method on a MC-ICPMS at Department of Earth and Planetary Sciences, University of New Mexico, USA and AMS radiocarbon dating at Ruđer Bošković Institute in Zagreb, Croatia and University of Georgia, USA. Subsamples of each collected speleothem were mineralogically characterized by XRD and optical microscopy at University of Ljubljana, Slovenia. For a comprehensive description of the methods and further details, refer to LONČAR et al. (2024).

3. Results

More than 20 caves were explored, with the majority of fully or partially submerged pits developed in stratified Cretaceous limestone. After detailed prospection, speleothem sampling was done in Medvjeđa špilja (northern Adriatic), Kravljačica (northern Adriatic) Šipun and Jabuka (southern Adriatic) caves (Fig. 1).

Medvjeđa Špilja Cave is an anchialine cave with vertical entrance situated in the central part of the Lošinj Island, ~55 m from the sea and 17.5 m a.s.l. Bell-shaped entrance ends with a lake at the bottom. The rest of the cave is a mostly submerged channel with a total length of 245 m. Medvjeđa špilja Cave provided the first documented Adriatic POS sample (MLp-1, Fig. 2a); 8 cm long calcite soda straw with a phreatic overgrowth. The overgrowth displays an uneven deposition pattern, widening at the bottom and terminating in a rounded base, similar to formations observed in Mallorcan caves (GINES et al., 2012; LONČAR et al., 2024). Mineralogical analysis confirmed that speleothem MLp-1 is composed of calcite and exhibits the typical morphology of POS. XRF and SEM-EDS analyses revealed no difference in trace element composition between the support and the overgrowth. U-series dating of five subsamples from MLp1; including the stalactite and four subsamples of the phreatic overgrowths reveals critical age data. The soda straw stalactite, representing growth above the water table, formed during a period of lower sea level, with a corrected age of 5948 ± 228 years. The phreatic overgrowth subsamples (1–8 mm) show a weighted average age of 2,759 ± 140 years, indicating periods of sea level stability. Individual ages for the overgrowth subsamples range from 2,624 ± 104 to 2,880 ± 90 years (LONČAR et al. 2024).

In addition, 34 cm long stalagmite sample ML-12 (Fif. 2b) was collected at -12 m, where marine environment is fully established. It is well laminated calcite stalagmite with detected growth hiatus. XRD and SEM analyses of ML-12 reveal quartz, halite, gypsum, muscovite, hematite, and an unidentified phosphate in the hiatus pores. A total of eight subsamples of ML-12 were dated. Subsamples 1–5, from depths of 6.6 mm to 66 mm, yield corrected ages ranging between 350,760 ± 30,481 years and 396,112 ± 10,207 years, showing increasing age with depth and consistent isotopic ratios. Subsamples 7 and 8, at depths of 114 mm and 122 mm, fall beyond the range of the U-Th dating method. The uncertainties in age estimates range from approximately ±10,207 to ±30,481 years, reflecting variations in U and Th concentrations and isotope ratios.

Kravljačica Cave is a sea cave (pit) in the bay of Kravljačica on the island of Kornat (Fig. 1). The irregular shaped entrance of 4 x 3 m is at a depth of 8 m. The main channel is vertical shaft which ends with a chamber and the depth of 42 m. Here, at 37 m we collected 20 cm long stalactite with biogenic overgrowth (KRA-1; Fig. 2c). The U-Th age of inner part of KRA-1 stalactite is 436,013 ± 25,099 years BP, while the worm tube incrusted at the outer layer is 12,146 ± 4 479 years.

Šipun Cave is an anhialine cave located on the Rat peninsula in Cavtat, at 24 m above sea level. It is a simple partially submerged cave, with one main 120 meters long channel divided into two parts by the flooding of the sea, the dry part and the “lake” i.e. submerged channel (LONČAR & KOVAČ KONRAD, 2024). Two presumably POS samples (SIP-1 and SIP-2; Fig. 2d and 2e) have been collected in Šipun Cave at - 1.2 m

and -2.2 m below current MSL. Cutting and XRD analysis revealed that SIP-1 was not a POS but rather a well-laminated stalactite (Fig. 2d). U-Th dating revealed that the youngest sections of SIP-1 were over 479,394 ± 33,634 years old. The inner (older) laminae, as well as all sampling spots of SIP-2, yielded ages beyond the effective range of the U-Th method, suggesting deposition over 600,000 years ago.

Jabuka Cave located at Koločep Island (Dubrovnik archipelago) is a simple fissure sea cave with one chamber that has an air pocket. Cave entrance is at depth of 9 m through a narrow 4 meters long passage. The cave walls are covered with biogenic overgrowth. All speleothems, mostly stalactites and a few small draperies, are deposited only on the rooftop and the side walls of the dry part (air pocket), including a number of actively depositing soda straws. Some stalactites are completely or partially submerged. Well laminated stalactite JAB-1 (Fig. 2f) was collected at around 0.2 m below current mean sea-level. ^{14}C dating revealed deposition between around 2,350 and 900 years BP.

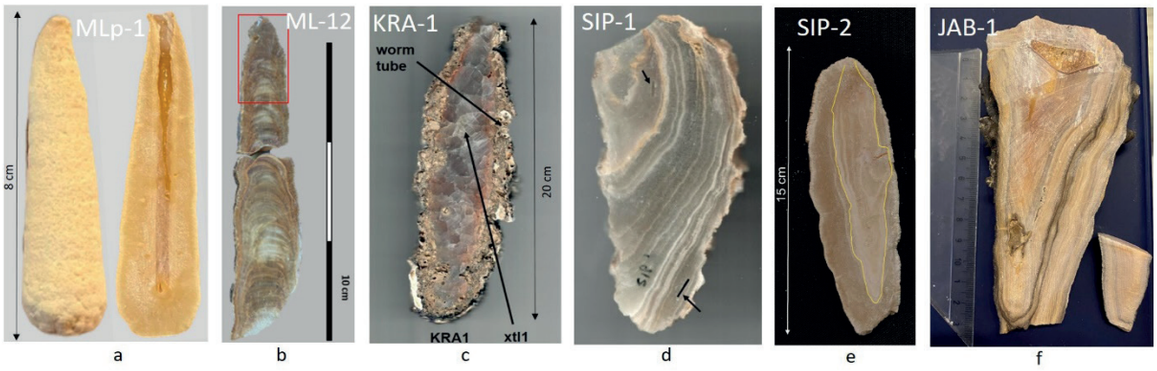

Figure 2: *Analyzed speleothems: (a) POS MLp-1 from Medvjeđa špilja Cave; (b) Stalagmite ML-12 from Medvjeđa špilja Cave; (c) Stalactite KRA-1 from Kravljačica Cave; (d) Stalactite SIP-1 from Šipun Cave; (e) Stalactite SIP-2 from Šipun Cave, with the yellow line marking the proposed boundary between the POS and the stalactite.; (f) Stalactite JAB-1 from Jabuka Cave.*

4. Discussion

The discovery of POS in the Adriatic Sea represents a significant advancement in eastern Adriatic coastal karst research. Medvjeđa špilja POS revealed that ca. 2800 years ago, the relative sea level was stable for about 300 years at a depth of 1.28 ± 0.15 m below the current MSL (LONČAR et al., 2024). This finding supports broader hypotheses regarding Holocene climate stability in the Mediterranean Comparisons with other Mediterranean POS studies (e.g., Mallorca, Sardinia) highlight similarities in formation conditions and sea-level stability (FORNÓS et al., 2002; TUCCIMEI et al., 2012).

Speleothems ML-12, SIP-1, SIP-2 and KRA-1 represent one of the oldest dated speleothems in Croatia. The dating of ML-12, SIP-1 and SIP-2 older laminae showed that they are deposited beyond the U-Th method, suggesting deposition over 600,000 years ago or possibly reflecting minor calcite alteration.

The worm tube encrusted on the outer layer of stalactite KRA-1, dated to 12,146 ± 4,479 years BP, provides valuable information about past sea-level changes in Croatia. Despite the large error margin, the age places the worm tube in the Late Glacial to Early Holocene transition, a period marked by significant SLR due to melting ice sheets (e.g., BARD et al., 1996; LAMBECK et al., 2014) when the Adriatic Sea experienced rapid transgression (SURIĆ et al., 2005; BRUNOVIĆ et al., 2020).

Mineral composition of ML-12 hiatuses indicates that the sea might have played a role in the speleothem formation environment and deposition of the minerals found in the hiatus. The detected hiatuses could be related to sea-level oscillations during the MIS11c interglacial (RAYMO & MITROVICA, 2012; TZEDAKIS et al., 2022). These findings are significant as they provide valuable insights into the interplay between sea-level changes and speleothem formation processes. Further detailed analyses and discussions on this relationship are necessary and will be conducted in future studies.

Outher part of SIP-2 (Fig. 2e) showed minimal values of Mg (XRD1, XRD2) which makes the interpretation of the origin inconclusive. Thus it could indicate marine or brackish origin, i.e. POS. The zoned crystals from the interior of sample SIP-2 resemble some crystals observed in POS from Japan (MIKLAVIČ et al., 2018), but are also very similar to diagenetic crystals observed in normal speleothems (LONČAR & KOVAČ KONRAD, 2024).

Deposition of JAB-1 suggests that all speleothem deposition within the cave stared after the cave was submerged by Pleistocene-Holocene transgression, and was ceased due to more recent SLR. Since is the only Holocene sample (except POS; LONČAR et al. 2024) collected within the project, it will be further examined.

5. Conclusion

Scientific cave diving for speleothem collection offers significant advantages for sea-level studies, providing unique insights into past climate and sea-level changes. Despite the inherent risks, the benefits of accessing submerged formations often outweigh these dangers. This study highlights the value of submerged coastal caves in paleoenvironmental research. All collected speleothems demonstrated their suitability for paleoclimate and sea-level studies.

The formation of both ML-12 and JAB-1 speleothems may have been influenced by sea-level oscillations. Therefore, further analyses are necessary to confirm this hypothesis. Additional dating, mineralogical, and stable isotope analyses will be conducted to obtain palaeoclimate records, contributing to more precise reconstructions of relative sea-level change in the eastern Adriatic.

Characterizing speleothems such as SIP-2, which exhibit diagenetic alterations, requires advanced geochemical analyses. Future exploration should prioritize unexplored caves with potential POS markers, leveraging technologies such as underwater drones to enhance accessibility. Improving safety and efficiency in diving operations will also be critical, as many

caves remain inaccessible due to challenging underwater conditions.

The discovery of Adriatic POS provides precise markers for reconstructing sea-level history and underscores the significance of Croatian karst systems in global climate studies. Advanced diving methodologies were pivotal in accessing these submerged environments and collecting speleothem samples. Future research should focus on expanding sampling efforts and refining sampling and dating techniques to further elucidate the Adriatic's environmental history.

Acknowledgments

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Early-middle holocene climate reconstruction from the qadisha record (Lebanon)

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Abstract

Stalagmites from the Qadisha Cave that is located at 1720 m asl in north mount Lebanon grew discontinuously from 9.2 to 5.7 and at 3.5 ka, revealing an overall trend from more negative oxygen isotope values at ~9.1 ka to more positive values at ~5.8 ka. This is believed to reflect a change from a wetter to a drier climate at such high altitudes. Our data also show rapid shifts throughout the record and a decreasing trend toward more negative $\delta^{13}C$ values in the mid-Holocene, suggesting enhanced soil activity. These results show good agreement between both geochemical proxies and stalagmite growth and might be affected by the seasonal variations in snow cover. The Qadisha record, while in good agreement with other Levantine record (more humid conditions from 9 to 7 ka., and drier climate after 7 ka), reflects unique mountainous climate characteristics, specifically the effect of snow cover and its duration regulating the effective infiltration in the cave.

Résumé

RECONSTRUCTION CLIMATIQUE DE L'HOLOCÈNE (INFERIEUR-MOYEN) À PARTIR DES STLAGMITES DE QADISHA (LIBAN). Deux stalagmites de la grotte de Qadisha, située à 1 720 m d'altitude au nord du Mont Liban, datées de 9,2 à 5,7 et à 3,5 ka, révèlent une tendance de valeurs isotopiques de l'oxygène, avec des valeurs plus négatives à ~9,1 ka évoluant à des valeurs plus positives à ~5,8 ka. Cette tendance exprime le passage d'un climat plus humide à un climat plus sec dans cette zone de hautes altitudes du Levant. Nos données montrent également des variations rapides au cours de la croissance des stalagmites et une tendance à la baisse vers des valeurs $\delta^{13}C$ plus négatives au milieu de l'Holocène, suggérant une activité accrue du sol. Ces résultats montrent un bon accord entre les indicateurs géochimiques et la croissance des stalagmites et pourraient être influencés par les variations saisonnières de la couverture neigeuse. Les résultats des stalagmites de Qadisha, bien qu'en bon accord avec d'autres études de spéléothèmes levantins (conditions plus humides de 9 à 7 ka et climat plus sec après 7 ka), montrent des caractéristiques climatiques montagneuses uniques, en particulier l'effet de la couverture neigeuse et sa durée régulant l'infiltration efficace dans la grotte.

Resumen

KLIMAREKONSTRUKTION DES FRÜHEN MITTLEREN-HOLOZÄNS AUS DEN STALAGMITEN VON QADISHA (LIBANON). Zwei Stalagmiten aus der Qadisha-Höhle, die sich auf einer Höhe von 1.720 m nördlich des Libanonbergs befindet und auf 9,2 bis 5,7 und 3,5 ka datiert sind, zeigen einen Trend in den Sauerstoffisotopenwerten, wobei sich negativere Werte bei ~9,1 ka zu positiveren Werten bei ~5,8 ka entwickeln. Dieser Trend zeigt den Übergang von einem feuchteren zu einem trockeneren Klima in diesem hochgelegenen Gebiet der Levante an. Unsere Daten zeigen auch schnelle Schwankungen während des Stalagmitenwachstums und einen abnehmenden Trend zu negativeren $\delta^{13}C$-Werten im mittleren Holozän, was auf eine erhöhte Bodenaktivität schließen lässt. Diese Ergebnisse zeigen eine gute Übereinstimmung zwischen geochemischen Indikatoren und dem Stalagmitenwachstum an und könnten durch saisonale Schwankungen der Schneedecke beeinflusst worden sein. Die Ergebnisse der Stalagmiten von Qadisha stimmen zwar gut mit anderen Studien zu levantinischen Speläothemen überein (feuchtere Bedingungen von 9 bis 7 ka und trockeneres Klima nach 7 ka), spiegeln jedoch einzigartige klimatische Gebirgsmerkmale wider, insbesondere die Wirkung der Schneedecke und ihrer regulierenden Wirkung auf die Dauer der effektiven Wasserinfiltration in die Höhle.

1. Introduction

Lebanon is located on the eastern coast of the Mediterranean Sea, in the heart if the Levant region (Fig. 1). Previous paleoclimatic studies cover the Holocene period throughout this region (e.g., BAR-MATTHEWS et al., 2003; VERGEYDEN et al., 2008; CHENG et al., 2015); among which, only a few records are from high mountainous areas, such as Mizpe Shelagim Cave in Mount Hermon and Incesu Cave in the Taurus Mountains (Fig. 1). Lebanon consists of imposing mountainous ranges facing the moisture coming from the Mediterranean Sea and creates therefore a

special local climate system. None of the Lebanese records spanning the Holocene were retrieved in areas located at high altitude, except for the El-Jurd marsh (CHEDDADI & KHATER, 2016) and Yammouneh lake records, which both provide low-resolution (millennial-scale) data. To analyze the effect of the mountainous climate and its variability during the Holocene, a reconstruction of past climate variations from speleothems, such as stalagmites, is needed. These are believed to be the most suitable terrestrial archives for establishing high-resolution proxy time series in paleoclimate research (GENTY et al., 2003; CHENG et al., 2012; FAIRCHILD & BAKER, 2012).

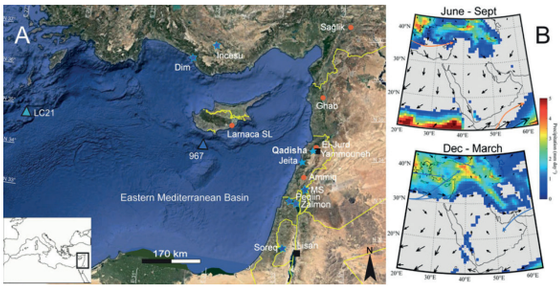

Figure 1: *(A) Location of the Qadisha Cave and other published Holocene paleoclimatic records in the Levant. (B) Maps showing seasonal precipitation rates in the eastern Mediterranean region. Gray areas are regions where daily precipitation is below 0.5 mm. From ERA-Interim reanalysis data set (1979 to 2015 CE; BERRISFORD et al., 2011).*

The Qadisha Cave is located at 1720 m asl, in northern Lebanon, in the vicinity of the Mount Makmel, the highest peak of the northeast–southwest trending Lebanese western mountain range, reaching 3088 m asl. This cave develops in Quaternary deposits derived principally from weathered Cretaceous limestone and dolostone rocks, located in the Qadisha catchment basin (DUBERTRET, 1975; NADER, 2007; NADER, 2014). The basin is fed by snowmelt and has a mean elevation of 2244 m, where the snow cover yearly duration may reach 6 months (TELESCA et al., 2014; FAYAD & GASCOIN, 2020). The cave network is overall horizontal, with 1076 m of explored galleries, comprising an upper relict part and lower active part with a permanent spring (discharge rate up to 1m^3/s) (EDGELL, 1997). Qadisha Cave was partially transformed into a tourist cave in 1934 (first show cave in Lebanon). It is located near, probably below the cedar forest of Bsharreh. Today, the Quaternary deposits above the cave, consisting mainly of scree and cemented rock debris, are covered with shrub vegetation. A previous monitoring study in the cave (NEHME et al., 2019) showed a mean cave air temperature of 9.0 ± 0.5°C and a pCO_2 concentration of 600 ppmv. Water percolation through the cave persists generally throughout the year and the calcite precipitation is observed to be relatively fast (e.g., calcite covered electrical wires). Two speleothems, Qad-1 and Qad-2, were retrieved from the upper gallery of the cave.

The content of this contribution is part of a larger study (NEHME et al., 2024), reporting new high-resolution, well-dated stable isotope ($\delta^{13}C$, $\delta^{18}O$) record from the Qadisha Cave stalagmites. Results of this study enabled us to characterize the regional climate trend versus the local mountainous effect on high-altitude records.

2. Materials and methods

The chronologies of Qad-1 and Qad-2 were established using 10 and 9 ^{230}Th dates, respectively. Exploratory ^{230}Th dating was performed first at Xi'an Jiaotong University (China) in 2011 and 2014, and the rest was completed at the University of Minnesota (USA) in 2018, by using Thermo-Finnigan Neptune/Neptune Plus multi-collector inductively coupled plasma mass spectrometers. The methods in both laboratories were identical (CHENG et al., 2013). Standard chemistry procedures (EDWARDS et al., 1987) were used to separate uranium and thorium. Atriple-spike (^{229}Th-^{233}U-^{236}U) isotope dilution method was used to correct instrumental fractionation and to determine U/Th isotopic ratios and concentrations. U and Th isotopes were measured on a MassCom multiplier behind the retarding potential quadrupole in the peak-jumping mode using standard procedures (CHENG et al., 2013). Uncertainties in U/Th isotopic measurements were calculated offline at 2σ, including corrections for blanks, multiplier dark noise, abundance sensitivity, and contents of the same nuclides in spike solution. Corrected ^{230}Th ages assume an initial ^{230}Th/^{232}Th atomic ratio of 4.4 ± 2.2 × 10−6, the values for a material at secular equilibrium with a bulk earth ^{232}Th/^{238}U value of 3.8 (CHENG et al., 2013).

Overall, 230 samples were taken for $\delta^{13}C$ and $\delta^{18}O$ analyses from Qad-1 and Qad-2 stalagmites. Samples were drilled along the stalagmite growth axis at 2.5 mm resolution using a Merchantek Micromill mounted on a Leica microscope, with a 0.3 mm resolution for specific parts. Between every sample, the drill bit and sampling surface were cleaned with compressed air. The samples were analyzed using a Nu Carb carbonate device coupled to a Nu Perspective mass spectrometer (MS) at Vrije Universiteit Brussel (Belgium). Parts of the samples were measured at the Laboratory for Environmental and Raw Material Analysis at the Karlsruhe Institute of Technology (Germany), using a Thermo Gasbench II connected to a DELTA V IRMS in continuous-flow mode. All $\delta^{18}O$ and $\delta^{13}C$ values are calibrated against Vienna Pee Dee Belemnite (VPDB) and are reported in per mil (‰). Analytical uncertainties were better than 0.1‰ (1σ) for oxygen and 0.05‰ (1σ) for carbon on both instruments. Percolation, stream waters, and recent calcite samples underneath active drip water were collected previously from Qadisha Cave in 2011 and 2014 (NEHME et al., 2019).

3. Results

Qad-1 (11 cm) and Qad-2 (13 cm) display translucent to whitish calcite with a columnar fabric along growth axis. Both stalagmites are highly laminated. Microscope images of laminae were taken at several depths. Layer thickness of laminae varied between 60 and 280 µm. The laminar growth is irregular and alternates between thin (60–70 µm) to thick laminae (200–280 µm). A total of 19 U/Th ages were obtained from Qad-1 (Fig. 2) and Qad-2 (Fig. 3). The age distribution indicates that stalagmite Qad-1 grew from 6.643 ± 0.038 to 3.247 ± 0.127 ka, with 2 discontinuities: D1, from 5.787 to 3.247 ka (extrapolated ages), and D2, a shorter period from 6.408 to 6.108 ka (extrapolated ages).

The age model of Qad-1 was constructed with eight ages, with one other age (Qad-stm1-00) considered to be an outlier. The latter is sampled on the edge of the growth axis and is not in stratigraphic order with the other dating points. At the base of Qad-1, the growth rate is ~60 µm/yr, evolving to a higher rate around 150 µm/yr and up to 500 µm/yr in the upper part of the stalagmite.

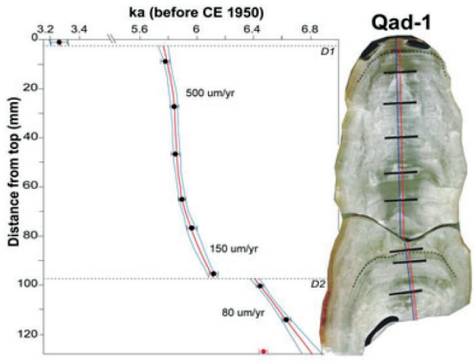

Figure 2: Age model of Qad-1 stalagmite using StalAge (SCHOLZ & HOFFMANN, 2011).

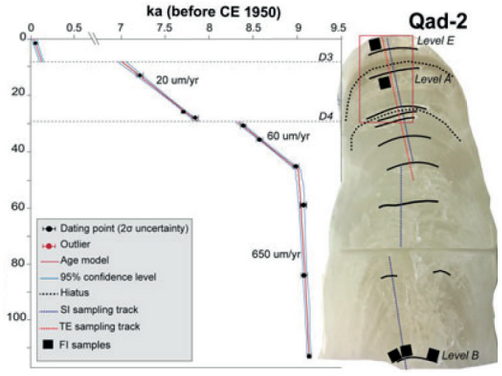

Figure 3: Age model of Qad-2 stalagmite using StalAge (SCHOLZ & HOFFMANN, 2011). Sampling track for stable isotopes along the growth axis are shown.

Qad-2 grew from 9.145 ± 0.021 to 0.005 ± 0.007 ka (Fig. 3), including two discontinuities: D3 (7.016 to 0.005 ka) and D4 (7.844 to 8.326 ka). All the ages are in stratigraphic order and were used in the calculation of the age model.

The growth rate at the base of Qad-2 is very high, reaching 650 µm/yr and is reduced to 60 and 20 µm/yr in the middle and upper part of the stalagmite.

Calcite $\delta^{18}O$ and $\delta^{13}C$ values were analyzed at a multi-annual to decadal resolution. The $\delta^{18}O$ values for the Qadisha record (Fig. 4) range from −5.7‰ to −7.5‰, with a mean of −6.8‰. The $\delta^{13}C$ values range from −6.2‰ to −8.6‰, around a mean of −7.5‰. Both $\delta^{18}O$ and δ13C values generally covary during the entire period from ~9.1 to ~5.7 ka but are distinct in the medium- and long-term trends. For example, the $\delta^{18}O$ values show an overall trend toward more positive values from the Early to the Middle Holocene, unlike the $\delta^{13}C$ values, which show a trend toward more negative values when reaching the mid-Holocene. Significant variations are noticeable in the stable isotope curves, with clear $\delta^{18}O$ and $\delta^{13}C$ excursions around ~9.1, ~8.9, ~7.7, ~7.4-7.2, ~6.5, and ~5.9 ka.

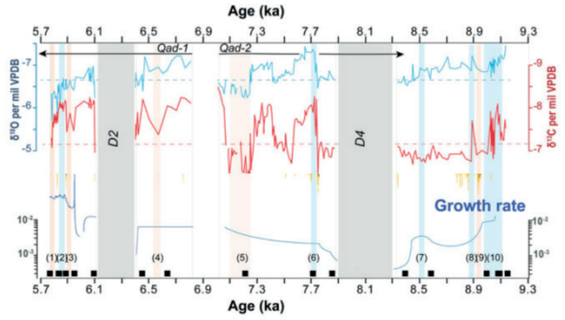

Figure 4: $\delta^{18}O$ and $\delta^{13}C$ profiles of Qad-1 and Qad-2 stalagmites against time (yr 1950 CE), using StalAge. Black dots refer to dating points and gray shading to discontinuities (D2, D4). Blue rectangles highlight variations toward wetter conditions, and orange rectangles drier conditions. Dashed lines indicate present-day isotope values. Rapid dry and wet events are 1 to 10.

Stable isotopes of Qad-2 calcite dated at 0.005 ± 0.007 ka (calcite age between 1938 and 1952 CE) show average $\delta^{13}C$ and $\delta^{18}O$ values of −7.2‰ and −6.6‰, respectively. Present cave and spring water sampled in 2011 and 2014 in Qadisha Cave (NEHME et al., 2019) show average values of −8.6‰ for δ18Ow and −46.9‰ for δ2Hw.

4. Discussion

The Qad-1 and Qad-2 stalagmites grew during the Holocene, roughly between 9.2 and 5.7 ka, one succeeding the other, suggesting favorable (humid and warm) conditions for stalagmite deposition at the high altitude of Qadisha Cave. Previous studies demonstrate that cave calcite precipitation, and thus growth in the central Levant, is conditioned by effective infiltration (VERHEYDEN et al., 2008; CHENG et al., 2015; NEHME et al., 2015, 2018). Growth cessation may be site-specific but could also reflect unfavorable conditions for calcite deposition, such as dry conditions with low effective infiltration within the epikarst or scarcer vegetation with less bio-vegetation activity. Growth rates of both Qadisha stalagmites are of the same order, reflecting similar drip rates and cave pCO2. Similarities in the petrography of both speleothems corroborate consistent growth conditions. High growth rates of 0.15–0.6 mm/yr between 6.1 and 5.8 ka and of 0.3–0.9 mm/yr between 9.15 and 9.0 ka allow for annual and higher-resolution climate reconstruction. Growth rates of 15–50 µm/yr for most other parts of the record allow at least for multi-annual resolution using a traditional micro-milling technique for stable isotope analysis. Two growth pauses at 8.3–7.8 ka and 6.4–6.1 ka are supported by clear petrographic discontinuities. The growth pauses between 8.3 and 7.8 ka in the Qad-2 stalagmite, although supported petrographically by a thin dust layer, are not supported by changes in other proxies before or after the hiatus. If regional aridification characterized the 8.2 ka event, as inferred from the lowland Jeita Cave record (CHENG et al., 2015), then a combination of low infiltration and scarcer vegetation within the Qadisha karst basin would make speleothem growth highly unfavorable, plausibly leading to a centennial-scale hiatus. Such a hiatus is observable in Qad-2 but cannot be attributed confidently to climatic change. Unlike the growth stop dated between 8.3 and 7.8 ka in Qad-2, the one dated between 6.5 and 6.1 ka in Qad-1 seems to be clearly framed by changes in stable isotope values and trace elements. More positive $\delta^{18}O$ and $\delta^{13}C$ values suggest drier conditions before and directly after the growth stop and may record unfavorable growth conditions, although prior calcite precipitation related to local factors at the drip rate may occur, and other speleothems need to be studied to confirm our hypothesis.

The $\delta^{18}O$ signal is commonly interpreted in the Levant as related to effective recharge in the epikarst (precipitation amount vs. evapotranspiration, P-E), and therefore indicates water balance (P-E) in the epikarst (BAR-MATTHEWS et al., 2003; VERHEYDEN et al., 2008; CHENG et al., 2015; NEHME et al., 2020). Higher infiltration (more positive P-E) is related to pronounced low-pressure systems with significant rainfall. Higher rainfall amounts are known to cause more negative rainfall $\delta^{18}O$ values (e.g., AOUAD-RIZK et al., 2005) and reduced annual rainfall (with reduced P-E) produces more positive rainfall δ18O values. GENTY et al. (2001a, 2001b)

showed that at mid-latitudes, $\delta^{13}C$ and growth rate in speleothems are related to biological CO_2 production, which is dependent on soil and vegetation conditions in the catchment. They demonstrated that warmer and wetter periods usually enhance the production of biogenic, $\delta^{13}C$-depleted CO_2 and increase the growth rate. Cold/dry conditions reduce the vegetation cover and the biogenic CO_2 supply. Lower/higher calcite $\delta^{13}C$ values and faster/slower growth rates are therefore usually indicative of soil development/disruptions and can be related to warmer-wetter/colder-drier conditions. An additional control on $\delta^{13}C$ is exerted by the hydrologic state of the aquifer. Partial dewatering of the drip-feeding system induces longer residence times and prior calcite precipitation, leading to higher $\delta^{13}C$ during drier periods (FAIRCHILD & BAKER, 2012).

The stable isotopic $\delta^{18}O$ values of both Qadisha stalagmites display a general trend toward more positive $\delta^{18}O$ values from 8.5 to 5 ka. This trend comprises three independent segments that include several rapid shifts toward negative values at ~9.1 ka (10), ~8.9 ka (8), ~8.5 ka (7), ~7.7 ka (6), and 5.8 ka (2) (see Fig. 4 for numbers in parentheses). Such negative "peaks" are interpreted as wet intervals with high effective recharge (high growth intervals of the stalagmites) and a positive water balance (P-E) (CHENG et al., 2015). Rapid changes toward more positive δ18O at ~9.0 ka (9), ~7.2–7.1 ka (5), ~6.6 ka (4), ~5.9 ka (3), and ~5.7 ka (1), are particularly well expressed and chronologically constrained. Some of these periods interpreted here as "drying" events, particularly at ~9.0 (9), are characterized by unusually high growth rates. Such peculiar periods seem to indicate, at least locally, a wet period, as confirmed by negative (lower) $\delta^{13}C$ values, before the short dry period of ~80 yr, but still with high growth rates. Albeit with low resolved growth rates compared with the resolution of geochemical proxies, such peculiar drying events preceded by short wet events reflect a rapid decadal variability, inferring a shift in the distribution of effective infiltration. The general tendency from more negative $\delta^{18}O$ values during the Early Holocene toward more positive $\delta^{18}O$ values at the end of the Holocene optimum, may reflect, therefore, a change from a wetter (more positive P-E) toward a drier climate (reduced P-E) in this high-altitude area. This trend is also noticeable at low altitude; for example, in the Jeita $\delta^{18}O$ record and in other speleothem records from the southern Levant (e.g., Mizpe Shelagim and Soreq Caves; Fig. 5).

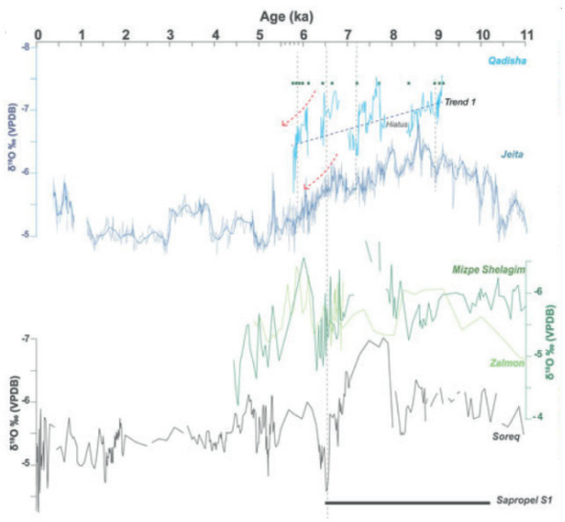

Figure 5: *The Qadisha stable oxygen isotope curve compared to other Levant speleothem records. Black dots represent U-Th dating points in the Qadisha record.*

The carbon signal in Qadisha indicates values reaching −8‰ during wet peaks and shifts to −6‰ during dry events (Fig. 6), reflecting higher soil and vegetation activity during humid periods. The $\delta^{13}C$ curve overprints the short-term changes with a slow long-term increasing trend toward more negative values when reaching the mid-Holocene, suggesting overall improved bio-pedological soil activity in the Makmel mountains from 9 to 6 ka.

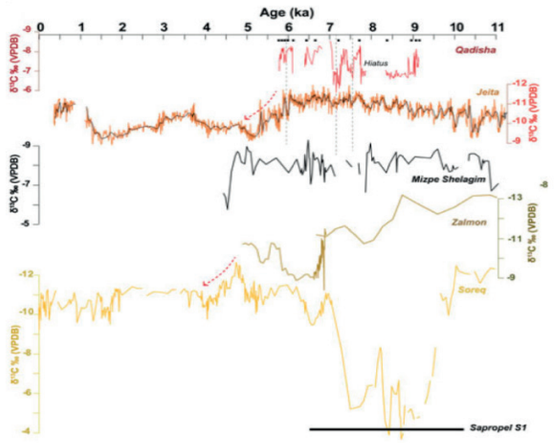

Figure 6: *The Qadisha stable carbon isotope curve compared to other Levant speleothem records. Black dots represent U-Th dating points in the Qadisha record.*

Most of the Levant published speleothem records are located at low altitudes facing the Mediterranean Sea, except for the Incesu and Mizpe Shelagim records located at 1615 m and 2180 m, respectively. Only at Mizpe Shelagim a plausible link between the effect of snow cover at high altitudes and speleothem growth was established on glacial–interglacial timescales. During the Holocene interglaciation, the snow cover in mountain areas participated actively in the epikarst water budget, fed drip sites, and favored speleothem growth in caves located at high altitudes, as well as affecting the vegetation dynamics. Whereas temperature remains close to 0°C during winter over large areas of Mt.

Lebanon (FAYAD & GASCOIN, 2020), the soil beneath the snow does not freeze under present winter conditions, except during exceptional cold events. Comparison of the Qadisha records with those located at low altitudes helps in deciphering altitudinal trend and local particularities.

The Qadisha stalagmites show more negative $\delta^{18}O$ values (Fig. 5) than those recorded by the Jeita stalagmite related to the altitudinal effect expressed in the rain and cave water isotopic signals (NEHME et al., 2019). Also, the contribution of snow to the infiltration and the percolation water in caves (AOUAD-RIZK et al., 2005) may lead to more negative drip-water and calcite δ18O values. It is noteworthy that the Qadisha stalagmites display a larger amplitude in the $\delta^{18}O$ changes and therefore have a more dynamic response to changes than the Jeita record. This behavior may be related to the higher altitude and the enhanced convective rainout at mountain ranges as well as to the generally lower $\delta^{18}O$ values of snow. An increase in low-pressure systems can disproportionally increase the rainfall/snow amount in high-altitude mountain regions. Qadisha records can therefore better, or at least more clearly, indicate RCC than the low-elevation Jeita speleothems. In contrast, short-term dry conditions may be better recorded by the lower-elevation archive sites, as they are more sensitive to droughts and PCP, which enhances the isotope and element signal.

The Qadisha stalagmites carbon isotope signal reflects, similarly to Mizpe Shelagim – Mount Hermon – a higher sensitivity of the vegetation to humidity changes with step changes (< 2‰), compared Jeita. In Soreq Cave located to the south, the shift to less negative carbon values that are closer to the bedrock signal throughout the Holocene optimum, is interpreted as reflecting a soil denudation by intensive storms. The vegetation cover appears to be more stable at Jeita and changes drastically only during larger climatic shifts (e.g., 6 ka), whereas the soil system at highaltitude sites (Qadisha and Mizpe Shelagim) is more sensitive to rapid changes in the water budget and the snow cover dynamics and indicates short-term erosional phases between 7 and 6 ka.

5. Conclusion

New stalagmites from Qadisha Cave located in Mt. Makmel at 1720m asl, north of Lebanon, provide a well-dated record for the northern Levant with high-resolution $\delta^{18}O$ and $\delta^{13}C$ values. The Qadisha stalagmites grew from 9.2 to 5.7 ka, albeit with discontinuities, showing a general tendency from more negative $\delta^{18}O$ values during the Early Holocene toward more positive $\delta^{18}O$ values at the end of the Holocene optimum. This trend is in agreement with a change from a wetter to a drier climate in this high-altitude area. The $\delta^{13}C$ values show rapid shifts along the record and a decreasing trend toward more negative values when reaching the mid-Holocene, suggesting overall improved bio-pedological soil activity.

The Qadisha record reflects particularities of a mountainous climate compared with other Levant records: (1) more negative stable isotope values than the Jeita record due to the altitudinal rainout effect; (2) a larger amplitude in the oxygen isotopes, reflecting a more dynamic response to RCC than records located at lower altitudes; and (3) the effect of snow cover and duration regulating the effective infiltration in the Makmel area.

Acknowledgments

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Stable isotope geochemistry in speleothems for the development of paleoclimatic and paleoenvironmental studies

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Abstract

Stable isotope studies, such as those of oxygen (O) and carbon (C), are fundamental for understanding the chemical composition and proportions of these elements in nature, especially in the hydrological cycle. These isotopes are influenced by climatic factors that vary according to geographic location and soil organic activities. In karst environments, secondary deposits of calcite ($CaCO_3$) known as speleothems are excellent proxies for these isotopes due to the environmental conditions of caves, which minimize water evaporation and contribute to the preservation of isotopic signals from the time of precipitation. The geochemistry of stable isotopes of O and C in speleothems is an analytical tool that enables the interpretation of past climatic conditions and their variations over time, providing information on natural geological processes and the influence of anthropogenic actions on contemporary environmental changes. This study revisits existing studies on stable isotope geochemistry in speleothems to establish a methodology applicable to the context of the Federal University of Ouro Preto for the development of paleoclimatic and paleoenvironmental research of the Cenozoic based on the records contained in speleothems.

Résumé

Les études des isotopes stables, tels que ceux de l'oxygéne (O) et du carbone (C), sont fondamentales pour comprendre la composition chimique et les proportions de ces éléments dans la nature, em particulier dans le cycle hydrologique. Ces isotopes sont influencés par des facteurs climatiques qui varient selon la localisation géographique et les activités organiques du sol. Dans les environnements karstiques, les dépôts secondaires de calcite ($CaCO_3$), connus sous le nom de spéléothèmes, sont d'excellents indicateurs de ces isotopes em raison des conditions environnementales des grottes, qui minimisent l'évaporation de l'eau et contribuent à la préservation des signaux isotopiques au moment de la précipitation. La géochimie des isotopes stables de l'O et du C dans les spéléothèmes est um outil analytique qui permet d'interpréter les conditions climatiques passées et leurs variations au fil du temps, fournissant des informations sur les processos géologiques naturels et l'influence des actions anthrpíques sur les changements environnementaux contemporains. Cette étude evisite les recherches existentes sur la géochimie des isotopes stables dans les spéléothèmes afin d'établir une méthodologie applicable au contexte de l'Université Dédérale d'Ouro Preto pour le développement de recherches paléoclimatiques et paléoenvironnementales du Cénozoique à partir des enregistrements contenus dans les spéléothèmes.

Resumo

Os estudos de isótopos estáveis, como os de oxigênio (O) e carbono (C) são fundamentais para entender a composição química e as proporções desses elementos na natureza, especialmente no ciclo hidrológico. Esses isótopos são influencias por fatores climáticos que variam conforme a localização geográfica e as atividades orgânicas do solo. Em ambientes cársticos, depósitos secundários de calcita ($CaCO_3$) conhecidos como espeleotemas, são excelentes proxies desses isótopos devido às condições ambientais das cavernas, que minimizam a evaporação da água e contribuem para a preservação dos sinais isotópicos do momento da precipitação. A geoquímica de isótopos estáveis de O e C em espeleotemas é uma ferramenta analítica que possibilita interpretar condições climática pretéritas e suas variações ao longo do tempo, fornecendo informações sobre o processo geológico natural e a influência de ações antrópicas nas mudanças ambientais contemporâneas. Este estudo revisita estudos já existentes de geoquímicas de isótopos estáveis em espeleotemas a fim de estabelecer uma metodologia aplicável ao contexto da Universidade Federal de Ouro Preto para o desenvolvimento de pesquisas paleoclimáticas e paleoambientais do cenozoico a partir dos registros contidos nos espeleotemas.

1. Introdução

O estudo de isótopos estáveis em espeleotemas é uma importante ferramenta na determinação dos registros geoquímicos e de modelos de reconstituição paleoambiental e paleoclimática. Durante o processo de gênese, os isótopos de oxigênio e carbono presentes na água são incorporados à estrutura dos minerais precipitantes, registrando informações sobre o clima e o ambiente no momento da deposição.

Em ambientes cársticos, a formação dos espeleotemas se dá pelo processo de carstificação representado pela dissolução de rochas solúveis, sendo comumente calcários e dolomitos (MCDERMOTT 2005). Os espeleotemas são depositados lentamente por desgaseificação de CO_2 de gotas meteóricas saturadas em carbonato (CO_3^{2-}) alimentadas pela água vadosa de infiltração (FORD & WILLIAMS 2007). A maioria dos estudos geoquímicos de isótopos estáveis em espeleotemas utiliza-se de estalagmites em decorrência da sua simples geometria e taxas de crescimento relativamente rápida.

O interesse nos estudos de isótopos estáveis de oxigênio e carbono em espeleotemas como proxies climáticos foi desenvolvido pela primeira vez por Hendy & Wilson (1968) e Thompson (1974) fornecendo estimativas paleoclimáticas por meio de dados de isótopos de oxigênio. Entretanto, as interpretações desses dados são complexas em virtude dos múltiplos fatores que afetam as concentrações de $\delta^{18}O$ e $\delta^{13}C$ das águas de infiltração nas cavernas. Desde então, houve importantes avanços analíticos como os espectrômetros de massas e as técnicas de preparação de amostras para medidas de razões de isótopos estáveis que podem fornecer informações importantes sobre o paleoambiente, origem da água e origem geográfica, por exemplo.

Fatores internos como o ar cavernícola, que é caracterizado pela alta umidade relativa (95 a 100%), promove a mínima evaporação dos gotejamentos de água na caverna e favorece a presença de depósitos de calcita (espeleotemas) em equilíbrio isotópico com a água de percolação que, por sua vez, facilita a reconstrução paleoclimática (FAIRCHILD & BAKER 2012). As taxas de crescimento de estalagmites são variáveis (geralmente de 20 a 300µm/ano) e são controladas por parâmetros climáticos (pluviosidade, vazão/fluxo de gotejamentos, temperatura média anual e umidade relativa do ar do local), disponibilidade de água de gotejamento e a concentração de cálcio das águas de gotejamento (GENTY 2001; POLYAK & ASMERON 2001; FLEITMANN 2004). Esses são fatores externos que influenciam os sinais isotópicos nas taxas de crescimento dos espeleotemas e podem registrar sutis alterações químicas (MCMILAN 2005).

Uma técnica utilizada para a determinação da razão isotópica de oxigênio e carbono em carbonatos, consiste na utilização do IRMS (*Isotope Ratio Mass Spectrometry*) acoplado ao *GasBench* II. As amostras analisadas no IRMS apresentam-se na forma de um gás puro, o que requer o uso de sistemas complexos para a preparação de amostras antes de sua introdução e análise isotópica. O *GasBench* II é uma interface online que permite a determinação da razão isotópica dos gases de amostras. Para essa determinação é necessário que o gás analisado seja parte da amostra original, ou seja, formado a partir de fases líquidas ou sólidas por diferentes métodos de preparação (DIC - carbono inorgânico dissolvido e carbonatos) ou que o gás seja adicionado à amostra de água original em equilíbrio (NOGUEIRA 2018). No caso dos estudos em espeleotemas, este dispositivo pode ser utilizado para análises de alterações globais, com a determinação de $^{13}C/^{12}C$ de DIC da água do mar e água doce e em paleoclimatologia, na determinação simultânea de $^{18}O/^{16}O$ e $^{13}C/^{12}C$ de carbonatos.

Sendo assim, este trabalho tem como objetivo apresentar as análises isotópicas de C e O da estalagmite SL utilizando o espectrômetro de massas de razões isotópicas (IRMS) acoplado ao GasBench II para o desenvolvimento do método de análise de isótopos estáveis em estalagmites.

2. Materiais e Métodos

2.1. Dados pré-existentes

Foi realizado uma revisão bibliográfica dos trabalhos já existentes no Brasil e no mundo que utilizam a ciência espeleológica e a geoquímica isotópica como embasamento para a compreensão de aspectos paleoclimáticos e paleoambientais no tempo geológico. A partir do levantamento bibliográfico, pôde-se definir as metas propostas para o presente estudo: organizar, adaptar e aplicar a metodologia da geoquímica isotópica em estalagmites para o contexto da pesquisa na Universidade Federal de Ouro Preto.

2.2. Escolha da amostra

A Estalagmite SL pertence a Reserva Técnica do Museu da Escola de Minas e a Sociedade Excursionista e Espeleológica (SEE) e foi escolhida a partir de critérios macroscópicos focados nas dimensões e a variabilidade textural e mineralógica ao longo do seu eixo de crescimento (Figura 1).

Figura 1: *Estalagmite SL da Gruta de Inhaúmas, Sete Lagoas (MG).*

2.3. Preparação da Estalagmite SL

A amostra foi cortada ao meio para observar feições irregulares e residuais da serra na superfície axial da estalagmite, portanto foi necessário realizar repetidas técnicas de polimento. Inicialmente, utilizou-se um polidor fixo, em seguida o abrasivo de Carboneto de Silício Grão SIC n° 500 para aprimorar o polimento inicial. Na última etapa, utilizou-se um polidor móvel com pano de polimento metalográfico de 200 mm de diâmetro e alumina.

2.4. Produção das lâminas

Os parâmetros estabelecidos para a escolha das regiões que seriam feitas as lâminas compreenderam uma análise macroscópica que detalhasse as mudanças texturais e mineralógicas ao longo do eixo de crescimento da Estalagmite SL (Figura 3a). Após a determinação dos locais mais adequados, os cortes perpendiculares à superfície axial foram realizados no Laboratório de Laminação (LAMIN) seguido da organização das peças (Figura 3b, 3c) e identificação dos blocos de amostragem (Figura 3d): AM-01, AM-02, AM-03, AM-04 e AM-05, da base para o topo, respectivamente, para posterior confecção das lâminas (3 mm).

2.5. Produção de amostras pulverizadas

A aquisição das alíquotas pulverizadas retiradas ao longo do eixo de crescimento da Estalagmite SL foram extraídas com o auxílio de uma furadeira de bancada com morsa FG-13 350W Ferrari e brocas PM 2, 3 e 4. Após a obtenção das amostras, colocou-se em pequenos recipientes identificados alfanumericamente, da base para o topo, respectivamente.

2.6. Análise isotópica

Nesta etapa, utilizou-se o IRMS no Laboratório de Geoquímica (DEGEO/UFOP) para a determinação das razões isotópicas de $\delta^{18}O$ e $\delta^{13}C$ das alíquotas pulverizadas retiradas ao longo do eixo de crescimento da Estalagmite SL. As análises de isótopos estáveis de carbono e oxigênio em carbonatos foram realizadas simultaneamente e consiste na reação em tubo fechado de, aproximadamente, 500 µg de amostra com ácido fosfórico 100% a 70°C durante uma hora utilizando o Espectrômetro de Massas de Razões Isotópicas Delta V advantage – Thermo acoplado ao GasBench II. A precisão das análises foi baseada nas análises dos padrões NBS-19, NBS-18 e LSVEC para os isótopos $\delta^{18}O$ e $\delta^{13}C$.

2.7. Tratamento e interpretação dos dados

A caracterização macroscópica da Estalagmite SL foi realizada com o auxílio de uma lupa para analisar as diferentes texturas e mineralogia presentes. Além disso, foi utilizado papel vegetal e lapiseira 7 mm para confeccionar o desenho esquemático da superfície estudada. A caracterização microscópica da Estalagmite SL foi realizada com o auxílio de um microscópio com câmara acoplada para a obtenção das fotografias das lâminas e detalhamento dos aspectos texturais e mineralógicos previamente descritos na etapa macroscópica.

Todas as etapas citadas compreenderam os caminhos necessários para a elaboração de um padrão de procedimentos técnicos e analíticos para o desenvolvimento de estudos paleoclimáticos a partir dos espeleotemas.

3. Resultados

3.1. Caracterização Petrográfica

A Estalagmite SL possui dimensões de 60 cm de altura e 14 cm de largura, caracterizada por camadas de calcita predominantemente milimétricas a centimétricas intercaladas com cristais fraturados e clivagem romboédrica bem definida. Os cristais apresentam variabilidade de coloração ao longo do seu eixo de crescimento, com alternância entre tons esbranquiçados/amarelados e tons acastanhados principalmente em sua base. O topo da estalagmite apresenta uma variação de tonalidade entre camadas esbranquiçada, cinza escuro e laranja/acastanhado, até então associadas, à presença de calcita, possivelmente óxidos de ferro e argilominerais, respectivamente.

Na análise macroscópica, pôde-se identificar ao menos quatro fases de crescimento a partir dos aspectos texturais e dos eixos de crescimento da amostra (Figura 2). A Fase 1 foi analisada a partir da base e compreende 11 cm de espessura da amostra ao longo de seu eixo, registrando uma deposição de camadas horizontais, de coloração esbranquiçada/amarelada e acastanhada, indicando o predomínio de calcita. A Fase 2 compreende 30 cm da amostra, apresentando uma dinâmica de crescimento e coloração similar à fase 1, embora ressalta-se o crescimento lateral de camadas onduladas que reflete o fluxo hídrico de escorrimento. A Fase 3 compreende 50 cm de espessura da amostra, registrando uma intercalação entre camadas horizontais e onduladas, de coloração esbranquiçada/amarelada e acastanhada. A Fase 4 compreende 2 cm de espessura da amostra, demonstrando a última fase de crescimento da estalagmite até sua interrupção. Além da presença de calcita, foi observada uma composição mineralógica com camadas predominantemente de materiais terrosos com tonalidades laranja/acastanhado. Ao longo da estalagmite SL, observou-se mudança de direção nos eixos de crescimento entre as fases 2 e 3.

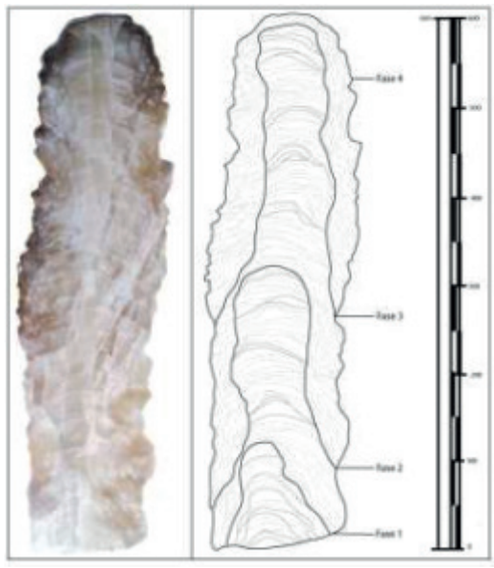

Figura 2: *Hiatos e fases de crescimento da Estalagmite SL.*

3.2. Análise Microscópica

A partir dos resultados obtidos na caracterização macroscópica, pôde-se correlacioná-los com os aspectos texturais e mineralógicos observados ao longo das superfícies das lâminas.

A lâmina AM-01 da estalagmite SL foi retirada da base e compreende o intervalo da fase 2 descrita na análise macroscópica. Observa-se grandes cristais de calcita que nos permite inferir a sua recristalização devido a impossibilidade de visualização de texturas primárias (Figura 3).

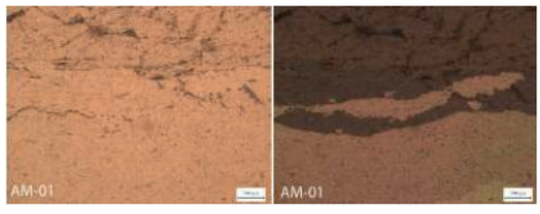

Figura 3: *Fotomicrografia de calcita recristalizada.*

A lâmina AM-2 da estalagmite SL compreende um recorte da fase 2 descrita na análise macroscópica. Observa-se intercalações de grandes cristais de calcita evidenciando sua clivagem romboédrica bem definida (Figura 4a) e a presença de camadas onduladas (Figura 4b) seguidas de fraturas que acompanham a direção de clivagem do mineral.

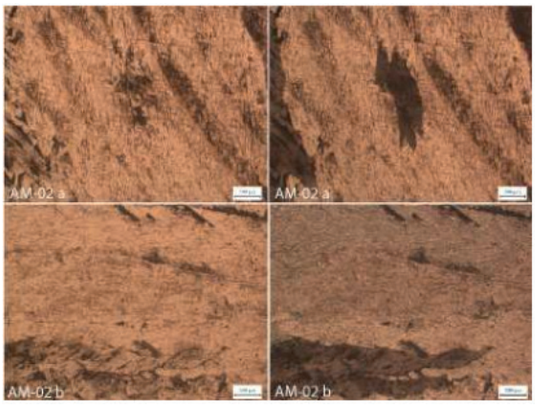

Figura 4: *Fotomicrografia de (a) calcita bem definida e de (b) camadas onduladas seguidas de fraturas.*

A lâmina AM-3 da estalagmite SL foi retirada de uma região compreendida na fase 3 que demonstra novamente a intercalação de grandes cristais de calcita com suas direções de clivagem bem demarcadas (Figura 5), como pode-se observar claramente quando a lâmina está sob efeitos dos nicóis cruzados. Observa-se ainda áreas onde houve perda de material devido ao predomínio de fraturas ao longo de sua estrutura.

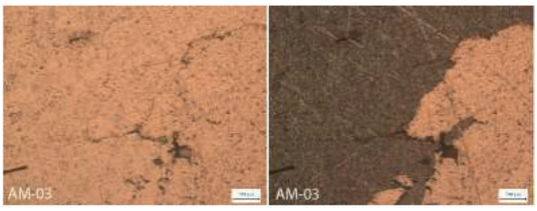

Figura 5: *Fotomicrografia de calcita com clivagens bem demarcadas.*

A lâmina AM-4 da estalagmite SL foi retirada na parte lateral da amostra e compreende as fases 3 e 4, evidenciando uma mudança textural entre camadas horizontais (fase 3) e camadas onduladas (fase 4). Observou-se à nicóis cruzados a presença de clivagens bem definidas e cristais de calcita com variada granulometria (Figura 6).

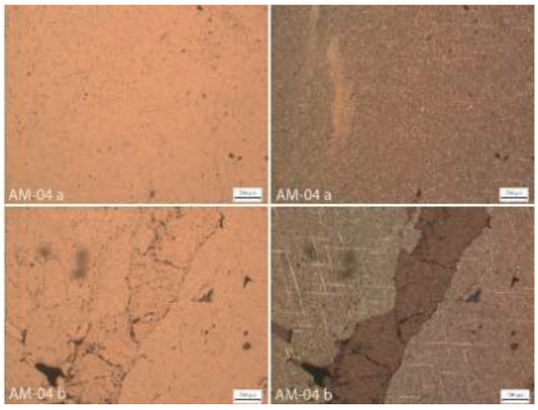

Figura 6: *Fotomicrografia de calcita com clivagens bem definidas e variação granulométrica.*

A lâmina AM-05 da estalagmite SL foi retirada na faixa de transição entre a fase 3 e 4, evidenciando uma mudança mineralógica de calcita com a inclusão de materiais terrígenos de texturas dentríticas (Figura 7b). Visualizou-se a presença de um cristal com hábito hexagonal, apresentando, entretanto, cores de interferências similares aos da calcita, indicando um processo de substituição mineralógica (Figura 7a).

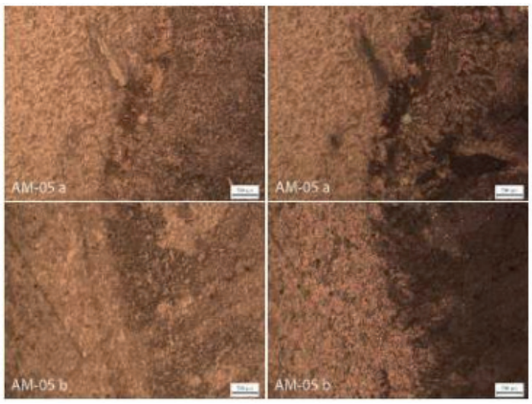

Figura 7: *Fotomicrografia do (a) processo de substituição mineralógica e (b) de calcita com inclusão de materiais terrígenos de textura dentrítica.*

3.3. Geoquímica Isotópica

Os resultados obtidos a partir da geoquímica isotópica foram tratados (Tabela 1) e organizados de modo que facilitasse a compreensão do comportamento isotópico de $\delta^{18}O$ e $\delta^{13}C$ ao longo da Estalagmite SL para então correlacioná-lo com as descrições obtidas anteriormente.

Num	Sample	13C VPDB	18O VSMOW	18O VPDB	Accepted Value
1	NBS-18	-4.97	7.20	-23.00	**-5/7.2**
2	NBS-19	1.95	28.60	-2.24	**1.95/28.6**
3	LSVEC	-46.38	3.68	-26.41	**-46,60**
4	LIE	2.07	29.48	-1.38	**2.12/29.35**
5	LIVM3	1.96	29.48	-1.38	**1.96/29.09**
6	IE-1	-6.94	23.40	-7.28	
7	IE-2	-7.11	23.20	-7.47	
8	IE-3	-8.84	22.59	-8.07	
9	IE-4	-7.17	23.27	-7.40	
10	IE-5	-4.96	24.51	-6.21	
11	IE-6	-8.65	21.77	-8.86	
12	IE-7	-9.04	22.45	-8.21	
14	IE-8	-8.85	22.51	-8.14	
15	IE-9	-8.88	22.20	-8.45	
16	IE-10	-9.88	21.30	-9.32	
20	LSVEC	-46.82	2.04	-28.00	**-46,60**

Tabela 1: *Resultados obtidos a partir da determinação das razões isotópicas de $\delta^{18}O$ e $\delta^{13}C$ no IRMS baseadas nas análises dos padrões NBS-19, NBS-18 e LSVEC para isótopos $\delta^{18}O$ e $\delta^{13}C$.*

4. Discussões

Ao analisar o comportamento isotópico com valores mais positivos para $\delta^{18}O$ (Gráfico 1), observou-se coincidências com as fases marcadas na descrição da Estalagmite SL. Este comportamento indica uma diminuição na precipitação externa e, consequentemente, define uma fase de perda hídrica do sistema cárstico que influenciou diretamente na diminuição da taxa de gotejamento. Isso demonstra uma tendência a períodos mais secos até a cessão do gotejamento, representado pelos hiatos observados na análise macroscópica. Em contrapartida, o comportamento isotópico com

valores mais negativos de $\delta^{18}O$ coincidem com as fases de crescimento demonstradas na figura 5. Essa característica indica um aumento da precipitação externa que abastece o sistema, que adquire maior fluxo hídrico e influencia no aumento das taxas de gotejamento. Essa característica marca uma tendência a períodos mais úmidos indicando um período de crescimento da Estalagmite SL. A oscilação entre valores isotópicos mais negativos e mais positivos demonstra a alternância no ciclo de precipitação externa.

Ao observar o comportamento isotópico do $\delta^{13}C$ que varia de -5 a -10 ‰ (Figura 8) que o carbono preservado no sistema demonstra um predomínio de vegetação do tipo C4, isto é, maior contribuição de carbono disponibilizado pelas gramíneas (NOVELLO et al., 2021).

Os três primeiros ciclos possuem uma amplitude isotópica similar e o último ciclo apresenta uma amplitude isotópica maior que a distingue dos demais. Tais informações nos levam ao entendimento de que as amplitudes similares registram o período de desenvolvimento da estalagmite e a amplitude que se destoa marca a fase final de crescimento até sua interrupção.

A correlação (0,89) entre os isótopos de $\delta^{18}O$ e $\delta^{13}C$ indicam um comportamento síncrono que pode estar relacionado aos fatores de fracionamento cinético durante o processo de desgaseificação.

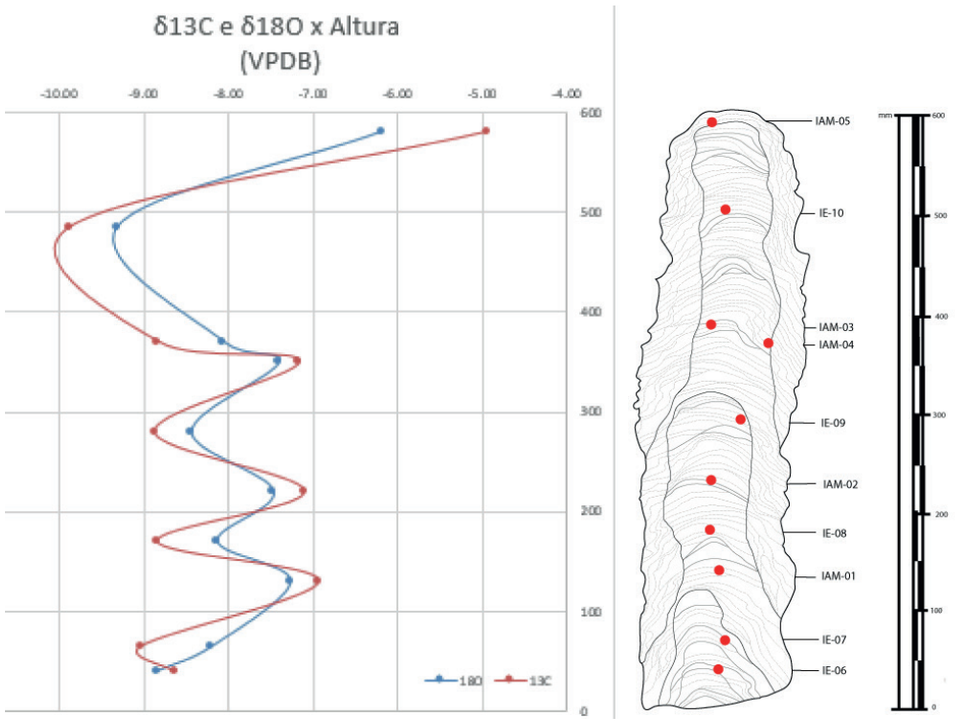

Figura 8: *Comportamento isotópico dos $\delta^{18}O$ e $\delta^{13}C$ correlacionados com os aspectos petrográficos da Estalagmite SL.*

5. Conclusões

Na análise macroscópica, pôde-se identificar ao menos quatro fases de crescimento a partir dos hiatos e do eixo de desenvolvimento da Estalagmite SL. Estes pontos correlacionam-se à sazonalidade paleoclimática, isto é, a alternância dos valores isotópicos de $\delta^{18}O$ que confirma os hiatos e nos indica que houve períodos chuvosos quando mais negativos e períodos secos quando mais positivos. Na análise microscópica, a impossibilidade de reconhecer as texturas primárias indica um processo de recristalização da calcita ao longo do seu crescimento.

A geoquímica isotópica confirma a variabilidade presente no fluxo hídrico externo e interno da caverna e, corrobora para o entendimento do comportamento de $\delta^{18}O$ em diferentes períodos climáticos no passado geológico. A faixa amostral de $\delta^{13}C$ variando entre -10 a -5‰ indica um predomínio de gramíneas, vegetação caracterizada pelo tipo C4.

Agradecimentos

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The coupling between monsoon rainfall and sea surface temperatures in the subtropical South Atlantic during the Last Glacial Period

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Abstract

Here, we display high-resolution trace element data from the Botuverá Cave (27ºS) as a proxy for paleo-precipitation amount covering the Last Glacial Period. Our record highlights an in-phase variation between Mg/Ca, Sr/Ca, and $\delta^{18}O$ for the first two insolation cycles suggesting increased precipitation due to enhanced monsoon activity during high austral summer insolation. Furthermore, this comparison of speleothem records allows us to discuss the relationship between the monsoon circulation and variations in Sea Surface Temperature (SST) in the South Atlantic. In this regard, we compare the speleothem to marine SST records to identify feedback mechanisms between the atmosphere circulation and the South Atlantic. Two modes of precipitation variability are proposed: 1) from 115 to 55 kyrs, an in-phase precipitation variability between the areas affected by the South Atlantic Convergence Zone (SACZ) and the Andean Low-Level Jet (ALLJ) moisture trajectories; and 2) from 55 to 13 kyrs, a precipitation dipole is identified between SACZ and ALLJ monsoon domains.

1. Introduction

The speleothem isotope records from subtropical South America have revealed changes in rainfall regime during the Last Glacial Period as a response to the precession cycles and millennial climatic events. In southern-Brazil, the negative (positive) oxygen isotope ratios ($\delta^{18}O$) values in stalagmite-calcite reflect a higher amount of rainfall sourced from the Amazon (South Atlantic) regions in periods of enhanced (weakened) South America Monsoon System (SAMS), in phases of high (low) austral summer insolation (CRUZ et al., 2005). As for millennial events, negative $\delta^{18}O$ incursions are associated with temperature cooling and ice volume expansion in the North Atlantic (CRUZ et al., 2005; CRUZ et al., 2006; WANG et al., 2007). However, the effect of the seasonal changes in moisture source areas prevent a direct rainfall amount reconstruction based on of the speleothem $\delta^{18}O$ records. Furthermore, BAO et al. (2023a, 2023b) recently provided evidence, based on climate model simulations, indicating that $\delta^{18}O$ variations in speleothem records do not directly correspond to changes in local precipitation. Instead, these variations are primarily influenced by isotopic fractionation in the rainfall source regions, which is associated with changes in the intensity of convection within the Intertropical Convergence Zone (ITCZ). This evidence challenges the traditional interpretation of $\delta^{18}O$ in speleothems as a direct proxy for local hydroclimatic conditions and raises broader concerns about its reliability as a climate proxy.

The use of trace element ratios (E/Ca) as a proxy for local aquifer recharge made it possible to associate the moisture source area with changes in the annual average rainfall for paleoclimate interpretations from south-Brazil stalagmites during last glacial period and Holocene (CRUZ et al., 2007; BERNAL et al., 2016). The cave monitoring of drip water's Sr/Ca and Mg/Ca ratios in the region revealed that prior calcite precipitation (PCP) is the main mechanism responsible for the trace elements variation in the modern speleothems (KARMANN et al., 2007). The pioneer study based on Sr/Ca and Mg/Ca records by using electron microprobe technique in the Bt2 stalagmite from Botuverá cave indicated that lower (higher) Sr/Ca and Mg/Ca ratios correlate with phases of negative (positive) $\delta^{18}O$ values and high (low) summer austral insolation, corresponding to periods of increased (decreased) rainfall (CRUZ et al. 2007). This multiproxy approach also demonstrated that the period between 60 and 19 ky BP had an anomalous increase in local rainfall amount that is not well coupled with precession cycles but with the full glacial boundary conditions associated with cooler North Atlantic Ocean (CRUZ et al., 2007). However, this data lacks temporal resolution and presents high instrumental noise that inhibited precise interpretations of the millennial scale variability during the last glacial period. To date, a relationship has not yet been established between changes in the monsoon regime and the climatic conditions of the South Atlantic Ocean as observed in modern times. Addressing this gap is imperative given the emergence of new paleoceanographic reconstructions from the (sub)tropical South Atlantic, extending back to the Last Glacial Period.

Advancements in the use of LA-ICP-MS method (Laser Ablation-Ion Coupled Plasma-Mass Spectrometry) enabled data acquisition close to annual resolution even for stalagmites with low growth rates like Bt2, from Botuverá cave (BERNAL et al., 2016) among other speleothem records. BERNAL et al. (2016) used LA-ICP-MS data record from Botuverá to confirm the in-phase changes in trace element and isotopic data following the summer insolation curve during the Holocene. With the increased resolution of trace element data using LA-ICP-MS, it was possible to identify the climate response to broader discussed millennial scale events such as the 8.2 ky BP and Little Ice Age, which were undistinguishable in the lower-resolution δ18O curve. In this regard, the application of the same technique on a stalagmite covering the entire Last Glacial Period could offer a unique possibility to refine the interpretation of the δ18O during millennial scale events during the last glacial period by comparing with trace element data from the same speleothems.

The present work presents a high-resolution trace element record from LA-ICP-MS in the Bt2 stalagmite for the whole Last Glacial period. We aim to discuss variations in moisture source area and changes in local rainfall recharge amount on orbital and millennial timescales. The data also allows discussion of the relationship between monsoon continental isotope records and the sea surface temperature (SST) reconstructions from the South Atlantic, aiming to debate the influence of summer insolation and Atlantic meridional overturning circulation (AMOC) on the SAMS and the feedback between the SAMS and South Atlantic SSTs.

2. Materials and methods

Stalagmite Bt2 was collected from Botuverá cave (27°13′24″S; 49°09′20″W) (Fig. 1), southern Brazil. The stalagmite Bt2 speleothem record chronologically uses 33 $^{234}U/^{230}Th$ dates published by MILLO et al. (2017). It ranges from 2.78 to 113.47 ky BP, and all dates are in stratigraphic order without long hiatus and inversions. Most dates have an error (2σ) of under 1.0%. Speleothems from the Botuverá Cave present very slow growth that range between ~12 mm/ky BP and ~8 mm/ky BP. For this reason, the resolution of stable isotopes is relatively low. The new δ18O curve presented here has 879 samples. The oxygen isotope ratios are expressed in δ notation for carbonate speleothems, the per mil deviation from the Vienna Pee Dee Belemnite (VPDB) standard.

Trace element ratios were obtained by Laser-ablation ICP-MS using a Resonetics L-50 excimer laser-ablation workstation (ArF, λ=193 ns, 23ns FWHM, fluence of ~6 J/cm^2) at Centro de Geociencias, Universidad Nacional Autónoma de México (UNAM), following methods described in BERNAL et al. (2016). The Bt2 trace element data presented in this work is a composite of normalized data from two different sections of the sample analyzed at different times (one in 2016 and the other in 2023) in the same laboratory and method constructed by the intra-site correlation model (ISCAM) (FOHLMEISTER, 2012).

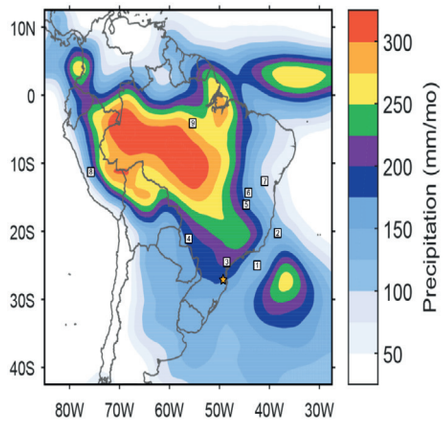

Figure 1: *Location of records used for paleoclimatic comparisons. Botuverá cave (yellow star; data from this paper), 1: marine core GL-1090 (SANTOS et al., 2017; MATHIAS et al., 2021), 2: marine core M125-55-7 (HOU et al., 2020); 3: Santana cave (KARMANN et al., 2007); 4: Jaraguá cave (NOVELLO et al., 2017), 5: Lapa Sem Fim cave (STRIKIS et al., 2015), 6: Lapa Grande cave (STRIKIS et al., 2017), Paixão cave (STRIKIS et al., 2015), 8: Pacupahuain cave (KANNER et al., 2013), and 9: Paraíso cave (WANG et al., 2017).*

3. Results

The Mg/Ca and Sr/Ca records from Bt2 consist of nearly 173,000 points, resulting in a sub-annual resolution. The values presented throughout this work were reduced using a 50-point running means to improve data visualization. Advances in the data acquisition method via LA-ICP-MS, when compared to the Electron Microprobe, measured data from CRUZ et al. (2007), enable us to further discuss orbital and millennial scale changes since the resolution is improved and instrumental noise reduced. The ln(Sr/Ca) vs. ln(Mg/Ca) slope for the Bt2 stalagmite is 0,91388 ± 0,0013 (r^2 = 0,69) showcasing the expected trend if Prior Calcite Precipitation (PCP) is the major process dictating the abundances of Mg and Sr in the stalagmite (SINCLAIR, 2011).

The Sr/Ca and Mg/Ca values are positively correlated with $\delta^{18}O$ of Bt2 speleothem (r^2 =0.40) indicating a significant relationship between increased local rainfall with intensification of monsoon circulation as indicated by lower values of both trace element and stable oxygen ratios. We also observe a near perfect fit between Sr/Ca, Mg/Ca, $\delta^{18}O$ and insolation curves during the first two precession cycles of the last glacial period (Fig. 2). From ~65 ky BP to ~44 ky BP the Sr/Ca and Mg/Ca normalized data stay close to neutral values in the first's values in orbital scale and persistently negative in the case of latter ratios, both curves show a plateau-shaped curve. Unlike the isotopic curve, the trace element ratios are decoupled from the insolation curve, which shows a very good match with it until ~44 ky BP. The trace element and isotopic data have a strong correlation within themselves but a weaker one with the insolation curve from ~42k yrs onwards as the amplitude of insolation decreases with the lower eccentricity that characterizes the Marine Isotope Stage (MIS) 3 and 2. As the amplitude of the insolation decreases, the signal of millennial-scale events becomes a key feature of the speleothem trace element variability.

At the millennial timescales, some of the negative anomalies observed in the speleothem $\delta^{18}O$ are also identified in both Mg/Ca and Sr/Ca ratios of Bt2 speleothem, for instance in the HS10, HS6, HS4, HS3, HS2 and HS1 events and some Greenland Stadials events (GS-5.2, 10, 15.2, 16.1 and 25) (Fig. 2). The climatic responses in other events are not very clear like in the HS7a or even absent, as appears to be the case with the events HS5 and 5a (Fig. 2). In contrast, the relationship between trace elements and $\delta^{18}O$ during the Greenland Interstadial (GI) periods have a less consistent signal on the Bt2 multiproxy time series. An exception occurs during the GI-1 (Bølling–Allerød Event) when we observe one of the highest positive anomalies of trace element ratios on the entire Bt2 record. A couple of positive anomalies are present only on the $\delta^{18}O$ record (GI-4 to 5.2, 14, and 19.2 to 22), suggesting a difference in the amplitude of response between the source area of moisture ($\delta^{18}O$) and amount of rainfall (Mg/Ca and Sr/Ca).

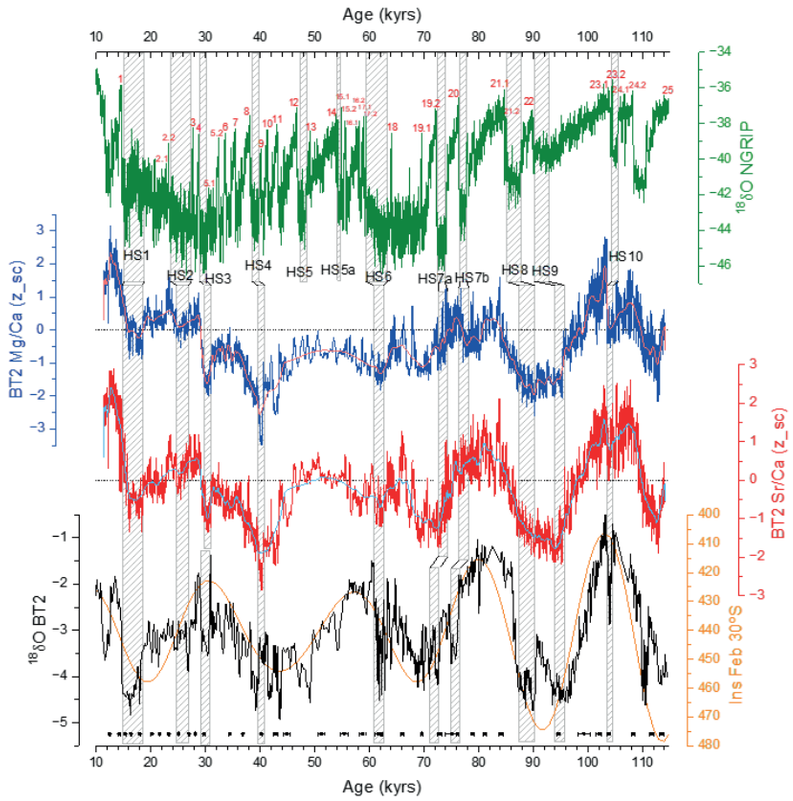

Figure 2: *Bt2 stalagmite (Botuverá cave) δ^{18}O (‰VPDB) (black), Sr/Ca (z-score) (red) and Mg/Ca (z-score) (blue) data covering the last 113.5 kyrs. δ^{18}O NGRIP record (‰V-SMOW) from SEIERSTAD et al. (2014) (green). Dashed gray boxes indicate Henrich stadials events and red numbers on top of the NGRIP curve marks Greenland Interstadials periods. February Insolation for 30°S (W/m^2) (orange) (BERGER and LOUTRE, 1991).*

4. Discussion

Due to the complexity in interpreting δ^{18}O variability because of the different moisture sources affecting southeastern Brazil, we are now presenting high-resolution trace elements data from a Botuverá cave speleothem, which allows us to compare the changes in SAMS intensity with moisture sources, providing a more robust paleoclimate reconstruction at distinct time scales. Because of the higher coherence between trace elements and δ^{18}O data throughout the record, we are interpreting the lower (higher) Sr/Ca and Mg/Ca point towards more (less) rainfall recharge in the vadose zone of the karst due to less (more) intensification of Prior Calcite Precipitation (PCP) in caves over subtropical Brazil (KARMANN et al., 2007). A significant outcome of this comparison is the identified correlation between monsoon intensity variations and annual average precipitation (CRUZ et al., 2007; BERNAL et al., 2016), even if the region is influenced by a bimodal rainfall regime characterized by distinct rain source areas.

Between 114 and 65 ky BP, the δ^{18}O, Sr/Ca and Mg/Ca show a good match with changes in summer insolation over two precession cycles. Periods of high summer insolation align with decreased values in oxygen isotope ratios and trace element ratios. In contrast, periods of low summer insolation correspond to increased values (Fig. 2). In this regard, the increase in local rainfall recharge on orbital timescales during periods of enhanced monsoon rainfall in the region coincides with phases of high austral summer phases as it was already discussed in previous works (CRUZ et al., 2007; BERNAL et al., 2016).

In comparison, the trace element curves from 65 to 10 ky BP do not seem to follow the variation in insolation so well. The Mg/Ca and Sr/Ca suggest that other climatic forces have a major influence on the changes in rainfall over subtropics. The Bt2 geochemical record consistently exhibits negative or neutral anomalies in trace element ratios. These anomalies were initially attributed to cooler water conditions in the North Atlantic, which enhanced moisture transport from the equatorial Atlantic Ocean to the Amazon Basin, thereby contributing to the intensification of the SAMS (CRUZ et al., 2007). These prevailing negative δ^{18}O anomalies are also observed in other speleothem isotope records from subtropical Brazil like in Santana cave (CRUZ et al., 2006).

During most of Heinrich Stadials events, both negative isotopic and trace element incursions confirm the coupling between increased monsoon-amazon sourced moisture and higher rainfall amount in the region. The results indicate the common occurrence of wet events in South American subtropics marked by lower Mg/Ca and Sr/Ca values as a response to the SAMS intensification, as reported in the speleothem δ^{18}O records from tropical eastern Brazil during cold stadials in the North Atlantic (STRIKIS et al., 2018). This is an important result because, even though the impact of the Heinrich events is already well known, there was still no confirmation of the increase in the average annual rainfall so far. In addition, these findings indicate that the isotopic signal of speleothems primarily reflects local rainfall dynamics rather than solely the upstream fractionation of moisture through the Degree of Rainout process along its trajectory from the Amazon (AMPUERO et al., 2020) or at its origin in the Atlantic Ocean (BAO et al., 2023).

Although warm Greenland Interstadials (GIs), also known as Dansgaard-Oeschger (DO) events, are distinctly visible in tropical speleothem records from the Intertropical Convergence Zone (ITCZ) region, the Peruvian Andes, and eastern Brazil, their expression is less pronounced in

the trace element records of the Botuverá speleothem. However, some events, such as GI 14 and GI 22, are discernible in the $\delta^{18}O$ records (Fig. 2). An exception is the Bølling-Allerød event, which exhibits one of the most pronounced Sr/Ca and Mg/Ca anomalies between 15 and 12 kyr BP, indicating one of the driest periods recorded in the region during the last glacial period.

For the first time, we can describe a very consistent relationship between increased (decreased) monsoon rainfall during the last glacial period, as defined by lower (higher) values in trace element ratios, and cooler (warmer) sea surface temperatures (SST) in the subtropical South Atlantic. An interesting aspect of this comparison is that the speleothem-Sr/Ca and marine-SST data follow together the summer insolation phases according to the precession cycle between 116 and 65 ky BP. Furthermore, the relationship remains consistent even in the period in which the proxy data decouple from the insolation curve. Notably, the plateau observed in the Sr/Ca data from 65 to 45 kyr BP coincides with elevated SST values. Similarly, the trend of increase in trace elements follows the increase in SST observed from 40 ky BP to 25 ky BP and between 15 and 13 ky BP, during the Bølling–Allerød Interstadial event. On the other hand, the strong relationship between lower Sr/Ca values of Bt2 speleothem and cooler SSTs in subtropical data is also noteworthy during HS4, HS3, and HS1 events.

The comparison between the geochemical data of speleothems and ln(Ti/Ca) from the same cores used to discuss SST variations allows us to suggest two modes of long-term precipitation variability. The first is associated with a rainfall pattern that encompasses a large region from about 20°S in the central region of the SACZ (core M125-55-7; HOU et al., 2020) to 27°S, where the Botuverá cave is located. This pattern extends southward to the region of the La Plata Basin, from where most of the river sediments transported to the site at 25°S (GL-1090) were carried (MATHIAS et al., 2021). It likely reflects a rainfall variation in phase across the area covered by SACZ and ALLJ, which operated between 115 and approximately 55 ky BP in the region with a first-order control of insolation forcing on climate. This regional hydrological pattern is supported by the speleothem isotope record from Santana Cave, located at 24°S (CRUZ et al., 2006; 2007).

The other mode of variability identified was a precipitation dipole between the SACZ region and the area fed by the moisture path related to the ALLJ. This mode can be observed from 55 to 11 ky BP, observed between the ln(Ti/Ca) data of marine sedimentary cores located at 20°S and 25°S in the western margin of the Atlantic. This dipole-like pattern of opposing summertime rainfall anomalies is well known in Southern Brazil and the La Plata Basin on modern time scales and resembles the intraseasonal mode known as SACZ and Southeast South America (SESA) (DIAZ and ACEITUNO, 2003). We consider that the drought trend indicated in the BT2 speleothem data from 40 ky BP onwards represents both a retraction of SACZ rainfall northwards towards its modern axis and a decrease in rainfall associated with a weaker moisture transport by the ALLJ. This precipitation pattern makes perfect sense with the variations of SST observed in this period, which is characterized by cooling in the adjacent ocean in the SACZ region and warming further south, in the subtropical region of South America that correspond to the wet and dry areas of the South American Monsoon during this period, respectively.

5. Conclusion

Our new LA-ICP-MS trace element data from Botuverá Cave indicates that periods with enhanced (weakened) SAMS correspond to increased (decreased) local rainfall amount, signaled by lower (higher) $\delta^{18}O$, Sr/Ca and Mg/Ca values during the Last Glacial Period. On orbital time-scale, we have identified that insolation is the main climate forcing at the first half of Last Glacial Period from 115 to 65 kyrs, while climate conditions associated with AMOC seems do exert a more important control on the long-term change in SAMS rainfall between 65 to 15 kyrs. By comparing our speleothem isotope record and marine sediment core data from the subtropical South Atlantic, it is observed a clear relationship between increased local precipitation and cooler SST in the subtropical western South Atlantic throughout the Last Glacial Period, a result indicating that cloud cover can significantly influence sea surface temperature during the first high austral summer insolation phases. In that sense, the increased Zonal SST gradients due to weakened AMOC conditions towards MIS 3 and 2 can explain the warming SST trend at 25°S, but not the cooling one at the 20°S site after 55 ky BP, which highlights the importance of cloud cover in modulating SST variations over the South Atlantic.

On millennial-scale, we observed that the negative isotopic and trace element anomalies during most HSs are strong evidence of SAMS intensification and local rainfall increase over South Brazil during most of the cold North Atlantic events. However, the climate response to GIs or DOs events are barely observed in the Sr/Ca and Mg/Ca record, while some of them result in positive $\delta^{18}O$ anomalies at Botuverá. This suggests a weakening in the influence of North Atlantic warm millennial variations when we compare our subtropical South America record in relation to the consistent positive $\delta^{18}O$ speleothems record from lower latitudes during GIs. It is important to note that the Bolling-Allerod event is an exception, with one of the highest trace element values on our record, indicating an extremely dry period. For the HS1 in particular, we propose a precipitation dipole between sectors of the SACZ, because the dry phase centered around 16 ky BP for the northern sector interpreted by positive $\delta^{18}O$ anomalies is contemporaneous to a wet period on the southern sector responsible for negative $\delta^{18}O$, Sr/Ca and Mg/Ca anomalies.

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Eiskapelle – 33 years of monitoring a firn ice field with the Eiskapelle cave system in the German Alps

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Abstract

The Eiskapelle cave ('ice chapel') is situated at the foot of the Watzmann east face in the German Alps. It is the lowest lying permanent firn ice deposit in the Bavarian alpine region. Avalanches from the steep face in winter and spring feed the firn ice areas, which are traversed by an active cave system due to the infiltrating meltwater. Depending on the time of year and precipitation in the last winter, the shape of the firn ice areas and caving system changes. Since 1991, the Institute for Applied Karst and Cave has measured and surveyed the entire Eiskapelle and its surroundings in fourteen survey campaigns. The cave system is surveyed annually in late autumn. From 1953 to 2024, fourteen geodesic surveys of the firn ice areas were done. Despite an increase of area growth in the years 1961 - 1983 as well as 2018 - 2019, an accelerating massive loss of ice mass can be observed as a general trend. Goals of long-term monitoring are the generation of detailed maps and 3D models for the creation of mass balances and long-term predictions, as well as a need-based visualisation of the changes of the firn ice field and the cave system in context with current climate change developments.

Résumé

La grotte d'Eiskapelle (« chapelle de glace ») est située au pied de la face est du Watzmann dans les Alpes allemandes. Il s'agit du dépôt permanent de glace de sapin le plus bas de la région alpine bavaroise. Les avalanches de la face raide en hiver et au printemps alimentent les zones de glace de sapin, qui sont traversées par un système de grottes actif en raison de l'infiltration des eaux de fonte. Selon la période de l'année et les précipitations de l'hiver précédent, la forme des zones de glace de sapin et du réseau de grottes change. Depuis 1991, l'Institut pour le karst appliqué et les grottes a mesuré et étudié l'ensemble de l'Eiskapelle et de ses environs au cours de quatorze campagnes d'étude. Le réseau de grottes est étudié chaque année à la fin de l'automne. De 1953 à 2024, quatorze levés géodésiques des zones de glace de sapin ont été effectués. Malgré une augmentation de la superficie dans les années 1961-1983 et 2018-2019, une perte massive et accélérée de la masse de glace peut être observée comme une tendance générale. Les objectifs de la surveillance à long terme sont la génération de cartes détaillées et de modèles 3D pour la création de bilans de masse et de prévisions à long terme, ainsi que la visualisation nécessaire des changements du champ de glace de sapin et du système de grottes dans le contexte des développements actuels du changement climatique.

Resumo

A caverna Eiskapelle ("capela de gelo") está situada no sopé da face leste do Watzmann, nos Alpes alemães. É o depósito permanente de gelo de firn mais baixo da região alpina da Baviera. As avalanches da face íngreme no inverno e na primavera alimentam as áreas de gelo de firn, que são atravessadas por um sistema ativo de cavernas devido à infiltração de água derretida. Dependendo da época do ano e da precipitação do último inverno, a forma das áreas de gelo de firn e do sistema de cavernas muda. Desde 1991, o Institute for Applied Karst and Cave mediu e pesquisou todo o Eiskapelle e seus arredores em quatorze campanhas de pesquisa. O sistema de cavernas é pesquisado anualmente no final do outono. De 1953 a 2024, foram realizados quatorze levantamentos geodésicos das áreas de gelo de firn. Apesar de um aumento do crescimento da área nos anos de 1961 a 1983 e de 2018 a 2019, uma perda maciça e acelerada da massa de gelo pode ser observada como uma tendência geral. Os objetivos do monitoramento de longo prazo são a geração de mapas detalhados e modelos 3D para a criação de balanços de massa e previsões de longo prazo, bem como uma visualização baseada na necessidade das mudanças do campo de gelo de firn e do sistema de cavernas no contexto dos atuais desenvolvimentos da mudança climática.

1. Introduction

The so-called ice chapel (Eiskapelle) area at the foot of the Watzmann east face is the deepest perennial accumulation of firn ice nourished by avalanches in the German Alps. The ice masses are pervaded by an extensive cave system. The surface and the firn ice body of the ice chapel and the cave system are subject to large annual fluctuations. The Institute for Applied Karst and Cave Research Germany (IKH) explores and documents the ice cave system on an annual basis with private funding and carries out geodetic measurement campaigns in collaboration with the Munich University of Applied Sciences and the Technical University of Munich to determine the firn ice masses and the cave. The most important results are briefly presented here.

Figure 1: *Eiskapelle at the foot of the Watzmann east face in autumn 1994. Photo W. Vogel.*

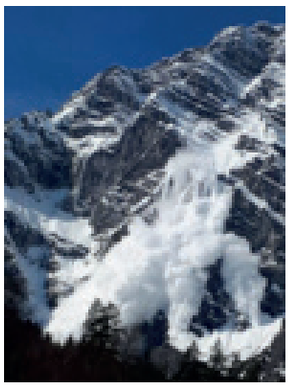

Figure 2: *Avalanches feed the firn ice body of the Eiskapelle in winter 2019. Photo G. Orterer.*

Figure 3: *Eiskapelle in autumn 2020. Photo A. Wolf.*

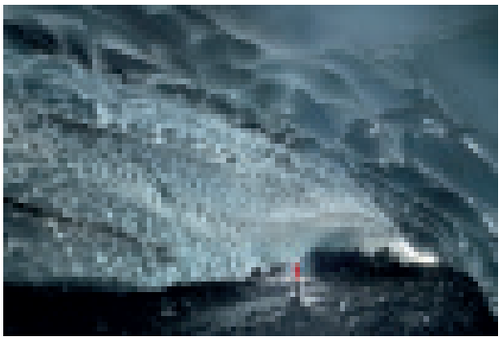

Figure 4: *Main passage 2018. Photo: Ph. Crochet.*

2. Genesis of the cave system

The accumulation of firn ice at an altitude of between 850 m and 1,000 m above sea level is nourished by winter precipitation and spring avalanches from the Watzmann east face. The cave passages are largely filled with snow masses. In spring and summer, warm water masses from the Watzmann east face melt the snow masses in combination with the weathering of summer draughts, creating tunnel-like cave passages.

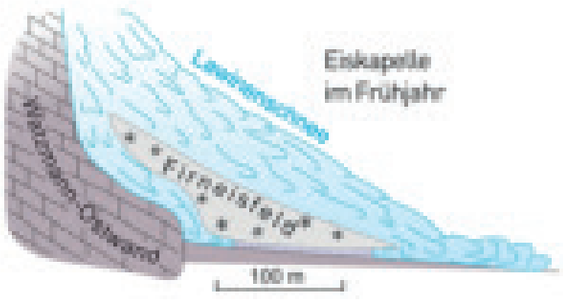

Figure 5: *Genesis of firn ice field in spring. From Bavarian State Office for the Environment.*

Figure 6: *Simplified genetic sketch of the Eiskapelle. From Bavarian State Office for the Environment.*

3. Description and changes to the cave system

The cave system basically consists of a west-east orientated tunnel--like main passage and is supplemented on its south side by the south passage and on the north side by two north passages (see Fig. 8 and 9). All passages end at the exposed rock passages of the Watzmann east face. The length of the main passage is between 100 and 400 m, depending on the year, with a width of up to 30 m and a height of 15 m. The length of the side passages is between 50 - 100 m, 5 - 10 m wide and up to approx. 5 m high. Depending on the vintage, the side aisles do not always exist.

A special feature of the Eiskapelle are the tile-like facets on the cave walls, which create a chapel-like atmosphere depending on the position of the sun, the incidence of light and the quality of the firn ice, hence the name ice chapel.

The “fever curve” (Fig. 7) shows the dynamics in the total length of the passage as well as in the main passage length of the cave system. The main passage length also reflects the length of the firn ice body of the Eiskapelle. The light blue equalising straight line shows the change

in the length of the firn ice body with the question mark as to when this, or the cave system, could disappear if the climate change trend remains the same.

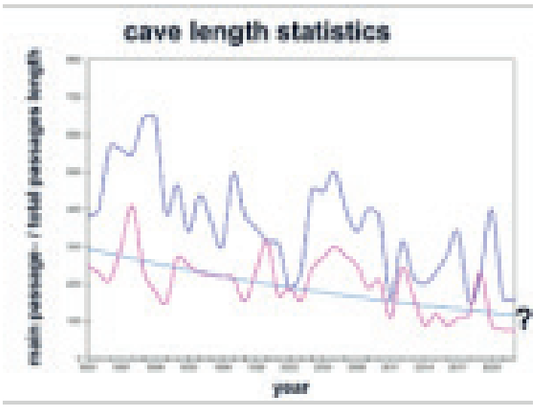

Figure 7: *Eiskapelle cave length statistics. Lower curve in pink: main passage lengths in m, upper curve in blue: total number of passages in m, light blue straight line: tendency of the main passage in the firn ice field. Graphics A. Wolf.*

Over the last 33 years, the cave system has been surveyed and documented annually in late autumn. As an example, see the situation of the main passage in 1994 (Fig. 11) and 2024 (Fig. 12).

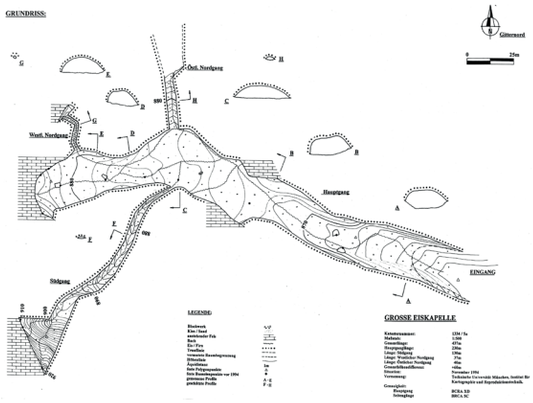

Figure 8: *Floor plan of the cave passages in 1994. Map A. Wolf.*

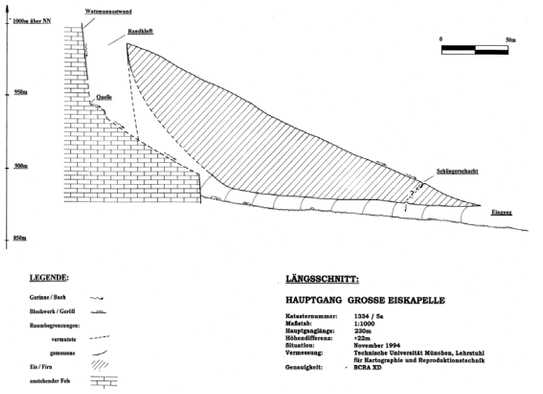

Figure 9: *Main passage west-east section in 1994. Drawing A. Wolf.*

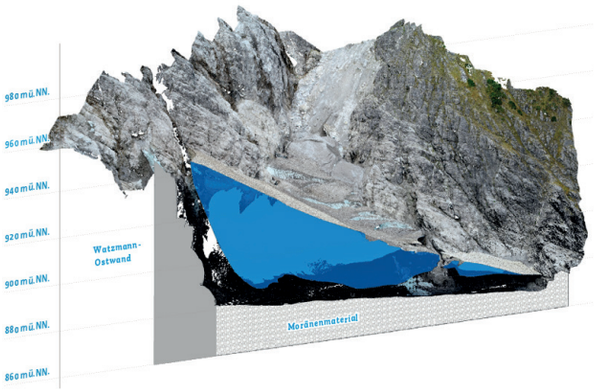

Figure 10: *Main passage west-east section with Watzmann east face in autumn 2022. Source: University of Applied Sciences Munich.*

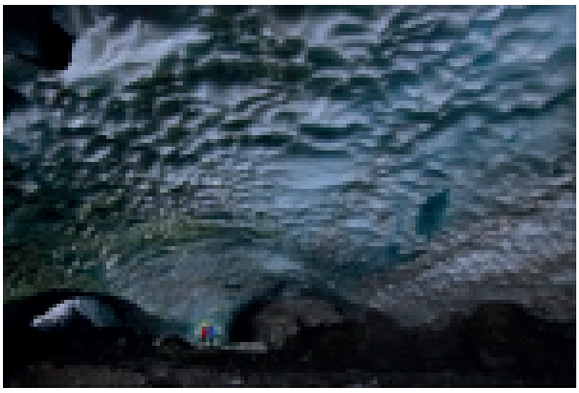

Figure 11: *Eiskapelle main passage in 1994. Photo A. Wolf.*

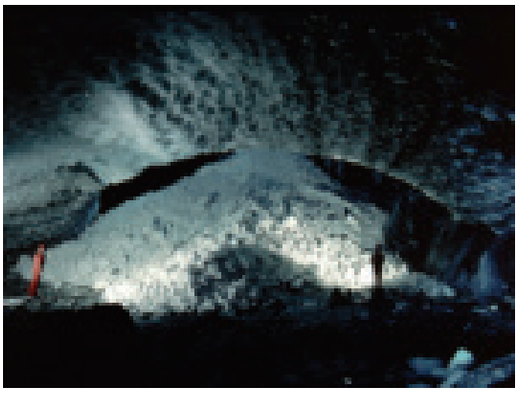

Figure 12: *Eiskapelle main passage in 2024. Photo G. Taffet.*

4. Methods of underground and surface surveying and their objectives

The underground cave system was mapped using a tape measure, compass and clinometer, which have been replaced by electronic measuring devices (Disto or similar) since 2000. The use of laser range finders on ice surfaces is only possible due to the organic material on them. The surface was surveyed using photogrammetric analogue cameras and theodolites, and since around 1985 with electronic total station equipment, which has been supplemented with mobile and terrestrial laser scanners and UAVs since 2007. Since 2020, the cave system has also been monitored with mobile laser scanners. The increasingly high-resolution measuring devices are currently used as practical tools for combined underground and surface monitoring

The objectives of long-term monitoring are the generation of detailed plans and 3D models for the creation of mass balances, long-term developments and forecasts, as well as the visualisation of changes.

Figure 13: *Terrestrial laser scanner in 2007. Photo A. Wolf.*

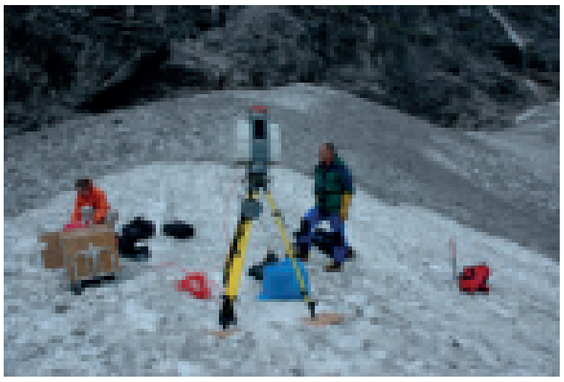

Figure 14: *Handheld scanner in 2022. Photo: A. Wolf.*

5. Results of the underground and surface surveys

From 1953 to 2024, 14 geodetic images of the firn ice areas are available, including annual data sets from 2017 to 2024. With the positive area increases due to the snowy winters between 1961 and 1973, as well as between 2017 and 2019, there was great hope of reaching ice levels like those of the 1980s again. While the area of firn ice in 2019 was again more than 37,800 m² compared to 2017 (12,000 m²), this number has fallen back to 18,900 m² by 2022. The analyses for 2023 and 2024 are not yet available, but visual comparisons show areas well below 15,000 m². An accelerating loss of space can therefore be observed. In correlation to the changes in area, there were increases in mass between 1961 and 1973, as well as 2017 and 2019. Since 1973 and after 2019, however, significantly increasing mass losses have been observed. In total, a mass loss of -750,000 m³ must be recognised between 1953 and 2022.

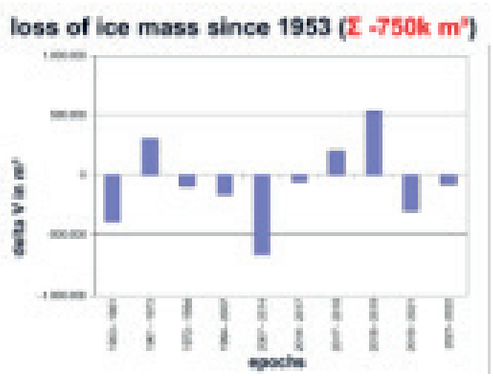

Figure 15: *Changes in the firn ice field between 2019 and 2022.*

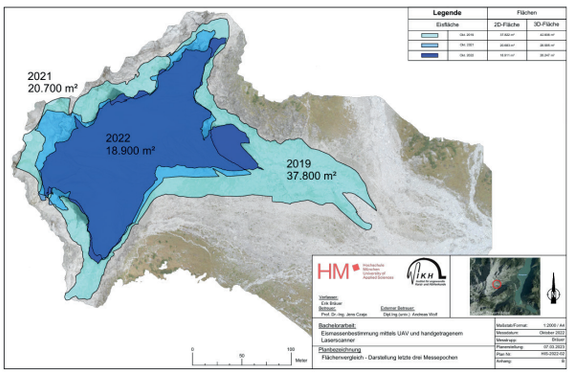

Figure 16: *Firn ice mass balance between 1953 and 2022.*

6. Conclusions

Does the Eiskapelle and its cave system have a future? Will the Eiskapelle survive in the long term despite climate change? Due to its special location, the Watzmann east face acts as a natural precipitation trap that will continue to provide avalanche snow as the basis of the firn ice field. The future will show to what extent the area will stabilise and a trend reversal can be seen. The existence, size and extent of the Eiskapelle is also dependent on the shift in the 0 °C limit. The findings of the geodetic underground and above-ground surveys by organised speleology are an important building block for knowledge and behaviour about the local climate. The measurements from 2023 and 2024 are currently being analysed, and there is great excitement about the extent and trend of changes in the Eiskapelle in these two years.

Monitoring will continue over the next few years and the results will be published.

Acknowledgements

We gratefully thank countless volunteers from speleological associations for measurement campaigns since 1991, Nationalpark Berchtesgaden, Hochschule für angewandte Wissenschaften München, Technische Universität München, Karlsruher Institut für Technologie and Bergwacht Bayern for all their support and constant commitment.

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