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Escola de Ciências

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Educational and Tourism Tools to Promote Geodiversity and Geoheritage in Show Caves: A Proposal for Grutas da Moeda, Portugal

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julho de 2025

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DECLARATION OF INTEGRITY:

I declare that I have acted with integrity in the preparation of this academic work and confirm that I have not resorted to the practice of plagiarism or any form of misuse or falsification of information or results in any of the stages leading to its elaboration.

I further declare that I know and have respected the Code of Ethical Conduct of the University of Minho.

ABSTRACT

An internship was carried out at the Grutas da Moeda showcave with the aim of developing educational and tourism proposals for the valorization of the cave's geodiversity and geoheritage. The 350-metre-long cave is located on the São Mamede Plateau, in Batalha, Central Portugal. It is a natural limestone cave discovered in 1971 and opened to the public in 1974. The São Mamede Plateau forms part of the Estremadura Limestone Massif (ELM), which is considered the most important limestone massif in Portugal due to its level of protection, paleontological value (notably its dinosaur track sites), size, thickness, well-developed karst landforms, high calcium carbonate content, and the tectonic uplift of the entire massif relative to surrounding areas. The ELM lies within the Serras de Aire e Candeeiros Natural Park (established in 1979), in the Lusitanian Basin. The extensive presence of limestone in the region has led to the formation of various karst features and subterranean structures, which are characteristic of the showcaves in the area. Despite the evident aesthetic, cultural, and ecological values associated with cave geodiversity, its scientific significance remains under-explored in the context of cave tourism and interpretation centres. Current tourism and educational offerings at Grutas da Moeda include guided tours, films, as well as rock and mineral exhibitions. The management aims to strengthen these initiatives by disseminating knowledge to the general public while providing memorable experiences for visitors. During the internship period, several educational programmes and materials were developed that integrated geology with other disciplines such as biology, chemistry, environmental science, history, and culture, thus offering a holistic educational experience. Likewise, a variety of engaging activities were created for visitors of all ages. These programmes were implemented within the cave and interpretive centre, offering interactive experiences designed to foster curiosity, promote critical thinking, enhance appreciation of the cave's natural environment, and inspire a love of learning. Feedback from tourists and students indicated that the activities successfully met their intended objectives. Additionally, a geotouristic itinerary was proposed for the surrounding region, incorporating sites of geological, paleontological, archaeological, and cultural interest related to limestone and karst landscapes.

Keywords: education, tourism, showcaves, geodiversity, geoheritage.

RESUMO

Um estágio foi realizado nas Grutas da Moeda, com o objetivo de desenvolver propostas educativas e turísticas para a valorização da geodiversidade e do património geológico das grutas. Esta gruta turística, com 350 metros de extensão, está localizada no Planalto de São Mamede, no concelho da Batalha, região Centro de Portugal. Trata-se de uma cavidade natural em calcário, descoberta em 1971 e aberta ao público desde 1974. O Planalto de São Mamede integra o Maciço Calcário Estremenho (MCE), considerado o mais importante maciço calcário de Portugal devido ao seu grau de proteção, valor paleontológico (nomeadamente pelos sítios com pegadas de dinossauros), dimensão, espessura, formas cársicas bem desenvolvidas, elevado teor de carbonato de cálcio e pelo levantamento tectónico de todo o maciço em relação às áreas envolventes. O MCE encontra-se inserido no Parque Natural das Serras de Aire e Candeeiros (criado em 1979), na Bacia Lusitânica. A grande ocorrência de calcários na região favoreceu a formação de diversos fenómenos de carsificação e estruturas subterrâneas, características das grutas turísticas. Apesar da evidente correlação entre os valores estéticos, culturais e ecológicos e a geodiversidade presente nas grutas, o valor científico da geodiversidade e do patrimônio geológico permanece subexplorado no contexto da visitação turística e dos centros interpretativos. As atividades turísticas e educativas atualmente oferecidas nas Grutas da Moeda incluem visitas guiadas, projeção de filmes e exposições de rochas e minerais. A gestão do espaço busca consolidar esses programas, disseminando conhecimento ao público em geral e, ao mesmo tempo, proporcionando experiências memoráveis aos visitantes. Durante o período do estágio, foram desenvolvidos diversos programas e materiais educativos que integraram a geologia com outras áreas do conhecimento, como biologia, química, ciências ambientais, história e cultura, proporcionando uma experiência educativa holística. Da mesma forma, foram criadas atividades interativas para visitantes de todas as idades. Esses programas foram aplicados na gruta e no centro interpretativo, oferecendo experiências interativas que visam fomentar a curiosidade, promover o pensamento crítico, estimular o gosto pela aprendizagem e aprofundar a compreensão do ambiente natural da gruta. As reações por parte de turistas e estudantes indicaram que os programas e atividades estavam a cumprir os objetivos propostos. Além disso, foi proposto um itinerário geoturistico na região envolvente à gruta, integrando locais de interesse geológico, paleontológico, arqueológico e cultural relacionados com os calcários e paisagens cársicas.

Palavras-chave: educação, turismo, grutas turísticas, geodiversidade, património geológico.

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Chapter 1: Introduction

1.1. Scope, objectives, and methodologies

Caves are environments characterized by significant heterogeneity in both geological and biological features, referred to as the geodiversity and biodiversity of the subterranean ecosystem. The biotic and abiotic characteristics of caves, along with their historical elements, are the foundations of their high scientific value (Sanna et al., 2023). Due to these exceptional characteristics, some caves are suitable for commercial use as show caves, while simultaneously serving as valuable tools for disseminating knowledge to the general public. In fact, caves—along with canyons and volcanoes—are among the most visited geodiversity features worldwide, with over 1,200 show caves attracting more than 70 million visitors annually (Chiarini et al., 2022).

Despite the evident connections between the aesthetic, cultural, and ecological values and the geodiversity found in caves, the scientific importance of geodiversity and geoheritage remains underexplored in the context of cave visitation and interpretive centres. The Grutas da Moeda, one of 17 show caves in Portugal (Brandão, 2009), has been open to visitors since 1974. In addition to offering a unique experience, its proximity (3 km) to the Sanctuary of Fátima has made it one of the most visited caves in the country. Education and sustainable tourism are two of the primary areas of focus within geoheritage and geoconservation studies (Newsome and Dowling, 2018).

Geoparks and other geotourism initiatives promote educational and tourism activities such as specialized educational programs, "children ambassadors" projects, environmental clubs, the use of local legends to explain geoheritage (and vice versa), child-friendly interpretive panels, comic books and videos, and hands-on training. These educational programs integrate geology with other disciplines—such as biology, chemistry, environmental science, history, and culture—thus offering a holistic educational experience. Similar initiatives could be studied and adapted for implementation at Grutas da Moeda, including in the cave, the interpretive centre, and the museum. These would provide a wide range of interactive activities enabling students and tourists to enjoy the natural environment, foster curiosity and a love of learning, promote critical thinking, and deepen their understanding of the cave ecosystem.

With the primary goal of developing educational and tourism programmes to enhance the geodiversity of Grutas da Moeda, an internship was conducted at the site from February to June 2025. These proposals were intended to focus on initiatives to be developed within the cave itself, as well as in the adjacent museum and interpretive centre. The specific objectives were: (1) to characterize geodiversity and geological heritage of the area based on bibliographical research; (2) to observe and characterize the impacts of visitation on geodiversity; and (3) to propose ideas and tools for promoting and increasing the appeal of the cave's geodiversity and geoheritage to specific educational and tourism audiences.

Accordingly, the main tasks and activities carried out during the internship included: bibliographic research on Grutas da Moeda, local geodiversity, and educational and tourism strategies; accompanying cave guides during school and tourist visits; implementing visitor surveys focused on geodiversity promotion tools;

assessing the effcets of visitation on the cave's geodiversity; and researching, developing, and testing educational and tourism tools and ideas for geodiversity promotion.

1.2. Study Area

1.2.1. Overview of the Grutas da Moeda Cave and Geology of the Area

Located in the scenic São Mamede Plateau (39°37'26.83" N; 8°42'18.49" W), Batalha, Central Portugal (figure 1), Grutas da Moeda is a natural limestone caves, discovered in 1971.

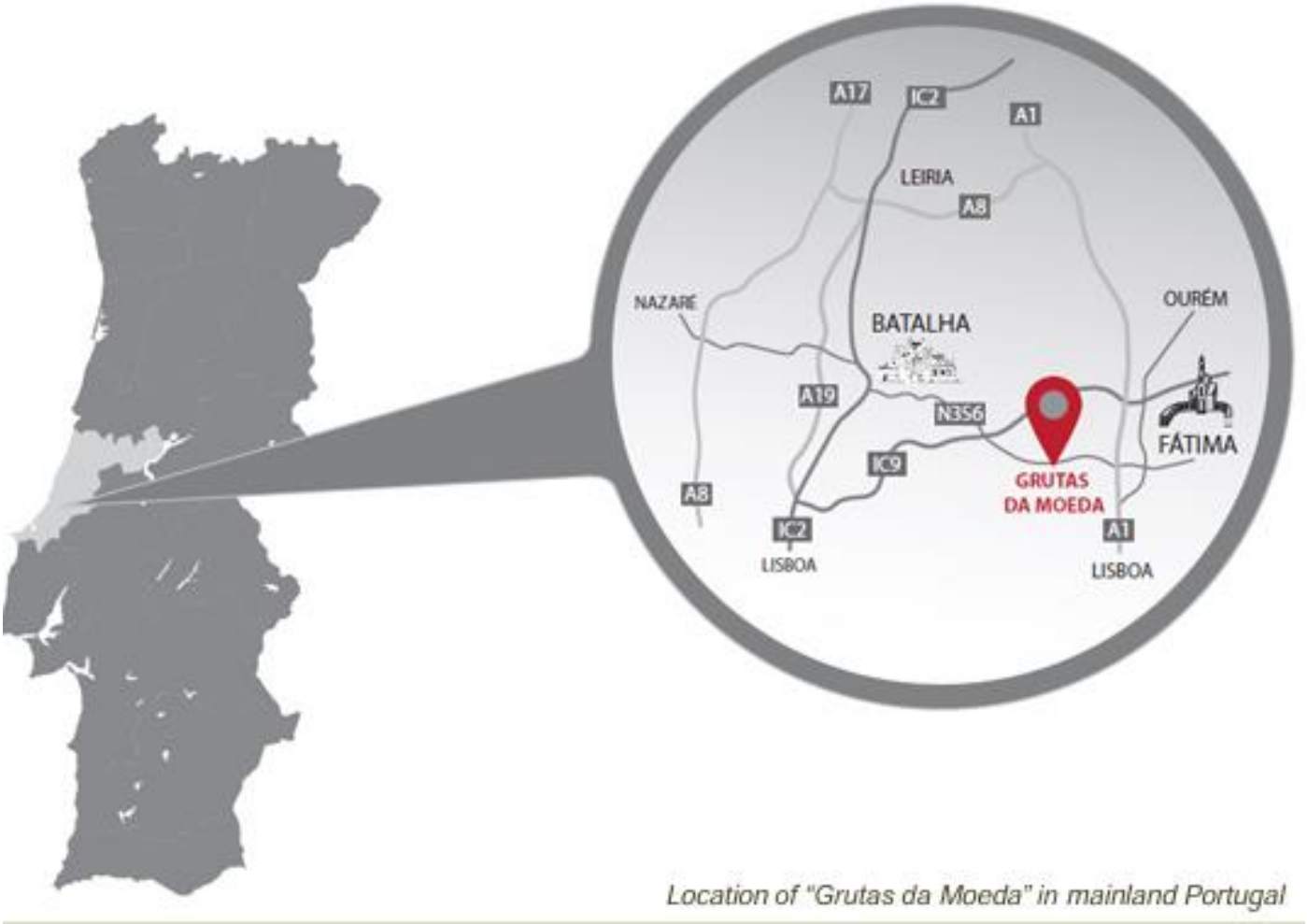


Figure 1. Location map of Grutas da Moeda in Mainland Portugal. It is 3km away from the Sanctuary of Our Lady of Fatima, a popular Catholic site and tourist destination in Portugal. *Image credit: Grutas da Moeda.*

The cave is 350-metre-long, and has twelve galleries (figure 2) with distinct characteristics that afford visitors the opportunity to learn while they explore the cave.

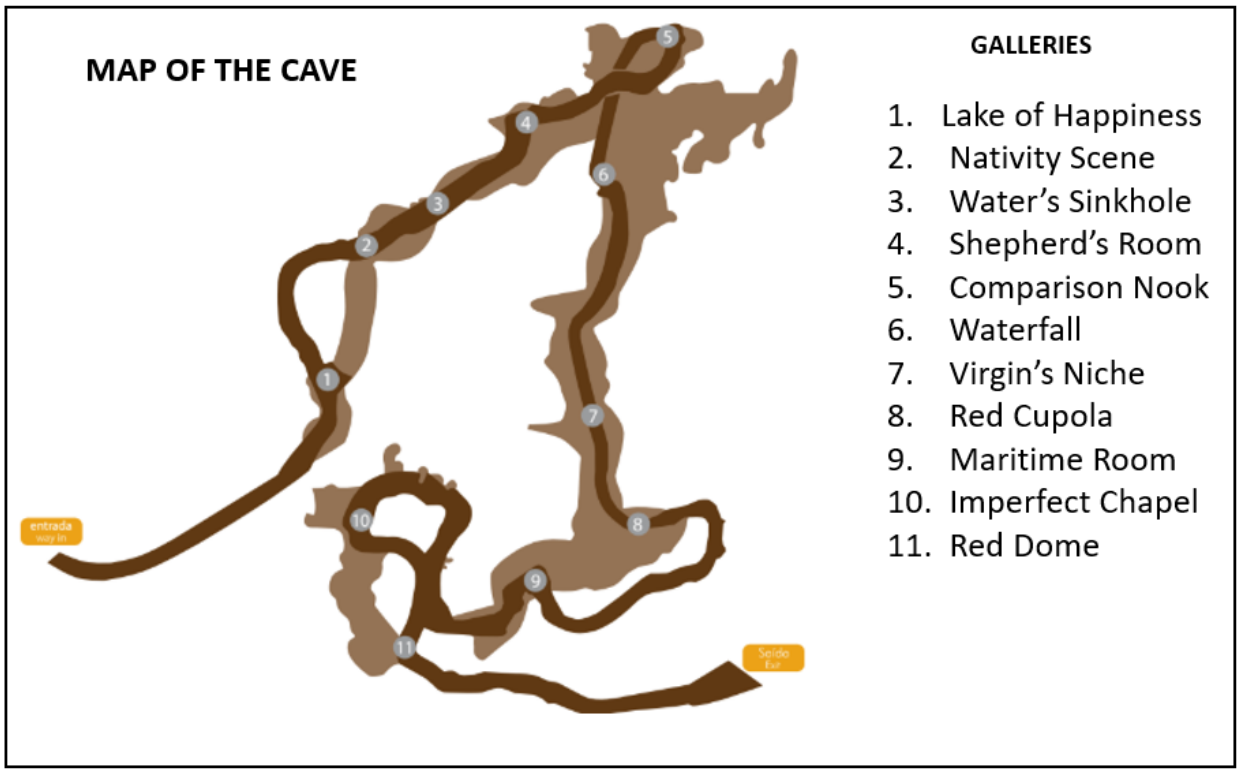


Figure 2. Map of the cave. The names of the galleries are mostly a representation and not all geological. Eleven of the 12 galleries are captured on the map. (After Grutas da Moeda, 2025).

The cave has an average temperature of eighteen degrees Celsius (18^{0}C), and a maximum depth of 45 metres below the entrance. From the entrance to the deepest part of the cave (waterfall), it takes 109 steps, and 66 steps to step up again. Hence, there are a total of 175 steps in the cave.

It is one of the few caves in Portugal with audio-guided self-tours in different languages (English, Portuguese, Spanish, French, and German) designed to cater for diverse categories of visitors and to allow for visitors to explore the cave at their own pace.

Besides the caves, there is a demonstration area, garden, and an interpretation centre (Scientific-Environmental Interpretation Centre, locally known as Centro de Interpretacao Cientifico-Ambiental. The interpretation centre houses panels, models, microscopes, specimens, as well as minerals, rocks and fossil collections from all over the world (figure 3). It also has a movie room with video collections for all categories of students' and tourists, all highlighting the processes behind the formation of the caves and other educational materials in audio-visual formats. Grutas da Moeda is a well-structured centre as it also has gift shops with lots of regional products, café/coffee shop, picnic centre, spacious parking lots, and toilet facilities.

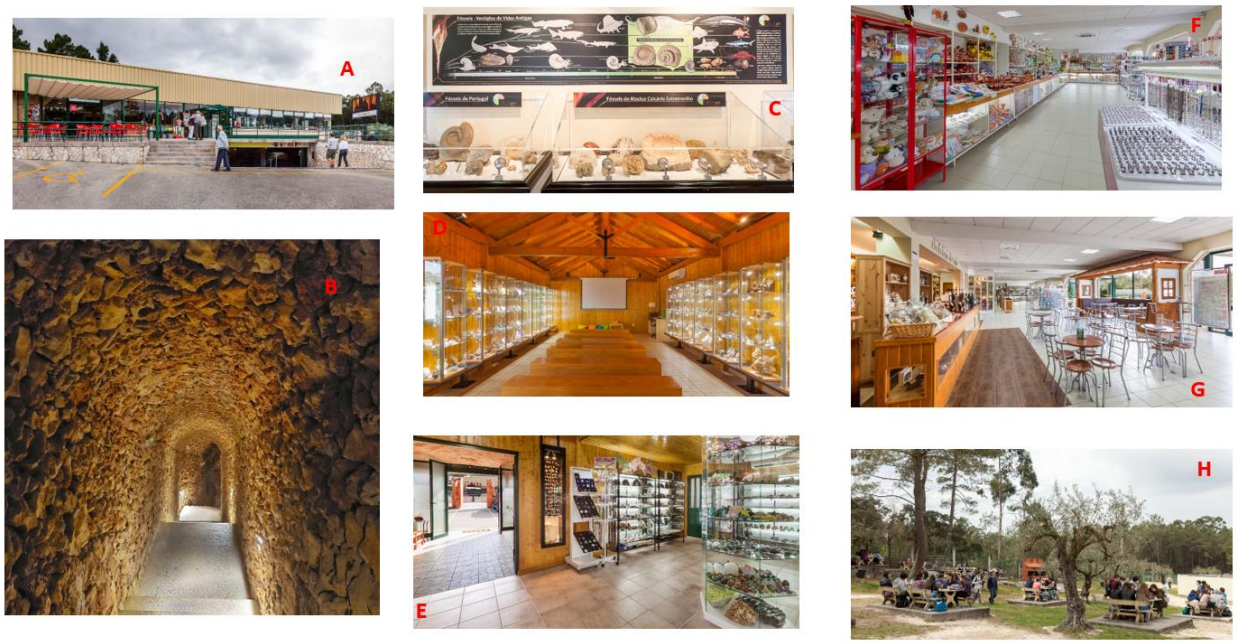


Figure 3. Different sections of the cave centre. (A) outside the cave premises, (B) cave's entrance, (C) interpretation centre with fossils and rock samples, (D) movie room which also double as mineral display room, (E) mineral and rock model gift shop, (F) gift shop with local products, (G) café/coffee shop, (H) picnic area. *Image credit: Grutas da Moeda.*

1.2.2. Estremadura Limestone Massif

The karst areas of Portugal occupy a sizeable part of the country's territory with over 2,000 known caves (Reboleira et. al. 2013). The carbonate rocks in Portugal are known to support important karstlands, which include ten protected areas of different status (Crispim, 2005). Under the national framework of geological heritage, the Portuguese geological community recognizes karst systems as one of the fourteen methodologies for defining geological heritage of international relevance (Brilha et. al. 2005). Over fourteen karst units (figure 4) are known from Portugal, with Jurassic limestones and dolomites being the most relevant (Reboleira et. al. 2013; Reboleira et al. 2011). Amongst the fourteen limestone massifs, the Estremadura Limestone Massif (ELM) stands out because of its level of protection, paleontological value (dinosaur track sites), size, thickness, well developed karst landforms, high content of calcium carbonate and tectonic uplift of the whole limestone massif with respect to the surrounding areas (Rodrigues, 2020). The ELM lies within the Serras de Aire and Candeeiros Natural Park (created in 1979), in the Lusitanian Basin and it is considered to have the best representation of karst landscape in Portugal (Rodrigues, 2020; Martins, 2013; Rodrigues and Fonseca 2010; Azerêdo and Crispim 1999). The ELM is akin to a large block that is somewhat folded and uplifted as a result of large fault systems (Azerêdo 2017; Reis et al. 2023).

The Massif is shaped by the two Plateaus; São Mamede and the Plateau of Santo António, as well as two mountains; Aire Mountain and the Candeeiros Mountain.

Figure 4. The Main karst units of Portugal and a model of the Estremadura Limestone Massif; (1) Dine and Vimioso; (2) Outil-Cantanhede; (3) Mealhada; (4) Sicó; (5) Estremenho/Estremadura; (6) Cesaredas; (7) Montejunto; (8) Lisbon Peninsula; (9) Arrábida; (10) Estremoz-Cano; (11) Adiça-Ficalho; (12) Algarve. *(After Reboleira et. al., 2013).*

The major geomorphology or landforms produced has been described by Rodrigues (2020) on the basis of their sizes and they include large karst landforms such as poljes, uvalas, and amphitheatre head valleys, medium karst landforms such as dolines, dry valleys, and karst springs, while karren features/swallow holes were the small karst landforms represented.

The huge occurrence of limestone in the region led to the formation of various karstification phenomena and subterranean structures which are characteristics of the five major showcaves in the area, including Grutas da Moeda, Santo António, Mira de Aire, Algar do Pena, and Alvados caves. There are also numerous unexplored/undeveloped caves as seen at Lapa da Cerejeira (39.52922N; -8.7371W) in Santo António (figure 5) which has been overgrown by trees and a man-made entrance constructed by the owner close to the base for cattle herding.

Figure 5. The entrance and inside of the undeveloped cave at Santo Antonio.

The ELM can be described as a rock unit that 'rocks' the entire Municipality of Batalha. There is a strong connection between the limestone and the development of the area. It cuts across so many aspects of its history, culture, gastronomy, leisure, sports, natural parks, and heritage. It is expressed in quarries, buildings, monasteries, vegetation, topography, windmills, millstones, ceramics, tiles, lacy walls, Portuguese-styled pavements, water harvesting systems, drystone walls, sculpture, arts, gift items, and tourism.

1.2.3. Lapias/Karren Fields

Lapias/karren fields are unique landscape in Sao Mamede and its environs. Lapias are remains of limestone strata that have been dissolved by carbonic acid. They are millimeter to centimeter thick grooves, which furrow the surface of rocks, and the areas covered by lapies are called lapiás fields or karren fields (Jennings, 1971; Böegli, 1980). Figure 6 shows the limestone pavements in the forested area above the cave where the main sinkhole that led to its discovery is situated. As shown, it is now closed for security reasons.

Figure 6. Characteristic limestone pavements on the surface above the cave. The area marked with a white square indicate the sinkhole through which the cave was discovered in 1971.

Figure 7 is a Karren Field in the Natural Park of the Aire and Candeeiros Mountain ranges. It gives a better view of the karst landscape created as a result of the dissolution of the limestones.

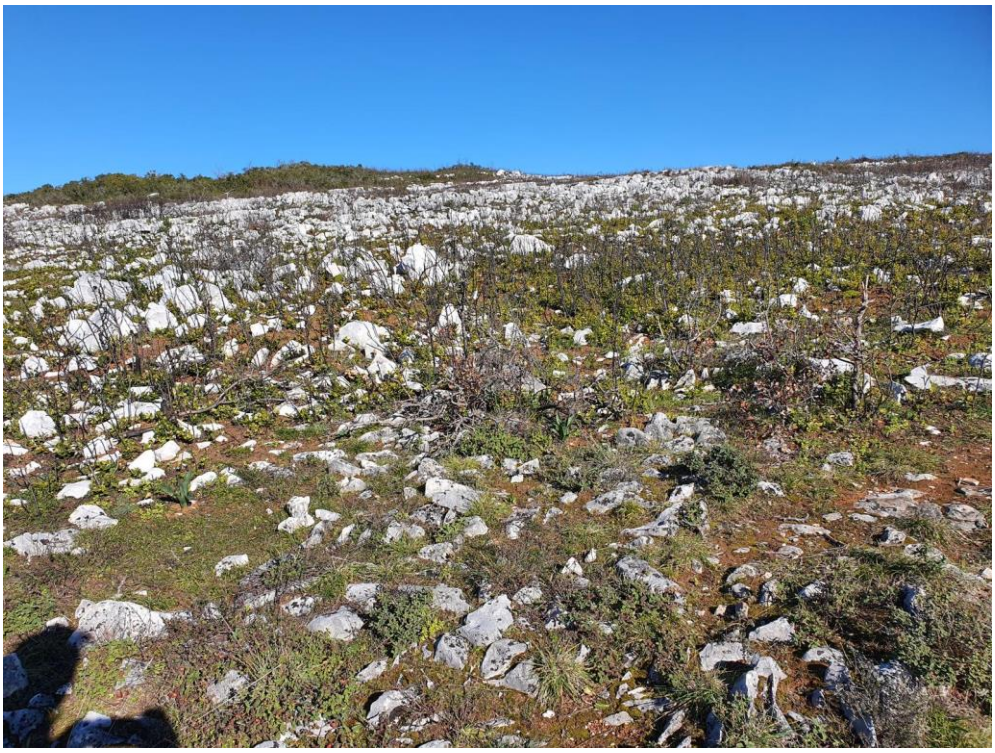


Figure 7. karren fields in the Serras de Aire and Candeeiros Natural Park Portugal. Karren fields at the vast landscape created a result of dissolution of limestone.

Inside the Coin caves, the limestone displays continuous layers or strata that are generally horizontal, but also inclined in places, with hematite-rich reddish clayey residual soil, *terra rossa* in-between the bedding planes (figure 8). The plane beddings can be used to infer undisturbed sedimentary sequences and also used to explain the principle of superposition to students and other tourists.

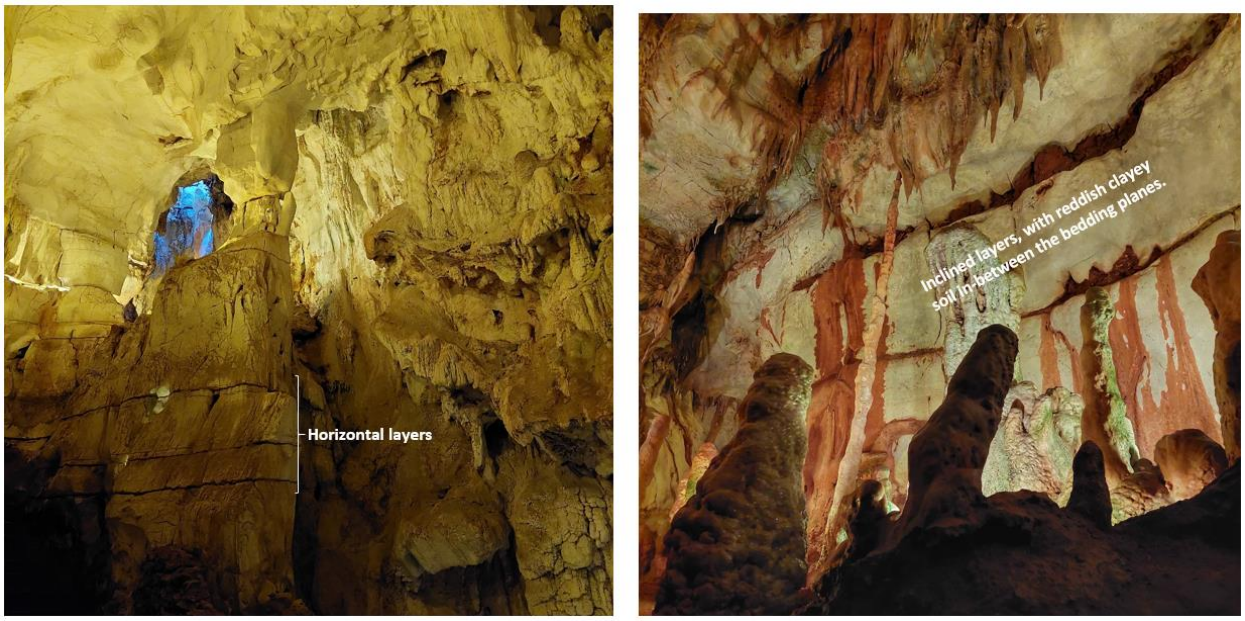


Figure 8. Horizontally layered and inclined limestone beds in the cave. This gallery is best used to explain the principle of superposition to students and tourists. *(Modified after Grutas da Moeda).*

1.2.4. Fórnea Amphitheatre Head Valley

Considered as one of the most well preserved amphitheatre-shaped depression in Europe, the Fórnea de Alvados amphitheatre head valley (figure 9) located in the Serras de Aire and Candeeiros Natural Park, is a magnificent fornea carved by headward erosion by rain and spring waters in the mountain range (Rodrigues, 1991). The Fornea is 250 metres high and about one kilometer in diameter. At the top of the fornea are hard, but permeable limestone slabs and less hard marly limestones at the base of the valley. The Fornea contains valuable remnants of relict slope deposits from Quaternary cold periods (Rodrigues, 2020).

Figure 9. Fornea amphitheatre in the Candeeiros Mountain range, Central-West Portugal.

The rich and diversified landscape of the ELM is characterized by great diversity of flora species that are supported by the soils produced by limestones. The major plant species are the butcher's broom (*Ruscus aculeatus*), wild olive tree (*Olea europaea subsp. europaea var. sylvestris*), cork oak (*Quercus suber*), kermes oak (*Quercus coccifera*), Portuguese oak (*Quercus faginea*), and the holm oak (*Quercus rotundifolia*). The smaller species of plants include several variety of orchids (*Orchidaceae*), fennel (*Foeniculum vulgare*), rosemary (*Rosmarinus officinalis*), the herbal plant 'origanum' (*origanum vulgare),* rosa-albardeira (*paeonia broteri*) with their rose-pink fragrant flowers, Laurestine (*Viburnum tinus*), with their colourful berries, thyme (*thymus vulgaris*), French lavender (*Lavandula stoechas*), hawthorn (*Crataegus*), fig tree (*Ficus carica*), and strawberry tree (*Arbutus unedo*) that grow in fractures within the limestone (figure 10).

Figure 10. Some low-lying plant species in the Serras de Aire and Candeeiros Natural Park

1.2.5. Traditional Drystone Walls

The peculiar nature of the environment in Sao Mamede has led the inhabitants to create innovative ways to adapt to the environment. The dry stone walls (figure 11) which are structures made from the abundant limestone in the area is one of such cultural heritage in area.

Figure 11. Dry stack stone walls in Sao Mamede. They serve various purposes such as fences, land demarcation, shelter or cows and for erosion control along the slope.

The structures serve many purposes such as fences, shelters for cows and sheep, property demarcations, as well as the prevention of topsoil from erosion along the slopes.

1.2.6. Cave Water Analysis

As a result of the high rate of water infiltration in the limestone area and dryness in the summer months, water availability and quality used to be a major issue in some rural areas in Portugal (Carlon, 2005; Oliveira et al (n.d)). This is evident in many of the old houses that are built with rain water harvesting and storage systems (figure 12).

Figure 12. Rainwater harvesting system from different houses in Sao Mamede. The rainwater is collected from the roof and channeled to the storage system where the water is collected manually with rope ad bucket.

The system involves capturing rainwater from the roof, and channeling it to the storage systems. However, there is now public water supply system, and equipment available to drill as much as 150-200 metres to reach water. It was on the basis that the cave water analysis was carried out as part of the educational

activities to demonstrate the water quality lessons that the students must have taken in their chemistry classes.

Inside the cave, the waters in parts of the lakes are isolated and controlled such that they do not totally infiltrate and cause the lakes to dry out. This is the case with the 'waterfall', the deepest part (45m) of the cave (figure 13).

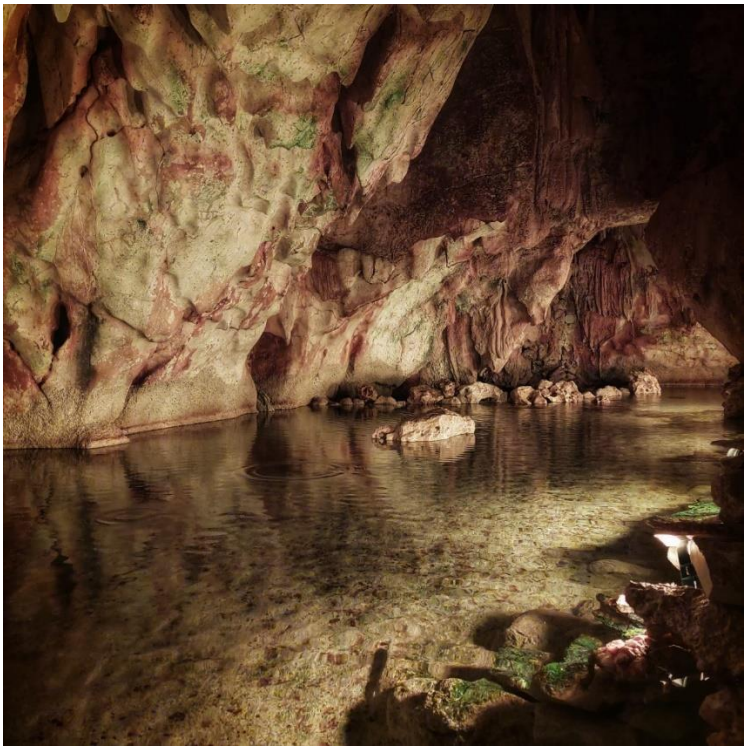


Figure 13. Cemented floor and rocks placed in the direction of flow to serve as barriers to control the rate of flow and infiltration of water. *Image credit: Grutas da Moeda.*

As part of the research, water dripping directly from the rock formations were collected and tested for pH to measure the acidity and base quality of the water, as well as for temperature; which is a major factor in the physicochemical properties, and hence the quality of water. The water samples were collected in plastic cups, and tested in-situ with the easy-to-use and waterproof handheld ''HANNA COMBO'' pH/temperature/conductivity tester. The tests were conducted for 30 days (11th April to 10th May, 2025). This activity was also used to teach students on how to carry out data interpretation.

The result (figure 14) showed a temperature range from 17-19.6^{0}C. The lowest was recorded on 18th, 21st to 23rd, 28th and 30th April, as well as 5th and 8th May. The highest value was measured on 11th April. The pH ranges from 7.04 to 7.73, indicating that the water is neutral to slightly alkaline. The highest pH value was recorded on April 14, while the lowest was on April 16. The pH values fall within the World Health Organization (WHO) standard of 6.5 - 8.5 for drinking water. This activity was used to teach the secondary school students some aspects of water quality analysis, as well as data collection and interpretation.

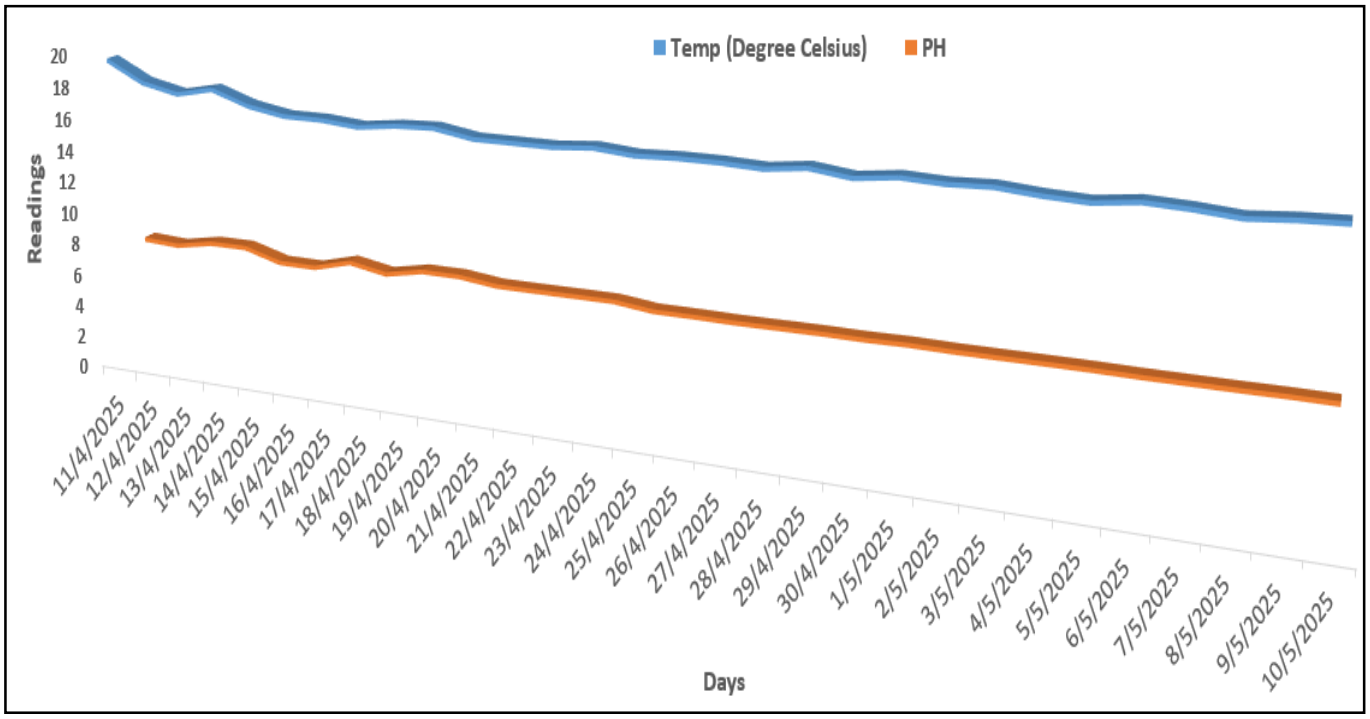


Figure 14. Graph of temperature and pH values of water recorded in the cave from April 11 to May 10, 2025. The temperature vales range from 17-19.6^{o}C. The lowest was recorded on 18th, 21st to 23rd, 28th and 30th April, as well as 5th and 8th May. The highest value was measured on 11th April. On the otherhand, the pH ranges from 7.04 to 7.73, indicating that the water is neutral to slightly alkaline, and falls within the World Health Organization (WHO) standard of 6.5 - 8.5 for drinking water.

The pH of water is a crucial indicator of both the biological and chemical processes, and hence a measure of water quality.

It is important to note that the ambient temperatures in the cave were also recorded and ranges from 18 - 20.60^{o}C. It should also be noted that a comprehensive water quality assessment should involve the measurement of other parameters such as electrical conductivity, total dissolved solids, total suspended solids, hardness, turbidity, heavy metal analyses, as well as fungi and coliform counts. These were outside the scope of this research.

Chapter 2: Materials and Activities

2.1. Educational Materials

From February 2025 to May 2025, a total of 7,925 school children visited the cave. This was an average of 66 school children per day (figure 15).

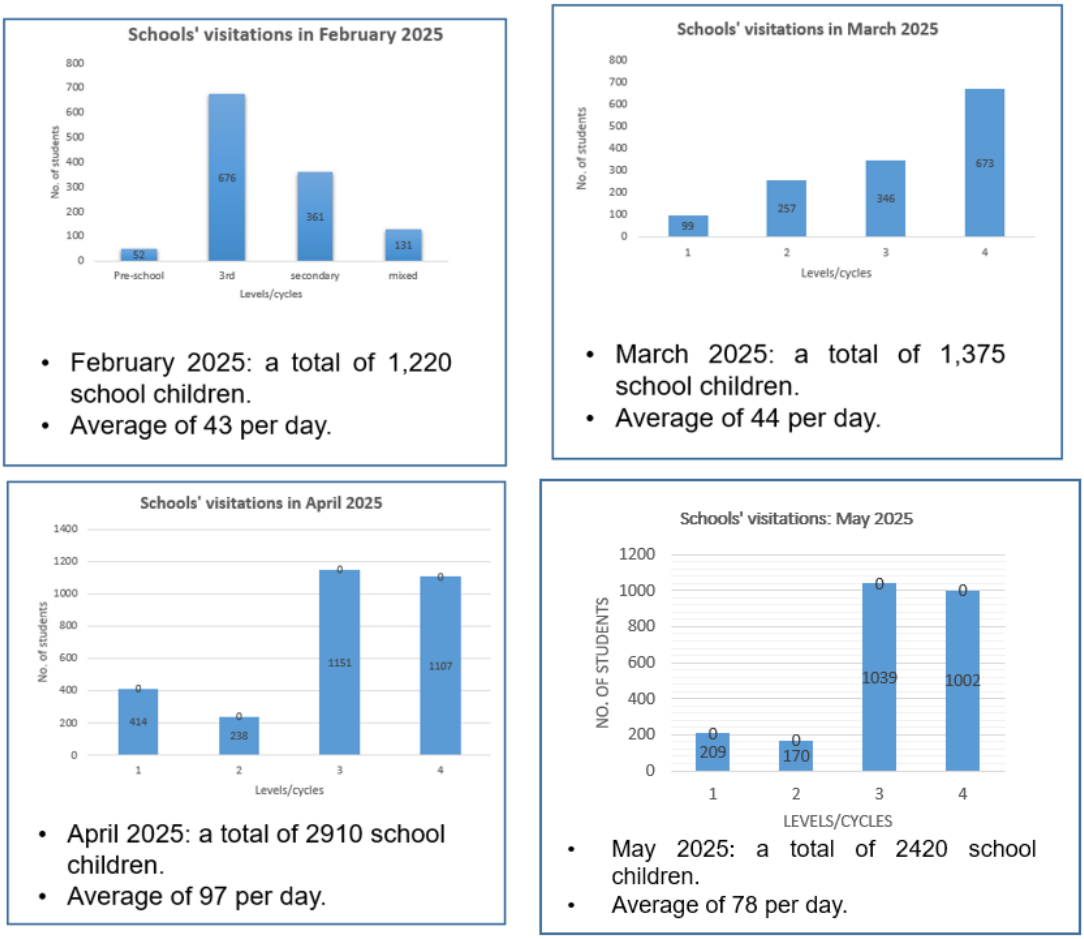


Figure 15. Schools' visitations from February to May 2025. A total of 7,925 school children visited the cave within his period.

The month of April was the highlight, as the number was more than February and March combined. Why were the teachers bringing their pupils and students? This was due to the fact that the cave has put some educational materials (figure 16) and activities adapted to the different levels of the students (1st cycle:6-10 years; 2nd cycle: 11-12 years; 3rd cycle: 3-15 years, secondary education: 15-18 years) and curricula of the schools.

The materials contain introductory sections that explain cave formation processes, the history of Grutas da Moeda, and the limestone formations in the region. The other sections contain exercises, quizzes, games and puzzles that are both didactic and entertaining. After touring the caves, the museum, the mineral section, fossil room, and watching the audiovisuals in the movie room, students are expected to attempt these tasks. Each student gets a copy of the educational materials which they take back to their respective schools and continue learning under the guidance of their teachers.

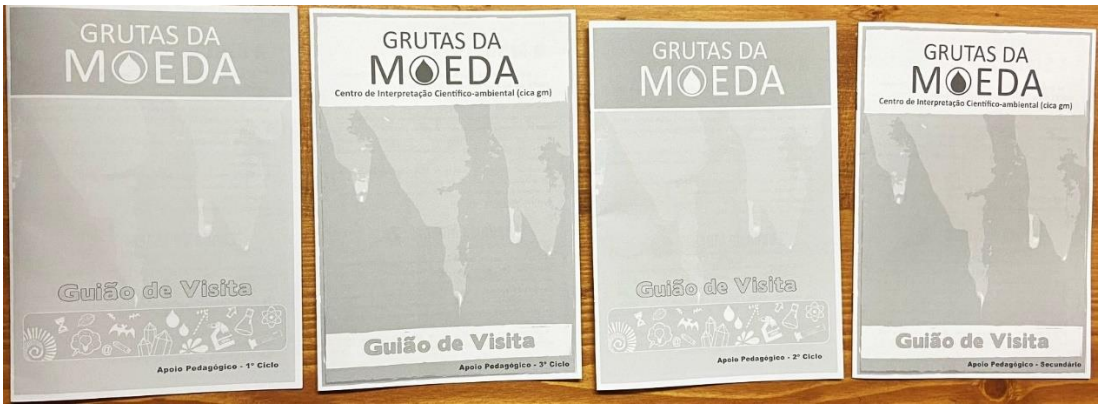


Figure 16. Educational materials developed by the Grutas da Moeda Team for different age groups, containing history of the cave, limestone formation processes, as well as quizzes and fun activities.

A glossary (Coin Cave Glossary) (Appendix A) was developed by the researcher. It contains some words related to limestones, caves, the Estremadura Limestone Massif, the Batalha Municipality, and speleotourism. It is meant to serve as a handy booklet that would be useful for the other activities as well as for tourists, teachers and students who wish to know more about caves, tourism and the geology of the locality. The glossary was written a simplified language in order to be understood by young students and non-geologists.

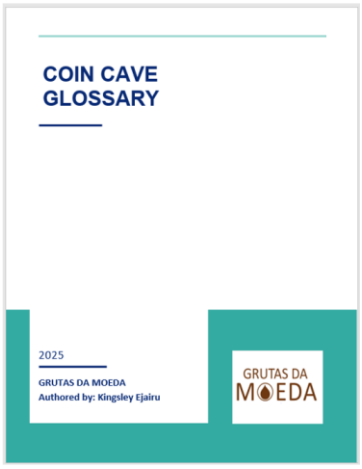


Figure 17. Cover page of the coin cave glossary developed by the researcher

2.2. Activities Based on Visits to the Cave and Interpretation Centre

2.2.1. Speleomath

The activity was designed by the researcher for the 3rd grade and secondary school students. The aim of the speleomath was to make students think in 'geological time' and understand that cave formation processes do not occur within human life span. It was intended to also help students test their critical thinking, problem-solving, and mathematical skills. The tallest stalagmite (2.2 metres) in the cave which has been shown to students while touring the cave was used as reference for this activity. An example of exercise that can be

given to students after the tour of the cave is shown in figure 18. If the average growth rate of stalagmite is taken as 1cm per 100 years, and the tallest stalagmite is 2.2 metres tall, what is the age of the stalagmite?

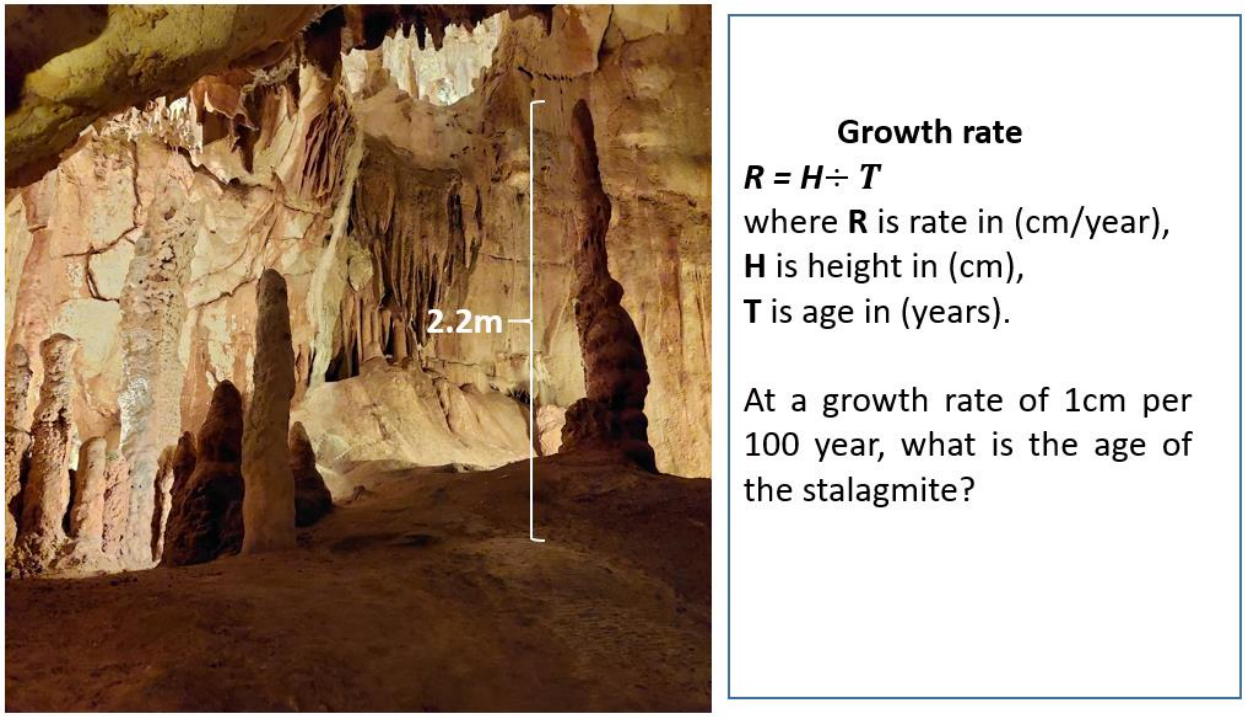


Figure 18. Tallest stalagmite (left) measuring 2.2 metre in the cave, used for the speleomath problem-solving activity.

Students were guided to develop the mathematical formula;

R = H/T; where R is rate, expressed in (cm/year); H is height in (cm), and T is age in (years).

In this case, the missing variable was T. Thus, it would test the students' ability to think and make 'T' subject of the formula (T = H $/R$).

The correct answer to this exercise is 22,000 (twenty-two thousand) years. Students should only be told after making attempts.

The instructor can change the numbers and the missing variables so that the students can solve the problem in different perspectives.

2.2.2. The Limestone Fizz/ Effervescent Reaction

The limestone fizz activity was created by the Grutas da Moeda Team for the 2nd and 3rd cycles, as well as secondary school students.

Objectives: To test for limestone, demonstrate the limestone dissolution reaction, and cave formation processes (figure 19).

Materials: limestone, crushed limestone, and lemon juice (acting as the acid). Lemon juice contains citric acid, and it is used here in place of hydrochloric acid because it is easy to get and can be used with children.

Figure 19. The limestone fizz experiment being demonstrated to secondary school students. Whole rock limestone, crushed limestone, and lemon juice were used for this experiment. The crushed limestone reacted faster because of the exposed surfaces. The fizz experiment is a quick test for limestone on the field. ***The faces of the students have been blurred for the purpose of privacy.***

Methodology: Haven visited the caves and taken through the processes of cave formation, the students are asked if they remembered the characteristic the water has to have in order to dissolve limestones and create caves. Students are reminded that it is the acidity, which arise when water reacts with atmospheric carbon dioxide to create carbonic acid. For the 3rd and secondary school students, the chemical equation can be written out;

$H_2O + CO_2 \rightleftharpoons H_2CO_3$.

Where: (H_2O = water; CO_2 = carbondioxide; H_2CO_3 = carbonic acid)

The next step involves adding a few drops of the lemon juice to the limestone block, and asking students what they can observe. Why is the fizz not much? At this stage, students are reminded that cave formation processes are slow and do not occur within human life span, but in geological time which are expressed in thousands and millions of years. At this stage, students are told that the process can be speed up if the limestone block is broken down. In the limestone block, it takes time for the bonds to be broken down. The

instructor can make an analogy to cooking of potatoes, and explain that when the whole potato is cut into smaller pieces, it cooks faster. The lemon juice is dropped into the crushed limestone and the fizzing rate is observed and compared with the first one. Student are made to understand that the more the surface area exposed to the acid, the faster the process. Students can then relate the importance of fractures and cavities to the rate of dissolution and cave formation processes. The chemical equation is stated in the case of 3rd and cycle and secondary school students.

$CaCO_3$ (limestone) + H_2CO_3 (carbonic acid) $\rightarrow$ $Ca(HCO_3)_2$ (calcium bicarbonate).

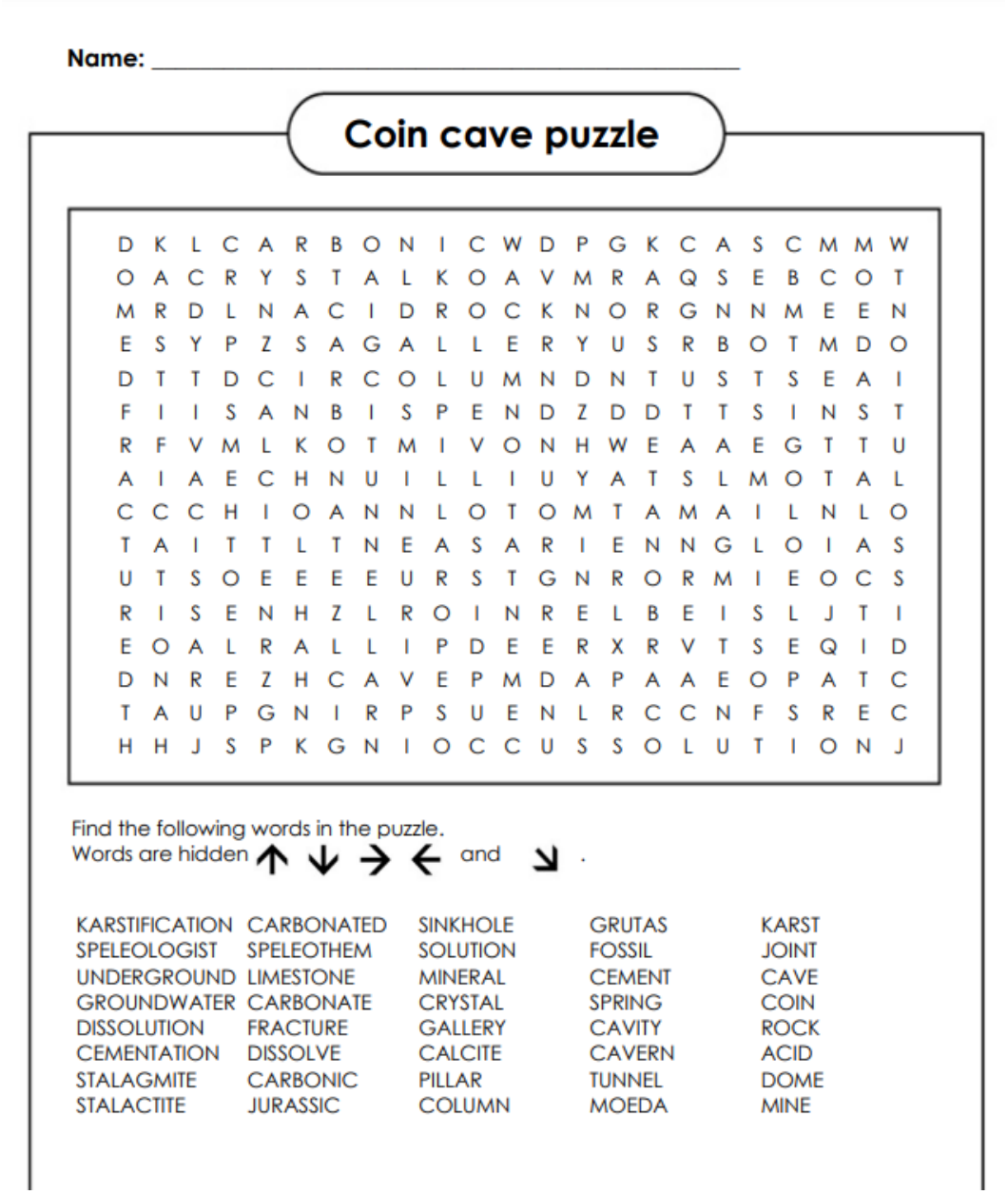
2.2.3. Preschool Activities

These activities were also designed for preschool children by the Grutas da Moeda Team. These included a movie explaining the formation of the cave with animations, as well as introduction to the basics of rocks, minerals and fossils (figure 20).

Figure 20. Pupils from Preschool, aged 5 years being introduced to rocks, minerals, fossils, and animated movies related to cave formation processes. Activities designed by Grutas da Moeda Team. ***Faces of the children in the first image have been blurred for the purpose of privacy.***

2.2.4. Coin Cave Puzzle

The coin cave puzzle (figure 21) was created by the researcher for the 3rd cycle and secondary school students. It was aimed at introducing participants to the unique vocabulary associated with caves and karst systems. Also incorporated were biological and geological terms, as well as cultural references. The puzzle contained forty words that are related to caves. Before searching for each word, students are encouraged to first of all check the meaning of the words in the coin cave glossary provided. The words can search vertically, horizontally, diagonally, and backwards.



Name: _____

Coin cave puzzle

D K L C A R B O N I C W D P G K C A S C M M W
O A C R Y S T A L K O A V M R A Q S E B C O T
M R D L N A C I D R O C K N O R G N N M E E N
E S Y P Z S A G A L L E R Y U S R B O T M D O
D T T D C I R C O L U M N D N T U S T S E A I
F I I S A N B I S P E N D Z D D T T S I N S T
R F V M L K O T M I V O N H W E A A E G T T U
A I A E C H N U I L L I U Y A T S L M O T A L
C C C H I O A N N L O T O M T A M A I L N L O
T A I T T L T N E A S A R I E N N G L O I A S
U T S O E E E E U R S T G N R O R M I E O C S
R I S E N H Z L R O I N R E L B E I S L J T I
E O A L R A L L I P D E E R X R V T S E Q I D
D N R E Z H C A V E P M D A P A A E O P A T C
T A U P G N I R P S U E N L R C C N F S R E C
H H J S P K G N I O C C C U S S O L U T I O N J

Find the following words in the puzzle.
Words are hidden ↑ ↓ → ← and ↘ .

KARSTIFICATION	CARBONATED	SINKHOLE	GRUTAS	KARST
SPELEOLOGIST	SPELEOTHEM	SOLUTION	FOSSIL	JOINT
UNDERGROUND	LIMESTONE	MINERAL	CEMENT	CAVE
GROUNDWATER	CARBONATE	CRYSTAL	SPRING	COIN
DISSOLUTION	FRACTURE	GALLERY	CAVITY	ROCK
CEMENTATION	DISSOLVE	CALCITE	CAVERN	ACID
STALAGMITE	CARBONIC	PILLAR	TUNNEL	DOME
STALACTITE	JURASSIC	COLUMN	MOEDA	MINE

Figure 21. Coin cave puzzle, with words pertaining to caves.

2.2.5. Grain Size Analysis Activity

The activity was designed by the researcher for the secondary school students using different sizes of limestones (figure 22). The principle and the importance of the experiment was told to students. First aspect was to explain the concept of ''sorting'' as a measure of the variation in grain sizes present in the rock, and how it reflects the process of transportation and deposition of sediments. In addition, students are told how to differentiate well sorted, moderately sorted and poorly sorted grains, depending on when the sizes of the grain are uniform, slight difference in the grain sizes, and much differences in the sizes of the grains respectively.

Figure 22. Grain size analysis used to demonstrate sorting, transportation and provenance.

The colour and structures were used to explain the history of the rocks and used to infer their depositional environments. The dark-coloured grains were interpreted to contain more organic matter compared to the light-coloured grains. The shapes of the grains were used to tell their geologic history in terms of the distance of transportation from their source areas to their environments of deposition. Coarse grains were interpreted as being transported over a short distance, while rounded grains were interpreted to have undergone long distance of transportation. Also, the sizes of the grains were used to explain the amount of water needed to transport them, with small grains requiring lesser amount of water compared to larger grains.

The uses of limestone in construction, making of road pavement, walkways, sculpture, correcting the pH of soil were also discussed.

The process of quarrying was explained to students and the strategic position of the ELM in relation to the location of several quarries in the Sao Mamede-Batalha region. The environmental impacts of quarrying of limestones such as land degradation, noise pollution from machinery, air pollution resulting from dust, breeding of insects, and flooding of abandoned limestone mines were all talked about during the activity.

The concept of sustainability in mining was introduced to students and they were encouraged to suggest ways it could be better achieved.

Due to the various applications of this activity, a set of sieves and a digital weighing balance were proposed so that students can have the privilege of carrying out the sieving analysis themselves and better appreciate the activity.

2.2.6. Microscope and Magnifier Activities

The activity was designed by the cave for students of all age groups. The aim was to offer students an opportunity to see the limestone rocks in another perspective. The activity was a follow-up to the previous ones that had introduced students to rocks. As shown in figure 23 below, this activity sparked up the curiosity in the preschool and 1st grade students. It was also an engaging activity for the secondary school students.

Figure 23. Secondary Students (A) introduced to microscopic observation of limestone. Preschool kids and 1st grade students (B) introduced to observation of limestone with an electric binocular magnifier. *Image credit: Grutas da Moeda.*

For the secondary school students, they are encouraged to make a sketch of the cement and fossil fragments they can observe on the field of view and compare with the chart that had been provided for this activity.

2.2.7. Exploring Cave's Biodiversity: From Bats to Bacteria

2.2.7.1. Lamp Flora and Photosynthesis

The lamp flora photosynthesis activity was created by the researcher. Lamp flora were found inside the caves, and restricted to the areas where the lighting bulbs have been placed within the caves. Since the cave is a closed system, it can be inferred that the growth of the lapmflora was induced by the artificial lights from the bulbs. As shown in figure 24 below, the left part of the stalagmite receiving light had turned green compared to the right part which received less light.

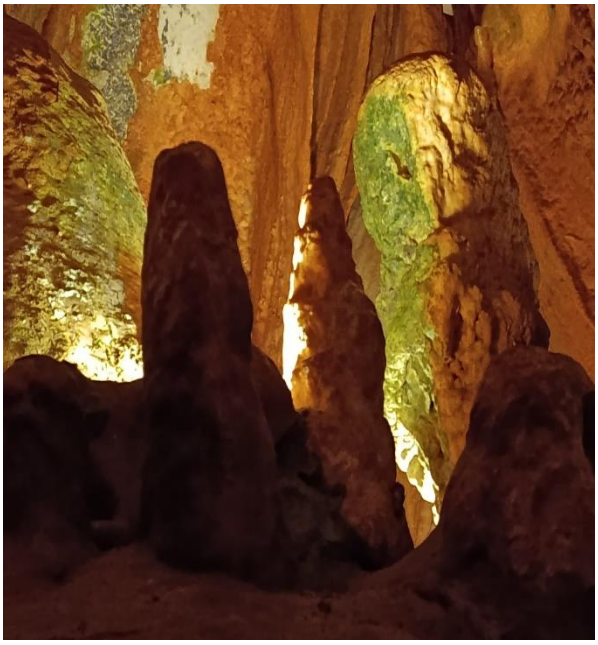


Figure 24. Lampflora, induced by artificial light bulbs.

The lamp flora was also observable on the walls of the cave. The observation became more visible over a period of four months (February to May, 2025). Specie of fern and moss were also observable (figure 25). Similar observations were made by Antonella *et. al.* (2020) and they found six taxa, including six moss species, one liverwort and one fern.

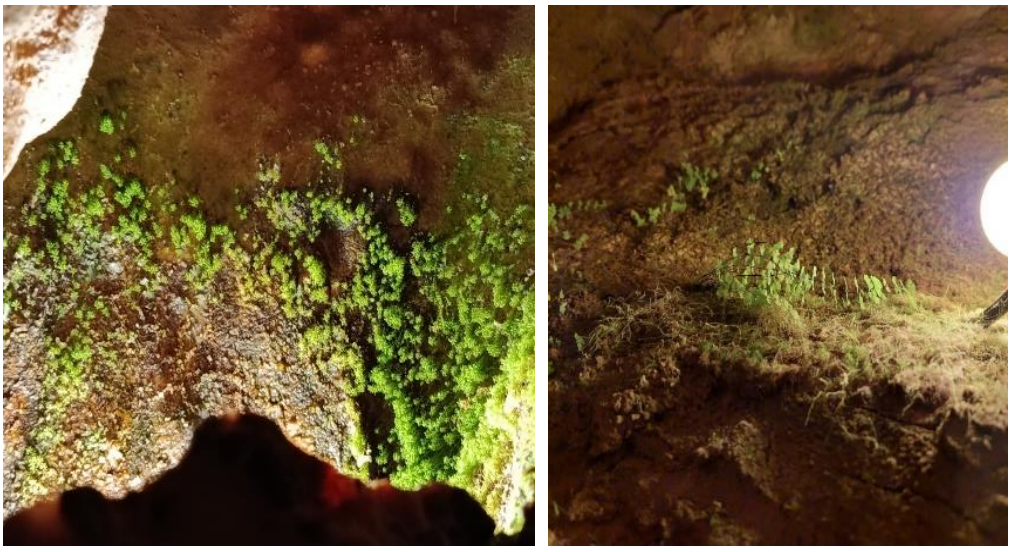


Figure 25. Moss and fern striving along the oxidized limestone underlayer and close to the artificial light.

The lampflora is used to explain the concept of photosynthesis and conversion of light energy to chemical energy to the 3rd cycle and secondary school students. For the secondary school students, the photosynthesis equation is quoted because they must have heard of the term 'photosynthesis' in their biology class.

$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Recall that for photosynthesis to take place, water, light, and carbdioxide must be present. Visitors constantly entering the cave release carbondioxide, water gets into the caves through the fractured limestones, while the bulbs generate the light.

2.2.7.2. Cave Activities that link Geodiversity and Biodiversity

Caves are also important place to highlight the relationship between geodiversity and biodiversity. They provide shelter for animals that love to live in the dark. Fox, bats, lizards, otter, swallows, cave beetles, swiftlets, heron, worms, spiders, snake, millipedes, centipedes, crustaceans, salamander are few troglofauna or troglophiles (animals adapted to live in caves). This activity was developed by the researcher.

2.2.7.3. Cave Animals/Cave Scavenger Hunt

The cave animals or cave scavenger hunt (figure 26) involved participants searching for cave animals (improvised touchable animals) which had been placed at strategic locations in the cave. This activity gave the participants an idea of the different animals that live in a cave environment and how they are able to adapt.

Different educational activities were created based on the ages and academic needs of the students.

For the preschool and first cycle: The animals were improvised and placed at strategic locations inside the caves. As the children were being taken through the caves, they were shown these animals and told how they adapt to survive in the caves. This aspect of the activity was designed by Grutas da Moeda Team.

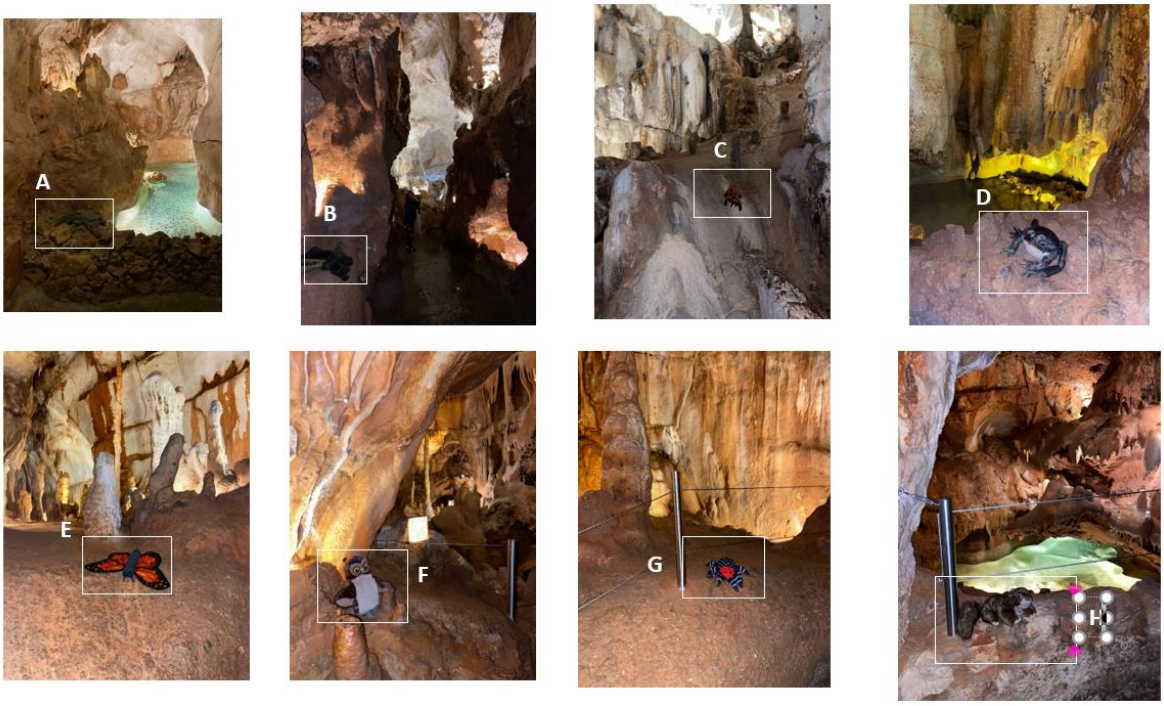


Figure 26. Improvised cave animals; (A) crocodile, (B) bat, (C) ant, (D) frog, (E) butterfly, (F) owl, (G) spider, (H) squirrel. After Grutas da Moeda, 2025.

For second and third cycles: different specimens of the animals were sourced and preserved in alcohol. The specimens were numbered and activities were organised for students to identify the animals and mark them on bingo cards. This activity helped students to have fun, enhance their vocabulary, observational and matching skills. Students' responsiveness to this activity as shown in figure27 below was something to behold, and the activity had thus been retained.

Figure 27. Activity with specimens of cave animals designed to develop observational skill, enhance students'' vocabulary and also learn about animals that live in caves. ***The faces of the students have been blurred for the purpose of privacy.***

For the fourth cycle/secondary education: an activity was developed by the researcher with the theme ''Life in the Dark: Cave Ecology and Unique Adaptations''. Students were given a task (appendix B) to list the adaptive feature(s) and list example(s) of the animals based on different classifications and criteria such as aquatic, non-aquatic, amphibians, reptiles, mammals, fish, insects, and birds. Example is given in each case to guide the students.

2.3. Other Activities and Resources

2.3.1. Herbarium Activity

The activity was created by Grutas da Moeda Team for the 1st and 2nd cycles students, with the aim of introducing them to the common plants in the area. Parts of the plants were collected, dried and preserved. Students were arranged in groups of three or four and each group was given a pencil, a pair of scissors, sticky paper, glue, plain white sheet, as well as a specimen sheet. The task was to identify and fill in the common name of the plant on the specimen sheet, and the corresponding scientific names (figure 28) which they could unravel by matching the common names with the scientific names on the reverse side of the specimen sheets. The second part of the task was to trim the specimen sheet with the pair of scissors and attach to the bottom right corner of the plain sheet with the aid of the glue provided.

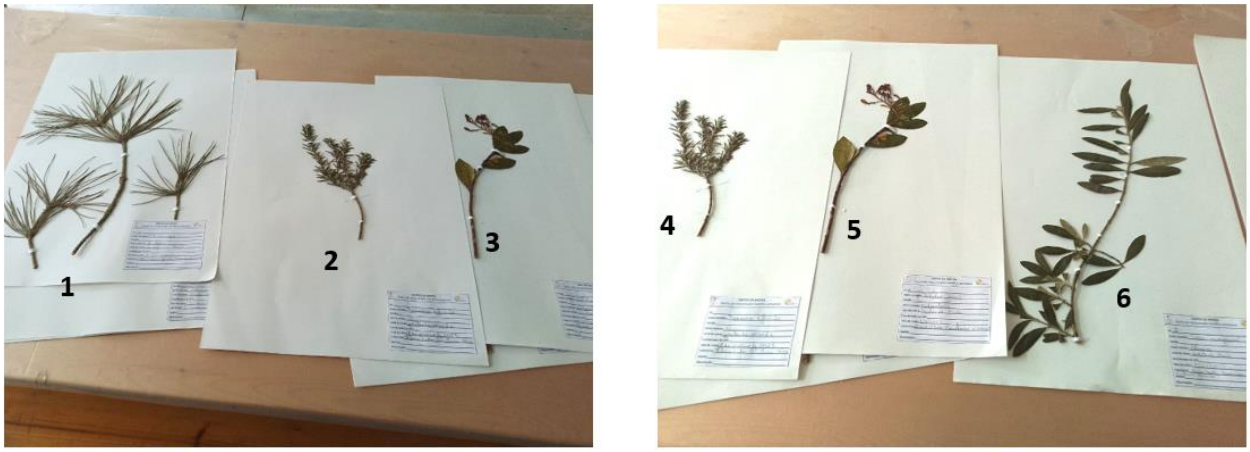


Figure 28. Results of herbarium activity as carried out by students in the 1st and second cycles. 1 = Pine tree (*Pinus*); 2,4= Rosemary (*Salvia rosmarinus*); 3, 5 = Strawberry tree (*Arbutus unedo*); 6 = Olive tree (*Olea europaea*).

The third part of the activity was to place the specimen vertically on the plain sheet with the sticky paper provided, ensuring that it does not cover the specimen sheet already glued to sheet. Students were encouraged to check out each other's work at the end of the task so they were not limited to only the specimens they had worked with.

At the end of this task, students would have known some plants and their scientific names, and also gained teamwork skill.

2.3.2. Coin cave maze puzzle

The cave maze puzzle (figure 29) helped the 3rd cycle and secondary school students to develop observational, critical thinking and problem solving skills. Solving the cave maze challenge was like exploring a cave. The idea was to locate an entrance and go through the narrow passages like the ones in the cave, and reach the exit before the time (five minutes) ran out. Students are advised to play the game and test their ability with an unresolved puzzle before checking out the solution. The activity was created by the researcher.

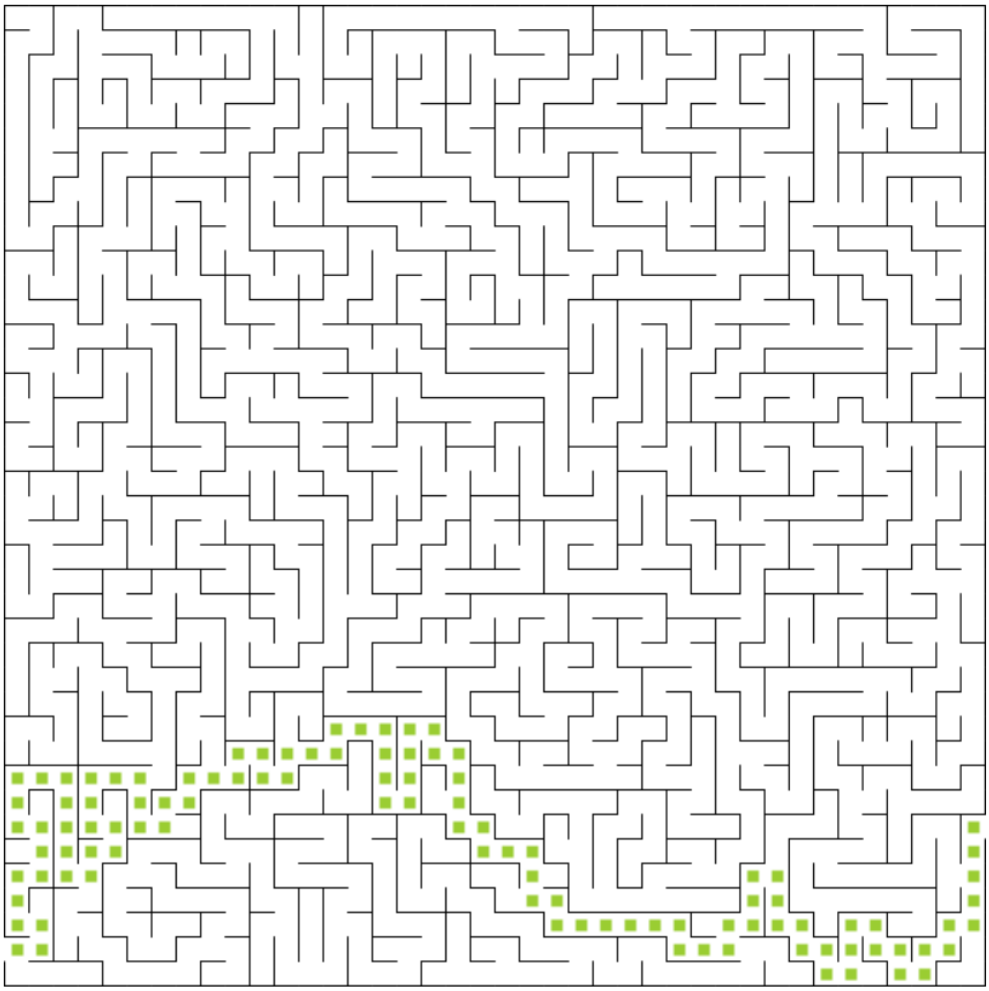


Figure 29. Coin cave maze puzzle, used to test critical and problem-solving skills.

2.3.3. The Joint Grutas da Moeda and Sensorial Ecoparque (Sensory Eco-Park) Trail

The joint activities were developed by the Grutas da Moeda Team and it involved the cave and the Ecoparque-Sensorial-Trail which offered schools and tourists the opportunity to embark on an educative and adventurous tours through the Serras de Aire and Candeeiros Natural Park (figure 30). The activity was restricted to 2nd, 3rd cycles, and secondary school students because of its challenging nature and the distance covered. Interested tourists were also allowed to participate. The trail began in the picturesque mountain village of Pia do Urso, and students get to see the village houses, the six interactive sensory stations for kids and people with low vision, the pedestrian circuit adapted to the blind, Pia do Urso olive oil factory, fountain, drystone walls, lapias and karren fields, different sinkholes (sinkhole of love, bear's sinkhole, Gralhas sinkhole), windmills, stonemills, old limestone quarries, different flora and fauna, as well as a good view of Sao Mamede and Fatima from the Lamp Hill.

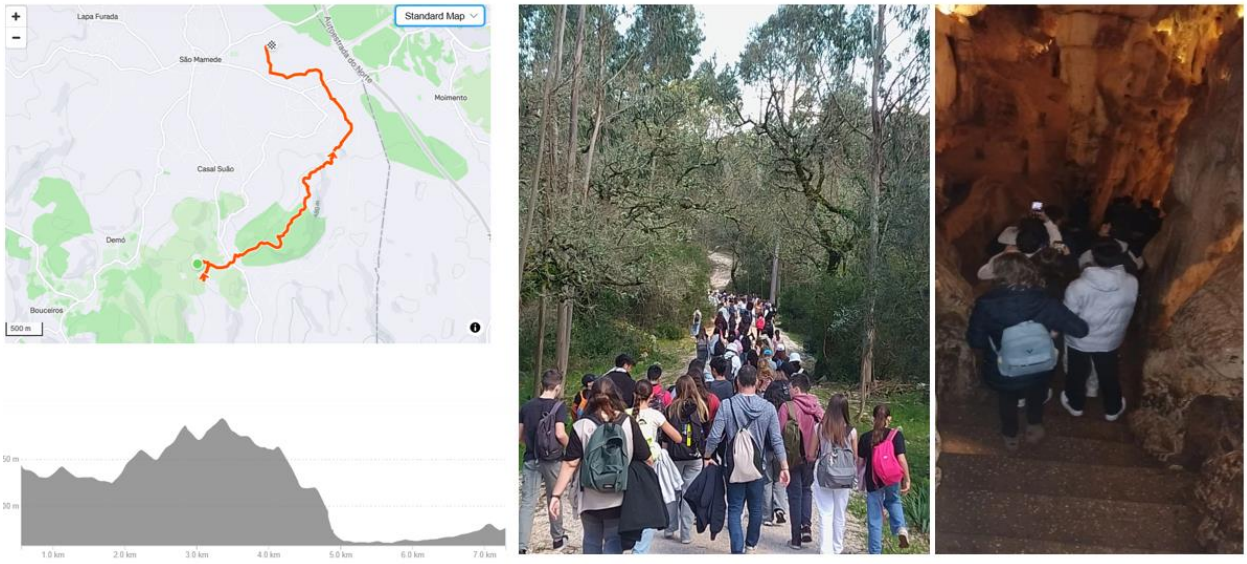


Figure 30. The Ecoparque-sensorial trail from Pia do Urso and back to the cave. The map and cross section show the areas covered in a total time of one hour, 56 minutes and 34 seconds. The participants journeyed through the Serras de Aire and Candeeiros Natural Park and returned to the cave to wrap up the visit. A total of 101 participants took part in this event.

The learning experience ended with the cave to deepen their knowledge of the geological formations and natural processes.

2.4. Tourist Activities

2.4.1. Coin-Cave Tie

How to play:

Two words were selected; **COIN, CAVE**

The game is played on a 3 by 3 grid (figure 31) and was created by the researcher.

It is played by two persons at a time. One player choses COIN and the other CAVE at the beginning of the game. Players take turns writing COIN and CAVE in the empty squares.

The first player to successfully write ''COIN'' or ''CAVE'' in a row (downwards, upwards, diagonally, across) wins the game. When all the nine (9) squares are full with words (coin, cave), the game is over, whether there is a winner or not. An example of the empty grid, and a completed game with the player having CAVE as winner are shown in figure 31. The game can be designed on an erasable board to save cost and use of papers.

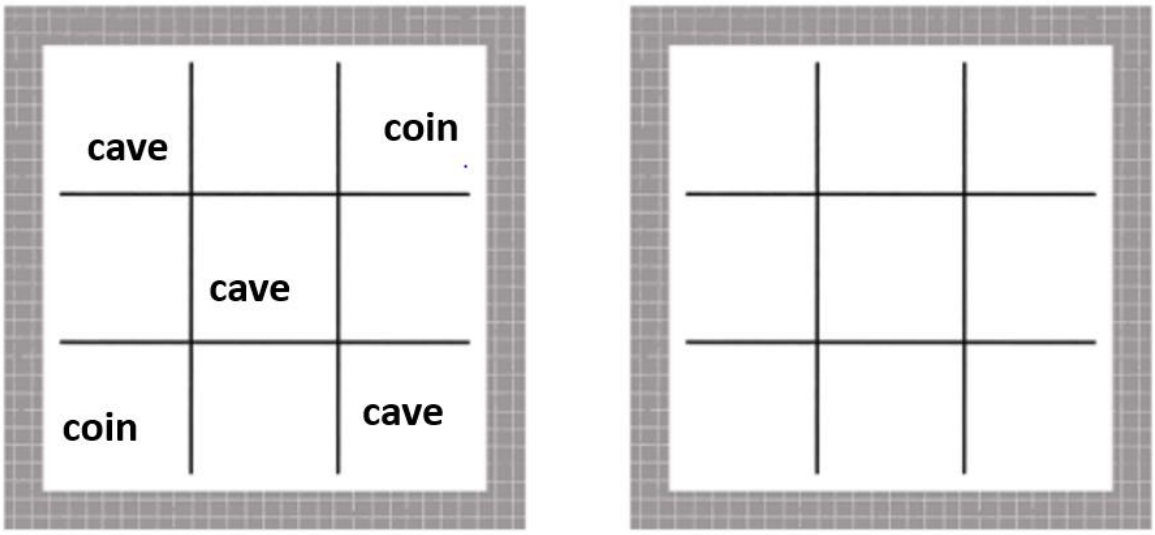


Figure 31. Coin cave tie. Played between two persons at a time. The player to have same words vertically, diagonally or horizontally wins.

2.4.2. Cave Mapping Challenge

The cave mapping challenge involved students and tourist using compasses/GPS apps on their smartphones to create their own layout of the cave using the positions of the twelve galleries as reference points. At each point, the students/tourists take the coordinates and elevations. The values are used in making the layout and determining the depths of the different galleries from the entrance point. The aim of this activity was to teach tourist/students about spatial reasoning, measurement, and data analysis.

2.4.3. Cave Conservation Tour

This activity was aimed at taking participants through areas of the cave that have been impacted by human activities, such as touching causing stunted growth, vandalism or pollution, and discuss the importance of responsible exploration and protection. By engaging in hands-on activities and learning about the threats to cave ecosystems, participants developed a deeper understanding of their responsibility in safeguarding the cave's heritage.

2.4.4. Use of Myth and Local Legend in Explaining Heritage

''Moeda'' is the Portuguese word for ''coin''. Have you ever wondered why the cave is called ''Grutas da Moeda'', that is ''coin cave?''. According to a myth, the name of the area where the cave was found is linked to a wealthy man who was wandering around the forested area and was stopped by a group of thieves who made attempt to steal the bag of coins he was carrying close to a sinkhole. As the confrontation continued,

the man and his bag of coins fell into the sinkhole, with the coins scattering in different directions. This was the origin of the name 'coin cave'.

It is a cultural belief that one can offer prayers with a coin, make a wish and throw the coins into the lakes (figure 32) in the caves with the belief that the prayers would be answered and wish come true. Consequently, visitors are often seen throwing coins inside the lakes.

Figure 32. Coins on the floor of the lake symbolizing the origin of the name ''coin cave'.

CHAPTER 3: Geotouristic Itinerary

As part of the internship, there were other activities organized outside the cave which were relevant. These included conferences, visits, trails, tours to heritage sites, partners' organizations, and other caves around the neighbourhoods. A proposal of geotourism itinerary can include these points of interest in the surrounding region of Grutas da Moeda.

3.1. Serras de Aire and Candeeiros Natural Park: Created in 1979, the Serras de Aire and Candeeiros Natural Park is considered one of the oldest natural parks in Portugal, and It is being managed by the Institute for Nature Conservation. The natural park is characterized by limestone, karstic systems, distinct vegetation cover, and framework of dinosaur footprints which constitute a natural monument inside the natural park. The Municipality is also involved in infrastructural development in the natural park with the creation of trails, relaxation areas, greenery, toilets, bins and other facilities (figure 33) required to boost tourism in the area.

Figure 33. Panel and infrastructure put in place by the Municipality.

3.2. Monumento Natural das Pegadas De Dinossaurios Serra de Aire (Aire Mountain Range Natural Dinosaur Footprint Monument- N39º34'20.97336"; W8º35'20.84316": Discovered in 1994 in a huge limestone quarry which has ceased operation in order to preserve the paleontological heritage. The old quarry which lies within the Serras de Aire and Candeeiros Natural Park has since 1996 been classified as a national monument. The monument has 20 trails and 147 metres long tracks of sauropod footprints which is considered as one of the longest in the world. The dinosaur tracks occur at 30 - 40º slope in the limestone (figure 34).

Figure 34. The old Pedreira do Galinha quarry and dinosaur tracks at Torres Novas.

3.3. Jurassic Beach/Sitio Paleontologico do Cabeco da Ladeira: Located in Central Portugal, the Cabeco da Ladeira paleontological site was an active limestone quarry that was later halted to protect and preserve the abundant trace fossils found in the Middle Jurassic tidal flat in the quarry area (Machado et al. 2021). At the site (figure 35), visitors can easily spot species of echinoderm (starfish), ammonites, bivalves, crinoids, gastropods, and brachiopods (Machado et al. 2021). There is a nice interpretation panel, but the site is poorly managed. Although it is fenced with wires, there is no personnel to monitor the activities of visitors.

Figure 35. The Jurassic Beach, poorly-managed paleontological site. Starfish, ammonites and other trace fossils are found at the site.

There are several holes indicating where fossils have been taken away by visitors. A good management and monitoring is required to safeguard the site.

3.4. Alqueidao de Serra (39°36'38.59''N; 8°46'10.41''W): considered as the only place in Portugal with the black limestones (figure 36). Mining of the limestone here is carried out mainly by artisans using hammer to shape the limestones into the characteristic square shape, and getting them ready for sales according to their grades. The limestones are used mainly for walkways and pavements.

Figure 36. Black limestone from the Alqueidao de Serra which lies in the horizon behind.

3.5. Monastery of Batalha: The monastery 9figure 37) is a magnificent edifice managed by the Municipality. Besides serving as a religious centre, it also serves as a tourist destination. The monastery is put into other uses such as concerts, marriages, conferences, and other social events. It is worthy to mention that it offers educational services through tours and presentations about the limestones and quarries in the area, as well as the associated environmental concerns.

Figure 37. A tour of the Monastery of Batalha and the lecture in the conference room on limestone and history of quarrying in the Batalha region.

3.6. Templar Castle, Charola, and the Convent of Christ Tomar: The convent of Christ is regarded as the 'crown jewel' in the Templar City of Tomar which was built around a castle. The castle is an imposing monument with a rich history and heritage. The castle is a classic example of a well-thought-out military architecture with its walls and fortress characterized by an impermeable defensive framework. The Convent was designated as a World Heritage Site in 1983 by UNESCO, and as a National Monument since 1910. It is characterized by multiple architectural styles, manueline-styled decorated windows, the initial Templar Church (Charola), and motifs (figure 38).

Figure 38. The Templar castle built in 1160 by Gualdim Pais (who was Master of the Order of the Temple) and inside the Charola with abundant Portuguese-inspired decorations.

The visit to the castle also afforded the opportunity to see the eight cloisters with various rooms such as the water storage room, dining, heating rooms, kitchen, toilets, laundry, conference rooms, as well as those for religious activities. The conservation and restoration works outside and inside the castle has made it to retain its aesthetic, cultural, religious and historical values as a UNESCO World Heritage Site.

3.7. Renova: A Portuguese company located in Zibreira, near the city of Torres Novas. It is renowned for the production of quality tissue papers for domestic and sanitary uses. Right in the company's premises is a karst spring flowing from a partly-underwater cave behind the factory (figure 39).

Figure 39. The cave spring, water channel, imagery of the cave's interior, and the collection room at Renova.

The spring serves as source of water for its operations, and also of immense value to the host community. The company has maintained a great deal of responsibility by releasing more water to the environment than it takes. Cellulose, which is the main material used for the paper production generates a lot of water, which is treated by the company and released back into the natural system.

The company has developed a great sense of environmental awareness, conservation strategies, and educational activities for schools. Renova has collections of earliest machinery used for tissue paper production, as well as tools, accessories, and work of arts that have been carefully stored and now used for educational purposes. It also has materials, archaeological findings, and samples of rock formations from parts of the underwater cave that had been explored. The visit to the factory also marked the beginning of partnership with the Grutas da Moeda cave.

3.8. Centre for Interpretation of the Battle of Aljubarrota, 1385 (CIBA) (39°35'55.80''N; 8°49'10.05''W): The centre is well revered in Portugal, as it marks part of the identity of the people that is being told and passed from generations to generations. Visitors get the opportunity to see weapons used for the battle, bones of humans who died in the battle, as well as the re-enactment of the 1385 grandiose battle in a mind-blowing multimedia show. The different characters, strategies, logistics, advancements, positions, attacks, counter-attacks and the end of the battle were all depicted in the movie. The interpretation centre also adopts different interactive multimedia, including the use of chrono-telescopes, and portable devices (figure 40) for audio-guided self-tours in Portuguese and English at the listening points which have been marked out

Figure 40. The interpretation centre of the battle of Aljubarrota. The top images show the entrance of the centre, and some ammunitions used for the battle. The image on the bottom-left indicate the chrono-telescopes for 3D visuals of the battlefield settings. The middle image is a close-up shot of the image on the telescope which is a recreation of the battle filed. The last image on the bottom-right is the portable device for audio-guided self-tours with provision for Portuguese and English speakers.

Visitors also get the chance to explore the battlefield of Saint George, considered as one of the most well-preserved battlefield in Europe

3.9. Museum of the Municipal Community of Batalha (MCCB): The museum houses collections and interpretations that tell the stories about the geological, biological, paleontological, archaeological, cultural, historical aspects of the Batalha Municipality (figure 41). The museum is also accessible to the blind, as special features have been put in place.

Figure 41. Different sections of the museum linking the cultural, historical, geological, archaeological and biological aspects of the territory. The first image is a statue of a Roman Magistrate reflecting an important period in Portuguese history.

3.10. Gargula Gotica, Batalha: A company that specializes in cantaria, conservation, and restoration work. It works with marbles, gypsum, and limestones to create different ornaments and gift items (figure 42).

Figure 42. Materials produced from limestones, gypsums, and marbles and a section of the Gargula Gotica factory in Zona Industrial da Jardoeira, Batalha.

The company is renowned for producing works for top musicians, artistes, and celebrities around from around the world. Gargula Gotica is also associated with restoration works at the Batalha Monastery, and others within the Municipality.

CHAPTER 4: Assessments

4.1. Assessing Programmes Effectiveness and Continuous Improvement

To ensure positive learning experience and ascertain the effectiveness of the educational and tourist programmes of the caves, a short survey was created to assess the effectiveness of the various programmes and make adjustments as needed to ensure they are meeting their objectives and engaging participants. The survey was based on participants' satisfaction, knowledge gained, behavioural change, and the likelihood of revisiting or recommending the caves to friends or family members.

4.2. Methodology

The opinions of one hundred visitors were sought using questionnaire that could be answered within two minutes. The questionnaire was titled ''visitors satisfaction survey'' and consisted of five questions. It was written in English and Portuguese. The English version is shown in appendix C. The population comprises students (schools in Portugal) from 1st cycle (6-10 years), 2nd (11-12 years) cycle, 3rd (13-15 years) cycle, secondary education (15-18 years) and tourists of all ages from different parts of the world. The responses were collected onsite at the cave immediately after the visits. The collected responses were analyzed using wordcloud generator (https://www.wordclouds.com), and excel.

Figure 43 below shows the distribution of the 100 respondents; 1st to 3rd cycle students (N=30), secondary education (N=30), tourists of all ages (N=40).

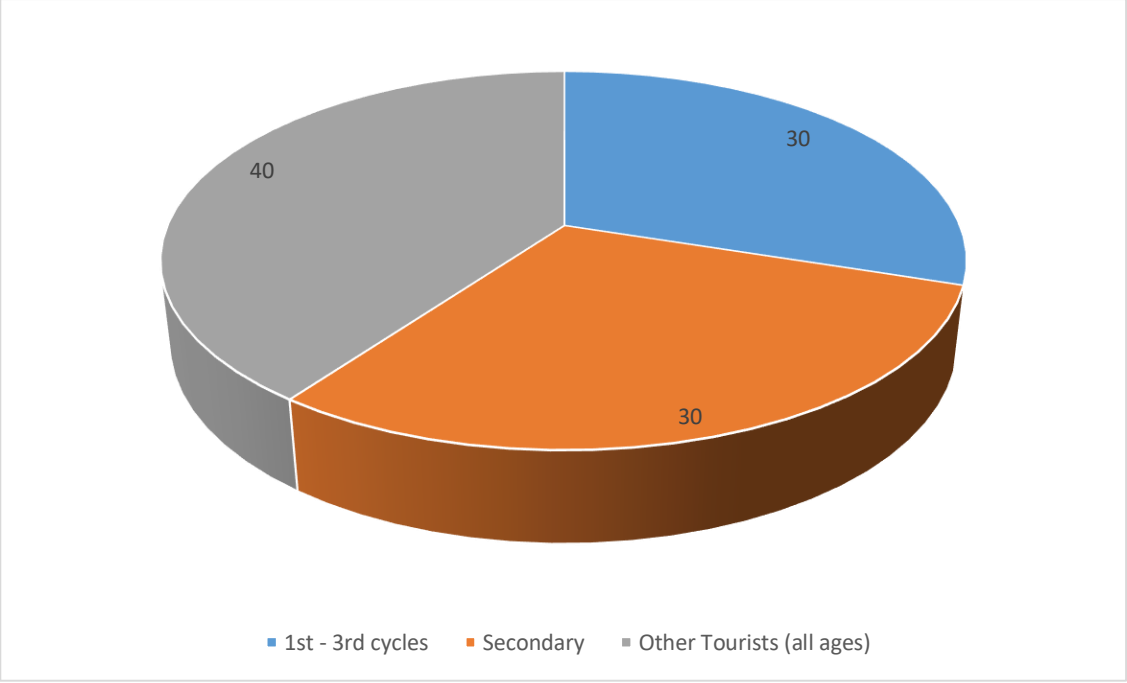


Figure 43. Distribution of the 100 respondents used for the survey.

4.3. Results and Discussion

Figure 44 shows the wordcloud generated from the respondents answering the question ''describe your experience in one word''. The responses were positive indicating fulfilling experiences. The central word was ''amazing'' which was used by twenty-seven (27) respondents.

Figure 44. Wordcloud representation of visitors' responses to the question ''describe your experience in one word''.

Figure 45 shows the chart generated from the respondents when asked 'if they would love to visit again or refer the cave to a friend or family member. 81% of the visitors who responded answered in the affirmative, 12% in the negative, while 7% were indifferent (with responses such as 'may be', and 'I think so'). In situations where the question was not answered, they were counted as indifferent.

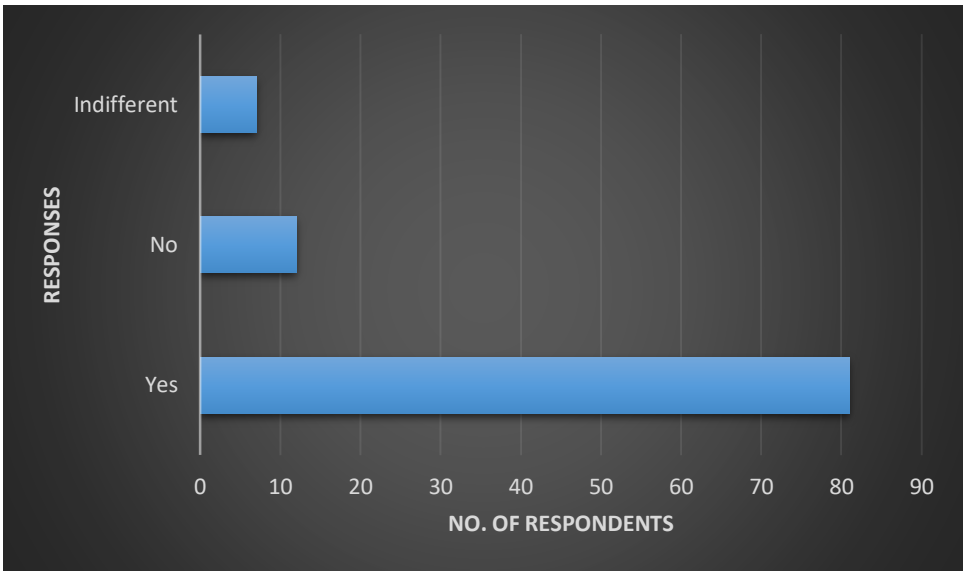


Figure 45. Visitors response to the question ''would you like to visit again or recommend the cave to a friend or family member?''

CHAPTER 5: Observations and Characterization of the Effects of Visitation on the Caves

Speleotourism is very popular in the ELM area because of the several showcaves around the region. This has helped in attracting large number of tourists, promotion of the region, boosting of economic activities, awareness of the region's heritage, cultural exchange, and giving life to the calm and serene environment around Sao Mamede and Batalha. While the Grutas da Moeda cave possess significant potential to provide visitors with an enriching and memorable experience, this must be carefully balanced with the need to protect the fragile cave environment, as the impacts of mass tourism can pose serious threat to the delicate geological and ecological features within these underground systems.

The observed effects of visitations on the caves are;

1. Touching of some of the stalagmites which has resulted in their discoloration with dark patches resulting from oxidation (figure 46). Continuous touching has also created an impermeable layer that causes the water droplets to slide sideways resulting in stunted growth of the stalagmites. These stalagmites are all located close to the walkways in the caves and thus easily accessible to visitors to touch.

Figure 46. Dark colouration and stunted growth observed in stalagmites along the walkways of the cave.

Along the tunnel, the lowest part of the walkways, and where the rate of droplets is high, the growth of new stalactites is being interfered with by visitors who break or touch them because they are directly above the

head and the water droplets easily draw attention to them (figure 47). Additionally, there is no corresponding growth of stalagmites from the floor.

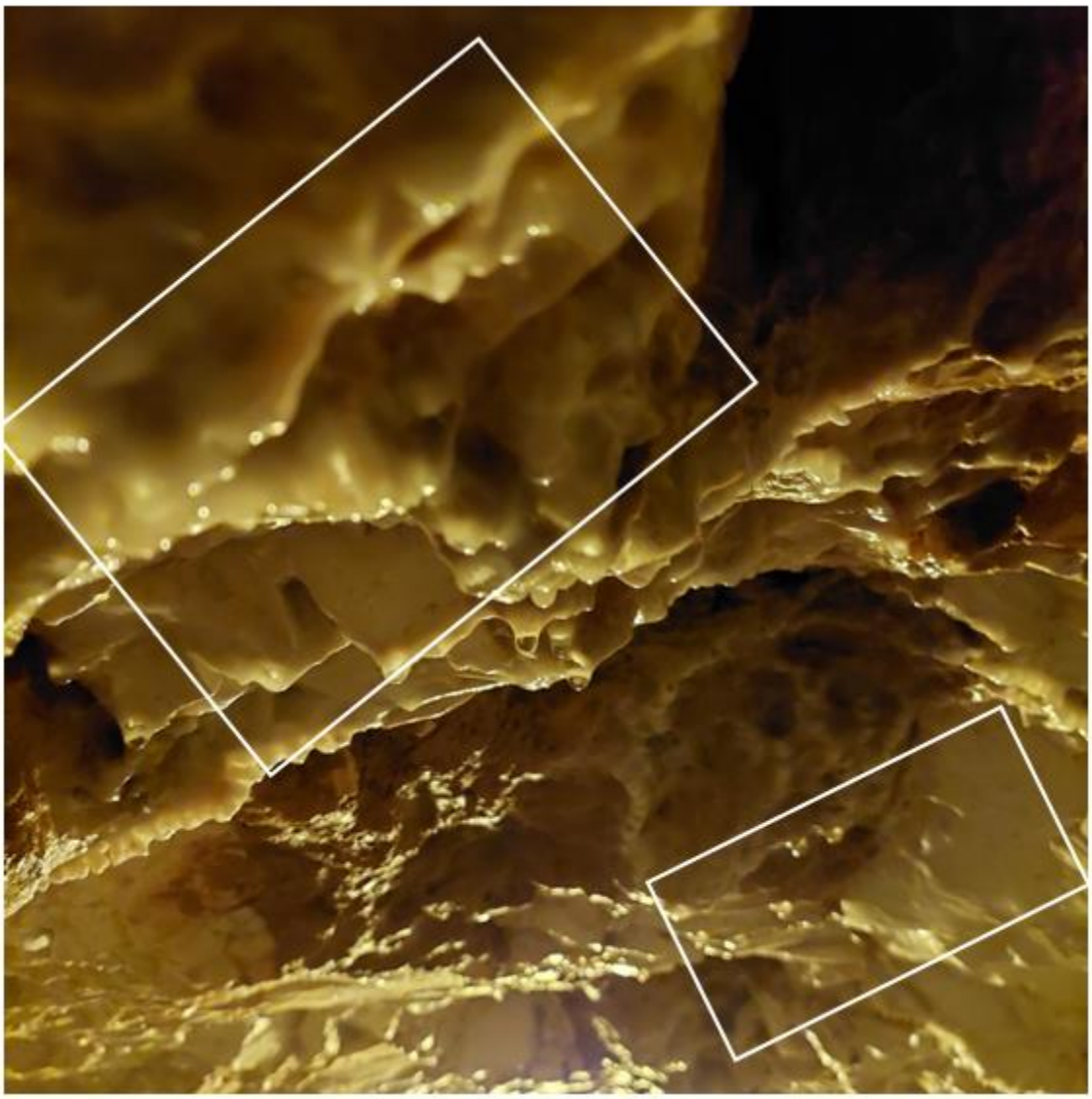


Figure 47. Growing stalactites crystal (whitish) on the roof along the tunnel

2. There are lots of coins in the lakes within the caves. More are being thrown into the lakes on a daily basis by visitors. These coins are made up of metals and when they react with the water, they are likely to cause negative impacts on water quality. There is also interference with the water in the lakes. An occasion was recorded where a visitor's phone fell into the lake. In a bid to recover the phone, the visitor also fell into the lake. Similarly, children were observed in many cases leaning against the rock formations, attempting to break rock out of curiosity.
3. Growth of green lamp flora: from a combination of artificial lighting systems in the caves, lights from phone cameras and torchlights used by visitors in the caves, in addition to carbon dioxide released by visitors inside the caves.

In addition, visitors drop items such as paper, tissue, and even the tickets they obtained before accessing the cave. They do not only constitute an eyesore; they also find their way into the lakes thereby interfering with the natural environment. In the course of cleaning up the debris from the lakes, there are also unintentional interference with the cave's environment. To prevent this kind of situation, a waste bin was situated near the entrance and at the back of the cave's entrance door, but are hardly used by visitors. This situation calls for concern and visitors need to be educated on environmental stewardship and responsible tourism.

5.1. Conservation Efforts By Grutas da Moeda Management Team.

Some measures have been put in place by the managemenent of the cave to conserve it. These include;

Controlled visitation: when a large number of visitors arrive the cave at same time, they are divided into groups, and a 10-20 minutes time lag is observed to avoid overcrowding/overtoursim.

Panel with galleries and warning notes at the entrance of the cave.

Installation of controlled lighting sources which can easily be turned on and off from the office space, and ensuring that it is only switched on when there are visitors in the cave.

Dedicated wifi connection and audio guides with QR codes at each of the 12 galleries in the caves. The audio guides are in five languages (English, Portuguese, Spanish, French, and German). Visitors have access to both the text and voice-over on their mobie phones, and it can be repeated as many times as possible. This allows for crowd control and for visitors to explore the caves at their own pace, with minimal contact with the speleothems.

Barriers (figure 48) are also erected around the speloethems close to the walkways to prevent touching and visitors climbing over.

Figure 48. Barrier to prevent visitors from destroying the speleothems.

Video cameras (figure 49) placed at strategic positions to transmit real time images that are monitored by a dedicated staff on a large television screen. The cameras are also placed outside the caves and thus also serve as security measures within the cave's environment.

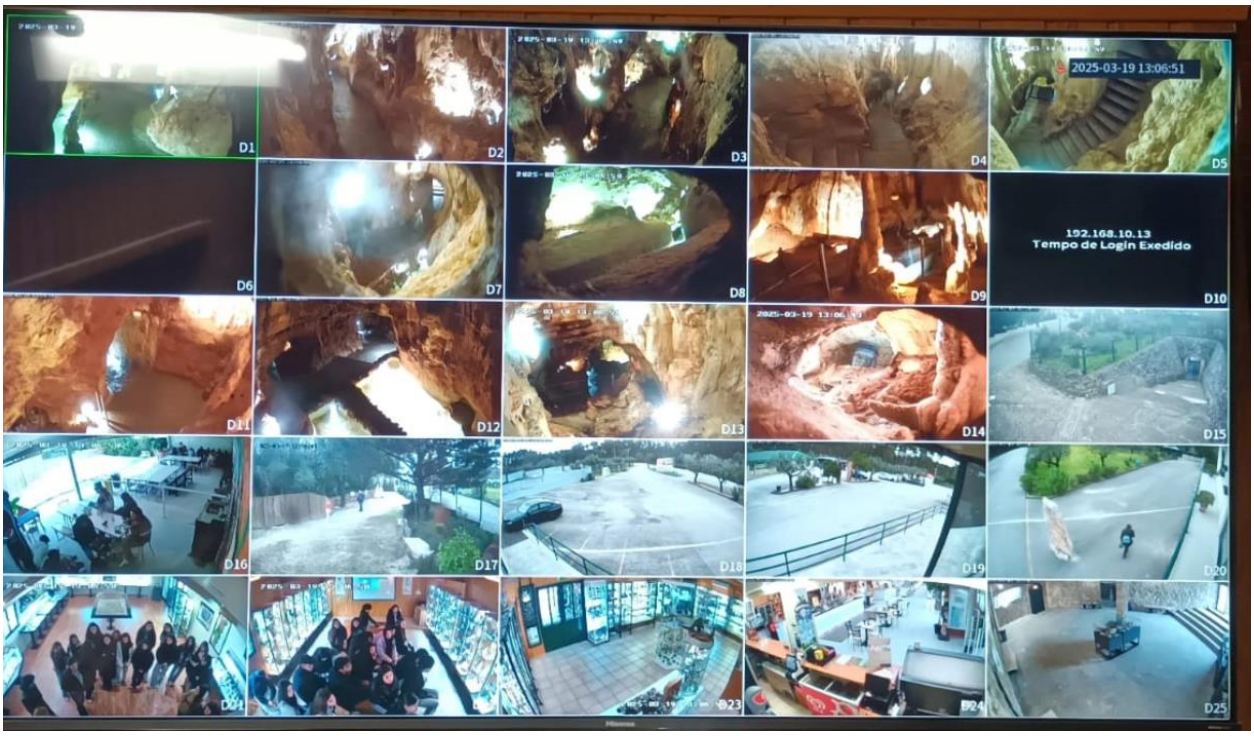


Figure 49. Real time images from inside the cave and its environs, for monitoring visitors' activities and also for security purposes.

CHAPTER 6: Conclusion

The geology of Central Portugal as expressed by the ELM were highlighted and the Grutas da Moeda was used as case study to illustrate how the limestone massif and the caves have been used to enhance educational and tourism activities in the Batalha Municipality. To ensure the success of its touristic and educational activities, Grutas da Moeda has established a strong and long standing partnerships with schools within Sao Mamede, Batalha, Fatima, Leiria, Porto, and beyond.

The internship at Grutas da Moeda was a fulfilling one as all the set-out objectives were achieved. The geoeducational and geotourism sectors driven by showcaves in the region were highlighted, with different interactive, fun and didactic activities created for schools and tourists. During the five months' period, a total of 7, 925 school children visited the cave. Similarly, tourists from different parts of the world came visiting. Several materials and activities were put together by the cave to create lasting memories for visitors of all categories. There were also activities jointly organized by the cave with other partners such as the Ecoparque trail at Pia do Urso, activities marking the international day of tour guides, the International Workshop on Religious Tourism, as well as the Annual Meeting of the Partners of Portugal's Mines and Mining and Geological Points of Interest. In addition, there are also partnerships with community organizations, museums, and interpretation centres to promote the limestone that unites everyone in the Municipality.

Students and tourists were given the opportunity to rate the relevance of the activities, itinerary themes, and their level of satisfaction with the programmes contents. A semi-structured survey was conducted and one hundred responses were collected from different tourists, as well as students from the 1st to the 4th grades. The responses indicated that majority of the visitors were satisfied with the activities at the cave. Out of the 100 responses, 81% of the visitors who participated in the survey expressed their interest in visiting the cave again and also recommending it to friends and family members. Similarly, 12% of the respondents expressed their dissatisfaction, while 7% were indifferent (with responses such as 'may be', and 'I think so').

The various programmes and activities at the Grutas da Moeda cave have shown that caves are key geological heritage with immense scientific, educational, cultural, intrinsic, aesthetic, spiritual, and ecological values. The engaging educational and tourists' activities which has been proven to enhance visitors' experience has made the cave stand out amongst other caves in the Sao Mamede region. The school activities in the caves go beyond cave exploration. These programmes cut across biology, geology, environmental science, history, culture, and chemistry. Thus, the schools have incorporated them into their curriculum and post-visit manuals have been developed with further activities, quizzes, and games for all ages.

Despite its significant potential to providing visitors with an enriching and memorable experience, this must be carefully balanced with the need to protect the fragile cave environment, as the impact of mass tourism can pose a serious threat to the delicate geological and ecological features within these underground systems. By implementing a holistic approach that combines educational initiatives, sustainable management practices, and a focus on ethical principles, the Grutas da Moeda caves can become a model for responsible speleotourism, offering visitors a deeper understanding and appreciation of the natural wonders they are privileged to.

The internship also included a geotouristic itinerary which provided the opportunity to visit different sites of geological, paleontological, archaeological, and cultural heritage interests within Portugal. The relevance, conservation, management and interpretation strategies adopted by each of these sites have greatly enhanced the understanding of geoheritage management and promotion.

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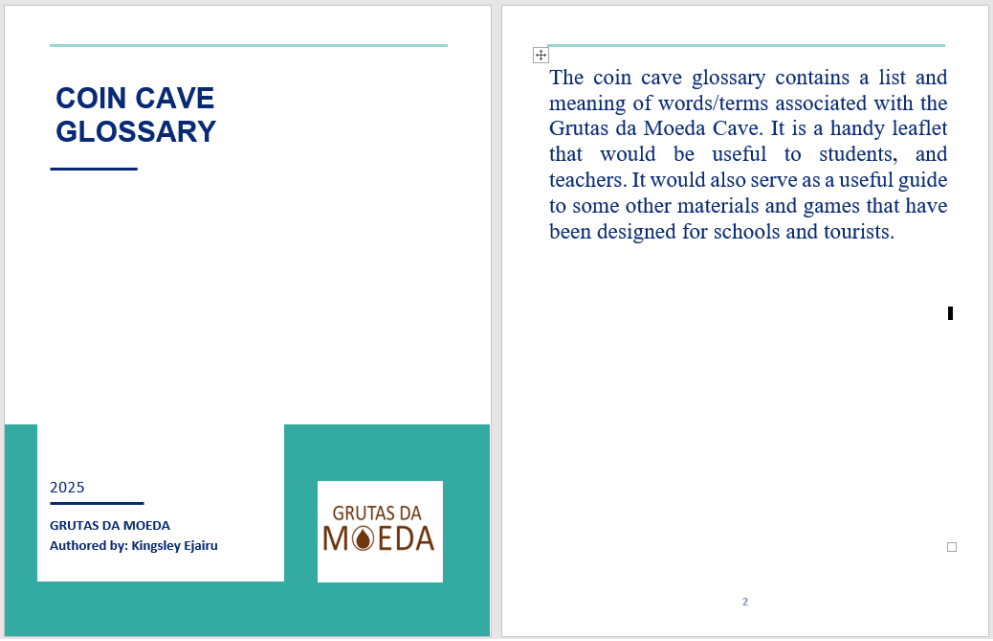
APPENDICES

Appendix A: Coin Cave Glossary



Cave: natural opening or cavity in the earth, usually formed in sedimentary rock deposits such as limestone, gypsum.

Cave conservation: protecting and conserving caves in order to ensure they are available for many Geert rations.

Cavern: 'cave' and 'cavern' are sometimes used interchangeably. However, cavern is a particular type of large cave, and it is sometimes highly decorated.

Caving: the act of exploring caves.

Cavity: a hole or space inside a rock.

Carbonic acid: a weak acid containing carbon dioxide and water. It has the formula H_2CO_3.

Calcite: it is a rock forming mineral and it is the major mineral in limestone.

Column/pillar: when stalactites and stalagmites grow to meet each other, they form columns/pillars.

Crystal: a solid material whose atomic constituents, molecules, or ions are arranged in a highly ordered repeating pattern. Crystals are made up of minerals. The process of formation of crystal is called crystallization. In this cave, the crystals are formed by crystallization of calcite.

Curtain: a cave feature formed when water runs don the wall of the caves. It is formed by calcite minerals in the water, and usually wavy or folded.

Dissolution: occurs when acidic water (water rich in carbonic acids) dissolves the rock along cracks, fractures or weaknesses.

Dome: circular-shaped deposits formed in the roof a cave when water dissolves calcium carbonates in limestones and deposits them on the ceiling of the cave.

Fracture: an opening in a rock.

Fossil: the remains or impressions of ones living organisms.

Gallery: an underground passage

Groundwater: water that exist underground.

Grutas: The Portuguese word for cave.

Jurassic: a geologic period of around 201.3 to 145.0 Million years ago. It is regarded as the age of the dinosaur because they were abundant at this time.

Karst: a landform produced by limestone (carbonates) or gypsum (evaporites) and which has been eroded by dissolution, resulting in the production of caves, sinkholes, springs, ridges, sinking streams, fissures, and other characteristic features.

Karstification: is the process involving the chemical dissolution of soluble bedrock.

Limestone: a sedimentary rock made up of mainly calcium carbonate (calcite).

Moeda: The Portuguese word for 'coin'.

Mine: a place in the earth/ground where natural resources are extracted. It can be either at the surface or underground.

Mineral: a solid, naturally occurring inorganic crystalline substance with a definite chemical composition. Examples are quartz, feldspar, calcite.

Polje: a large, flat-floored depression in a karst region.

Rock: an aggregate of minerals. Examples are limestone, shale, sandstone.

Speleogenesis: the process through which caves are formed.

Showcave: a cave that is open to the public.

Speleogens: these are features developed in cave walls as a result of flowing water.

Speleology: the scientific study of caves

Speleologist: people who study caves professionally.

Speleothems: these are cave features which can be stalactites or stalagmites, and are formed when flowing water keeves mineral deposits behind.

Stalactites: speleothems hanging from the roof of the cave as a result of calcite deposition by dripping water.

Stalagmites: speleothems formed on the floor of the cave as a result of calcite deposition by dripping water.

Sinkhole: a depression or hole in the earth caused by collapse of surface layer (of limestone) usually caused by water. The process becomes faster when the water is acidic.

Subterranean: existing or operating under the earth surface.

Solution cave: caves formed by the dissolution of limestone.

Sump: a cave passage that is submerged in water.

Wild cave: a cave that has not been prepared and made open to the public.

APPENDIX B: Table 1. Activity on cave animal ecology and unique adaptive features

CLASSES OF ANIMALS	**EXAMPLES**	**FEATURES**
Amphibians	Frog	Lungs, skin, webbed feet, cold-blooded. ....
Reptiles	Lizard	Scales on skin ....
Mammals	Bat	Nocturnal (loves to live in the dark) ....
Birds	Heron	Beak for feeding on worms, wings for flying ....
Insects	Spider	Antenna to feel their way around ....
Fish	Blind cavefish	Gills for breathing ....
Aquatic	Salamander	Gills for breathing ....
Non-aquatic	Heron (bird)	Wings for flying ....

APPENDIX C: Questionnaire used to assess the programmes and activities at the cave.

These questions were selected because they are easy to understand, quick to answer and more relevant to talk about tourists and students at the cave.

1. Did you visit the cave as a tourist or student?
2. If your answer to question 1 is 'student', what level/grade are you in? What is the location of your school?
3. Did you gain something new after the visitation? YES/NO. If YES, could you briefly explain?
4. Describe your experience at the cave and interpretation centre in one word
5. Would you like to visit again or recommend the cave to a friend or family member?