PROCEEDINGS

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Edited by Trần Nhị Bạch Vân & John Brush

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CONTENTS

Cave management and protection

Sustainable use of volcanic caves – an impossible dream?

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Abstract

Every person entering a cave will have some impact on the cave environment. Visitors breathe. They shed hair, skin fragments and clothing fibres. They track in dirt and spores on their feet. They may also touch cave surfaces or leave behind litter. Or worse. The impacts will depend on many factors including the nature of the cave, the frequency and purpose of visitation, the "cave" awareness of individual visitors and the management arrangements for the cave. This paper draws on the author's experiences with cave access and management issues in Australia over the past half century during which time (a) recreational use of caves has boomed, (b) governments have implemented strategies for managing caves to protect cave ecosystems, monitor research activities and provide for recreational access, and (c) the speleo community has introduced codes/ guidelines for minimising visitor impacts on caves, risk management, safety, training, ethics and scientific investigations. This framework will serve as a basis for making observations on management practices in volcanic caves in Australia, California (USA) and the Galapagos Islands (Ecuador) and draw some conclusions about sustainable use.

Keywords: volcanic caves, sustainable use, cave management.

Introduction

In this paper I offer some comments on human impacts on caves. To an extent they are based on my own observations and experiences over the more than 50 years that I have been involved with organised speleology in Australia. This includes continuous membership since 1969 of speleo groups that are members of Australian Speleological Federation Inc, which is the peak national body for speleo groups in Australia; participating in activities of the Australasian Cave and Karst Management Association Inc (ACKMA) over the past 14 years. In addition I have been a member of the Commission on Volcanic Caves of the International Union of Speleology for many years and have been President since 2017.

At first, my caving activities were confined to the karst areas of southeastern Australia, apart from an occasional trip to volcanic caves in western Victoria. In the mid-1970s I visited caves in more distant parts of Australia and first ventured into limestone caves in other countries in the 1980s. Since then, I have been fortunate to have been able to visit a considerable number of wild caves and show caves in many different countries.

I first attended an International Symposium on Vulcanospeleology (ISV) in Iceland in 2002, and I have attended most ISVs since then.

Over the years I have become increasingly involved in cave management issues. I have been a member of formal and informal advisory bodies and have helped to prepare management plans covering at least ten karst areas in southeastern New South Wales (NSW). I have also initiated, or otherwise participated in, many projects to address visitor impacts in wild caves and also in show caves.

Much of my experience relates to limestone caves, but many issues are common to both limestone and volcanic caves.

Visitor impacts on caves

Every person entering a cave, any cave, will have an impact on the cave environment.

All visitors to a cave breathe. They also shed skin fragments, hair and clothing fibres. They walk on the cave floor, they may track in dirt, microbes and organic matter on their footwear. They may also touch the walls and other surfaces in the cave. Visitors can also leave behind rubbish, food scraps or human waste. Some visitors also damage cave features, intentionally or otherwise, and may deliberately disturb or harm cave organisms, such as bats.

When humans enter a cave, they have the potential to:

- alter the cave atmosphere;
  (by, for example, increasing carbon dioxide levels, reducing oxygen, increasing the humidity and air temperature);
- change the nutrient balance;
  (lint, food scraps and organic matter tracked in on footwear can all make a significant difference in caves that have naturally low nutrient levels);
- inflict wear and tear on cave surfaces;
  (for example, both limestone and porous basalt surfaces in caves are readily worn down by passing foot traffic);
- adversely impact on the physical, historical and archaeological values; and also
- adversely impact on cave biology (microbes, invertebrates and vertebrates and their habitats).
- diminish aesthetic values;
  (such as leaving footprints and marks on cave walls, creating muddy trails, damaging cave features);

The nature and magnitude of the impacts will depend on the cave itself as well as on a range of factors concerning the visitor, such as the type of visit (for example is it a show cave trip, a recreational caving trip or for scientific work), the route through the cave, how careful or "cave-aware" the visitor is, how long they spend in the cave and the nature of clothing and other items they take into the cave. When considering impacts, it is also important to take into account the total number of visitors and the frequency of visitation.

Some caves, or parts of them, are extremely susceptible to damage (Figure 1) or change from even very low levels of visitation. Others are more robust and can withstand high levels of daily or monthly visitation without significant impacts.

Figure 1: A group of lava straws in Kazumura Cave, Hawaii. The straws were extruded from the ceiling as gases escaped from the cooling lava. They usually have very thin walls and are extremely delicate; once they are broken there is absolutely no scope for regrowth, as there might be with calcite straws in a limestone cave.

Even if the impact of a single visit is negligible, the cumulative effects of many visitors over a period of time can be significant.

It has been argued that visitors to a show cave have less impact on the cave environment than do recreational cavers in a wild cave, but it really depends on the nature of the cave in question, the number and frequency of visitors, and also on how much a cave was modified to turn it into a show cave in the first place.

Cave management and increasing awareness of cave values

Over the last several decades in Australia there have been increasing pressures on both volcanic and karst caves but there has also been significant change in how caves are managed and in how the organised caving community has responded to the challenge of minimising the impact of its activities. While this paper focus on focuses on NSW, the management arrangements in other states and territories is broadly similar. This section also primarily refers to karst caves as there are no significant volcanic caves in NSW.

In the 1970s and 1980s, there was a rapid rise in the popularity of many outdoor recreation activities, including caving. This was accompanied by increasing availability and affordability of camping equipment, climbing gear and topographic maps. Suddenly, the remote outdoors were not quite so remote. Fortunately, most of the major karst areas in NSW were, or soon became, included in National Parks. A permit was required to enter almost all caves within the parks and the permits were only issued to speleo groups that belonged to the Australian Speleological Federation (ASF) Inc, the national organisation for organised caving in Australia. This is discussed in more detail in the next section.

Graeme Worboys, a ranger based in the Yarrangobilly karst area of the Kosciuszko National Park in southern NSW, developed proposals for a rational and scientific basis for managing caves and karst. He presented a paper on his proposals to a national speleological conference in 1976 (Worboys, 1977). After further refinement and in collaboration with Mark Butz, another National Parks employee, a paper was presented at the Third Australian Conference on Cave Tourism and Management (WORBOYS & BUTZ, 1979).

A critical element of the joint paper was to recognise the variability of management requirements in karst areas and proposed a three-level system for classifying (a) karst areas, (b) caves and also (c) classifying areas within individual caves.

Over the years, the cave classification scheme evolved and broader cave and karst management policies were developed in consultation with state-level expert and community advisory bodies, including the Karst Management Advisory Council and the National Parks Advisory Council. There were also many discussions at the regional and individual park levels through advisory committees and reference groups.

A tangible result of the policy development work has been the implementation of standalone Karst Area Management Plans to cover karst areas within several national parks. These plans supplement the overall management plans for each park and focus purely upon the issues that are pertinent to protecting the integrity of individual cave and karst systems with a particular national park.

Using the Kosciuszko National Park as an example, the Kosciuszko Karst Area Plan of Management (KAMP) was endorsed in 2015 and is linked to the broader Kosciuszko Plan of Management released in 2006 and as amended in 2010, 2014, 2021 (NPWS, 2021) and again in 2022.

In the Kosciuszko KAMP, the zoning system first proposed by Worboys has been simplified to a 5-level system (NPWS, 2015):

- Reference Cave (ie, for approved scientific studies);
- Limited Access Cave (open to speleological groups meeting specified requirements and holding a permit);

- Show Cave (generally equipped with lighting and formed pathways and open for public tours, usually accompanied by a guide);
- Adventure Cave (open to the public on guided tours); and
- General Access Cave (robust caves that are considered to be safe for inexperienced visitors).

Each cave in a particular karst area is classified into one of these categories and may be reclassified on the basis of new information.

An in-cave classification scheme is used in several large caves that have areas with particular sensitivities, such as high risk areas, bat roosting sites, or high geological, biological or archaeological values.

For the Limited Access Caves, the KAMP specifies the maximum (and also minimum) party size, and the number of trips permitted each year. The party size limits for a trip generally range from 4 to 8 people and, if there is a cap on the number of trips, it usually ranges between 4 and 12 trips a year. A permit is required for each trip and it will specify a range of conditions that must be complied with. It will also require that a written report (on a standard form to ensure consistency) is submitted after each trip and this provides an opportunity for recording any observations or changes in the cave and thus is an important management tool.

Even at relatively modest levels of annual visitation, cumulative impacts of visitors can emerge and this is managed by amending the access conditions, reducing the visit frequency, undertaking remedial works and defining specific routes to follow, which may include use of markers, signs and cord lines.

Evolving attitudes within the speleological community

As noted above, most major karst areas in NSW are in national parks and for most caves, a permit is required to enter them.

Until the early 1980s, speleo groups were required to undertake 'useful' work, such as surveying and documentation to obtain a permit. In the 1980s, recreational caving was recognised as a legitimate activity in some national parks. This became more widely accepted and also more achievable from the management perspective with the implementation of zoning systems for karst areas and caves. A permit was (and is) still required for a trip into a restricted access cave, but 'recreation' was accepted as a legitimate reason, provided that certain conditions were complied with, such as having a suitably experienced leader and complying with a range of codes and guidelines developed and implemented by ASF. The key ASF codes are:

- Code of Ethics (Introduced 1974, formally adopted 1992, revised 2013, 2014 and 2021).
- Minimal Impact Caving Code (Adopted 1995, amended in 2010 and 2021).
- Safety Guidelines (Adopted 1972, revised 1984, 2007-2010, 2021).
- Risk Management and Emergency Procedures Guidelines (Adopted 2005, amended 2006, 2021).

ASF is a federation of speleo groups and adoption of any new or revised code/ guideline places an obligation on member clubs to ensure their member comply.

Management of caves in volcanic areas of Australia

<u>Western Victoria</u>

In western Victoria, the two major cave areas (Byaduk) and (Mt Eccles) lie within the Mt Napier State Park and the Budj Bim National Park respectively. In both areas, several caves are classified as public access caves. These caves are robust and are in good condition apart from minor abrasion wear on floor features. Access to other caves in both parks requires a permit. At the current time there is no full time on-site management presence at either park, but most of the limited access caves are in good condition, in part because many have entrances that are either vertical, small, or are hidden away in the bush some distance from roads and walking tracks. It also helps that there are no nearby major population centres. In other words, the overall level of visitation is relatively low.

There are several volcanic caves on privately owned rural properties across western Victoria. Some of the caves are not well known or regularly visited, but two in particular (Mt Hamilton and Mt Widderin) are of sufficiently large size to attract visitor interest. Permission to enter the caves must be obtained from the respective property owners but there appears to be little direct management of the caves.

Mt Hamilton Cave has 1200m of passage and is the longest volcanic cave in Victoria. It has a good range of lava features as well as a variety of secondary minerals, including gypsum crusts and radiating clusters of opaline needles. Over the years the cave has suffered a little from compaction of earth-floored areas, some scratched graffiti and minor muddying of, or damage to, secondary mineral growths.

Mt Widderin Cave comprises two large, mud-floored chambers. The cave was once a major bat roosting site. It had large accumulations of guano that were mined in the mid-19th century and which may have contributed to the disappearance of the bats. The guano hosted a range of unusual phosphate minerals and it is (was) the type locality for several of them. The cave has extensive graffiti, the oldest of which dates back to the 1850s and the early 20th Century at which time the cave was used for dances and other social gatherings.

Although this is still an interesting cave, it has been significantly impacted over the years, especially in the 19th and early 20th Centuries.

Figure 2. Graffiti in the entrance area of Mt Widderin Cave

<u>Undara, Queensland</u>

The Undara Volcanic National Park is in the inland of far north Queensland. The caves are all in a flow that originated at the Mt Undara volcano about 190,000 years ago.

More than 60 caves, totalling in excess of 7km of passages, are known. Some of the caves have important cultural and biological values and have restricted access, as do caves that are considered unsafe (for example because of high levels of carbon dioxide or roof stability concerns). However, several caves are reasonably robust and are open to the public for guided tours. Most of these caves are segments less than 200m long and are separated by large collapse entrances. This means light penetrates into them and there is no need for installed lighting. The original basalt floors are generally covered with fine sediments, or mud. Some caves have elevated walkways for the convenience and comfort of visitors, but this also greatly reduces floor compaction and damage to tree roots growing in the soil (Figure 3).

Figure 3. The entrance area of Stephensons Cave showing the elevated walkway that keeps visitors off the earth floor and in doing so, protects tree roots and habitat for invertebrates.

Lines of small rocks are also used to define a route in Mikoshi Cave and this also limits the area of compaction. In the longer Wind Tunnel, there are few convenient rocks to use for defining a route along the earth-floored areas of passage, but cord lines could be easy installed to limit the area of foot-traffic impact and could be sited to avoid sensitive areas.

Barkers Cave is one of the longest (~900m) and most impressive caves in the Undara area (Middleton, 2010). Elevated stairs have been installed down the steep entrance slope. Beyond that, there an elevated walkway leading to a route directly on the lava floor. At first the floor is ropy lava with lateral gutters along both walls but further in, the lava is largely covered with breakdown, sediments and mud. In some areas tape (Figure 4) has been used to define the route. Tour groups generally do not progress very far into the cave, in part to avoid disturbing bat roosting sites. The cave is a major roosting site for five species of bat, of which four breed in the cave. The most noticeable visitor impacts are mud compaction and abrasion wear on the lava floor. Ideally, the track marking should be extended to include the whole route beyond the boardwalk that is normally accessible to visitors to limit mud/ earth tracking and further abrasion damage.

Figure 4. Typical passage near the entrance of Barkers Cave showing how tape is used to define the walking trail.

Volcanic caves in other countries

In view of space and time constraints, this paper only considers public access caves in northern California (USA) and on Santa Cruz in the Galapagos Islands (Ecuador).

California

There are many volcanic caves in California and management arrangements are in place to control access to many of them. In this very brief overview, the focus is on public access caves in the Klamath and Lassen National Forests, managed by the US Forest Service and in the Lava Beds National Monument, managed by the US National Parks Service.

Subway Cave in the Lassen National Forest is just off State Highway 89 and has a sealed road to a good car park and a pleasant picnic area. A wide pathway leads to the cave where there are well constructed concrete and steel steps at both of its entrances and it is an easy horizontal walk between them. A permit is not required and there is no entry fee to the forest or the cave. It is open for all but the winter months. Not surprisingly, the cave is a very popular attraction.

Much of the solid pahoehoe (ropy) lava floor of the cave has a thin covering of earth or sand (Figure 5) . Some of this has probably washed or blown in, but it is likely some of it was tracked in on the footwear of the many thousands of visitors who are likely to have visited the cave.

The section of cave between the two entrances has a range of features in good condition. Even though the features are hardly stunning, they give visitors a good impression of what a lava cave is like. Another section of cave down-flow from the entrance steps is more interesting as it is in better condition, exhibits a wider range of features, is more colourful and has little mud or sand covering the lava floor. To its credit, the Forest Service actively discourages visitors to this section. There is no mention of it on any interpretive signs or in brochures and the passage could be easy to miss.

The site is obviously well managed. The surface facilities are in good condition and are clean. There are interpretive signs at the car park and at several points in the cave. Although there were obvious signs of wear and tear, principally the erosional effects of foot traffic on the pahoehoe lava floor, the cave is in good condition. There was virtually no rubbish and graffiti had been disguised by paint daubing (Figure 5), in an attempt to discourage the practice and improve the appearance of the cave.

Figure 5. Passage in Subway Cave showing abrasion-damaged pahoehoe lava floor (partly obscured by a thin coating of earth); and painted-over graffiti, an attempt at disguise to discourage further vandalism.

Pluto's Cave is in desert country of the Klamath National Forest about 140 kilometres north of Redding. The turnoffs to the cave are not well signposted, the car park is rudimentary and there is an unmarked and narrow 400m foot track leading to the second of the cave's five collapse entrances. Like Subway Cave, there is no fee or permit required for entry. The cave is spacious and is reputed to be about 1500m long.

As Pluto's cave is relatively old, around 190,000 years, many of the passage features commonly seen in lava caves have been destroyed, or obscured, by breakdown. The cave also looks very 'used' with footprints everywhere and worn trails across the breakdown. There is a lot of painted graffiti throughout the cave (Figure 6). Some of it may be historic, but much of it looks to be quite recent and is mindless. There is also some littering.

Figure 6. An example of the spray-painted graffiti in Pluto's Cave.

The cave and its surrounds appear to have a less obvious and less effective management regime than there is at Subway Cave. The Forest Service website and a rudimentary sign at the carpark have a little basic information about protecting the cave and what gear to take. However there is little evidence of an active management presence in terms of maintaining access tracks and signage, dealing with graffiti and directing where visitors should walk in the cave.

<u>Lava Beds National Monument</u> is in the far north of California, close to the Oregon border. More than 800 caves are known and, as they are relatively young (30,000 to 40,000 years), they exhibit a wide range of spectacular volcanic features. Around 25 caves are open to the public, although some are closed seasonally to protect hibernating bats and active maternity sites. Some caves have been closed to help prevent the introduction of white-nose syndrome, a fungal disease that is impacting on bat populations elsewhere in the US.

The open caves are signposted and have tracks to their entrances and, where necessary, steps, handrails and bridges for safe access. In several caves, breakdown has been moved aside to further facilitate access. Much of this work was done soon after the Monument was established in 1925. One cave has electric lighting, concrete paths and illuminated interpretive signs and in effect, is a self-guiding show cave.

There is an entry fee to the monument and a permit is required to enter any of the open caves. The cave permits are free and are issued at the Visitor Centre, which gives management an opportunity to brief visitors on caving safely and softly and on white-nose.

Staff in the Visitor Centre are helpful and project appropriate messages to intending cave visitors in a positive manner and appear to take their obligations to minimise WNS risk very seriously. Rangers regularly patrol the area in their vehicles, but over the several days that the author was in the area, only was one seen underground and that was on a special ranger-led interpretive trip.

Many tens of thousands of people visit the Lava Beds area each year and, as there is little direct supervision of cave visitors, it is not surprising that there are a few broken lava stalactites, some finger mark graffiti in bacterial (slime) coatings (Figure 7) and abrasion wear on lava floors in several caves (Figure 8). But considering how many visitors have passed through the caves over the years, they appear to be in remarkably good condition.

Lava Beds National Monument is a good example of how active and positive management can help to achieve sustainable use of volcanic caves.

Figure 7. Finger-mark graffiti in the gold bacterial coating ("cave slime") in Hopkins Chocolate Cave, Lava Beds National Monument.

Figure 8. Entrance area of Valentine Cave showing good examples of lava levees and lateral gutters, but also wear on floor features from passing foot traffic.

Galapagos Islands

The Galapagos Islands area is an active volcanic province. Caves are known on several islands and many of them, particularly in the Galapagos National Park have restricted access.

In the highlands of Santa Cruz Island there are many private properties where the lush vegetation has been cleared for grazing or farming purposes. Some have been developed as tourist attractions and are popular destinations for visitors seeking giant tortoises, a cool drink or a pleasant meal. However, there are also opportunities for wandering into a cave. Three caves (El Chato, Primicias and Tortuga Crossing) can be explored by anyone during daylight hours. In addition there is Bellavista Cave, which essentially operated as a standalone show cave operation, and Royal Palm Cave. This cave is located in the grounds of an exclusive hotel that offers guided tours to its guests.

All five caves have sections that are equipped with rudimentary lighting for the convenience of visitors. Lampenflora occurs in four of the caves and in three of them, it appears the lights are left on all day long, resulting in a luxuriant growth of algae, mosses and ferns (Figure 9). Several of the caves have wooden steps, handrails and light stands and in one, it appears that when wooden infrastructure is replaced, the old is simply cast aside in the cave. In the warm and humid climate of the caves, all the wood soon becomes a convenient nutrient source for a wide range of fungi.

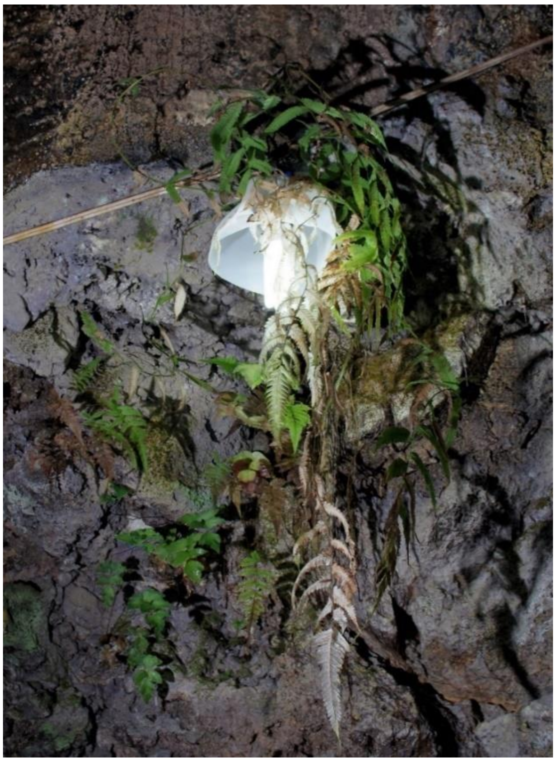

Figure 9. Significant lampenflora growths are a problem in the warm and moist conditions of caves on the Galapagos Islands when the lights are left on for long periods each day.

Some of the caves have areas of mud, and in the absence of any designated trails, tracking the mud onto adjoining areas of lava has diminished the value of the flow features. One of the caves also has spectacular displays of lava straws on a low roof and a nearby forest of tall lava stalagmites is surrounded by muddy footprints. These delicate features are being broken and muddied (Figure 10) even though they are a long way into the cave and beyond the extent of the lighting system.

In summary, the most readily accessible caves on Santa Cruz are long, have generous passage dimensions and have a spectacular range of lava cave features. Unfortunately, the caves are suffering from uninformed or inactive management and from inadequate supervision of visitors; issues that are, to an extent, linked

Figure 10. An area of delicate lava stalagmites and stalactites that have been damaged and partly covered by lumps of mud by careless visitors.

Summary and conclusions

Humans can and do have adverse impacts on caves. The impacts may be either unintentional or deliberate and may be transitory or permanent. The extent of visitor impact depends on the nature of the cave, how careful or 'cave-aware' the visitor is and also what they do and where they go. Some caves are highly susceptible to changes and can result from only a small number of visitors and, even if the effect of a single visit is negligible, it is important to consider the cumulative impacts of visitors over time.

Concerns over visitor impacts was an underlying reason for introducing a structured system of cave management in national parks in New South Wales. The system has evolved over the years and at its heart is a five-level classification scheme for individual caves. Highly classified caves receive very few visitors to protect their values. In limited access caves, which can be accessed by speleo groups, visitor impacts are controlled by management plans that specify limits on party size and on the number of trips each year. These arrangements are used in conjunction with a permit system that requires visitors to be led by an experienced leader and comply with various codes of ethics, minimal impacts and safety, among others, developed by the Australian Speleological Federation. The NSW system is comprehensive and balances protection of cave values with generally modest levels of access by speleos.

While NSW system was developed for limestone caves, the management principles, and also the codes and guidelines implemented by the speleo community, are equally applicable to volcanic caves.

Whether the NSW system could be considered to result in truly sustainable use of caves across the state is open to question. By its very nature, the cave classification system results in more impact on some caves, but less on others. However, if the cave classifications are done in an objective manner, based on good information on cave values, then it could be considered to have achieved its objectives.

Successful management of caves, irrespective of the type of rock in which they are formed, requires an understanding that not all caves are the same and that those that have the highest scientific, cultural or archaeological values should have higher levels of protection and this means allowing few visitors. It also means that most visitors should be directed to caves that are more robust, or to caves where effective management strategies are in place to limit the range of impacts.

In conclusion, sustainable use of caves is not an impossible dream. Truly sustainable use is difficult to achieve, but it is an admirable goal to aim for.

References

BRUSH, JOHN (2018). An Overview of Public Access Caves in California. *Journal of the Australasian Cave and Karst Management Association Inc, No 113*, pp30-35.

MIDDLETON, GREG (2010), compiled by. *Undara Field Guidebook*, 14th International Symposium on Vulcanospeleology, August 2010.

NPWS (2021). *Kosciuszko National Park Plan of Management, 2006* (As amended in 2010, 2014 and 2021). Published by the NSW National Parks and Wildlife Service, Department of Planning, Industry and Environment.

NPWS (2015). *Kosciuszko Karst Area Management Plan*. Published by the NSW National Parks and Wildlife Service, Office of Environment and Heritage.

WORBOYS, G (1977). A Basis for Cave Management. In: *Proceedings of the Eleventh Biennial Conference of the Australian Speleological Federation*, 1976, pp 7-16.

WORBOYS, G and BUTZ, M (1979). Principles of Karst Management. In: *Proc. 3rd Australian Conference on Cave Tourism and Management*. Published jointly by the National Parks and Wildlife Service of South Australia and the Australian Speleological Federation.

Heritage protection zoning principles and a planned pilot application for volcanoes and volcanic caves in the Dak Nong UNESCO Global Geopark

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Abstract

The Dak Nong Aspiring Geopark was established in 2015 and officially recognized as a UNESCO Global Geopark on July 7, 2020, covering an area of 4,760 km^2 of the Krong No, Cu Jut, Dak Mil, Dak Song, Dak G'long districts and the provincial city of Gia Nghia. The geoheritage system in the Geopark was initially inventoried by the Museum of Geology (General Department of Geology and Minerals of Vietnam), Vietnam National Museum of Nature (VNMN) and then by the Vietnam Institute of Geosciences and Mineral Resources (VIGMR) and preliminarily classified according to the "Criteria for provisional classification of geoheritage" adopted by UNESCO's World Heritage Committee when preparing the "Global Indicative List of Geological Sites" (GILGES), with more than 100 geoheritage sites distributed throughout the Geopark.

Similar to other types of heritage, with regard to geoheritage, after being discovered, identified, preliminarily classified and ranked, the next important task is to undertake protection zoning to ensure their integrity and identify risk factors, both existing and latent, natural and man-made, which may affect them, thereby proposing measures to be taken to protect, conserve and promote their values. Measures may include both non-structural and structural, but more importantly, they should be holistically integrated with other types of heritage, ensuring the conservation and promotion of their overall values. Moreover, at present, there are many “geosites” with outstanding scientific and aesthetic values which also require protection zoning.

Among the identified heritage sites, the Dak Nong UNESCO Global Geopark is well known for the presence of several young volcanoes and a rigorous volcanic lava tube system. This article discusses some principles in the heritage protection zoning and a planned pilot application for volcanoes and volcanic caves in this area. In addition to the protection zoning for surficial heritage sites, it discusses also the protection zoning for underground ones. And in addition to the two-level protection zoning, it recommends the third zone for landscape and environmental protection which is particularly appropriate in case of cluster-type sites.

Keywords: geopark, geoheritage, volcanic caves, heritage zoning

Images of the PowerPoint presentation appear on following pages.


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September 22Sd - 26th 2022
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Presented by: Do Thi Yen Ngoc, Tran Tan Van, Doan the Anh, Hoang Xuan Duc, Doan Thi Ngoc Huyen
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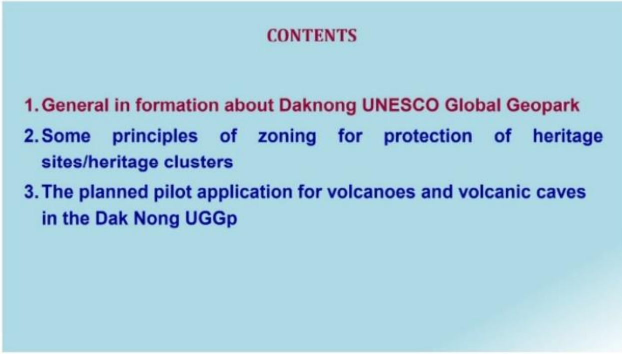
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2. Some principles of zoning for protection of heritage sites/heritage clusters
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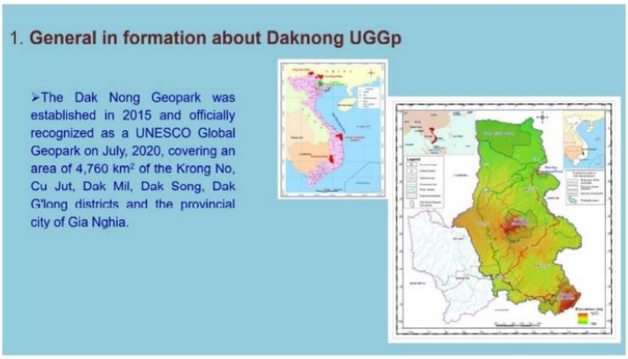
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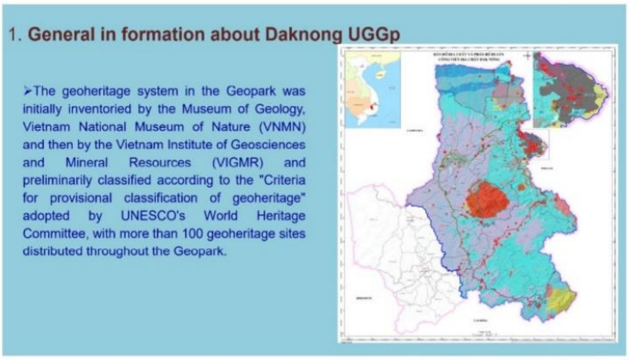
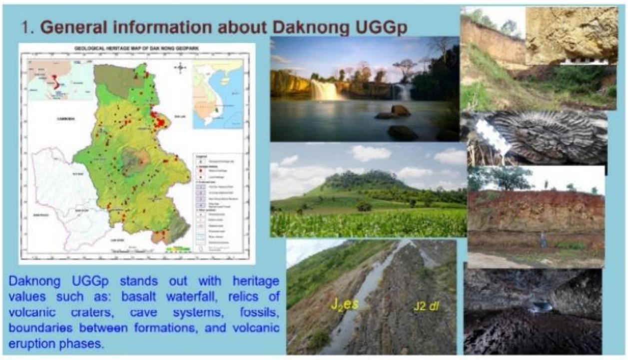
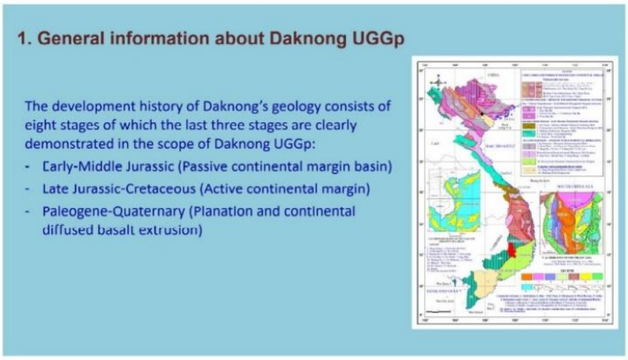
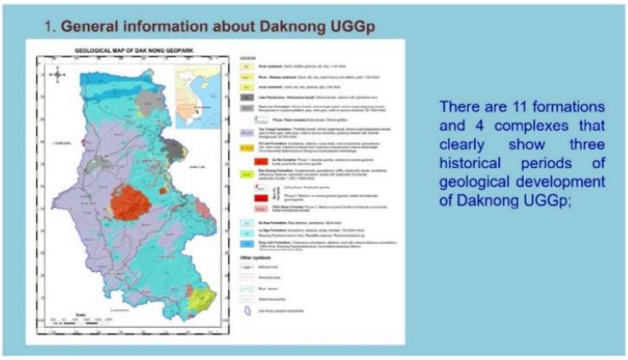
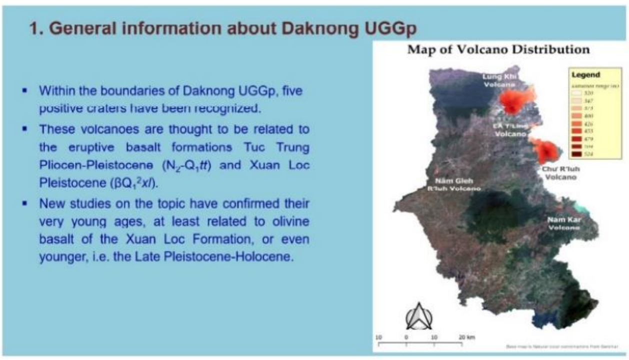
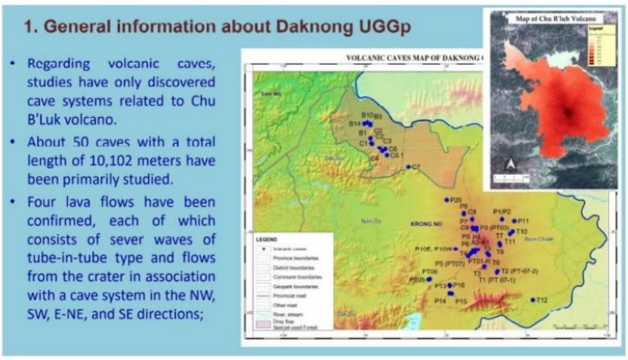

1. General in formation about Daknong UGGp
➢The geoheritage system in the Geopark was initially inventoried by the Museum of Geology, Vietnam National Museum of Nature (VNMN) and then by the Vietnam Institute of Geosciences and Mineral Resources (VIGMR) and preliminarily classified according to the "Criteria for provisional classification of geoheritage" adopted by UNESCO's World Heritage Committee, with more than 100 geoheritage sites distributed throughout the Geopark.

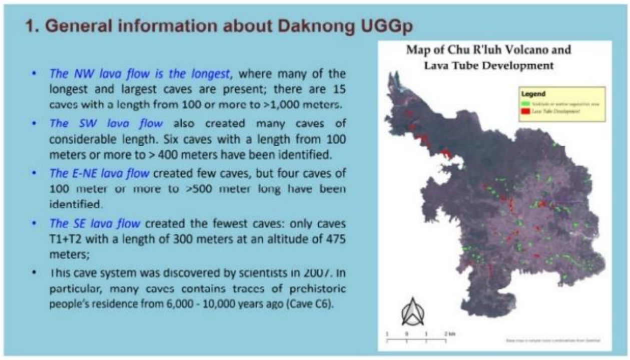

1. General information about Daknong UGGp
GEOLOGICAL HERITAGE MAP OF DAK NONG GEOPARK
Daknong UGGp stands out with heritage values such as: basalt waterfall, relics of volcanic craters, cave systems, fossils, boundaries between formations, and volcanic eruption phases.
J2 df


1. General information about Daknong UGGp
The development history of Daknong's geology consists of eight stages of which the last three stages are clearly demonstrated in the scope of Daknong UGGp:
- Early-Middle Jurassic (Passive continental margin basin)
- Late Jurassic-Cretaceous (Active continental margin)
- Paleogene-Quaternary (Planation and continental diffused basalt extrusion)


1. General information about Daknong UGGp
GEOLOGICAL MAP OF DAK NONG GEOPARK
There are 11 formations and 4 complexes that clearly show three historical periods of geological development of Daknong UGGp;


1. General information about Daknong UGGp
Map of Volcano Distribution
Within the boundaries of Daknong UGGp, five positive craters have been recognized.
These volcanoes are thought to be related to the eruptive basalt formations Tuc Trung Pliocen-Pleistocene (N_2-Q_1tt) and Xuan Loc Pleistocene (βQ_1^2xl).
New studies on the topic have confirmed their very young ages, at least related to olivine basalt of the Xuan Loc Formation, or even younger, i.e. the Late Pleistocene-Holocene.
Chu R'luh Volcano
Nam Kar Volcano


1. General information about Daknong UGGp
Regarding volcanic caves, studies have only discovered cave systems related to Chu B'Luk volcano.
About 50 caves with a total length of 10,102 meters have been primarily studied.
Four lava flows have been confirmed, each of which consists of sever waves of tube-in-tube type and flows from the crater in association with a cave system in the NW, SW, E-NE, and SE directions;
VOLCANIC CAVES MAP OF DAKNONG
Map of Chu R'luh Volcano


1. General information about Daknong UGGp
The NW lava flow is the longest, where many of the longest and largest caves are present; there are 15 caves with a length from 100 or more to >1,000 meters.
The SW lava flow also created many caves of considerable length. Six caves with a length from 100 meters or more to > 400 meters have been identified.
The E-NE lava flow created few caves, but four caves of 100 meter or more to >500 meter long have been identified.
The SE lava flow created the fewest caves: only caves T1+T2 with a length of 300 meters at an altitude of 475 meters;
This cave system was discovered by scientists in 2007. In particular, many caves contains traces of prehistoric people's residence from 6,000 - 10,000 years ago (Cave C6).
Map of Chu R'luh Volcano and Lava Tube Development

2. Some principles of zoning heritage sites/heritage clusters

- Similar to other types of heritage, with regard to geoheritage, after being discovered, identified, preliminarily classified and ranked, the next important task is to undertake protection zoning to ensure their integrity and identify risk factors, both existing and latent, natural and man-made, which may affect them;
- Thereby proposing measures to be taken to protect, conserve and promote their values.
- Moreover, at present, there are many "geosites" with outstanding scientific and aesthetic values which also require protection zoning.

2. Some principles of zoning heritage sites/heritage clusters

2.1. Position of Geoheritage and Geoparks in Mineral Law

Research and analysis of Articles 1 and 2 Mineral Law found that:

- Mineral Law does not cover all types of geological resources. Therefore, because geoheritage is a type of geological resource and not exploited as a type of mineral, it is not classified as minerals;
- Research and investigation activities on geoheritage, protection and promotion of geoheritage values, geopark development, and state management of geoheritage and geoparks... are not subject to the application of Mineral Law.

2. Some principles of zoning heritage sites/heritage clusters

2.2. Position of Geoheritage and Geoparks in Law on Cultural Heritage

According to Article 4 of the Law on Cultural Heritage, it can be seen that:

- In general, geoheritage can be considered a type of artifact or national treasure, that is, a type of tangible cultural heritage.
- Geoparks can be considered as a type of landscape. Geoheritage and geoparks can be evaluated as of local, national or special national importance;

However, more specific instructions and explanations on geoheritage and geoparks should be given.

In summary, in consideration of the Law on Cultural Heritage as mentioned above, zoning for conservation and promotion of geoheritage values could be implemented in the same way as for tangible cultural heritage sites.

2. Some principles of zoning heritage sites/heritage clusters

2.3. Protection zoning of heritage sites

As mentioned above, according to the Law on Cultural Heritage, geoheritage can be considered as scenic spots or relics of scientific, educational, aesthetic and landscape values...). Data required for zoning:

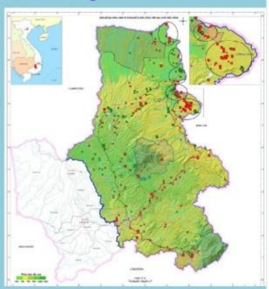
- Results of field survey and assessment of heritage site;
- Specialized maps such as: geological, geomorphological - tectonic maps;
- Topographic maps, digital elevation maps (DEMs);
- Reports on economic development and tourism planning of the study area;
- Data on current status of mining sites that can affect heritage sites in need of zoning...

2. Some principles of zoning heritage sites/heritage clusters

2.4. Protection zoning of heritage clusters

The process of investigation, survey, research, and evaluation of heritage types and geopark establishment often results in the identification of several heritage clusters, including cultural, historical, archeological, biodiversity as well as geological and geomorphological values ...

Heritage sites in each cluster are often relatively close to each other and shared some common features such as being controlled by some factors of topography, terrain, geology, natural geography, climate conditions, ecology, and other social factors. These heritage sites often support and complement each other...



2. Some principles of zoning heritage sites/heritage clusters

2.4. Protection zoning of heritage clusters

- Therefore, it is quite convenient if all of them are managed and conserved and have their values promoted as a whole.
- Within the scope of a geopark, there is another concept of heritage cluster and accordingly the need for zoning for conserving and promoting its values.
- For each heritage site in the cluster, the boundaries of protection zones I and II are still identified in accordance with regulations.

Conclusions

- Among the identified heritage sites, the Dak Nong UNESCO Global Geopark is well known for the presence of several young volcanoes and a rigorous volcanic lava tube system.
- This article discusses some principles in the heritage protection zoning and a planned pilot application for volcanoes and volcanic caves in this area. In addition to the protection zoning for surficial heritage sites, it discusses also the protection zoning for underground ones.
- And in addition to the two-level protection zoning, it recommends the third zone for landscape and environmental protection which is particularly appropriate in case of cluster-type sites.

Outstanding Heritage values of Volcanic caves and their significance for Tourism and Sustainable development in Dak Nong UNESCO Global Geopark

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Abstract

Over the last 15 years, there have been many specialized, interdisciplinary, and multidisciplinary research projects in geology, biology, and archaeological culture for the volcanic caves in Krongno, since they were first discovered in 2007. The results of these works have recognized/established in the Krongno volcanic cave system a very rich and diverse complex of mixed heritage, including geological and non-geological heritages containing global outstanding value in both scientific and practical significance as well. They are invaluable resources for scientific study, education, and tourism development. The achievements of Dak Nong UNESCO Global Geopark depend on the unique valuable heritages recognized and presented in the geopark scientific dossier and the effectiveness of spreading the heritage values to the community and tourists for the conservation and development objectives during the development process of the Geopark. This article introduces the outstanding heritage values of the volcanic caves and the role of heritage interpretation in boosting sustainable tourism development in Dak Nong UGGp.

Keywords: outstanding heritage values; heritage interpretation, sustainable tourism development.

I. Introduction

After being discovered, established, recognized, and conserved, natural heritages (geological heritage and biodiversity) and cultural heritages (archaeological and historical, etc.) must be used for tourism and sustainable socio-economic development. It is the third but the most crucial goal among the three goals for all geoparks in the UNESCO Global Geopark Network (UNESCO GGN).

Dak Nong UNESCO Global Geopark (Dak Nong UGGp) containing numerous outstanding valuable heritages, including volcano and volcanic cave heritages, is the third UNESCO Global Geopark of Vietnam, which was recognized in 2020 and is now in the third year of the noble title. So, it is crucial to have the proper method and activities of heritage promotion to make "sleeping heritages" in the geopark scientific dossier become lively and attractive tourism products to obtain economic effectiveness. In fact, some heritages in the Geopark seem "sleeping" and need to wake them up for sustainable socio-economic development in the locality. The problem-solving in this first stage is essential to make everything smooth in the future geopark management and development process. In this paper, the authors would like to introduce the outstanding heritage values of the volcanic caves in the Dak Nong UGGp, and the crucial role of heritage interpretation and promotion in boosting tourism development in the frame of the geopark's activities in Dak Nong UGGp.

II. Heritage Values of the Volcanic Caves in Dak Nong UGGp

II.1 Heritage values in the ABC component system

Geoparks contain natural heritages (geological heritage, biodiversity) and cultural ones. They all contain both scientific and practical significance. In this paper, all the heritages just mentioned will be listed and described in "the ABC component system" in the approach of the "ABC Interpretation Method" [13, 14]. This system includes three components: A, B, and C:

- "A" is "ABIOTIC" ("A" is the abbreviation for the "Abiotic" component, which refers to the "nonliving" attribute of heritage);

- "B" is "BIOTIC" ("B" is the abbreviation for the "Biotic" component, which refers to the "living" attribute of heritage); and:

- "C" is "CULTURAL" ("C" is the abbreviation for the "Cultural" component, which refers to the human's attribute).

This system classifies all heritage values in geopark for proper conservation and development by their own attributes.

II.2 Heritage values of the volcanic caves in Dak Nong UGGp in the ABC component system

The Krongno volcanic cave system is located northeast of Dak Nong UGGp. It has been known as the outstanding heritage of Dak Nong UGGp with approx. 50 lava caves were discovered and located on the map; 21/50 of those caves have been surveyed measured and mapped to define heritage values. As usual in almost geoparks, both natural and cultural heritages defined in the Krongno volcanic caves consist of geological heritage, biodiversity value, and cultural/archaeological heritage. So, what are the "A, B, C components" in the Krongno volcanic caves? Why could they become the pillar heritages, supporting the noble title the Dak Nong UGGp? The study results of the projects conducted in the area showed that all A, B, C components of the Krongno volcanic caves contributed to creating their outstanding values of the Krongno volcanic cave in Dak Nong UGGp. They all are contained in the Krongno volcanic caves in Dak Nong UGGp.

II.2.1 The A component (Abiotic component) in the Krongno volcanic caves is geological heritage values occur in 7/10 heritage types according to the UNESCO's GILGES classification of geological heritages, including:

* Type A – Paleontological: Lava tree moulds have been found in caves: C2, C3, C4, etc. (Figure 1). It demonstrates the environment of the tropical forest with many big trees, on which the basaltic lava flowed from the Chu B'Luck volcano eruption in the southeast [5, 6, 7].

* Type B – Morphological: Cross-section shapes of lava tubes, cupolas, lava falls, lava levees, lava seals, lava windows, lava lakes, lava linings, tube-in-tube structures, lava stalactites, lava bridges, and numerous lava formations in the caves, etc. are all grouped in the Morphological type B of the Krongno volcanic cave [5, 6, 7], (Figures 2, 3).

* Type C – Paleo-environmental belonging to this type of heritage, has a pillow bridge basalt at the end of cave T1, formed by the later phase of lava flowing into the cave and meeting with floodwater at the end of the cave, [5,6,7]. Or another one was expressed in the shape of multi-generation lava stalactites (Figure 4, Cave C6.1).

* Type D – Rock: a series of lava formations in the Krongno volcanic caves such as porous basalt, lava stalactite, lava glaze on the wall and ceiling, pahoehoe lava, and A'a lava, belong to this type (Figure 5). They are evidence of the endogenous origin of the Krongno volcanic caves.

* Type E – Stratigraphical: In the case of the Krongno volcanic cave, stratigraphical heritage is defined as boundaries between eruption phases that were sharply retained on the lava marks on the wall or pillars of the cave, generations of lava linings, lava shelves, multi-generation stalactites, etc. (Figure 6) [5,6,7].

* Type F – Mineral and Mineral Resources: In the Krongno volcanic caves, endogenous minerals of the basaltic rock are dominant, meanwhile some secondary minerals such as calcite in the secondary stalactites were also found. Especially, in several cases, we have right found opal-chalcedony in basalt. Although the presence of opal-chalcedony in the Krongno lava caves is a rare and quite strange phenomenon, it could be scientifically explained (Figure 7).

* Type I – Tectonics: The tectonic heritage type in the Krongno volcanic caves is demonstrated by tectonic fissures, cutting through all lava formations or different eruption phases in the cave (Figure 8). It is possible to distinguish from co-formed occurring cracks due to volume shrinkage when lava cooling and solidifying [5,6,7].

	
Figure 1. Type A: Paleontological heritage.	*Figure 2. Type B: Morphological heritage.*
	
Figure 3. Type B: Morphological heritage.	*Figure 4. Type C: Paleo-environmental heritage.*
	
Figure 5. Type D: Rock.	*Figure 6. Type E – Stratigraphical heritage.*
	
Figure 7. Type F: Minerals & Mineral Resources.	*Figure 8. Type I – Tectonics.*

II.2.2 The B component (Biotic component) in the Krongno volcanic caves is the biological world: "B" is the abbreviation for the "Biotic component", which is grown based on the "A" component –

geological foundation. B component contains the biodiversity in the volcanic caves, demonstrated in a flora and fauna world that differs from those living in the out-cave habitat. The A (Abiotic - geological) and B (Biotic) components belong to the "Natural Heritages" group in the UNESCO's heritage classification. However, in the ABC system, “natural heritages” in the UNESCO's heritage classification are divided into two different components by nonliving (A) and living (B) attributes. In detail, The “B” component in the Krongno volcanic caves consists of:

- Creatures in the biological world (Plantae, Fungi, Protista, Archaea, Bacteria, etc.) from the relatively light entrance cave to the utterly dark area of the volcanic caves demonstrate markedly change in both species composition and the density: from the bushy complex of vines species living in the entrance areas → ferns → mosses, lichens → saprophytic fungi → to luminescent fungi, different bacteria in the dark and deep segments of lava tubes [4; 6; 7], (Fig.9a; 9b).

- Diversity of animals: Krong No volcanic caves are a shelter and gathering place for many species of wildlife, ranging from mammals to insects, such as pigs, weasel, hedgehog, squirrel, mice, monitor, lizard salamanders, bats, snakes, toad and frogs. These are "temporary residents" in volcanic caves, including many species listed in the Red Book of Vietnam that need to be protected and preserved [4; 6; 7], (Figures 9a and 9b).

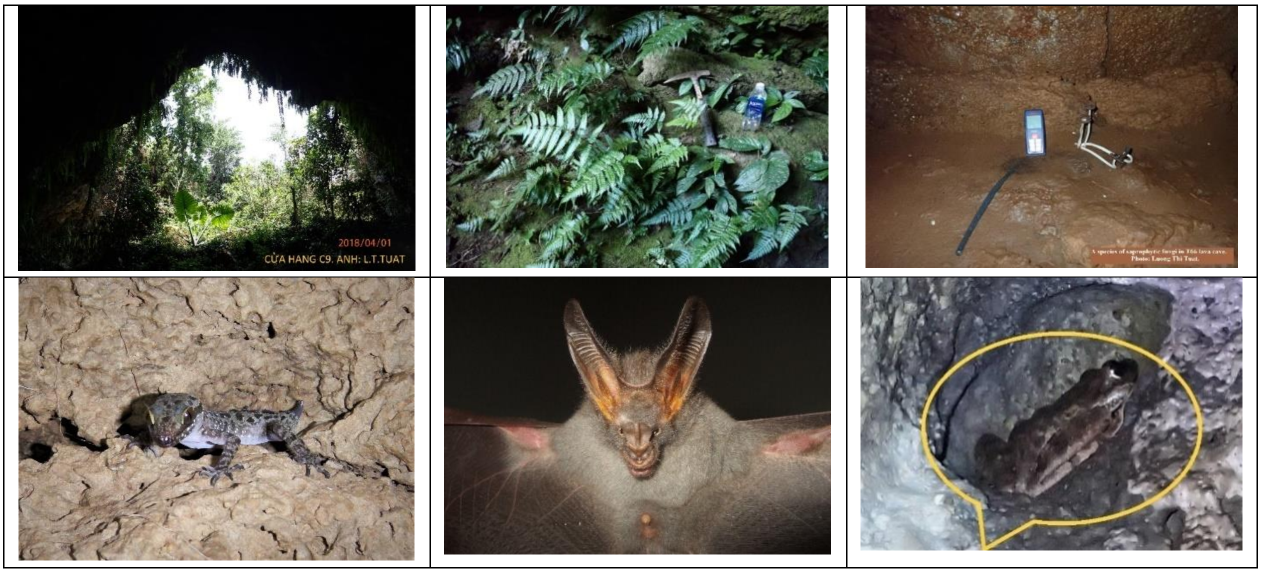

Figure 9a. Biodiversity in the Krongno lava caves.

Figure 9b. Biodiversity in the Krongno lava caves.

- Diversity of invertebrates (including insects), out of 10 surveyed caves, researchers found 240 individuals, including 54 families belonging to 7 classes, and 21 orders; identified 69 species of organisms, many of which may be new to science, including an international publication: the scorpion *Chaerilus chubluk* (named Chu B'Luk volcano, endemic to the cave) Krong No volcanic cave [4,6,7].

II.2.3 The C component (Cultural component): "C" is the abbreviation for the "Cultural" value, which was grown based on the foundation of both "A" and "B" components in the lava caves. In the case of the Krongno lava caves, "C" is the heritage value of prehistoric archaeological remains, discovered and contributed to the Krongno volcanic cave becoming the highlight and pillar heritage of the Dak Nong UGGp.

As far as we know, because of some reason, prehistoric human remains have not been found/discovered in almost volcanic caves of the world. So, the presence of this heritage type in the Krongno cave has been evaluated as the rarest, most unique, and most important cultural heritage of the region and the world as well. Of course, it belongs to the C component in the A, B, C component system mentioned above.

Figure 10. Artifacts from the excavation pit in cave C6.1.

Fig.11. Panorama location graves in the excavation pit in cave C6.1.

Figure 12. Artifacts in the excavation pit in cave C6.1.

Figure 13. The skull M1. has been restored.

Thanks to the result of excavation in the C6.1 cave, tens of thousands of valuable artifacts have been collected (Figures 10 to 13). Different types of archaeological relics in Krong No volcanic caves have been established, including residence relics, workshop relics, relics of burial sites (Figure 11), temporary hunting camps, and religious ritual relics (?) (the last relic type has not been excavated) [4, 6, 7, 9, 10]. In the burial sites (graves) in the C6.1 excavation pit, a series of human skeletons have been found, some of them in well-preserved conditions such as M1, M2, and M4 (Figure 11). The prehistoric archaeological relics in the C6.1 cave have been recorded as a heritage of global outstanding value. Especially, prehistoric human remains - very rare in volcanic caves in the world - have been honoured as one of the 10 domestic typical science and technology events in 2018 [6, 7]. This important discovery and study result have got the attention of many domestic and international scientists and scientific research organizations, including the world's leading experts and prestigious scientific research institutions such as the Centre for Geogenetics at the Natural History Museum of Denmark, the University of Copenhagen of Denmark, where their scientists have been cooperating with Vietnam in-depth research. The results will be gradually published, which will answer the related anthropological questions in the region and the world. Also, as far as the study results on the prehistoric relics that we've obtained in the C6.1 cave, this heritage showed an important chain, marking the adaptation of humans to the natural environment in Vietnam and the regional context.

III. The Role of Heritage Interpretation and Promotion in Boosting Tourism Development in Dak Nong UGGp

III.1 Overview of the state of the conservation and development of volcanic geological heritages in the world:

Scientifically, on the geological aspect, volcanoes and volcanic caves are important heritages, mainly related to the activities of tectonic plates distributed along the Ring of Fire rings of the Pacific Ocean. On the other hand, they could also be considered memories of Mother Earth's waves of anger from the past left on the Earth's surface. Therefore, volcano and volcanic cave geoparks are a very important part, that needs to be conserved and developed as valuable tourism resources. Recently, we are all on the way to protecting this treasure. UNESCO's international conservation titles for volcanic landscapes include:

1. World heritage;
2. Biosphere Reserves, and
3. Geoparks.

Many of them in different related nations and territories (Japan, Korea, China, USA, Australia, New Zealand, Turkey, etc.) have obtained great success in conserving and developing this heritage type. However, there are still many failures somewhere, even in developed countries. So, what is the lesson for Dak Nong UGGp?

III.2 Conservation and "exploitation" volcanic geological heritages in Dak Nong UGGp

Vietnam has nobly achieved the title Dak Nong UGGp thanks to numerous geological heritages related to volcanic eruption activities. Volcanic geological heritages are considered "the soul" of Dak Nong UGGp, especially volcanic caves are the highlights attracting all tourist segments. Recently, three geo-trails have been operated in the Geopark, including:

- The Lands of sounds;
- The Rhapsody of Fire and Water;
- Wind of Changes Concerto.

Each geo-trail leads tourists to an integrated/alternating group of geological and cultural heritage sites to experience and share mixed heritage values in only a geo-trail. Generally, they are excellent geo-trail structures that have often been set up for tourists in almost UGGps. Taking these geo-trails, the tourists could feel the harmony or connection between geological and cultural heritages with their eager expectations.

However, it seems that heritages, especially volcanic cave heritages in Dak Nong UGGp haven't been perfectly conserved and developed as they've been expected to meet the requirements of typical geo-tourism tours.

The reality often happens: at first, tourists usually are eager to rush into the cave, look through, then go out without any impression. And their feedbacks are often "karstic caves are much more beautiful", then they immediately listed a series of karstic that they have been to. If we receive much of that feedback type, obviously we will fail. The reason is that a karstic cave display is more attractive than a lava cave due to the formation mechanism. So, we must "exploit" the interior beauty of lava caves by paying much attention to "heritage interpretation". Heritages in geopark scientific dossier are "sleeping heritages". All heritages in the ABC component system are considered "sleeping heritages". Hence, they are not helpful in socio-economic life. Sometimes, they are even damaged by exterior effects.

III.3 State of the heritage interpretation in Dak Nong UGGp

On the geo-trails in Dak Nong UGGp, we can see "heritage interpretation panels" at the geosites. However, they are still monotonic, less attractive, have less information, and even make mistakes in scientific content. Almost heritages in lava caves are still not set up for "heritage interpretation" (Figure 14).

Figure 14. Examples of interpretation panels and tourists visiting lava caves in Dak Nong UGGp.

Taking an observation of some tourist groups by chance, we realized that: After visiting the lava cave in Krongno, many people expressed their disappointment. They often complained without hesitating: “There’s nothing in the lava cave. The karstic caves in Phong Nha – Ke Bang and Ha Long Bay World Natural Heritages are more beautiful and attractive”, so they said: “That’s enough for it now” then never come back. Almost visitors get in, then rush disappointedly out without any impression. Why? Who’s fault? Of course, it isn't lava cave fault. The more tourists are disappointed about the lava cave, the more we all - scientists, managers, travel agencies, and the geopark management board - feel sad. It's our failure in the community approach to the amazing heritage values of the Krongno lava caves. So, how to solve and improve that problem? One of the best solutions is "heritage interpretation" and "professional geo-tour guide".

III.4 Using a proper heritage interpretation system as by the ABC component system in Dak Nong UGGp as an effective tool to wake heritage up for tourism development in Dak Nong UGGp

As mentioned above, in II.1, Prof. Ross Dowling proposed a new approach to the natural environment. He divided NATURE into three groups [13, 14]. By that, heritages in the Krongno lava caves contain all three A, B, and C components. The proper heritage interpretation system should be used as an effective tool to wake heritage up for tourism development in Dak Nong UGGp. An appropriate interpretation of heritage in Dak Nong UGGp must cover all fields of heritage: "A" component: 7 geological heritages; "B" lava cave biodiversity and last: C - cultural values. They should be explained in a popular, vivid, attractive way by the A, B, C component system as an effective tool to wake heritage up for tourism development in Dak Nong UGGp. All lava formations in the lava caves could be vivid tourism resources with a proper heritage interpretation (Figures 15 to 24), and the same for B and C components.

Figure 15. Glaze in P11 cave. Interpretation?

Figure 16. Lava lining in P11. Interpretation?

	
Figure 17. Cupola in C8. Interpretation?	*Figure 18. Lava pile in P10: interpretation?*
	
Figure 19. Scroll lava lining in T6.1	*Figure 20. Multi-color stalactites in C6.1*
	
Figure 21. Secondary stalactites in T1 cave.	*Figure 22. Unique structure in A.1 lava cave*
	
Figure 23. Lava pit in T66 cave	*Figure 24. A joint of two lava flows in C2 have met and created "ship-bow structure" in C2 cave*

IV. Conclusions

1. The Krongno volcanic cave with the largest scale, length, and uniqueness in Southeast Asia, and China, contains outstanding global values in all three areas of heritage: geological heritage, biodiversity, and cultural heritage; is the special highlight and the soul of Dak Nong UGGp.

2. Volcanic caves in Dak Nong Geopark are of great scientific and practical value. In terms of science: this is an open-air museum about a combination of natural and cultural heritage types for scientific research on nature and people. They are a set of vivid natural educational tools in many fields of natural sciences (cave geology, cave biology, paleogeography, climate change, etc.), socio-sciences (Archaeology, Ethnology, and history of human development, etc.) of the Central Highlands in the regional context. In practice, they are a special highlight attracting domestic and

international communities to research, study, visit and enjoy. So, it is an invaluable resource for sustainable tourism and socio-economic development.

3. The aesthetic value of the volcanic cave is shown in the lava cave shapes and a lot of interior lava formations. Most of them look very fancy and unique, arousing the desire to explore, unleashing your imagination, enjoying and creating art and culture, and hiding unexpected aesthetic values in painting and artistic creation.

4. The economic value of the cave is tourism development. So it is necessary to invest in research to ensure the safety of the heritage and tourists. Also, heritage interpretation must be considered an effective tool for improving public awareness of the conservation and sustainable development of Dak Nong UGGp's heritage, including lava caves.

6. It is necessary to invest in implementing specialized, multi-disciplinary, and interdisciplinary studies related to volcanic caves to meet the demand for conservation and effective development of heritage in Dak Nong UGGp in regional integration and linkage.

References

1. HIROSHI TACHIHARA, YURIKO CHIKANO (2018). Vietnam volcanic cave 2017 survey report, NPO Vulcano Speleological Society, Japan. Archives of the Vietnam National Museum of Nature, Hanoi.

2. LA THE PHUC (2008). Report "Investigation and research on geological heritage for construction of geopark and environmental protection in Trinh Nu waterfall area, Cu Jut district, Dak Nong province, Vietnam". Archives of the Vietnam Geological Museum, Hanoi.

3. LA THE PHUC, HIROSHI TACHIHARA, TSUTOMU HONDA, TRUONG QUANG QUY, LUONG THI TUAT (2015). The unique geological heritage of volcanic caves in Dak Nong has been discovered and set a record. Journal of Geology, Series A, issue 349, 1-2/2015, p. 28-38.

4. LA THE PHUC (2018). Report "Research, investigation, and assessment of geological heritage, construction of geopark in Krong No area, Dak Nong province". Archived at the Vietnam Museum of Nature, Hanoi.

5. LA THE PHUC, LUONG THI TUAT, HIROSHI TACHIHARA, TSUTOMU HONDA, BUI VAN THOM, NGUYEN BA HUNG, TRAN MINH DUC, NGUYEN TRUNG MINH, NGUYEN HOANG, YURIKO CHIKANO, KATSUI YOSHIDA, NGUYEN THANH TUNG, PHAM NGOC DANH, NGUYEN THI MAI HOA, HOANG THI BIEN, TRUONG QUANG QUY (2018). Geological values of lava caves in Krongno Volcano Geopark, Daknong, Vietnam. Vietnam Journal of Earth Science 40(4), 299-319

6. LA THE PHUC (2020). Report "Study on the value of cave heritage, propose to build museums and preserve in situ in the Central Highlands; Take for example the volcanic cave in Krong No, Dak Nong province", code TN17/T06. Archived at the Vietnam National Museum of Nature, Hanoi.

7. LA THE PHUC, HIROSHI TACHIHARA, TSUTOMU HONDA, LUONG THI TUAT, BUI VAN THOM, PHAM DINH SAC, NGUYEN KHAC SU, NGUYEN TIEN HOA, VU TRONG TAN, NGUYEN TIEN SON, NGUYEN LOI LOC, DINH XUAN HOANG, NGUYEN THANH TUNG, DANG THI HAI YEN, NGUYEN TRUNG MINH (2020). Volcanic caves - a special highlight of the outstanding global value of the UNESCO global geopark Dak Nong, 2020. Geology Journal, series A, No. 373 - 374/2020, Tr.100 - 113 (The 45th anniversary of the establishment of the Southern Geological Mapping Federation).

8. LA THE PHUC, LUONG THI TUAT, HIROSHI TACHIHARA, TSUTOMU HONDA, BUI VAN THOM, NGUYEN BA HUNG, TRAN MINH DUC, NGUYEN TRUNG MINH (2020). Volcanic caves in Vietnam. Sciences and practical interdisciplinary journal. Publishing

Moscow State University. 2020, Vol. 42 (No 1). 13-23. DOI: 10.29003/m876.0514-7468. 2020_42_1/13-23

9. NGUYEN KHAC SU, LA THE PHUC (2020). The historical and cultural value of Dak Nong volcanic cave relic. Vietnam Journal of Social Sciences, Issue 4:58 -66.

10. NGUYEN KHAC SU, NGUYEN LAN CUONG, LA THE PHUC, NGUYEN TRUNG MINH, LUONG THI TUAT, LE XUAN HUNG, VU TIEN DUC (2020). Excavation of volcanic cave C6-1 Krong No (Dak Nong) - Documentation and new awareness about the prehistory of the Central Highlands. Vietnam Archaeology No. 4-2020, pp.16-22

11. NGUYEN NGOC TRUONG, LA THE PHUC, NGUYEN TRUNG MINH, BUI QUANG ANH, LUONG THI TUAT AND DANG THI HAI YEN (2021). Comparison of the characteristics of sediment composition in the C6.1 cave culture and volcanic caves in Krong No area, Dak Nong, Journal of Archaeology, No. 2/2021, Hanoi.

12. WILSON R. LOURENCO, PHAM DINH SAC, TRAN THI HANG (2020). The genus Chaerilus Simon, 1877, in Vietnam with the description of a new species found in a volcanic cave (*Scorpiones, Chaerilidae*). Bulletin de la Société entomologique de France, 2020, vol 125 (1), 19-28. doi.org/10.32475/bsef_2106

13. ROSS DOWNING (2010). Geotourism's Global Growth. Geoheritage. http://dx.doi.org/10.1007/s12371-010-0024-7

14. ROSS DOWNING (2020). Interpreting Geological and Mining Heritage" in The Geotourism Industry in the 21st Century. The Origin, Principles, and Futuristic Approach. *Edited By Bahram Nekouie Sadry.* https://doi.org/10.1201/9780429292798

15. www.vulcanospeleology.org

A preliminary planning proposal for conservation and sustainable development of Volcanic Cave heritages in Dak Nong UNESCO Global Geopark

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Abstract

Natural and cultural heritages in the volcanic caves of Dak Nong UNESCO Global Geopark are invaluable resources for scientific research, education, national security, and, especially for tourism, socio-economic sustainable development in Dak Nong province. However, the current situation of conservation and development of volcanic caves in the geopark is still inadequate and has not been effectively implemented. Hence, there is an important and urgent need for adequate and scientific planning to reasonably conserve and develop the heritages within regional linkages and international integration. The article introduces some major scientific ideas concerning using orientation, and a preliminary proposal for planning on conservation and sustainable development of the volcanic cave heritages in Dak Nong UNESCO Global Geopark. Looking forward to the cooperation and sharing of experiences in the fields relating to conservation research and sustainable development of volcanic cave heritages from domestic and foreign scientists, managers, and investors.

Keywords: planning; conservation; development.

Introduction

In the Krongno volcanic cave system in Dak Nong UGGp, 50 volcanic caves have been discovered so far, including 21 caves measured and initially studied with a total length of 8,073.3 metres and 12 caves with prehistoric relics; two caves excavated (Cave C6.1 and C6'), in which the cave C6.1 has been excavated for on-site conservation and exhibition with the purposes for scientific research, education and tourism promotion; eight caves sampled for biodiversity research with the discovery of new species, etc. [7;8;9]. Outcomes of five projects at different levels (international cooperation, institutional, provincial, academy, and state levels) in various fields of geology, geological heritage, biodiversity, cultural heritage/prehistoric archaeological sites, the paleogeographic and biogeochemical environment in volcanic caves, etc., showed that this cave system has the most outstanding scale, length, and uniqueness in Southeast Asia and China, and becomes the special highlight of Dak Nong UGGp [1;2;3;6;7;8;9;10;11;12;13;14;15]. Heritage in the volcanic caves comprises both geological and non-geological values with significant scientific research and education values and priceless resources for tourism promotion and sustainable socio-economic development. Derived from the diverse and unique features of these volcanic caves and their heritage categories, the management capacity for heritage conservation and development, and practical demand for development, there is an important and urgent need for adequate and scientific planning to reasonably conserve and develop the heritages for the sustainable development of Dak Nong UGGp.

Conservation and Sustainable Development Planning of the Volcanic Cave System in Dak Nong UGGp

Planning basis

The conservation and sustainable development planning of the volcanic cave system in Dak Nong UGGp is based on three fundamental principles: Planning perspective and objective; scientific basis; and objective practical needs.

<u>Planning perspective</u>
(and with an objective of conservation and development planning of volcanic cave heritage values)

Volcanic caves are priceless and non-renewable resources granted by Mother Nature. If heritages are damaged leading to destruction, they will be lost forever. Therefore, protecting volcanic cave heritages against the invasive effects of nature and humans during reasonable management and development of heritage values for sustainable socio-economic development is a necessary and objective demand. Having a roadmap for reasonable conservation and development is crucial to avoid all invasive and destructive risks of the–values. Heritages must initially be protected and preserved to be “exploited” for development. The relationship between heritage conservation and development of heritage in general and volcanic cave heritages, in particular, is two-way, objectively dialectic, and inseparable as two sides of a unified entity: conservation for development and development for conservation. “Heritage development” is the development of heritage *values* (not of *physical/material* aspects of the heritage) for multiple purposes. Related scientific research must be considered the first necessary and important step to achieving effective conservation and sustainable development of volcanic cave heritage values.

From a macro perspective, up to now, the conservation task of volcanic caves in Dak Nong UGGp has been well done. Recently, some related schemes on volcanic cave distribution with possible negative impacts and invasive risks on volcanic cave heritages have been handled such as the Scheme on potential assessment of pozzolanic ore in Buon Choa’h - Quang Phu, Krong No, Dak Nong toward exploiting and processing pozzolanic ore for economic development has been revoked by the Ministry of Natural Resources and Environment (MONRE) after a short-time implementation, or Plan for Buon Choa’h landfill of Krong No, near the Chu B’Luk crater has been relocated, etc.

The volcanic cave system is mostly located within the area of 3 communes: Dak Sor, Nam Da, and Buon Choa’h of Krong No district [4;7] and within the area of Dray Sap Special Use Forest Landscape (under the management of Nam Nung Natural Reserve Area), Dray Sap tourism site (under the management of Lien Thanh Construction and Investment Joint Stock Company, Dak Nong) and Buon Choa’h Protection Forest (under the management of Phu Gia Phat - HCM Investment Joint Stock Company). Professional management of volcanic cave heritages belongs to the Management Board of Dak Nong UGGp. Some key volcanic caves such as C6.1 and its surroundings are under the protection and management of the Krong No Information Center. The above-mentioned management structure of volcanic cave heritage has shown that organization structure and conservation activities in Krong No have been receiving remarkable attention. However, further effective conservation and development still require unity and detailed assignments. Currently, the development of volcanic cave heritages in Dak Nong UGGp has not yet been implemented due to many reasons such as insufficient infrastructure, lack of equipment to keep safety for heritages and visitors, unavailable preparation for emergency response, etc.

<u>Scientific basis</u>

Study outcomes of 10 scientific research projects (directly and indirectly) related to volcanic cave heritages in different fields of geology, geological heritage, biology, biodiversity, cultural heritages and prehistoric relics, paleogeographic and biogeochemical environment in the volcanic caves, etc are the useful scientific basis for conservation and development of volcanic cave heritages and relevant plannings.

- In terms of geology and geological heritages: Each cave is a mixed entity of geological heritages, including 7/10 types of heritages (A - Palaeontology, B - Geomorphology, C – Paleo-environment, D - Rock, E - Stratigraphy, F – Minerals-Mineral Resources, and I - Tectonics) [4;7]. Due to the formation mechanism, volcanic cave rock was formed by the solidifying process of moving molten lava flow, so it was highly cracked with unstable interior structure, especially in shallow caves with less than 10m distribution compared to the terrain surface). Hence, almost volcanic caves are vulnerable to natural and human impacts as well (Figures 1 & 2). To secure the safety of volcanic cave heritages and visitors, there must be a survey and study for safety reinforcement of cave ceilings and walls. In the Krong No volcanic caves, this task has not yet been done, so the caves are not open for visiting. Geological heritages and interior formations of volcanic caves are diverse, however, not fairly and fully distributed in all caves with special features. Some volcanic caves contain especially outstanding scientific values which are "sensitive" to human impacts, hence, they must be carefully preserved for scientific research (caves: C7; C8). Some caves with vertical entrances around 25-26 metres (caves: P8; P20) [1;2;3;12;13;14;15] are extremely dangerous, yet able to develop for adventure tourism under a professional organization with full equipment for emergency response. For the caves with prehistoric remains excavated and on-site exhibited, there is the possibility of a simultaneous combination of volcanic cave visiting and spiritual tourism. Additionally, some submerged caves (caves: DS1; DS2) need further study for appropriate conservation and development proposals, etc.

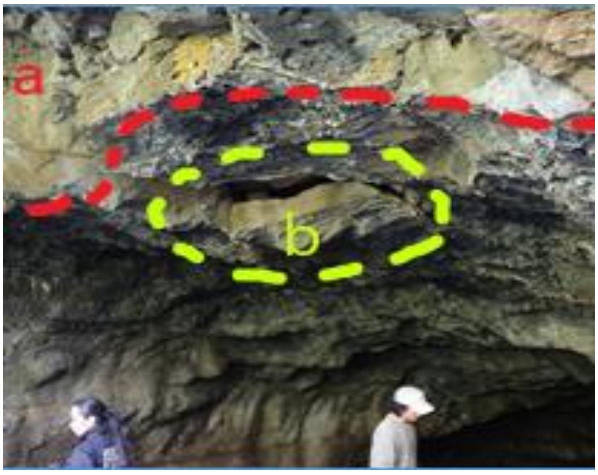

Figure 1. The C6.1 cave ceiling: a. has collapsed; b. risk of collapse and needs to be reinforced for safety.

Figure 2. A stainless steel pillar was built to support the cave ceiling from the risk of collapse and ensure safety during excavation.

- In terms of biology and biodiversity: Study outcomes have shown that volcanic caves in Krong No contain high biodiversity. Survey results and collecting samples of eight caves (at shallow level) have identified 69 in-cave species with 30 possibly new and endemic ones for volcanic caves [15], including new species of scorpion named *Chaerilus chubluk* (named after the Chu B'Luk volcano) (Figure 3 with red frame) which has been internationally published [9]. This is one of the very rare publications of invertebrates in volcanic caves in not only Vietnam but also the world. In-depth expert analysis of the in-cave species is still being focused on for further action of discoveries. The biodiversity of each cave is different, and some cave still contains species of creatures that have not been studied and deciphered, hence, there is a need for further study before opening for visitors. The animal world has established food chains with balanced biology and maintains sustainably the ecosystems within volcanic caves. In-cave creatures, especially those in dark areas, are sensitive to environmental changes such as temperature, light, noise, smog, etc. Therefore, effective/reasonable conservation and exploitation of volcanic heritages must consider carrying threshold before opening for visitors.

Figure 3. Temporarily and permanently settled creatures in the volcanic caves in Krong No [7;8].

- In terms of cultural heritages and prehistoric relics: Cultural heritages within volcanic caves in Dak Nong UGGp mostly are prehistoric archaeological relics, including 1. settlement relics, 2. workshop relics, 3. grave relics, 4. relics of temporary hunting camp, 5. relics of religious rituals [7;10]. The fifth one has recently been discovered in 2020 and has not yet been excavated, hence, volcanic caves containing them need to be protected and preserved without being opened for visitors to avoid heritage encroachment. While heritages have not been studied in detail/excavated, visitors entering the caves may blur or even erase the cultural vestiges and destroy the relics. Cave C6.1 containing three types of relics (settlement, workshop, and grave ones) has been excavated about 10.3m^2. All structures of the cultural layer, featuring relics in the excavation pit are preserved on-site (Figure 4) and scanned with 3D technology for printing display versions on-site and in different exhibit facilities as needed. Based on the detailed study, the in-cave environment/habitat of prehistoric people has been restored with 1:1 scale mannequins for on-site display and conservation (Figure 5). However, so far, the on-site exhibition in cave C6.1 has not yet been conducted for visitors due to limited control of infringing factors such as cave ceiling collapse, rain seepage, moisture, etc. causing the collapse risk in the excavation pit, mould damage to the relics/artifacts, etc. Therefore, besides reinforcement of the ceiling, some caves (e.g. C6.1) with on-site exhibitions must also be waterproofed.

Within the volcanic cave system in Dak Nong UGGp, some caves are measured and surveyed (21 caves) yet not investigated for archaeological details, while some relics have not been excavated, hence, should not be opened for visitors to protect heritage from damage.

- In terms of the paleogeographic and biogeochemical environment: The outcomes show that the paleogeographic and biogeochemical environment in volcanic caves of Dak Nong UGGp is favourable for the preservation of organic relics (bones, animal teeth, human remains, etc.) due to the main factors of temperature, sedimentary composition and microbiology/bacteria. In-cave temperature is stable at a low level (22-26^{0}C) which is unfavourable environmental conditions for the intrusion and growth of micro-organisms/bacteria, so organic relics are difficult to decompose. The sedimentary composition of prehistoric cave C6.1 has a weak alkalinity-neutral level with high CaO content due to the addition of mollusc shells thrown out by humans after eating. When rainwater seeps down from the cave ceiling and permeates through the cultural layer, the acidity of the rainwater is neutralized, causing no dissolution, or washing/diffusion of CaO out of the remains. The CaO content in the cultural sedimentary layer of cave C6.1 is even higher than that of the skeletal remains, while in-cave micro-organisms/bacteria amount of C6.1 is even lower than that of the surroundings, causing unfavourable conditions for the organic and bone decomposition process [7;11].

The above-mentioned study outcomes have shown that conservation of volcanic cave heritages is urgent and must be conducted before any development of heritage values for tourism. The work of waterproofing in caves with archaeological relics is the most necessary to protect relics/heritages and prevent mould and mildew from destroying the in-cave cultural relics and artifacts. The processing and reinforcement of cave heritage for tourism exploitation must be selected and conducted in steps and phases by the capacity and development practices of Dak Nong UGGp.

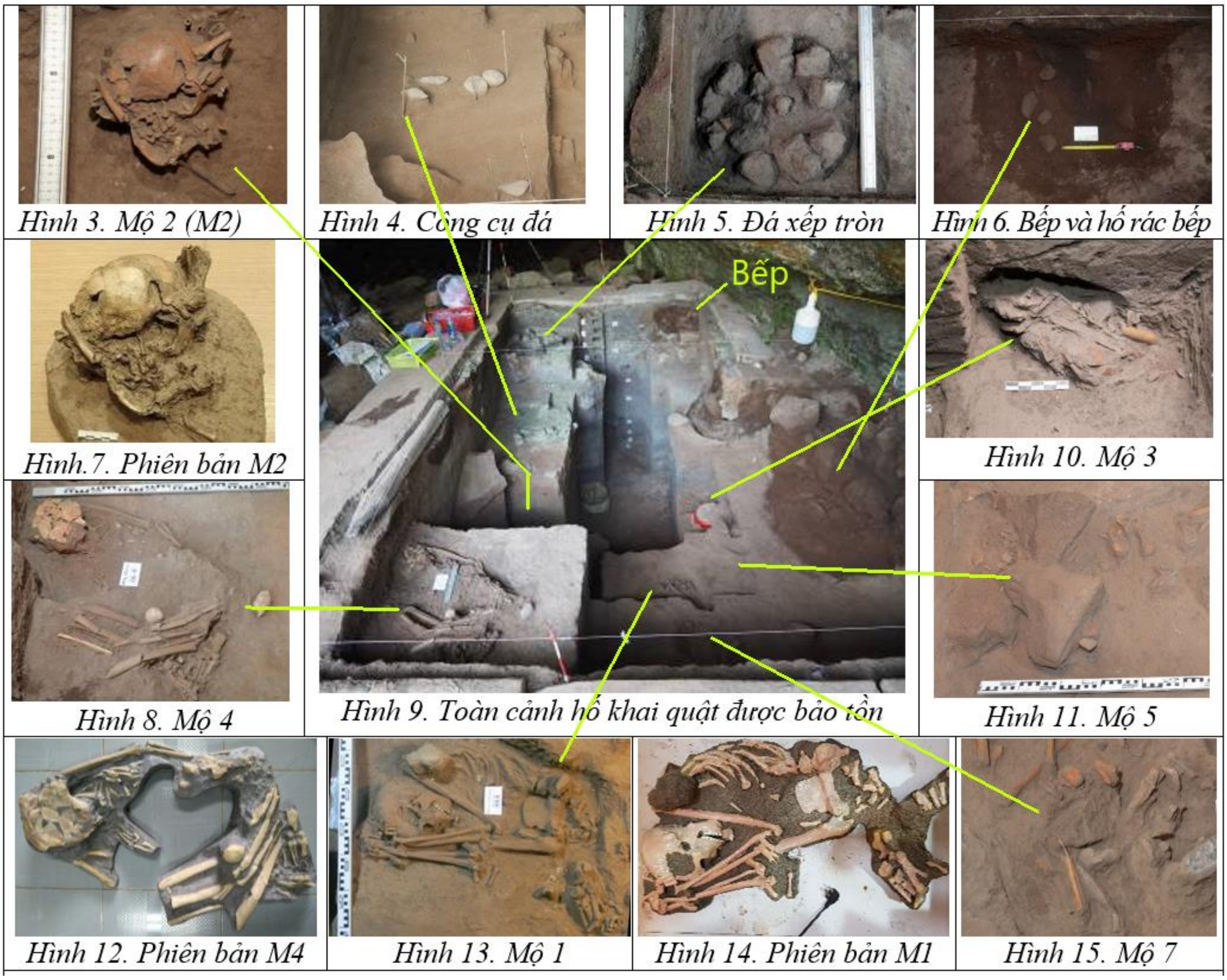

Figure 4. Panorama of the excavation pit and typical relics preserved on-site [7].

Figure 5. Mannequins re-creating daily life scenes around the fire of prehistoric people [7].

Practical needs

All planning, including those for conservation and development of volcanic caves, must be suitable to practical needs, specifically the following main issues: level and outcomes of basic research on cave heritages, infrastructure for exploitation of cave heritages, community demand and investment capacity, management and organization of the implementation as well as carrying threshold of the volcanic cave heritage system.

- Level and outcomes of basic research on cave heritages: Scientific research and surveying assessment must be conducted first and foremost. In Dak Nong UGGp, this task has been partially conducted with initial positive outcomes. Among mapped 50 caves, there are only 29 caves without measurement and detailed study of geological, biodiversity and cultural heritage values (including submerged caves) [7;8]. Those caves should not be opened to visitors.

- Infrastructure and technical equipment relating to the conservation and exploitation of volcanic caves are still limited and outdated. There is no specialized equipment and guarantee for heritage conservation and exploitation as well as organization for emergency response. For caves with steep entrances more than 10 metres deep, it is yet impossible for visiting without specialized equipment due to fatal danger (there are rumours that someone had even been found dead because of falling into a deep and dangerous cave without specialized equipment). Adventure tourism with an exploration of submerged caves is new and attractive, yet not able to be promoted. There are also difficulties in the traffic system within the cave distribution area while the demands of disabled, marginalized visitors are unsatisfied.

- Community demand: There are numerous interests and demands for visiting volcanic caves. However, visitors are diverse, hence, their demands/purposes for visiting are different, including scientific research, teaching, and training, adventure tourism, sightseeing, experiencing, and spiritual activities, etc. Therefore, detailed planning must consider each group of visitors to meet the various and increasing needs of the public.

Although outstanding values and highlights for tourist attractions, now volcanic caves in Dak Nong UGGp are still not open to visitors for security reasons. Since the establishment of Dak Nong UGGp, at least three scientific research projects on tourism at provincial and national levels have been undertaken.

Up to now, three geo-trails have been operated in the Geopark, including:

- The Lands of Sounds;
- The Rhapsody of Fire and Water; and
- Wind of Changes Concerto.

However, the core value at the international level of Dak Nong UGGp, namely volcanic cave heritages, still is not promoted and developed reasonably and effectively. It is indeed wasteful and regrettable. On the other side, although lava caves have not been officially opened for visitors, there is still daily visit of people (spontaneous tourism) despite all warnings and lack of supervision from management agencies, damaging the safety of both heritages and visitors. This means improper protection and conservation of volcanic cave heritages while there is a high demand from the public for cave visiting. Hence, it is crucial to promote tourism based on the heritage values of volcanic caves for socio-economic development as soon as possible.

Conservation and development planning of volcanic cave heritage in Dak Nong UGGp

Planning for volcanic cave conservation

All volcanic caves in Dak Nong UGGp need to be protected and preserved for multiple purposes, including scientific research and education, tourism development, and sustainable socio-economic development.

Planning for volcanic cave development

In principle, surveyed, measured, and studied caves can be reinforced for safety and assessed for the carrying capacity of the heritages for development. Otherwise, they should not be tourism developed. The volcanic caves will be categorized based on their featuring values to serve the diverse and increasing needs of the public and practical demands. Based on criteria on featuring values, volcanic caves in Dak Nong UGGp can be categorized as follows:

- Scientific caves containing significant scientific values, which are preserved specially for scientific research (e.g. caves C7, P20, etc.) [7;8].

- Spiritual caves containing prehistoric human remains, and religious ritual relics (e.g. cave C6.1, XY (XY: an anonymization cave for protection and conservation), etc. can be developed for spiritual tourism [7;8].

- Adventure caves, having vertical entrances with over 20m depth (e.g. caves: P8, P20, etc.) or submerged underground caves (e.g. cave DS1, DS2, etc.) which can be developed for adventure tourism [7;8] with considerable investment, special instruction for heritage conservation and strict safety regulations for visitors.

- Public/ common caves (e.g. caves: P1, P2, P3, P11, A1, etc.) [7;8].

The development of volcanic caves will be conducted step by step and in different phases (this is the divergence of planning) depending on the investment and management capacity as well as the infrastructure development, and social demand and must be attached to the historical, cultural scenic landscape of Dray Sap - Gia Long waterfall complex, Buon Choa'h Special Use Forest Landscape, Chu B'Luk Volcanic Landscape, Lava Field in close linkage with heritages sites in Dak Nong UGGp and its surrounding areas.

Transportation system planning

Planning for tourism development in the volcanic caves of Dak Nong UGGp must be attached to the overall planning for the development of the geopark as well as local infrastructure planning within the volcanic cave heritage area, especially with transport system planning. Due to features of volcanic caves as shallow underground caves with weak structures, location in special use, and protected forest areas, cave ecology is very sensitive to environmental changes such as vibration, noise, smog, pollution, etc. Therefore, it is not recommended to make roads for large tonnage and internal combustion engine vehicles yet it is recommended to use monorail technology - electric vehicles on rails (Figure 6) for traffic systems within volcanic caves due to its benefits, including no tree-cutting for road clearance, no impacts on underground caves and forest's natural environment, no CO_2 emission and noise to the in-cave environment, no vibrations that can cause ceiling collapse, no disruption to the biodiversity and the balance of ecosystems in the caves, effective management over visitor volume and tourism waste, minimized negative impacts on cave heritage and natural environment.

Figure 6. Applying monorail technology in transport and tourism development for conservation of geological heritages, ecological landscape, and environment (Source: Nikkari Co., Ltd, Japan).

The volcanic cave traffic/tourism routes here should be designed with the Chu B'Luk volcano as the centre. The monorail system will start from three departure stations, reach most of the volcanic caves and the crater of Chu B'Luck volcano, lead up to the rim of the volcano, and even down to the bottom of the Chu B'Luk volcano. It is required to design monorail lines close to the cave entrance so visitors leaving the monorail can walk right into the cave. For Cave C9, a monorail can be designed to go through the cave to inspire visitors.

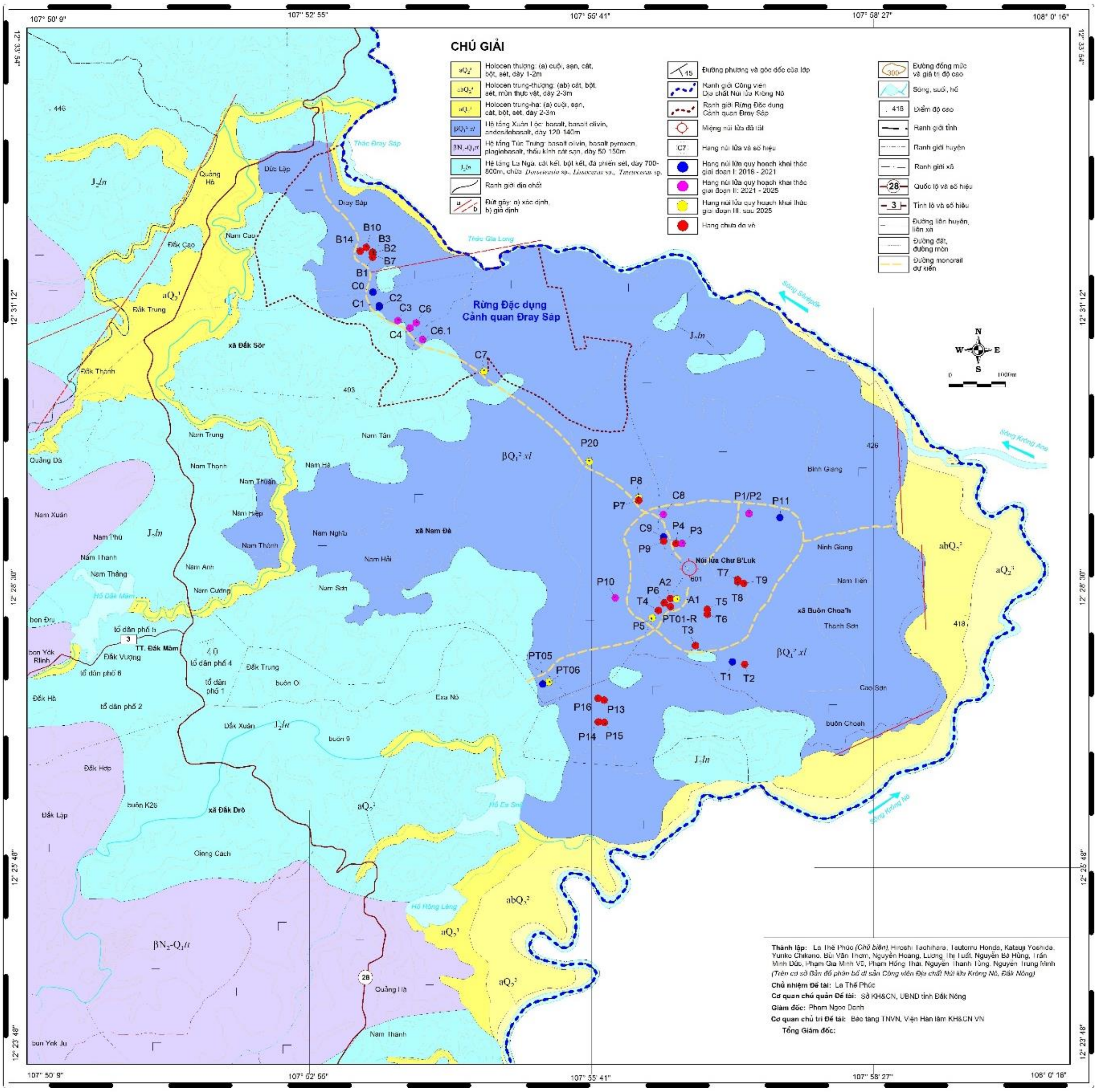

Figure 7. Distribution and planning of the volcanic caves in Dak Nong UGGp.

Three departure stations for visitor welcome (Figure 7) include:

- *The first direction:* from Dray Sap to volcanic caves in the Special Use Forest Landscape of Dray Sap. This is a welcome point for visitors from Buon Ma Thuot down to Ho Chi Minh City, along the National Road 14 to Cu Jut into the National Road 28 (linking route with tourist attractions/heritages/relics in the northern part of Dak Nong UGGp).
- *The second direction:* from Quynh Ngoc ferry port (Krong Ana, Dak Lak) into the volcanic caves within Buon Choa'h. This is a welcome point for visitors from Krong Ana (linking route with tourist attractions/heritages/relics in Buon Me Thuot and Krong Ana).

- *The third direction:* from Dak Mam into the Protection Forest of Buon Choa'h. This is a welcome point for visitors from Dak Mil to Dak Lak, Lam Dong, and Gia Nghia from the National Road 28 (linking route with tourist attractions/heritages/relics in the central and southern parts of Dak Nong UGGp).

Caves distributed along these three directions will be developed/opened for visitor welcome sequentially in steps depending on the levels/outcomes of research.

Discussion

Transportation is among the most prominent/important in planning for heritage development and conservation of volcanic caves in Dak Nong UGGp. Attention should be paid to how to develop a traffic system to meet the diverse and increasing requirements of the public (including disabled and marginalized visitors) as well as to ensure the effective and sustainable exploitation of the heritages.

Regarding the means of transport to ensure the safety of volcanic cave heritages, vehicles using internal combustion engines and large tonnage vehicles are not allowed in the cave area. Without considering the requirement of heritage conservation, there are main types of transport that can be constructed, including tram road, monorail, and cable car. Constructing tram roads requires cutting down trees, site clearance, leveling, and building roads which will inevitably infringe on the natural environment and volcanic cave heritages. Constructing a cable car would not be appropriate since the heritage complex of volcanic caves has a wide distribution of up to 60 to 80 km square with scattered caves which is difficult to locate cable stations and very costly with low efficiency. Meanwhile, applying monorail will need almost no tree cutting or road building, creating no negative impacts on the natural environment and heritages. Based on the SWOT analysis, the application of the monorail technology is the optimal option that is recommended for selection in planning for the construction of a transportation system within the heritage complex of volcanic caves in Dak Nong UGGp.

Conclusions and Recommendations

1. The perspective of "conservation for development of volcanic cave heritages" and "development for conservation of volcanic cave heritages" must be considered as a core guideline throughout the process of research, planning, management, development, and development of Dak Nong UGGp.

2. All volcanic caves in Dak Nong UGGp must be protected and preserved while further investigated fully and in detail to provide an addition to the diverse heritage values of the volcanic cave system and other multiple purposes, including tourism development and preparation of re-assessment for title award of Dak Nong UGGp (every four years).

4. Developing a transportation system within the volcanic cave area requires a system that is compatible with the protection of conservation values and would support the effective and sustainable development of the volcanic cave heritage. It is considered that the application of monorail technology would be the most suitable option.

5. Before being opened for tourism development, volcanic caves must be surveyed and assessed for the safety and carrying capacity of the heritages, processed, and reinforced for the safety of both heritages and tourists.

6. Heritage in the volcanic caves comprises geological and non-geological values, significant scientific research and education values, and priceless resources for tourism promotion and sustainable socio-economic development. Therefore, it is necessary to have expert support/advice in different fields (geo-heritage, biological, cultural-archaeological, planning, tourism development, marketing, etc.).

This paper results in the first stage of two projects:

- The State Project: "Research on the scientific basis and solutions for sustainable tourism development at the Dak Nong UNESCO Global Geopark", coded DTDLXH-11/22, under the Decision 768/QD-BKHCN, dated 13th May 2022.

- The research cooperation project at the Institutional and Provincial level: “Conservation and promotion of heritage value of the outdoor archaeological relics in the Dak Nong UNESCO Global Geopark” (2022-2024).

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References

1. HONDA, TSUTOMU; TACHIHARA, HIROSHI (2015). *Vietnam Volcanic Cave Survey*, e-Newsletter, UIS, Commission of Volcanic Caves, 69, 11-12p. http://www.vulcanospeleology.org/newsletters/Vulcano 69.pdf.

2. HONDA, TSUTOMU; TACHIHARA, HIROSHI; LA THE PHUC; LUONG THI TUAT; TRUONG QUANG QUY (2015). *Lava tube caves and tree moulds of Chu B’luk volcano in The Central Highlands of Vietnam, 2015*. Fall meeting of the Volcanological Society of Japan. https://www.jstage.jst.go.jp/article/vsj/2015/0/2015_185/_pdf/-char/ja.

3. HONDA, TSUTOMU; TACHIHARA, HIROSHI; LA THE PHUC; LUONG THI TUAT; TRUONG QUANG QUY (2016). *Vietnam Volcanic Cave Survey Project Report*, 17th International Symposium of Vulcanospeleology, Hawaii, 2016. http://www.cavepics.com/IVS17/HONDAIII.pdf.

4. LA THE PHUC *et al*. (2018). *Researching, investigating, and evaluating geological heritages, establishing geopark in Krong No area, Dak Nong province (2016-2018).* Final report of the provincial project on Sciences and Technology. Archived at the Department of Sciences and Technology of Dak Nong province, and Vietnam National Museum of Nature, Hanoi.

5. LA THE PHUC, LUONG THI TUAT, HIROSHI TACHIHARA, TSUTOMU HONDA, BUI VAN THOM, NGUYEN BA HUNG, TRAN MINH DUC, NGUYEN TRUNG MINH, NGUYEN HOANG, YURIKO CHIKANO, KATSUJI YOSHIDA, NGUYEN THANH TUNG, PHAM NGOC DANH, NGUYEN THI MAI HOA, HOANG THI BIEN, TRUONG QUANG QUY (2018). *Geological values of lava caves in Krong No Volcano Geopark, Dak Nong, Vietnam.* Vietnam Journal of Earth Sciences, 40(4), 299-319, https://doi.org/10.15625/0866-7187/40/4/13101.

6. LA THE PHUC, LUONG THI TUAT, HIROSHI TACHIHARA, TSUTOMU HONDA, BUI VAN THOM, NGUYEN BA HUNG, TRAN MINH DUC, NGUYEN TRUNG MINH (2020). *Volcanic caves in Vietnam.* The Life of The Earth - Sciences and practical interdisciplinary journal. Publishing Moscow State University. Vol. 42(1), 2020, pp.13-23. DOI: 10.29003/m876.0514-7468.2020_42_1/13-23.

7. LA THE PHUC *et al* (2020). *Study the heritage values of the caves, propose building on-site conservation museums in The Central Highlands; take an example of the volcanic cave in Krong No, Dak Nong province (2017-2020)* - Final report of the project coded TN17/T06, under the National Programme Tay Nguyen 2016-2020. Archived at Vietnam National Museum of Nature, Hanoi.

8. LA THE PHUC; TACHIHARA, HIROSHI; HONDA, TSUTOMU; LUONG THI TUAT; BUI VAN THOM; PHAM DINH SAC; NGUYEN KHAC SU; NGUYEN TIEN HOA; VU TRONG TAN; NGUYEN TIEN SON; NGUYEN LOI LOC; DINH XUAN HOANG; NGUYEN THANH TUNG; DANG THI HAI YEN; NGUYEN TRUNG MINH (2020). *Volcanic the caves – global outstanding, unique highlight of Dak Nong UNESCO Global Geopark*. Journal of Geology. Series A. N0 373-374, pp.100-113.

9. LOURENÇO W.; TRAN T.-H; & PHAM D.-S (2020). *The genus Chaerilus Simon, 1877, in Vietnam with the description of a new species found in a volcanic cave (Scorpiones, Chaerilidae).* Bulletin de la Société entomologique de France, 125 (1) : 19 28. Doi: 10.32475/bsef_2106.

10. NGUYN KHAC SU, NGUYEN LAN CUONG, LA THE PHUC, NGUYEN TRUNG MINH, LUONG THI TUAT, LE XUAN HUNG, VU TIEN DUC (2020). *Excavation of volcanic cave C6-1 Krong No (Dak Nong) - Documentation and new awareness about the prehistory of The Central Highlands.* Vietnam Archaeology N04 - 2020, pp.16-22, Hanoi.

11. NGUYEN NGOC TRUONG, LA THE PHUC, NGUYEN TRUNG MINH, BUI QUANG ANH, LUONG THI TUAT, DANG THI HAI YEN (2021). *Comparison of the sediment composition in the cultural stratum of the C6.1 cave and other volcanic caves in Krong No, Dak Nong.* Vietnam Archaeology, N02 - 2021, pp.38-48, Hanoi.

12. TACHIHARA, HIROSHI (Editor), NPO Vulcano-Speleological Society (2012). *Vietnam Volcanic Cave Project Preliminary Report 17~23, April 2012*, Sakae Print Company. http://volcanocave.kitakaruizawa.net/documents/vietnam201204-2.pdf.

13. TACHIHARA, HIROSHI (Editor), NPO Vulcano-Speleological Society (2014). *Vietnam Volcanic Cave Project Intermediate Report 28 December 2013~4 January 2014*, Sakae Print Company.

14. TACHIHARA, HIROSHI (Editor), NPO Vulcano-Speleological Society (2015). *Vietnam Volcanic Cave Project Third Report 26 December 2014~3 January 2015*, Sakae Print Company.

15. TACHIHARA, HIROSHI; CHIKANO, YURIKO, Editors (2017). *Vietnam volcanic cave 2017 survey report*. NPO Vulcano-Speleological Society, Japan.

Sustainable development in Laauoleola Cave, Savai'i, Samoa

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Abstract

Laauoleola Cave lies in the north of Savai'i, the largest and highest of the Samoan islands. Savai'i is a massive basaltic shield volcano rising to 1,858m, and the cave was probably formed in the eruptions of the 1700s. In early 2019 Auckland Speleological Group (New Zealand) were contacted by TRC Tourism Limited for help with exploring and surveying the cave. The plan for the project was to fully explore the cave, to help the cave owners formalise their caving trip, and to provide photographs and a cave map to promote the cave. The Samoa Tourism Authority, the NZ Aid Programme, and the New Zealand Ministry of Foreign Affairs and Trade provided financial support as part of the 'Beautiful Samoa' initiative, assisting the local community to develop independent tourism ventures. The project scope covered upgrading facilities, improving signage, building a nature walk to the cave entrance, and promoting sustainable family-run cave tours. The surveyed cave is 5km long and is currently the longest in Samoa.

Key words: volcanic caves; exploration; sustainable development.

Background

In 2017 the Samoa Tourism Authority (STA) looked for natural locations that could be a focus for tourism across their country. STA established their five year "Beautiful Samoa" project to fund improvements at selected sites with a goal of building a more sustainable tourism industry. The government of New Zealand helped fund this initiative through their NZ Aid Programme and the New Zealand Ministry of Foreign Affairs and Trade.

The international organisation TRC Tourism Limited was selected to implement changes at some of the selected locations. Their focus is on creating sustainable solutions for people, places, and cultures, balancing both environmental and visitor management. In early 2019 Auckland Speleological Group (ASG) were contacted by TRC Tourism Limited to help with exploring and surveying the Laauoleola lava cave in Samoa. Auckland, New Zealand has many lava caves, and Auckland Speleological Group has experience in exploring, mapping, and conserving these.

Laauoleola Cave, commonly known as A'opo Cave, is situated in the small village of A'opo in the north of the island of Savai'i. The current village leader, Chief Umamoa Laauoleola, discovered the cave in 1954. The family name means 'Tree of Life', and the family's timber business manages a sustainable plantation of mahogany, teak, ifilele, kava, eucalyptus, and banyan trees. Cave tours with small groups are solely run by the Laauoleola family. Their trips cover the first few hundred metres of the cave, but Chief Umamoa had explored it further, reaching a large lake which he suspected to be the sea seeping into the cave. While this seemed unlikely given that A'opo is 5km from the nearest coastline, we sought to prove whether this was the case.

The plan for the project was to fully explore the cave, to help the cave owners formalise their tourist caving trips, and to provide photographs and a cave map to promote the cave. Murray Wilson and Karl Burt coordinated the discussions with TRC Tourism. It was agreed that a group of five cavers would travel to Samoa in May 2019 for nine days to complete the tasks: Karl Burt, Peter Crossley, Kevin Jose, Paul Rowe, and Pete Smith.

A survey of the lava caves of the Independent State of Samoa (formerly called Western Samoa) had already been undertaken by the Australian caver Greg Middleton over June and July 2002. His research and the caves he mapped are published in the Sydney Speleological Society journal (MIDDLETON, 2003). The caves documented on this trip include a map covering 400m of passage in Laauoleola Cave. The cave has been labelled as "A'opo Cave" on this early map and in most online references.

Location

Savai'i, the largest and highest of the Samoan islands, consists of a massive basaltic shield volcano rising to 1,858m (Savai'i Volcano Profile). Many cinder cones and lava cones cover the higher levels of Savai'i. The volcano is currently dormant, with the most recent eruptions occurring in 1905 and 1911.

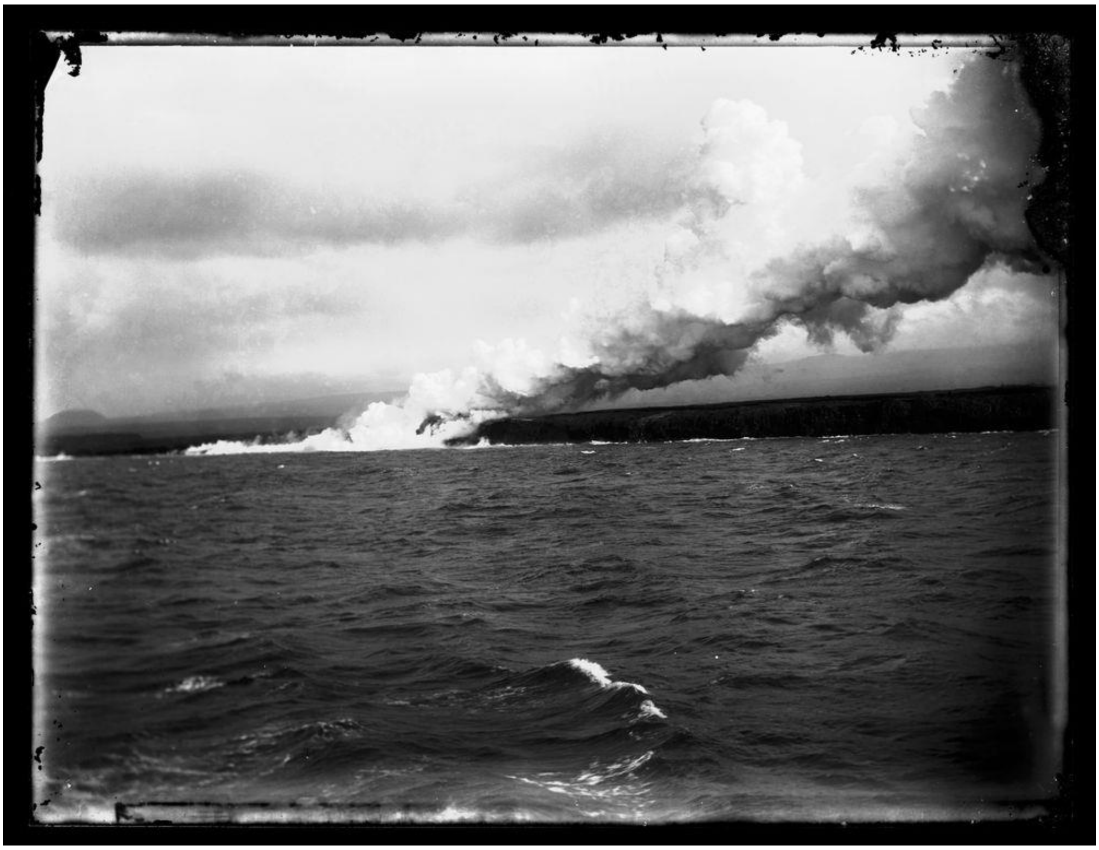


Figure 1. Eruption of Matavanu in 1905. Te Papa photographic collection. Photograph: Thomas Andrew.

Travel off the tracks is difficult in the rainforest and, as a result, all the known lava caves lie close to villages, roads, or tracks. Much of the northern area of Savai'i is covered is rough broken lava flows with very little soil. The village families each have a scattering of hardy taro plants, banana palms, and a few pigs (pua'a / Sus Scrofa). The pigs roam freely but return home for food and shelter. Every village has high raised platforms for rubbish to be placed ready for collection and out of the reach of the pigs.

Laauoleola Cave appears to lie in a lava flow from the 1700s. Well-established lowland broadleaf rainforest covers the land above the cave. Laauoleola Cave has been only narrowly missed by the 1902 lava flow to the west where currently only small trees have established themselves over the flow.

A gravelled path lined with native plantings leads past the family's houses and down through the forest. It is a 20-minute walk to reach the collapsed lava tube which forms the entrance of the cave at 13.53242° South, 172.52937° West WGS, at an altitude of 160m above sea level.

The lower levels of the cave should not be visited in moderate to heavy rain. A prominent surface valley appears to feed a significant water catchment into the system a few hundred metres southeast of the entrance. There is no obvious entry point within the cave for this surface valley, but all the rock is extremely porous.

Figure 2. Levitiko (Levi) Laauoleola stands in the entrance of the cave. Photograph: Kevin Jose.

Exploration

From Samoa's international airport on the island of Upolu, it is a two-hour ferry journey across to the island of Savai'i. The exploration team was transported by a local van driver another two hours to the north of the island on the sealed ring road that hugs the coast. The island is only lightly populated, particularly because the 1902 and 1911 eruptions covered some of the fertile land and forced many families to move to Upolu.

Samoa is a strongly Christian society and most of the people attend church services on Sundays. The driver picked the exploration team in the afternoon after church services for their first visit to Laauoleola Cave. It was a 20-minute drive with good views of the highest peak, Mount Silisili. The team were formally introduced to Chief Umamoa, the grandfather of the family, and he shared his knowledge of the cave. The team also met the extended Laauoleola family, learnt about the current caving trips (usually led by Levi Laauoleola), and explained to the family how a typical cave map is created.

The team's first goal was to view the parts of the cave regularly accessed. The cave temperature is about 27 Celsius, with 100% humidity and constant drips from the ceiling. Levi Laauoleola joined the team as a guide for the first trip, and he pointed out features in the entrance series. The cave begins with an easy walking passage in 3-5m diameter lava tubes, followed by two locations with holes dropping to lower levels, before finally reaching a short drop down to a much larger tube. The lowest level section of a few hundred metres was notable for the big, rounded stones and the thick deposits of silt. It was clear that at times a high-volume river must flow through this section of the cave. Levi Laauoleola was impressed with the brightness of the caving lights and when the group reached a rockfall he was keen to crawl through the boulders to try and find a way on. The group spent half an hour trying to find different routes through, but it was completely blocked with mud and silt. This section must often be a lake, and it seems likely this is the 'sea' that earlier visitors had reached. The exploration team were worried at this point that the cave was not going to be much longer than the section they had already seen, but on their way out another crawl was found leading to a 7 m diameter tube. This was followed for a few hundred metres before running out of time.

Figure 3. London Missionary Society church destroyed in the 1905 eruption. Photograph: Paul Rowe

Figure 4. Ladder descent to the lower level. Photograph: Paul Rowe.

Figure 5. Levi Laauoleola in a passage near the entrance. Photograph: Peter Crossley

Figure 6. Kevin Jose looks at the silt level at the lower end of the cave. Photograph: Pete Smith

For the rest of the week exploring the cave, the group usually split into two teams: Karl Burt, Pete Smith, and Paul Rowe formed a survey team, while Peter Crossley and Kevin Jose were the photography and 3D scanning team. This worked well as the two teams continually overtook each other in the cave. The survey team would let the photography team know of significant features, while the photography team let the survey team know of less obvious side passages. Levi Laauoleola joined the exploration team for the first couple of trips. The upper-level circuit near the entrance is well worn and includes a confusing array of arrows spray-painted on the walls. Some of the arrows lead into the cave and some lead out. Once the large lower-level tube is reached, there is a slightly worn path going uphill several hundred metres and this was limit of Levi Laauoleola's knowledge of the cave. At this point there is an unstable crawl leading to further side passages as well as a fork in the main passage heading uphill.

Figure 7. Main lower-level passage. Photograph: Peter Crossley.

The range of rock formations and passage shapes is remarkable. There are perfectly circular tubes heading straight into the distance. Ledges sometimes form such even patterns that they appear man-made. In rare locations calcium seeps through the ceiling to create small patches of calcite stalactites. Large sections of the molten cave roof have been frozen mid-drip as it cooled. Ripples of pahoehoe lava are present in many of the small sloping side passages. Some flat areas have slowly cooled into smooth, glassy sheets. Several tree moulds (Figure 11), the voids left by large trees encased in the lava flow and then burnt to ash, can be seen in the walls. Many of the flatter passages are formed by rough ‘a’ā lava and are very uncomfortable to crawl through.

Each day the survey team surveyed around one kilometre of passage and each day we felt we were nearing completion of the exploration only to discover more passage. The main passage ended in an area of loose scoria breakdown. Pete Smith pushed through an increasingly unstable belly crawl before deciding it was too dangerous to continue. On Google Maps there is a large scoria depression overlaying this section of the cave. There have been very few visitors to this point although there was a small rock cairn and a discarded battery pack. The battery packaging had an expiry date of 2015, so at least one trip has travelled to the furthest end of the cave in the 2010s. Less obvious side passages, particularly where access required climbing or crawling, had no evidence of previous visitors. Hidden on a high-level shelf was a rock shaped like a large squatting rodent or frog, giving rise to the name "The Mouse" (Figure 12).

Figure 8. Lava stalactites. Photograph: Kevin Jose

Figure 9. Sculpted ledge. Photograph: Paul Rowe

Figure 10. Floor patterns in the 'a'ā lava. Photograph: Kevin Jose

Figure 11. Tree mould in the ceiling. Photograph: Paul Rowe.

Figure12. "The Mouse" formation. Photograph: Pete Smith

Heading back downhill there is an obvious side branch to the right. This splits into several smaller tubes that all finish in crawls on 'a'a lava. There was an unusual formation in this section – a 30cm wide bulge that has sagged from the ceiling. This feature was named the "Elephant's Foot" (Figure 13).

Figure 13. "Elephant's Foot" formation. Photograph: Peter Crossley

On the last surveying day, the only lead left was the crawl heading east halfway along the main passage. The surveying team left bags in the main chamber thinking there would be little to see, but hours later the exploration team had surveyed another kilometre of passage in a series of complex

interconnecting tubes ending in tight crawls. In the evening the final survey data was plotted, only to find that these passages were almost connecting with the crawls from the previous day. It is almost certain that these connect.

The most noticeable animal in the cave (Figures 14-16) is the white-rumped swiftlet (pe'ape'a / *Aerodramus spodiopygius*). During the project's visits more than one hundred were found nesting in the cave, sometimes as far as one kilometre from the entrance. They navigate with echolocation (BRINKLØV, FENTON, RATCLIFFE, 2013) by using distinctive clicking sounds, and they can relocate their nests within the complex cave system. They can be disturbed by the sounds and lights of visitors in the cave, although they primarily fly in and out of the cave at dawn and dusk to feed in the forest.

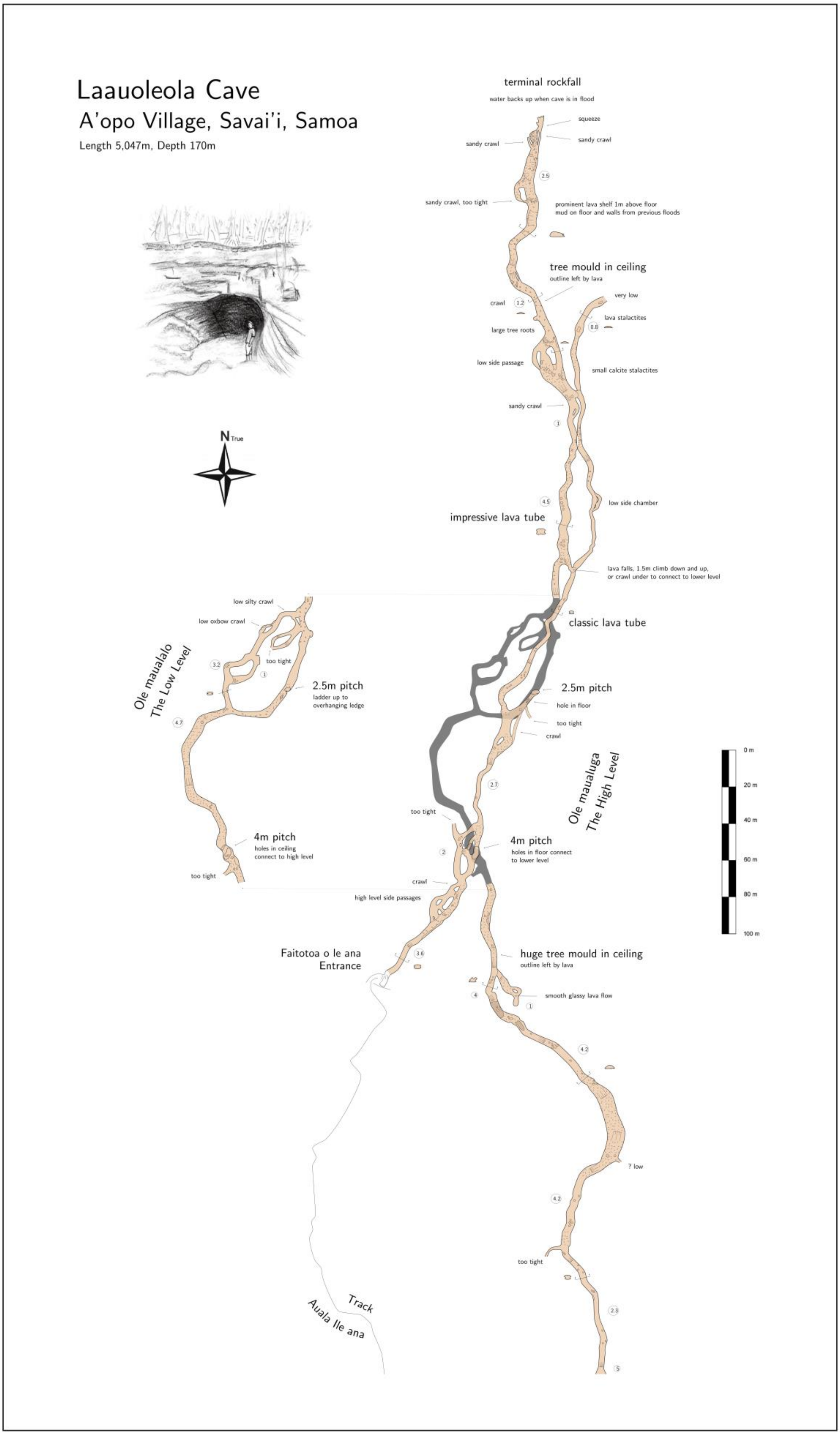
No bats were found in the cave and their populations have suffered considerably from the effects of several large cyclones. Cockroaches were present in most wet areas of the cave. They are large and fast and are attracted quickly to food. More than once the exploration team put down a pack to find a cockroach running out of the bag. Small mites, at least two species of moth, one worm, one crab, and one albino slater (possibly a specialist cave species) were also found during the trip.

Figure 14. Swiftlet (pe'ape'a / Aerodramus spodiopygius) nesting in the cave. Photograph: Peter Crossley

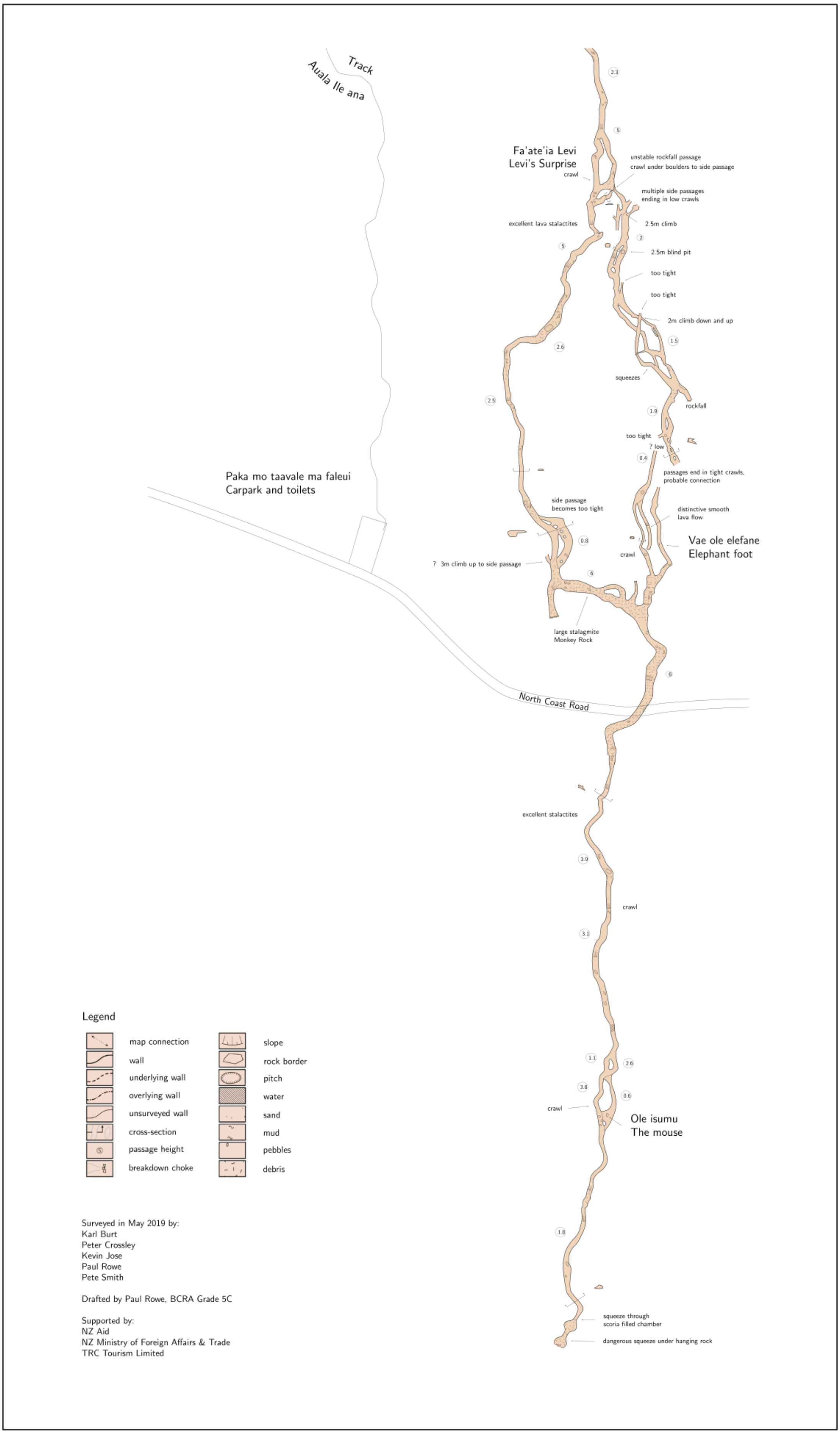
Figure 15. Swiftlet egg in a nest in the cave. Photograph: Kevin Jose

Figure 16. Swiftlet in flight in the cave. Photograph: Peter Crossley

Figure 17. Unidentified moth in Laauoleola Cave. Photograph: Kevin Jose.



Figures 18 and 19. Completed survey – two pages


Track
Auala Ile ana
Fa'ate'ia Levi
Levi's Surprise
crawl
unstable rockfall passage
crawl under boulders to side passage
multiple side passages
ending in low crawls
excellent lava stalactites
2.5m climb
2.5m blind pit
too tight
too tight
2m climb down and up
squeezes
rockfall
too tight
? low
passages end in tight crawls,
probable connection
Paka mo taavale ma faleui
Carpark and toilets
side passage
becomes too tight
distinctive smooth
lava flow
Vae ole elefane
Elephant foot
crawl
? 3m climb up to side passage
large stalagmite
Monkey Rock
North Coast Road
excellent stalactites
crawl
crawl
Ole isumu
The mouse
squeeze through
scoria filled chamber
dangerous squeeze under hanging rock
Legend
map connection
wall
underlying wall
overlying wall
unsurveyed wall
cross-section
passage height
breakdown choke
slope
rock border
pitch
water
sand
mud
pebbles
debris
Surveyed in May 2019 by:
Karl Burt
Peter Crossley
Kevin Jose
Paul Rowe
Pete Smith
Drafted by Paul Rowe, BCRA Grade 5C
Supported by:
NZ Aid
NZ Ministry of Foreign Affairs & Trade
TRC Tourism Limited

Outcomes

During the trip the Auckland Speleological Group team entered the raw survey data into the cave mapping system Therion each evening. On returning to Auckland the bigger job of redrawing the sketches into Therion was completed over a couple of months. The final statistics for the cave gave us a total length of 5,047m and a depth of 170m. It is currently Samoa's longest cave by a large margin, and as of January 2020 it was the 26th longest lava cave in the world. The completed map, a report summarising the exploration with our recommendations, and a selection of the photographs and 3D scans was sent through to TRC Tourism.

Our recommendations covered:

- Removing the painted arrows in the cave as these distract from the natural features and do not improve the safety of the tours;
- Avoiding dawn and dusk visits to the cave to minimise the impact on the swiftlet colony;
- Identifying a longer possible tourist loop in the cave that takes in additional interesting features, without adding any major obstacles; and
- Identifying one small pit that should be avoided or protected to avoid it being a hazard to visitors.

The "Beautiful Samoa" project has led to many changes at the site:

- The walkway to the cave has been upgraded to a gravelled path to improve safety;
- New native plantings have been added to the walkway;
- New signage now highlights the flora and fauna of the area;
- Toilet facilities have been upgraded; and
- Photography from our trip has been used for the new signage and in printed and web marketing material.

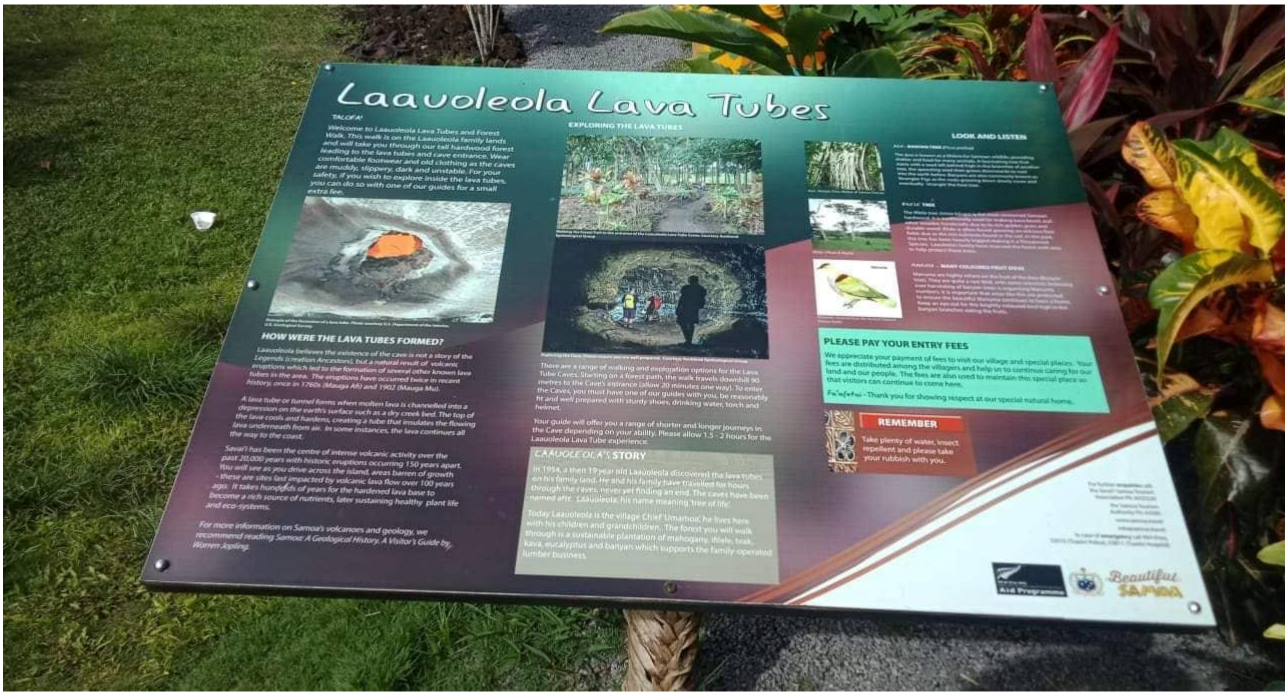


Figure 20. New signage incorporating photographs from the Auckland Speleological Group trip. Photograph: Lagi Laauoleola

The close partnership with the site owners in developing the site has now transformed the site from a hidden gem to a popular attraction for visitors to Savai'i. Covid-19 travel restrictions significantly limited visitors from 2020-early 2022, but cave tours are now running again.

Figure 21. New gravelled path with native plantings. Photograph: Paul Rowe

The Auckland Speleological Group team would like to thank the Laauoleola family for access to the cave during this project and we hope to return in the future as Savai'i holds the potential for the discovery of more large cave systems. Pleasant snorkelling, good local beer, and superb lava caves await those willing to make the long journey.

Sitography

Auckland Speleological Group: https://asg.org.nz (last accessed 11/11/2022)

Savai'i Volcano Profile: https://volcano.si.edu/volcano.cfm?vn=244040 (last accessed 11/11/2022)

TRC Tourism Limited: https://www.trctourism.com (last accessed 11/11/2022)

Bibliography

Brinkløv S, Fenton MB, Ratcliffe JM. (2013) Echolocation in Oilbirds and swiftlets, in "Front Physiol.", 2013 May 28;4:123.

Middleton, G. (2003) The Lava Caves of Samoa – A Preliminary Investigation, in "The Journal of the Sydney Speleological Society", 2003 47(4):79-102.

A sustainable future for the Harmans Valley lava flow?

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Abstract

The 40,000 year old Harmans Valley lava flow in Western Victoria is commonly regarded as having the most intact and significant collection of young volcanic features in Australia as well as being the best local example of a lava flow constrained by a valley. The flow also contains the renowned Byaduk caves. The caves and the Mount Napier volcano, the source of the flow, are protected as they lie within the Mount Napier State Park. However, for most of its length, the flow is on privately-owned rural lands where until recently, features on and in the flow had been afforded very little official protection. In 2004 and again in 2015 and 2016, areas of the flow were crushed and levelled to improve farming potential. This obliterated surface features and diminished landscape values. A concerted campaign to halt further damage achieved a significant milestone on 26 October 2016. That is when the Victorian Government imposed a temporary landscape protection order over all of the lava flow on private land within the Southern Grampians local government area, pending further consideration on whether the protection order should be made permanent. This paper reviews efforts to protect the geological, ecological, cultural and landscape values of the Harmans Valley lava flow and considers its future prospects.

Keywords: volcanic features; landscape protection; sustainable use.

Introduction

The Harmans Valley basalt lava flow in Western Victoria originated at Mt Napier and flowed down a pre-existing valley (Figure 1) for more than 20 kilometres in a westerly then southeastly direction. For most of this distance, the flow is located within the Southern Grampians Shire, but the last several kilometres fall within the Glenelg and Moine Shires and in these lower reaches, much of the flow is swamp covered, with no outcrop.

Figure 1. Harmans Valley lava flow as it was in 1975, with the source of the flow, Mt Napier, clearly visible in the background.

The remarkable Byaduk lava caves occur within the flow and many surface features are still visible, including Tumuli, or lava blisters, lave lakes, levees and examples of a'a and pahoehoe lavas. The flow is regarded by many vulcanologists as the best preserved in Australia and is regarded as being very important for education and research purposes. The flow also has aboriginal and early-European cultural heritage significance as well as dramatic landscape values.

Mt Napier and the upper part of the flow, containing many of the Byaduk caves, are protected as they are within the boundaries of the Mt Napier State Park. However, most of the flow is on private property (Figure 2) where, until recently, it had been afforded almost no official protection.

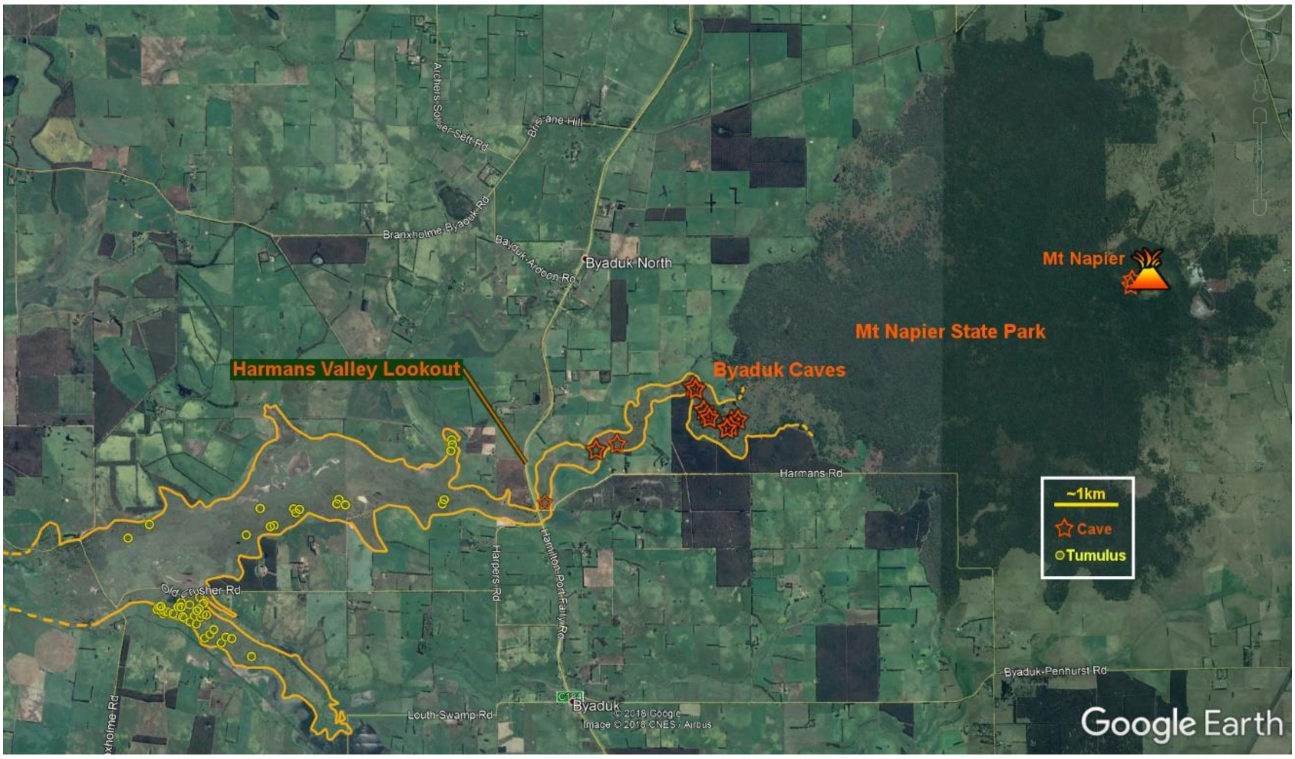


Figure 2. Major features of the Mt Napier State Park and the Upper Harmans Valley.

In 2004 and again in 2015-16, a large area of the flow was bulldozed and levelled, an operation called rock crushing, to improve its farming potential. The rock crushing operations obliterated some surface features and, because the most significant damage was in an area visible from a public viewing point (the Harmans Valley lookout), the landscape significance has been diminished (BRUSH, 2018).

Geological setting

The Harmans Valley area lies within the Newer Volcanic Province (Figure 3), which covers an area of 25,000 Km^2 in western Victoria and southeast South Australia (CAS, 2018). It is an intra-plate continental basaltic province that has been active for around 8 million years. It comprises extensive lava flows, scoria cones and more than 400 eruption sites. Some of the oldest eruption sites are in the north and in the east near Melbourne and the most recent eruption occurred at Mt Shank (near Mt Gambier) just 5000 years ago. However, based on the limited amount of dating work carried out to date, there is no obvious migration pattern of volcanism across the province. Available data suggest that volcanism occurred in particular parts of the province at different times but more age data is required to detect any patterns (CAS *et al*, 2017). On the basis of the dating data, and given the number of eruption sites, CAS (2018) suggests eruptions occur every 15,000-20,000 years and that since the last eruption was only 5,000 years ago, further eruptions are likely in the future. Cas considers that as the Newer Volcanic Province is the only still-active volcanic province in Australia, it is of national scientific significance.

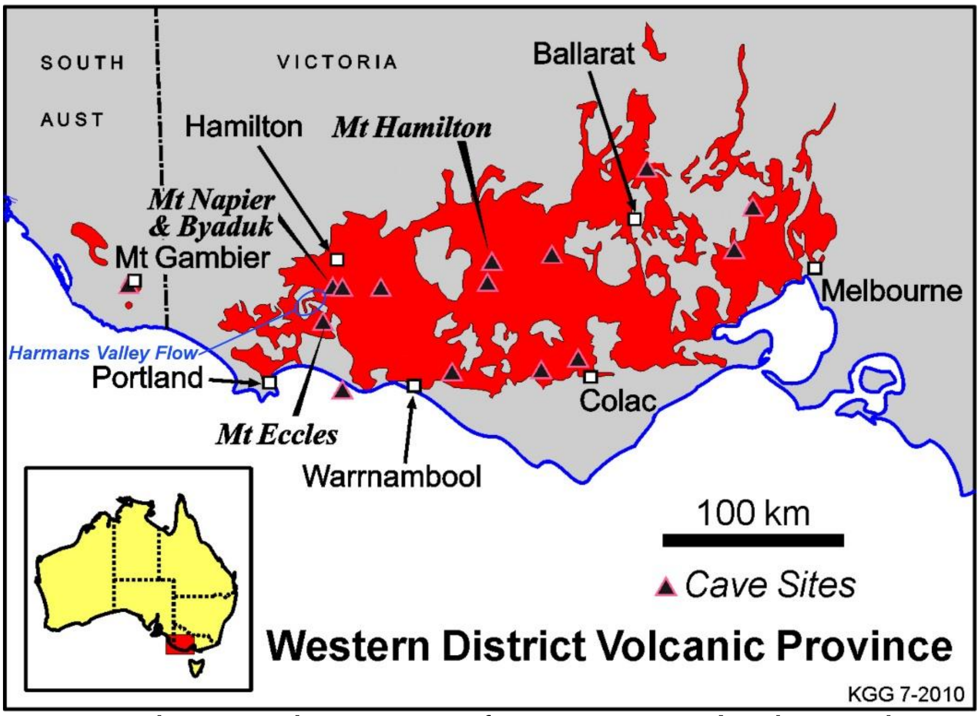


Figure 3. The Newer Volcanic Province of Western Victoria and southeast South Australia (Modified from Grimes, 2010).

Mt Napier, the source of the Harmans Valley flow, is one of the youngest eruption sites. The most recent studies suggest an age of about 40,000 years (Cas, 2018). This is very young in geological terms and explains why many surface features of the flow are still visible and why a range of dramatic lava cave features remain intact.

Features of the flow

From a speleo perspective, the most important features of the Harmans Valley flow are the caves (Figure 4). Many of these are within the Mt Napier State Park and as such, their conservation status is not an issue.

Figure 4. Cave entrance in the Mt Napier State Park.

Caves also occur on privately-owned land further down the flow. The late Ken Grimes, who was a geologist and keen speleo, documented a number of these, but access constraints limited the thoroughness of his work. A large entrance occurs in the middle of the area that was rock crushed in 2004 and again in 2015-16 (Figure 5). The entrance does not appear to have been damaged, but Grimes considered it likely that at least one other small cave was obliterated.

From a geological perspective, the most striking features are the tumuli (Figure 6), or lava blisters as they are sometimes called. These are steep-sided mounds of rock up to 10m high and 30m across that are thought to result from underlying pressure of lava forcing up the solidifying but still plastic surface of the flow.

Figure 5. Large collapse entrance in an area subjected to rock crushing in 2004 and 2015-16. Note the large rubble piles remaining after the rock crushing.

It is possible that steam, generated where the lava flows over wet or swampy areas, played a role in their formation. The tumuli are more common in areas where the lava flow is thin, such as near the edge of the flow and in side valleys. Tumuli have been documented in volcanic areas in other countries, but they are generally of a much smaller size than the ones found in Harmans Valley.

Figure 6. Three Tumuli, or lava blisters, on the Harmans Valley lava flow.

Other features of the flow include lava ridges, hummocky terrain (known locally as stony rises), lateral levees, lava canals and drained lava lakes, as well as smaller-scale features such as columnar jointing and pahoehoe and a'a surfaces. While these are common in many volcanic areas, they are invaluable at the state and national level in Australia for education and research purposes as the Harman's valley flow is relatively intact, very young and readily accessible.

Rock removal and quarrying operations

The first inhabitants of the area, ancestors of the Gunditjmara people, fashioned loose basalt boulders into shelters. Foundations of these structures can still be seen in the area.

Since the early days of European settlement, local residents have been modifying the surface of the flow. At first, farmers improved the grazing value of their land by picking up loose rocks and using them to build dry stone walls (Figure 7). Later, farm tracks were pushed across the flow. As the broken surface of the flow was a readily available source of loose rock, it was removed by the truckload for road construction works in the district. There are also several small quarries in the area where the objective was to dig beneath the basalt to access underlying limestone, which was in demand for agricultural and construction purposes.

Figure 7. Typical dry stone wall fashioned from loose blocks of basalt.

None of these small-scale operations had major impacts on either surficial geological features or on the overall landscape vista, such as is visible from the Harmans Valley Lookout beside the Hamilton-Port Fairy Road. Indeed, one of the valuable landscape attributes of the area is now considered to be the dry stone walls. They are also regarded as contributing to the cultural significance of the area.

In mid-2004, heavy machinery was used to break up and flatten an 800 metre long section of flow to the east of, and visible from, the lookout. An area of approximately 15 hectares was crushed and 'surplus' rock was pushed into several large heaps. Further rock crushing operations occurred in 2015 and 2016. These works, which had a major impact on the surface of the flow, are discussed in more detail in the following section.

Moves to protect the flow

In the 1990s the Victorian Division of the Geological Society of Australia assigned the Mt Napier volcano area, including the Harmans Valley flow, national significance as a Geological Heritage feature (ROSENGREN, 1994). It also assigned individual listings to three sites within the valley: the Wallacedale Tumuli were assigned international significance as particularly well-formed examples of lava mounds or "blisters". The Byaduk Caves and the Great Barrier, a lava levee feature, were assigned national significance. The current status of the listings could be ascertained but, this is largely irrelevant as the listings afforded no legal protection. In Victoria, there is no protection for geological sites unless they are on the National Heritage List (which does not include anything in the Harmans Valley area) or are within a National or State Park. Fortunately, Mt Napier, many of the Byaduk Caves and other features are within the Mt Napier State Park. However, in other areas, for example on private land, protection is only possible by indirect means – that is, if the geological sites also happen to have other values that are covered by environmental, planning or aboriginal heritage legislation.

In the early 2000s, Ken Grimes provided information for several interpretive signs that were installed at the Harmans Valley lookout. The site soon became a popular tourist attraction.

At the time of the crushing work in mid-2004, many geologists, including Grimes, pushed for protection of significant geological features located on private land. Amid widespread local concerns about the rock crushing, which had already obliterated 15 hectares of the flow, the landowner agreed to halt work pending consideration of the issue by Southern Grampians Shire Council. The Council proposed seeking an Environmental Significance Overlay (ESO) under the Victorian *Planning and Environment Act 1987* for all areas of the flow on private land within the shire. In October 2004, the (then) Victorian Department of Sustainability and the Environment

(DSE) drew up a map of the proposed ESO over the area of the flow based on information provided by Grimes. Unfortunately, the ESO was never gazetted.

Tragically, Ken passed away in 2016, but his archived emails suggest that in 2005, DSE was more focussed on negotiating with the landowner to "offset" the damage to native vegetation from the rock crushing by undertaking plantings elsewhere on his property. This, in effect, recognised there was no legal basis for taking action for the destruction of geological features. It is not clear whether an agreement was reached with the landowner and there is no on-the-ground evidence of any planting ever taking place.

In 2012, the (then) Department of Planning and Community Development completed a landscape assessment study in southwestern Victoria (*The South West Landscape Assessment Study*) in partnership with shire councils in the region. The aim of the study was to identify and assess key landscapes and make recommendations regarding their protection and management. The Harmans Valley, as viewed from the Harmans Valley lookout, was identified as being of state-level significance and proposed a Significant Landscape Overlay (SLO) for the area, noting rather poetically that:

> *"The view (from the lookout) is contained within the sweeping curve of the valley, with Mount Napier visible in the background. While other parts of the surrounding landscape are visible, the view cone describes the extent of the view that is dominated by the lava flow.*
>
> *The open, cleared foreground and elevated position of the viewing location allows for excellent, uninterrupted views over the lava flow. There is a high contrast between the rough texture of the flow and the dark, scrubby bracken growing in its crevices, and the smooth, grassy slopes of the valley walls. The lava flow is a dramatic visual feature that twists across the middle ground. The central location of Mount Napier and the span of the landscape between it and the viewing location makes it easy to appreciate the distance that the river of lava travelled when the volcano was active. This is further highlighted by dark vegetation that frames the valley and directs the eye across the volcanic features".*

Despite these fine words, there was no immediate action to implement an SLO.

Ownership of the area visible from the lookout changed and in November 2015, the new owner started to rework the area crushed in 2004. The works were soon halted when the Southern Grampians Council issued a stop-work order and asked the owner to complete a Cultural Heritage Management Plan (CHMP) under the terms of the State *Aboriginal Heritage Act 2006*.

Early in 2016, the Victorian Government enacted the *Aboriginal Heritage Amendment Act 2016* which among other things, sought to clarify when a CHMP was required and also changed the nature of the CHMP from a guidance document to an approval process. The extent to which the landowner resolved the CHMP issues is not known.

In mid-2016 the landowner re-commenced rock crushing works (Figure 8), which included a new 5-hectare area to the east of the previous works (Figure 9). On 8 July 2016, another stop-work order was issued under the Act. As was the case in 2004, there was adverse comment about the works in the local media. In response the landowner noted there was no SLO over his land and that the real damage was done ten years earlier by the former owner.

Figure 8 – Rock crushing works in progress, July 2016. Photo courtesy of Professor John Sherwood.

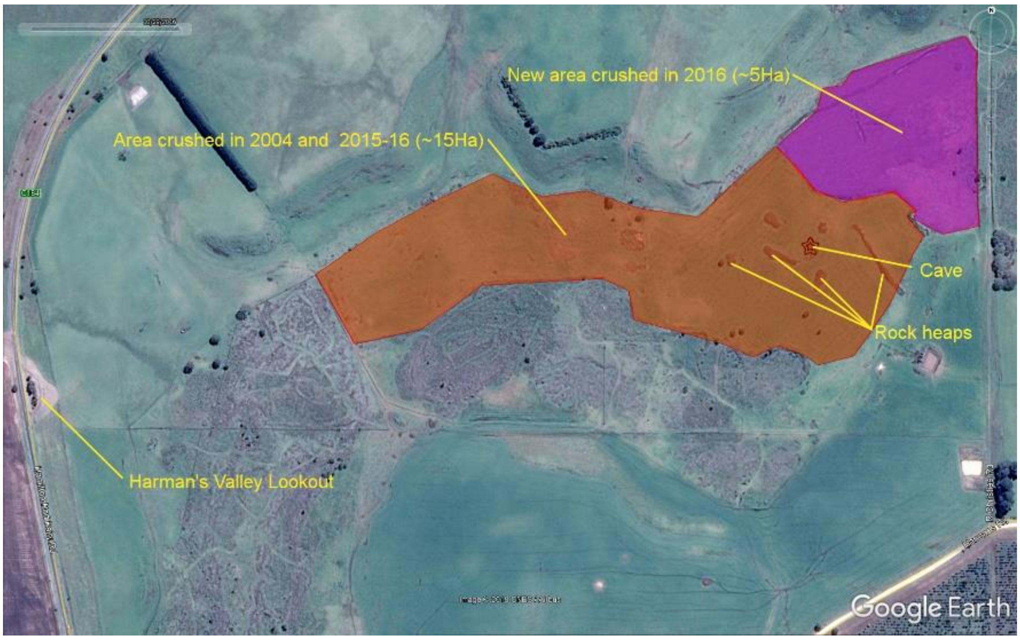


Figure 9. Satellite imagery showing the area of rock crushing in 2004 and 2015-16.

Interim protection

In the third quarter of 2016, a visitor travelling through the area stopped at the Harmans Valley lookout and was so appalled by the damage that he made representations to the Victorian Minister for Planning (Figure 10). The representations appear to have been successful as an interim Significant Landscape Overlay was gazetted on 26 October 2016. It had effect until 31 October 2018. The interim SLO applied to all parts of the flow on private land within the Southern Grampians Shire. In essence this meant there was a planning objective to maintain the landscape character and setting of the lava flow. However, despite a requirement to obtain a permit to damage any stone wall or to build a new one, there was no requirement to obtain a permit for any for earthworks.

Figure 10. View of Harmans Valley and the Mt Napier volcano from the roadside lookout. The area of rock crushing is indicated by the extensive grassy areas on the valley floor and heaps of surplus rock (photo taken March 2018).

In 2017, the Southern Grampians Shire Council drafted a proposal for a permanent SLO in consultation with the Victorian Department of *Environment, Land, Water and Planning (*DELWP). Under the planning policy framework in Victoria, as set out in the *Planning and Environment Act 1987* (PEA), Council was the designated planning authority for the proposal. The draft was on public exhibition between 12 September and 20 October 2017. Council received 75 written submissions (KIRSCH & DONOVAN, 2018), including 13 from speleological organisations and individual speleos. Most submissions supported the SLO being made permanent.

DELWP established a planning panel to consider the submissions and in March 2018, it convened a 2-day public hearing in Hamilton where people were given an opportunity to speak to their submissions. There were 18 presentations including by the Shire Council, representatives of the Gunditjmara people, academic institutions, community groups, landowners, the Victorian Environment Department, geotourism organisations, the UIS Commission on Volcanic Caves and the Australasian Cave and Karst Management Association Inc. The hearing and associated field inspection (Figure 11) generated a wide range of views. The discussions were respectful and also productive, resulting in several proposals to amend the draft SLO.

A major concern of landowners was the SLO area was based on cadastral boundaries. This meant some large parcels of land were included even they covered only very small areas of the flow. To address this, it was suggested the SLO area should be re-defined as the actual area of the flow, plus a 50 metres buffer zone to cover potential errors in defining the flow margins. It was also suggested there was little reason to include areas where the flow was completely soil covered. As an aid to further discussions, these proposals were illustrated on a map that was prepared by Council over a lunch recess (Figure 12) . The resulting proposal to amend the SLO to the visible lava flow and its associated geological features, plus the 50 metre buffer, addressed the main concerns of landowners. The buffer also had the advantage of protecting the landscape setting of the flow within its constraining valley.

Several speakers at the hearing proposed specific restrictions on rock crushing, quarrying and rock removal on the basis that the definition of works was too vague. On the other hand, some landowners considered permit conditions under the interim SLO were already too prescriptive and argued for an easing in the permanent SLO. This issue was not resolved during the hearing but was subsequently addressed in the planning panel's report.

Figure 11. Field inspection of a rock-crushed area during the public hearing.

Permanent protection

Following the public hearing, the planning panel evaluated submissions and the evidence presented at the public hearing. It then prepared a report with recommendations that was submitted to the Southern Grampians Shire Council on 16 April 2018.

Council adopted the planning panel recommendations on 19 July 2018. On the same date, the proposed amendments to the Southern Grampians Planning Scheme were submitted to DELWP, which later approved the amendment, with changes. The formal notice to amend the Planning Scheme by including a permanent Significant Landscape Overlay for the Harmans Valley lava flow was published in the Victorian Government Gazette on 18 October 2018 and came into effect the same day.

The permanent SLO states "the Harmans Valley is a landscape of State significance, as a unique collection of volcanic features" and that the landscape character objective is "to protect the landscape geological, scientific, aesthetic, cultural and biodiversity significance of Harmans Valley" (Southern Grampians Planning Scheme, 2018)

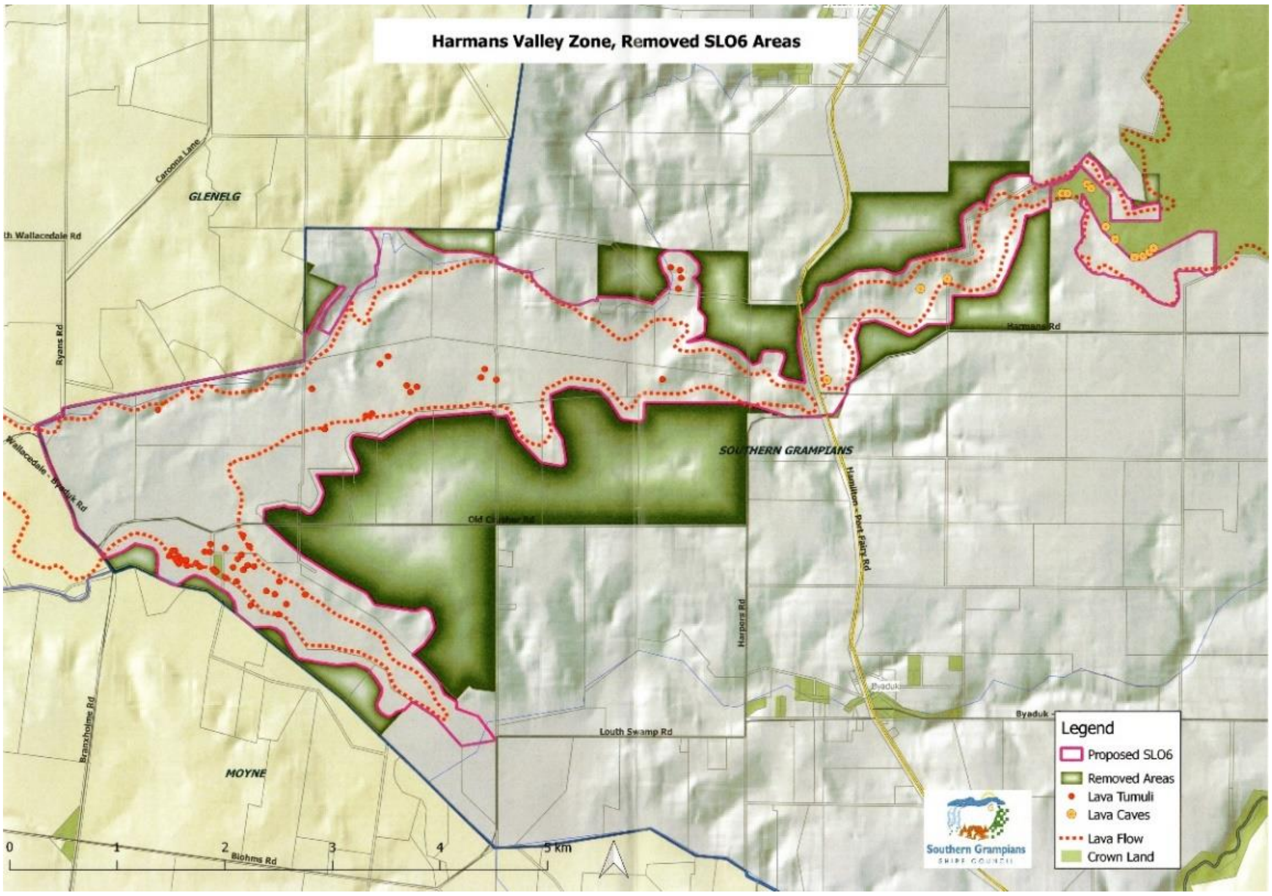


Figure 12. Map showing the areas that would be removed if the SLO was defined in terms of the margins of the lava flow plus a buffer zone, rather than on a cadastral basis.

It includes requirements to obtain a permit to demolish or remove a dry stone wall or to construct a fence except for post and wire fencing that does not damage or require modification to the lava flow or associated geological features or structures.

The SLO also states that a permit is not required for the construction of a farm access track that does not change the topography of the land or damage or require modification to the lava flow or associated geological features or structures.

Before deciding on an application for a permit, there is a requirement for Council to consider:

- the landscape character objective articulated above;
- The impact of the buildings or works on the landscape significance of Harmans Valley;
- Whether proposed buildings or works have attempted to avoid and minimise impacts on the landscape and any significant geological features, including the lava flow, tumuli and caves;
- Whether prominent view-lines have been avoided; and
- Whether building forms, colours and materials integrate with the landscape setting.

Community groups had argued for specific restrictions on rock crushing but these were not directly addressed in the permanent SLO as the planning panel report (Kirsch & Donovan, 2018) noted that as defined in case law, “works’ includes any works altering the topography of the land and would therefore cover rock crushing.

After many years of campaigning to protect the landscape and geological values of the Harmans Valley lava flow, the policy and regulatory framework established in October 2018 is welcome. Advice from local residents in August 2022 suggests the SLO is currently achieving its stated objectives.

Conclusions

The vista of the Harmans Valley lava flow from the viewing point on the Hamilton - Port Fairy Road has changed significantly since I first visited the area in 1975. Farm management tracks have been pushed across the rocky surface of the flow, native vegetation has been removed and a 20 hectare area has been crunched, levelled and sown with pasture grasses. In addition, the visual connection between the flow and its source at Mt Napier is slowly disappearing as trees in adjacent softwood plantations grow taller. As a result, the landscape values of the volcanic terrain have significantly diminished and its value as an education and research tool has almost certainly lessened. Nevertheless, the flow remains the best preserved, dramatic and most readily observable flow in Australia. The flow also remains very important for aboriginal and early European cultural heritage reasons.

The extent to which the amended planning controls will be successful in protecting features of the flow in future years will be dependent on effective management of the planning scheme by local and state governments; careful scrutiny of permit applications by Council; cooperation from landowners; and continuing interest in the area within the local community. There is scope for optimism that implementation of a permanent Significant Landscape Overlay will continue to deliver a sustainable future for the Harmans Valley lava flow.

References

BRUSH, John (2018). *The Harmans Valley lava flow and its tortuous path.* Proceedings, 22nd Conference, Margaret River, Western Australia. Australasian Cave and Karst Management Association Inc.

CAS, R A F (2018). *Expert Witness Statement* - Re Amendment C36 Planning Scheme, Southern Grampians Shire Council Permanent Significant Planning Overlay to Harman Valley, scheduled hearing dates 6th-7th March 2018.

CAS, R A F, Van OTTERLOO, J, BLAIKIE, T N and Van Den HOVE, J (2017). *The dynamics of a very large intra-plate continental basaltic volcanic province, the Newer Volcanics Province, SE Australia, and implications for other provinces.* Geological Society, London, Special Publications 446 (1):123-171

GRIMES, K G (2010). (Editor) *Field Guide to the Volcanic Caves of Western Victoria.* 14th International Symposium on Vulcanospeleology. Published by the UIS Commission on Volcanic Caves.

GRIMES, K G (2004). *Harman Valley volcanic features – geological significance.* Unpublished discussion paper, courtesy of Janeen Samuel (Grimes).

KIRSCH, Michael and DONOVAN, Jenny (2018). *Panel Report- Southern Grampians Planning Scheme Amendment C36*. Published by Planning Panels, State Government of Government of Victoria. SouthernGrampiansC36PanelReport.pdf (sthgrampians.vic.gov.au) (Last accessed 12 September 2022).

ROSENGREN, N (1994). *Eruption Points of the Newer Volcanics Province of Victoria - an Inventory and evaluation of scientific significance.* Report prepared for the National Trust of Australia (Victoria) and the Geological Society of Australia (Victorian division).

SOUTHERN GRAMPIANS SHIRE COUNCIL (2018). *Southern Grampians Planning Scheme, Amendment C36 – Explanatory Report Approval Gazetted*. Victorian Department of Environment, Land, Water and Planning. Southern Grampians Planning Scheme - Amendments (Last accessed 12 September 2022).

SOUTHERN GRAMPIANS PLANNING SCHEME (2018). *Schedule 6 to Clause 42.03 Significant Landscape Overlay*. Microsoft Word - 42_03s06_sgra.doc (dpcd.vic.gov.au) (Last accessed 12 September 2022).

Overview of volcanic caves that have been opened for tourists around the globe

Gregory J. Middleton

Abstract

Caves have been attractive to tourists since people started travelling to enjoy scenic beauty and natural curiosities around the world. In the main, it has been limestone or karst caves that have aroused interest and been developed to provide tourist access. While volcanic caves, being less numerous than those in karst, have attracted less attention, some have been promoted as show caves. This paper will attempt a preliminary overview of volcanic caves that have been opened for tourists around the globe, together with some personal observations on their attributes and management.

Keywords: lava caves; tourism; management

AUSTRALIA

Undara Lava Caves, Queensland.

A number of caves in the Cretaceous lava at Undara are included in the 65,800 ha Undara National Park. While the park is managed by the Queensland Parks & Wildlife Service, the former owners of the property have, since 1990, had a licence to operate cave tours and an exclusive licence to provide accommodation at the site. Other operators based outside the park are authorised to also offer cave tours. Provisions for tourists include stairways with handrails where entrances have rockfalls (Figure 1) and wooden walkways where floors are uneven. At times flooding restricts access to some parts of some caves. While over 60 caves have been documented in the region only parts of six or seven 7 regularly feature in guided tours. There is no fixed lighting; guides carry flashlights and visitors are expected to bring their own. The guides are experienced and trained "Savanah Guides" who also conduct wildlife and geological tours in the region.

Figure. 1. Entrance to Misplaced Arch; stairs with handrails

The caves include impressive tunnels up to 18 m high and 18 m wide; many are partially filled with silt, providing level floors for walking (Figure 2). There are lava flow features such as benches, marginal gutters, glazes and wall linings. Stalactites occur but are generally small. Wildlife encountered include bats and snakes. Details are in ATKINSON & ATKINSON, 1995; PEARSON, 2010 and MIDDLETON & KEMPE, in press.

Figure. 2. Barkers Cave consists of an impressive tunnel.

Undara Experience offers two cave tours, each of two hours duration: Archway Explorer, visiting up to three sections of different caves; Wind Tunnel Explorer, visiting up to three sections of lava caves.

Bedrock Village offers an all-day tour to the national park, Kalkani Crater and lava caves; and a half-day tour including the crater and three sections of lava caves.

Western Victoria.

There is a large number of generally small caves in the Western District Volcanic Province of Victoria (GRIMES 2010). Some of the most significant of these are contained within the Budj Bim (formerly Mt Eccles) National Park and Mt Napier State park. Some pathways have been cleared and constructed to facilitate access to some of these caves (Figure 3) and interpretive signs erected to inform visitors. There are no lights or guided tours.

Figure. 3. Cleared paths and stairs in Natural Bridge, Budj Bim National Park.

Equador – Galapagos Islands

Cuevas de Bellavista (Bellavista Caves or Cueva Gallardo), Santa Cruz Island.

This privately-owned pyroduct is open to the public for a small fee; tours are self-guided. There is occasional electric lighting but flashlights are also provided. Evidently the lights are left on for extended periods as lampenflora has become established (MIDDLETON 2015). There are stairs and handrails where necessary (Figure 4) but otherwise the path is natural and rough in places. Lava benches are a feature and there are a few stalactites (lava and depositional). Of the 2.25 km total length, less than a kilometre of the cave is accessible (BALAZS 1975). A plan of the cave is on display but there is no other interpretation.

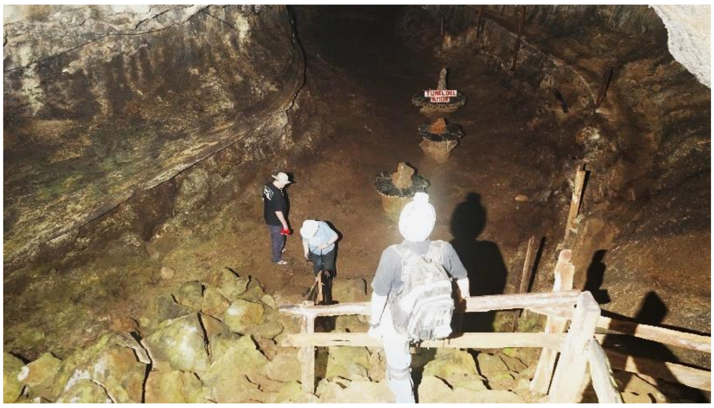


Figure. 4. Stairs and pathways are provided in Cuevas de Bellavista.

Cueva Primicias, Santa Cruz Island.

Self-guided tours of this pyroduct are offered as an adjunct to the main attraction of Rancho Primicias, which is its population of giant tortoises. The cave has stairs and occasional electric lights (Figure 5), resulting in the growth of lampenflora.

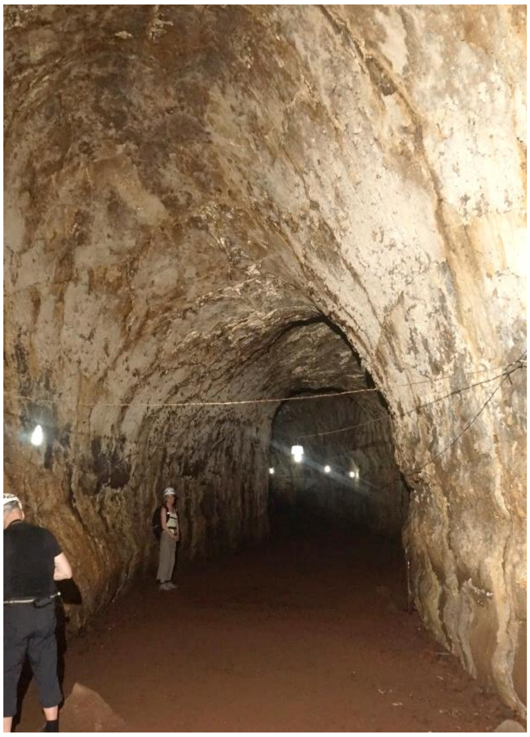


Figure 5. Obvious, occasional lighting, Cueva Primicias.

Tortuga [Tortoise] Crossing Cave, Santa Cruz Island.

One section of this pyroduct, on another ranch open for giant tortoise viewing, is available for inspection, having had steps, handrails and electric lighting installed. Lampenflora grows around the lights (Figure 6) A notable feature is a spectacular, thin lava bridge which divides the passage for a distance (BRUSH 2014).

Figure 6. Well established lampenflora in Tortuga Crossing Cave.

Royal Palm Cave, Santa Cruz Island.

Tours of this pyroduct are available to guests at the Royal Palm Resort and other visitors for a fee. Access is facilitated by the provision of wooden pathways, ladders and bridges (Figure 7), together with electric lighting (BRUSH 2014). Once again, lampenflora is a problem because lights are left on for long periods.

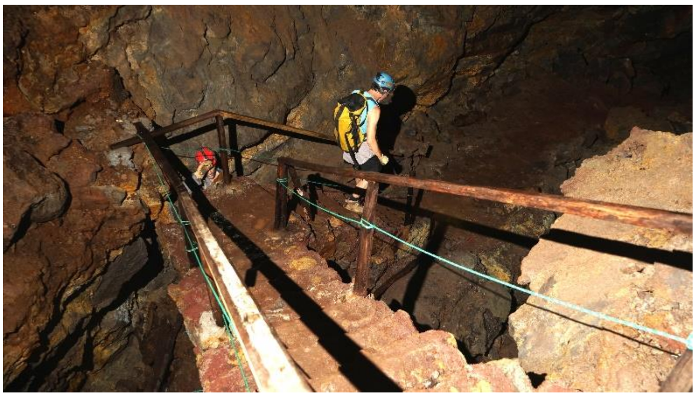


Fig. 7. Substantial pathway constructed in Royal Palm Cave.

El Chato Caves, Santa Cruz Island.

El Chato is another ranch offering tours of its pyroducts. The show cave section is about 800 m long and consists of two parallel passages joined at either end. The smaller of these two passages is lit with compact fluorescent tubes. This is arguably the less interesting part, but it does have a smoother floor with less breakdown and so makes for an easier trip for visitors (BRUSH 2014). Some steps and rope handrails are provided (Figure 8).

Figure 8. The Rope handrails in El Chato Cave provide little support.

Other caves

Other caves in the islands, such as *Triple Volcán* (an impressive but poorly-fitted out lava chamber in the highlands of Isabela Island (Figure 9) is offered as an 'adventure tour'), *Sucre Cave* (Isabela Island) and *Post Office Cave* (Floreana Island) can be visited by arrangement with the owners or national park authorities (BRUSH 2014).

Figure 9. Triple Volcán has adventure but little infrastructure.

FRANCE – La Réunion

Réunion Island is a French department in the southern Indian Ocean, off Madagascar. The island has an active volcano, so it has many lava caves.

Grotte des Premiers Français (or Cave of the first Reunionese)

Grotte des Premiers Français is one of few lava caves widely known and formerly easily accessible by visitors. It was promoted in the 1st Edition of the *Lonely Planet Guide* (WILLOX 1989). Legend has it that it was the original shelter utilised by the first settlers. In 2010, due to fears of rockslides, the cave was closed to the public.

Lava caves in Piton de la Fournaise volcano

Adventure tours of 3 hours duration in caves formed in the 2004 eruption, south of Sainte Rose, are offered by *Réunion Mer et Montagne* (2022) and other companies. Helmets and lights are provided (Figure 10).

Figure 10. Helmets and lights are provided on tours of lava caves in Piton de la Fournaise.

Iceland

Many lava caves in Iceland are available to visit, with a range of facilities such as designated pathways and ladders. Tours are offered by various companies, some of which unfortunately show little respect for the caves they exploit.

Surtshellir and Stephánshellir, Hallmundarhraun

These large caves are signposted and available for public inspection (Surtshellir has been surveyed for 1970 m, Stephánshellir for 1520 m). There is no infrastructure (Figure 11), no lighting and no supervision of visitors. People generally visit as part of guided tour groups.

Figure 11. There are few restraints on the movement of visitors in Stefánshellir.

Viðgelmir, Borgarfjörður

Viðgelmir This very large, privately-owned cave contains interesting ice formations (Figure 12). Tours are conducted (90 mins) along a sturdy wooden walkway with some electric lighting.

Figure 12. Ice persists year-round in Viðgelmir.

Lofthellir, North Iceland

This cave is remarkable for its ice formations (Figure 13). Although it has few facilities, it is visited by guided tour groups.

Figure 13. Remarkable ice chamber in Lofthellir (lighting by John Brush).

Vatnshellir ('Water Cave') Snæfellness

This cave is some 205 m long, on three levels (STEFÁNSSON 2010). It lies within the Snæfellsjökull National Park but has been sub-let to a private operator (MIDDLETON 2014). It is a fully-equipped show cave which has been open to the public since 2011, thanks to the efforts of local authorities and volunteers. There are well-crafted spiral staircases (descending 35 m) and handrails; helmets and flashlights are provided. Many lava stalagmites in the cave had been broken or stolen prior to the development; these were repaired or replaced by Árni Stefánsson (Figure 14).

Figure 14. Extremely fragile lave stalagmites can be broken and stolen from unprotected caves. These have been repaired and replaced in Vatnshellir.

Þríhnúkagígur (‘Three Peaks Crater’)

The descent of 120 m (Figure 15) into this stunningly beautiful volcanic chamber is a truly unique experience and the most rewarding of any volcanic cave visit. Safety harness, helmet and light are provided for the descent, which is accomplished in an open cable elevator holding about 5 people and the driver. After a six or seven minute ride the floor of the chamber one reaches, formed of breakdown material which plugs the shaft, and visitors can walk around admiring the colourful walls and the remarkable view up to the entrance (Figure 16) (MIDDLETON 2014). This Tour, which is the brainchild of Árni B. Stefánsson (who was the first to descend this volcano in 1974 (STEFÁNSSON 1992)), is the ultimate volcanic cave experience. Access is possible mid-May to mid-October; forward bookings are essential (INSIDETHEVOLCANO 2022).

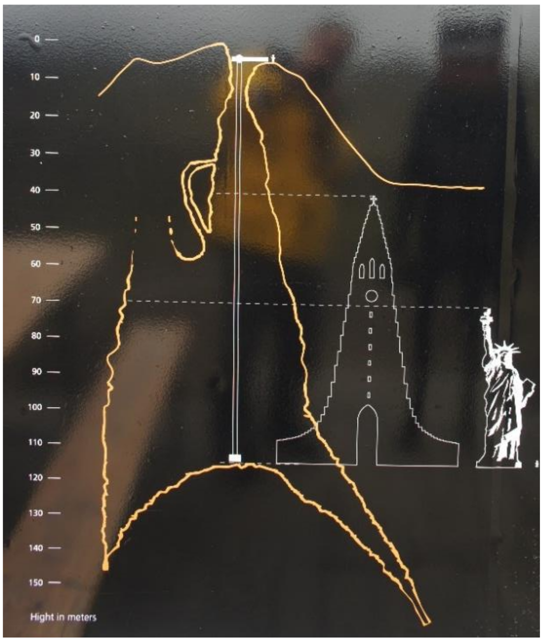


Figure 15. Section through Þríhnúkagígur, comparing it to the Statue of Liberty.

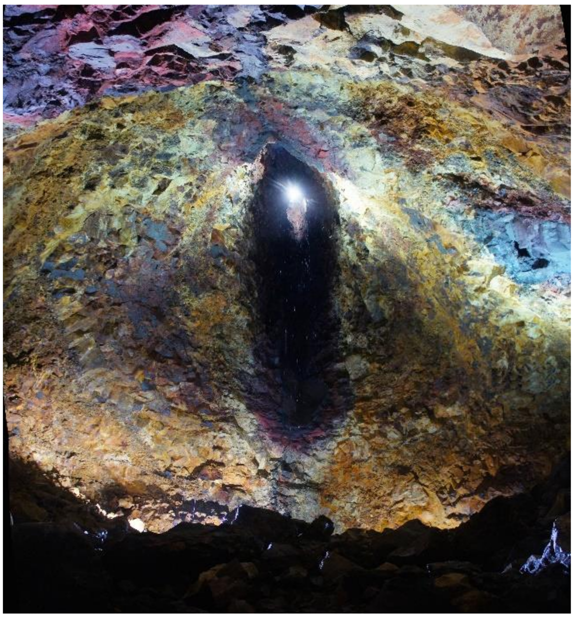


Figure 16. The spectacular view of the chamber from the base to the entrance.

KENYA

Mount Suswa lava caves

Many lava caves at Mt Suswa, about 80 km west of Nairobi, have been explored and documented in recent years by the late Jim Simons and members of the Cave Exploration Group of East Africa (CHECKLEY 2008). With their encouragement, the local Maasai community has established the Mt Suswa Conservancy to protect the area, encourage community participation in biodiversity conservation, provide local employment and to provide camping facilities, hiking guides and cave guides for visitors to the area (MIDDLETON & SIMONS 2015). The caves include some grand and well-decorated passages (Figure 17).

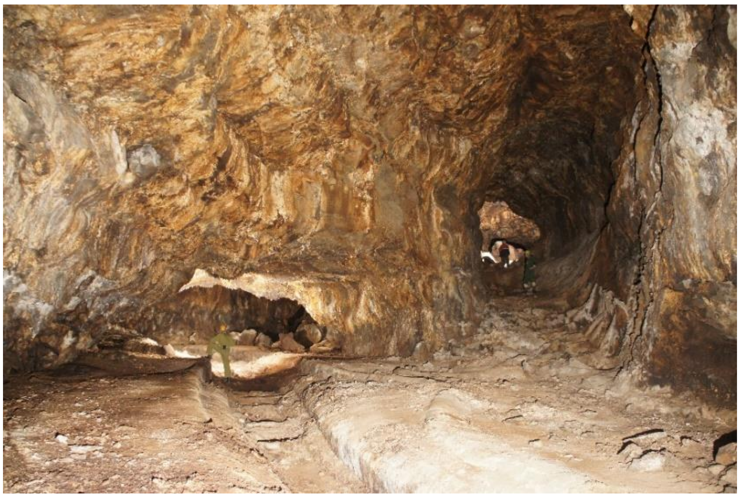


Figure 17. Impressive passages in Mt Suswa’s Cave 20.

The Conservancy has a Facebook page: https://www.facebook.com/Mountsuswaconservancy/.

Korea, Republic of – Jeju Island

Manjanggul ("Ten Thousand Long" Cave).

Manjang Cave is very long, approaching 9 km in total, though less than 1 km is covered by the show cave paths. (Despite exaggerated claims, it is about the 14th longest known lava cave.) Apart from its sheer length, Manjang Cave displays many interesting features, paramount among them being the 7.6 m high lava column at the far end of the show cave section (which is among the largest lava columns in the world) (Figure 18). Tours are run on a self-guided basis with a level of interpretation provided by signs on notable features. The passage is now well illuminated. The cave is within a Global Geopark and was World Heritage listed in 2007; it is government operated.

Figure 18. The 7.6 m lava column is a grand feature of Manjanggul.

Hyopchae and Ssangyong Caves, Hallim Park.

These two caves are open to the public as part of the Hallim Park tourist complex which also includes gardens, aviaries and a traditional village. The caves are well presented, with unobtrusive lighting and informative, multilingual interpretive signs. The floors have been paved over with stone and statues have been added. Although not particularly large, these caves contain typical flow features and are easily accessible. They may be the only lava show caves to contain examples of calcite speleothems (MIDDLETON 2004).

Figure 19. Most unusual calcite stalactites occur in lava caves at Hallim Park, due to calcite-rich sands overlying the caves.

Micheongul ("Ilchulland Resort").

This lava cave has been heavily modified in its conversion to a private show cave in 2002. Many of the additions, including statues, stone pillars, coloured lights and fountains would be regarded as inappropriate elsewhere. There is very little interpretation and lighting is of variable quality. The tour length is 365 m.

Mauritius

Pont Bondieu

This ‘bridge’ is the remains of a very wide (up to 40 m), though short (about 80 m) pyroduct in the Belvedere region of Mauritius. It was formerly used for dumping rubbish but was cleaned up by youth groups and the Department of Environment in the 1990s and stone stairs with handrails provided access to the collapse pit (Figure 20) from which the remnant passage (the ‘bridge’) opens (MIDDLETON 1997). In 2006 the site was purchased and a Buddhist meditation centre has been constructed. Entry to the cave is still allowed, for a cash donation (DUCKECK 2022).

Figure 20. The large entrance to the ‘bridge’ that is Pont Bondieu.

Cave Madame (Womens Cave), Roches Noires

A small lake in this 28 m long cave had traditionally been used by local women for washing clothes. It fell into disuse and became a rubbish dump before being rehabilitated by the Department of Environment in 2003. Pathway, stairs and handrail now facilitate access to the lake (Figure 21). Entry is free to visitors.

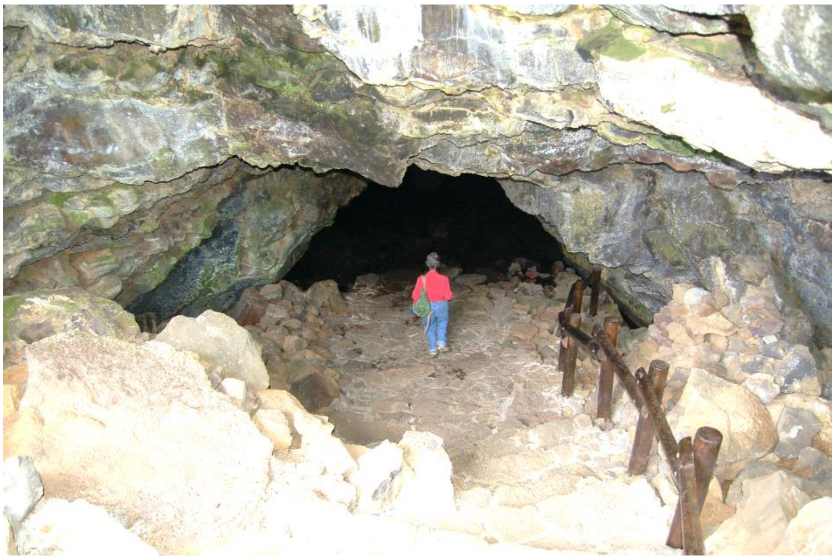


Figure 21. The pathway to the lake in Cave Madame, Roches Noires.

NEW ZEALAND

While New Zealand is well known for its (karst) glowworm caves, such as those at Waitomo, it also has volcanic caves – in the Auckland area of the North Island. Many of these are under private land or streets and are inaccessible but the island of Rangitoto is both a volcano and a reserve. A group of caves on the island, known as the ‘Tourist Caves’ are signposted and accessible from formed paths. They are *Northern Cave*, *Middle Cave*, *Southern Cave* and *Wallaby Cave* (CROSSLEY 2014). They can be safely visited by fit members of the public who must provide their own lights.

Figure 22. Entrance to one of the Tourist Caves, Rangitoto Island.

Portugal – Azores Islands

<u>Gruta das Torres, Pico Island</u>

This volcanic cave, at 5150 m, is the longest in Portugal; 450 m of it has been made accessible to visitors. Paths and handrails have been constructed and there is a visitor centre providing information (VIEIRA DA SILVA & VIEIRA 2004). The cave is not illuminated; visitors are provided with flashlights for the 1 hr tour.

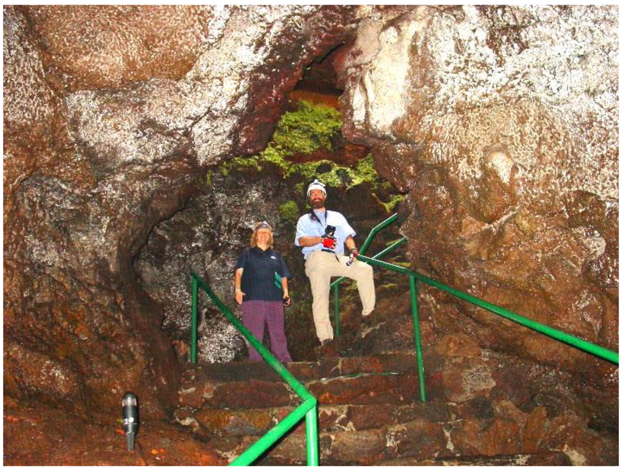
Figure 23. Visitors need to provide their own lights on the Gruta das Torres tour.

<u>Algar do Carvão, Terceira Island</u>

This volcanic cave is situated in a volcanic cone near the middle of Terceira. It is a volcanic chimney, extending down 90 m to a clear water lagoon 400 m^2 in extent (OS MONTANHEIROS 2022a). The chambers contain stalactites and other deposits of amorphous silica, obsidian and the ferric mineral, limonite. This truly extraordinary and spectacular cave is managed by a local caving group, Os Montanheiros, which has been conducting visitors to the cave since 1963. Access has been progressively improved by the excavation of tunnels and the construction of stairways. As a site of geological interest, Algar do Carvão is a Regional Natural Monument, now within the Azores Geopark.

Figure 24. Algar do Carvão contains massive deposits of amorphous silica, obsidian and limonite.

Gruta do Natal (Christmas Grotto), Terceira Island.



This cave is a pyroduct with a total length of 697 m that permits a circular tourist path on the natural, if uneven, cave floor. The managers, Os Montanheiros, have fitted the cave with electric lighting and have conducted tours since 1999 (Figure 25). Helmets are provided for all visitors (OS MONTANHEIROS 2022b).

Figure 25. Well-appointed stairs with handrails in Gruta do Natal.

Gruta do Carvão, São Miguel Island

The 'Cave of Carbon' or 'Coal Grotto' is the longest lava cave on the island, extending for over 1900 m beneath Ponta Delgada City (Figure 26). Promotion of the cave for educational tours has been undertaken by the group Amigos dos Açores since the 1990s, 1441 students being conducted through the cave between 1998 and 2003 (BRAGA 2004). Subsequently, cleaning and provision of facilities allowed the cave to be opened for tourist visits in 2007. Two tours are available: short (200 m) with a maximum of 15 visitors over 30 minutes; helmets provided; long (800 m) with a maximum of 5 participants; gloves, knee-pads and helmet with light provided (AMIGOS DOS AÇORES 2022). Because of its location, size, variety of geological structures and associated volcanic phenomena, Gruta do Carvão was classified as a Regional Natural Monument in 2005.

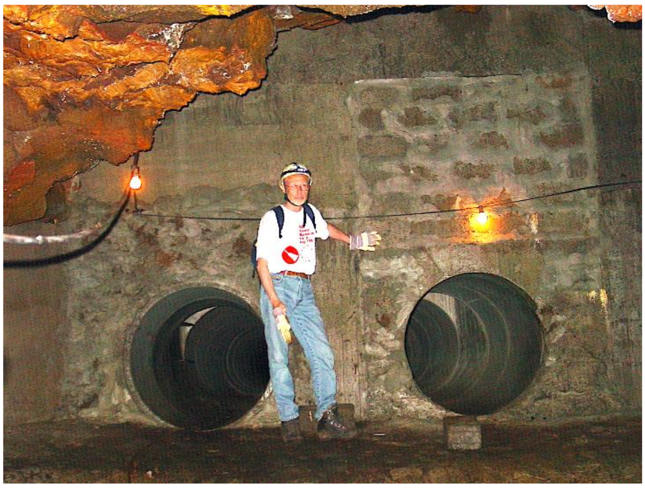


Figure 26. Parts of the Gruta do Carvão serve practical purposes beneath the streets of Ponta Delgada City.

Furna do Enxofre (Sulphur Cavern), Graciosa Island

This impressive lava cave, the main feature of which is a chamber 194 m long and 40 m high with a perfect dome-shaped roof (Figure 27), is reached via a 37 m high stone tower, completed in 1939. There is a lake at the lowest point. Beside the lake there is a degasification field consisting of a mud fumarole and diffuse gaseous emanations of carbon dioxide. The level of carbon dioxide in the cave is constantly monitored and visitors are excluded if it reaches dangerous levels. A visitor centre provides information on the cave and the surrounding Biosphere Reserve and Graciosa Natural Park.

Figure 27. The roof of Furna do Enxofre is a perfect dome.

Samoa

Ana Pe'ape'a ('Swiftlet Cave'), O Le Pupu Pue National Park, Upolu.

This is a pyroduct about 1 km long which is home to a large population of the white-rumped swiftlet *(Aerodramus spodiopygus)* (MIDDLETON 2003). The cave is signposted for tourists but there are no lights, handrails or other facilities. Visitors either need to hire a local guide or rely on their own abilities.

Figure 28. Exploration of Ana Pe'ape'a can bring its own rewards.

Laauoleola Cave (or A'opo Cave), A'opo, Savai'i.

For many years, locals have been showing visitors the first part of this 5 km lava cave (Samoa's longest by far). Following a study by Auckland Speleological Group in 2019, the full extent of the cave has been surveyed and a longer visit is now being provided by the owners (ROWE 2020).

Figure 29. The beautiful passages of Laauoleola Cave.

Letui Pe'ape'a Cave, Savai'i.

A small (about 70 m long) lava cave near the village of Letui has been open to visitors for some years. For a small fee a guide conducts tourists through this pyroduct which is illuminated by a few electric lights (MIDDLETON 2003).

United States Of America

California

Lava Beds National Monument, Tulelake

The monument includes over 800 lava caves, 24 of which are open to the public for self-guided tours; requires a (free) permit, helmet and adequate lights. There is excellent interpretation in the visitor centre and signs at caves. There are stairs, bridges and some walkways; paths have been cleared to facilitate access (Figure 30). Some caves may be closed temporarily to protect breeding bats or because of wildfires or other management issues. Managed by National Parks Service.

Figure 30. the appropriately named Golden Dome is a cave at Lava Beds NM.

Hawaii – Big Island

Nāhuku (Thurston Lava Tube), Hawaii Volcanoes National Park

This has been called “the most visited lava tube in the world” (KEMPE & HENSCHEL 2006) (though the title is probably more deserved by Manjunggul) and it is probably one of the less interesting (Figure 31). About 180 m of pyroduct is illuminated by most unimaginative lighting and it displays few features of interest (MIDDLETON 2002). Entry is free, after paying the national park entry fee; the cave is self-guided, with interpretive signs.

Figure 31. Nāhuku is almost devoid of features of interest.

Kaumana Cave, Kaumana Caves Country Park

A 2.2 km long pyroduct on the slopes of Mauna Loa, managed by the Dept. of Parks & Recreation. There are protective fences and stairs but no guides; access is free and visitors provide their own lights. There are interesting lava flow features (Figure 32) and internal waterfalls after heavy rain (MIDDLETON 2002).

Figure 32. Kaumana Cave has comfortable passage ways and numerous features.

Kazumura Cave, NE flanks of Kilauea Volcano

At 65.5 km, this is by far the longest known pyroduct system (Figure 33). At over 1,100 m from highest to lowest point it is also the 'deepest' cave in the USA (though rarely 20 m below the surface). Unfortunately, none of this huge cave is formally protected, lying entirely under private lands. Two private companies provide guided tours of parts of the system (LOVE BIG ISLAND 2022). *Kazumura Cave Tours* offer tours of 2, 4 and 6 hrs (the latter for experienced cavers only). Headlamps and equipment are provided and the sections visited on the two shorter trips have been fitted with ladders (MIDDLETON 2002). *Kilauea Caverns of Fire* offer tours of 1 and 3 hrs and all day (adventure); prior reservation essential.

Figure 33. There are numerous unexpected lava features in the extensive Kazumura Cave.

Kula Kai Caverns, within Kipuka Kanohina Cave System, Ocean View

This system is the third longest known lava cave, at over 42 kms. The system is heavily braided and maze-like, has multiple levels and contains native Hawaiian artifacts and stalactites, large lava balls (see Figure 34, left), significant gypsum deposits and paleontological remains (LOVE BIG ISLAND 2022). Standard guided tours are 1 hour' but longer tours can be negotiated; all equipment is provided by *Kula Kai Caverns* (prior reservation essential).

Figure 34. Spectacular lava ball in Kula Kai Caverns

Hawaii – Maui

Ka'eleku Caverns (or Hana Lava Tube), Hana.

This privately-owned cave offers self-guided tours of about 40 minutes. Flashlights are provided and there are informative signs (LOVE BIG ISLAND 2022).

Idaho

Craters of the Moon National Monument

This National Parks Service-managed reserve features dramatic volcanic landscapes, including cinder cones (Figure 35), spatter cones, tree moulds and a few lava caves. The modest entry fee entitles the visitor to a cave permit and an obligatory talk at the visitor centre by a ranger on how to safely and responsibly visit the area. Visits to the caves are then self-guided; facilities are minimal (MIDDLETON 2013). Caves may be subject to seasonal closures.

Figure 35. Large cinder cones are a feature of Craters of the Moon Nat M.

Idaho Mammoth Cave, Shoshone

This large, privately-owned, pyroduct (up to 6 m in diameter) is quite impressive (though the mesh fencing detracts from the aesthetics)(Figure 36). Tours, of about 400 m, are self-guided with provided lights but there is no interpretation (MIDDLETON 2013).

Figure 36. Imposing passage at Idaho Mammoth Cave, with excessive fencing.

Shoshone Ice Cave, Shoshone

Guided tours are provided of this large, privately-owned pyroduct which retains large amounts of ice through the summer. The lighting is poor and the wooden walkways and bridges (Figure 37) are obtrusive, if functional (MIDDLETON 2013). Tours take up to an hour. Open from May to September.

Figure 37. Imposing walkways over frozen lakes, Shoshone Ice Cave.

Washington

Ape Cave, Gifford Pinchot National Forest. This 4.1 km long pyroduct is open for inspection from May to October for a small fee which includes use of a flashlight. There are stairs and handrails. Family-friendly and more adventurous self-guided routes are offered. Reservation is essential (FOREST SERVICE 2022).

CONCLUSION

This brief survey shows the range of lava cave types and sizes available for inspection and enjoyment by visitors in many countries around the world where suitable volcanic rock types exist. The survey is selective and does not claim to be exhaustive, but it is probably representative.

A range of facilities and management approaches are demonstrated from full development such as at *Manjunggul* to virtually no modifications as at *Ana Pe'ape'a.* Self-guided tours are the norm and in some cases safety equipment is not even provided. A level of physical fitness beyond that generally expected of visitors to karst caves is often required and floors are often uneven and/or slippery. Interpretation is often minimal or non-existent. Nevertheless, these accessible lava caves provide an opportunity for members of the public without special skills or knowledge to enjoy and better understand these interesting geosites.

References

AMIGOS DOS AÇORES (2022). Gruta do Carvão. http://grutadocarvao.amigosdosacores.pt/en/gruta-do-carvao (accessed 11/9/22).

ATKINSON, A. AND ATKINSON, V. (1995). *Undara Volcano and its lava tubes.* The authors; Brisbane, Qld.

BALAZS, D. (1975). Lava Tubes of the Galapagos Islands. *NSS Bulletin*, 37(1): 1-4.

BRAGA, TEÓFILO (2004). Gruta do Carvão in the island of S. Miguel (Azores) and environmental education. Proceedings, 11th International Symposium on Vulcanospeleology, *Association for Mexican Cave Studies Bulletin* 19: 70.

BRUSH, JOHN (2014). Lava cave meanderings in the Galapagos Islands. *ACKMA Journal*, 95:16-23.

CHECKLEY, D. (Editor) (2008). Mt Suswa Lava Caves, Kenya (A project to map and review the tourism potential of Mt Suswa's principal cave group). *Berliner Höhlenkundliche Berichte*, 31: 1-50.

CROSSLEY, P. (2014). Auckland lava caves. *N.Z. Speleological Bulletin*, 208: 202-206.

DUCKECK, J. (2022). La Cave Madame. https://www.showcaves.com/english/other/caves/Madame.html (accessed 20/9/22).

FOREST SERVICE (2022). Ape Cave Interpretive Site. https://www.fs.usda.gov/recarea/giffordpinchot/recarea/?recid=40393 (accessed 24/9/22).

GRIMES, K.G. (2010). *Field Guide to the volcanic caves of Western Victoria.* 14th International Symposium on Vulcanospeleology.

INSIDETHEVOLCANO (2022). Þríhnúkagígur: The Tour. https://insidethevolcano.com/the-tour/ (accessed 18/09/22).

KEMPE, S. & HENSCHEL, H-V. (2006). Thurston Lava Tube, the most visited lava tube in the world. What do we know about it? Proceedings, 12th International Symposium on Vulcanospeleology, *Association for Mexican Cave Studies Bulletin* 19: 219-228.

LOVE BIG ISLAND (2022). 5 popular lava tubes on the Big Island. https://www.lovebigisland.com/activities-to-do/lava-tubes/ (accessed 24/09/22)

MIDDLETON, G. (1997). Rambles under Mauritius #9 — Pont Bondieu: A spectacular lava cave and associated tubes. *J. Sydney Speleological Society,* 41(2): 25-30.

MIDDLETON, G. (2002). Some lava show caves of Hawaii & Iceland. *ACKMA Journal,* 47: 7-11.

MIDDLETON, G. (2003). The lava caves of Samoa – a preliminary investigation. *J. Sydney Speleological Society,* 47(4): 79-109.

Middleton, G. (2004). Jeju Island lava caves – World Heritage? South Korea – 2003. *J. Sydney Speleological Society,* 48(6): 185-199.

MIDDLETON, G. (2013). Cave-hopping across the USA July-August 2011. *J. Sydney Speleological Society,* 57(6): 155-166.

MIDDLETON, G. (2014). Iceland 2013 – Þríhnúkagígur and other lava caves. *J. Sydney Speleological Society,* 58(11): 323-330.

MIDDLETON, G. (2015). 16th International Symposium on Vulcanospeleology – Galapagos Islands, Ecuador, March 2014. *J. Sydney Speleological Society,* 59(4): 93-101.

MIDDLETON, G.J. AND KEMPE, S. (in press). North Queensland Lava Caves [in] Webb, J. & White, S. (Eds) *Australian Caves and Karst Systems*. Springer Nature, Switzerland.

MIDDLETON, G. AND SIMONS, J. (2015). Protection and management of the Mount Suswa Lava Caves, Kenya: an overview and update. [in] Toulkeridis, T. & Addison, A. (eds) *Abstract Volume & Field Guide. 16th Int. Symp. of Vulcanospeleol. Galápagos, Ecuador March 2014.* pp. 53-61.

OS MONTANHEIROS (2022a). Algar do Carvão. https://www-montanheiros-com.translate.goog/algarCarvao/?_x_tr_sl=pt&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=sc (accessed 11/09/22).

OS MONTANHEIROS (2022b). Gruta do Natal. https://www-montanheiros-com.translate.goog/gruta-do-natal/?_x_tr_sl=pt&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=sc&_x_tr_sch=http (accessed 11/09/22).

PEARSON, L. (ed.) (2010) *Field Guide to the lava tubes of the McBride Volcanic Province in North Queensland.* Chillagoe Caving Club Inc.; Cairns, Qld.

PLAY ICELAND (2022). 10 Best caves to visit in Iceland. https://playiceland.is/guide/10-best-caves-to-visit-in-iceland. (accessed 18/09/22)

REUNION MER ET MONTAGNE (2022). Lava tubes in the volcano of Piton de la Fournaise, Réunion Island. https://www.manawa.com/en-GB/activity/reunion-island/piton-de-la-fournaise/caving/lava-tubes-in-the-volcano-of-piton-de-la-fournaise-reunion-island/11722 (accessed 23/10/22)

ROWE, P. (2020). Laauoleola Cave, Savai'i, Samoa. N.Z. Speleological Bull. 11(218): 521-530.

STEFANSSON, Á. B. (1992) The Þríhnúkagígur pit of Southwest Iceland. *NSS News,* 50(8): 202-208.

STEFÁNSSON, Á. B. (2010). The Vatnshellir Project - a first for Iceland. *Proceedings 14th International Symposium on Vulcanospeleology* pp. 115-121.

VIEIRA DA SILVA, INÊS & VIERIA, MIGUEL (2004). The project for the visitors centre building of the Gruta das Torres volcanic cave, Pico Island, Azores. Proceedings, 11th International Symposium on Vulcanospeleology, *Association for Mexican Cave Studies Bulletin* 19: 72-73.

WILLOX, R. (1989). *Mauritius, Réunion & Seychelles: a travel survival kit.* Lonely Planet Publications, Hawthorn, Victoria. p. 176.

The possibility of APGN Lava Tube Tour Project: A proposal based on a case study in Aso UGGp

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1. Background

Aso caldera was formed by four huge eruptions about 27-90,000 years ago. Many volcanoes were formed in the centre of the caldera by volcanic activities after 90,000 years. However, due to nature's recovery and the fact that people have been burning the fields and maintaining the grasslands since more than 1,000 years ago (geological evidence shows that it was about 10,000 years ago), the area is now a vast expanse of grassland, which covers an area of 1.5 square kilometres, is one of the most popular tourist destinations in Japan.

2. Lava tunnels in Kometsuka and their use as a tourist attraction

Kometsuka is one of a group of volcanoes in the centre of the caldera. It formed a scoria cone about 3,000 years ago and flowed about 3 km of lava. Lava tubes were formed at that time. One lava tube is mainly used for educational purposes, but tours are also offered exclusively to guests by the Aso Hot Springs Ryokan and Tourism Association, which has signed a partnership agreement with Aso UGGp. Under this agreement, only a limited number of people are allowed to tour the lava tubes, and the tour guides are geoguides, so there is no excessive burden on the resource.

3. Possibility of utilizing the lava tubes in cooperation with APGN

The lava tube tours at Aso UGGp can be conducted with geoguides who are experts in conservation and preservation through a partnership agreement with the local community, thus creating a special geotour that only a limited number of people are allowed to enter. The aim is to add value as a special geotour for only a limited number of people. Discussions about such utilization are currently being held with Rinjani-Lombok and Dak Nong UGGp using application “What’s App”. Most UGGp are located in the countryside far from the capital, making it difficult to set up as a travel destination. However, it would be more effective if they could be promoted in their respective capitals, such as Tokyo, as Asian lava tunnels that one would like to visit at least once in one's lifetime, as the title suggests. And this is where I feel the importance of networking activities as APGN.

Keywords: APGN, SNS, Promotion

Images of the PowerPoint presentation appear on following pages.

The possibility of APGN Lava Tube Tour Project: A proposal based on a case study in Aso UGGp
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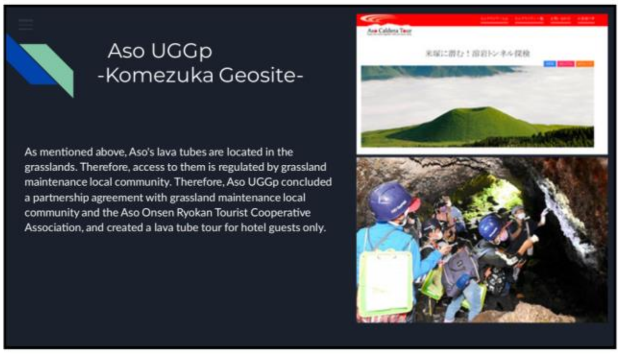
Van Tran, Acting Vice-Director of Dak Nong UNESCO Global Geopark
Mohamad Farid Zaini, General Manager of Rinjani-Lombok UGGp
unesco
RINJANI LOMBOK

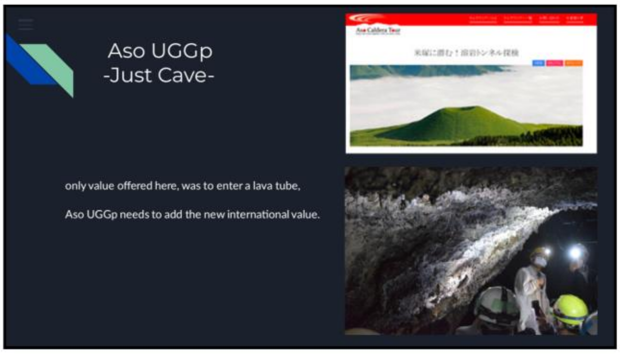
Content
1. Introduction of Aso UGGp
2. APGN Volcanic cave
3. New Promotion project
4. Power of Netowork

Cheon song UGGp
Aso UGGp
Jeju UGGp
Hong Kong UGGp
Dak Nong UGGp
Linjani-Rombok UGGp
Toba Caldera UGGp
change

Aso UGGp
-Komezuka Geosite-
Aso UGGp has a "Kmezuka", a scoria cone about 3,000 years old, with a lava tube underneath. Recent surveys have shown that there are about 1,700 skylites.

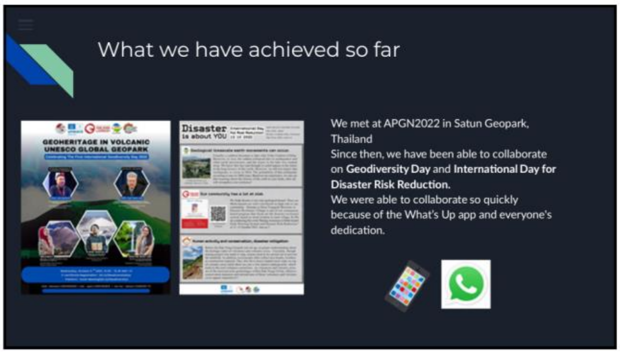


Aso UGGp
-Komezuka Geosite-
As mentioned above, Aso's lava tubes are located in the grasslands. Therefore, access to them is regulated by grassland maintenance local community. Therefore, Aso UGGp concluded a partnership agreement with grassland maintenance local community and the Aso Onsen Ryokan Tourist Cooperative Association, and created a lava tube tour for hotel guests only.

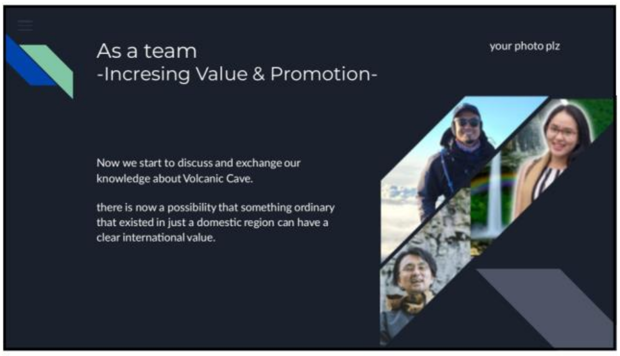


Aso UGGp
-Just Cave-
only value offered here, was to enter a lava tube,
Aso UGGp needs to add the new international value.

APGN
Satun UNESCO Global

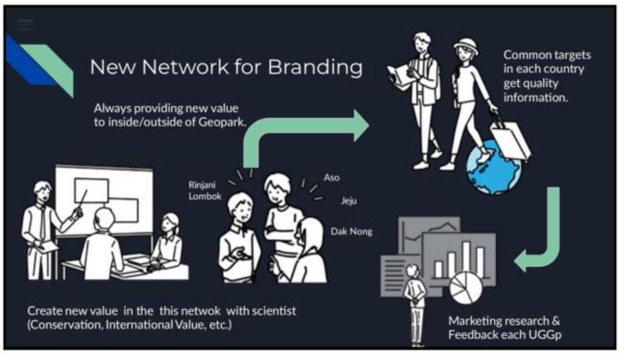


What we have achieved so far
GEOHERITAGE IN VOLCANIC UNESCO GLOBAL GEOPARK
Disaster
We met at APGN2022 in Satun Geopark, Thailand
Since then, we have been able to collaborate on **Geodiversity Day** and **International Day for Disaster Risk Reduction.**
We were able to collaborate so quickly because of the What's Up app and everyone's dedication.

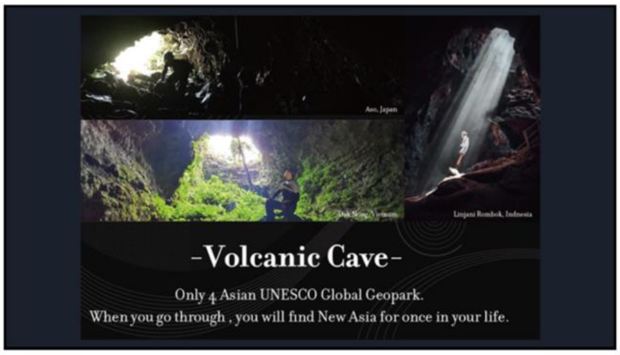


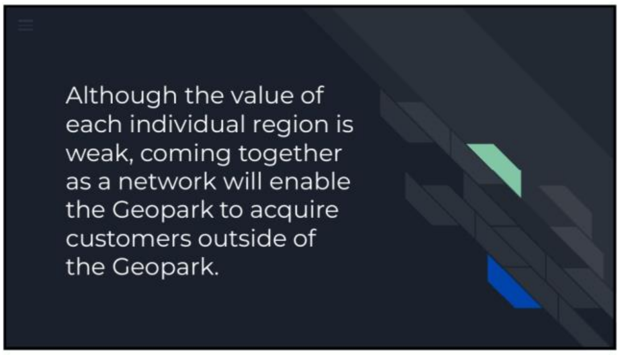
As a team
-Incresing Value & Promotion-
your photo plz
Now we start to discuss and exchange our knowledge about Volcanic Cave.
there is now a possibility that something ordinary that existed in just a domestic region can have a clear international value.

To have more tourist choose our cave.
Rural
Rural
the promotion sites should not only be inside the Geopark Network, but also in places where many people gather, such as capital cities, to catch the attention of the tourists.
and we should find more international value
As New Asia
Rural
Rural
Rural
Rural
Urban


New Network for Branding
Always providing new value
to inside/outside of Geopark.
Common targets
in each country
get quality
information.
Rinjani
Lombok
Aso
Jeju
Dak Nong
Create new value in the this netwok with scientist
(Conservation, International Value, etc.)
Marketing research &
Feedback each UGGp


for example
"4 Greate volcanic cave in Asia you must visit at least once in your lifetime"

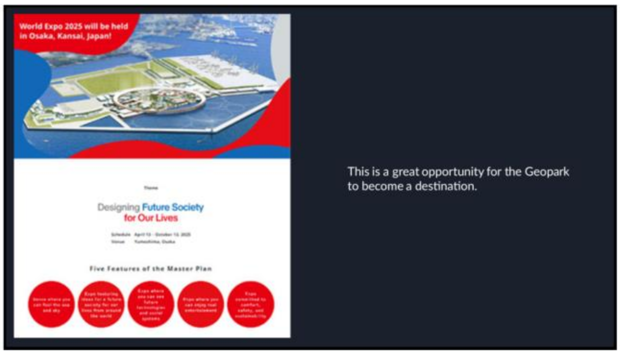

Aso, Japan
Dak Nong, Vietnam
Linjani Rombok, Indonesia
-Volcanic Cave-
Only 4 Asian UNESCO Global Geopark.
When you go through , you will find New Asia for once in your life.


Although the value of
each individual region is
weak, coming together
as a network will enable
the Geopark to acquire
customers outside of
the Geopark.


New Challenge

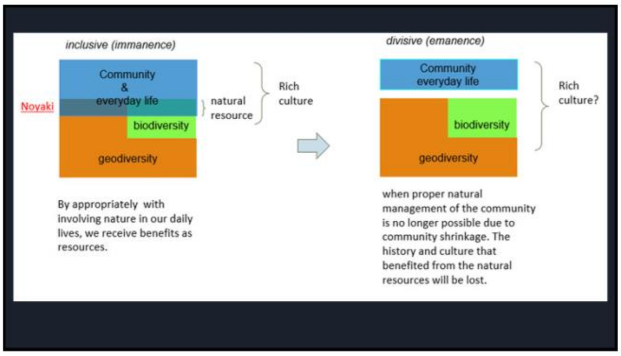

UNESCO Global Geoparks
have the goal of becoming
destinations for travelers.
To achieve this objective,
common tourism and tools
should be created and
promoted in international
showcases in each Geopark.

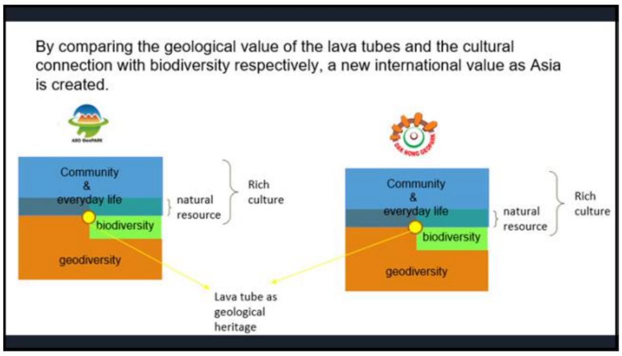

An example for challage to outside geopark promotion
Promoting the glamour of domestic travel!
Discover new encounters!
Japan Tourism Showcase in Osaka/Kansai
The 2nd
Japan Tourism Showcase in Osaka/Kansai
2023
3.24▶3.26
INTEX OSAKA


World Expo 2025 will be held
in Osaka, Kansai, Japan!
Designing Future Society
for Our Lives
This is a great opportunity for the Geopark
to become a destination.

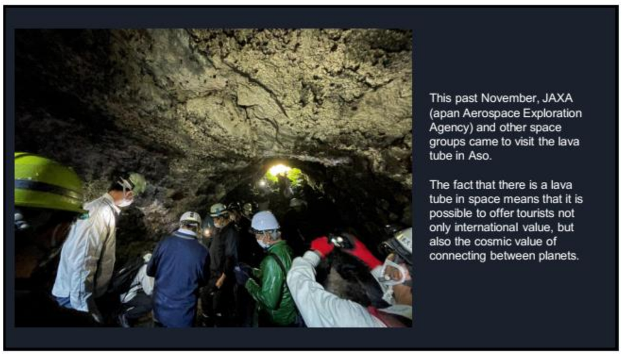

Promote GeoTour in each UGGp to other country or
join international tourism event together
The ITB Berlin, World Travel Market London, Japan Tourism Showcase,
Indonesian Travel Fair, etc.
ITB
BERLIN
THE WORLD'S
LEADING TRAVEL
TRADE SHOW
Japan Tourism Showcase in Osaka/Kansai
2023
3.24▶3.26
INTEX OSAKA

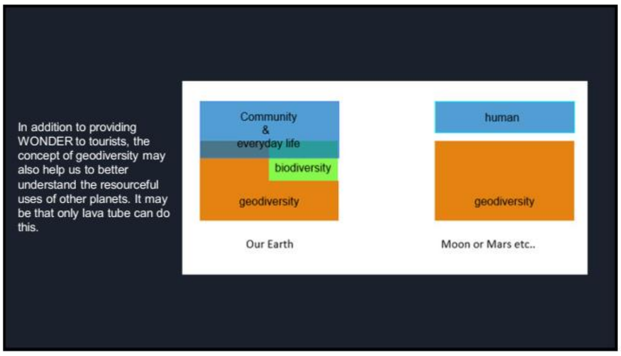

Future Plan
Our lava tubes are the gateway to the Asia
Its New ASIA!

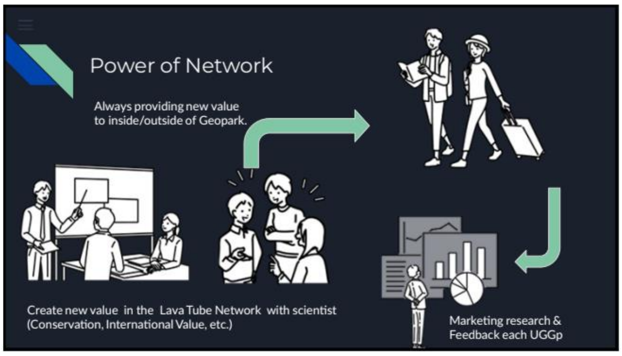

inclusive (immanence)
divisive (emanence)
Noyaki
Community & everyday life
biodiversity
geodiversity
natural resource
Rich culture
By appropriately with involving nature in our daily lives, we receive benefits as resources.
Community everyday life
biodiversity
geodiversity
Rich culture?
when proper natural management of the community is no longer possible due to community shrinkage. The history and culture that benefited from the natural resources will be lost.

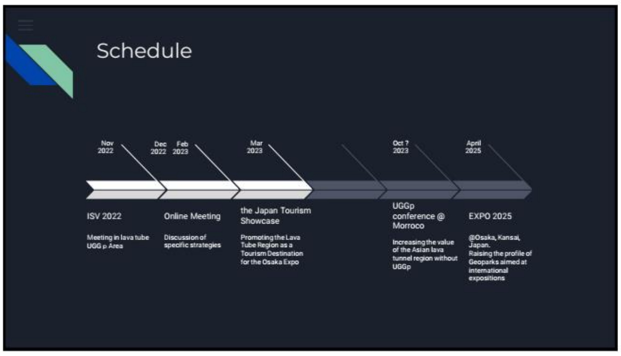

By comparing the geological value of the lava tubes and the cultural connection with biodiversity respectively, a new international value as Asia is created.
Community & everyday life
biodiversity
geodiversity
natural resource
Rich culture
Community & everyday life
biodiversity
geodiversity
natural resource
Rich culture
Lava tube as geological heritage


We can find New ASIA as UNESCO Global Geopark
More discussion
Common Cultural diversity
Agriculture (Rice field) and agricultural event
Common Geodiversity
Volcani cave, Volcanic Rock and Ash…etc
Aso UGGp
Jeju UGGp
Dak Nong UGGp
Rinjani-Lombok UGGp


This past November, JAXA (apan Aerospace Exploration Agency) and other space groups came to visit the lava tube in Aso.
The fact that there is a lava tube in space means that it is possible to offer tourists not only international value, but also the cosmic value of connecting between planets.


In addition to providing WONDER to tourists, the concept of geodiversity may also help us to better understand the resourceful uses of other planets. It may be that only lava tube can do this.
Community & everyday life
biodiversity
geodiversity
Our Earth
human
geodiversity
Moon or Mars etc..


Power of Network
Always providing new value to inside/outside of Geopark.
Create new value in the Lava Tube Network with scientist (Conservation, International Value, etc.)
Marketing research & Feedback each UGGp


Schedule
Nov 2022
Dec 2022
Feb 2023
Mar 2023
Oct ? 2023
April 2025
ISV 2022
Meeting in lava tube UGG p Area
Online Meeting
Discussion of specific strategies
the Japan Tourism Showcase
Promoting the Lava Tube Region as a Tourism Destination for the Osaka Expo
UGGp conference @ Morroco
Increasing the value of the Asian lava tunnel region without UGGp
EXPO 2025
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The volcanic caves of Auckland, New Zealand
Part 1 – Conservation successes and failures

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Abstract

Auckland is the largest city in New Zealand and its 1.6 million residents account for more than 30% of the country's population. This vibrant and rapidly growing city also happens to be built on a dormant volcanic field with the most recent eruption occurring just 500 years ago. There are more than 50 volcanoes within the city area and some of these produced basaltic lavas. More than 250 caves have been recorded in lava flows ranging in age from 500 to 60,000 years. However, urban development has resulted in major impacts. Many caves have been badly damaged or destroyed by quarrying, road construction and building works. Some have been completely removed while others have been filled in or have had their entrances concreted over. Of the caves that remain, some have been used as convenient rubbish dumps, others have been significantly modified and, in several cases, used as convenient drains for stormwater or sewage. Unfortunately, important archaeological features have been compromised. For many years the caves had little official protection and, until recently, were not recognised by government even though some were of deep cultural significance to Maori people and others have, or had, significant archaeological and geological values. This paper highlights some conservation success stories but also considers some unfortunate, non-sustainable outcomes.

Keywords: volcanic caves; cave documentation; cave protection.

Introduction

Auckland is a vibrant, rapidly expanding city located on the North Island of New Zealand. With a population of around 1.6 million, it is home to about one-third of New Zealand's population.

The city is the largest in New Zealand and is one of the fastest growing cities in Australasia. It is also New Zealand's dominant commercial centre and has a diverse manufacturing and industrial base.

These factors result in considerable pressure for urban development and re-development and that in turn has implications for the caves.

The city covers an area of about 5000 km2 and is built around four harbours and 53 volcanoes.

The volcanoes produced large volumes of ash, tuff, scoria and importantly, basaltic lava flows (Figure 1). The map in Figure 2 covers a slightly small area than Figure 1, focussing on the built-up areas of the city. It also shows the location of significant cave entrances to illustrate how widely they occur across the city. More than 250 caves have been recorded, but not all of them still exist.

Caves have been found in lava flows that range in age from around 60,000 to 600 years BP. The most recent eruption was on Rangitoto Island.

This paper considers some cave protection successes, some total failures and also some with reasonable outcomes.

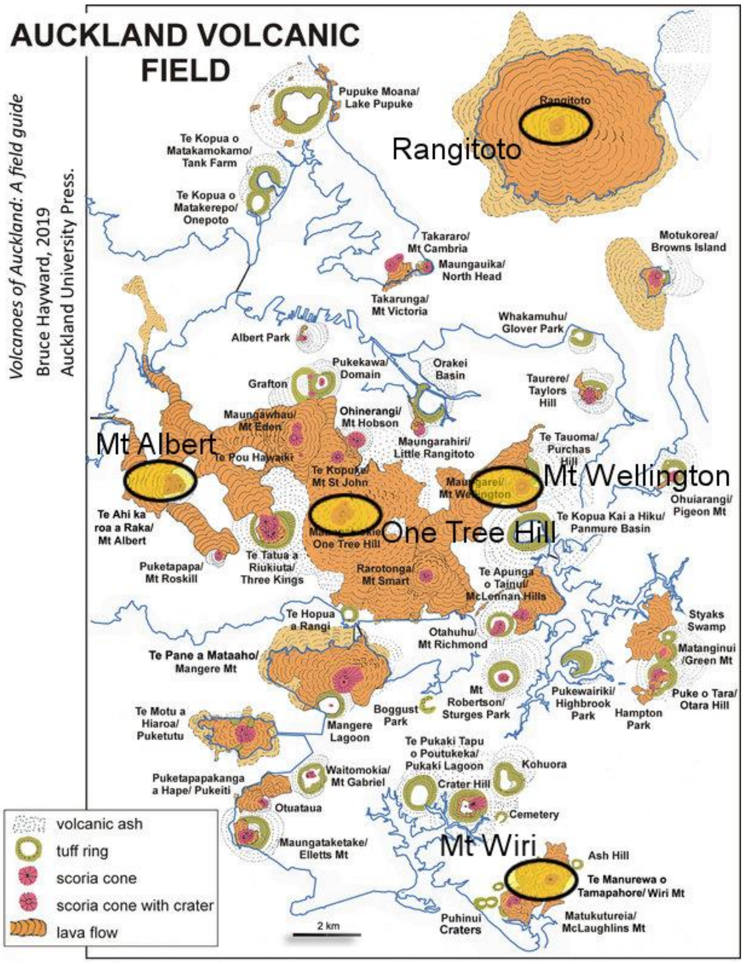

Figure 1. A map of the Auckland Volcanic Field showing the location of volcanoes, lava flows and other eruption features. (From Hayward, 2019). The five areas of the city covered in this paper are indicated by the black/ yellow ellipses

Figure 2. A map of the main city area of Auckland showing the location of significant caves.

Human use of Auckland's volcanic caves

In the past most of the open lava caves were used as Maori burial caves, but little evidence of this remains. In the earlier days of European settlement, many human bones were souvenired or, ground up for fertilizer when there were not enough animal bones available for processing.

There are legends of Maori using some lava caves to escape invaders and they probably have some basis in fact as evidenced by the stone walls that have been found in several caves.

Other caves were used as Maori middens. Almost all caves have at least a few shells, and some have quite a lot.

Some caves in farmland have been used as convenient pits for disposing rubbish (Figure 3) and offal and those in the back gardens of the suburbs have been used as handy rubbish holes with rusty tins and bottles jumbled up with lawn clippings and worse.

Figure 3. The appropriately named Rubbish Cave, which was used as a farm rubbish dump and offal pit for many years.

An early industrial use of the caves was for mushroom farms. Stewarts Cave was probably the most organized operation with built-in shelving and a concrete ramp going down the entrance for the trolleys to take the compost in and the mushrooms out. This use was discontinued by 1960. Until the 1960s there was also another smaller mushroom farming operation in the caves on Harris Road, Greenhill. Unfortunately, all of the Harris Road Caves were buried beneath the Greenmount rubbish dump which, following its closure in 2006, has been progressively redeveloped into an area for sporting and recreational activities.

Some caves were modified for use as air raid shelters during the Second World War. One such cave was Mt Royal Avenue Cave, which is discussed in more detail below.

The use of Ambury Road Cave has not been established. It contains a plastic water pipe and what looks like provision for lights – perhaps for some form of 'underground farming' that needed to be kept well hidden. The second and larger cave on the property has been extensively modified by blasting to widen it and to level the scoria floor. Again the purpose is not clear, but in more recent times it has served as accommodation for a homeless person.

Rangitoto Island

Rangitoto is a short ferry ride from Auckland city and it is a very popular recreation site. As the whole island is a Department of Conservation (DOC) Scenic Reserve, the surface and underground features are well protected. Several caves have free public access and have signposted walking tracks leading into them. These public-access caves are all comparatively short (50-100 metres long) and are reasonably robust. While they are not especially notable, they do exhibit some typical lava features (Figure 4) and are a valuable recreational and educational resource.

In addition to the public access caves, there are less well known, and unmarked, caves hidden away in the bush on more remote parts of the island. Finding them can be a challenge and this helps to protect them.

Figure 4. Two views of typical passages in the public access caves on Rangitoto Island

The most notable cave on Rangitoto and also one of the finest in the Auckland area is Kermies Cave. It is about 180 metres long and has a good range of features in excellent condition (Figure 5). However it has a difficult vertical entrance and also has loose rock in its upper parts where the thin glazed lining has fallen away to expose partially consolidated scoria as the walls and ceiling.

Figure 5. Passage towards the lower end of Kermies Cave on Rangitoto Island.

Mt Wiri (Matukutururu) area

Wiri Cave is the longest known volcanic cave in New Zealand, but with just 290 metres of passage it is relatively short by international standards. It is commonly regarded as the finest volcanic cave in New Zealand. It mostly of walk-through size and has a good range of intact lava features, including flow structures, benches and drip formations (Figure 6).

Figure 6. The central section of Wiri Cave. It is generally regarded as New Zealand's finest volcanic cave.

Wiri cave is located in the southern part of the city not far from Auckland Airport. It is on the slopes of Mt Wiri (Matukutururu), a former volcanic cone that has been almost totally removed by quarrying.

That Wiri Cave still exists is a miracle. It is surrounded on the three sides by quarry sites and on the remaining side, there was a time when road construction works threatened the northern end of the cave.

It was a frustrating 20 year campaign to save Wiri from destruction. Even after a Parliamentary Commission of Enquiry recommended protection of the cave in 1990, it took another eight years before the area was formally gazetted as a scientific reserve and the quarrying operations ceased.

Today, the cave is protected within the reserve. Its main entrance is securely gated and a small vertical entrance shaft near the northern end is concealed beneath a heavy cast iron manhole cover sitting right beside a busy road. But in recent years commercial developments have occurred very close to the reserve boundaries.

In Figure7, the reserve boundaries and cave entrance locations are overlaid on Google Earth imagery dating from 2005. At that time a quarry was still operating to the north of the reserve. But the quarries close to the cave that were once operated by New Zealand Railways, had closed and there was a 'lake' in a former quarry that was where the cone of Mt Wiri once stood.

Figure 8 (see over) covers the same area as Figure 7, but shows Google Earth imagery taken in early 2022. A considerable amount of development has taken place in the intervening 17 years. The former quarry sites have been filled in or levelled and are now largely covered by roads, parking areas and buildings in what has become a busy centre for commercial and industrial activity in the city.

Immediately to the west of the Wiri Reserve lies Rumney Cave. It formed in a parallel flow to the one that formed Wiri and has about 60 metres of passage up to 1.7 metres high and is accessed through a manhole cover. At one stage the cave contained shells and several Moa bones indicating it is a former Maori habitation site. The cave is on a rather neglected site owned by the New Zealand Government but is managed on its behalf by Auckland City Council.

Although Wiri Cave is well protected and Rumney Cave is on government land, a number of other small caves in the area have disappeared (CROSSLEY, 2014).

Some caves in other parts of Auckland have not fared so well.

Figure 7. Google Earth Image of the Mt Wiri (Matukutururu) area in 2005 showing the Wiri Cave Scientific Reserve and nearby caves and quarry sites.

Figure 8. Google Earth Image of the Mt Wiri (Matukutururu) area in 2022 and showing the extensive commercial and industrial development that taken place in recent years in areas adjacent to the Wiri Cave Scientific Reserve

Mt Wellington (Maungarei) area

Mt Wellington, or Maungarei, erupted about 9000 years ago and, after Rangitoto, is the most recent eruption site in the Auckland area. Today, the cone rises above the surrounding industrial and suburban areas of the eastern part of Auckland. In the mid-20th Century, it was surrounded by quarries and in the course of quarrying operations, several caves were intersected. In the 1960s several of the caves, collectively known as Sanders Quarry Caves, were explored. The caves survived the quarrying and were later used as soakage pits for industrial sludge (Figure 9). However, all the entrances disappeared as the quarry site was redeveloped. Whether the cave passages still exist beneath the surface is not known.

Figure 9. A photo from the 1960s showing one of the entrances to the group of caves known as Sanders Quarry Caves. The caves survived the quarrying activity, were later used as soakage pits for industrial sludge and then disappeared when the site was redeveloped for commercial and industrial purposes.

In the Mt Wellington area of the city, two caves were discovered during excavation works at the end of Fraser Rd. The most significant of these, Motor Holdings Cave is 120 metres long. It was intersected during excavation works in 1975 and the survey showed it extended under the Mount Wellington Domain. The cave is a solid basalt tube within welded scoria and basalt lobes. However, the cave is no longer accessible as the entrance was sealed over for a carpark a few days after its discovery. Access to the second cave, Motor Holdings Manhole Cave, is still possible (Figure 10). This cave extends about 30 metres to a silt blockage, probably resulting from a stormwater sump that flows into the cave.

Several other caves recorded in the Mt Wellington area have been removed or completely covered.

Figure 10. The new access point to Motor Holdings Manhole Cave. The original entrance, marked with a red cross was covered when the site was turned into a parking area on the edge of Mt Wellington Domain.

One Tree Hill (Maungakiekie) Area

The volcanic cone of One Tree Hill, or Maungakiekie, has survived relatively intact as it is one of the largest public parks in Auckland. At one time there were many small caves in the area but most, including all those in the park, have been covered over. The cave passages should still be there; they just don't have any access.

Further afield in the One Tree Hill area, three important caves survive. One of them is the Cave of a Thousand Press-Ups. It is a maze of low passages, formed when a thin flow spread out in several lobes before draining. Much of the cave lies at a shallow depth below Campbell Road, but two passages curve around three sides of a nearby house (Figure 11).

Figure 11. Map of Cave of a Thousand Press-Ups overlaid on Google Earth imagery showing the extent of the cave and how the passages wrap around a nearby house.

The cave is entered through a manhole in the footpath. The entrance passage is about a metre high and is quite pleasant, but most passages are only half a metre high and it is not an easy cave to explore. The cave name is apt. Most of the cave is in good condition, but storm water from the road enters through the entrance and carries in silt and rubbish. The most significant feature in the cave is wind striping on the ceiling, which is the best example in the Auckland area (Figure 12, at right).

Figure 12. Wind striping in Cave of a Thousand Press-ups.

Another cave in the One Tree Hill area is the Helena Rubenstein Complex. It is a series of low, lobe-shaped passages, in many ways similar to Thousand Press-Ups Cave. The complex has three separate sections that were discovered during excavation works in the early 1970s. Initially the entrances were covered over, but manhole entrances were able to be installed for two of the sections when commercial buildings were being built in the 1980s.

Access to the largest central section has been lost and siltation from stormwater inflows affects the two accessible sections, one of which is known as Ratcliffes Cave.

Ratcliffes Cave can be freely entered provided nothing is parked over the entrance. Its main feature of interest is good lava rolls. It once contained Maori and early European artefacts (shell, bones and pottery).

Mt Albert area

At about 30,000 years old, Mount Albert is a moderately young eruption site. Some of the central cone has been levelled for sporting fields and the lower slopes have been covered with suburbia. Two main lava flows originated at Mt Albert. One flowed north towards Meola Creek and a smaller one flowed to the south. Both flows generated a number of caves.

Mount Royal Avenue Cave lies about 400 metres south of the Mt Albert crater.

The entrance is through a door at the back of a garage (Figure 13) attached to a suburban house.

During the Second World War it was set for use as an air raid shelter. The floor was levelled to accommodate many people, and walls and a water tank (Figure 14), which has now fallen off its pedestal, were constructed.

Figure 13. Mt Royal Avenue cave, looking back at the entrance door.

Figure 14. Central part of the cave, looking back towards the tank platform

From the entrance door, the passage goes back under the house, the one next door and continues under another house next door and then under another house at the back (Figure 15) . Although the cave is relatively short - total length is about 80 metres - it is a very fine cave. It is well preserved and most of the passage is about 5 metres wide and is up to 5 metres high.

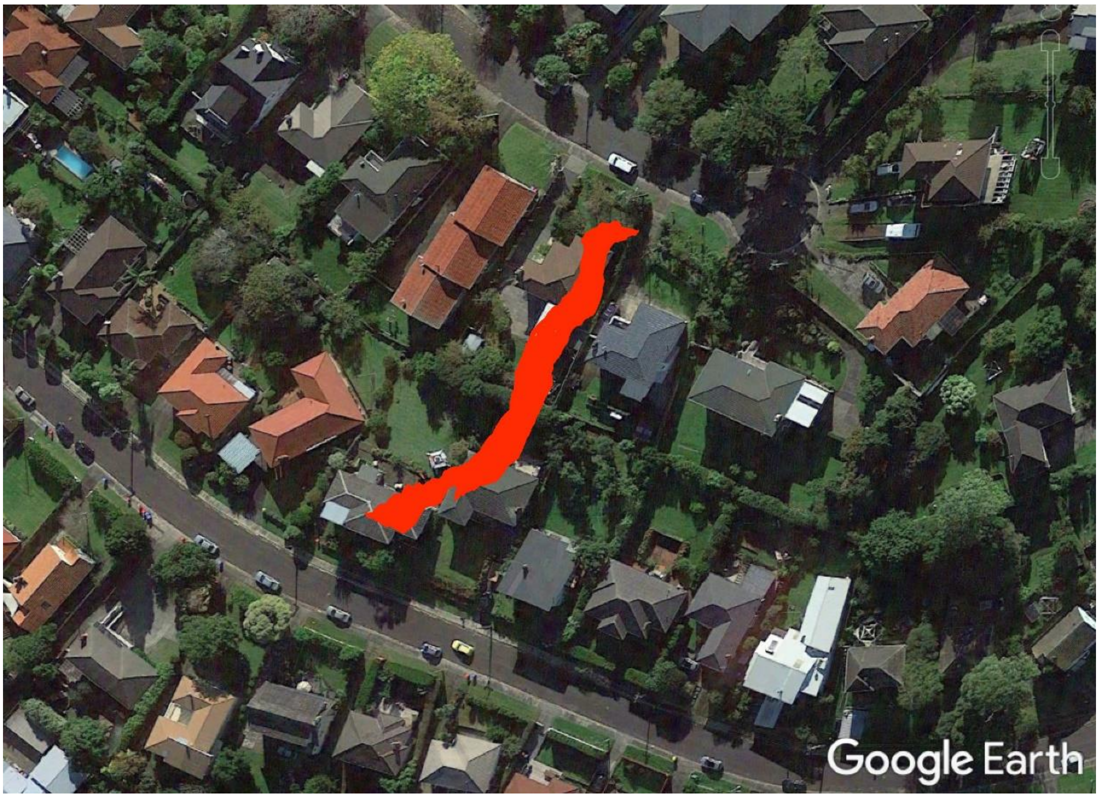

Figure 15. Map of Mount Royal Avenue Cave overlaid on Google Earth imagery showing how it passes under three houses in its short (less than 80 metres) length.

Conclusions

The caves referred to above are representative examples of the volcanic caves that exist in the Auckland area. They also cover the range of protection mechanisms to protect them and the failures that have occurred in the past.

By world standards, the lava caves around Auckland are relatively small. Nevertheless, they are interesting and many have significant scientific values as well as important Maori and European heritage values. They are also an important educational and recreational resource. And they are of considerable interest and value to speleos.

Some caves are well protected, for example in reserves. However, many caves have been lost or badly damaged over the years though ignorance, carelessness or laziness at a time when official recognition and effective protection measures for caves and their contents were lacking.

There is now increased public awareness of caves in the Auckland area and importantly, there is official recognition of them at both national and local government levels and with the current planning regulations, the future looks more promising than it has done for some decades.

However, as Auckland continues to grow, balancing cave protection with urban development is likely to be an on-going challenge.

References

HAYWARD, BW (2019). *Volcanoes of Auckland: A field guide*. Auckland University Press.

CROSSLEY, Peter (2014). Inside Auckland Lava Caves. *Speleological Bulletin* Vol 11, No 208 Published by the New Zealand Speleological Society Inc. 60pp.

Conservation Projects in Mudeungsan UNESCO Global Geopark of Republic of Korea

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The Mudeungsan UNESCO Global Geopark is located at the southwestern part of the Korean peninsula. Administration is shared between Gwangju Metropolitan City and two counties (Damyang-gun County and Hwasun-gun County) of Jeollanam-do Province. In and around the area there are many villages and cultural features closely connected to Mudeungsan (Mudeung Mt.). Twenty geosites have been identified in the 1,051 km^2 mountainous UNESCO Global Geopark area. The core area of 75 km^2 is within Mudeungsan National Park. Seven geological periods are represented. The worldwide geological sites range from five large colonnades of polygonally jointed tuff columns recording at least three phases of Cretaceous volcanic activity, extensive periglacially-produced block streams and cryoplanation surfaces, unusual wind-hole within talus accumulations, very unique dinosaur footprints and trackways, and a variety of other geological and geomorphological features such as lengthy scenic cliff-lines and waterfalls. Among them, outstanding universal value sites are colonnades of Mudeung Mountain, Unjusa stratified tuff, Hwasun Dolmen site and Seoyuri dinosaur fossil site.

Among the various projects for conserving in the Mudeungsan Global Geopark, the citizen movements is the most outstanding and interesting. The program is developed to combine indoor and outdoor classes in conjunction with geosites. In 1972, the Mudeungsan was designated as a provincial park of Jeollannam-do Province, Korea. During the 1980s the area was one of the most popular vacation destinations in South Korea. The two districts at the entrance of Mudeungsan, Jeungsimsa Temple district and Wonhyosa Temple district were crowded with many recklessly established restaurants and lodgings. Such densely located group facilities emitted waste water and caused serious natural damage. In this situation, the local government and citizens who loved to protect Mudeungsan was forces to native people to move such facilities from 2003 to 2010 firstly. In 2010, all restaurants and lodgings in Jeungsimsa Temple district was moved to new area in the lower part of Mudeungsan. After 2016, the Wonhyosa Temple district only remained as unlawfulness commercial facilities. Now this area also is working to relocate to the other area in lower part of Mudeungsan. The Military base located at Mudeungsan summit in 1966 has begun the relocation project by concluding an agreement with the air force bases in November, 1996. The citizens and municipal government intends to continue consultation with the air force to make the relocation project for returning to visitors of the Mudeungsan Global Geopark in its natural status. Fortunately the Korean Government was announced the relocation project last month. The large-sized Shinyang Park Hotel set up in 1981 also was returned to citizens by the national trust movement. Three visitor centres have been newly secured after its designation, and the Geo Archive Room with all the arranged data related to geoparks was newly established. To establish the "UNESCO Global Geopark Asia Platform Center," (Investment cost: 30 million US Dollar) was secured in October 2020. The detailed design and display project about the building was started in 2021. This building is trying to open in 2025. In order to improve the recognition of the geopark and enhance its brand value, the Mudeungsan UGGp has been attempting various promotions.

Keywords: Mudeungsan UNESCO Global Geopark, Cretaceous volcanic rocks and sedimentary rocks, Conservation projects.

Images of the PowerPoint presentation appear on following pages.


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Conservation Projects in Mudeungsan UNESCO Global Geopark of Republic of Korea
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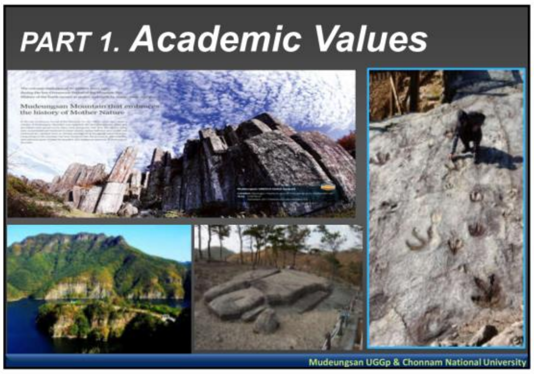
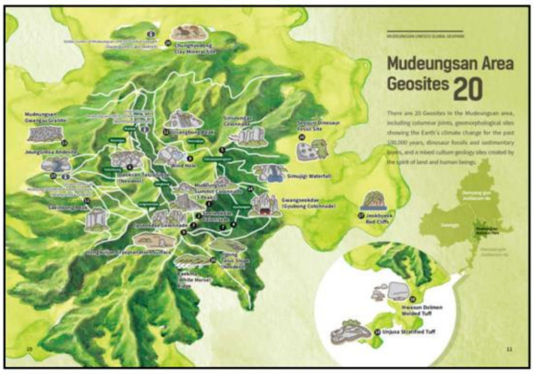
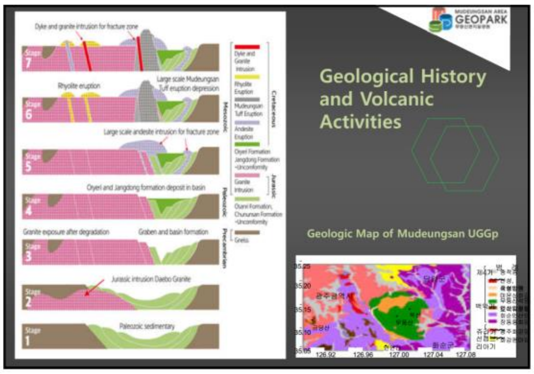
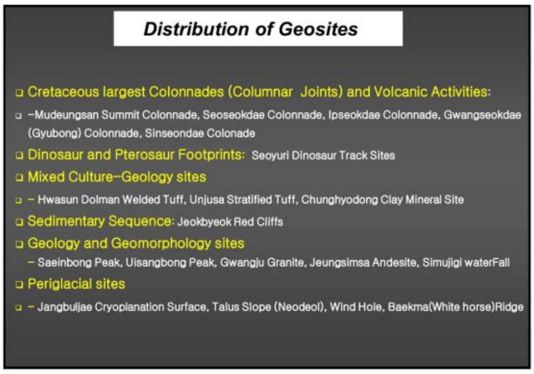
3 Geopark Team, Green City Office, Gwangju Metropolitan City, Republic of KOREA

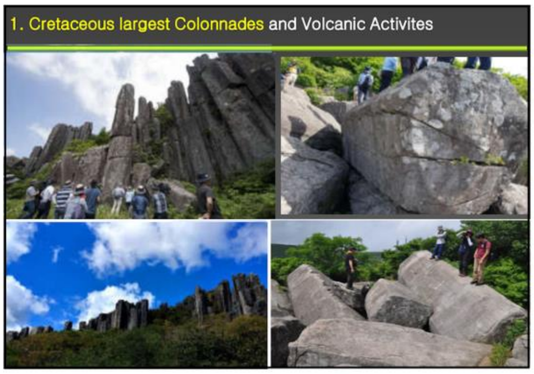

Mudeungsan UNESCO Global Geopark
• Location : Gwangju Metropolitan city, Damyang-gun County and Hwasun-gun County
• Area : 105,136 ha
• Sites : Geosite 20, Historical Culture site 42
• Designation : National Geopark (2014), Global Geopark (2018) ★★★★★
Korea Dinosaur Research Center and Mudeungsan Area Geotourism Center, CNU


PART 1. Academic Values
Mudeungsan UGGp & Chonnam National University


Mudeungsan Area Geosites 20


GEOPARK
Geological History and Volcanic Activities
Geologic Map of Mudeungsan UGGp


Distribution of Geosites
Cretaceous largest Colonnades (Columnar Joints) and Volcanic Activities:
–Mudeungsan Summit Colonnade, Seoseokdae Colonnade, Ipseokdae Colonnade, Gwangseokdae (Gyubong) Colonnade, Sinseondae Colonade
Dinosaur and Pterosaur Footprints: Seoyuri Dinosaur Track Sites
Mixed Culture-Geology sites
– Hwasun Dolman Welded Tuff, Unjusa Stratified Tuff, Chunghyodong Clay Mineral Site
Sedimentary Sequence: Jeokbyeok Red Cliffs
Geology and Geomorphology sites
– Saeinbong Peak, Uisangbong Peak, Gwangju Granite, Jeungsimsa Andesite, Simujigi waterFall
Periglacial sites
– Jangbuljae Cryoplanation Surface, Talus Slope (Neodeol), Wind Hole, Baekma(White horse)Ridge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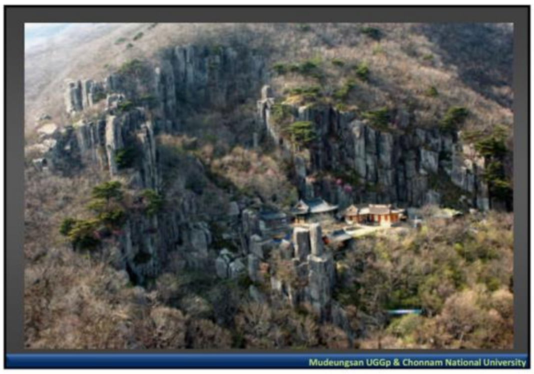
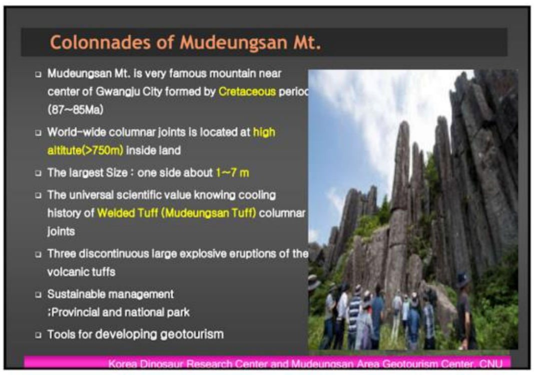
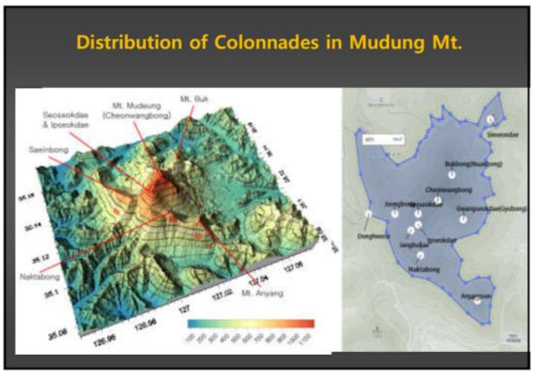

Mudeungsan UGGp & Chonnam National University


Colonnades of Mudeungsan Mt.
Mudeungsan Mt. is very famous mountain near center of Gwangju City formed by Cretaceous period (87~85Ma)
World-wide columnar joints is located at high altitute(>750m) inside land
The largest Size : one side about 1~7 m
The universal scientific value knowing cooling history of Welded Tuff (Mudeungsan Tuff) columnar joints
Three discontinuous large explosive eruptions of the volcanic tuffs
Sustainable management :Provincial and national park
Tools for developing geotourism
Korea Dinosaur Research Center and Mudeungsan Area Geotourism Center, CNU


Distribution of Colonnades in Mudung Mt.
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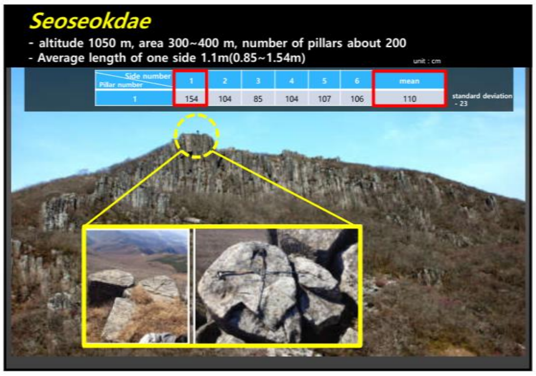
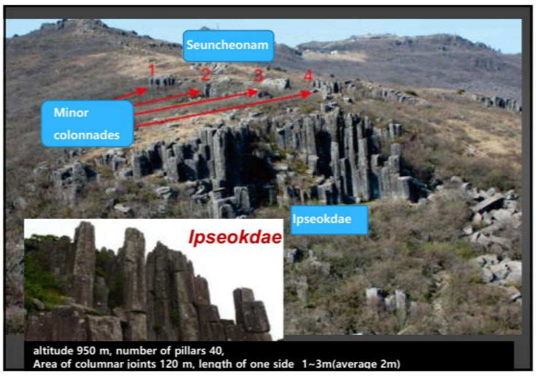
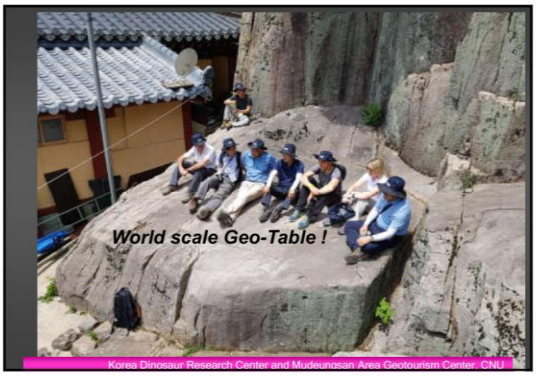
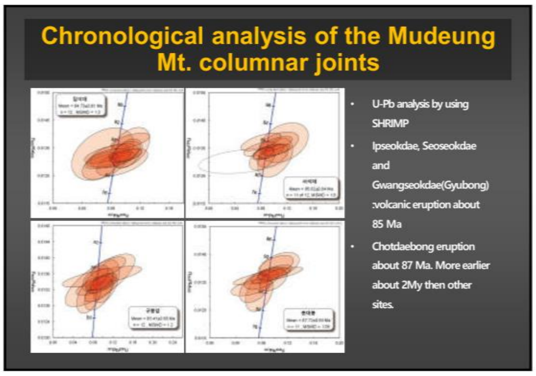
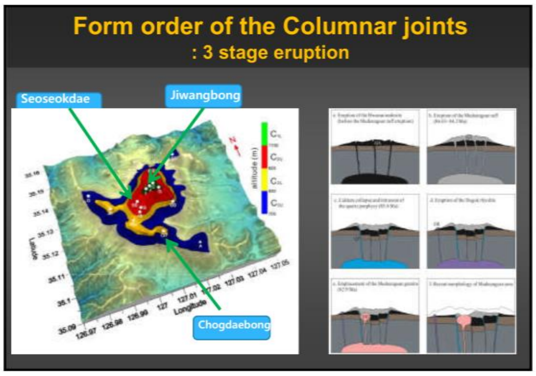
Mt. Mudeung (Cheonwangbong)
Seoseokdae & Ipseokdae
Saeinbong
Naktabong
Mt. Anyang

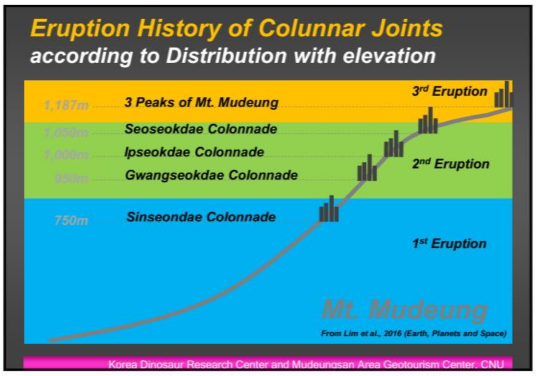


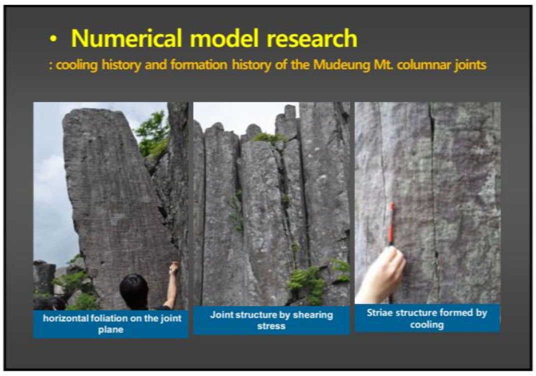


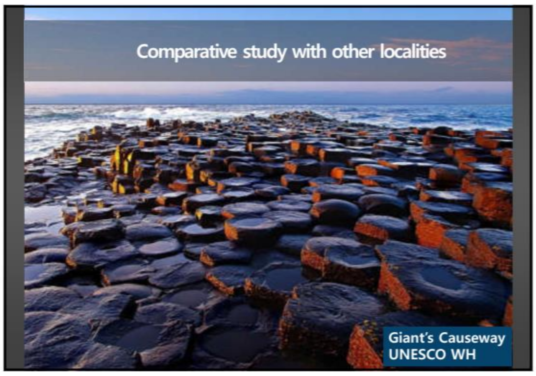


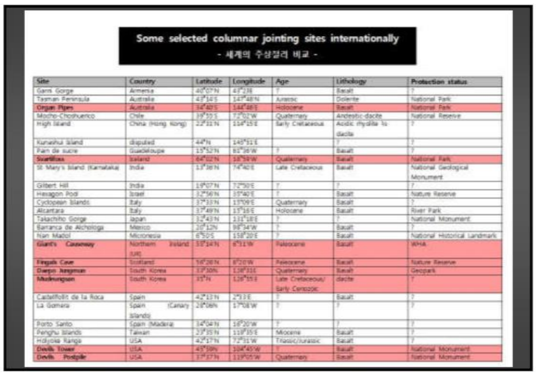






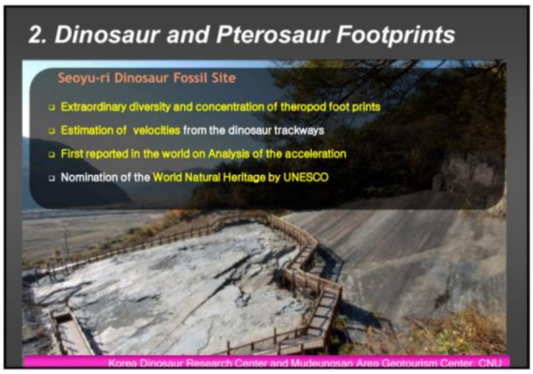


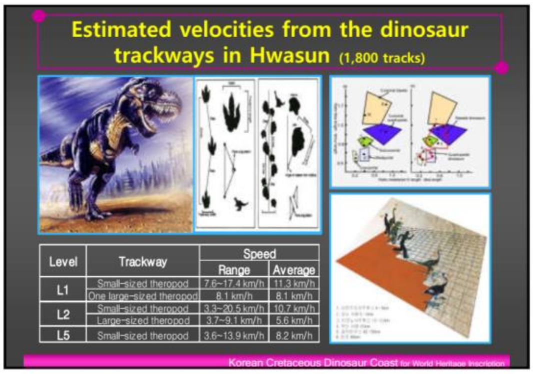




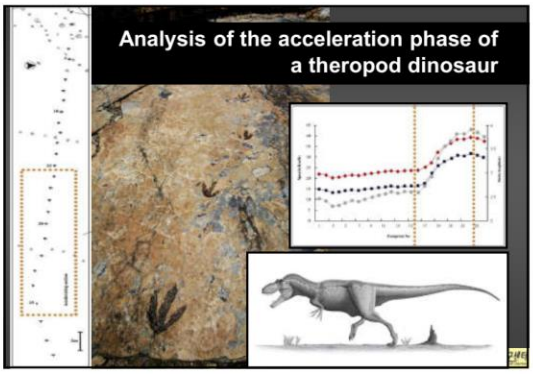
Some selected columnar jointing sites internationally
- 세계의 주상절리 비교 -

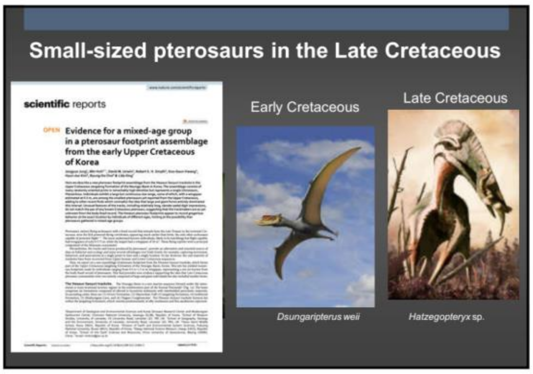
Site	Country	Latitude	Longitude	Age	Lithology	Protection status
Garni Gorge	Armenia	40°07'N	43°23'E	?	Basalt	?
Tasman Peninsula	Australia	43°14'S	147°48'N	Jurassic	Dolerite	National Park
Organ Pipes	Australia	34°40'S	144°46'E	Holocene	Basalt	National Park
Mocho-Choshuenco	Chile	39°55'S	72°02'W	Quaternary	Andesitic-dacite	National Reserve
High Island	China (Hong Kong)	22°21'N	114°15'E	Early Cretaceous	Acidic rhyolite to dacite	?
Kunashui Island	disputed	44°N	145°51'E		?	?
Pain de sucre	Guadeloupe	15°52'N	61°36'W	?	Basalt	?
Svartifoss	Iceland	64°02'N	16°59'W	Quaternary	Basalt	National Park
St Mary's Island (Karnataka)	India	13°38'N	74°40'E	Late Cretaceous	Basalt	National Geological Monument
Gilbert Hill	India	19°07'N	72°50'E	?	?	?
Hexagon Pool	Israel	32°56'N	35°40'E	?	Basalt	Nature Reserve
Cyclopean Islands	Italy	37°33'N	15°09'E	Quaternary	Basalt	?
Alcantara	Italy	37°49'N	15°16'E	Holocene	Basalt	River Park
Takachiho Gorge	Japan	32°43'N	131°18'E	?	?	National Monument
Barranca de Alchologa	Mexico	20°12'N	98°34'W	?	Basalt	?
Nan Madol	Micronesia	6°50'S	158°20'E	?	Basalt	National Historical Landmark
Giant's Causeway	Northern Ireland (UK)	55°14'N	6°31'W	Paleocene	Basalt	WHA
Fingal's Cave	Scotland	56°26'N	6°20'W	Paleocene	Basalt	Nature Reserve
Daepo Jungmun	South Korea	33°30'N	126°31'E	Quaternary	Basalt	Geopark
Mudeungsan	South Korea	35°N	126°55'E	Late Cretaceous/ Early Cenozoic	dacite	?
Castellfollit de la Roca	Spain	42°13'N	2°33'E	?	Basalt	?
La Gomera	Spain (Canary Islands)	28°06'N	17°08'W	?	?	?
Porto Santo	Spain (Madeira)	34°04'N	16°20'W	?	?	?
Penghu Islands	Taiwan	23°35'N	119°35'E	Miocene	Basalt	?
Holyoke Range	USA	42°17'N	72°31'W	Triassic/Jurassic	Basalt	?
Devils Tower	USA	45°59'N	104°45'W	?	Basalt	National Monument
Devils Postpile	USA	37°37'N	119°05'W	Quaternary	Basalt	National Monument

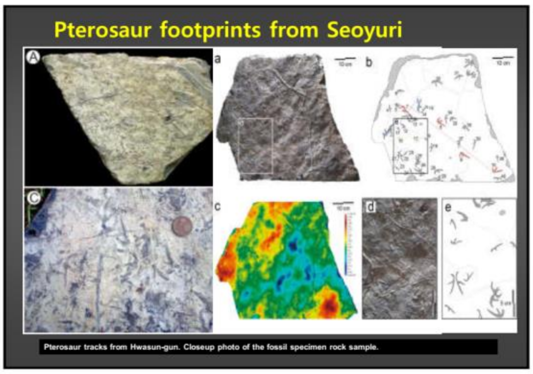


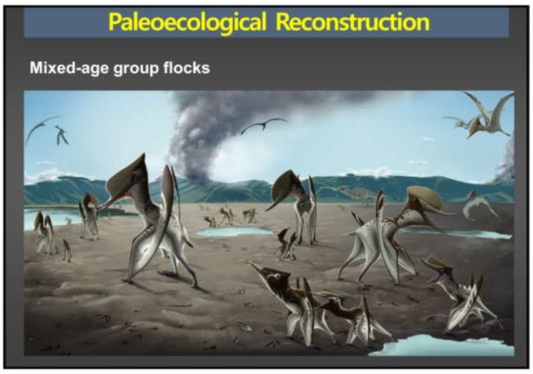


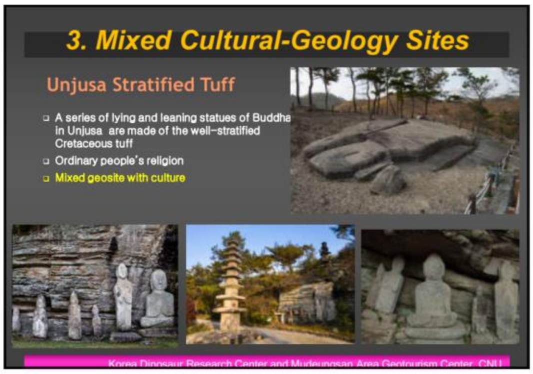
Level	Trackway	Speed	
		Range	Average
L1	Small-sized theropod	7.6~17.4 km/h	11.3 km/h
	One large-sized theropod	8.1 km/h	8.1 km/h
L2	Small-sized theropod	3.3~20.5 km/h	10.7 km/h
	Large-sized theropod	3.7~9.1 km/h	5.6 km/h
L5	Small-sized theropod	3.6~13.9 km/h	8.2 km/h

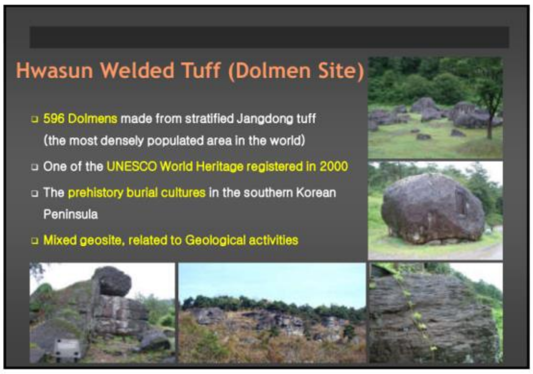


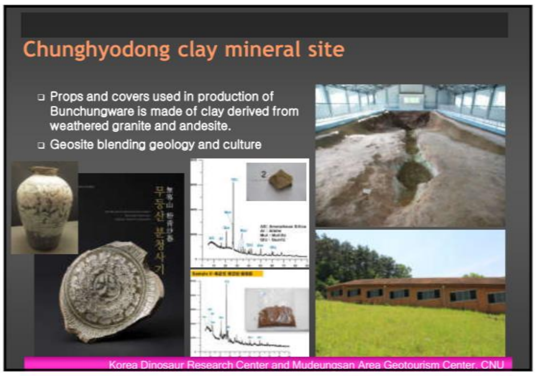


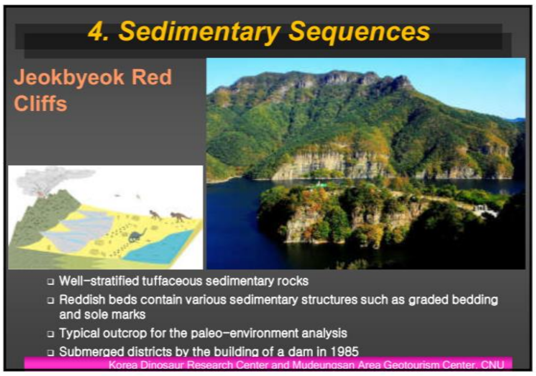


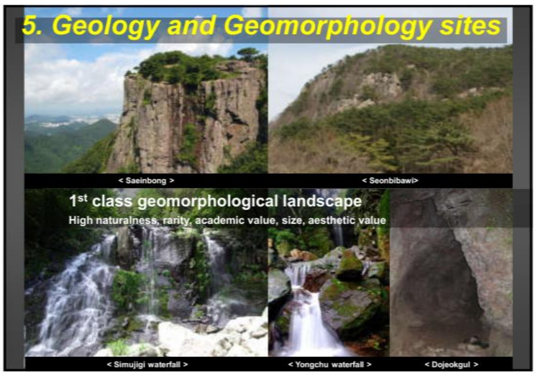


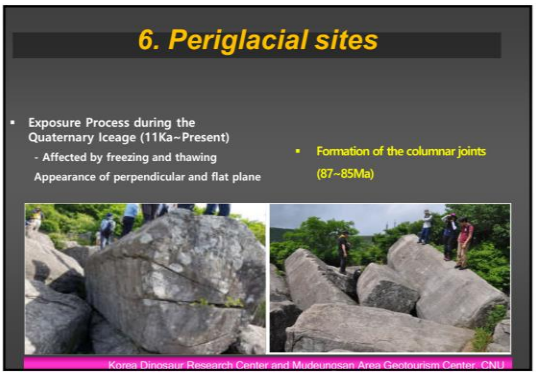


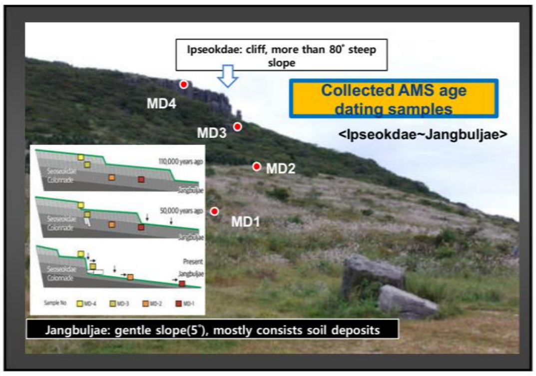



Chunghyodong clay mineral site
Props and covers used in production of Bunchungware is made of clay derived from weathered granite and andesite.
Geosite blending geology and culture
Korea Dinosaur Research Center and Mudeungsan Area Geotourism Center, CNU

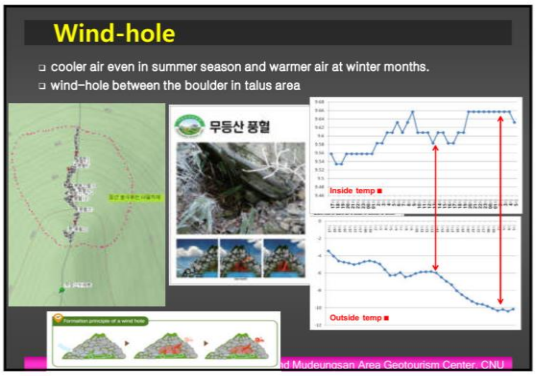

4. Sedimentary Sequences
Jeokbyeok Red Cliffs
Well-stratified tuffaceous sedimentary rocks
Reddish beds contain various sedimentary structures such as graded bedding and sole marks
Typical outcrop for the paleo-environment analysis
Submerged districts by the building of a dam in 1985
Korea Dinosaur Research Center and Mudeungsan Area Geotourism Center, CNU


5. Geology and Geomorphology sites
< Saeinbong >
< Seonbibawi >
1st class geomorphological landscape
High naturalness, rarity, academic value, size, aesthetic value
< Simujigi waterfall >
< Yongchu waterfall >
< Dojeokgul >

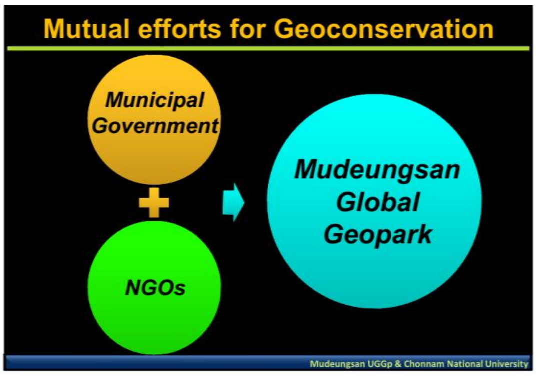

6. Periglacial sites
Exposure Process during the Quaternary Iceage (11Ka~Present)
- Affected by freezing and thawing
Appearance of perpendicular and flat plane
Formation of the columnar joints
(87~85Ma)
Korea Dinosaur Research Center and Mudeungsan Area Geotourism Center, CNU


Ipseokdae: cliff, more than 80° steep slope
Collected AMS age dating samples
<Ipseokdae~Jangbuljae>
MD4
MD3
MD2
MD1
Jangbuljae: gentle slope(5°), mostly consists soil deposits


Talus slope (Neodeol)
Highest density of block stream in Korea (3%)
High naturalness, rarity, academic value, size, aesthetic value
Korea Dinosaur Research Center and Mudeungsan Area Geotourism Center, CNU

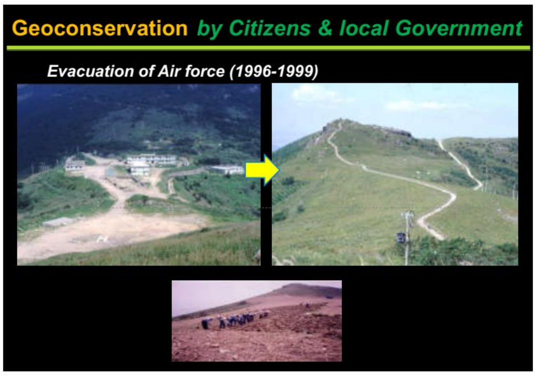

Wind-hole
cooler air even in summer season and warmer air at winter months.
wind-hole between the boulder in talus area
무등산 풍혈
Inside temp
Outside temp
d Mudeungsan Area Geotourism Center, CNU

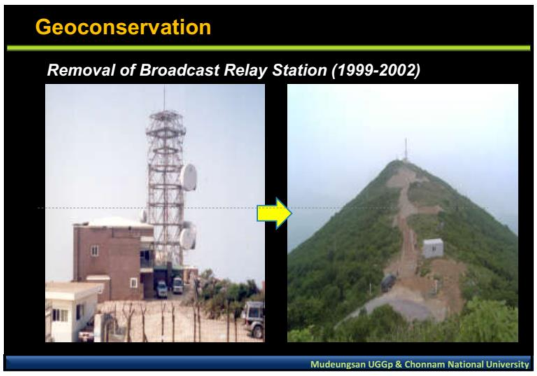

PART 2. Conservation
Mudeungsan UGGp & Chonnam National University


Mutual efforts for Geoconservation
Municipal Government
NGOs
Mudeungsan Global Geopark
Mudeungsan UGGp & Chonnam National University

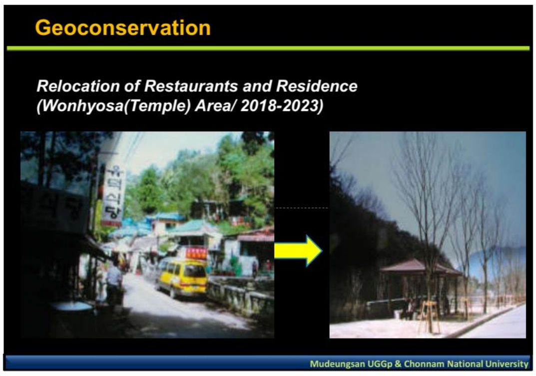

Geoconservation by NGOs
Mt. Mudeung Sharing Campaign
National Trust Movement
Initiated in 1991 (40 years)
무등산 공유화 기금 2차 전달식
Mudeungsan UGGp & Chonnam National University


Geoconservation by Munhwa Broadcast Corp. (TV)
무등산을 사랑하자
Mudeungsan Mt. Love Campaign during 40 years
Mudeungsan UGGp & Chonnam National University


Geoconservation by Citizens & local Government
Evacuation of Air force (1996-1999)

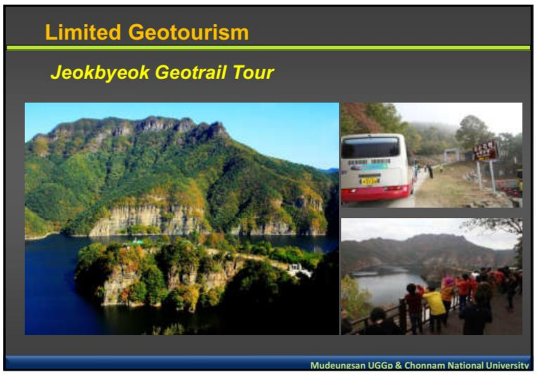

Geoconservation
Removal of Broadcast Relay Station (1999-2002)
Mudeungsan UGGp & Chonnam National University


Geoconservation
Relocation of Restaurants and Residence (Jeungshimsa(Temple) Area/ 2003-2010)
Mudeungsan UGGp & Chonnam National University


Geoconservation
Relocation of Restaurants and Residence (Wonhyosa(Temple) Area/ 2018-2023)
Mudeungsan UGGp & Chonnam National University


New Geoconservation
Changing to New Eco Area from old Hotel (Shin Yang Park Hotel/5 stars/2021-2025)
Shin Yang Park Hotel
Cooperation for Eco Area:
Committee+Citizens
Mudeungsan UGGp & Chonnam National University


Future Conservation:
Mudeungsanjang (Ancient Mudeungsan Tourist Hotel)
Main Building in 1962
Now
Mudeungsan UGGp & Chonnam National University


Limited Geotourism
Jeokbyeok Geotrail Tour
Mudeungsan UGGp & Chonnam National University


Campaign of Mudeungsan UGGp
GWANGJU MBC(MUNHWA BROADCASTING CORP.) Documentary Film
Mudeungsan UGGp & Chonnam National University


Campaign of Mudeungsan UGGp
Geopark Documentary film (2019. 02)
Mudeungsan UGGp & Chonnam National University


20min. to Mudeungsan Mt. from Gwangju Metropolitan city
Mudeungsan UGGp & Chonnam National University

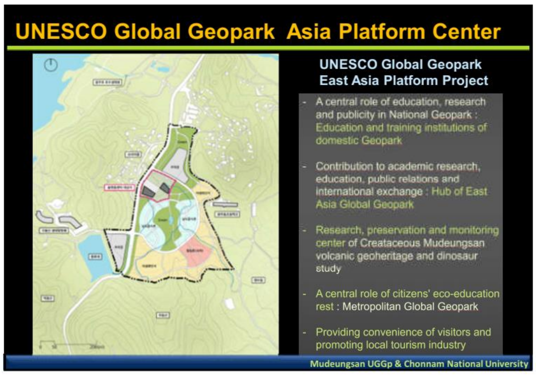

The 1st International Workshop on Metropolitan Global Geopark in 2019
The 1st International Workshop on Metropolitan Global Geopark &
The 3rd International Comprehensive Field Workshop on Geopark
Mudeungsan UGGp & Chonnam National University


1st Geo-Marathon in 2019
Mudeungsan UGGp & Chonnam National University

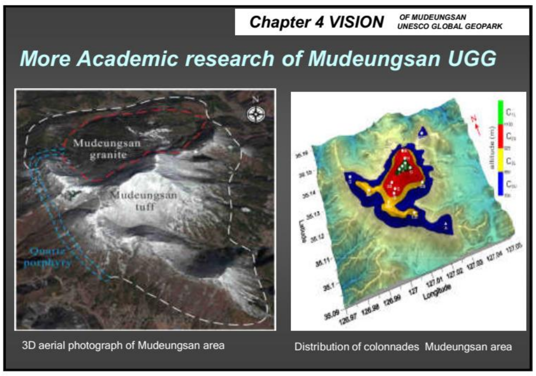

Mudeungsan Globalization
Your brand is one of your most important assets!
Mudeungsan UGGp & Chonnam National University

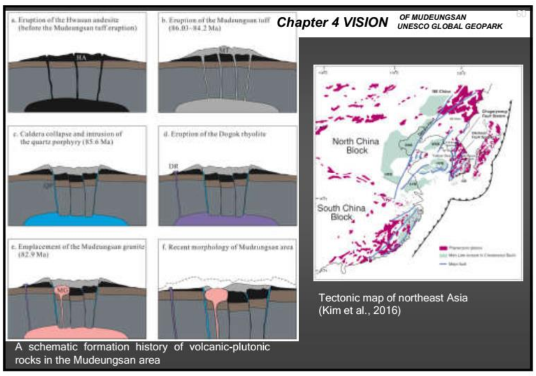

Geoconservation movement by NGO
Mudeungsan Protection Association awarded by UNESCO
"Education of Sustainable Development"
(Topic: Protection Program of Mt. Mudeung)
Initiated in 1989 (42 years)
Endorsed Certificates for 2,094 people
Mudeungsan UGGp & Chonnam National University

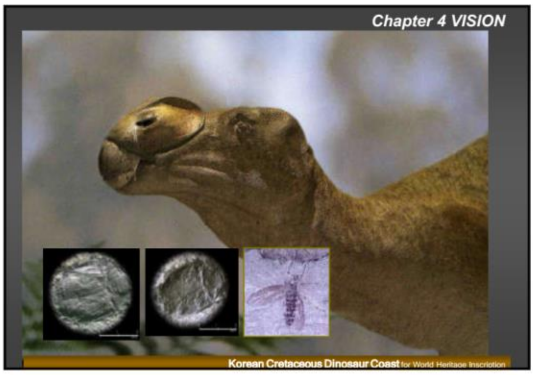

UNESCO Global Geopark Asia Platform Center (2019-2025)
Vision: International Global Geopark Platform
Establish a center for geological, historical, cultural and ecological resource management and effective delivery
Hub of East Asia Global Geopark
Mudeungsan UGGp & Chonnam National University


UNESCO Global Geopark Asia Platform Center
UNESCO Global Geopark East Asia Platform Project
A central role of education, research and publicity in National Geopark : Education and training institutions of domestic Geopark
Contribution to academic research, education, public relations and international exchange : Hub of East Asia Global Geopark
Research, preservation and monitoring center of Creataceous Mudeungsan volcanic geoheritage and dinosaur study
A central role of citizens' eco-education rest : Metropolitan Global Geopark
Providing convenience of visitors and promoting local tourism industry
Mudeungsan UGGp & Chonnam National University

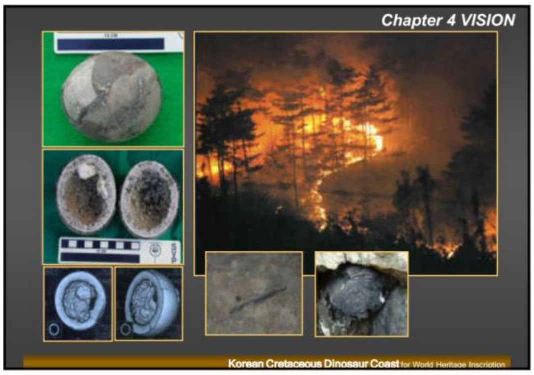

UNESCO Global Geopark Asia Platform Center
International Education and Academic organization
Utilizing educational tourism in geological survey database, attracting APGN World Congress
Mt. Popa in Myanmar
Chongseongjeon in N. Korea
Gobi Desert in Mongolia
Mudeungsan UGGp & Chonnam National University


Chapter 4 VISION OF MUDEUNGSAN UNESCO GLOBAL GEOPARK
More Academic research of Mudeungsan UGG
Mudeungsan granite
Mudeungsan tuff
3D aerial photograph of Mudeungsan area
Distribution of colonnades Mudeungsan area


Chapter 4 VISION OF MUDEUNGSAN UNESCO GLOBAL GEOPARK
North China Block
South China Block
Tectonic map of northeast Asia (Kim et al., 2016)
A schematic formation history of volcanic-plutonic rocks in the Mudeungsan area



Chapter 4 VISION
Korean Cretaceous Dinosaur Coast for World Heritage Inscription



Chapter 4 VISION
Korean Cretaceous Dinosaur Coast for World Heritage Inscription

Proornis coreae (Archaepterix koreanica)
-From Sinuiju, North Korea (1973)
-L. Cretaceous Sinuiju Fm. from lacustrine deposits
-Fossils: dinosaur tooth, protomammalia bones, fishes, plants, insects, ostracods, molluscs.. (refers in the abstract book)
-Possible Serial Nomination with North Korea?

Campaign of Mudeungsan UGGp
Mudeungsan UGGp & Chonnam National University

- Busan, Korea
- Field Area: Korea, China and Gobi Desert in Mongolia
- UGGp Sites: Mudeungsan
Chapter 4 VISION
OF MUDEUNGSAN UNESCO GLOBAL GEOPARK
the 37th International Geological Congress 2024
Busan Korea for Host City of IGC 2024
Korea Dinosaur Research Center and Mudeungsan Area Geotourism Center, CNU

We hope that
the Mudeungsan Global Geopark will be together
with the people's future.
unesco
무등지오파크

Lava tube education program at Kometsuka Geosite, Aso UGGp, Japan

Koki NAGATA

Aso Geopark Promotion Council.

koki@aso-geopark.jp

1. Background:

Aso caldera was formed by four huge eruptions about 27-90,000 years ago, and a lot of volcanoes were formed in the centre of the caldera after 90,000 years. Pyroclastic flows at that time covered not only the area around Aso but also the northern part of Kyushu Island. Therefore, 90,000 years ago, Aso would have been uninhabitable for living creatures. However, due to nature's recovery and people's continuous efforts, the area is now a vast expanse of grasslands covering more than 200 square kilometres. In fact, history books show that they have been burning fields and maintaining grasslands for more than 1,000 years, and geological evidence shows that they have been doing so for about 10,000 years. The landscape of Aso is made up of three elements: geodiversity, biodiversity, and culture.

2. Lava tube at Kometsuka Geosite

Kometsuka is one of the volcanoes in the central caldera. I t formed a scoria cone about 3,000 years ago, and lava flowed for about 3 kilometres. The lava tube was formed at that time. Above these scoria cones and lava tubes, there are grasslands where people forage and graze animals. Of course, if the field is not burned “Noyaki”, it will turn into a forest, so the “Noyaki” is done once a year.

This lava tube is known locally as a 風穴 (Fu-ketsu) or wind-hole and is recognized as a natural part of life, with people saying that their cows have fallen into the hole, they have seen water being sucked into the hole, and they have played in it as children. Even now, research is being conducted, albeit slowly, as its distribution was studied in 2017.

3. Educational use

The lava tubes in Kometsuka are being used to help children develop an eye for the wonders of the land they live on, learn about the origins of the grasslands and how they came to be, and think about what actions they should take for the future. For this educational use, Aso UGGp signed an agreement with the local grassland management association and held discussions with the Ministry of the Environment to establish rules on how to use the grassland, based on an understanding of the risks to the inhabiting organisms. Even after the Kumamoto earthquake 2016, the use of one lava tube was suspended after understanding the risk of its collapse. Today, the Aso Grassland Restoration Committee, the Aso Kujyu National Park Management Office of the Ministry of the Environment, local schools, local education coordinators, local grassland management associations, and Aso UGGp collaborate to hold an annual school education program for 10 year-olds. As a Geopark, we tell the children why rich grasslands are formed on stones like lava tubes while exploring with them at the site. This is a successful example of an ESD program using lava tubes, and details will be reported in the presentation.

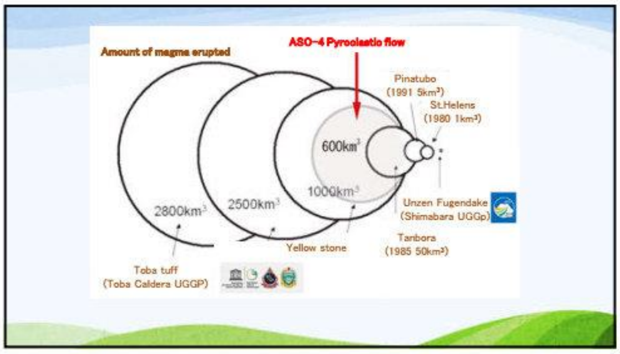
Keywords: ESD (Education for Sustainable Development), Geodiversity, Grassland

Images of the PowerPoint presentation appear on following pages.

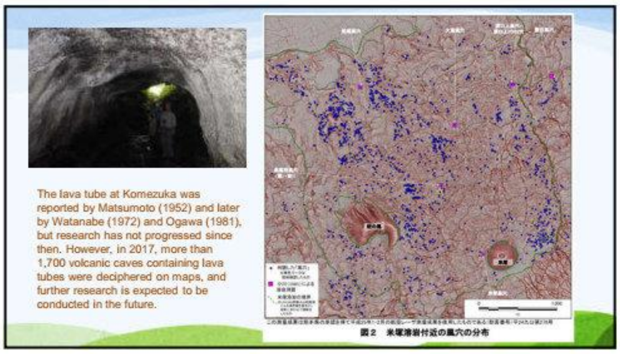

Lava tube educational program at Komezuka Geosite, Aso UGGp, Japan
Koki Nagata Aso Geopark Promotion Council Office, Japan
unesco

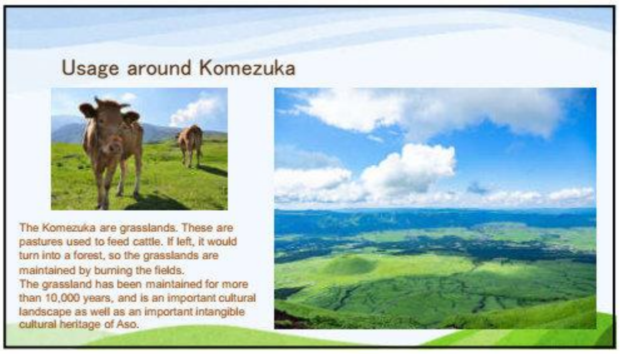

Aso UGGp
Aso UGGp
Aso UGGp
Toya-Usu UGGp, Northern part Japan


Before 90,000 years ago,
One of the bigest eruption in the world occurred at Aso.
Pyroclastic flow reached as far as near Oki-islands UGGP.
Mt. Apoi UGGp
Toya-Usu UGGp
Volcanic ashes reached as far as near of Mt Apoi.
Oki-islands UGGp
Unzen volcanic area UGGp
Izu Peninsula UGGp
Kumamoto City
Muroto UGGp
Aso UGGp

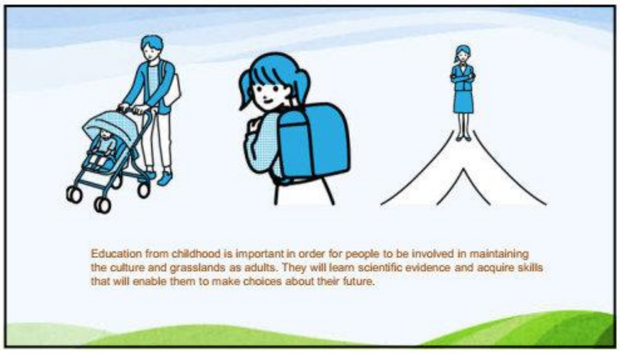

Amount of magma erupted
ASO-4 Pyroclastic flow
Pinatubo (1991 5km³)
St.Helens (1980 1km³)
600km³
1000km³
2500km³
2800km³
Unzen Fugendake (Shimabara UGGp)
Yellow stone
Tanbora (1985 50km³)
Toba tuff (Toba Caldera UGGP)

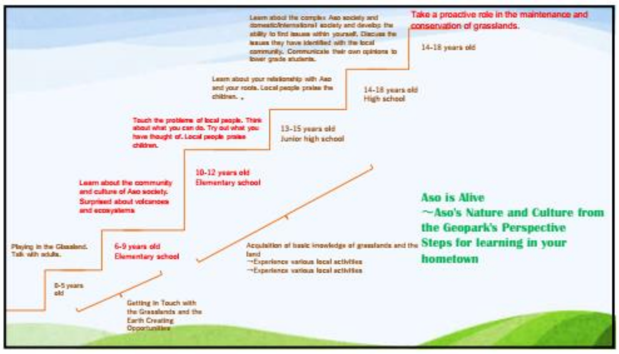

Komezuka Geosite (Scoria cone)


The lava tube at Komezuka was reported by Matsumoto (1952) and later by Watanabe (1972) and Ogawa (1981), but research has not progressed since then. However, in 2017, more than 1,700 volcanic caves containing lava tubes were deciphered on maps, and further research is expected to be conducted in the future.
図2 米塚溶岩付近の風穴の分布


Usage around Komezuka
The Komezuka are grasslands. These are pastures used to feed cattle. If left, it would turn into a forest, so the grasslands are maintained by burning the fields.
The grassland has been maintained for more than 10,000 years, and is an important cultural landscape as well as an important intangible cultural heritage of Aso.

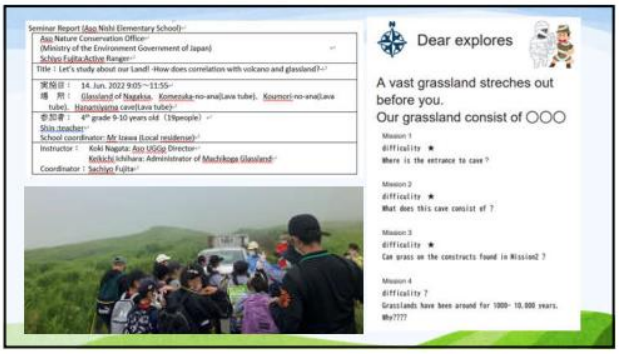

Thus, Komezuka has both cultural and geoscientific importance for Aso.
In recent years, however, the grassland area has been shrinking due to a decrease in the number of cattle used for farming and a decrease in the number of wild land burners due to the declining birthrate and aging population.
Therefore, the Aso Grassland Restoration Council has been conducting educational activities using the Geopark Program in order to spread the importance of Field burning (Noyaki).
草原
明治～大正期
昭和20年代
現代
Group photo session before cleaning work
Kuyaku (common group work)
some examples


Education from childhood is important in order for people to be involved in maintaining the culture and grasslands as adults. They will learn scientific evidence and acquire skills that will enable them to make choices about their future.


Take a proactive role in the maintenance and conservation of grasslands.
Learn about the complex Aso society and domestic/international society and develop the ability to find issues within yourself. Discuss the issues they have identified with the local community. Communicate their own opinions to lower grade students.
14-18 years old
Learn about your relationship with Aso and your roots. Local people praise the children.
14-18 years old
High school
Touch the problems of local people. Think about what you can do. Try out what you have thought of. Local people praise children.
13-15 years old
Junior high school
10-12 years old
Elementary school
Learn about the community and culture of Aso society. Surprised about volcanoes and ecosystems
Playing in the Glassland. Talk with adults.
6-9 years old
Elementary school
0-5 years old
Getting in Touch with the Grasslands and the Earth Creating Opportunities
Acquisition of basic knowledge of grasslands and the land
→Experience various local activities
→Experience various local activities
Aso is Alive
～Aso's Nature and Culture from the Geopark's Perspective
Steps for learning in your hometown

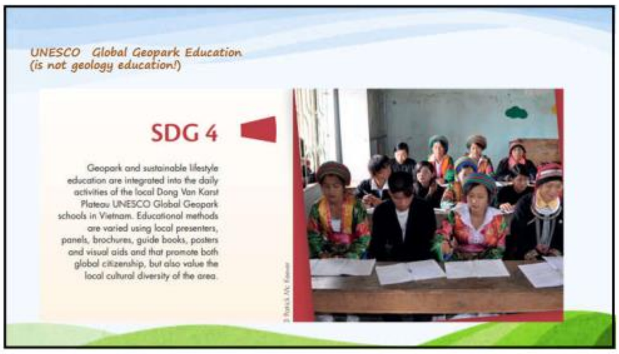

Curiosity!
The key here is curiosity. This kind of learning should not be forced.


INDIANA JONES
and the
KINGDOM OF
THE CRYSTAL SKULL
Lava tube are a good tool to improve our curiosity about the land we live on.


Seminar Report (Aso Nishi Elementary School)
Aso Nature Conservation Office
(Ministry of the Environment Government of Japan)
Schiyo Fujita:Active Ranger
Title：Let's study about our Land! -How does correlation with volcano and glassland?-
実施日： 14. Jun. 2022 9:05～11:55
場 所： Glassland of Nagakusa, Komezuka-no-ana(Lava tube), Koumori-no-ana(Lava tube), Hanamiyama cave(Lava tube)
参加者： 4th grade 9-10 years old（19people）
Shin :teacher
School coordinator: Mr Izawa (Local residense)
Instructor： Koki Nagata: Aso UGGp Director
Keikichi Ichihara: Administrator of Machikoga Glassland
Coordinator：Sachiyo Fujita
Dear explores
A vast grassland streches out before you.
Our grassland consist of ○○○
Mission 1
difficulity ★
Where is the entrance to cave？
Mission 2
difficulity ★
What does this cave consist of？
Mission 3
difficulity ★
Can grass on the constructs found in Mission2？
Mission 4
difficulity ?
Grasslands have been around for 1000- 10,000 years. Why????


「マグマの威力すごい」 阿蘇西小、溶岩トンネルを見学
火山がつくる地形や草原について学んでいる阿蘇西小（阿蘇市）の4年生19人が14日、同市の米塚周辺を地質の専門家らの案内で訪問。約3千年前の噴火でできた「溶岩トンネル」と呼ばれる珍しい地形や、草原の


Lava tubes are not only fun to explore,
but also improve their curiosity to look their land!


UNESCO Global Geopark Education
(is not geology education!)
SDG 4
Geopark and sustainable lifestyle education are integrated into the daily activities of the local Dong Van Karst Plateau UNESCO Global Geopark schools in Vietnam. Educational methods are varied using local presenters, panels, brochures, guide books, posters and visual aids and that promote both global citizenship, but also value the local cultural diversity of the area.


Education for Sustainable Development(ESD)
This is a concept of education proposed by the Japanese government.
ESD is an abbreviation for Education for Sustainable Development.
In short, ESD is education that fosters the builders of a sustainable society.

Lava Tubes in Jeju Island and Management Method

Aejin Lee, Jung-goon Koh, Yongmun Jeon,

Jinseok Ki, Ung-san Ahn, Taeyoon Kim

World Heritage Headquarters, Jeju Special Self-Governing Province,
Jeju 63341, Republic of Korea

Abstract

Jeju Island is the largest volcanic island situated off the southern coast of the Korean Peninsula. The island was created by volcanic activity, which occurred from about two million years ago until historic times. Because the original topographic features formed by volcanic activities are relatively well-preserved, it serves as a natural site to learn about volcanoes and to observe different phenomena (KIGAM and JRI, 2021).

About 170 lava tubes (caves) and 30 sea caves are distributed around Jeju Island. The lava caves are mainly distributed in the eastern and western areas of the island where the topography is more gently sloping. It is thought that the flatter terrain is related to the caves as lava can flow further when it is travelling through caves compared to when it is flowing on the surface.

Among the tubes in Jeju Island, 14 caves are designated as natural monuments, managed by the Cultural Heritage Administration and Jeju Special Self-Governing Province.

In addition, the Manjanggul Lava Tube and the connected lava tube system formed by the Geomunoreum lava flow have been recognized for their academic, scenic, and geological values and are listed as a UNESCO World Natural Heritage named as the 'Geomunoreum Lava Tube System.'

In the case of numerous non-designated caves are underway to secure current status survey data through academic services and to prevent damage and loss of caves. Jeju Island has established a conservation management plan and has conducted high-density 3D scanning.

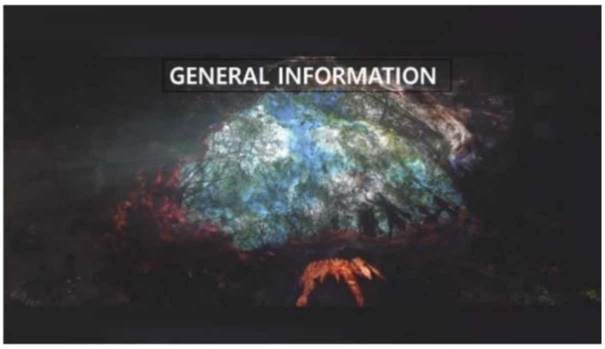
For the sustainable development of the region, regional festivals are held every year under the theme of volcanic islands and lava tubes.

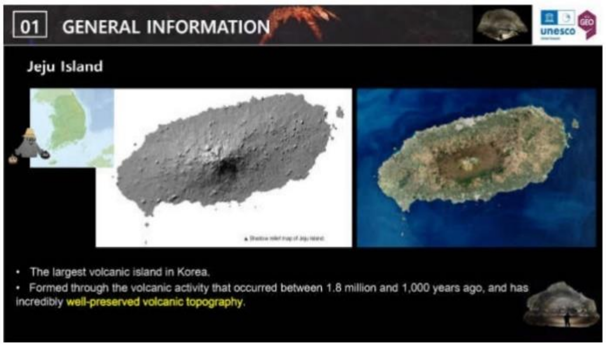
This presentation, introduces the management plan for the lava tubes and the case for sustainable development in Jeju UNESCO Global Geopark.

Keywords: Jeju Island, Lava Tube, Manjanggul Lava Tube, Management Method, Sustainable Development

Images of the PowerPoint presentation appear on following pages.


LAVA TUBES IN JEJU ISLAND
AND MANAGEMENT MEASURE
Jeju Island UNESCO Global Geopark
Lee Aejin


GENERAL INFORMATION


01 GENERAL INFORMATION
unesco
GEO
Jeju Island
• The largest volcanic island in Korea.
• Formed through the volcanic activity that occurred between 1.8 million and 1,000 years ago, and has incredibly well-preserved volcanic topography.


01 GENERAL INFORMATION
unesco
GEO
Jeju Island UNESCO Global Geopark
2010, Global Geoparks Network
2012, National Geopark of Korea
The entire Jeju Island is designated as a UNESCO Global Geopark.
There are 13 representative geosites.


01 GENERAL INFORMATION
unesco
GEO
Lava Tube in Jeju Island
용암동굴
해식동굴
• There are 170 lava tubes and 30 sea caves in Jeju Island.
• Lava tubes are mainly distributed in the eastern and western gentle areas of the island
• It is estimated that the distribution of lava tubes and the gentle terrain located at the west and east of Jeju Island are related.
• And if the lava flows through the lava tube, it can spread farther and it flows in the form of a lava stream.
• 14 lava tubes have been designated and protected as National Natural monument


The Lava Tube on Jeju Island


02 Lava Tube at Jeju Island UNESCO Global Geopark
unesco
GEO
Geomunoreum Lava Tube System
The Geomunoreum lava tube system
• A group of lava caves formed by lava flowing out of the Geomunoreum scoria cone.
• It erupted from Geomunoreum and flowed for about 14km, forming nine representative Lava Tubes.
• In the upper reaches of Manjanggul Cave, Seonheul vertical cave, Bengdwigul, Utsanjeungul, Bukoeumgul, and Daelim Cave are distributed, while in the downstream area, Gimnyeonggul, Yongcheondonggul, and Dangchemuldonggul are distributed.


02 Lava Tube at Jeju Island UNESCO Global Geopark
unesco
GEO
Bengdwigul (Natural Monument)
The total length of the cave is 4,4Km, a complex maze-shaped cave with 25 entrances, of which 18 entrances are accessible.


02 Lava Tube at Jeju Island UNESCO Global Geopark
unesco
GEO
Gimnyeonggul (Natural Monument)
The total length is 705m, and because of the cave's winding path, it is called a 'Sagul or Snake Cave'
Flowline
Cave entrance


02 Lava Tube at Jeju Island UNESCO Global Geopark
unesco
GEO
Yongcheondonggul (Natural Monument)
The total length is 3.4km, with high landscape value and well developed unique bicarbonate products.
Yongcheongul interior
Yongcheungul Lake


02
Lava Tube at Jeju Island UNESCO Global Geopark
Yongcheondonggul (Natural Monument)
The total length is 3.4km, with high landscape value and well developed unique bicarbonate products.
Carbonate Speleothems (cave features) such as Soda straw, stalactites, stone pillars, and cave pearls


02
Lava Tube at Jeju Island UNESCO Global Geopark
Dangcheomul gul (Natural Monument)
The length of the cave is short at 110m, but the density of secondary carbonate cave products in the cave is the highest
Carbonate Speleothems


02
Lava Tube at Jeju Island UNESCO Global Geopark
Manjanggul Lava Tube
With a length of 7.4km, it is the largest and most magnificent in the Geomunoreum lava cave system, with a multi-story structure.
Open section
Open and undisclosed sections of Manjanggul Lava Tube
Manjanggul Lava flow line


02
Lava Tube at Jeju Island UNESCO Global Geopark
Manjanggul Lava Tube
There are various and well-developed micro-landforms such as the lava column, lava bridge, etc.
V-shaped collapsed floor
Lava column
Lava bridge

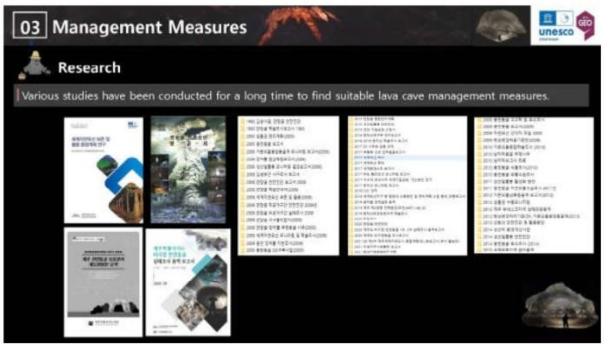

02
Lava Tube at Jeju Island UNESCO Global Geopark
Micro-landforms of the Manjanggul Lava Tube
Ropy lava in the wild cave area of Manjanggul lava tube
Pahoehoe lava in the wild cave area
'Shark's tooth-like' lava stalactites
Ropy structure near the ticket office
Ropy lava near the ticket office


02
Lava Tube at Jeju Island UNESCO Global Geopark
Utsanjeongul Lava Tube
Utsanjeongul Lava Tubes


02
Lava Tube at Jeju Island UNESCO Global Geopark
Bugoreumgul Lava Tube
Bugoreumgul Lava Tube


02
Lava Tube at Jeju Island UNESCO Global Geopark
Daerimgul Lava Tube
Daerimgul Lava Tubes

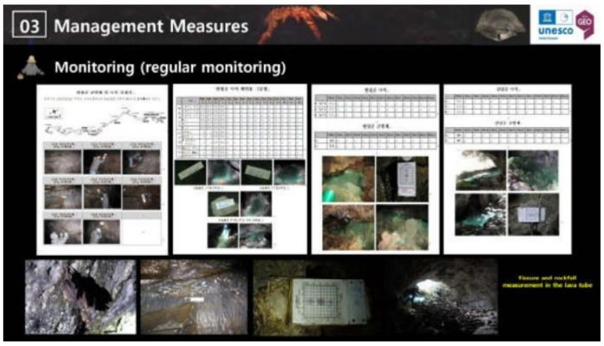

Management Measures

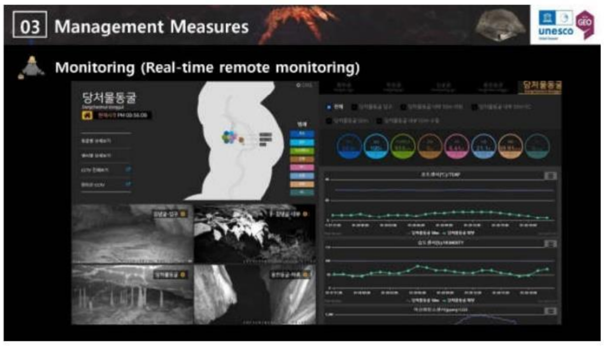

03 Management Measures
Research
Various studies have been conducted for a long time to find suitable lava cave management measures.

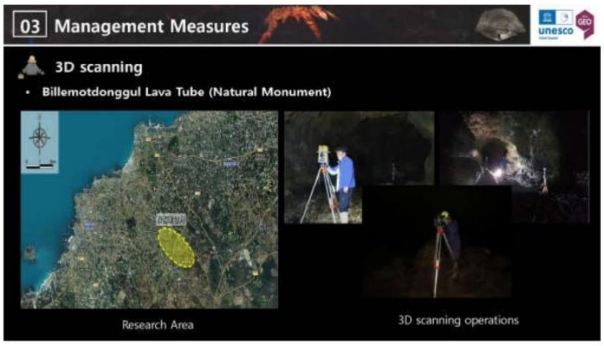

03 Management Measures
Operation of the Cave Experience Center
Conducts regular monthly monitoring, prepare reports that are published annually
unesco

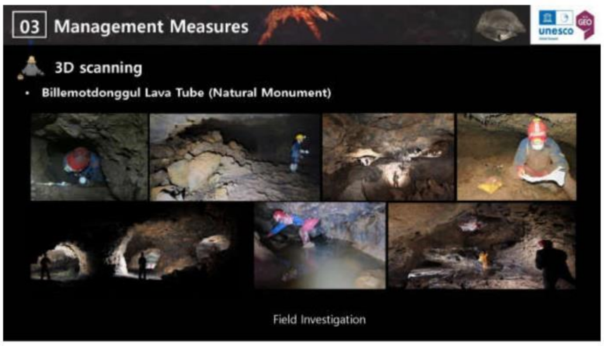

03 Management Measures
Monitoring (regular monitoring)
Conducts regular monthly monitoring, prepare reports that are published annually.
unesco

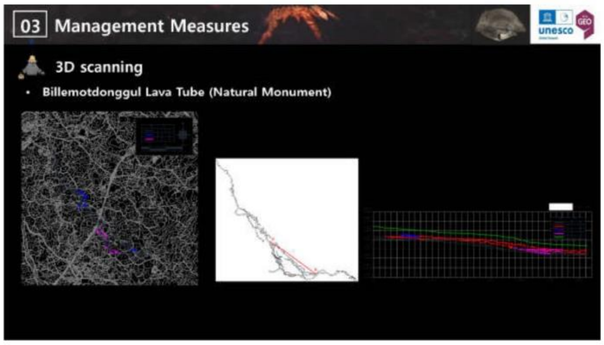

03 Management Measures
Monitoring (regular monitoring)
Facility conditions (lighting, information board), cave-in and fissure conditions, internal environment (temperature, CO2 concentration, radon concentration, etc.), external environment, animal, and plant distribution, etc.
unesco


03 Management Measures
Monitoring (regular monitoring)
Fissure and rockfall measurement in the lava tube
unesco


03 Management Measures
Monitoring (Real-time remote monitoring)
당처물동굴
unesco


03 Management Measures
3D scanning
Billemotdonggul Lava Tube (Natural Monument)
Research Area
3D scanning operations
unesco


03 Management Measures
3D scanning
Billemotdonggul Lava Tube (Natural Monument)
Field Investigation
unesco


03 Management Measures
3D scanning
Billemotdonggul Lava Tube (Natural Monument)
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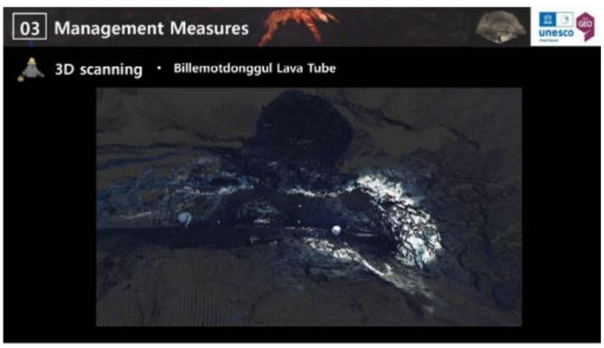
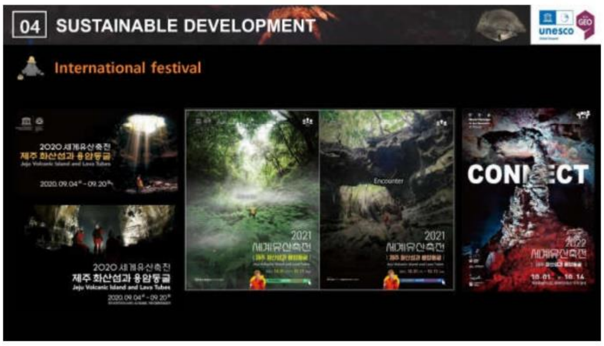
03 Management Measures
3D scanning
Billemotdonggul Lava Tube
unesco

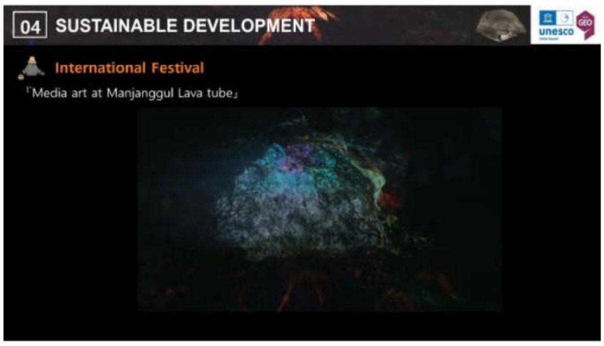

03 Management Measures
3D scanning
Billemotdonggul Lava Tube
unesco


04 SUSTAINABLE DEVELOPMENT


04 SUSTAINABLE DEVELOPMENT
International festival
2020 세계유산축전
제주 화산섬과 용암동굴
2021
세계유산축전
2021
세계유산축전
CONNECT


04 SUSTAINABLE DEVELOPMENT
International Festival
「Media art at Manjanggul Lava tube」
VOLCANOES
GEOGRAPHIC
ZONE A
ZONE B
ZONE C
ZONE D


04 SUSTAINABLE DEVELOPMENT
International Festival
「Media art at Manjanggul Lava tube」


04 SUSTAINABLE DEVELOPMENT
International Festival
「Media art at Manjanggul Lava tube」


04 SUSTAINABLE DEVELOPMENT
EDUCATIONAL ACTIVITIES 「GEO SCHOOL」


04 SUSTAINABLE DEVELOPMENT
Development of Learning Material


04 SUSTAINABLE DEVELOPMENT
Development of Learning Material 「Animation」
거문오름 용암동굴계
Geomunoreum Lava Tube System


Thank you for your Attention ☺

Management of Volcanic Caves in US National Parks

Dr. Patricia E. Seiser

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National Park Service – USA

International Union of Speleology (UIS) Adjunct Secretary

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Abstract

Volcanic caves are often seen as indestructible and relatively uniform in character compared to limestone caves, neither of which is true. Management of such caves must consider all components of the ecosystem including human visitation and surface usage. The development of accurate maps is critical to documenting cave resources. An inventory of cave resources (biological, geological and cultural), as well as surface resources associated with the caves should be conducted. To assess the health of the caves monitoring should occur with a randomized selection of caves throughout the park as well as a select number of caves open to visitation by the public. Monitoring considerations should be given to looking at bat nurseries and hibernaculums as well as other key species, the presence of invertebrates and macrobiology, cave atmosphere, ice and water measurements, visitation numbers and human impact. Developing an understanding of cave conditions aid in making informed management decisions.

Biodiversity of Volcanic Caves in Krong No, Dak Nong Province, Vietnam

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Abstract

Cave fauna is an important component of biodiversity. Dak Nong province has the most spectacular volcanic caves system in Vietnam with many little-explored caves and their fauna. We collected and identified the invertebrate specimens from eight volcanic caves in Krong No district, Dak Nong province. These specimens belonged to 3 classes, 13 orders, 32 families, and 58 species. Among them, cave spiders, crickets and millipedes are the most widely occurring invertebrates. A new species of *Chaerilus*, also collected in a cave, *Chaerilus chubluk* Lourenco, Tran & Pham was collected in C0 Cave, a volcanic cave which belongs to the Krong No Volcanic cave system. It represents the first scorpion to be found in a volcanic cave in Vietnam, and probably in the world. There are more cave invertebrates in longer caves than in shorter ones. In the same cave, the dry segment has fewer cave invertebrates than the wet segment. In general, moderate temperature, high humidity, a stable cave environment and an absence of exotic invasive species provide an ideal habitat for cave animals.

Keywords: biodiversity, volcanic cave, Vietnam

First time ever discovery of ancient human remains in a Krong No volcanic cave (Dak Nong Province Vietnam)

Associate Prof. Dr. Nguyễn Lân Cường

Vietnam Archaeology Association

Abstract

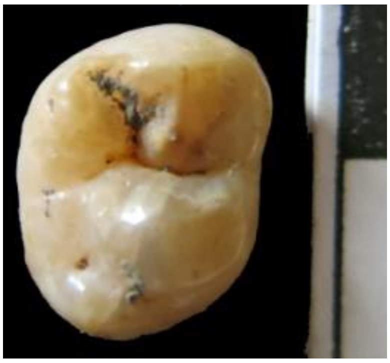
Archaeologists did not find human remains in Tay Nguyen (Central Highland, Vietnam) until March 18th, 2018 although they had excavated around 100 archaeological sites. Why? The reason is that the basalt terrain in the region cannot preserve organic matter. The research titled: *Study on Values of Cave Heritage & Proposals for on-site Museums in Central Highland of Vietnam through the Example of the Volcanic Cave in Krong no, Dak Nong Province*(Code N0 TN17/T06), which is part of the Central Highland Program 2016-2020, was conducted by Vietnam National Museum of Nature - an agency of Vietnam Academy of Science and Technology. The research team was headed by Dr. La The Phuc (as Head) and Ass. Prof. Dr. Nguyen Trung Minh (as Deputy Head). As the study also relates to archaeology, several scientists from the Vietnam Archaeology Association were invited to join the team.

1. Research Documents

1.1 Cave C6'

Exploration holes in C6' Cave found only cervine remains and teeth, one complete set of bat bones and no human remains.

1.2 Cave C_{6-1} L_{3-1}.C_2



On March, 18, 2018 an upper right wisdom tooth was found (coded as C_{6-1} (L_{3-1}.C2). This has been so far the first ancient human tooth found in Tay Nguyen. Near-far diameter: 8.72. External-Internal diameter: 11.61.

On March 22, 2018, at the western wall of the excavation site the thigh bones (femur) and the shinbone (tibia) of an adult body were found, which were coded as burial N1 (18C_{6-1M1}). However, the body part and the skull still remained in the west wall, so we decided not to dig them until next excavation

Two days later, on March 24, 2018 burial No2 was found (18$_{C6-1}$$D_2$$L_{4-8}$M2). Based on the position of the bones below the skull, it can be concluded that these are the remains of a child buried in a sitting position grasping the knees,

Burial No3, coded as 18.C6-1.C2.L4.9.M3, is covered by a layer greyish white soil which is smooth and plain. M3 was located in the southern wall and initial excavations revealed several and limb bones and ribs. These bones were laid one on top another while the body and other parts located in the South wall remain uncovered. M3 might have been reburied.

A year later, in March 2019, experts from Vietnam National Museum of Nature, Vietnam Archaeology Association and Central Highland Academy of Social Sciences returned to C6-1, expanded the east wall of the hole where the lower limb bones were found previously in Burial No1. At the depth of 1.25 m we discovered the cranium and almost all skull bones of an adult human.

2. Study of the remains

2.1 Cranium 18$C_{6-1}D_2L_{4,8}$M2

The cranium was broken into 100 pieces. The bones were very thin and fragile, so it was very difficult to restore. However, after 2 months we succeeded in restoring the cranium. The cranium base was gone, and so was the right temporal bone, but most of others including the lower jaw bones remained.

Anterior view

Wide forehead (frontal-breadth index: 71.27). The eye socket is almost round and of average height more likely to be low (orbital index- from mf: 76.72) The upper face is of the low type (upper face index 64.04). The nose is too wide (nasal index: 70.46). Simotic index 18.33.

Lateral view

Glabella is not convex, mastoid process is very small; the face is straight not projecting. Although basion point is lost, the skull is thought to be generally high.

Superior view

As it was pressed by the soil, the skull is a bit curved to the right. The *superior view* has a pentagonal shape with the skull lines still clearly visible. Vault shape is dolichocranic (cranial index is 72.73)

Figure 1. Associate Prof. Dr. Nguyen Lan Cuong with skull 18$_{C6-1}$D$_2$L$_{4-8}$M2

Inferior view

The basion point cannot be found, but the opisthion is still there helping to measure the length of sagittal arc (n-o). The 109axilla-alveoral arc is of short type (109axilla-alveoral index is 133.55). The hard palate is wide (palatal index is 103.48) The hard palate is of medium height with an index of 28.48)

+ maxilla

The following deciduous teeth are found on the upper jaw:

On the right: i^1, i^2, c', m^1, m^2.

On the left: i^2, c', m^1, m^2.

The incisor teeth are rather worn-out and big. Behind milk tooth m^2, in the jaw arch of mandible, M^1 is revealed.

+ mandible

The following teeth are found on the mandible:

- On the right: i_2, c, m_1, m_2
- On the left : i_2, c, m_1, m_2

Below skull bones

Most bones below the skull retain the stems without any boneheads. These bones are generally very thin with the edges not clearly visible. Some metacarpals and metatarsals remain and the 2 taluses are almost intact.

2.2 Cranium 19C6-1-C2L4.6 M1

+ The cranium was broken into 100 pieces. After 2 months' restoration, we managed to recover almost complete cranium except for some parts: the skull bone around occipital, the left cheekbone and left parietal bone. All 32 teeth were found. Especially, the left hand and thigh bones remain almost intact, therefore it is possible to estimate the exact height of this body.

Description of cranium and lower cranium bones

By standard, the top of the cranium is egg-shaped and of average length, which is considered quite long (cranial index: 75.52). The forehead is narrow (forehead- index 64.48). The cranial side is high (height-longitudinal index: 64.58, and the jaw is a little protruding.

By anterior standard, the skull is of a large face (the general facial index:82.28). The eye socket low (orbital index- from mf: 76.72). The nasal cavity is very large (nasal index: 61.71). By basion standard, superior alveolar artery index is 117.51. The bone below skull is very long (the phalanges are also long).

3. Comments

3.1 Age and Sex

+ The 18C6-1D2L4,8M2 Skeleton

Based on the growth of the teeth, it can be concluded that the skeleton belonged to a 4-year-old child. The structure of the bone is not obvious making it difficult to identify the sex of the child. However, the eye socket has sharp edge and tiny mastoid bone, which suggests that the remains could have been those of a little girl.

+ The 19C6-1-C2L4.6 M1 Skeleton

A: Frontal view *B: Lateral view* *C: Superior view*

Figures 2A-C. Skull from 19C6-1-C2L4.6M1).

Based on the seamlessness of the skull line, we believe that this person could be 25-35 years of age. The mastoid bone is large; the upper edge of the eye socket is; the mandibular bone is high with the lower jaw sticking out. It can be concluded that these belong to a male skull.

Using M. Trotter (1958)'s height measurement formula, we have calculated the height of this person:

+ According to thigh bone (51.8cm) this body is : 1m84 ± 3.8mm high

+ According to arm bone (37.9cm) this body is : 1m85± 4.16mm high

Figure 3. The skeleton from 19C6-1C2L4.6M1

3.2 Racial Type:

+ The 18C6-1D2L4,8M2 Skeleton

It cannot be concluded which race it is as this is the skull of a child whose racial characteristics were not fully evident. But it should be noted that the child has too wide a nose (index 70.46). The eye socket is of the average type but tend to be low (index 76.72. The teeth were of large size. These characteristics are often seen in the black race.

+ The 19C6-1-C2L4.6 M1 Skeleton

We have used cluster analysis for Correlation Coefficient Q-mode based on 9 metric characteristics of M1 Skull to compare with 9 other skull groups:

1- Sumatra (Indonesia)
2- Mongol
3- Gua Harimau (Indonesia)
4- Hoabinh culture (Vietnam)
5- Australia (aboriginal)
6- Melanesian
7- Ban Chiang (Thai Lans)
8- Philippines
9- Cambodia
10- Krong no (M1)

1 Var1	2 M1	3 M8	4 M9	5 M45	6 M48	7 M51	8 M52	9 M54	10 M55
1. Sumatra QĐ	181.7	139.8	95.2	131.3	69.6	41.8	34.1	26.2	52.
2. MONGOL	182.6	149	94.6	141.3	77.3	43.4	35.9	27.6	55.
3. Gua Harimau	175.8	139.3	94.1	134.8	70.2	39.3	33.9	25	51.
4. HOABINH	186.71	136.43	95.33	136.5	63.79	42.78	32.34	27.98	48.
5. THODAN UC	185.9	126.9	95.3	132.4	64.8	45.7	32.9	28.6	49.
6. MELANESIEN	186.9	137.4	95.8	132.5	66.9	43.7	34.7	27.3	51.
7. Ban Chiang	181.5	138.5	99.1	135.6	71.8	43	34.5	26.2	52.
8. Philipin	175.9	141	95.1	137.5	66.3	41.9	33.4	27.5	52.
9. Cambodia	171.6	141.7	94.8	132.9	68.8	42.1	33.7	27.8	50.
10. KRONGNO	192	145	93.5	130	76.18	46.57	33.57	32.97	53.4

Table 1. Comparison of 10 metric features of Krong No skull (M1) with 9 other skull groups (ancient and modern).

From Figure 4 (next page) it can be seen that Krongno ancient skull is very similar to that of Melanesian and Australian aborigines. It is also similar to the ancient skulls of Hoabinh Culture and Indonesian types but very different from those of the Mongol and Chiang Village, Thailand. Further research is ongoing to support the above claim.

3.3 Burial methods

Based on the bones under the skull (limb bones) it can be concluded that the deceased 19C6-1-C2L4.6M1 was buried sitting up with his/her knees folded, faced down, two arms placed under neck. No tools were found in the burial.

3.4 Dating

Analyses by latest American and Russian C14 methods revealed that Burial 18$C_{6-1}D_2L_{4.8}$M2, may date back to 5,000-6,000 years ago.

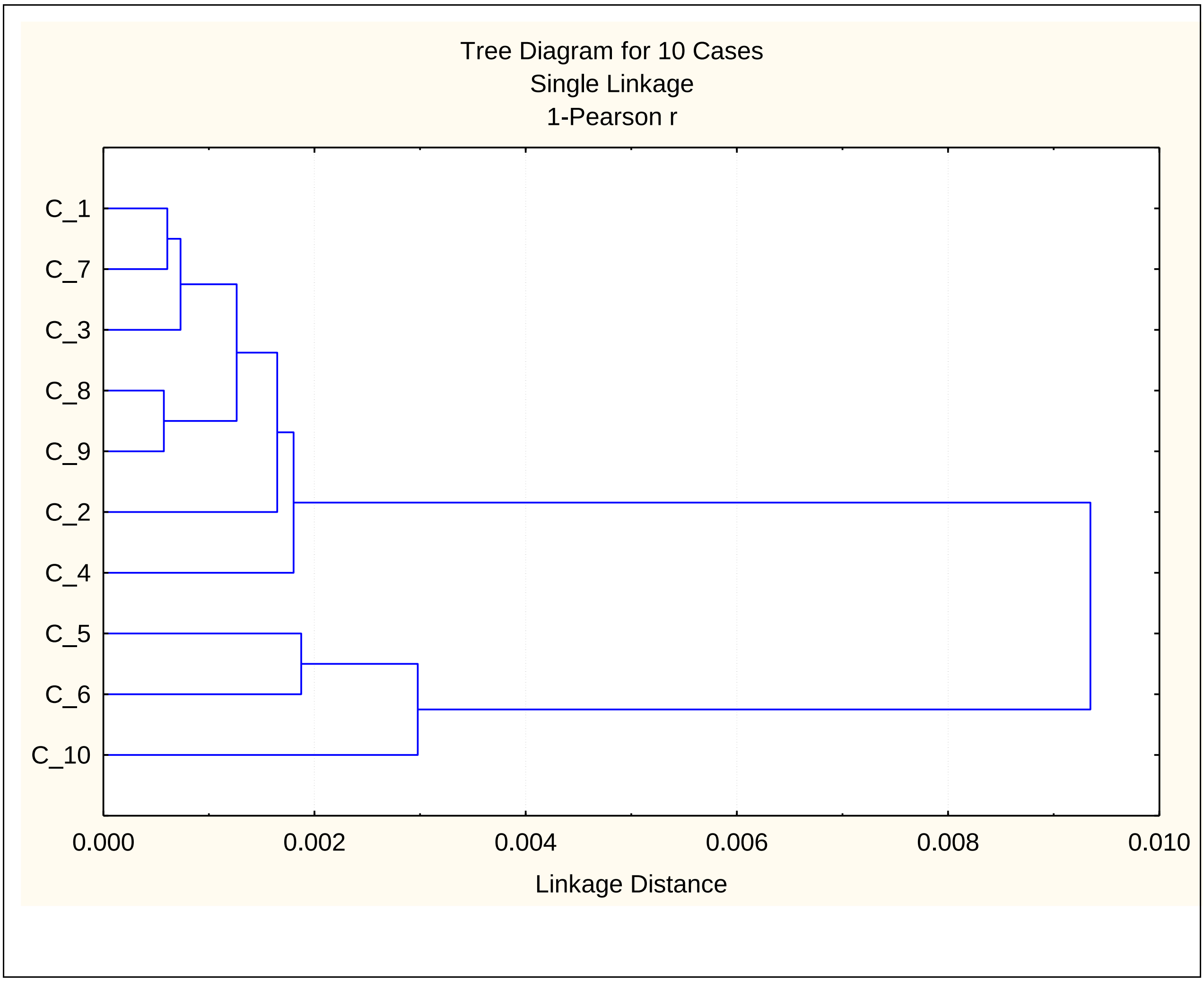


Figure 4. Dendrogram of cluster analysis applied to Q-mode based on the 10 cranial measurements (man)

4. Summary

In summary, in Cave C_{6-1} we have found 3 burials with human remains, and at the excavation site traces of at least 10 bodies were discovered of which 5 were infants, 4 adults and 1 teenage.

It can be said that these discoveries have marked a turning point for Vietnam's palaeontology. According to some foreign experts, there are similar volcanic caves in the world but with no human remains being discovered.

The discovery of human remains in Burial No1 have opened a new chapter for us to search for the real owners of a land which remains uncovered to researchers.

Prehistoric Archaeological Sites in the Krongno Volcanic Caves – Outstanding Historical and Cultural Values

Assoc. Dr. Nguyễn Khắc Sử[(1)], Assoc. Dr. Nguyễn Lân Cường[(1)], Dr. La Thế Phúc[(2)], Lương Thị Tuất[(2)], Th.S. Vũ Tiến Đức [(3)], Th.S. Nguyễn Thành Vương[(3)], Dr. Lê Xuân Hưng[(4)], Phạm Thị Phương Thảo [(4)].

[(1)] Vietnam Archaeological Association

[(2)] Vietnam Geological Association

[(3)] Central Highlands Institute of Social Sciences

[(4).] Da lat University

Abstract

The results of excavations in the Krông Nô volcanic caves have given a standard stratigraphy of the prehistoric cultural process of the middle Holocene period, providing a lot of documentary information about the prehistoric human habitation patterns: through the remains of the kitchen fire pit; strategies to exploit food sources through traces of hunting-gathering; cultural behaviour of people through the technique of making and using tools; spiritual culture of people through funeral rites and other vestiges of activities. Through the geo-archaeological approach, we have gained more evidence about people's adaptability to the fluctuations of climate and the regional environment, the changes in the local landscape, and the flora and fauna ecosystem in the broader context. The documents on the characteristics of tools, burials, flora, and fauna, and the dating system from 7,000 years BP to 4,000 years BP of the archaeological sites in the Krông Nô volcanic caves are uncommon in Vietnam, Southeast Asia, and over the world. Because of these reasons, the archaeological remains in the Krông Nô volcanic caves - an outstanding cultural heritage of Đắk Nông UGGp - should be scientifically recognized as a typical chain in The Central Highlands region, and should be protected and have its heritage values promoted to meet the demands for sustainable tourism development.

Keywords: Krongno volcanic caves, Prehistoric, Neolithic, Archaeological site; Đắk Nông

1. Introduction

Prehistoric archaeology research in Vietnam has more than 100 years of history. However, the archaeological sites in volcanic caves were first discovered and excavated in the early 20s of the 21st century. In the first excavation of the archaeological sites in the Krông Nô volcanic caves, a 1.8m thick and relatively intact stratigraphy was discovered, dating back to the middle Holocene, from 7,000 years to 4,500 years BP. The data acquired has provided important information about habitation patterns, food procurement activities, and cultural behaviour through product-making activities and funeral rites. The geo-archaeological evidence collected further elucidates the changes in climate and environment of volcanic fields, the changes in the local landscape, flora and fauna, and the human adaptation to the changes in nature at the time.

This study presents some outstanding cultural and historical values of the archaeological sites in volcanic caves, their contributions to the study of the prehistoric culture of Vietnam and Southeast Asia, and the responsibility of today's generations in conserving and promoting the archaeological sites in volcanic caves of Đắk Nông UNESCO Global Geopark, and contributing to sustainable socio-economic development in the Central Highlands.

2. Literature Review

2.1. Over a century of discovery and research into Vietnam's prehistoric archaeology, archaeologists have excavated and studied hundreds of caves and rock shelters, all of which are Karst caves. In these types of monuments are found not only the remains of *Homo erectus* fossils, dating from the Early Pleistocene, but also the cultural sites of *Homo sapiens*, dating from the Late Pleistocene to the Holocene[1].

The most active volcanic region in Vietnam is in the Central Highlands Provinces. There were also hundreds of open-air archaeological sites, dating from the Early Pleistocene to the Late Holocene, but all the organic remains have been destroyed[2]. Therefore, the discovery of volcanic cave sites in the Central Highlands, where animal bones and human remains are still preserved, is a turning point in the history of Vietnamese Prehistoric Archaeology Research, because it has provided a lot of scientific information for the comprehensive study of the historical and cultural picture of the ancient inhabitants of Vietnam.

2.2. Volcanic caves, also known as lava tubes, are of primary origin and formed by the volcanic eruptions of Pleistocene volcanoes in Krông Nô district, Đắk Nông Province. The first caves were discovered by La The Phuc and his colleagues in 2007 and studied by the Geological Museum of Vietnam and Japan Caving Association (2011 - 2014), later taken over by the Vietnam National Museum of Nature and the Japan Caving Association (2015 - 2018)[3]. So far, 45 volcanic caves have been discovered in this area, of which 20 have been measured, studied in detail, and clarified in terms of the origin, formation mechanism, and geological, biological and archaeological values[4].

Traces of prehistoric humans have been found in 10 of the 45 caves. Those caves are C1, C2, C3, C4, C4.1, C6 (Đắk Sor commune); C6’ and C6.1 (Nam Đà commune); P1 and P2 (Buôn Choa’h commune), Krông Nô district, Đắk Nông Province. All are archaeological sites in volcanic caves. Basalt rocks with vertical grooves and twisted lines representing the lava flow are on the two sides of the cave walls. The stratigraphy of the archaeological sites in volcanic caves shows the natural preservation of manufacturing activities of stone tools and pottery; the remnants such as coal ash, stoves, graves and human remains; the remains of hunter-gatherer groups such as animal bones, shells or seeds left after human consumption[5].

Of the ten caves mentioned above, C6.1 and C6’ caves were selected for exploration and excavation. In 2017, a 2m^2 excavation pit was dug at C6.1 cave with a cultural layer of 0.8m. In 2018, according to Decision No. 52/QD-BVHTTDL, dated January 9, 2018, approved by the Minister of Culture, Sports and Tourism, the Ministry of Culture, Sports and Tourism of Đắk Nông Province and the Viet Nam National Museum of Nature are allowed to coordinate in excavating the sites of two caves C6-1 and C6’ with each cave’s area being 20m^2, Nguyễn Khắc Sử being in charge of the excavation.

[1] Nguyễn Khắc Sử (2006). Prehistoric Cultures in limestone Caves and Shelters in North Vietnam, *Vietnam Social Sciences Review*. N^0 1 (111), pp. 89 - 102.

[2] Nguyễn Khắc Sử (2007). *Khảo cổ học tiền sử và sơ sử Tây Nguyên*, Nxb. Giáo dục, Hà Nội (*Prehistory and protohistory of the Central Highlands*, Vietnam Education Publishing House, Hanoi).

[3] La The Phuc, Hiroshi Tachihara, Tsutomu Honda, Truong Quang Quy, Luong Thi Tuat (2015). The unique geological heritage in volcanic caves of Dak Nong was discovered and recognized as a record, *Journal of Geology*, Series A, no. 349, 1 - 2, pp.28-38.

[4] La The Phuc, Hiroshi Tachihara, Tsutomu Honda, Luong Thị Tuat, Bui Van Thom, Nguyen Hoang, Yuriko Chikano, Katsuji Yoshida, Nguyen Thanh Tung, Pham Ngoc Danh, Nguyen Ba Hung, Pham Gia Minh Vu, Nguyen Thi Mai Hoa, Hoang Thị Bien, Truong Quang Quy, Nguyen Trung Minh (2018). Geological values of lava Caves in Krongno volcanic geopark, Dak Nong, Viet Nam, *Vietnam Journal of Earth Sciences*, 40 (4), pp.299-319; La The Phuc (2020). *Report on the “Research on the value of cave heritage and proposal to build an on-site museum in the Central Highlands, for example, Krong No volcanic caves, Dak Nong”*, No. TN17/T106, archived at the Vietnam National Museum of Nature.

[5] La The Phuc, Nguyen Khac Su, Vu Tien Duc, Luong Thi Tuat, Phan Thanh Toan, Nguyen Thanh Tung, Nguyen Trung Minh (2017). New discovery of prehistoric archaeological remnants in volcanic caves in Krong No, Dak Nong Province, *Vietnam Journal of Earth Sciences*, 39 (2), pp.97-108; Nguyễn Khắc Sử, Lê Xuân Hưng, La Thế Phúc (2019). Kết quả khai quật hang C6-1 Krông Nô (Đắk Nông), *Những phát hiện mới về khảo cổ học năm 2018*, Nxb. Khoa học xã hội, Hà Nội, tr 77-81 (Excavation results of C6-1 cave in Krông Nô (Đắk Nông), *New findings on archaeology in 2018*, Social Sciences Publishing House, Hanoi, pp. 77-81).

The C6.1 cave was excavated during the years 2018 and 2019 with an area of 10,3m^2; the excavation area of the C6' cave in 2018 was 13m^2. These excavations are within the framework of State-level scientific project No. TN17/T06, chaired by the Institute of the Vietnam National Museum of Nature and administered by La Thế Phúc[6].

The primary objective of the excavations is to collect data to build the profile of cultural heritages in Đắk Nông Global Geopark, supplement prehistoric research materials, collect specimens for Đắk Nông Museum, exhibit on-site displays in association with tourism, and contribute to the socio-economic development of Đắk Nông province.

3. Methodology

For the first time when excavating volcanic cave relics in Vietnam, archaeologists have used modern archaeological excavation methods. When excavating according to grid coordinates, each mesh is 1m^2. The excavation pit is 10.3m wide, including coordinates b,c,d (horizontally), 1,2,3 (vertical) and depth, each layer is 8cm deep, including 23 layers, in the entire terrain 185cm thick layer.

During the excavation, samples were collected according to coordinates, applied natural scientific methods in the study of minerals, animal bones, molluscs, pollen spores, ancient magnetism, human remains, ^{14}C age (radiocarbon) and stratigraphic structure.

The relics of the tomb, the stove, as well as the stone, bone, and pottery items are measured, photographed, qualitatively and quantitatively studied, characterized, and their relationship determined in space and time. The topic uses an integrated research method to determine the nature and age of the monument, as well as outlining the prehistoric cultural appearance of the residents who used to live here in a broader relationship.

4. Results And Discussion

4.1. Excavation results of Krông Nô volcanic caves

4.1.1. C6-1 Cave

The cave is located at 12˚30'47.6" Latitude and 107˚54'06.2" Longitude, with a height of 346m above sea level (Figure 1). The cave's entrance was created by collapse of the weakest part of the cave roof, resembling a skylight. Three cave entrances leading to the lava tube are in different directions and located at the skylight's bottom. C6-1 cave has two connecting entrances since the lava tube curves in a C shape, with a total length of 293.7m.

Figure 1. Cave C6-1 excavated in 2018 and 2019 (Photo: Le Xuan Hung).

[6] Nguyễn Khắc Sử (chủ biên), Nguyễn Lân Cường, Lê Xuân Hưng, Vũ Tiến Đức, La Thế Phúc, Lương Thị Tuất, Phạm Thị Phương Thảo, Nguyễn Thành Vương (2019). *Báo cáo khai quật hang C6-1 Krông Nô (Đắk Nông) năm 2019.* Tư liệu Bảo tàng Thiên nhiên Việt Nam, Hà Nội (*Excavation report on C6-1 cave in Krông Nô, Đắk Nông Province in 2019,* Vietnam National Museum of Nature, Hanoi); Phan Thanh Toàn, Vũ Tiến Đức, Nguyễn Thanh Tùng (2018). Phát hiện các di tích hang động núi lửa thời tiền sử ở Krông Nô (Đắk Nông), *Những phát hiện mới về khảo cổ học năm 2017*, Nxb. Khoa học xã hội, Hà Nội, tr.46-50 (The discovery of prehistoric archaeological sites in volcanic caves in Krông Nô (Đắk Nông), *New findings on archaeology in 2017,* Social Sciences Publishing House, Hanoi, pp.46-50).

The prehistoric archaeological sites are located at the mouth of the cave. The cave's entrance is semi-annular, 15.0m wide, and 3.2m high. The cave floor is flat, wide, airy, and slopes inward. The structure of the cave arch is relatively stable and convenient to commute. The cave is approximately 2 km from the Dray Sap waterfall, near the Serepok River, with a good flow of water, raw materials for tool making, and a great source of aquatic animals meeting humans' needs. The cave is surrounded by temperate broadleaf forests rich in flora and fauna, benefiting hunting and gathering activities.

The excavation at C6-1 cave was conducted in an area of 10.3m^2; the 1.85m stratigraphy indicates 13 ages, dating from 6,090±25 years BP (the adjusted figure is 6,954 years BP) to 4,680±20 years BP (the adjusted figure is 5,391 years BP). In the excavation pit, archaeologists have found 14 stoves, 7 graves where the bodies were placed in a flexed position with the legs bent, and remnants after meals of ancient people, including 76,425 pieces of animal bones and over 100,000 pieces of mollusc shells. Other items obtained are 3,967 stone artifacts, 66 bone artifacts, 10 jewellery artifacts made out of sea snail shells, 1 bronze arrow, and 1,276 pieces of pottery. C6.1 cave is the residence, burial and tool-making site of the prehistoric inhabitants of the Neolithic period and the latest known archaeological site in volcanic caves in Vietnam.

4.1.2. C6' Cave

The cave coordinates are 12°30'55.4" Longitude and 107°54'04.4" Latitude; it is 424m above sea level and about 250m southeast of the C6-1 cave. The passage is over 100m long, up to 15m wide and 13 m high. Cave sediments are soil and basalt rock clustered into three circle-like piles; two of which were excavated in 2018. Cluster 1's code is 18.C6'.F1, its base size is 3m x 3.5m with a height of 0.6m; Cluster 2's code is 18.C6'.F2, with a base area of 2.5 - 3m[7] (Figure 2).

a. Cluster 18.C6'.F1 *b. Cluster 18.C6'.F2*

Figure 2. Location of F1 and F2 stoves in C6' Cave (Photo: Nguyen Lan Cuong)

The two excavation pits share the same stratigraphy from top to bottom, including the top layer - a natural basalt layer with the size of rocks over 20cm; the second layer is a dark brown soil layer containing some fragments of animal bones. One layer under is a dark brown soil layer lying on the cave floor with small stones < 5cm. Surrounding each cluster are basalt stones arranged in an arc.

Fourteen fragments of deer bone, bat skulls and land snails were found in cluster 18.C6'.F1. Twenty pieces of deer bone and teeth were obtained from cluster 18.C6'.F2. The age of this excavation pit dates back to 4,160±20 years BP, with the adjusted figure being 4,707 years BP, resembling the age of the latest layer in the C6.1 cave. Excavators believe the clusters are hunter's stone structures to make a fire, in which there are teeth and bone remains of wild animals hunted and discarded. These hunters were temporary residents of the same period as the dwellers of the C6.1 cave.

[7] Vũ Tiến Đức, Phạm Thị Phương Thảo, Lương Thị Tuất (2019). Kết quả khai quật hang C6'(Đắk Nông) năm 2018, *Những phát hiện mới về khảo cổ học năm 2018*, Nxb. Khoa học xã hội, Hà Nội, tr.97-99 (Excavation results of C6' cave (Đắk Nông) in 2018, *New findings on archaeology in 2018*, Social Sciences Publishing House, Hanoi, pp.97-99).

4.2. Discussion

4.2.1. Archaeological sites in volcanic caves - a specific type of archaeology in Vietnam's prehistory

Over 100 years of research in prehistoric archaeology in Vietnam, we have acknowledged some types of archaeological sites such as hills, river beds, karst caves, and midden (it is called *kjokokenmodding* in Indonesian). The discovery of archaeological sites in lava caves in 2017 in Krông Nô (Đắk Nông province) has added another type of prehistoric site to the prehistoric archaeological map of Vietnam. The archaeological sites in volcanic caves distinguish them from those in karst caves in terms of formation mechanism, stratigraphic characteristics, and geo-archaeological values. Karst caves were formed in limestone; due to water flow, the limestone was dissolved, creating caves beneath the surface. There are two types of archaeological sites in karst caves: One is the cave inhabited by primitive people, forming the cultural layer in the cave; the second is the cave containing the sediments of the Pleistocene, in which there are human and animal fossils clinging to the wall or ceiling, sometimes falling to the cave floor. Meanwhile, volcanic caves result from volcanic eruptions, when molten lava in the interior of a flow drains out, leaving behind a void. Archaeological sites in this type of cave were formed after the structure of the lava tube was stabilized; a part of the roof collapsed to form the cave entrance. Humans started to reside and leave traces inside. No sediment is clinging to these caves' walls and ceilings compared to karst caves.

Organic remains such as human bones and animal teeth are relatively intact in karst caves since there are very high levels of CaO. CaO is formed by rainwater eroding limestone, creating calcium carbonate that penetrates the tiny holes in the bones and hardens them. Due to volcanic eruptions, the pH in the red basalt soil is high, so most of the bones are destroyed in a short time. However, the C6.1 cave is in a volcanic region where human and animal bones are preserved quite well.

In 2018, a group of geologists from Hanoi University of Natural Sciences analysed the chemical composition of C6.1 cave stratigraphic sediments using X-XRF 1800 Shimadzu fluorescence and the mineral composition using the Siemens X-ray Diffractometer, model D5005. By processing the mineral phases with BGMN - Rietveld software, they found that the chemical composition of sediments in layers at different depths does not fluctuate much. The most significant element is CaO with a high content (50.51 – 60.10%) and SiO2= 8.70 -13.03%; sub-components such as Al2O3, FeO*, P2O5, MgO have contents of less than 5% and do not change much between layers. In this cave, the mineral composition is mainly carbonate, in which calcite is the mineral phase with the highest content, followed by aragonite, calcium silicate, dolomite, witherite, and cerussite. The high ratio of these minerals is a key factor in preserving human and animal bones, as well as shells of molluscs that were not destroyed in volcanic caves[8].

In 2021, Nguyen Ngoc Truong, studying the composition of sediments in the C6-1 cave, noted that the calcium oxide (CaO) content at this place is very high, 39.54% to 45.57%. As a result, organic matter was likely to be preserved in the cultural layer. Lime CaO, an anthropogenic mineral, is formed by human use of carbonate rocks (limestone), biochemical carbonate rocks, or mollusc shells heated at a temperature of 800°C[9].

However, limestone is absent in the highlands of Đắk Nông. We believe that the origin of CaO in the C6.1 cave can only be from the shells of molluscs collected by humans in nearby rivers and streams and brought into the cave as food; the shells were burned and left at the cave. Statistics show that the ratio of CaO between the layers of 7,000 years to 4,500 years is hardly different, indicating that the exploitation of terrestrial molluscs is a tradition of local prehistoric inhabitants.

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[8] Tạ Hòa Phương, Nguyễn Thùy Dương, Nguyễn Thị Ánh Nguyệt, Phan Thạnh Toàn (2018), *Phân tích trầm tích di chỉ hang động núi lửa C6-1 (Đắk Nông)*, trong *Những phát hiện mới về khảo cổ học năm 2017*, Nxb. Khoa học xã hội, Hà Nội, năm 2018, tr.54-56. (Sediment analysis of C6-1 volcanic cave (Dak Nong), *New findings on archaeology in 2017*, Social Sciences Publishing House, Hanoi, 2018, pp.54-56).

[9] Nguyễn Ngọc Trường, La Thế Phúc, Nguyễn Trung Minh, Bùi Quang Anh, Lương Thị Tuất, Đặng Thị Hải Yến (2021), So sánh đặc điểm thành phần trầm tích trong tầng văn hóa hang C6-1 và hang ní lửa khu vực Krong Nô, Đắk Nông, trong tạp chí *Khảo cổ học*, số 2-2022, tr. 38-48. (Comparison in terms of the characteristics of sediments in the C6-1 cave and the volcanic caves in Krong No, Dak Nong, *Journal of Archeology*, No. 2-2022, pp. 38-48).

Determining the reasons why human and animal remains are preserved in Krông Nô volcanic caves has a significant and practical value, opening the prospect of finding more ancient human and animal fossils, developing the mechanism of long-term conservation of human and animal remains in the cave when building on-site museums in the Đắk Nông UNESCO Global Geopark.

4.2.2. C6.1 cave – A standard archaeological stratigraphy of volcanic caves in the Central Highlands

The stratigraphy of the excavation pit in the C6.1 cave is 1.85m thick, including eight successive layers of sediment from top to bottom:

- Layer 1 (top) is 35cm thick; the soil is non-cohesive, grey to dark grey, with few roots. Eight stoves, grinding axes, grinding tables, pestles, bone needles, crushing tables, ceramics, and a grave where the body was placed in a flexed position with legs bent were found in this layer.
- Layer 2 is 30cm thick, with smooth, grey-white to light grey soil; they found one stove, a great number of mollusc shells, animal teeth, stone tools, bones and pottery.
- Layer 3 is 25cm thick; the soil is smooth, non-cohesive, and dark brown; many basalt stones are arranged almost in a circle, in which there are many ash coals and burnt bones. The structure looks like a trash pit.
- Layer 4 is 45cm thick; the soil is smooth, solid, and ash-grey, with some milky kaolin lumps, many mollusc shells and animal bones. There are graves with codes M 1, M2, M3, M4, M5, M6, and M7. The bodies in graves were buried in a flexed position with the legs bent. Artifacts obtained are flaking tools, blade-sharpening axes, anvil stones, flakes, raw materials, bone tools, and mollusc shell jewellery.
- Layer 5 is 25cm thick; the soil is solid and light brown, with F12, stone tools and a few bone tools; the number of mollusc shells is less than that of the upper layers; there is no evidence of grinding tools.
- Each of the three layers (6,7 and 8) has an average thickness of 10cm to 15cm, with alternating grey-white or grey-brown basalt layers of soil; burning marks of F13 and F14 stoves with milky kaolin lumps are occasionally found. The soil in these three layers is compacted with a few stone artifacts, flaking tools, animal bones and few crumbling mollusc shells.

There are 13 ages in this stratigraphy, analysed at the Radiocarbon Laboratory of the Institute of Geography RAS (Russia) and the IGAN Laboratory of the Center for Applied Isotope Research, University of Georgia (USA) (Table 1).

The stratigraphy of the C6-1 cave shows that humans had a continuous residence for nearly 3,000 years, from 7,000 to 4,500 years BP. The first residence dates back to 6,090 ±25 years BP; the adjusted figure is 6,954 years BP. The latest age dates back to 4,680 ±20 years BP, but it is not the last layer of the archaeological site. The prediction is that the end of the cave habitation was around 4,000 years BP[10] (Figure 3).

The period from 7,000 to 4,000 years BP matches the residence of the inhabitants of the Middle Neolithic period in Vietnam; typical are the Cái Bèo culture (Quảng Ninh Province – Hải Phòng City), the Đa Bút culture (Thanh Hóa - Ninh Bình Provinces), Quỳnh Văn culture (Nghệ An - Hà Tinh Provinces), groups of archaeological sites in Bầu Dũ (Quảng Nam Province) and Thôn Tám - Làng Gà - Buôn Khiêu (Central Highlands)[11].

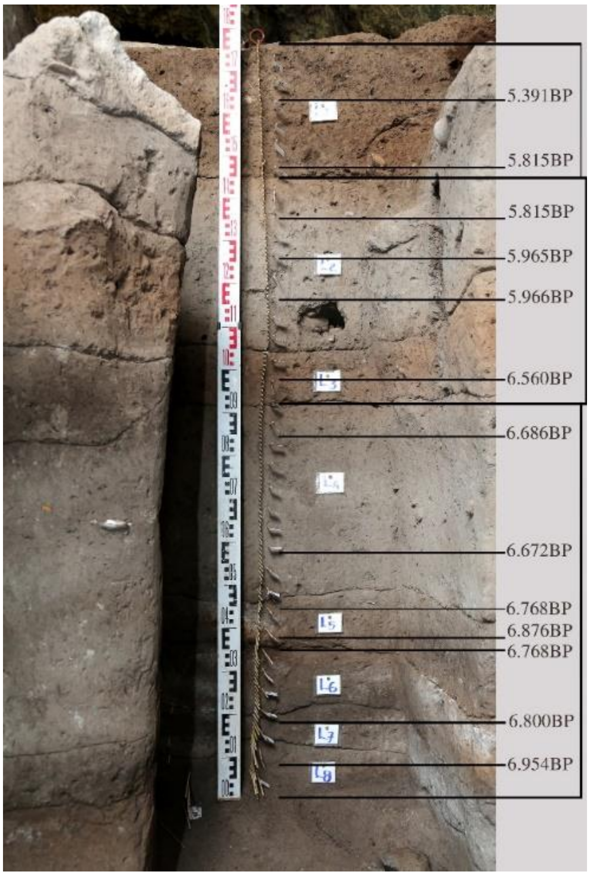
[10] Nguyễn Khắc Sử, Nguyễn Lân Cường, La Thế Phúc, Nguyễn Trung Minh, Lương Thị Tuất, Lê Xuân Hưng, Vũ Tiến Đức (2020). Khai quật hang ní lửa C6-1 Krông Nô, Đắk Nông: Tư liệu và nhận thức mới về Tiền sử Tây Nguyên, *Tạp chí Khảo cổ học*, số 4-1920, tr.16-30 (Excavation of volcanic cave C6-1 in Krông Nô, Đắk Nông: Documentation and a new perception on Prehistory of the Central Highlands, *Journal of Archaeology*, No. 4-1920, pp.16-30).

[11] Nguyễn Khắc Sử (chủ biên), (2016). *Khảo cổ học tiền sử miền Trung Việt Nam*, Nxb. Khoa học xã hội, Hà Nội (*Prehistoric archaeology of Central Vietnam'*, Social Sciences Publishing House, Hanoi).

Table 1. Results of C14 dating of the C6-1 cave in Krông Nô (Đắk Nông)

No.	Sample code	Sample location (cm)	Material	Dating back - BP	Figure after adjustment
1	18.C6-1.C4.L1.2	16	Charcoal	4.680±20	5.391BP
2	17.C6-1.D3.L3	32	Charcoal	5.070±20	5.815BP
3	17.C6-1.D3.L.6	43	Charcoal	5.110±20	5.815BP
4	17.C6-1.D3.L.7	56	Charcoal	5.225 ±20	5.965BP
5	17.C6-1.D3.L.8	63	Charcoal	5.230±20	5.966BP
6	18.C6-1.C2.L4.3	58	Charcoal	5.760±25	6.560BP
7	18.C6-1.D4.L4.5	99	Charcoal	5.780±25	6.686BP
8	18.C6-1.D2.L4.7	125	Charcoal	6.030±25	6.876BP
9	18.C6-1.C2.L4.9	126	Charcoal	5.850±25	6.672BP
10	18.C6-1.D4.L4.10	138	Charcoal	5.945±25	6.768BP
11	18.C6-1.C4.L4.12	154	Charcoal	5.945±25	6.768BP
12	18.C6-1.D4.L4.13	175	Charcoal	5.970±25	6.800BP
13	18.C6-1.C3.L4.16	183	Charcoal	6.090±25	6.954BP

Figure 3. Stratigraphy and ages of C6-1 Cave (Source: Nguyen Khac Su, 2018)



4.2.3. C6-1 cave - a historical source outlining the prehistoric culture of Krông Nô

Climate, environment, and landscape of Krông Nô in the Holocene period: Analysis of 19 pollen/ spore samples in C6.1 cave stratigraphy shows that tropical plants play a dominant role, with little temperate and subtropical pollen. The pollen of herbaceous plants accounts for 74%; fern spores with 12%; pollen from woody plants with 8% and 6% for unspecified elements[12]. The paleoclimate in this area changes from early to late stage according to the depth of culture layers. At the earliest layer, 156cm - 185cm (from 6,954 to 6,900 years BP), fern spores, mainly *Polypodiaceae*, make up the majority (65%); 30% of herbaceous plant pollen including *Poaceae* and *Pilea* sp., and 5% of the pollen of woody plants (only pollen of *Rubiaceae*). It is the beginning of the middle Neolithic period of C6.1 cave; the climate was cool, slightly dry, warm and humid. In the middle Neolithic period, with the cultural layer's depth from 155cm to 46cm (5,900BP to 5,300 years BP), the herbaceous plant pollen remains its portion of 60%, including *Pilea* sp., *Poaceae*, *Vilebrunea* sp; fern spores make up 20%, woody plant pollens make up 20%, including *Myrica* sp., *Carex* sp., *Magnoliaceae*, which are typical for warm and humid yet cool climate (with the *Sequoia* sp. pollen of temperate species). The latest layer, at a depth of 45cm, presents the Late Neolithic habitation (from 5,200 BP to 4,300 years BP). Herbaceous plants account for 80%, such as *Pilea* sp., *Poaceae*, and *Vilebrunea* sp.; ferns spores account for approximately 20%, including Polypodiaceae, *Lygidium* sp., *Cyathea* sp., with pollen of *Sequoia* sp. flowers, reflecting a cool, humid, and tropical climate. Overall, the inhabitants of the C6.1 cave belong to the tropical monsoon period, with alternating warm/humid and cool weather, open forest, and low forest cover related to human luminescence activities.

From the analysis data of 185 ancient samples using magnetic susceptibility in 185cm thick stratigraphy at the C6-1 cave, Luu Thi Phuong Lan has divided the stratigraphy into four cold periods (blue): C6.1-1, C6.1-3, C6.1-5, C6.1-7 and four warm periods (red): C6.1-2, C6.1-4, C6.1-6, C6.1-8. The cold period of C6.1-5 is classified in more detail: there is a short warmer period (C6.1-5-2) between the two colder periods (C6.1-5-1 and C6.1-5-3). During the period from 6,900 to 5,391 BP year, there are two overlapping weather cycles in cave C6-1, a cycle of 475 years and another of 317 years[13] (Figure 4).

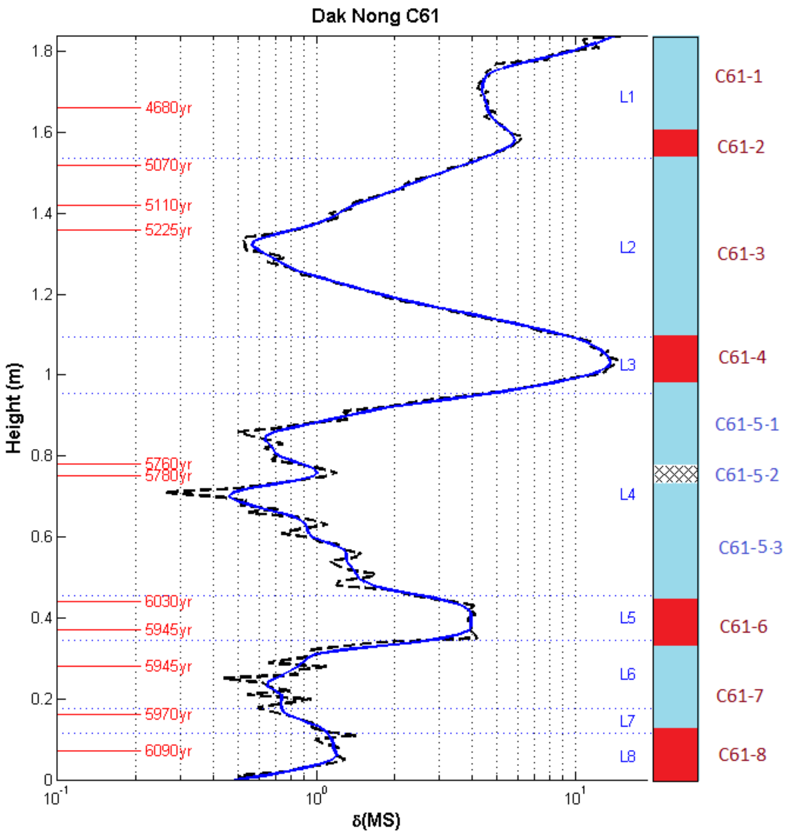


Figure 4. Magnetic domains
(Source: Lưu Thị Phương Lan, 2019)

[12] Nguyễn Thị Mai Hương, Phạm Văn Hải, Phan Thanh Toàn, (2019). Kết quả phân tích bào tử phấn hoa hang C6-1 Krông Nô (Đắk Nông), *Những phát hiện mới về khảo cổ học năm 2019*, Nxb Khoa học xã hội, Hà Nội, tr.45-48 (Analysis results of spores from pollen from C6-1 cave in Krông Nô (Đắk Nông), *New findings on archaeology in 2019*, Social Sciences Publishing House, Hanoi, pp.45-48)

[13] Lưu Thị Phương Lan, nnk (2018). *Sử dụng số liệu từ cảm nghiên cứu cổ khí hậu tại hang C6.1 Đăk Nông, Tây Nguyên*, Tư liệu Bảo tàng Thiên nhiên Việt Nam (*Using data from Magnetic Susceptibility Research at C6.1 Đăk Nông cave, Central Highlands*, Report on the *Research on the value of cave heritage and proposal to build an on-site museum in the Central Highlands, for example, Krông Nô volcanic caves, Đăk Nông*, No. TN17/T106, archived at the Vietnam National Museum).

The fauna assemblage of the C6.1 cave is represented by 76,425 animal bones and thousands of shells of molluscs, hunted and gathered by humans, brought into the cave as food, and left in the cave. Most of them are modern animals, typical for the tropical monsoon climate. They are monkeys (*Macaca* sp.), orangutans (*Pongo* sp), sambars (*Rusa unicolor*), Indian hog deers (*Axis porcinus*), wild boars (*Sus scrofa*), wild buffaloes /bison, tigers (*Panthera tigris*), hog badgers (*Artonyx collaris*), Asian small-clawed otters (*Aonyx cinerea*), bears (Ursidae), civets (*Viverridae*), jackals (*Canidae*), rhinoceros (*Rhinoceros* sp.); turtles/softshell turtles account for a large number; Birds and fish account for a majority of, gathering mainly in the upper layers. Megabats (*Pteropodidae*) and the Old World leaf-nosed bats (*Hipposideridae*) make up a certain proportion, suggesting that the cave was accompanied by human habitation. The most significant are molluscs, such as snails with a gill and an operculum (*Sinotaia aeruginosa*) (85.4%). In comparison, freshwater mussels (*Oxynaia micheloti*) (9.77%) and a species of freshwater clam (*Corbicula fluminae*) were found only in the upper layers, representing the period of heavy rain, abundant water resources, and the rapid growth of freshwater molluscs[14]. The collection of large volumes of mollusc shells and the CaO ratios in the basal soil layers suggest the tradition of mollusc collection in the Hòa Bình culture of Neolithic inhabitants in the Central Highlands.

Tool and pottery manufacturing: the C6.1 cave dwellers crafted stone tools at the residence. The artifacts obtained are 3,788 scrap pieces (flakes) and raw stone, in which there are only 179 stone tools, including 25 oval axes, 4 short axes, 2 iron-shaped tools, one disc-shaped tool, one blade sharpening axe, 28 rough chopping tools, 14 slicing tools, 2 sharp cutting tools, 13 flaking tools, 13 grinding tables, 23 anvil stones, 3 stone slabs, 11 incomplete axes, 5 stone nodes, 33 axe shards, and one quartz crystal.

The highlight feature of residents living in volcanic caves is exploiting local materials such as basalt, chert or stream pebbles to make tools that have a quite similar shape to those of Hòa Bình culture (Hoabinhian), such as oval axes, short axes, disc-shaped scrapers, and iron-shaped tools. The difference is that this area's tools are smaller, primarily double-sided and finely worked (Figure 5, see next page). This sign indicates the preservation of the tool-making tradition of the prehistoric inhabitants in the Central Highlands[15].

The other artifacts obtained from the cave are 66 bone tools with sharp tips as awls, formed by polishing technique; they function as sewing needles or fishing spears; 10 shells of sea snails (*Cypreae* sp.) with pierced backs and threaded to make jewellery. The ancient people in the cave used pottery after 5,225 ±20 years BP; 1,276 pieces of pots, bowls, and plates with decorative patterns, such as twisted rope, dashed lines, dot-dash, and dotted lines. All were made from fine-grained sand clay and fine-grained ceramics (Figure 6). The only bronze item is a two-pronged arrow with a short neck; it was cast from a small mould with two pieces joined together, found in Layer 1 (the latest layer).

Hunting-gathering is the main activity of the prehistoric inhabitants of the C6.1 cave. Among the 76,425 animal bones found, there is no evidence of domesticated animals. Hunting and gathering activities increased from the earliest to the latest stage, as demonstrated by an increase in animal bones and mollusc shells from bottom to top. The animals hunted and gathered by the local inhabitants are modern species that still exist in the Draysap forest surrounding the cave.

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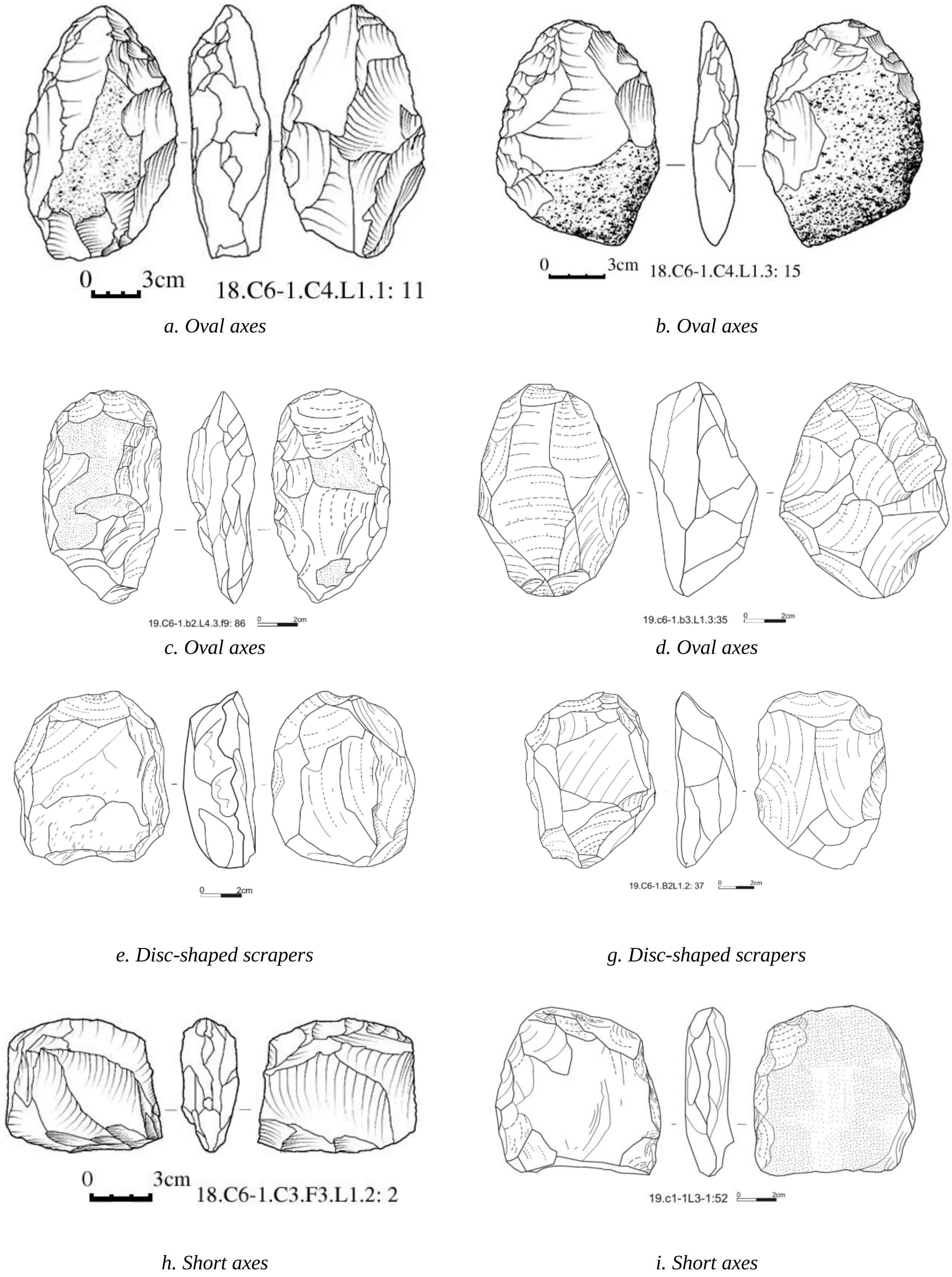
[14] Nguyễn Anh Tuấn, Vũ Tiến Đức, Nguyễn Thành Vương (2019). Xương răng động vật và vỏ nhuyễn thể khai quật hang C6-1 năm 2018, *Những phát hiện mới về khảo cổ học năm 2018*, Nxb. Khoa học xã hội, Hà Nội, tr 85-89 (Animal tooth and bones, mollusc shells excavated in the C6-1 cave in 2018, *New findings on archaeology in 2018*, Social Sciences Publishing House, Hanoi, pp. 85-89). Nguyễn Anh Tuấn, Trần Thị Minh (2020). Xương răng động vật và vỏ nhuyễn thể khai quật hang C6-1 năm 2019, *Những phát hiện mới về khảo cổ học năm 2019*, Nxb. Khoa học xã hội, Hà Nội, tr. tr.40-45 (Animal tooth and bones, mollusc shells excavated in the C6-1 cave in 2019, *New findings on archaeology in 2019*, Social Sciences Publishing House, Hanoi, p. p.40-45).

[15] Nguyen Khac Su (2021). Hoabinh Culture in Vietnam after Nearly A Century of Discovery, *Vietnam Social Sciences Review*, No. 2, pp.26-42.



a. Oval axes *b. Oval axes*

c. Oval axes *d. Oval axes*

e. Disc-shaped scrapers *g. Disc-shaped scrapers*

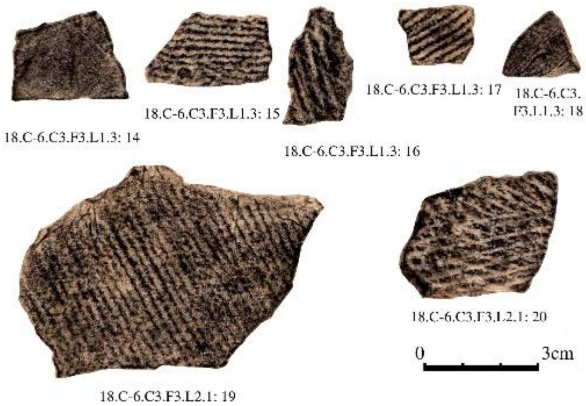
h. Short axes *i. Short axes*

Figure 5. Typical stone tools in C6-1 cave (Source: Nguyễn Khắc Sử, 2019)

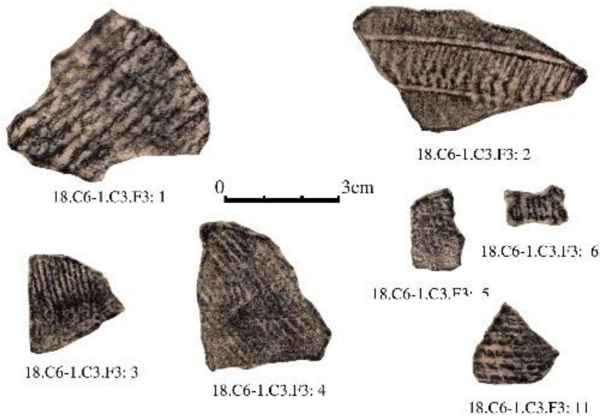
With the number of animal bones identified, turtles have the most numerous, accounting for 27.1%, followed by fish with 24.6%, bats with 17.1%, deer with 7.71%, and monkeys with 5.14%. These species groups are in all layers, while other mammals are in smaller numbers. Some animals hunted by C6-1 cave dwellers are monkeys (*Macaca* sp.), orangutans (*Pongo* sp), sambars (*Rusa unicolor*), Indian hog deers (*Axis porcinus*), wild boars (*Sus scrofa*), wild buffaloes /bison; tigers (*Panthera tigris*), hog badgers (*Artonyx collaris*), Asian small-clawed otters (*Aonyx cinerea*), bears (*Ursidae*), civets (*Viverridae*), jackals (*Canidae*), rhinoceros (*Rhinoceros* sp.); turtles/softshell turtles account for a large number and are considered a common source of food of the ancient people.

a. Bone tools with sharp tips

b. Sea snail jewellery (Cypreae sp.)



c. Pottery



d. Pottery

Figure 6. Bone tools, molluscs, and pottery in the C6-1 cave
(Source: Nguyễn Khắc Sử 2019)

Only a few bone remains of any particular animal are found in the cave; the bones of a complete animal are rarely seen. It indicates that individuals hunted small animals while bigger groups went for larger mammals; many people got involved, so the game was shared by many people. Therefore, the bones found are not from a whole animal. Mollusc shells are a frequent object collected by humans, increasing over time from the earliest to the latest stage. The majority is a species of freshwater snail with a gill and an operculum (*Sinotaia aeruginosa*) (85.4%), while freshwater mussels (*Oxynaia micheloti*) account for 9.77%; a species of freshwater clam (*Corbicula fluminae*) embodies the fluctuations of the hot and humid environment with increasing rainfall and abundant water resources, allowing the rapid growth of freshwater molluscs. It also reflects the tradition of eating snails in caves of Hòa Bình culture's inhabitants in Southeast Asia prehistory (Figure 7).

In the spiritual life, the ancient people of the C6.1 cave knew how to beautify themselves with jewellery. The jewellery used was made from the shells of sea snails (*Cypreae* sp.) with an oval body, a narrow and long mouth, and a profoundly concave inward with a smooth and white shell. The shell was pierced on the back to make a chain worn as a necklace. Some of these shells were dyed with ochre and buried with the dead. To get these snails, the dwellers of C6-1 must trade with inhabitants living by the sea. The closest sea is the South Central Sea of Vietnam, over 100km from the cave. The use of sea snail shells as jewellery and burial items was widespread in the Hòa Bình culture in North Vietnam thousands of years ago[16].

Monkey jaw

Orangutan tooth

Deer jaw

Wild boar jaw

Jackal jaw

Turtle jaw

Bird bones

Snake bone

Iguana bones

Fishbones

Chevrotain (deer) bones

Turtle bone

Figure 7. Animal remains in the C6-1 cave (Source: Nguyen Anh Tuan, Tran Thi Minh 2020)

The culture of handling death: The inhabitants of volcanic caves buried the dead in a flexed position with their legs bent at their residence, next to the fire. Seven graves were discovered in the excavation pit. Human remains in these graves have been preserved relatively intact. Grave 1 is in a layer dating to 5,780 BP (the adjusted figure is 6,686 BP); the dead body is a man about 25 to 35 years old. Based on the length of the limb bones, this person is believed to be about 1.84m to 1.85m tall. In terms of the composition of anthropology, the skull is similar to the Melanesian and the Indonesian, which is common in Hòa Bình culture (Figure 8.1a.1b.1c). The body in Grave 2 at a depth of 68cm, dating to 5,230±20 BP, is a baby about four years old buried in the sitting position with legs flexed closely to the chest. The skull bone is thin, broken into more than 100 pieces.

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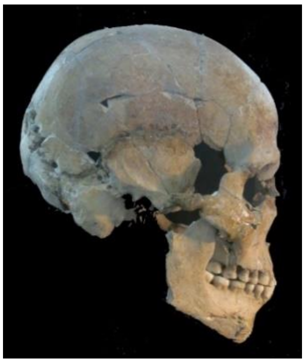
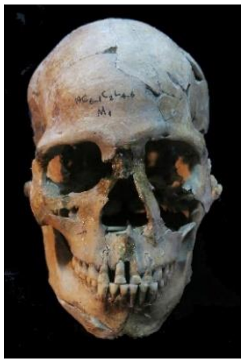
[16] Hoàng Xuân Chinh (chủ biên) (1998), *Văn hóa Hòa Bình ở Việt Nam*, Nxb. Khoa học xã hội, Hà Nội (*Hoa Binh Culture in Vietnam*, Social Sciences Publishing House, Hanoi).

These pieces are reattached to form a skull, but its ethnicity is unknown. The baby has a wide nasal cavity, a low-slanted eye socket, and large teeth, commonly seen in the Negroid race[17] (Figure 8.2a, 2b, 2c).

1a. Grave 1. A grave where the body was placed in a flexed position with the legs bent.



1b. Lateral view M 1.



1c.Frontal view M 1.

2a. Grave 2.

2b. Frontal view M 2.

2c. Lateral view M 2.

Figure 8. Grave 1, Grave 2 and skulls in the C6-1 Cave (Photo: Nguyễn Lân Cường 2019).

The other graves have been processed and conserved in the excavation pit for later research. Some graves are surrounded by stone barriers; others are buried with stone artifacts and jewellery. In addition, fragments of human bones and teeth are scattered in the cultural layers in the excavation pit. The burial process and anthropological composition initially indicate that the inhabitants in this area are related to the Hòa Bình culture people in North Vietnam in the Neolithic period after Hòa Bình[18].

Stoves and community structures: In the excavation pit of Cave C6-1, 14 stoves distributed at different depths were discovered and coded from F1 to F14. A stove is usually formed by soil piling up; the soil used is black or dark black, round or oval; a thick layer of ash coal is placed in the middle, with a thin outer layer; a large stove has a diameter of 0.6m; smaller stoves have a diameter of 0.4m. There are stoves with basalt stones piled around, in which there are ash coals, animal bones, burnt mollusc shells, and a few scraps and pieces of pottery. A stove is a place to cook food, get warm, gather all community members, and fight wild animals and harmful insects to protect people. Most stoves in cave C6-1 are small, possibly owned by households with two generations, including husband and wife and their children.

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[17] Nguyễn Lân Cường (2019), *Di cốt người cổ đầu tiên được phát hiện ở hang động núi lửa Krông Nô (Đắk Nông)*, trong tạp chí *khảo cổ học*, số 2, tr. 33-52 (The first ancient human remains discovered in Krong No volcanic caves (Dak Nong), *Journal of Archeology*, No. 2, p. 33-52).

18 Nguyễn Khắc Sử (chủ biên), Nguyễn Lân Cường, Lê Xuân Hưng, Vũ Tiến Đức, La Thế Phúc, Lương Thị Tuất, Phạm Thị Phương Thảo, Nguyễn Thành Vương (2019). *Báo cáo khai quật hang C6-1 Krông Nô (Đắk Nông) năm 2019.* Tư liệu Bảo tàng Thiên nhiên Việt Nam, Hà Nội (*Excavation report on C6-1 cave in Krông Nô, Đắk Nông Province in 2019*, Vietnam National Museum of Nature, Hanoi).

In the C6' cave, two large stoves of overnight hunters were found, dating back to the latest stage of the C6-1 cave. It is more likely that the owners of these hunting campfires are residents of the nearby C6-1 cave. Therefore, there was a division of labour in the community, such as tool makers, hunters and gatherers of herbs and molluscs. It is possible that there was a division of labour by sex and age in a clan commune.

5. Conclusion

5.1 For the first time, Vietnamese archaeologists learned about a type of archaeological site in volcanic caves, added to the prehistoric archaeological site distribution map of Vietnam. Volcanic caves have preserved a relatively intact stratigraphy, reflecting the historical process from 7,000 to 4,000 years BP and clarifying the stages from the earliest to the latest based on cultural layers[19].

The early stage, from the 3rd to 8th cultural layers (7,000 to 5,500 years BP), demonstrated a humid tropical climate alternated by cooler periods; humans resided, made tools, and buried the dead in caves. People at this stage used the grinding technique, but it was not typical; they encountered only one blade sharpening axe. Local inhabitants quarried local stream pebbles such as quartz, quartzite, schist-silica, chert or basalt. The raw materials then got hewn and slightly modified to create oval axes, sharpening axes, disc-shaped graters, short axes with chopped handles, and thin flakes similar to those of Hòa Bình culture; the primary technique is the bifacial technique. Besides, ancient people made and used small, sharp bone tools that smoothed the whole body. During this time, people hunted animals, such as rhinos, tigers, buffaloes, bison, deer, wild boars, iguana, turtles, softshell turtles, crabs, fish and molluscs, such as mussels, snails, worms, and freshwater mussels; there is no evidence of domesticated animals. The early inhabitants maintained the tradition of burying the dead in caves with their bodies placed in a flexed position with the legs bent, resembling *Melanesian* and *Indonesian* ethnic characteristics found in the Hòa Bình people.

In the late stage, from 5,500 years to 4,000 years BP, people resided in caves, but some chose to live outdoors, around Dray Sáp waterfall - Gia Long, where cultural relics have been found. The cave people perfected tools for hedging and sharpening; the shape was more stable; there were many punches, grinding tables used in food processing, and sharp bone tools, especially tools made of opal and pottery. A few opal tools and crude pottery obtained indicate that the inhabitants of this period had contact with groups of people of the Late Neolithic in the area where stone axe and opal quadrilateral manufacturer was.

In this layer, there is only one grave (Grave 4); the body was placed in a flexed position with legs bent and head facing the northwest; four small basalt stones (stalagmite) were placed under the skull; the soil at the bottom of the grave is grey and smooth; burial items are snails and stone tools. Similar to the early stage, a few fragments of the remains of different individuals are scattered throughout the culture layer of this stage. The inhabitants hunted small animals, such as bats, snakes, iguanas, fish, birds, tortoises, scaly reptiles, porcupines, mice, chevrotains, monkeys, langurs, orangutans, etc., and freshwater molluscs such as snails with a gill and an operculum, freshwater mussels, and freshwater clams.

5.2. Geo-archaeological documents recorded indicate the adaptation of humans to changes in the environment of the volcanically active area on Krông Nô. Such compatibility is reflected in the exploitation of tool-making materials, bifacial and blade sharpening techniques, and the preservation of tool shapes of Hòa Bình culture people, such as oval axes, short axes, and disc-shaped scrapers. The volcanic stone tool industry in this area belongs to the Post-hoabinhian.

[19] Nguyễn Khắc Sử, Nguyễn Lân Cường, La Thế Phúc, Nguyễn Trung Minh, Lương Thị Tuất, Lê Xuân Hưng, Vũ Tiến Đức (2020). Khai quật hang ní lửa C6-1 Krông Nô, Đắk Nông: Tư liệu và nhận thức mới về Tiền sử Tây Nguyên, *Tạp chí Khảo cổ học*, số 4-1920, tr.16-30 (Excavation of volcanic cave C6-1 in Krông Nô, Đắk Nông: Documentation and a new perception on Prehistory of the Central Highlands, *Journal of Archaeology*, No. 4-1920, pp.16-30).

In the tropical environment of the red soil highlands, the inhabitants retained the tradition of living in caves, collecting molluscs, and hunting various species. However, they hunted a few individuals of each species to prevent species extinction, bringing ecological balance and allowing the human community to settle permanently in the cave. During the funeral, the inhabitants of the Krông Nô volcanic caves performed the tradition of burying the dead in their residences with the dead bodies in a flexed position with the legs bent or in a sitting position with legs flexed closely to the chest. Their graves were sprinkled with ochre; their bodies were buried with stone tools and sea snail shells of *Cypreae* sp, resembling Hòa Bình culture. In terms of ethnic composition, people of this period belonged to the Indonesian, originating from the Hòa Bình culture in North Vietnam.

5.3. The archaeological documentation of the C6-1 cave is reliable in terms of the Central Highlands prehistory from the Middle Neolithic to the Late Neolithic. The typical cultural relics of the Middle Neolithic in the Central Highlands are Krông Nô volcanic Caves, the relics of Làng Gà (Gia Lai Province), Buôn Kiều (Đắk Lắk Province), Thôn Tám (Đắk Nông Province), Gia Canh (Đồng Nai Province) and Eo Bồng (Phú Yên Province). These relics are in the same line as other Neolithic cultures in Vietnam, such as the Cái Bèo Culture (Quảng Ninh Province – Hải Phòng City), Đa Bút Culture (Thanh Hóa - Ninh Bình Provinces), Quỳnh Văn Culture (Nghệ An - Hà Tĩnh Provinces) (6,000-3,500 years BP) and Bầu Dũ archaeological site (Quảng Nam Province)[20].

In the Neolithic era in Vietnam, most of the inhabitants after the Hòa Bình Culture developed in the delta-coastal area, while some developed in the red soil plateau mentioned above. The inhabitants of the Central Highlands in the Neolithic period developed into the Late Neolithic period, typically the Lung Leng Culture (Kon Tum Province), the Biển Hồ Culture (Gia Lai Province), the Buôn Triết Culture (Đắk Lắk Province) and groups of residents of Hamlet Bốn (Lâm Đồng Province), Chu K'tur (Đắk Lắk Province), H'lang (Gia Lai Province)[21]. With the emergence of post-Neolithic cultures, the Hòa Bình Cultural tradition in the Central Highlands began to be broken. People did not see dwellers in caves, buried bodies in a flexed position with the legs bent, or Hòa Bình-style tools, but instead, the formation of axe and quadrangle or full-body grinding mills.

5.4. The presence of archaeological sites in the volcanic caves of Krông Nô clearly indicates an intact chronicle with outstanding environmental changes and human adaptation in the past; it is a typical example of the tradition of living in caves and using natural resources, representing the process of interaction between humans and the environment under the influence of changes in nature and society in the Central Highlands.

The archaeological evidence in volcanic caves in this area provides essential information about lost environments, the evolutionary history and diversity of nature, and human adaptation to environmental changes. The prominent findings on the characteristics of fauna and flora concerning the archaeological evidence of the Central Highlands volcanic region are not common in Vietnam and Southeast Asia. In this case, the prehistoric archaeology of the Krông Nô volcanic caves should be scientifically recognized as typical in the region. The prehistoric culture of the Krông Nô volcanic caves is an invaluable archive in terms of geology, biodiversity, cultural history of the past in Đắk Nông Global Geopark and a new resource contributing to socio-economic development in the Central Highlands[22].

[20] Nguyen Khac Su (2021). Coastal Plain Exploration Process of Inhabitants in Post-Hoabinhian Period in Vietnam, *Vietnam Social Sciences Review,* No. 5 (205), pp.78-92.

[21] Nguyễn Khắc Sử (2007), *Khảo cổ học tiền sử Tây Nguyên,* Nxb. Giáo dục, Hà Nội (*Prehistory and protohistory of the Central Highlands,* Vietnam Education Publishing House, Hanoi).

[22] Nguyễn Khắc Sử, Đỗ Thị Yến Ngọc, Trần Tân Văn, *Công viên địa chất toàn cầu UNESCO Đắk Nông những giá trị di sản địa chất và khảo cổ học nổi bật,* trong tạp chí *Di sản văn hóa,* số 1 & 4- 2021, tr.4-14 (Outstanding geological and archaeological heritage values of Đắk Nông UNESCO Global Geopark, *Vietnam Heritage Magazine,* No. 1 & 4-2021, pp.4-14).

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References

HOÀNG XUÂN CHINH (CHỦ BIÊN) (1998), *Văn hóa Hòa Bình ở Việt Nam*, Nxb. Khoa học xã hội, Hà Nội (*Hoa Binh Culture in Vietnam*, Social Sciences Publishing House, Hanoi).

LA THẾ PHÚC, HIROSHI TACHIHARA, TSUTOMU HONDA, TRƯƠNG QUANG QUÝ, LƯƠNG THỊ TUẤT (2015). Di sản địa chất hang động núi lửa độc đáo ở Đắk Nông đã được phát hiện và xác lập kỷ lục, *Tạp chí Địa chất, loạt A*, số 349, 1 - 2, tr.28-38 (The unique geological heritage in volcanic caves of Đắk Nông was discovered and recognized as a record, *Journal of Geology*, Series A, no. 349, 1 - 2, pp.28-38).

LA THE PHUC, HIROSHI TACHIHARA, TSUTOMU HONDA, LUONG THỊ TUAT, BUI VAN THOM, NGUYEN HOANG, YURIKO CHIKANO, KATSUJI YOSHIDA, NGUYEN THANH TUNG, PHAM NGỌC DANH, NGUYEN BA HUNG, PHAM GIA MINH VU, NGUYEN THI MAI HOA, HOANG THỊ BIEN, TRƯƠNG QUANG QUY NGUYEN TRUNG MINH (2018). Geological values of lava caves in Krongno volcano geopark, Đắk Nông, Viet Nam, *Vietnam Journal of Earth Sciences*, 40 (4), pp.299-319 (Geological values of lava Caves in Krongno volcano geopark, Đắk Nông, Viet Nam, *Vietnam Journal of Earth Sciences*, 40 (4), pp.299-319).

LA THE PHUC, NGUYEN KHAC SU, VU TIEN DUC, LUONG THI TUAT, PHAN THANH TOAN, NGUYEN THANH TUNG, NGUYEN TRUNG MINH (2017). New discovery of prehistoric archaeological remnants in volcanic caves in Krong No, Đắk Nông Province, *Vietnam Journal of Earth Sciences*, 39 (2), pp.97-108.

LA THẾ PHÚC (2020). *Báo cáo "nghiên cứu giá trị di sản hang động , đề xuất xây dựng bảo tàng tại chỗ ở Tây Nguyên, lấy thí dụ hang động núi lửa Krong Nô, Đắk Nông"*, mã số TN17/T106, lưu trữ tại Bảo tàng thiên nhiên Việt Nam (*Report on the "Research on the value of cave heritage and proposal to build an on-site museum in the Central Highlands, for example, Krông Nô volcanic caves, Đắk Nông"*, No. TN17/T106, archived at the Vietnam National Museum of Nature).

LƯU THỊ PHƯƠNG LAN, NNK (2018). *Sử dụng số liệu từ cảm nghiên cứu cổ khí hậu tại hang C6.1 Đăk Nông, Tây Nguyên*, Tư liệu Bảo tàng Thiên nhiên Việt Nam (*Using data from Magnetic Susceptibility Research at C6.1 Đắk Nông cave, Central Highlands*, Report on the *Research on the value of cave heritage and proposal to build an on-site museum in the Central Highlands, for example, Krông Nô volcanic caves, Đắk Nông*, No. TN17/T106, archived at the Vietnam National Museum).

NGUYỄN ANH TUẤN, VŨ TIẾN ĐỨC, NGUYỄN THÀNH VƯƠNG (2019). Xương răng động vật và vỏ nhuyễn thể khai quật hang C6-1 năm 2018, *Những phát hiện mới về khảo cổ học năm 2018*, Nxb. Khoa học xã hội, Hà Nội, tr 85-89 (Animal tooth and bones, mollusc shells excavated in the C6-1 cave in 2018, *New findings on archaeology in 2018*, Social Sciences Publishing House, Hanoi, pp. 85-89).

NGUYỄN ANH TUẤN, TRẦN THỊ MINH (2020). Xương răng động vật và vỏ nhuyễn thể khai quật hang C6-1 năm 2019, *Những phát hiện mới về khảo cổ học năm 2019*, Nxb. Khoa học xã hội, Hà Nội, tr. tr.40-45 (Animal tooth and bones, mollusc shells excavated in the C6-1 cave in 2019, *New findings on archaeology in 2019*, Social Sciences Publishing House, Hanoi, pp.40-45).

NGUYỄN KHẮC SỬ (2006). Prehistoric Cultures in limestone Caves and Rock Shelters in North Vietnam, *Vietnam social sciences Review*. N^0 1 (111), pp. 89 - 102.

Nguyễn Khắc Sử (2007). *Khảo cổ học tiền sử và sơ sử Tây Nguyên,* Nxb. Giáo dục, Hà Nội (*Prehistory and protohistory of the Central Highlands*, Vietnam Education Publishing House, Hanoi).

NGUYỄN KHẮC SỬ (CHỦ BIÊN), (2016). *Khảo cổ học tiền sử miền Trung Việt Nam,* Nxb. Khoa học xã hội, Hà Nội (*Prehistoric archaeology of Central Vietnam'*, Social Sciences Publishing House, Hanoi).

NGUYỄN KHẮC SỬ, LA THẾ PHÚC, LÊ XUÂN HƯNG (2018). Đào thám sát hang động núi lửa Krông Nô (Đắk Nông), *Những phát hiện mới về khảo cổ học năm 2017*, Nxb. Khoa học xã hội, Hà Nội, tr.42-45 (Excavation in Krông Nô volcanic caves (Đắk Nông), *New findings on archaeology in 2017*, Social Sciences Publishing House, Hanoi, pp.42-45).

NGUYỄN KHẮC SỬ, LÊ XUÂN HƯNG, LA THẾ PHÚC (2019). Kết quả khai quật hang C6-1 Krông Nô (Đắk Nông), *Những phát hiện mới về khảo cổ học năm 2018*, Nxb. Khoa học xã hội, Hà Nội, tr 77-81 (Excavation results of C6-1 cave in Krông Nô (Đắk Nông), *New findings on archaeology in 2018*, Social Sciences Publishing House, Hanoi, pp. 77-81).

NGUYỄN KHẮC SỬ (CHỦ BIÊN), NGUYỄN LÂN CƯỜNG, LÊ XUÂN HƯNG, VŨ TIẾN ĐỨC, LA THẾ PHÚC, LƯƠNG THỊ TUẤT, PHẠM THỊ PHƯƠNG THẢO, NGUYỄN THÀNH VƯƠNG (2019). *Báo cáo khai quật hang C6-1 Krông Nô (Đắk Nông) năm 2019.* Tư liệu Bảo tàng Thiên nhiên Việt Nam, Hà Nội (*Excavation report on C6-1 cave in Krông Nô, Đắk Nông Province in 2019*, Vietnam National Museum of Nature, Hanoi).

NGUYỄN KHẮC SỬ, NGUYỄN LÂN CƯỜNG, LA THẾ PHÚC, NGUYỄN TRUNG MINH, LƯƠNG THỊ TUẤT, LÊ XUÂN HƯNG, VŨ TIẾN ĐỨC (2020). Khai quật hang ní lửa C6-1 Krông Nô, Đắk Nông: Tư liệu và nhận thức mới về Tiền sử Tây Nguyên, *Tạp chí Khảo cổ học*, số 4-1920, tr.16-30 (Excavation of volcanic cave C6-1 in Krông Nô, Đắk Nông: Documentation and a new perception on Prehistory of the Central Highlands, *Journal of Archaeology*, No. 4-1920, pp.16-30).

NGUYEN KHAC SU (2021), Hoabinh Culture in Vietnam after Nearly A Century of Discovery, *Vietnam Social Sciences Review,* n$^{\underline{0}}$ 2 - 2021, pp.26-42.

NGUYỄN KHẮC SỬ, ĐỖ THỊ YẾN NGỌC, TRẦN TÂN VĂN (2021). Công viên địa chất toàn cầu UNESCO Đắk Nông những giá trị di sản địa chất và khảo cổ học nổi bật, *Tạp chí Di sản văn hóa*, số 1 & 4- 2021, tr.4-14 (Outstanding geological and archaeological heritage values of Đắk Nông UNESCO Global Geopark, *Vietnam Heritage Magazine*, No. 1 & 4- 2021, pp.4-14).

NGUYỄN KHẮC SỬ (2022), Vietnam's Middle and Late Neolithic marine cultures, *Vision and Mission Objection Strategy Tactics Journal of Social Science and Humanities*, Volume 64, No. 1-2022, pp.112-128).

NGUYỄN LÂN CƯỜNG (2019). Di cốt người cổ đầu tiên được phát hiện ở hang động núi lửa Krông Nô (Đắk Nông), *Tạp chí khảo cổ học*, số 2, tr. 33-52 (The first ancient human remains discovered in Krông Nô volcanic caves (Đắk Nông), *Journal of Archaeology*, No. 2, p. 33-52).

NGUYỄN NGỌC TRƯỜNG, LA THẾ PHÚC, NGUYỄN TRUNG MINH, BÙI QUANG ANH, LƯƠNG THỊ TUẤT, ĐẶNG THỊ HẢI YẾN (2021), So sánh đặc điểm thành phần trầm tích trong tầng văn hóa hang C6-1 và hang ní lửa khu vực Krong Nô, Đắk Nông, trong tạp chí *Khảo cổ học*, số 2-2022, tr. 38-48. (Comparison in terms of the characteristics of sediments in the C6-1 cave and the volcanic caves in Krong No, Dak Nong, *Journal of Archeology*, No. 2-2022, pp. 38-48).

NGUYỄN THỊ MAI HƯƠNG, PHẠM VĂN HẢI, PHAN THANH TOÀN (2019). Kết quả phân tích bào từ phấn hoa hang C6-1 Krông Nô (Đắk Nông), *Những phát hiện mới về khảo cổ học năm 2019*, Nxb Khoa học xã hội, Hà Nội, tr.45-48 (Analysis results of spores from pollen from C6-1 cave in Krông Nô (Đắk Nông), *New findings on archaeology in 2019*, Social Sciences Publishing House, Hanoi, pp.45-48).

PHAN THANH TOÀN, VŨ TIẾN ĐỨC, NGUYỄN THANH TÙNG (2018). Phát hiện các di tích hang động núi lửa thời tiền sử ở Krông Nô (Đắk Nông), *Những phát hiện mới về khảo cổ học năm 2017*, Nxb. Khoa học xã hội, Hà Nội, tr.46-50 (The discovery of prehistoric archaeological sites in volcanic caves in Krông Nô (Đắk Nông), *New findings on archaeology in 2017*, Social Sciences Publishing House, Hanoi, pp.46-50).

TẠ HÒA PHƯƠNG, NGUYỄN THÙY DƯƠNG, NGUYỄN THỊ ÁNH NGUYỆT, PHAN THANH TOÀN (2018), Phân tích *Phân tích trầm tích di chỉ hang động núi lửa C6-1 (Đắk Nông)*, trong *Những phát hiện mới về khảo cổ học năm 2017*, Nxb. Khoa học xã hội, Hà Nội, năm 2018, tr.54-56 (Sediment analysis of C6-1 volcanic cave (Dak Nong), *New findings on archeology in 2017*, Social Sciences Publishing House, Hanoi, 2018, pp.54-56).

VŨ TIẾN ĐỨC, PHẠM THỊ PHƯƠNG THẢO, LƯƠNG THỊ TUẤT (2019). Kết quả khai quật hang C6'(Đắk Nông) năm 2018, *Những phát hiện mới về khảo cổ học năm 2018*, Nxb. Khoa học xã hội, Hà Nội, tr.97-99 (Excavation results of C6' cave (Đắk Nông) in 2018, *New findings on archaeology in 2018*, Social Sciences Publishing House, Hanoi, pp.97-99).

Ewamian Archaeology at Undara Volcanic National Park, Northern Australia

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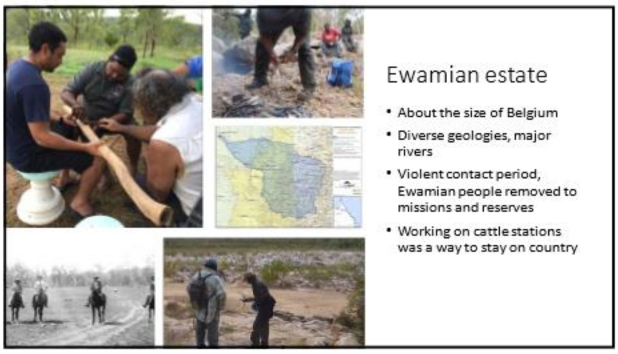
Abstract

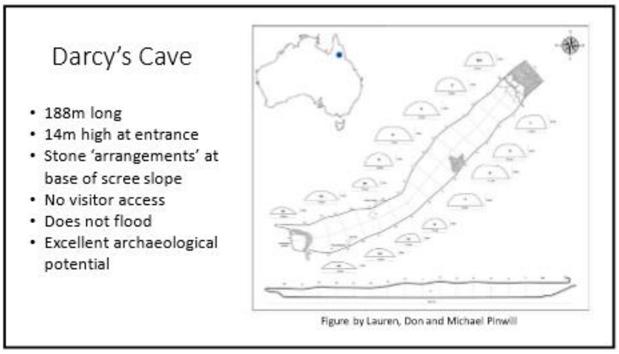
In 2020, the Ewamian Rangers and myself began a long-term investigation of the cultural values of the Undara volcanic area and lava tubes in Australia's tropical savannah. Our surveys identified cultural material in 11 of 15 of the lava tubes surveyed. Quartz, charcoal and broken macropod bones are the most common archaeological features, with nearly every occupied tube containing these three attributes. Stone arrangements, better described as small platforms cleared of rock, were found in five of the tubes. We also found hearths, used pieces of ochre, granite and basalt pounders, a partially formed hand axe, mussel shell and bone tools sharpened to a point.

We conducted a small test pit excavation at the entrance to Darcy's Cave, with controlled excavations to a depth of just 20cm. Radiocarbon dating of charcoal from the excavation revealed Aboriginal occupation dating to at least 1000 years. The excavation revealed 33 stone artefacts, 362 bone fragments and charcoal within the stone arrangements. Aboriginal custodians identified food and medicinal plants in the vine thickets at the entrance to the lava tubes. Different vegetation inside the Undara crater suggests the crater landscape has been managed by human fires in the past. Our project has begun to illustrate the exciting cultural landscape and archaeological values of the Undara Volcanic National Park.

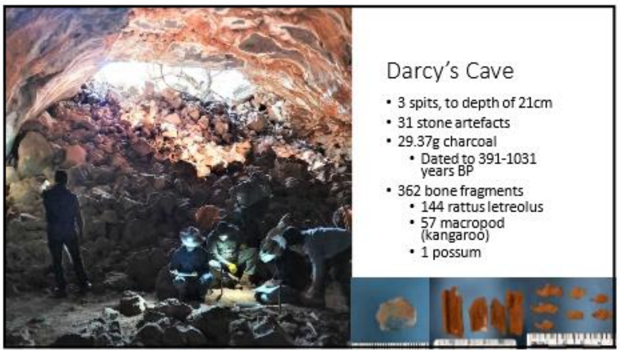
Images of the PowerPoint presentation:

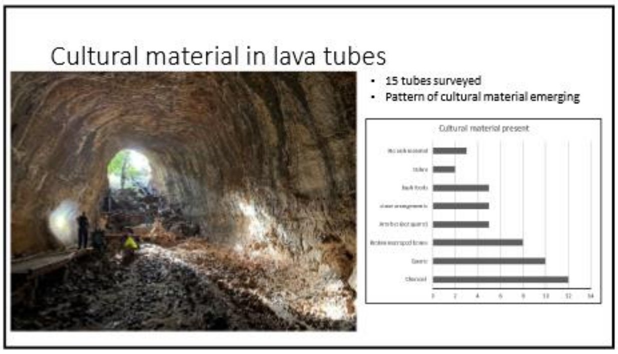



Decolonising the cultural landscape
We wanted to bust the myth that Aboriginal people did not use the lava tubes
Previous work: Artefacts recorded at entrance to 1 tube
Toe holds cut into trunks of food trees
Stone arrangements inside tube
Human remains had been found and removed by cavers, and reinterred when they were found to be pre-colonial
As a guide, JR had hidden special tools away from tourists and other guides.

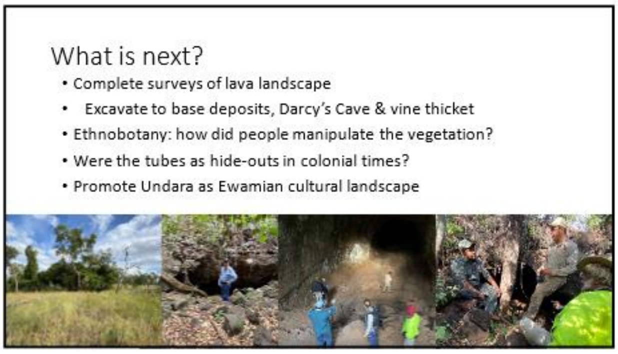

Darcy's Cave
188m long
14m high at entrance
Stone 'arrangements' at base of scree slope
No visitor access
Does not flood
Excellent archaeological potential
Figure by Lauren, Don and Michael Pinwill


Darcy's Cave
surface artefacts & charcoal at entrance
2 charcoal pieces on ledges
Stone arrangements
Faunal remains with artefacts


Darcy's Cave
3 spits, to depth of 21cm
31 stone artefacts
29.37g charcoal
Dated to 391-1031 years BP
362 bone fragments
144 rattus letreolus
57 macropod (kangaroo)
1 possum


Cultural material in lava tubes
15 tubes surveyed
Pattern of cultural material emerging
Cultural material present


Undara crater
Cultural fires have created the vegetation inside the crater
Bush foods and medicines
Basalt artefact


What is next?
Complete surveys of lava landscape
Excavate to base deposits, Darcy's Cave & vine thicket
Ethnobotany: how did people manipulate the vegetation?
Were the tubes as hide-outs in colonial times?
Promote Undara as Ewamian cultural landscape


Thank you
Ewamian Rangers, leaders and Elders: Sharon Prior, Jimmy Richards, David Hudson, Tania Casey, Tristin Lacey, Megan Mosquito, Michell Kapteyn, Steve Wargent, Jordan Kapteyn, Wallace Jensen, Konichi Shioji and Dale Murray
Archaeologists: Nick Roberts, Asa Ferrier, Nikki Winn, Owen Ray, Richard Cosgrove, Duncan Ray
Queensland Parks & Wildlife Service: Anthony Staniland, Jim Davies, Nick Smith and Dave Gutry, Ranger Roy
Previous landowners: Lauren, Don & Michael Pinwill
EWAMIAN LIMITED

Pyroducts (lava tubes) their genesis and importance

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Abstract

Pyroducts (or colloquially "lava tubes") are of great importance for the post-eruptional, gravitational transport of lava. Petrographically their genesis seems to be limited to the basalt-quadrant of the TAS-diagram, i.e., tholeiitic and alkali basalts (with very few documented examples from picritic, e.g., Keauhou Trail Cave, Hawai'i, and tephrite lavas, e.g., Cueva del Viento, Tenerife). Structurally two major modes of their genesis exist: Inflation and crusting over of channels (either by lateral shelf-growth or by the welding of floating clasts). Another documented way is the coalescence of several small conduits to form a larger tunnel (e.g., Kahuenaha Nui Cave, Hawaiʻi). Documentation of the roof structure can tell which of these modes has been responsible for cave formation. Internally, pyroducts are subject to a variable degree of thermos-mechanical erosion. It leads to the draining of initial, small conduits and the concentration of the lava in one, downcutting master-passage. It has the function and morphology of a subterranean canyon with a gas-space above it. The final cave therefore is not created at the end of the eruption by the drainage of lava from its "tube system". Erosion can lead to roof instability and to upward enlargement of the evolving cavity and to the opening of skylights. Through them cold air can enter, which in turn causes the freezing of secondary ceilings on top of the flowing lava. These separate the passage in two or more levels, which sometimes are mistaken for individual "tubes" stacked upon each other. This process maintains the high lava temperature, enabling it to flow for long distances. The longest continuously accessible passage is Kazumura Cave, Hawaii, 42 km long, dropping 1102 m with a slope of 1.5° and a sinuosity of 1.30. All the pyroducts in Hawaiʻi are in pahoehoe lavas, even if their slope is as high as 5°. On steeper slopes, like on Mount Etna, pyroducts also form in the interior of 'ā'a-flows. This is the only volcano for which this is documented. The longest pyroduct-sustained lava flow is the Undara-Flow, Australia. It is 160 km long with a slope of 0.3° only. It may be the best analogue for lunar rills with its elongated depressions and large discontinuous cavities. The rills could represent collapsed pyroduct sections that once were upward enlarged cupolas, such as the existing caves in Undara, while the actual pyroduct conduit is situated below and never was evacuated, just as for most of the length of the Undara flow.

Keywords: Pyroducts genesis, inflation, channels.

Processes described in this presentation have been published by the authors in many papers. The reader is therefore referred those, most of which are available on Research Gate for downloading (see over).

General overviews:

KEMPE S. (2019) Volcanic rock caves (revised). – In: White W, Culver DC & Pipan T (eds.), Encyclopedia of Caves, 3rd ed., London, Academic Press /Elsevier, Chapter 131: 1118-1127.

KEMPE S & KETZ-KEMPE C (2016) Pyroducts, the third most common cave type on Earth. – 17th Symp. on Vulcanospeleology, Ocean View, Hawaiʿi, 7th to 12th, Feb. 2016, 1-2.

KEMPE S (2012) Lava caves, types and development. – Abstracts and Proceedings 15th Intern. Symp. on Vulcanospeleology, Hashemite Univ. Zarka – Jordan, 15-22 March, 2012: 49-56.

KEMPE S (2009) Principles of pyroduct (lava tunnel) formation. – 15th Intern. Speleological Congress, Kerrville, Texas July 2009. Reprinted in: Hawaiʿi Speleological Survey Newsletter 28: 16-24.

KEMPE S (2002) Lavaröhren (Pyroducts) auf Hawaiʿi und ihre Genese. – In: Rosendahl W & Hoppe A (eds.): Angewandte Geowissenschaften in Darmstadt. Schriftenreihe der deutschen Geologischen Gesellschaft, Heft 15: 109-127.

Speleothems:

KEMPE S (2013) Morphology of speleothems in primary (lava-) and secondary caves. - In: Shroder J (Editor in Chief), Frumkin, A. (Ed.), Treatise on Geomorphology. Academic Press, San Diego, CA, vol. 6, Karst Geomorphology, pp. 267–285.

Geology and genesis of specific caves:

Australia

MIDDLETON, GJ & KEMPE S (2022) Caves and Karst of Australia: North Queensland Lava Caves. – Caves of Australia, Springer, submitted.

Galapagos

KEMPE S, MIDDLETON G, TOULKERIDIS T, ADDISON A & HOESE G (2021) New Insights into the Genesis of Pyroducts of the Galápagos Islands, Ecuador. – Acta Carsologica 50(1): 143-163.

Hawai'i

KEMPE S & KETZ-KEMPE C (1979) Fire and ice atop Hawaii. – Nat. Speleol. Soc. News 37/8: 185-188.

KEMPE S, KETZ-KEMPE C, HALLIDAY WR & WERNER MS (1993) The Cave of Refuge, Hakuma Horst, Kalapana, Puna District, Hawai'i. – Pacific Studies 16(2): 133-142.

KEMPE S & KETZ-KEMPE C (1993) Lava tube systems of the Hilina Pali area, Kaʿu District, Hawaiʿi. – Proc. 6th Intern. Symp. Vulcanospeleology., Hilo, 1991: 15-25.

KEMPE S & KETZ-KEMPE C (1993) Underground observations during the Puʿu Oʿo earthquake, 4.06 p.m., Aug. 8, 1990. – Proc. 6th Intern. Symp. Vulcanospeleology., Hilo, 1991: 29-34.

KEMPE S (1997) Lava falls: a major factor for the enlargement of lava tubes of the Ai-la'au shield phase, Kilauea, Hawaii. – Proc. 12th Intern. Congr. Speleol. 10.-17. Aug. 1997, La Chaux-de-Fonds, Switzerland, Vol. 1 : 445-448.

KEMPE S & KETZ-KEMPE C (1997) Archaeological observations in lava tubes on Hawaii. – Proc. 12th Intern. Congr. Speleol. 10.-17. Aug. 1997, La Chaux-de-Fonds, Switzerland, Vol. 3: 13-16.

KEMPE S, BUCHAS H, HARTMANN J, OBERWINDER M, STRASSENBURG J & WOLNIEWICZ K (1997) Mapping lava flows by following their tubes: The Keauhou Trail/ Ainahou Ranch Flow Field, Kilauea, Hawaii. – Proc. 12th Intern. Congr. Speleol. 10.-17. Aug. 1997, La Chaux-de-Fonds, Switzerland, Vol. 1: 453-455.

KEMPE S & OBERWINDER M (1997) The Upper Huehue Flow (1801 eruption, Hualalai, Hawaiʿi): An example of interacting lava flows yielding complex lava tube morphologies. – Proc. 12th Intern. Congr. Speleol. 10.-17. Aug. 1997, La Chaux-de-Fonds, Switzerland, Vol. 1(3): 449-452.

ALLRED K, KEMPE S & HALLIDAY WR (2000) Kenneth P. Emory and "Herbert C. Shipman Cave": a longstanding puzzle solved. – Pacific Studies 22(1): 77-92.

WERNER S, KEMPE S, HENSCHEL H-V & ELHARD R (2002) Kuka'iau Cave (alias ThisCave and ThatCave): Exploration report of a lava cave eroded by water, a new type of Hawaiian cave. – Nat. Speleol. Soc. News Dec. 2002: 346-351.

KEMPE S, BAUER I & HENSCHEL H-V (2003) The Pa'auhau Civil Defence Cave on Mauna Kea, Hawai'i, a lava tube modified by water erosion. – J. of Cave and Karst Studies 65(1): 76-85.

KEMPE S & WERNER MS (2003) The Kuka'iau Cave, Mauna Kea, Hawai'i, created by water erosion, a new Hawaiian cave type. – J. of Cave and Karst Studies 65(1): 53-67.

DONACHIE SP, HOU S, LEE KS, RILEY CW, PIKINA A, KEMPE S, GREGORY TG, BOSSUYT A, BOEREMA J, LIU J, FREIAS TA, MALAHOFF A, ALAM M (2004) The Hawaiian Archipelago: A microbial diversity hotspot. – Microbial Ecology 48: 509-520.

KEMPE S & HENSCHEL H-V (2008) Thurston Lava Tube, the most visited tube in the world. What do we know about it? – Proc. 12th Intern. Symp. on Vulcanospeleology, Tepotzlán, Mexico, 2-7 July, 2006, Assoc. for Mexican Cave Studies, Bull. 19 and Socieded Mexicana de Exploraciones Subterráneas Bol. 7: 219-228. Reprinted in: Hawai'i Speleological Survey Newsletter, Fall 2008, 24: 16-24.

KEMPE S. (2008) Immanuel Kant's remark on lava cave formation in 1803 and his possible sources. – Proceedings 13th Intern. Sympos. on Vulcanospeleology, Jeju Island, Korea, 1.-5. Sept. 2008: 35-37.

KEMPE S, HENSCHEL H-V, SHICK H & TRUSDELL F (2008) Geology and genesis of the Kamakalepo Cave System in Mauna Loa picritic lavas, Na'alehu, Hawaii. – Proc. 12th Intern. Symp. on Vulcanospeleology, Tepotzlán, Mexico, 2-7 July, 2006, Assoc. for Mexican Cave Studies, Bull. 19 and Socieded Mexicana de Exploraciones Subterráneas Bol. 7: 229-242.

KEMPE S, HENSCHEL H-V, SHICK H & HANSEN B (2008) Archaeology of the Kamakalepo / Waipouli / Stonehenge area, underground fortresses, living quarters and petroglyph fields. – Proc. 12th Intern. Symp. on Vulcanospeleology, Tepotzlán, Mexico, 2-7 July, 2006, Assoc. for Mexican Cave Studies, Bull. 19 and Socieded Mexicana de Exploraciones Subterráneas Bol. 7: 243-252. Reprinted in: Hawaii Speleological Survey of the Nat. Speleol. Soc., 2009 (25):10-19.

KEMPE S & HENSCHEL H-V (2009) Interpreting the genesis of Thurston Lava Cave, Kilauea, Hawai'i. – Proc. 15th Intern. Congress of Speleology, Kerrville, Texas, July 19-26, 2009: 675-681.

KEMPE S, HENSCHEL H-V, SHICK H & HANSEN B (2009) Archaeology and ^{14}C dates of the Kamakalepo/Waipouli/Stonehenge Area, Nahalehu, Hawaii. – Proc. 15th Intern. Congress of Speleology, Kerrville, Texas, July 19-26, 2009: 682-689.

KEMPE S, AL-MALABEH A, BAUER I & HENSCHEL H-V (2010) Pressure ridge caves, a comparison between the Jordanian caves of the Qais/Makais volcanic field and the Hawaiian Mauna Loa Eclipse Cave. – Proceedings 14th International Symposium on Vulcanospeleology, 12.-17. Aug. 2010, Undara Australia: 83 92.

KEMPE S, BAUER I, BOSTED P, COONS D, & ELHARDT R (2010) Inflationary versus crusted-over roofs of pyroducts (lava tunnels). – Proceedings 14th International Symposium on

Vulcanospeleology, 12.-17. Aug. 2010, Undara Australia: 93-101. Reprinted in: Hawaii Speleological Survey Newsletter 2012 (31): 21-30.

KEMPE S, BAUER I, BOSTED P & SMITH S (2010) Whitney's Cave, an old Mauna Loa/Hawaiian pyroduct below Pahala ash: an example of upward-enlargement by hot breakdown. – Proceedings 14th International Symp. on Vulcanospeleology, 12-17. Aug. 2010, Undara Australia: 103 - 113.

KEMPE S (2010) Longitudinal section through a lava pyroduct. – Hawaii Speleology Survey Newsletter, Spring 2010 (27): 18.

HALLIDAY WR, OKUBO CH, KEMPE S, GARMAN M, GARMAN S & WYNNE JJ (2010) Rheogenic caves and cavernous structures of Kalaupapa Peninsula, Molokai Island. Hawaii, USA, a Mars analogue revisited. – Hawai'i Speleological Survey Newsletter, Spring 2010 (27): 19-32.

KEMPE S, BAUER I, BOSTED P & BOSTED A (2012) The Queen's Bath, a littoral cave in Mauna Loa lava, formed by coastal erosion. – Hawai'i Speleological Survey Newsletter, Fall 2012 (32): 16-17.

BAUER I, KEMPE S & BOSTED P (2013) Kahuenaha Nui (Hawaii): A cave developed in four different lava flows. – In: Filippi, M. & Bosák, P. (eds.), Proceedings 16th Intern. Congr. Speleology, Brno, July 21 -28, 2013, Vol. 3: 231-236. Reprinted in: Hawai'i Speleology Survey Newsletter, Fall 2012 (32): 27-31.

BOSTED P, GRACANIN T, HACKELL V, BOSTED A, BAUER I & KEMPE S (2013) The Keokeo lava tube system in Hawaii. – In: Filippi, M. & Bosák, P. (eds.), Proceedings 16th Intern. Congr. Speleology, Brno, July 21 -28, 2013, Vol. 3: 243-246.

KEMPE S, HARTMANN J & WOO KS (2016) Comparison of main ion composition of water samples from lava caves on Hawaii, USA, and Jeju Island, South Korea. – 17th Symp. on Vulcanospeleology, Ocean View, Hawaiʻi, 7th to 12th, Feb. 2016.

BOSTED P, GRACANIN T, HACKELL V, SCHEFFLER T & KEMPE S (2016) The Keokeo Cave System in Hawaii. – Newsletter of the Hawaii Speleological Survey of the Nat. Speleol. Soc. 39 (Spring 2016): 10-15.

KEMPE S & KETZ-KEMPE C (2016) Towards understanding the structure of Kaumana Cave, Hawaii. – 17th Symp. on Vulcanospeleology, Ocean View, Hawaii, 7th to 12th, Feb. 2016. Reprinted in: Newsletter of the Hawaii Speleological Survey of the Nat. Speleol. Soc. 39 (Spring 2016): 16-24.

KEMPE S, KETZ-KEMPE C & SHICK H (2017) The complexity of pyroduct ("lava tubes") genesis: Bird Park Cave, Hawaii Volcanoes National Park. – K. Moore & S. White (eds.), Proceedings 17th Intern. Speleology Congress, Sydney, 22.-30. July, 2017, Vol. 2: 185-189. Reprinted in: Newsletter Hawaii Speleological Survey 42 (Fall 2017): 19-26.

KEMPE S (2018) The big connection trip: Huehue Cave. – Hawai'i Speleological Survey Newsletter 43: 14-26.

Jordan

KEMPE S, AL-MALABEH A, DÖPPES D, FREHAT M, HENSCHEL H-V & ROSENDAHL W (2006) Hyena Caves in Jordan. – Proc. 12th Intern. Cave Bear Symposium in Thessaloniki/Loutra, Sci. Annals, School of Geology, Aristotle Univ. of Thessaloniki, Spec. Vol. 98: 201-212.

KEMPE S, AL-MALABEH A & HENSCHEL H-V (2008) Kempe Cave: an unusual, meandering lava tunnel cave in NE-Jordan. – Proceedings 13th Intern. Sympos. on Vulcanospeleology, Jeju Island, Korea, 1.-5. Sept. 2008: 38-39.

AL-MALABEH A, FREHAT M, HENSCHEL H-V & KEMPE, S (2008) Al-Fahda Cave (Jordan): the longest lava cave yet reported from the Arabian Plate. – Proc. 12th Intern. Symp. on Vulcanospeleology, Tepotzlán, Mexico, 2-7 July, 2006, Assoc. for Mexican Cave Studies, Bull. 19 and Socieded Mexicana de Exploraciones Subterráneas Bol. 7: 201-208.

KEMPE S, AL-MALABEH A, FREHAT M & HENSCHEL H-V (2008) State of lava cave research in Jordan. – Proc. 12th Intern. Symp. on Vulcanospeleology, Tepotzlán, Mexico, 2-7 July, 2006, Assoc. for Mexican Cave Studies, Bull. 19 and Socieded Mexicana de Exploraciones Subterráneas Bol. 7: 209-218.

KEMPE S, AL-MALABEH A & HENSCHEL, H-V (2009) Jordanian lava caves and their importance to understand lava plateaus. – Proc. 15th Intern. Congress of Speleology, Kerrville, Texas, July 19-26, 2009: 690-697.

KEMPE S & AL-MALABEH A (2010) Animal mummies found in lava caves in the Jordanian desert. – In: Wieczorek A & Rosendahl W (eds.), Mummies of the World, Exhibition Catalog USA 2010-13, Prestel, Munich, London, New York 281-284.

KEMPE S, AL-MALABEH A, BAUER I & HENSCHEL H-V (2010) Pressure ridge caves, a comparison between the Jordanian caves of the Qais/Makais volcanic field and the Hawaiian Mauna Loa Eclipse Cave. – Proceedings 14th International Symposium on Vulcanospeleology, 12.-17. Aug. 2010, Undara Australia: 83 92.

KEMPE, S, AL-MALABEH A & HENSCHEL H-V (2012) Jordanian lava caves, an overview. – Abstracts and Proceedings 15th Intern. Symp. on Vulcanospeleology, Hashemite Univ. Zarka – Jordan, 15-22 March, 2012: 38-42.

AL-MALABEH A & KEMPE S (2012) Hashemite University Cave, Jordan. – Abstracts and Proceedings 15th Intern. Symp. on Vulcanospeleology, Hashemite Univ. Zarka – Jordan, 15-22 March, 2012: 43-48.

Korea, Jeju

KEMPE S, HARTMANN J & WOO KS (2016) Comparison of main ion composition of water samples from lava caves on Hawaii, USA, and Jeju Island, South Korea. – 17th Symp. on Vulcanospeleology, Ocean View, Hawaiʻi, 7th to 12th, Feb. 2016.

KEMPE S & WOO KS (2016) Geological observations in pyroducts of Jeju Island (South Korea). – 17th Int. Symp. on Vulcanospeleology, Ocean View, Hawaiʻi, 7th to 12th, Feb. 2016.

Planetary

HALLIDAY WR, OKUBO CH, KEMPE S, GARMAN M, GARMAN S & WYNNE JJ (2010) Rheogenic caves and cavernous structures of Kalaupapa Peninsula, Molokai Island. Hawaii, USA, a Mars analogue revisited. - Hawai'i Speleological Survey Newsletter, Spring 2010 (27): 19-32.

KEMPE S (2017) What if the "Seven Sisters" are not volcanic? A look at deep hypogene sinkholes in Arabia. - K. Moore & S. White (eds.), Proceedings 17th Intern. Speleology Congress, Sydney, 22.-30. July, 2017, Vol. 1: 371-374.

Spain, Canary Islands

REIN T, KEMPE S & DUFRESNE A (2016) The "Cueva del Viento" on the Canaries, Spain. - 17th Int. Symposium Vulcanospeleology, Ocean View, Hawaiʻi, 7th to 12th, Feb. 2016.

The role of pyroducts in the context of general volcanology can be found in:

LOCKWOOD J.P., HAZLETT R.W. & CRUZ-REYNA S. de la (2022) Volcanoes, Global Perspectives. – Hoboken & Chichester, Wiley & Sons.

OVERVIEW OF VOLCANIC CAVES IN VIETNAM

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Abstract

Vietnam's caves are rich and diverse with different origins, distributed in karstic and basaltic rocks. The first type - karstic cave with the exogenous origin - was formed in the limestone formations of the marine sedimentary source at different ages, distributed mainly in the Northern and Central parts of the country, which are not objects mentioned in this paper. That means, the paper focuses on presenting the second one - volcanic cave or lava cave – with the endogenous origin, formed right in the volcanic lava flow, and closely related to the volcanic eruptions in the Middle Pleistocene, located in Krongno district (Dak Nong prov.), Tan Phu and Dinh Quan districts (Dong Nai Prov.). The volcanic caves have been investigated and studied within the framework of scientific research projects at various levels on their scientific significance as well as heritage values. According to reliable statistics of the authors, in Krongno, Dak Nong Province, the total length of 21 volcanic caves measured among 50 caves discovered and located is 8,073.3m. In Dong Nai Province, the total length of 11 caves in the Tan Phu and Dinh Quan districts is 2,837m. Thus, the total length of 32 volcanic caves measured in both Dong Nai and Dak Nong is 10,910.3m. The research results have also shown that volcanic caves in Vietnam are a heritage complex of great significance for scientific research, education, and an invaluable resource for tourism development. The complex of volcanic cave heritages in Krongno plays an important and decisive role in the scientific dossier for the Dak Nong UNESCO Global Geopark (Dak Nong UGGp) title. Therefore, it is very important to continue studying effective conservation and reasonable use/sustainable development of diverse heritage values of volcanic caves in Dak Nong and Dong Nai as well. This paper introduces the overview of the discovery process and research situation on the volcanic caves in Vietnam, which could be considered as one of the preliminary reference sources, looking forward to receiving further research cooperation from domestic and foreign scientists as well.

Keywords*:* volcanic cave; Dong Nai; Dak Nong.

I. Introduction

Karstic rocks, where karstic caves are formed and developed, cover about 50,000-60,000 km2, equivalent to approx. 15% area of the country, mainly distributed in the North and Central parts. Meanwhile, basaltic rocks cover about 30,000-40,000 km2, approx. 10% of the country's area, distributed mainly in five provinces of The Central Highlands and the South Central part (Figure 1). Karstic caves were surveyed and located on the map by geologists from the early years of the 20th century during the fundamental investigation of mineral geology at different scales. However, it was not until 2007, volcanic caves were first recorded [4; 5], then measured and mapped from 2012-2018 [7] (several caves were even done later), and studied in detail, interdisciplinary, and specialized from 2016 to the present [8]. According to incomplete statistics, in Vietnam, there are >1,000 karstic caves, meanwhile, there are only approx. 100 volcanic caves in basaltic rocks in Dak Nong and Dong Nai provinces. Limestone caves are related to the geological formations at the ages of >200 million years, with the secondary origin - related to the karst process of the rocks; meanwhile, the "real" volcanic caves are often associated with young basaltic rocks (approx. 700-200 thousand years BP) with the endogenous origin - formed simultaneously with the volcano eruption and cooling of the lava flows [7; 8]. The heritage values of the caves consist of geological heritage (10 geo-heritage types), and non-geological heritages (biodiversity and cultural heritages/archaeological and historical) [8].

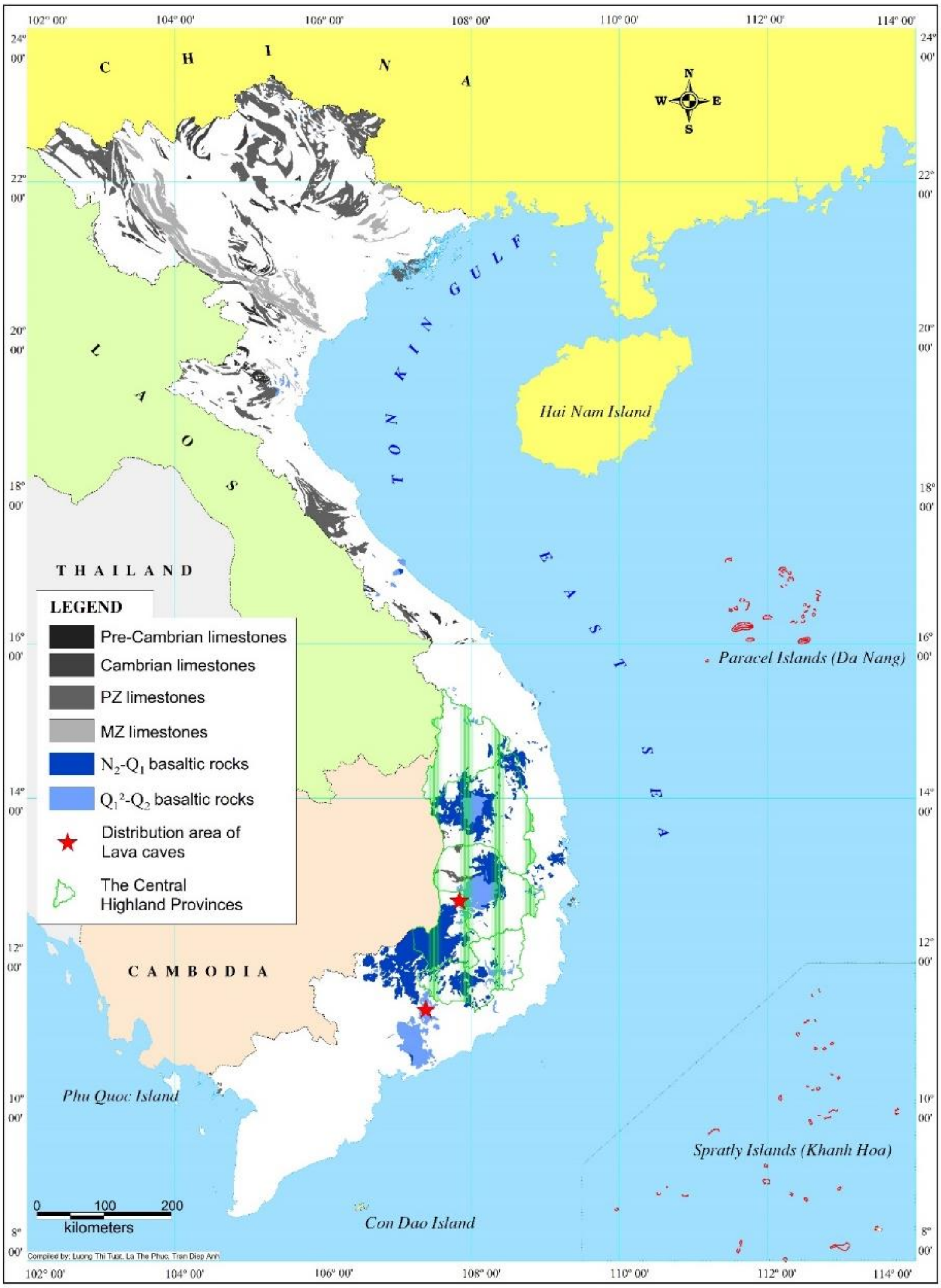

Figure 1. Distribution map of karstic rocks, basaltic rocks, and lava caves in Vietnam. (By Luong Thi Tuat et al., 2015).

Many caves in Vietnam and the world have been recognized with global outstanding landscape value and used to be the residence shelters of prehistoric people or the bases of revolutions against foreign invaders. Notice the fact that, in Vietnam, valuable natural caves were always important and essential highlights in the scientific profiles submitted to UNESCO for appraisal and recognition of UNESCO heritage titles, such as the caves Thiên Cung, Sửng Sốt, Đầu Gỗ, Thiên Cung, etc., in Ha Long Bay World Natural Heritage (Quang Ninh Prov.); the caves Phong Nha, Thiên Đường, Sơn Đoòng, etc. in Phong Nha - Ke Bang World Natural Heritage (Quang Binh Prov.); or numerous of the caves Thiên Hà (Galaxy), Thiên Thanh, Tiên, Thủy Cung, Bụt, Tam Cốc, Trống, Ốc, Múa, etc., in Trang An Scenic Landscape Complex (Ninh Binh Prov.); the caves Khố Mỷ, Phó Bảng, Sảng Tủng, Nà Luông, Lùng Khúy, etc., in Dong Van UGGp (Ha Giang Prov.); the caves Pac Bó, Ngườm Ngao, Mắt Thần, etc., in Non-Nuoc Cao Bang UGGp (Cao Bang Prov.). Like the karstic partners in the North and Central parts, the volcanic caves in Dak Nong province of The Central Highlands became the outstanding highlights in the scientific dossier for the noble title "Dak Nong UGGp", obtained in 2020. In Dong Nai province, the lava caves in Tan Phu and Dinh Quan districts also are important highlights attracting tourists to the Đồng Nai Biosphere Reserve (DNBR, which was expanded and renamed in 2011, and consists of three protected areas: Cát Tiên National Park (72,000 ha), Đồng Nai Cultural Nature Reserve (68,000 ha) and the Inland Wetland Protected Area of Trị An - Đồng Nai (32,400 ha), as well as other tourist destinations in the region [13; 14].

II. Methods of Investigating Volcanic Caves

Volcanic caves are completely different from their partners in karstic rocks in terms of origin, formation mechanism, distribution characteristics, landscape, topography/geomorphology, etc. To achieve high efficiency in the investigation and search of caves in the basaltic rock, the main investigation methods are applied as follows:

II.1 Inheritance method

Documents related to caves in basaltic rock and volcanic caves worldwide and some limited sources in Vietnam are collected and synthesized. These are very useful documents to enhance local volcanic cave knowledge and understanding and to help orient the investigation and research in the next steps.

II.2 Remote sensing method

Analysis of remote sensing images, google map images and flycam (drone) images are very effective in locating objects such as geomorphological landscapes, craters, lakes, waterfalls, and volcanic caves. Volcanic caves in the Buon Choa'h lava field (in Krongno, Dak Nong) are expressed as depressions from several to tens of metres deep, with a blue - darkish-grey colour on the coffee background colour of the lava field in the dry season. The field survey results have recorded the accuracy and efficiency of this method to be around 70-80%.

II.3 Methods of sociological investigation/interviewing local people

This method is implemented by interviewing the local/indigenous people for information about the volcanic caves, which are often so-called "Doi caves" in the locality, then asking them to directly lead the way to the caves for the survey. This method has been proven to be very effective, including saving time in seeking volcanic caves in bushy tropical forests, especially during the rainy season.

II.4 Methods of field investigating, collecting of primitive document/data

Generally, field surveys are conducted at two levels/steps; preliminary and detailed. The detailed survey is performed based on a typical selection after obtaining the initial results from the first field surveys.

The volcanic caves will be surveyed in the field, and identified heritages based on the following tasks: observation, description of the geographical location, scale, and typical features of the cave; detailed measurement, taking cave photos, recording/scanning, sampling for all kinds of analysis; evaluation of scientific values according to professional fields (geological heritage, biodiversity, cultural heritage), aesthetics, economic value, safety, load-bearing threshold, etc. for establishing a scientific profile and orienting conservation and promotion and development of the cave heritages.

II.5 Statistical classification method

The cave is a geological heritage entity of type B - Geomorphology. In geomorphological research, there are classification criteria or principles, including classification by morphology, by origin, and by morphology-origin. Depending on the purpose and using needs, data on the volcanic caves could be collected and classified into several different groups, for example: by origin and formation mechanism, distribution characteristics/depth of distribution, or by relation to the groundwater level, etc.

III. Overview of Volcanic Caves in Vietnam

According to the formation origin and mechanism, the volcanic caves in Vietnam are divided into 2 types: secondary and primary. Secondary caves consist mainly of "rocky shelter" caves, which were formed by the destruction and erosion processes of weak/unstable rock layers at the lower part of waterfalls such as Dray Sap, Dray Nur, Lieng Nung, Trinh Nu, Waterfall 50 (Fig.2; left and centre). This cave type is almost modest in size. Another secondary one of "rocky shelter" was formed by landslides of the basaltic blocks, then stacked on top of each other, distributed in the valleys with significant slopes, such as Thoat Y cave in the Cat Tien National Park, Dong Nai Prov. (Figure 2; right). In this case, the heritage value of the cave is associated with the landscape value of the waterfall and related to the tectonic heritage value.

Next, the primary cave also called the "real" volcanic cave was formed almost simultaneously with surrounding host basaltic rock, during the volcano eruption processes, distributed in the Tan Phu - Dinh Quan districts (Dong Nai Prov.), Krong No district (Dak Nong Prov.), which will be presented below.

Figure 2. The Waterfall 50, a rocky shelter in Kon Chu Rang Nature Reserve (left & centre), and Thoat Y rocky shelter in Cat Tien National Park (right). Source: La The Phuc [8].

III.1 Volcanic caves in the Tan Phu - Dinh Quan districts, Dong Nai province

Volcanic caves in Dong Nai province have been described since the 1990s by various authors, including French Zoologist and Speleologist Louis Deharveng in his report "Explorations au centre et au sud du Vietnam (in French) [2], after a collaborative research survey between the Institute of Tropical Biology of Vietnam and the Paris Museum of Nature in 1995. The caves were described as "formed when lava flowed from many small conical volcanoes in Tan Phu and Dinh Quan districts, Dong Nai province. This process created the typical tubular cave passages near the surface, which were discovered thanks to the roofs collapsing".

In February 2013, a team of speleologists from the German Speleoclub Berlin and scientists of the Institute of Tropical Biology of Vietnam (VAST) explored 11 lava tube caves with a total of 1.8km underground passages, in the Tan Phu and Dinh Quan districts, Dong Nai province. The cave system was distributed along National Road N^{o}20 from Bien Hoa to Da Lat, which was formed "in the extensive lava stream presumably of the Quaternary age" [9]. At that time, the longest lava tube cave known from SE Asia was the "Hang Doi 1, Km 122 + Hang Dơi 2, Km 122" cave with a total length of 559m, which was published by the team [9], (Fig.3a-Fig.3.b). Besides, this research showed that the creatures in caves had quite rich expressions. Bats were a species that commonly occurred with populations of up to thousands of individuals in some caves. Many other animals belonging to the groups of spiders, centipedes, scorpions, cave crickets, flies, and mammals like mink have also been recorded. Also, many different amphibians were found living in the wet lava cave there [9; 12].

Figure 3a. "Bat Cave" in Tan Phu, Dong Nai [12]

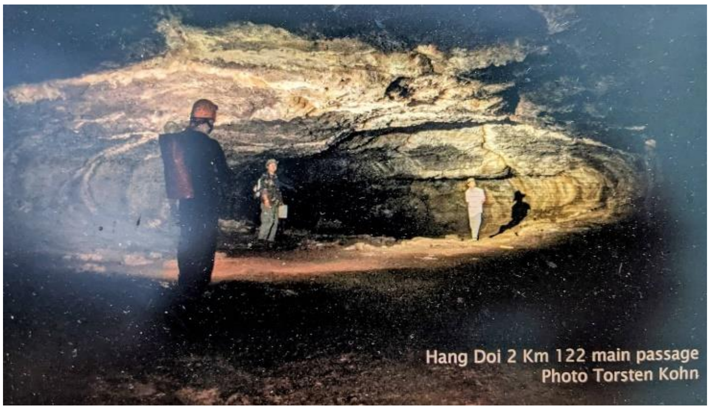

Figure 3b. "Bat Cave" in Tan Phu, Dong Nai [9].

Figure 4. Stone axe found in Doi Cave, Tan Phu in 2017 [8].

Figure 5. Scientists seeking archaeological remnants in Doi Cave in Dong Nai, in 2020 [10].

In 2016, the team of the Southern Sub-Institute under the Vietnam Institute of Geological and Mineral Resources (VIGMR) conducted additional measurements of the caves within the framework of the project "Dong Nai geological heritage investigation" [10].

On September 20, 2017, scientists of the Vietnam Museum of Nature and the Institute of Social Sciences of Central Highlands surveyed the cave in the Tan Phu area and discovered a shouldered - wholly polished axe (Figure 4) near the entrance of Bat Cave [8].

In October 2020, implementing the 2020 working plan of the Dong Nai Museum, the inter-agency team (including the Dong Nai Department of Culture, Sports and Tourism, the Dong Nai Museum, and The Vietnam National University - Ho Chi Minh City) organized to search for archaeological relics within the framework of the task "Archaeological investigation of basaltic lava cave system (bat cave) in Tan Phu and Dinh Quan districts, Dong Nai province" (Figure 5), agreed to name of caves according to the natural number sequence. The preliminary survey results showed that the remnants of prehistoric material culture have not yet been discovered [10].

So far, the Tan Phu - Dinh Quan volcanic cave system (Figure 6) has not been detailed and interdisciplinary studied on heritage (geological heritage, biodiversity, cultural heritage) as well as heritage conservation for tourism development. The level of investigation into this volcanic cave system is summarized in Table 1.

Figure 6. Distribution map of 11 volcanic caves in Tan Phu - Dinh Quan, Dong Nai province.

Table 1. List of the volcanic caves in the Tan Phu - Dinh Quan area, Dong Nai Prov. [10]

Nº	Name	Coordinates	Length (m)	Level of investigation/research	Entrance
1	Cave 1	X: 11^0 15’ 59.4”; Y: 107^0 24’ 25.9”.	142	Measured and mapped in detail; Preliminary study of biodiversity in caves; Preliminary search for archaeological remains in the cave.	Secondary
2	Cave 2	X: 11^0 15’ 02.9”; Y: 107^0 24’ 77.1”.	53		Secondary
3	Cave 3	X: 11^0 15’ 08.1”; Y: 107^0 24’ 20.4”.	437		Secondary
4	Cave 4	X: 11^0 15’ 08.1”; Y: 107^0 24’ 20.4”.	112		Secondary
5	Cave 5	X: 11^0 15’ 19.0”; Y: 107^0 24’ 27.5”.	189		Secondary
6	Cave 6	X: 11^0 15’ 19.0”, Y: 107^0 24’ 27.5”.	306		Secondary
7	Cave 7	X: 11^0 14’ 40.2”, Y: 107^0 24’ 12.2”.	226		Secondary
8	Cave 8	X: 11^0 14’ 58,8”; Y: 107^0 24’ 09.9”	271		Secondary
9	Cave 9	X: 11^0 15’ 01.9”; Y: 107^0 24’ 15.8”.	101		Secondary
10	Cave 10	X: 11°18'40.19"; Y: 107° 25' 4.35".	549		Secondary
11	Cave 11	X: 11°18'40.10"; Y: 107° 25' 4.50".	451		Secondary
Total length			***2.837***		

III.2 Volcanic caves in Krong No, Dak Nong

In 2007, within the framework of the project “Investigation and research on geological heritage to establish a geopark and protect the environment in the Trinh Nu waterfall area, Cu Jut district, Dak Nong province, Vietnam” sponsored by UNESCO, hosted by the Vietnam National Geological Museum, Dr. La The Phuc and his colleagues, with the practical help of Mr. Nguyen Thanh Tung (a local tour guide) surveyed the “bat caves” in the Dray Sap Landscape Special Use Forest. Regarding geology, the survey results have defined the so-called "bat caves" as proper volcanic caves, containing the features and geological heritage values of "real" volcanic caves. The discovery was reported and spread domestically and abroad via 2,000 bilingual leaflets of the UNESCO project mentioned above. Also, this amazing discovery was promoted by the Vietnamese media and has been widely released in many domestic and foreign scientific conferences, published in specialized journals, etc., and took the attention of domestic and foreign scientists, including the members of the NPO Vulcano-Speleological Society. From 2012-2017, with the approval of the competent authorities, NPO VSS officially cooperated with La The Phuc and his team and conducted a series of surveys, measured and mapped in detail 16 caves out of a total of 50 volcanic caves in the Krongno area [3; 5; 7; 8; 11].

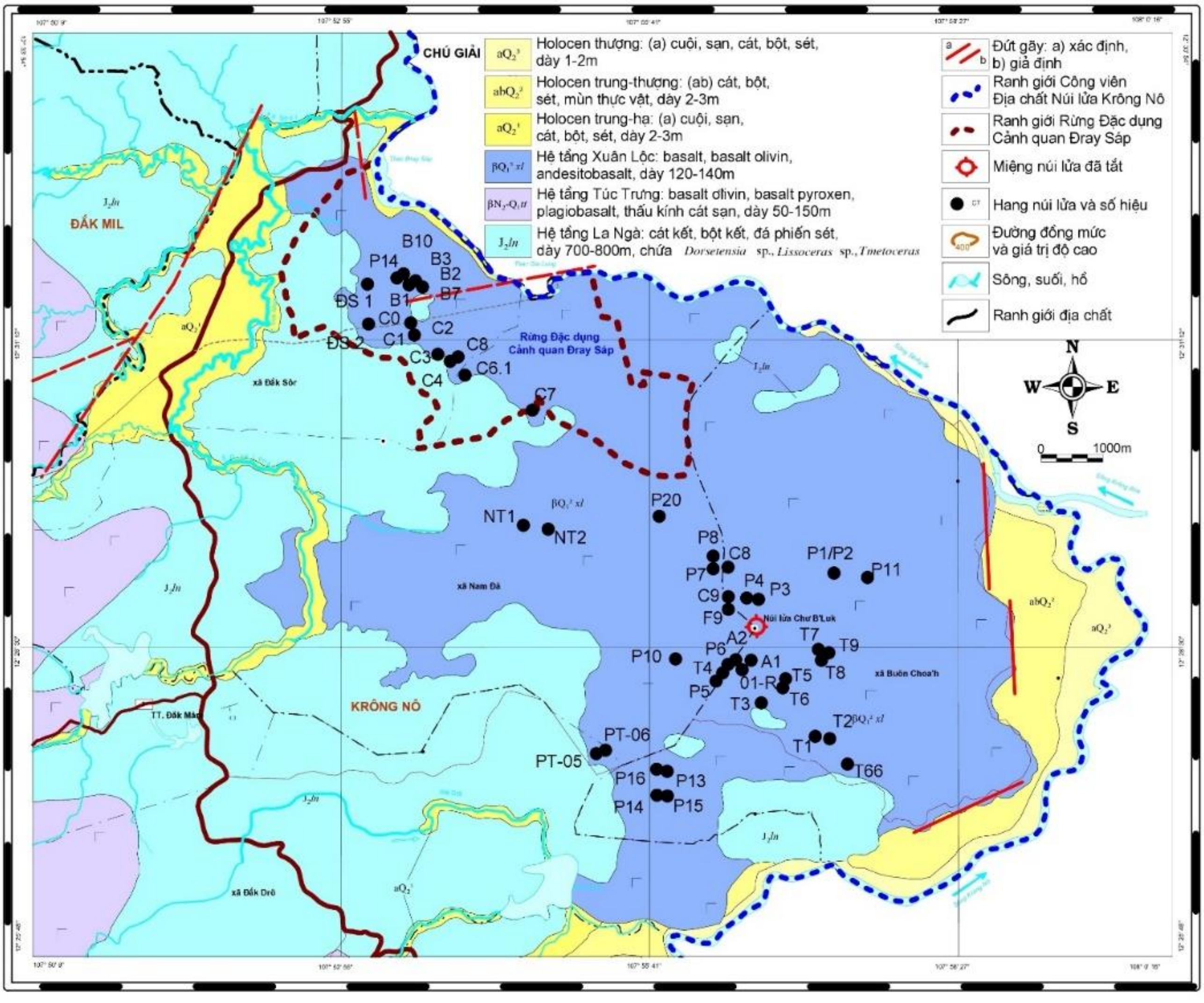

Figure 7. Distribution map of Krong No volcanic caves, Dak Nong [8]. (By La The Phuc et al.).

In 2016-2018, the geological heritages in the Krongno volcanic caves were studied in more detail within the framework of the provincial scientific and technological project "Research, investigation, and assessment of geoheritage to establish a Geopark in the Krong No area, Dak Nong province” to set up a series of volcanic cave heritage profiles [7].

In 2017, prehistoric relics in 10 Krong No volcanic caves were discovered and surveyed in detail; in which, cave C6.1 was explored within the framework of the institutional level project “Investigation and search for archaeological relics in Krong No Volcanic Geopark, Dak Nong Province” and the project of the Vietnam Academy of Science and Technology “Research, investigation, exploration (survey) archaeological volcanic caves in Krong No district, Dak Nong province” In 2016-2018, the geological heritages in the Krongno volcanic caves were studied in more detail within the framework of the provincial scientific and technological project "Research, investigation, and assessment of geoheritage to establish a geopark in the Krong No area, Dak Nong province” to set up a series of volcanic cave heritage profiles [7].

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In 2017-2020, the Krong No volcanic caves were officially implemented synchronous, intensive, and interdisciplinary research in many scientific fields within the framework of the state-level scientific and technological project “Research on the heritage values of the caves, propose to build on-site conservation museums in The Central Highlands; take an example of the volcanic cave in Krong No, Dak Nong province”, coded TN17/T06, under the Central Highlands Program, the 2016-2020 period [8]. From the end of 2017 – 2020, the Vietnamese geologists/speleologist team led by Dr. La The Phuc surveyed more in detail and mapped 5 caves. Up to now, according to statistics of the authors, a total of 50 volcanic caves have been discovered and are located in Krongno (Figure 7). E specially, 21 of them were thoroughly surveyed and mapped by the collaboration between Vietnamese and Japanese researchers. The combined length of the 21 above-measured caves is 8073.3m (Table 2).

Also in 2017-2020, the project *Study on formation characteristics and distribution of volcanic caves in The Central Highlands and Southeast region*, coded QG.17.23 was approved by the Hanoi National University, and conducted by the principal investigator Assoc. Prof. Dr. Dang Van Bao from the Department of Geography. The project results have established formation conditions and development of the volcanic caves; criteria and preliminary evidence of the volcanic cave distribution rule, and proposed conservation solutions associated with eco-tourism development in the volcanic cave region in The Central Highlands and the Southeast region.

In 2019-2021, the Department of Science and Technology of Dak Nong approved the project “Virtual reality space model and 3D technology products for the conservation of the volcanic cave system and sustainable tourism development in Dak Nong”, which was conducted by the principal investigator MSc. Nguyen Quang Huy, University of Science – Hue University. The project has applied information technology, used a flycam for some typical geological heritages, and scanned 3D caves for virtual display, promotion, and tourism development.

So, it can be seen that the investment level for the volcanic cave investigation and research in different localities is not the same and depends on the development strategy and specific goals in various stages. In detail, it can also be seen that the investment level in the Krongno area was much more than in the Tan Phu - Dinh Quan area. It is obvious that in recent years, in the Krongno system volcanic cave, many valuable new discoveries were made and recorded, in both scientific and practical aspects, opening up many new research directions in all 3 fields of geoheritage, biodiversity, and cultural heritage (Fig.8), [8]. The noble title Dak Nong UGGp obtained in 2020 is the most persuasive evidence of the success in the conservation and development of the volcanic cave thanks to appropriate investments in recent years.

Table 2. List of the volcanic caves in the Krong No area, Dak Nong province [8].

<table>
<tr><th>Nº</th><th>Name</th><th>Coordinates</th><th>Length (m)</th><th>Level of investigation/research</th><th>Entrance</th></tr>
<tr><td colspan="6">I. Caves measured and mapped in detail (21 caves with a total length of 8073.3m)</td></tr>
<tr><td>1</td><td>C0</td><td>X: 12° 31' 18.7"
Y: 107° 53' 32.9"</td><td>475.5</td><td rowspan="8">Measured and mapped. Researched geoheritage and biodiversity; Searched for archaeological remains.</td><td rowspan="8">Secondary</td></tr>
<tr><td>2</td><td>C1</td><td>X: 12° 31' 10.9"
Y: 107° 53' 34.4"</td><td rowspan="2">402.0</td></tr>
<tr><td>3</td><td>C2</td><td>X: 12° 31' 10.0"
Y: 107° 53' 35.4"</td></tr>
<tr><td>4</td><td>C3</td><td>X: 12° 31' 2.3"
Y: 107° 53' 47.2"</td><td>716.3</td></tr>
<tr><td>5</td><td>C4</td><td>X: 12° 30' 57.9"
Y: 107° 53' 52.3"</td><td>251.5</td></tr>
<tr><td>6</td><td>C6’</td><td>X: 12° 31' 0.9"
Y: 107° 53' 57.0"</td><td>180.3</td></tr>
<tr><td>7</td><td>C6.1</td><td>X: 12° 30' 51.2"
Y: 107° 53' 59.7"</td><td>293.7</td></tr>
<tr><td>8</td><td>C7</td><td>X: 12° 30' 32.5"
Y: 107° 54' 35.1"</td><td>1066.5</td></tr>
<tr><td>9</td><td>C8</td><td>X: 12° 29' 8.5"
Y: 107° 56' 19.2"</td><td>791.0</td><td rowspan="4">Measured and mapped; Researched geoheritage; Searched for archaeological remains.</td><td rowspan="4">Secondary</td></tr>
<tr><td>10</td><td>C9</td><td>X: 12° 28' 55.6"
Y: 107° 56' 20.0"</td><td>217.0</td></tr>
<tr><td>11</td><td>P1, P2</td><td>X: 12° 29' 8.6"
Y: 107° 57' 10.1"</td><td>530.5</td></tr>
<tr><td>12</td><td>P11</td><td>X: 12° 29' 5.9"
Y: 107° 57' 28.2"</td><td>498.1</td></tr>
<tr><td>13</td><td>P8</td><td>X: 12° 29' 18.1"
Y: 107° 56' 5.7"</td><td>344.1</td><td rowspan="2">Measured and mapped; Researched geoheritage.</td><td>Primary; 26m deep</td></tr>
<tr><td>14</td><td>P20</td><td>X: 12° 29' 39. 6"
Y: 107° 55' 37. 7"</td><td>568.0</td><td>Primary; 25m deep</td></tr>
<tr><td>15</td><td>A1</td><td>X: 12° 28' 19. 7"
Y: 107° 56' 28.7"</td><td>438.7</td><td>Measured and mapped; Researched geoheritage and biodiversity; Searched for archaeological remains.</td><td rowspan="7">Secondary</td></tr>
<tr><td>16</td><td>P3 (PT03)</td><td>X: 12° 28' 51.5"
Y: 107° 56' 32.8"</td><td>81.0</td><td rowspan="6">Measured and mapped; Researched geoheritage; Searched for archaeological remains.</td></tr>
<tr><td>17</td><td>P5 (PT07)</td><td>X: 12° 28' 8.8"
Y: 107° 56' 13.0"</td><td>204</td></tr>
<tr><td>18</td><td>P10E
P10W</td><td>X: 12° 28' 20.0"
Y: 107° 55' 54.2"
X: 12° 28' 20.8"
Y: 107° 55' 52.5"</td><td>160</td></tr>
<tr><td>19</td><td>PT06</td><td>X: 12°27'28.62"
Y: 107° 55' 16.7"</td><td>200</td></tr>
<tr><td>20</td><td>T1</td><td>X: 12° 27' 42.7"
Y: 107° 56' 59.8"</td><td>303.1</td></tr>
<tr><td>21</td><td>T66</td><td>X: 12°27'25.9"
Y: 107°57'1.8"</td><td>352</td></tr>
</table>

II. Caves not yet measured and studied in detail					
22	A2	X: 12° 28' 19.9" Y: 107° 56' 24.2"		Researched geoheritage, and biodiversity; Searched for archaeological remains.	Secondary
23	PT01-R	X: 12° 28' 15.4" Y: 107° 56' 23.5"		Researched geoheritage; Searched for archaeological remains.	
24	PT05	X: 12° 27' 31.5" Y: 107° 55' 7.9"			
25	T2 (PT-07-2)	X: 12° 27' 41.5" Y: 107° 57' 7.4"			
26	B1	X: 12° 31' 35.3" Y: 107° 53' 32.7"		Not studied yet	
27	B7	X: 12° 31' 40.6" Y: 107° 53' 32.8"			
28	B2	X: 12° 31' 41.6" Y: 107° 53' 32.3"			
29	B3	X: 12° 31' 41.7" Y: 107° 53' 30.3"			
30	B10	X: 12° 31' 44.9" Y: 107° 53' 28.0"			
31	B14	X: 12° 31' 42.5" Y: 107° 53' 22.6"			
32	P4	X: 12° 28' 51.5" Y: 107° 56' 26.6"		Preliminary study of geological heritage;	
33	P6	X: 12° 28' 17.5" Y: 107° 56' 27.2"			
34	P7	X: 12° 29' 16.8" Y: 107° 56' 5.8"			
35	P9	X: 12° 28' 53.1" Y: 107° 56' 21.4"			
36	P13	X: 12° 27' 21.5" Y: 107° 55' 42.9"			
37	P14	X: 12° 27' 8.9" Y: 107° 55' 42.5"			
38	P15	X: 12° 27' 8.7" Y: 107° 55' 46.0"			
39	P16	X: 12° 27' 22.7" Y: 107° 55' 42.4"			
40	T3	X: 12° 27' 52.6" Y: 107° 56' 39.5"			
41	T4	X: 12° 28' 12.9" Y: 107° 56' 17.2"			
42	T5	X: 12° 28' 13.2" Y: 107° 56' 44.2"			
43	T6	X: 12° 28' 10.4" Y: 107° 56' 46.5"			
44	T7	X: 12° 28' 30.3" Y: 107° 57' 4.1"			
45	T8	X: 12° 28' 29.3" Y:107° 57' 5.0"			

46	T9	X: 12° 28' 28.2" Y:107° 57' 5.5"			
47	NT1	X: 12^{0}29’23’’ Y: 107^{0}54’27’’		Not studied yet	
48	NT2	X: 12^{0}29’22’’ Y: 107^{0}54’37’’		Not studied yet	
49	ĐS1	X: 13^{0}31’14’’ Y: 107^{0} 53’25’’		Not studied yet	Submerged all year round
50	ĐS2	X: 13^{0}31’41’’ Y: 107^{0} 53’10’’		Not studied yet	Submerged all year round

As mentioned above, regarding geological heritage, 50 caves have been found (Figures 7 to 14) and classified according to many different purposes, of which 21 caves were measured, mapped, and initially studied in detail. Geoheritage in the caves has been studied with 8/10 geoheritage types, according to UNESCO's GILGES classification, which has established the scale, length, and uniqueness in the Southeast Asia region and China. The interior formations are abundant and diverse (Figures 9 to 26), proving the endogenous origin of these caves. On the contrary, almost cave entrances are of secondary origin, and were formed after the roof collapsed. The geo-bio-chemical environment in the cave has also been studied, which plays an essential role in heritage conservation, especially in the conservation of the thousand-year-age human skeletons [8], (Figure 8), (Table 2). However, the load-bearing threshold and the safety of volcanic caves for tourism development have not been studied, and the same situation also occurs in several in-depth study fields on volcanic caves [8]. Regarding this matter, the authors would like to mention both issues: 1. The safety of visitors entering some lava caves, for example, C1, C2, 3, and C4, etc. should be guaranteed by the result of evaluating the roof stability. That's because many lava caves in Krongno own their roofs so weak. Additionally, some years ago, loose rocks covering the roofs of the lava caves in the area were taken to build the road for visitors, despite experts' recommendations at that time. 2. The "carrying capacity" (maximum number of visitors that could be accommodated per week/month/year) of any lava cave, as usual, to prevent a lava cave from the risk of degradation of cave values.

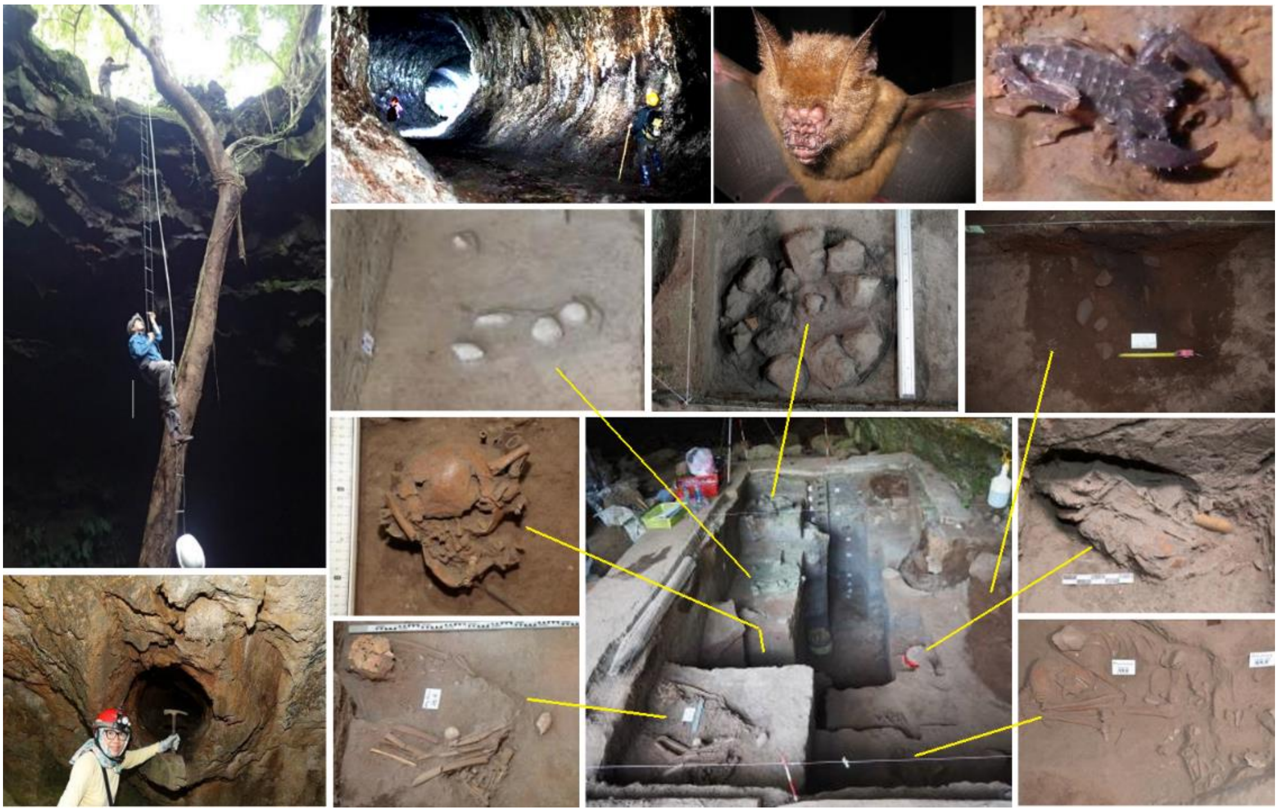


Figure 8. Typical representative of the heritage types in the Krong No volcanic caves [8].

- Regarding biodiversity, organisms have been sampled in eight caves, and have established diversity, endemism, and novelty/ new species to science (Figure 8). There are many caves, including the deep caves (P8; P20), and submerged caves that have not been studied on biodiversity. The load-bearing threshold of biodiversity for tourism development has also not been studied (Table 2) [8].

- Regarding cultural heritage, prehistoric relics have been found in 12 volcanic caves, among them, two caves have been excavated, and studied the relic types. The relic types have been studied and established in Cave C6.1, including residence site, workshop, and burial (Figure 8). Cave C6' was defined as a temporary hunting camp, and another relic may be related to religious rituals (?). So far, in-depth anthropological studies have not been conducted and relics related to religious rituals have also not been excavated yet (Table 2), [8].

Figure 9. Primary entrance of the P20 cave.

Figure 10. Secondary entrance of the C7 cave.

Figure 11. Secondary entrance the C8 cave.

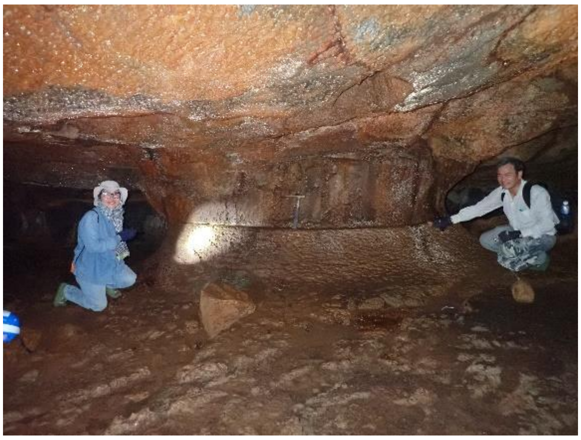


Figure 12. Trace of the last lava flow in the T66 cave.

Figure 13. A lava pit in the T66 cave.

Figure 14. Multi-generation stalactites in the C6.1 cave.

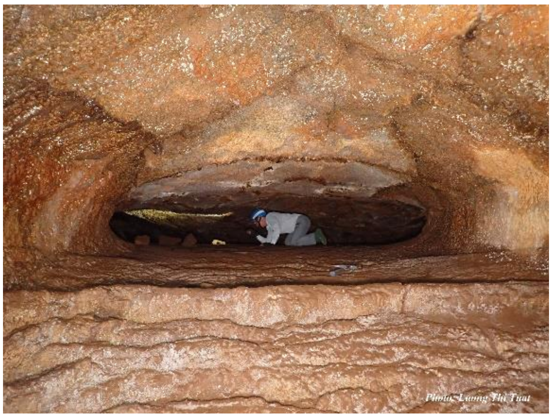
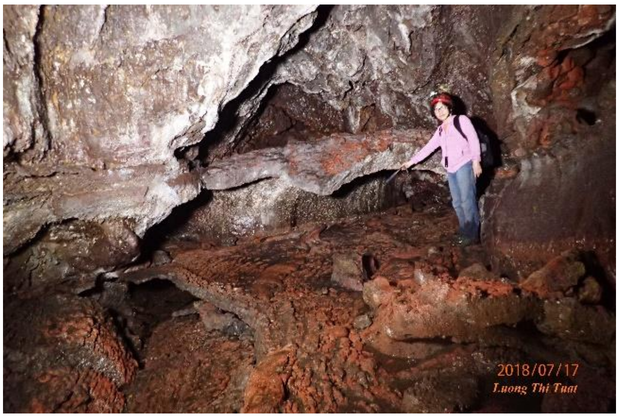


Figure 15. A tubular segment of the T66 cave.

Figure 16. A segment was narrowed by the later lava flows in the T66 cave.



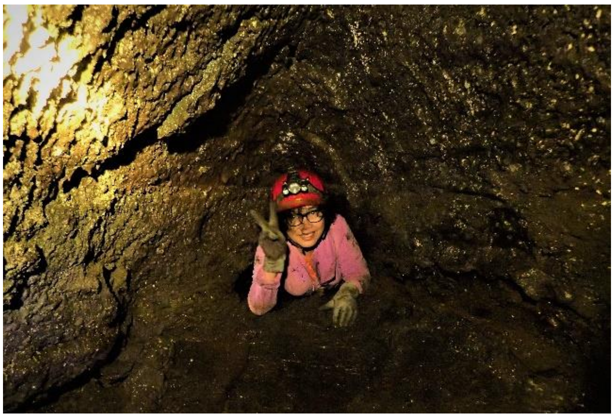


Figure 17. Tube-in-tube structure in the upper stream of the C7 cave.

Figure 18. Lava glazed wall in the narrowest tube in the upper stream of the C7 cave.

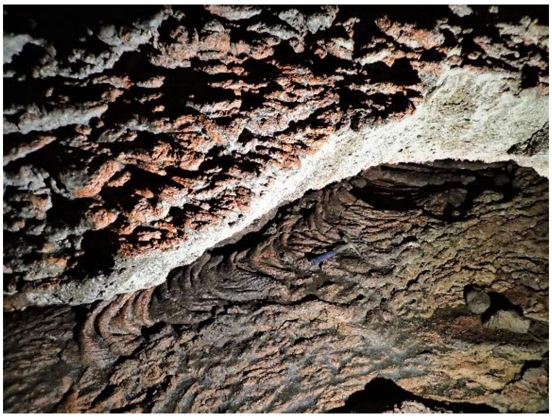


Figure 19. Scrolled lava in the T1 cave.

Figure 20. Ropy lava in the upper stream of the C7 cave.

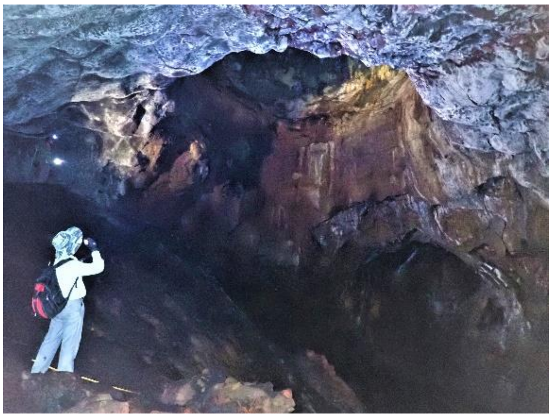


Figure 21. A huge cupola in the C8 cave.

Figure 22. A lava seal above, a lava pile below.

Figure 23. A big lava tree mould in the C3 cave.

Figure 24. A 4.9m long lava tree mould in C4 cave.

Figure 25. Neolithic relic: The 4-year-old skull revealed in the excavation pit in cave C6.1.

Figure 26. Neolithic relic: The complete skeleton of the 1.85m tall man in the C6.1 cave.

IV. Some remarks

- The first problem relates to the investment resource for research. The volcanic caves in Dong Nai and Dak Nong were discovered and published quite simultaneously. However, there is a big difference between them in terms of the level of research, conservation, and promotion for tourism development: In Dak Nong, the volcanic caves have been studied and established as having outstanding global values that became the pillar heritages of Dak Nong UGGp. Meanwhile, the volcanic caves in Dong Nai have received little attention and have not been studied in detail for conservation and development so far. That depends on the different investment levels for each of them. The practice in two localities proves that the more you pay attention to research investment, the more achievement you gain. On the other hand, it took a very long time from the point the volcanic caves were discovered to the point where they could be studied, protected, conserved, and promoted tourism development in a smooth management structure/model. The volcanic caves in Dak Nong are an excellent practical example of this. These caves were first discovered in 2007. However, it took 14 years for them to be protected and conserved in the frame of Dak Nong UGGp since July 2020. Although, up to now, in Dak Nong UGGp, the "real" volcanic cave tours have not been opened to tourists. Why? It is related to a series of socio-problems, that should be overcome in the development process in the future.

- The second problem relates to the investment resource to meet the demands for cave safety and the development of tourism infrastructure. Among them, the protection of heritages and tourists should be solved by investing in studies on cave safety issues, the capacity of each cave to handle (a certain number of) visitors without degradation, and on building tourism infrastructure (proper transportation system, the system of interpretation panels, different types of tourism services, etc.). Especially, the cave "load threshold" (in the broad meaning) should be considered the most important problem that needs to be solved for the protection of both heritages and tourists:

* Because of the weak structure of the lava caves, some cave roofs even were exposed to the air by losing the crust, so the lava caves proposed for tourism development should be evaluated for roof stability, and rockfall risk, and reinforced before opening to visitors. Also, in some places on the surface, where the roof collapsed, warning boards should be installed.

* For some sensitive and scientific caves: they should be allowed a limited number of visitors for a limited period of time in a year/month/week/day to minimize their impact on the heritage and protect the natural ecosystem of the lava cave [1].

* Detailed regulations on protecting heritage should be sent to all visitors via different media: guides, tour maps, interpretation boards, lively cartoons, etc. often reminding all people to follow these regulations.

* For the C6.1 lava cave (Prehistoric Cave): a walkway had been proposed and temporarily installed for visitors to minimize the bad impact on the valuable archaeological relics in the cave.

Besides, authorities and managers should "exploit" the knowledge of experts, and scientists, who have studied and thoroughly "understand" the lava cave system for the conservation and development work, to avoid regretful consequences in advance.

- The last problem is the adequate attention and investment from the national and local levels to research the different scientific fields in the volcanic cave region: The volcano and volcanic cave region in the Krongno area have been studied for quite a long time and significant results have been obtained, including obtaining the noble title "Dak Nong UNESCO Global Geopark" firstly thanks to an excellent scientific dossier. However, there are still existing questions, such as the age of the volcanoes within the geopark: less than ten thousand years or around 700,000 - 200.000 years as lava caves were formed? [7; 8]. What is the heritage value of the religious relics in the volcanic cave? [8]. And the same question to the paleolithic archaeological relics in the Krongno area. etc. They all should be clarified by conducting interdisciplinary and specialized scientific works. But not enough attention appears to have been paid to such issues so far. Hence, there are many research questions ahead that need to be solved by scientists.

To conclude the paper: Volcanic caves in Vietnam are a unique and mixed heritage with significant scientific and practical values. There should be comprehensive, interdisciplinary, and specialized studies to clarify their scientific values for conservation and sustainable socio-economic development in the long-term development strategy of the volcano and volcanic cave heritage regions.

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References

1. BRUSH, JOHN (2019). *Cave cleaning and maintenance*. Canberra Speleological Society Inc.
2. DEHARVENG, L., TRUONG QUANG TAM AND DUONG TIEN DUNG (1995). *Explorations au centre et au sud du Vietnam*. Spelunca 59: 8-10. In French.
3. HONDA, TSUTOMU AND TACHIHARA, HIROSHI (2015). *Vietnam Volcanic Cave Survey*, e-Newsletter, UIS, Commission of Volcanic Caves, N^{0}69, 11-12p. http://www.vulcanospeleology.org/newsletters/Vulcano69.pdf.
4. LA THE PHUC (2008). Report “Investigation and research on geological heritage for construction of geopark and environmental protection in Trinh Nu waterfall area, Cu Jut district, Dak Nong province, Vietnam”. Archives of the Geological Museum; Hanoi.
5. LA THE PHUC; TACHIHARA, HIROSHI; HONDA, TSUTOMU; TRUONG QUANG QUY; LUONG THI TUAT (2015). “The unique volcanic cave geological heritage in Dak Nong has been discovered and set a record”. Journal of Geology, Series A, No. 349, 1-2, pp.28-38; Hanoi.

6. LA THE PHUC (2017). Report “Research, investigation, exploration (survey) archaeological relics in the Krongno volcanic caves, Dak Nong province”. Archived at Vietnam Museum of Nature, Hanoi.

7. LA THE PHUC (2018). Report “Research, investigation, and assessment of geological heritage, to establish a geopark in the Krong No area, Dak Nong province”. Archived at the Vietnam Museum of Nature, Hanoi.

8. LA THE PHUC (2020). Report “Research on the value of cave heritage, propose building on-site conservation museums in the Central Highlands; take for example the volcanic cave in Krong No, Dak Nong province”, code TN17/T06. Archived at the Vietnam Museum of Nature.

9. LAUMANNS, MICHAEL (2013). Important lava tube caves found in Dong Nai province, Southern Vietnam. E-Newsletter N^{0}67. UIS. Commission on Volcanic Caves. p.13-16.

10. NGUYEN HONG AN (2020). Report “Results of archaeological investigation of basalt lava cave system (Bat cave) in Tan Phu and Dinh Quan districts, Dong Nai province. Archived at Dong Nai Museum.

11. TACHIHARA, HIROSHI & CHIKANO, YURIKO (2018). Vietnam volcanic cave 2017 survey report. NPO Vulcano Speleological Society, Japan.

12. TRUONG BA VUONG AND LAUMANNS, MICHAEL (2013). *Exploration of the lava-original caves in Dong Nai province*. Cổng TTĐT Viện Hàn lâm Khoa học và Công nghệ Việt Nam (vast.gov.vn). Accessed: 8:46, 29 Sep. 2022.

13. https://en.unesco.org/biosphere/aspac/dong-nai (last accessed: 13:05h; Sep 2022).

14. http://tapchimoitruong.vn/edition-2020-93/%C3%B0ong-nai-biosphere-reserve--wild-and-charming-25391 (last accessed: 13:15h; Sep 2022).

Possible primary cavities in Lower Permian rhyolite in the Thuringian Forest (Backofenlöcher, Bad Tabarz, Thuringia, Germany)

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Abstract

Caves in volcanic rocks can be primary or secondary. Most primary lava caves are pyroducts (colloquially called "lava tubes") occurring where recent basaltic volcanism acted. Pyroducts older than 100,000 years are already rare due to burial, erosion or being filled. Therefore, presence of primary caves in Lower Permian, 295 million years old quartz-porphyritic rhyolite seem exceptional. In the Thuringian Forest (State of Thuringia), rhyolites are exposed in the Lauchgrund- Valley, south of Bad Tarbaz. There the Backofenlöcher (Furnace-Holes) are situated, a triplet of grottoes, reaching (from S to N) 4, 23 and 13 m back from their dripline into the hill. Probably >90% of their volume is due to glacial frost- shattering combined with human enlargement. The remaining volume belongs to the central, up to 16 m long and 2 m wide, half-cylindric, low hole. The farthest-in section is of genetic interest. It was neither enlarged artificially nor by erosion. Texture of the layered rhyolite could suggest that this is a "flow-induced" primary cavity. It is, however, not a pyroduct.

Keywords: flow-induced cavities, primary caves, porphyritic rhyolite.

Introduction

Caves in volcanic rocks can be primary or secondary (KEMPE, 2008, 2019). Most primary caves are pyroducts (colloquially known as "lava tubes") but many other cave types exist, such as eruption vents, drained dikes, hornitos, hollow tumuli, gas blisters, pressure ridge caves, and cast of trees or even animals, to name a few (KEMPE, 2019). Often any lava cavity is called a "tube", even if it lacks any signs of lateral lava flow. Most pyroducts occur where recent basaltic volcanism acted (LOCKWOOD et al., 2022). Pyroducts of a few 100,000 years old are already rare. Therefore, presence of primary caves, such as the Backofenlöcher, in Lower Permian, 295 million years old quartz-porphyritic rhyolites (LÜTZNER et al., 2012) would seem exceptional and their classification as pyroducts would be even more surprising.

The Backofenlöcher

The Thuringian Forest is a NW-SE (i.e., "hercynian") striking mountain range in the south of the State of Thuringia, Germany. It has been uplifted since the Upper Cretaceous and exposes folded crustal rocks of variscan age and Permian vulcanites to erosion. In the Lauchgrund-Valley, south of Bad Tarbaz, the Harderholz-Porphyry of the Ilmenau Formation forms steep hillsides. There the Backofenlöcher (Furnace-Holes) are situated, a triplet of grottoes (Figure 1), reaching (from S to N) 4, 23 and 13 m back from their dripline into the hill (Figure 2). Probably >90% of the cave's volume is due to glacial frost- shattering combined with human enlargement, thus gaining space for temporary storage and habitation. This artificial enlargement is attested by an external planum at the level of the flat floor inside of the cavities (Figure 1).

Figure 1: Panorama view from the East of the four cavities described here. Numbers 1 to 3 are the Backofenlöcher proper. Number 4 to the right is an additional cavity not artificially enlarged. In red shirt: first author for scale (Photo: S. Kempe).

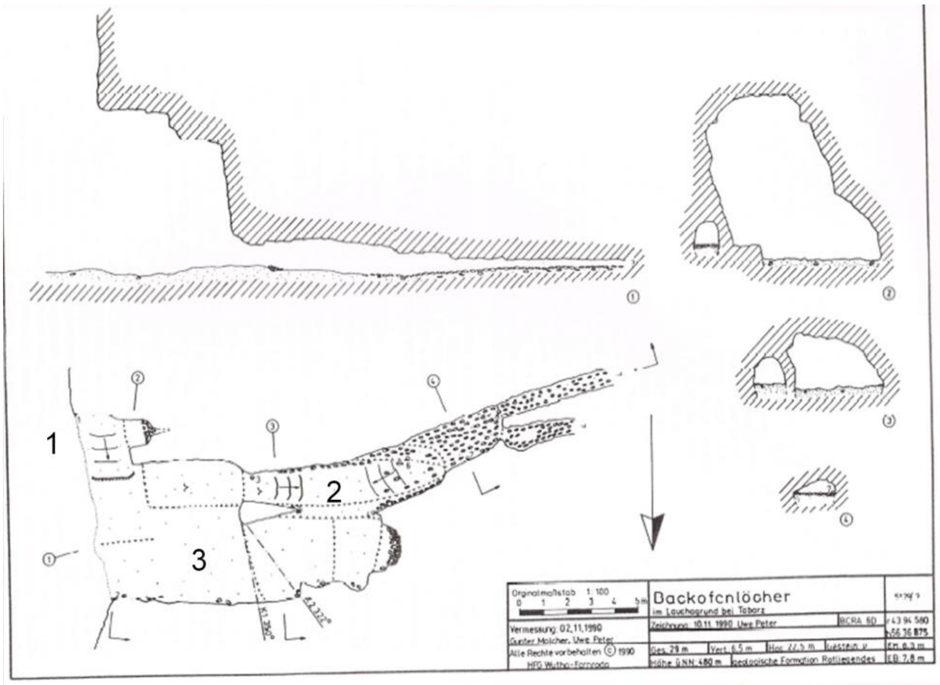

Figure 2: Map of Backofenlöcher (note that N is down).

The remaining volume belongs to the central, up to 16 m long and 2 m wide, half-cylindric, low hole. The first 7 to 8 m is a crawlspace that reconnects to the western grotto after a pillar (Figure 3).

It probably was also artificially enlarged by removing rubble. In Jordan such crawlspaces are used even today to keep mother sheep walled-in, protecting them from predators, while the herder is attending the main herd.

Figure 3: View out of the central cavity (cavity 2) towards the east. Note the low ceiling (sitting person) and the pillar and window toward the left (cavity 3). Also note the lineation along ceiling (Photo: S. Kempe).

This crawlspace is followed by a section with many fist-sized stones, possibly cast into the passage by visitors to test its length. Beyond, the cavity becomes too low for progress, it is the section of genetic interest. It was neither artificially enlarged nor created by erosion (Figure 4).

Figure 4: View into the very low back of cavity 2 beyond the crawl space (Photo: S. Kempe).

Possible Nature of Cavity

Rather, the rock texture offers clues: the rhyolite (Figure 5) is parallelly striated on shear-interfaces that separate the rock into layers a few cm thick (Figure 6). At the same time the rock is structured by fissures that curve from horizontal to vertical (Figure 7). The vertical sections give rise to the wall between grotto 2 and 3. It therefore is conceivable that the striated surfaces are due to early flow patterns while the curved fissures are due to vertical movement of material slipping down the flow-flank, creating horizontal, longitudinal cavities, opened by separation of the shear-interfaces in direction parallel of the striation.

Another example of such a cavity, a few meters long and 0.5 m wide, is found N of the Backofenlöcher (4 on Figure 1). It certainly lacks secondary, artificial widening and shows a similar structure with fissures curving from horizontal to vertical.

Such primary cavities could be called **"flow-induced".**

Outlook

In accepting the hypothesis, that the Backofenlöcher (before they were enlarged by frost shattering or artificially) were primary, caused by the separation of internal shear-interfaces by lateral pressure during the final movements of the lava flow, it is necessary to discuss how these cavities survived secondarily being filled.

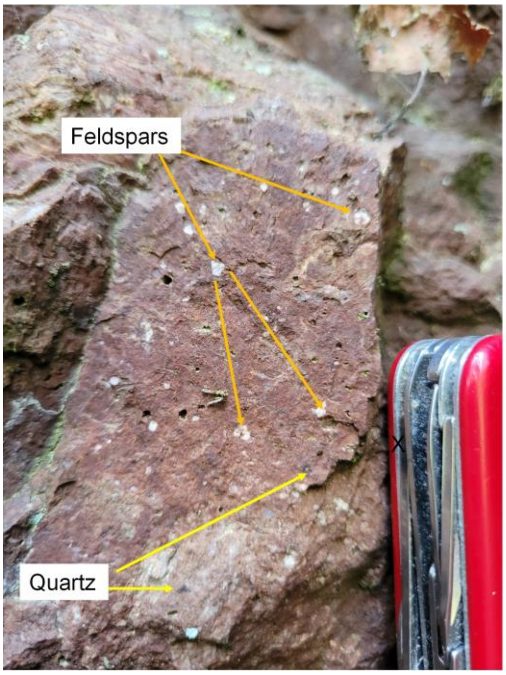

Figure 5: The rhyolite of the Backofenlöcher is characterized by quartz and feldspar phenocrysts in a reddish matrix (Photo: S. Kempe).

Figure 6: Striation on shear interfaces separating cm-thick layers of the rhyolite (Photos: S. Kempe).

Figure 7: Some of the fissures curve into vertical, giving the rock a larger sized-structure of weakness (Photo: S. Kempe).

The first such filling could have happened when the valley in front of the cavity was created. River gravel or sand could have entered it. There seems to be no evidence of this. The explanation could be, that the primary small cavities were not open during the downcutting millions of years ago in Tertiary times, but much later by frost-shattering during Pleistocene.

The second possibility to fill the cavities was during the ice ages. Loess could have entered the caves either by direct deposition of dry dust or by mud flows during summer thaw. In the central cavity there is in fact a layer of grey loam, a few cm thick (Figure 8). Its nature remains unknown since no mineralogical or grain-size analysis has yet been performed.

Figure 8: Loam at the bottom of cavity 2 (Photo: S. Kempe).

Bibliography

KEMPE S. (2008) Immanuel Kant's remark on lava cave formation in 1803 and his possible sources. – Proc. 13th Intern. Sympos. on Vulcanospeleology, Jeju Island, Kor. 1.-5. Sept. 2008: 35-37.

KEMPE S. (2019) Volcanic rock caves (revised). – In: White W., Culver D.C. & Pipan T. (eds.), Encyclopedia of Caves, 3rd ed., London, Academic Press /Elsevier, Chapter 131: 1118-1127.

LOCKWOOD J.P., HAZLETT R.W. & CRUZ-REYNA S. de la (2022) Volcanoes, Global Perspectives. – Hoboken & Chichester, Wiley & Sons.

LÜTZNER H., ANDRAS D., SCHNEIDER J.W., VOIGT S. & WERNEBURG W. (2012) Stefan und Rotliegend im Thüringer Wald und seiner Umgebung. – In: Deutsche Stratigraphische Kommission (edited by: Lützner H. & Kowalczyk G. for the Subcommission Permian-Triassic): Stratigraphie von Deutschland X. Rotliegend. Teil I: Innervariscische Becken. – Hannover, Schriftenreihe der Deutschen Gesell. für Geowissenschaften, Heft 61: 418-487.

The sequence of 2013-2021 eruption at Nishinoshima (Japan): New island made of lava flow accumulation and a single large scoria cone

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Abstract

The continuous emission of andesite lava created the new volcano about 2 km across consisting of thick lava plateau and a large central volcanic cone of ~300 m high and ~800 m across at a volcanic island, Nishinoshima, about ~900 km south of Tokyo. The lava tube system was the essential mechanism for the formation of the lava plateau, resulting in the extensive accumulation of multiple lava flows. When the magma discharge rate was relatively high, lava fountaining, rapid volcanic-cone grown and lava flooding were observed, whereas it was low, lava was sent to the coast effectively by utilizing the lava tube system. Magma's interaction with sea water was limited in the beginning of eruption when it started in the shallow sea and also in the late half of the explosive stage when tall volcanic ash emission continued from the deep and hollowed crater.

Keywords: Lava tube system, volcanic island, submarine eruption, repeated lava effusion, phreatomagmatic eruption

1. Background of volcanic eruption

The manner of volcanic eruption of andesite magma is controlled by the magma discharge rate and the eruption site environment. High discharge rate (>>100 m^3/s) tends the explosive eruptions such as Plinian eruptions while low rate (<<100 m^3/s) does effusion of lava flows (e.g., summary by KOZONO et al., 2013). The eruption when started under the shallow sea generates explosive interaction of magma with sea water. Mid-January 2022 extremely violent eruption at Hunga-Tong and Huna-Ha'apai in Tonga is the example of the eruption with very high discharge rate in the sea as shallow as around 200 m depth. Its eruption column reached ~50km a.s.l., being accompanied by strong atmospheric pressure waves. The August 2021 eruption at Fukutoku-Oka-no-Ba with the discharge rate high but lower than HTHH generated eruption column as high as 17 km a.s.l. A low discharge rate of eruption started in 2013 at the Nishinoshima island presented here. The lava tube system that is one of the essential mechanisms to create lava caves was observed in the eruption.

2. Eruption process of Nishinoshima

Nishinoshima is a small andesite volcanic island, which represents the flat top of a large volcanic body developing from the base around -2000 m a.s.l. (Figure 1). This volcano erupted in November 2013 after the hiatus of about 40 years. The eruption started with explosive phreatomagmatic events with cock's tail jets in the shallow sea close to the Nishinoshima Island (old island), and soon the vent appeared above the sea due to landfilling in the shallow sea by erupted materials (MANENO et al., 2016). Since then, Strombolian explosions with the formation of scoria cones and emission of lava flows continued. Lava flows from scoria cones advanced in the all directions and advanced into shallow sea with generating strong steaming of sea water. As a result, the area of the new island expanded gradually, and, a month later, it connected to the old island, and, furthermore, the latter was covered all by new lavas in the end of 2020 (MAENO et al., 2021; KANEKO et al., 2022). The new island is nearly circular in form, as of the end of 2021 with the diameter of ~2.2 km and the central cone of ~250 m high and ~900 m across, distributed slightly to the south of the middle.

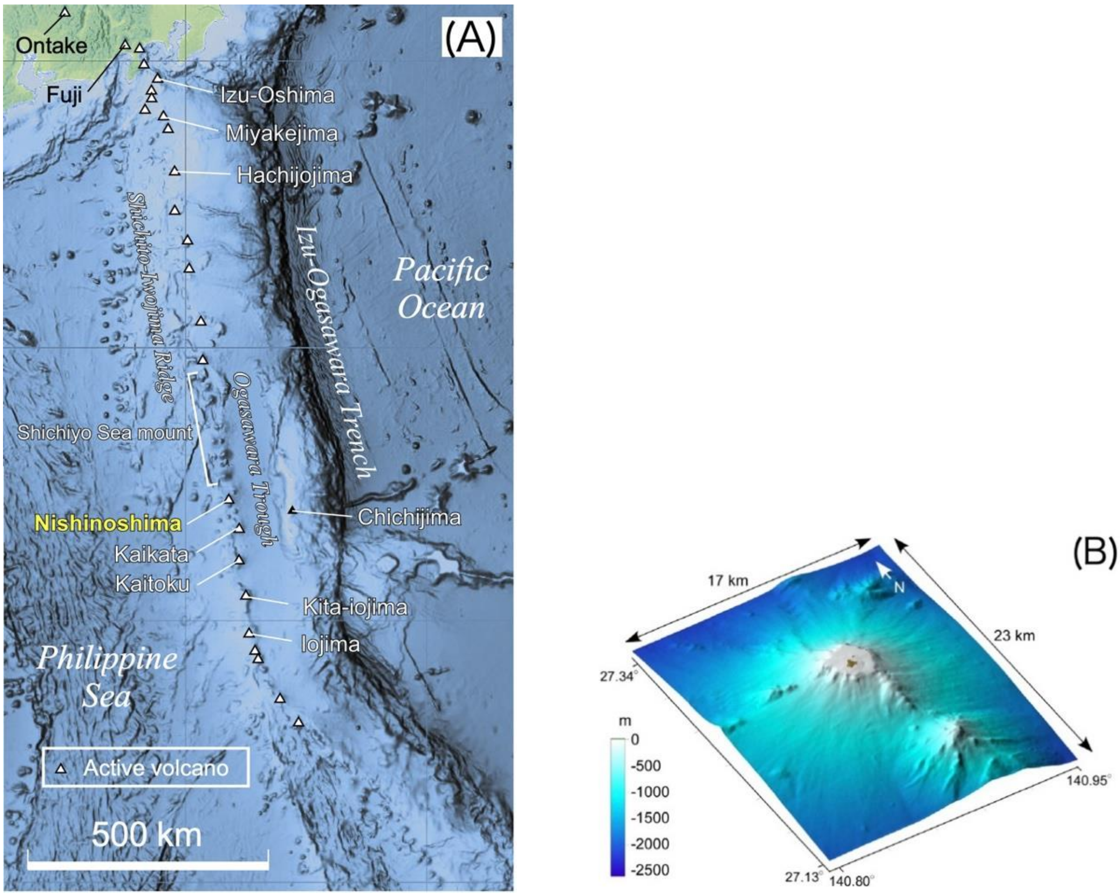

Figure 1: (A) location of Nishinoshima and volcanoes in the Izu-Ogasawara volcanic chain. (B) 3D image of Nishinoshima volcano with its appearance in the sea. (Quoted from Maeno et al., 2021)

3. Lava tube system

Lava flows developed mainly from the base or rarely from the top of growing scoria cone except in the beginning stage. The lava flow mode that is the key of the areal expansion was the maintaining of lava tube system when the magma discharge rate is around 2~7 m^3/s. In the night, it was clearly observed that incandescent lava emitted from the several points on the middle slope of lava flow field, travelled to the coast making the different channels, and entered into the sea (Figures 2a-c). New lava flowed over former lava flows, choosing the spaces between former lava flow's banks and thickening the lava plateau. The thickness of the lava lobes at the coast is around 5 to 10 m. In the case that lava within tubes flowed down, it is expected that hollow lava tubes would appear. However, we have not discovered yet such the hollow tubes either the air survey or from the landing research. On the other hand, when the magma discharge rate was high, lava appeared directly from the base of the scoria cone and flooded toward the periphery of the island covering wider areas.

4. Explosive stage

The eruption of Nishinoshima repeated at least four times with individual durations up to over 2 years. The last, most explosive stage started in the end of 2019 and climaxed around end of June and July 2020. The estimated magma discharge rate is ~30 m^3/s (KANEKO et al., 2022). At the last stage, lava fountain explosions (Hawaiian) with a rapid growth of central cone were observed and its partial collapse of the lowest, southern rim took place (Figure 3). The collapsed part was conveyed as the rafts on the lava flow issued as lava fountain. Following this, it was the first time that continuous volcanic ash was emitted continuously, whose column reached ~4 km a.s.l. in July 2020 (Figure 4). The manner was much different from the Strombolian explosions associating lava flowing before the June-July 2020. It is considered that phreatomagmatic events generated by the interaction of drain-back magma with the seawater which invaded into the deepened crater that was left behind the explosive eruption. The magma had changed its chemistry from andesite to basaltic andesite at the peak of the explosive stage (MAENO et al., 2021).

Figure 2a. Strombolian eruption at the summit and incandescent lava flows entering into the sea on the night of 15 March 2016. Development of lava tube system is evident.

Figure 2b. Close-up view of incandescent lava flows exiting from the lava tubes.

Figure 2c. Day time view of lava channels entering the sea and the central cone (left back) on the same day. Taken by SN from the Asahi Shimbun air jet.

Figure 3: Lava fountain on 29 June 2020 in courtesy of the Japan Marine Guard.

Figure 4: Continuous volcanic ash emission on 30 July 2020, taken by SN from the Asahi Shimbun air jet.

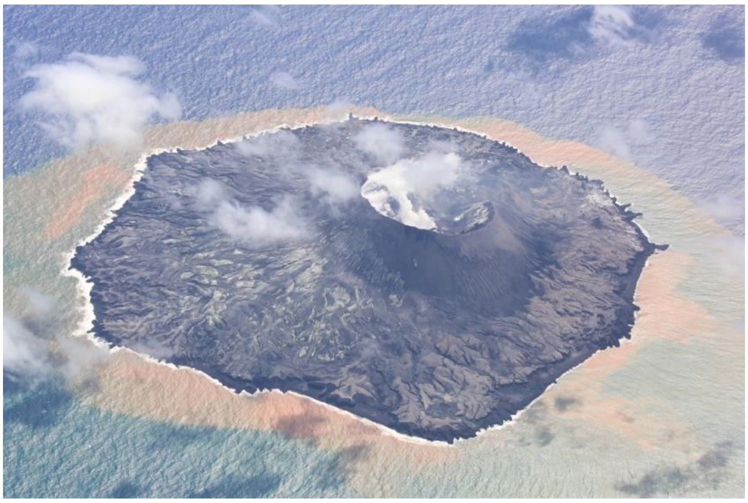

Figure 5: Aerial view of Nishinoshima on 15 October 2021, taken by SN from the Asahi Shimbun air jet. Discoloration of sea around the coastal lines shows continuously high activity.

5. Discussion and conclusion

At Nishinoshima, the eruptive activity that started in the shallow sea in November 2013 had grown into a new large volcanic island, connecting to and, then, involving the former Nishinoshima island.

The eruption was characterized mainly by frequent Strombolian explosion events and continuous lava emission during the several active stages. The activity resulted in the formation of single large central cone of scoria on the thick lava plateau consisting of accumulation of multiple lava flow channels and lava floods emitted from the central cone. From the above observation in Nishinoshima, it is evident that the magma discharge rate controlled the manner of eruption; the intermittent Strombolian events with lava flow channelling (roughly <5 m^3/s, the continuous Strombolian event with lava flooding (around >>5 m^3/s), and lava fountaining event (~30 m^3/s) in the increasing order of magma discharge rate. Phreatomagmatic explosions came from the magma's interaction with water when the eruption started in the shallow sea, and also, probably, when the deepened crater allowed the seawater invasion. The analogy of this system of andesite magma to basaltic system may be possible, though the parameters controlling the mode of eruption are different between andesite and basalt lavas. The lava tube system, where the solidified lava acts as insulator for the interior molten lava that can advance farther without cooling to the coast, may develop into the lava caves when the interior lava squeezes out. Although not only the case, this may be one of possible mechanisms for lava caves. The observations at Nishinoshima gave us a good example of the growth and formation process of a single large scoria cone over the lava plateau and its partial collapse. This may be a good reference for the formation processes of scoria cones in many volcanic areas such as Ly Son islands and Dak Nong UNESCO Global Geopark, Viet Nam.

Even when writing this, the volcano is still active, represented by occasional steaming from the central cone and strong discoloration of the sea around the coast line (Fig. 5). Once seismological monitoring was tried after the on-land observation in October 2016, though the observation site was covered by flowing lava. Onsite camera was settled on the island in recent years by drones, in order to observe the eruption activity and the biological rehabilitation after the formation of new land. Sampling of lavas and capturing images by drones were conducted several times when the research vessels approached this island. Observation from the air has been taken monthly by the Japan Coast Guard, and less frequently by the news media airplanes. Careful observation/monitoring has continued with the several technologies covering InSAR analysis with Satellites (EROS, Sentinel, etc.), Satellite images (Himawari, Shikisai, WorldView, Landsat, etc.), infrasonic and seismic observation in the Ogasawara island closest to Nishinoshima, and new methods developed such as wave-gliders and pressure-gauges installed Ocean-Bottom seismometers.

Acknowledgements

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References

KANEKO, T., MAENO, F., ICHIHARA, M. YASUDA, A., OHMINATO, T., NOGAMI, K., NAKADA, S., HONDA, Y., AND MURAKAMI, H. (2022) Episode 4 (2019-2020) Nishinoshima activity: abrupt transitions in the eruption style observed by image datasets from multiple satellites. Earth, Planet and Space, **74,** 34, doi:10.1186/s40623-022-01578-6

KOZONO, T., UEDA, H., OZAWA, T., KOYAGUCHI, T., FUJITA, E., TOMIYA, A., SUZUKI, Y.J. (2013) Magma discharge variations during the 2011 eruptions of Shinmoe-dake volcano, Japan, revealed by geodetic and satellite observations. Bull. Volcano., **75**: 695. doi: 10.1007/s00445-013-0695-4

MAENO, F., NAKADA, S., KANEKO, T. (2016) Morphological evolution of a new volcanic islet sustained by compound lava flows. Geology, **44**, 259–262. doi:10.1130/G37461.1

MAENO, F., YASUDA, A., HOKANISHI, N., KANEKO, T., TAMURA, Y., YOSHIMOTO, M., NAKANO, S., TAKAGI, A. TAKEO, M., NAKADA, S. (2021) Intermittent growth of a volcanic island and its feeding system revealed by geological and geochemical monitoring 2013–2020, Nishinoshima, Ogasawara. Front. Earth Science, **24**, doi:10.3389/feart.2021.773819.

Volcanic Activities of Biyangdo Islet on Jeju Island and its Utilization as a Geopark

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Abstract

The volcanic body of Biyangdo consists of spatter deposit, scoria deposit and lava flows from bottom to top. The lowest spatter deposit is exposed on the northern and western coasts of the islet and contains agglutinated spatters and large volcanic bombs. Biyangbong, the central part of the islet, is a scoria cone consisting of clast-supported scoria deposits. Its coastal areas are composed of the lava flows except the west, most of which possess the characteristics of pahoehoe lava flows. 40Ar-39Ar age dating suggests that the lava flows of Biyangdo formed around 26,000 years ago. The volcano was formed by strombolian eruption on land when the sea level was approximately 90 ~ 110 meters lower than it is at present. For a short period, spatters and large volcanic bombs were emitted to form a spatter cone. Its crater, then, shifted, followed by subsequent volcanic activities at Biyangbong to form Biyang Scoria Cone. During this process, the pahoehoe lava flowed through its base and formed scoria rafts and collapsed trench structures. Some lava flows formed chimney-shaped hornitos resulting from bubble burst phenomenon caused by the fuel-coolant interactions while flowing on the wetland. Volcanic activities came to an end with effusion of a small volume of aa lavas flowing southward after the pahoehoe lava flows. As the sea level rises, major portion of the spatter cone was removed by wave erosion, leaving behind several sea stacks including Elephant Rock, and Biyangbong, relatively less eroded, have remained in its original shape. Biyangdo is a textbook example to take a look at various products of terrestrial volcanic activity of monogenic volcanoes, which are hard to observe in Jeju Island. The island was thus included in the Jeju Geopark in 2014.

Keywords: Jeju, Scoria Cone, Lava flow

Images

A huge volcanic bomb; the tail direction of which is well-preserved.

A large Hornito

Estimation of lava flow temperature at lava tube cave formation (BC10,000- AD1,000) of Mt. Fuji

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Abstract

There are many lava tube caves formed in the past on Mt. Fuji (BC10000- AD1000) . We attempted to identify the lava flow temperature during lava tube formation of Mt. Fuji by using the yield strength obtained from the lava tube cave slope angle and height. The temperature dependent data of yield strength and viscosity measured in the laboratory for melted lava of Mt. Fuji 1707 eruption basalt are used. The obtained yield strength of the lava ranges from $1.0x10^4$ to $1.84x10^5$ dyne/cm^2 which leads to the range of 1016 ° C to 1070 ° C as lava tube cave formation temperature. Further. the viscosity coefficient of the lava flow was also estimated from these temperatures as in the range of $2.1x10^4$ to $1.6x10^5$ poise.

Keywords: lava tube cave, lava yield strength, lava temperature, Mt. Fuji

Introduction

There are many lava tube caves (Figure 1) formed in the past (BC10000-AD1000) [1,2] on the flank of Mt. Fuji (Figures 2 & 3). We attempted to identify the lava flow temperature during lava tube formation by using the yield strength obtained from the lava tube cave slope angle and height of Mt. Fuji. Further, the viscosity coefficient of the lava flow was also estimated from that temperature.

Figure 1 Mitsuike Ana lava tube cave (Inusuzumi lava flow, BC6000)

Figure 2 Mt. Fuji (A relief map image of the flank of Mt. Fuji is shown in Figure 3, over).

Figure 3 Mt. Fuji and the lava flow field (The red relief map image of Mt. Fuji is courtesy of Asia Air Survey Co. Ltd.), and photos of Mt. Fuji summit crater

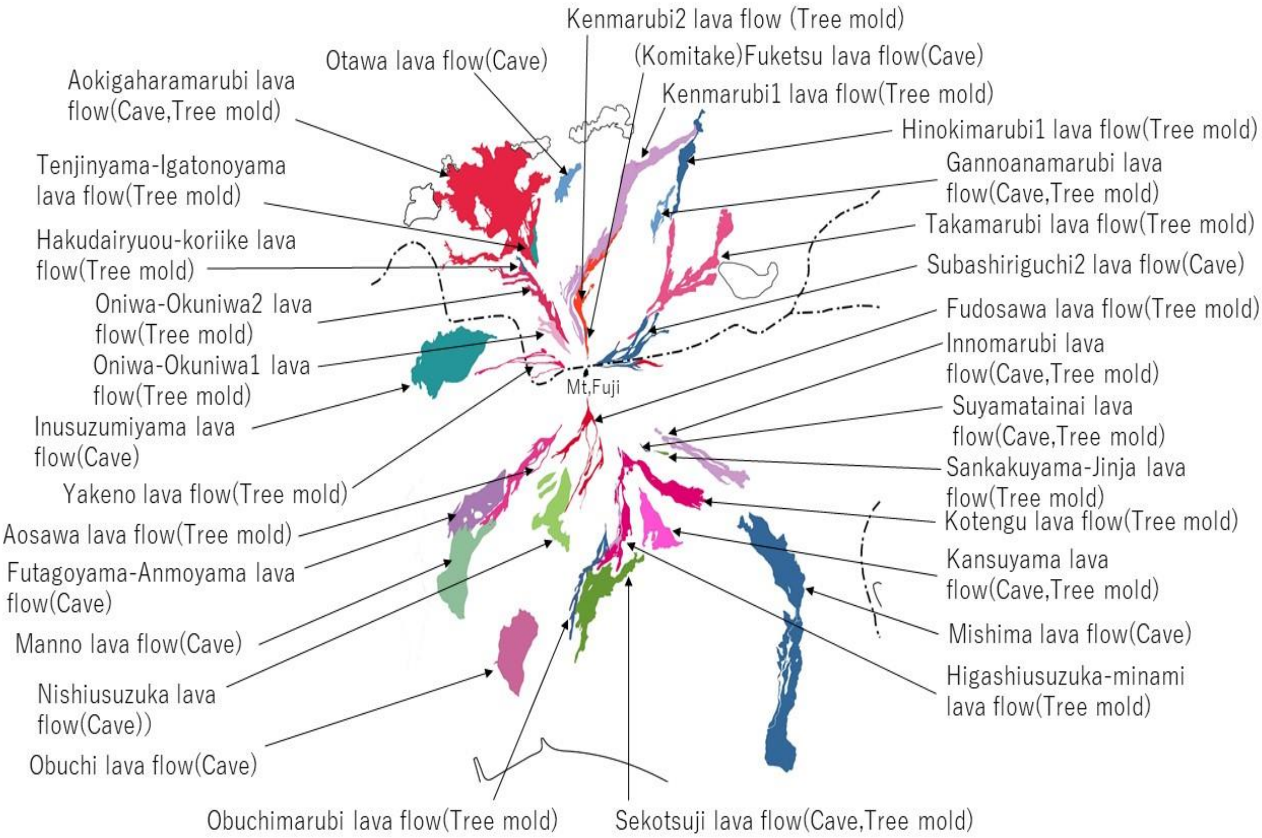

Figure 4. Distribution of lava flows with lava tube caves and tree mould on Mt. Fuji.

Distribution of lava flows/ lava tube caves on Mt. Fuji

Lava flow distribution erupted from BC10000- AD1000 is shown in Figure 4 for lava flow with lava tube caves and tree moulds. Table 1 shows a list of lava tube cave and corresponding lava flow names on Mt. Fuji and their eruption ages [3].

Name of lava tube cave (Lava flow name), Eruption age is referred from [3]	Slope angle: α	Cave height: H	Yield strength obtained form (eq-1): f_B	Temperature obtained from (eq-2)	Viscosity obtained from (eq-3): η_B
Subashiri Tainai, Upper part (Subashiri 2 lava flow), AD1000-1030	20°	1m	$2.79x10^4$dyne/cm^2	1052℃	$4.13x10^4$poise
Subashiri Tainai, Lower part (Subashiri 2 lava flow), AD1000-1030	15°	2m	$4.23x10^4$dyne/cm^2	1044℃	$5.58x10^4$poise
Jinza FuketsuNo.1 (Aokigaharamarubi lava flow), AD864-866	13°	5m ~10m	$9.19x10^4$~ $1.84x10^5$dyne/cm^2	1016℃~1029℃	$9.8x10^4$~ $1.60x10^5$poise
Jinza FuketsuNo.3 (Aokigaharamarubi lava flow), AD864-866	11.5°	5m	$8.14x10^4$dyne/cm^2	1032℃	8.76 $x10^4$poise
Shoiko Fuketsu1A (Aokigaharamarubi lava flow), AD864-866	10°	3.3	$4.68x10^4$dyne/cm^2	1042℃	6.02 $x10^4$poise
Shoiko Fuketsu1B(Aokigaharamarubi lava flow),AD864-866	7.6°	2m	$2.16x10^4$dyne/cm^2	1057℃	4.29 $x10^4$poise
Karumizu Fuketsu (Aokigaharamarubi lava flow), AD864-866	5.5°	4m	$3.13x10^4$dyne/cm^2	1049℃	5.38 $x10^4$poise
Fuji FuketsuNo.1 (Aokigaharamarubi lava flow), AD864-866	8.1°	10m	$1.15x10^5$dyne/cm^2	1020℃	$1.139x10^5$poise
Motosu Fuketsu (Aokigaharamarubi lava flow), AD864-866	3.6°	10m	$3.85x10^4$dyne/cm^2	1046℃	6.02 $x10^4$poise
Inusuzumiyama Fuketsu No.1 (Inusuzumiyama lava flow), BC6000	12°	5m	$8.49x10^4$dyne/cm^2	1031℃	9.09 $x10^4$poise
Mujina Ana (Inusuzumiyama lava flow), BC6000	8.5°	5m	$6.04x10^4$dyne/cm^2	1036℃	7.54 $x10^4$poise
Inusuzumiyama Fuketsu No.2 (Inusuzumiyama lava flow), BC6000	13°	2m	$3.67x10^4$dyne/cm^2	1047℃	4.99 $x10^4$poise
Mitsuike Ana (Inusuzumi lava flow), BC6000	3.2°	10m	$3.42x10^4$dyne/cm^2	1049℃	4.63 $x10^4$poise
Atsuhara Fuketsu (Obuchi lava flow), before BC8300	10°	2m	$2.84x10^4$dyne/cm^2	1051℃	4.29 $x10^4$poise
Banba Ana (Futagoyama-Anmoyama lava flow), BC3500	4.8°	5m ~10m	$3.42x10^4$~ $6.83x10^4$dyne/cm^2	1034℃~1048℃	4.8 $x10^4$ ~8.12 $x10^4$poise
Suyama Tainai (Suyamatainai lava flow), AD1030-1120	10°	1m~2m	$1.0x10^4$~$2.0x10^4$dyne/cm^2	1058~1070 ℃	$2.10x10^4$~$3.30x10^4$ poise
Manno Fuketsu (Manno lava flow), before BC10000	2.5°	~5m	$1.32x10^4$ dyne/cm^2	1066℃	$2.44x10^4$poise

Table 1. Lava tube caves of Mt. Fuji and physical properties of lava flows (slope angle & cave height is referred from [1])

Modelling of lava flow in the tube

Table 1 shows also their cavity heights and inclination angles. Figure 5 shows an example of a lava tube cave survey map. The inclination angle was calculated from the cave length and the height difference. Figure 6 shows the tube inside of Banba Ana lava tube cave. Figure 7 shows Banba Ana vertical pit, the inlet of lava tube cave.

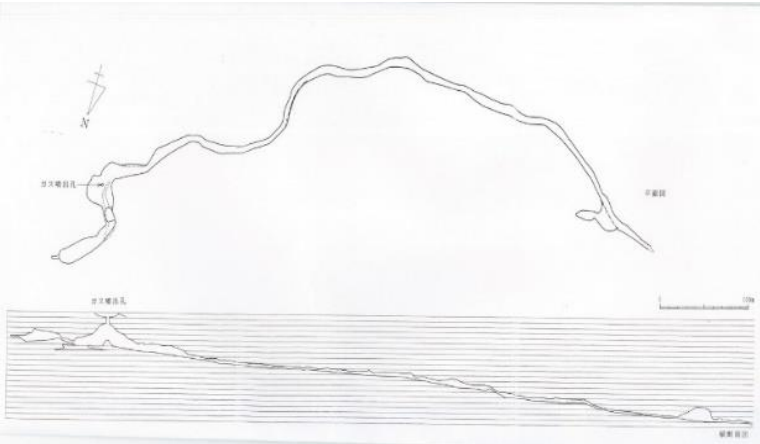

Figure 5. Map of Banba Ana (Futagoyama-Anmoyama lava flow, BC3500)[1]

Figure 6. Banba Ana lava tube cave (Futagoyama-Anmoyama lava flow, BC3500)

Figure 7 Banba Ana vertical pit (Futagoyama-Anmoyama lava flow, BC3500)

Figure 8 shows a gravitational flow model from the eruption point.

The lava flow (Bingham flow) speed distribution model in the inclined tube is shown as Figure 9.

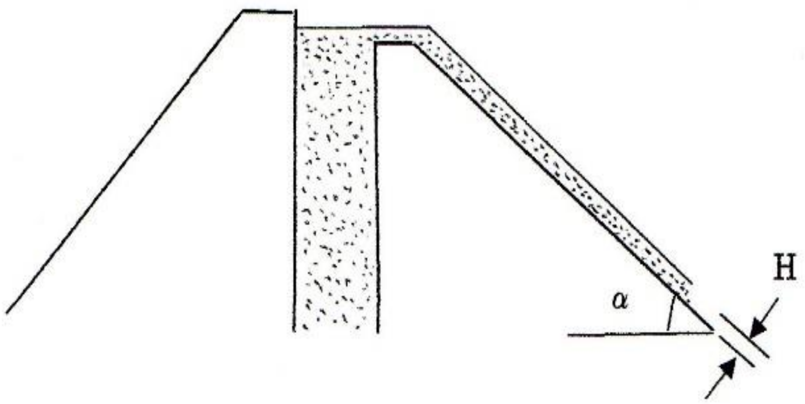

Figure 8. Gravitational flow model from the eruption point.

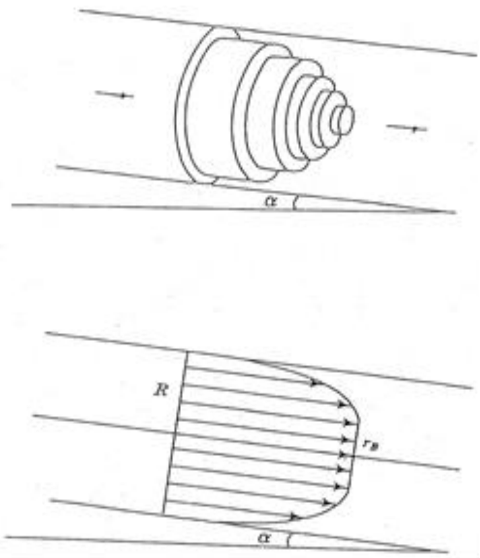

Figure 9. Bingham flow speed distribution model in the inclined tube

According to Figure 9, For laminar flow model in circular tube on the slope, the equation of the distribution of flow speed u of Bingham fluid are shown as follows:

For $\tau w = (\rho g \sin\alpha)R/2 > fB$,

$u=(R-r)^2 (\rho g \sin\alpha)/4\eta B$ $\quad r<rB$

$u=[R^2-r^2-2r (R-r)](\rho g \sin\alpha)/4\eta B$ $\quad r>rB$

For $\tau w = (\rho g \sin\alpha)R/2 < fB$,

$u= 0$

Here, α is angle of slope or inclination of tube, ρ: density of the fluid, g: gravity acceleration, R: radius of the tube, rB: radius of the flowing position where Bingham yield stress takes fB, ηB is Bingham viscosity. $H=2R=4\ fB/(\rho g \sin\alpha)$[4] is the limiting condition to see for the lava to be drained out or to be plugged in the tube.

Lava yield strength obtained from lava tube cave

Considering that the lava tube cave is due to the drainage of lava from the inside of the tube, the yield strength can be obtained from the drain limit condition[4] in the inclined tube.

$fB = H(\rho g \sin\alpha)/4$ ·················· (eq-1)

Here, fB is the yield value, H is the cavity height, ρ is the lava density, g is the gravitational acceleration, and α is the slope angle. The yield strength of the cave obtained from (eq-1) is shown in the right column of Table 1. Yield strength ranges from 1.0x104 to 1.84x105 dyne/cm^2.

Temperature dependent yield strength and viscosity coefficient of Mt. Fuji

ISHIBASHI & SATO [5] performed a temperature-dependent the data measured of Mt. Fuji 1707 eruption basalt by melting in his laboratory. The following equation can be obtained by setting the coefficient and constant of the temperature-dependent equation from the yield strength and viscosity coefficient at two points of 1197° C and 1157° C.

$\log10fB = 28.533-0.02290\theta$,········· (eq-2)

θ is the temperature in degrees Celsius, and the yield strength fB is dyne/cm2.

$\log10\eta B = 21.764-0.01630\theta$, ······· (eq-3)

θ is the temperature in degrees Celsius, and the viscosity coefficient ηB is poise.

The lava tube cave formation temperature is in the range of 1016° C to 1070° C as judged from the yield strength temperature dependent curve (eq-2) based on the yield strength 1.0x104 to 1.84x105 dyne/cm2 obtained from the cave. The lava viscosity coefficient with respect to the temperature at that time is in the range of 2.1x104 to 1.60x105 poise according to the viscosity coefficient temperature curve (eq-3) (Table 1)[6].

Conclusion

By obtaining the temperature-dependent curve of the lava yield strength in advance, it is possible to identify the lava temperature at the time of cave formation by obtaining the yield strength from the cave. Further, the viscosity coefficient can be obtained from the temperature-dependent curve of the lava viscosity coefficient. Therefore, it is considered that this method can be used to identify the temperature and viscosity coefficient of lava flow during the formation of lava tube caves whose temperature has not been measured in the past.

References:

[1] TAKANORI OGAWA (1980). Geological observation of lava caves and lava tree moulds on Mt. Fuji, Dojin, Vol. 2, No. 3, Japan Cave Association.

[2] TAKANORI OGAWA (1982). On Lava Caves in Japan and Vicinity. 3rd ISV, Bend, Oregon,1982

[3] AKIRA TAKADA,TAKAHIRO YAMAMOTO,YOSHIHIRO ISHIZUKA AND SHUN NAKANO (2016). Geological Map of Fuji Volcano (Second Edition) with Explanatory Text. Miscellaneous Map Series 12, Geological Survey of Japan, AIST, 56p. (in Japanese with English abstract 4p).

[4] TSUTOMU HONDA (2001). B-10 Mt. Fuji lava cave formation mechanism and findings, 2001 Volcanological Society of Japan Autumn Meeting.

[5] H.ISHIBASHI, H.SATO (2010). Journal of Mineralogical and Petrological Science, volume 105, pp334-339

[6] TSUTOMU HONDA (2020). P10 Identification of lava flow temperature by lava tube cave formation of Mt. Fuji, The Volcanological Society of Japan, Fall Meeting 2020.

Estimation of the lava flow temperature at the C2 lava cave formation of the Chu B'luk volcano in Vietnam

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Abstract

The C2 lava cave is one of the most typical caves of the Chu B'luk volcano in Krongno, Dak Nong, Vietnam. The K/Ar isotopic age dating on the basaltic rock sample collected in the C2 lava tube cave wall shows a value of 0.671 ± 0.17Ma. We attempted to identify the lava flow temperature during the C2 lava tube formation of Chu B'luk volcano by using the yield strength obtained from the lava tube cave slope angle and height. As the temperature-dependent data of yield strength and viscosity for Chu B'luk volcano's lava do not exist, those of Mt. Fuji 1707 basalt, Etna volcano basalt, and Izu-Oshima 1951 basalt are used. The obtained yield strength of the lava of $2.3x10^4$ dyne/cm^2 which leads to the range of 1045° C to 1067° C as lava tube cave formation temperature. Further, the viscosity coefficient of the lava flow was also estimated from these temperatures as in the range of $2.2x10^4$ to $2.5x10^5$ poise. These are reasonable values for basaltic lava flow.

Keywords: lava tube cave, lava yield strength, lava temperature.

1. Introduction

The Chu B'luk volcano (Figure 1) is located in the Krongno district, Dak Nong Province, in the Central Highlands of Vietnam. It is one of the continental volcanoes that blew a large amount of soft lava having a silicic acid weight fraction of 48.3 to 52.4%[1]. From 2012-2017, NPO VSS officially cooperated with Vietnamese geologists from the Vietnam Geological Museum (VGM); Vietnam National Museum of Nature (VNMN) respectively conducted a series of surveys, measuring and mapping in detail 16 caves out of a total of 50 volcanic caves in the Krongno area. After that, five more caves were measured and mapped by Vietnamese geologists. Hence, the whole number of measured and mapped caves is 21[2].

Figure 1. Chu B'luk (Nam B'Lang) volcano.

The C2 lava tube cave is one of the 21 measured, mapped lava tube caves and mentioned above. The K/Ar isotopic age dating on the basaltic rock sample collected at the highest lava level mark of the cave wall shows a value of 0.671 ± 0.17 Ma[3]. In this paper, the C2 lava tube cave was chosen as a case study in the Krongno lava cave system to identify the yield strength of lava flow, using the hydrodynamic model of Bingham fluid flow for a lava tube. In detail, we will attempt to estimate the lava flow temperature during the C2 lava tube formation of Chu B'luk volcano by using the yield strength obtained from the lava tube cave slope angle and height [4].

2. Hydrodynamic models of Bingham fluid flow for lava tubes

A considered schematic for lava tube flow is indicated in Figure 2 where $H=2R$ is tube diameter (or tube height), R is the radius of the lava tube, and α is the slope angle of the lava tube.

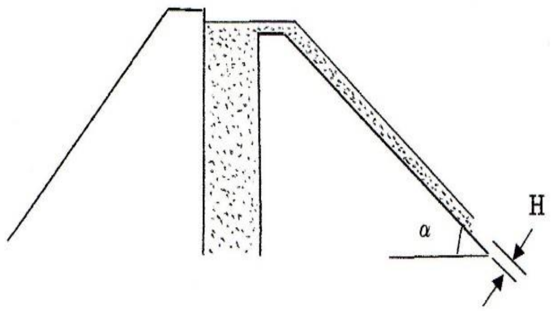

Figure 2. Schematic of lava tube flow

Figure 2 shows the lava spouted from a crater goes down a slope and forms a lava tube. The flow in the lava tube is controlled by gravity. After the termination of the eruption (drain back of magma), a hollow is formed in the tube producing a "lava tube cave" in which the lava in the tube could be drained out by gravitational flow.

The hydrodynamic model for lava tubes with the flow speed distribution in the tube is shown in Figure 3.

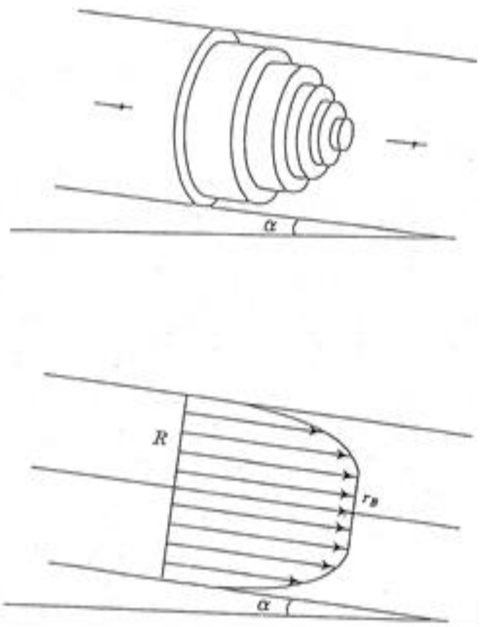

Figure 3. The flow speed distribution in a tube.

The equation of the flow speed distribution u in the tube is shown as below:

For $\tau_W = (\rho g \sin\alpha)R/2 > f_B$

$u=(R-r_B)^2(\rho g \sin\alpha)/4\eta_B \qquad r<r_B$

$u=[R^2-r^2-2r_B(R-r)](\rho g \sin\alpha)/4\eta_B \quad r>r_B$

For $\tau_W = (\rho g \sin\alpha)R/2 < f_B$

$u= 0$

Here, τ_W is shear stress on the tube wall surface, r_B is radius where shear stress is equal to f_B, f_B is Bingham yield strength, η_B is Bingham viscosity,

g is the gravity force and ρ is lava density. Critical condition for lava tube cave formation is: for $H=2R$, $H=4f_B/(\rho g \sin\alpha)$, then, $f_B= H(\rho g \sin\alpha)/4$.

3. Bingham yield strength estimated from lava tube cave height

Lots of lava tube caves are found between Chu B'luk volcano and Dray Sap Waterfall in a straight line distance of about 9 km. Among them, the lava tube cave C2 is used as a typical lava tube cave. The cavern height H of the C2 cave (Figure 4) is about 10m, the total length is 402.0m and the elevation difference between the upper and lower extremities is 15m, so the inclination angle is α=2.1 degrees.

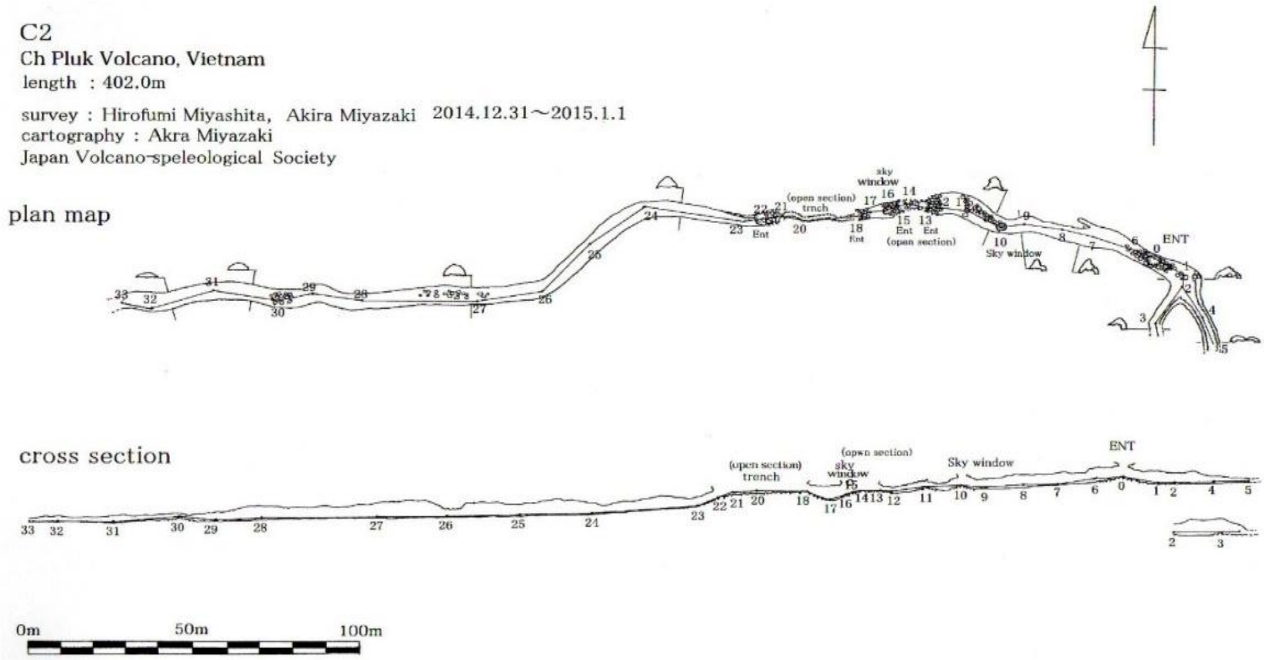

Figure 4. Horizontal and vertical cross - section of the C2 lava tube cave of the Chu B'luk volcano

From this cavern height and inclination angle α, we can estimate the Bingham yield value of lava. Bingham yield value $f_B=H(\rho g \sin \alpha)/4=2.3\times10^4$ dyne/cm^2 is obtained with ρ=2.5 g/cm^3. Here, g is the gravitational acceleration.

Item relating to yield strength	Numerical
Length of lava tube cave C2	402.0 m
Height of lava tube cave: H	~10m
Difference in elevation between the upper and lower extremities	15m
Slope angle α of the cave C2 (inclination of the cave C2)	2.1 degree
Yield strength: $f_B=H(\rho g \sin\alpha)/4$, ρ:2.5g/cm^3, g:980cm/sec^2	2.3×10^4 dyne/cm^2

Table 1. Yield strength of lava flow of Chu B'luk Volcano.

4. Temperature-dependent yield strength and viscosity

As the temperature-dependent data of yield strength and viscosity for the lava of Chu B'luk volcano do not exist, instead, those of Mt. Fuji 1707 eruption basalt (SiO_2 wt%: 51.5%), Etna volcano 1975 eruption basalt (SiO_2 wt%: 47.43%), and Izu-Oshima 1951 eruption basalt (SiO_2 wt%: 52~53%) were used[5].

4.1 Lava of Mt. Fuji

Ishibasi & Sato [6] performed a measurement of temperature-dependent yield strength and viscosity of Mt. Fuji 1707 eruption basalt (SiO_2 wt%: 51.5%) by melting in his laboratory. The following equation can be obtained by setting the coefficient and constant of the temperature-dependent equation from the yield strength and viscosity coefficient at two points of 1197° C and 1157° C.

$\log_{10} f_B$ = 28.533-0.0229θ, θ is the temperature in degrees Celsius, and the yield strength f_B is dyne/cm^2.

$\log_{10} \eta_B$ = 21.764-0.0163θ, θ is the temperature in degrees Celsius, and the viscosity coefficient η_B is poise.

The lava tube cave formation temperature is judged as 1056 ° C from the yield strength: 2.3×10^4 dyne/cm^2 .

The lava viscosity at that time is 2.2×10^4 poise according to the temperature dependent viscosity curve.

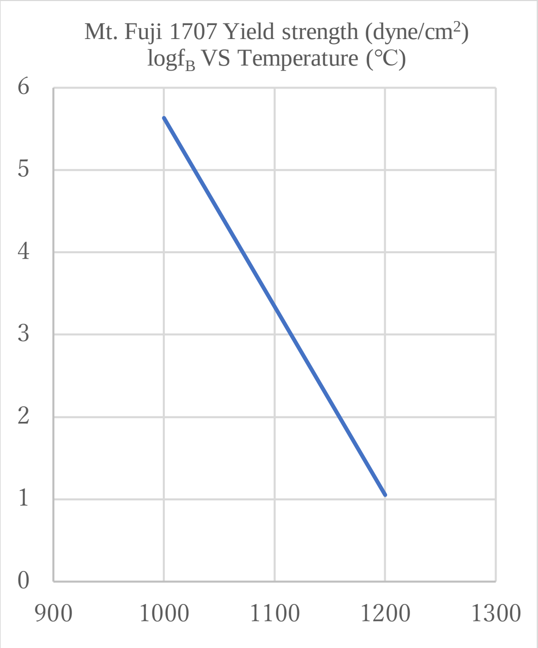

Figure 5. Temperature dependence of yield strength of the Mt. Fuji 1707 eruption.

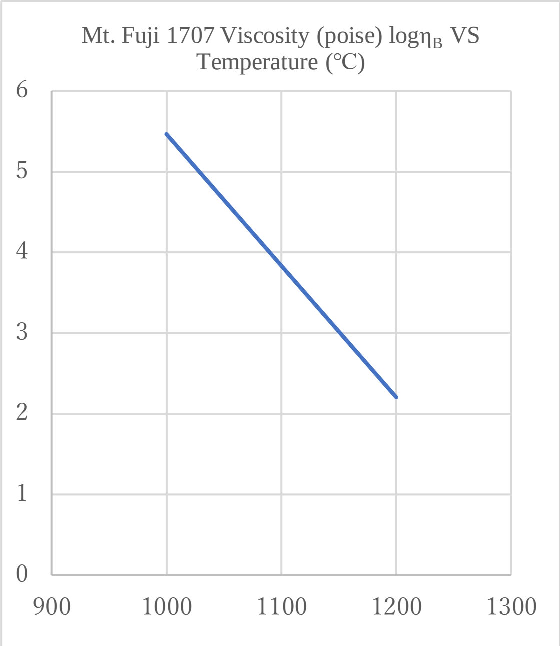

Figure 6. Temperature dependence of viscosity of the Mt. Fuji 1707 eruption.

4.2 Lava of Mt. Etna

Regarding the Etna volcano 1975 eruption (SiO_2wt%:47.43%)[7], the temperature-dependent curves of yield strength and viscosity coefficient are obtained by in situ actual measurement of lava flow [8,9]. Then a temperature-dependent equation is created from the data as:

$\log_{10} f_B$ = 35.1836-0.0289θ

Where the yield strength f_B is dyne / cm^2 and θ is the temperature in degrees Celsius.

$\log_{10} \eta_B$ = 24.0469-0.0175θ)

Here, the viscosity coefficient η_B is poise and θ is the temperature in degrees Celsius.

The lava tube cave formation temperature is 1067° C when calculated from the yield value temperature-dependent equation using the yield value 2.3×10^4 dyne / cm^2 obtained from the cave. The viscosity coefficient is 2.5×10^5 poise according to the viscosity coefficient temperature-dependent equation.

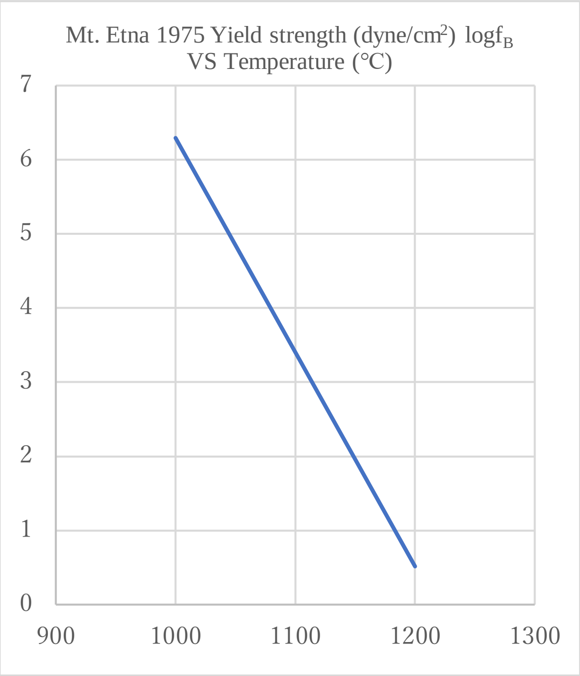

Figure 7. Temperature dependence of yield strength of the Mt. Etna 1975 eruption.

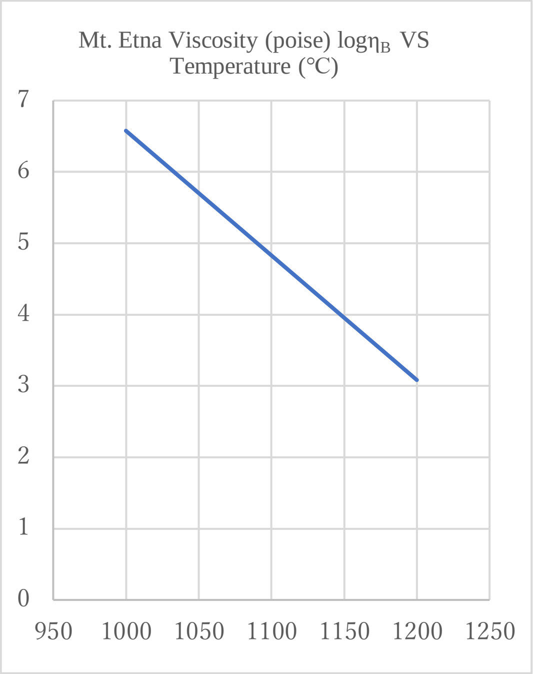

Figure 8. Temperature dependence of viscosity of the Mt. Etna 1975 eruption.

4.3 Lava of Mt. Mihara, Izu-Ooshima

Regarding the lava flow that erupted from Mt. Mihara, Izu Oshima in 1951 (SiO_2 wt%: 52~53%), the viscosity coefficient and yield value are in-situ measured [10,11].

The temperature-dependent regression equations for yield strength f_B and viscosity η_B are given as follows:

$\log_{10} fB = 13.67 - 0.0089\theta$

Here, θ is the temperature in degrees Celsius, and f_B is dyne / cm^2 (Ishihara et al [8]).

$\log_{10} \eta_B = 24.255 - 0.01810\theta$

Where θ is the temperature in degrees Celsius and η_B is poise (Minakami [11]).

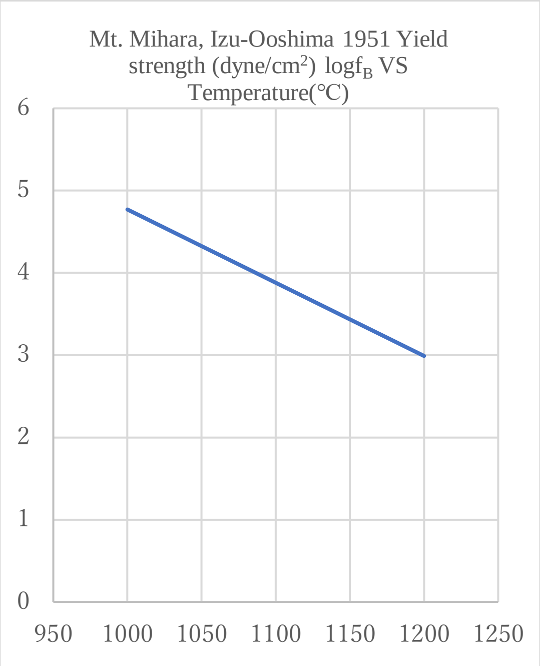

Figure 9. Temperature dependence of yield strength of Mt. Mihara, Izu-Oosjima 1951 eruption.

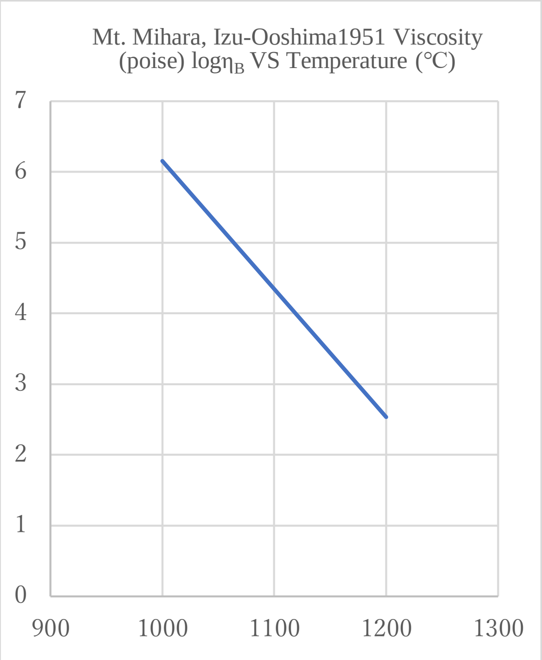

Figure 10. Temperature dependence of viscosity of Mt. Mihara, Izu-Ooshima 1951 eruption.

The lava tube cave formation temperature is 1045° C when calculated from the yield strength temperature-dependent equation using the yield value $2.3x10^4$ dyne/cm^2 obtained from the cave. The viscosity coefficient is $2.2x10^5$ poise according to the viscosity coefficient temperature-dependent equation.

Table 2 shows a summary of hydrodynamic aspects obtained on the physical properties (yield strength and viscosity) of lava by cave geometry and lava cave formation temperature of C2 cave.

The obtained yield strength of the lava of $2.4x10^4$ dyne/cm^2 which leads to the range of 1045° C to 1067° C as lava tube cave formation temperature. Further, the viscosity coefficient of the lava flow was also estimated from these temperatures in the range of $2.2x10^4$ to $2.5x10^5$ poise.

The obtained temperature range is comparable with that of the active lava flow of Kilauea[12] (core (>1050˚C).

Temperature θ obtained from temperature dependent equation of Mt. Fuji: $\log_{10}f_B = 28.533-0.0229\theta$, (θ is Celsius, unit of f_B is dyne/cm^2)	Viscosity η_B obtained from temperature dependent equation of Mt.Fuji: $\log_{10}\eta_B = 21.764-0.0163\theta$, (θ is Celsius, unit of η_B is poise).
1056°C	$2.2x10^4$ poise.
Temperature θ obtained from temperature dependent equation of Mt. Etna: $\log_{10}f_B=35.1836-0.0289\theta$, (θ is Celsius, unit of f_B is dyne/cm^2)	Viscosity η_B obtained from temperature dependent equation of Mt. Etna: $\log_{10}\eta_B=24.0469-0.0175\theta$, (θ is Celsius, unit of η_B is poise).
1067°C	$2.5x10^5$ poise
Temperature θ obtained from temperature dependent equation of Izu-Ooshima1951: $\log_{10}f_B = 13.67-0.0089\theta$, (θ is Celsius, unit of f_B is dyne/cm^2)	Viscosity η_B obtained from temperature dependent equation of Izu-Ooshima1951: $\log_{10}\eta_B = 24.255-0.0181\theta$, (θ is Celsius, unit of η_B is poise).
1045°C	$2.2x10^5$ poise

Table 2. Estimation of temperature and viscosity of lava.

5. Remark

The temperature and viscosity of lava flow at the C2 cave formation are estimated from the yield strength deduced from the C2 lava cave geometry. The temperature of the lava flow of the Chu B'luk volcano seems reasonable value as basaltic lava.

References

[1] N. HOANG & M. FLOWER (1998). Petrogenesis of Cenozoic Basalts from Vietnam: Implication for Origins of a 'Diffuse Igneous Province'. J. Petrology, vol 39, No3, pp. 369-395.

[2] LA THE PHUC *et al* (2020). Report "Research on the value of cave heritage, propose building on-site conservation museums in The Central Highlands; take for example the volcanic cave in Krong No, Dak Nong province", code TN17/T06. Archived at the Vietnam Museum of Nature.

[3] LA THE PHUC, H. TACHIHARA, T. HONDA, LUONG THI TUAT *et al* (2018). Geological values of lava caves in Krongno Volcano Geopark, Dak Nong, Vietnam. *Vietnam Journal of Earth Sciences*, 40(4), pp. 299–319. https://doi.org/10.15625/0866-7187/40/4/13101

[4] TSUTOMU HONDA, HIROSHI TACHIHARA, HIROFUMI MIYASHITA, AKIRA MIYAZAKI, LA THE PHUC, LUONG THI TUAT, TRUONG QUANG QUY (2018). Hydrodynamic aspects of lava tube caves of Vietnam Central Plateau, Dak Nong Area. 18th ISV, Lava Beds.

[5] TSUTOMU HONDA, JUNICHI HARUYAMA (2020). 3E11 Identification of lava temperature by lava tube cave structure on the Earth and the Moon. 64th Space Science and Technology Union Conference, The Japan Society for Aeronautical and Space Sciences.

[6] ISHIBASHI, H. AND SATO, H. (2010). Journal of Mineralogical and Petrological Science 105,334.

[7] ROSA ANNA CORSARO, MASSIMO POMPILIO (2004). Dynamics of magmas at Mount Etna, Geophysical Monograph, https://www.academia.edu/28037030/Dynamics_of_magmas_at_Mount_Etna

[8] TAKAHISA MIZUYAMA,JUNICHI KURIHARA, KAZUO KAWAMURA, IPPEI KITAHARA(1989). Computer Simulation on Lava Flow and Ideas of Countermeasures, Shinsabo, Vol.42, No.4(165), 12-17.

[9] PINKERTON, H and SPARKS, R.J.S. (1978). Field measurements of the rheology of lava., Nature (London), Vol. 2, 76, No. 5686, pp. 383-385.

[10] KAZUHIRO ISHIHARA, MASATO IGUCHI AND KOSUKE KAMO (1988). Reproduction of the l986 1zu-Ooshima Lava Flows by a Numerical Calculation, Kazan, Vol.33, Izu-Ooshima eruption special issue, S64-S76. https://www.jstage.jst.go.jp/article/kazanc/33/SPCL/33_KJ00003270732/_pdf

[11] MINAKAMI, T (1951). On the temperature and viscosity of the fresh lava extruded in the 1951 Oosima eruption, Bulletin of Earthquake Research Institute, University of Tokyo 29,487-491.

[12] HARRY PINKERTON, MIKE JAMES and ALUN JONES (2002). Surface temperature measurements of active lava flows on Kilauea volcano, Hawai'i, Journal of Volcanology and Geothermal Research, Volume 113, Issues 1–2, 15 March 2002, pp. 159-176

A Memorial to a Great Vulcano-Speleologist Mr. Hiroshi Tachihara - NPO Vulcano-Speleological Society, Japan

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Abstract

The research on the geological heritage in the Krongno area and the vicinity, of Dak Nong Province, The Central Highlands, Vietnam was started in 2007 by Dr. La The Phuc and his colleagues. The discovery of the volcanic caves in Krongno in 2007 was reported and spread domestically and abroad via 2,000 bilingual leaflets of the UNESCO project, which was conducted by La The Phuc. Also, this amazing discovery was promoted by the Vietnamese media. The NPO Vulcano-Speleological Society of Japan led by Mr, Tachihara, who immediately recognized its importance, conducted the first independent survey in 2011 (preliminary stage) after collecting the necessary information. He preliminary surveyed 10 lava caves and found lava tree moulds inside and outside the caves. From 2012 to 2017, Mr. Tachihara (NPO VSS's Honorary Chairman) and Dr. T. Honda (NPO VSS's Chairman) led the NPO Vulcano-Speleological Society's members of Japan to conduct a series of joint surveys together with Dr. La The Phuc and the Vietnamese colleagues and obtained significant results on lava caves in the Krongno area. These results are important documentation sources to build the scientific dossier of Krongno Volcano Geopark, which was established in 2015, and renamed Dak Nong Geopark later by Dak Nong People's Committee. After returning to Japan in February 2017, Mr. Tachihara's health was not good because of some very serious diseases, but he kept frequently in contact with his Vietnamese colleagues to propose many valuable ideas concerning the effective conservation and sustainable tourism exploitation of the Krongno lava caves. In the last days of his life, Mr. Tachihara still expressed his aspiration and passion for lava caves in Vietnam. He dreamed he could recover one day to fly immediately to Vietnam, and survey submerged lava caves, those we have not yet had a chance to survey. However, unfortunately, on 28 February 2021, he passed away at the age of 83, only 7 months after the land of volcanic geo-heritages and volcanic cave heritages in Dak Nong has been honoured as Dak Nong UNESCO Global Geopark in July 2020. On the occasion of the 20th ISV event, we respectfully present the profile of Mr. Tachihara, who is loved by both Vietnamese and Japanese colleagues. The noble title Dak Nong UGGp gives him credit for his enthusiasm and contribution to the Vietnam - Japan joint mission in the field of survey, study, conservation, and sustainable development of the heritage region of Dak Nong. He's gone, but his significant and important contributions are forever conserved as the invaluable volcanic cave heritages of Dak Nong UGGp. His generous, active appearance and his love and passion flame on the volcanic cave are forever kept and lit by a lot of his Vietnamese and Japanese as well as international colleagues.

Keywords: Hiroshi Tachihara; Krongno lava cave; contribution.

Photos of Mr. Hiroshi

(Tachihara: He has been known as not only a passionate and active vulcano-speleologist but also a humorous and comical person)

Proposal to adopt a revised inventory coding system for the caves on Lanzarote.
Goal: Protection and conservation through the anonymisation of caves

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Abstract

Lanzarote is one of the 8 main islands of the archipelago of the Canary Islands. All islands are of volcanic origin and the geological history on Lanzarote dates up to the early Miocene. The landscape and both its geological and biological environment are protected by European Nature 2000 laws and Lanzarote including the adjacent Chinijo-archipelago has been nominated as a UNESCO Biosphere reserve. Pressure on the environment is high due to an intensive tourist industry. The after-COVID statistics on visits to the island have more than doubled which could be of great concern to the conservation of the existing environment on the island. As result of an ongoing inventory project called "Estudios y Topografías para el Cuidado y Conservación de los Tubos Volcánicos", the cave list from 2003 increased from 73 to more than 160 caves in 2022. The volume of illegal visits to lava caves increased dramatically as a result of COVID restrictions, often guided to entrances by publications and pictures on the Internet. A proposal for the anonymisation of caves should decrease the "wild visits" in caves and increase the number of scientific investigations and publications. The proposed coding system should contribute to a better ecological and geological protection of the lava caves on the island. Essential for the success of the mission is the acceptance of the proposal by scientific and governmental institutes.

Keywords: UNESCO geopark, anonymisation, conservation,

Introduction

Lanzarote is an island nearly 21km wide and 61km long, part of the archipelago of the Canary Islands. The volcanic history dates up to the Miocene and the island was nominated as an UNESCO biosphere Reserve in 1993.

The population is around 157 000 and the pressure on the island from the tourist industry is enormous. Where in 2020 and 2021 during the covid pandemic there were about 1 million tourists visiting the island annually this number was already reached in 2022 in May .(ref. Centro de datos Lanzarote, see Figure 1).

Caves and especially tourist caves take a considerable share (Geoheritage 14.82.2022 a global perspective on sustainable show cave tourism, 70 million a year in >1200 caves, 800 million Euro, V Chiarini/J Duckeck/J de Waele) in the global tourist industry.

For Lanzarote which covers 2 tourist caves (Jameos del Agua and Cueva de los Verdes) the impact of COVID is enormous. As you can see in Figure 2 the increase in the number of visitors since covid has increased exponentially. As in 2021 the number of visitors of Cueva de Los Verdes was 302.000 and for Jameos del Agua it was 437.000 (ref. centro de datos lanzarote) in comparison to the almost 1.2 million visitors on the island in that year.

Figure 1

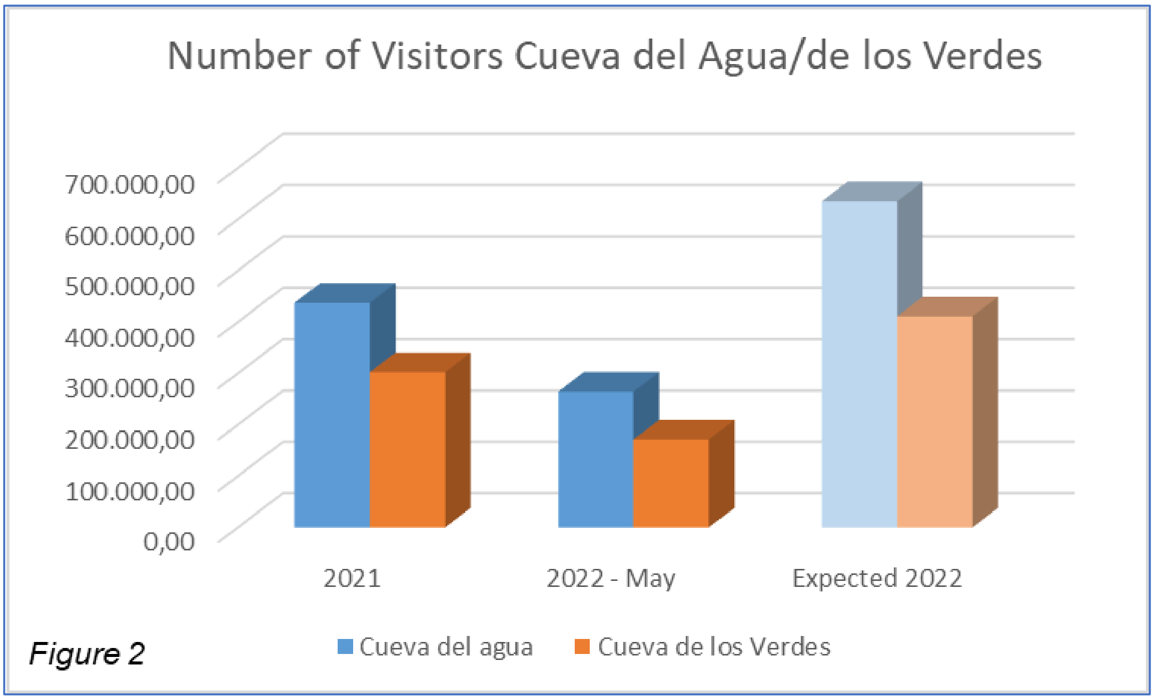


Figure 2

Logistically the tourist caves are not prepared for such numbers of visitors which is visible at the over-full parking spots and long queues at entrances all day long.

Beside tourist caves there are more than 200 other "wild" caves on the island. Covid time was a time of getting bored, caves became a good escape from civilized world and their covid restrictions. The number of visits to all caves grew enormously. Caves like Cueva de Maguez normally never were visited. Now suddenly one or two groups per day were observed.

A lava tube like Cueva de los Naturalistas in Covid times received day illegal visitors every day and even weekly visits of musicians practising their instruments were mentioned and complete families escaped underground for the restrictions on the surface.

It became a kind of geocaching game for the surplus tourists and adventurers on the island to find lesser known caves, matching vague pictures from cave entrances with Google and then put data onto TripAdvisor.

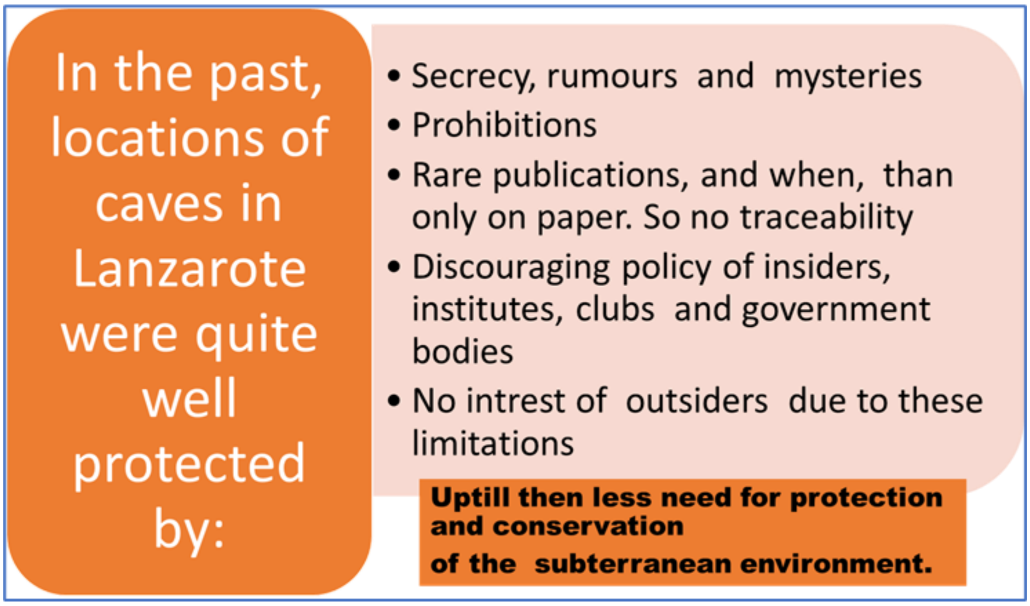


Figure 3

The result was more and more visitors illegally entered the geoheritage-protected caves and their biological environment. And as you know, once details are on the internet, they will never get off.

In the meanwhile the project Estudios y Topografías para el Cuidado y Conservación de los Tubos Volcánicos had to go underground. The misuse of the information on caves was enormous. The Facebook site had to be stopped and the information on the project website lanzarotecaves.com had to be blocked.

Demands for locations of caves were always refused.

The inventory project needed a new "way on" to publish caves without causing more and more damage to the caves.

At a conference November 2021 "Jornadas técnicas sobre Cuevas volcánicas de Lanzarote: Un patrimonio científico para proteger y valorizar" it was stated that an inventory is the start for scientific work., important for knowledge and important for protection and conservation.

It was Prof Bogdan Onac (from the university of South Florida) who reminded us on this possibility to leave out names in publications and instead of that use numbers. As a kind of digital protection of the link between name and location of the caves .

This system of coding cave names is already on site and working well in several areas over the world.

In 2003 already a first proposal was published by GUTIÉRREZ and FERNÁNDEZ. in Vulcania 6, "AVANCE GLOBAL DEL CATÁLOGO DE CAVIDADES DE LA ISLA DE LANZAROTE (ISLAS CANARIAS)".

Which in fact never got really accepted in later publications by scientists nor in governmental publications.

Based on this document a new inventory is now proposed to be accepted by the community.

Names will be deleted in publications and the related names to the codes including their coordinates will only be available to governmental offices up to their decision which figures can be handed out and which one not.

Only codes should be used in publications which should open up the route for more scientific investigations and publications in near future. Codes related to caves, in which these than better can be understood as result of these investigations. To know what has to be protected and what has to be conserved.

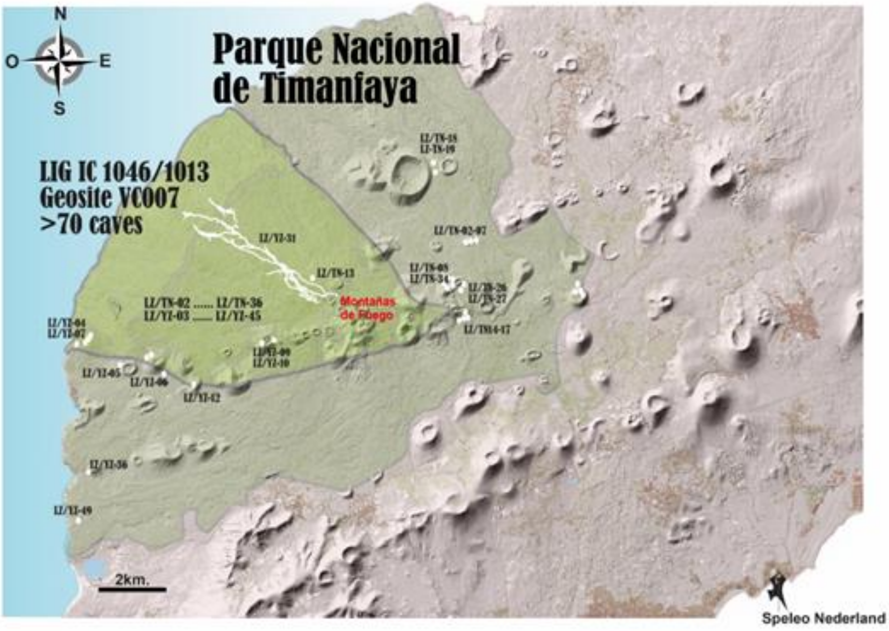
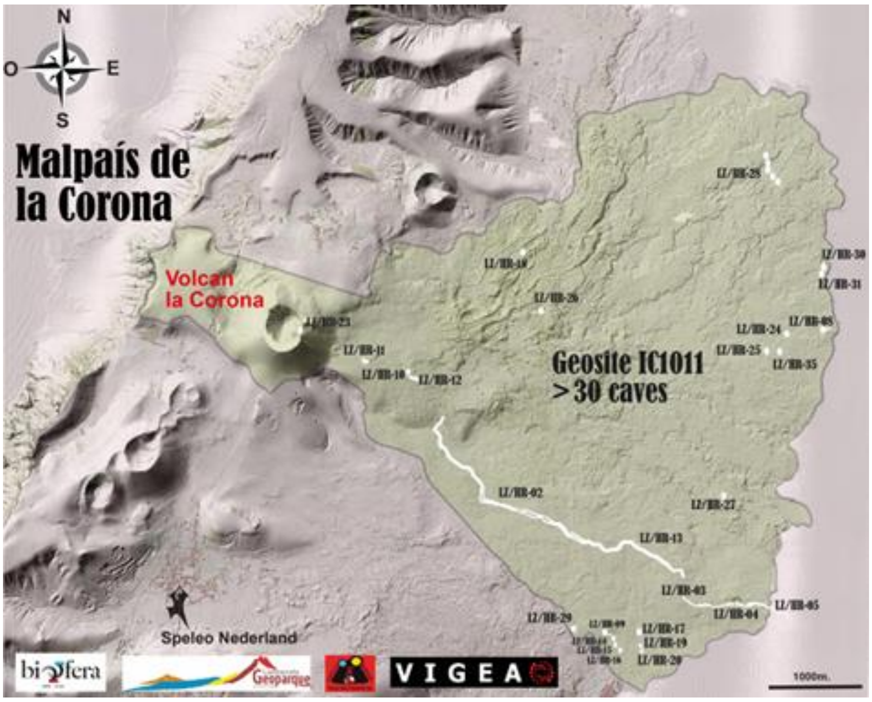


Figure 4

Figure 5



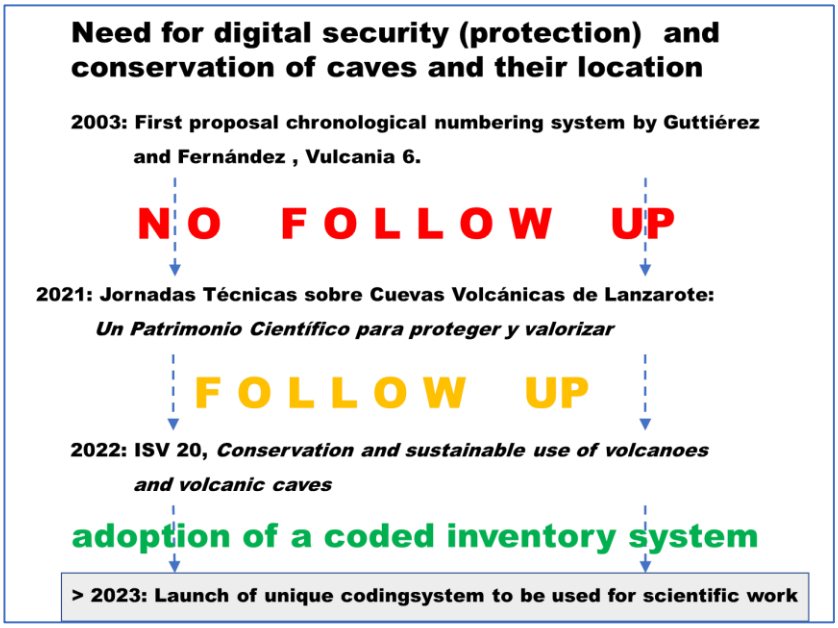


Figure 6

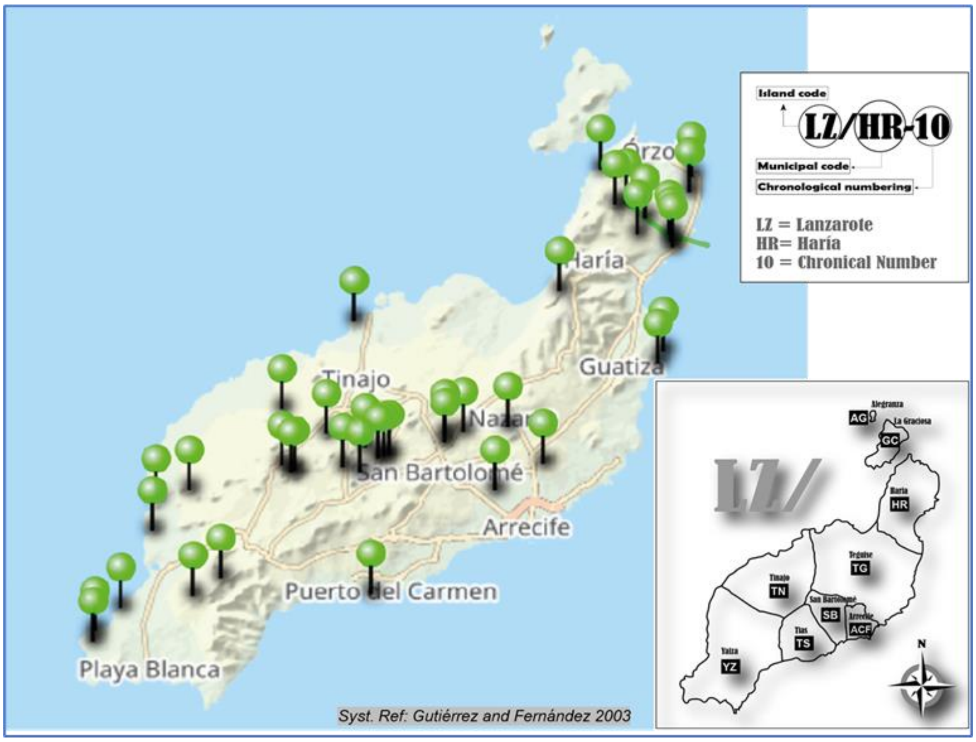


Figure 7

At this moment the inventory (See Table 1 on the next 2 pages) consists of a list of 160 most important caves on the island with a total length of more than 40km. A considerable increase since the amount of 73 caves in 2003 with a total length of 17km.

The goal of this document is the adoption of this proposed coded cave inventory by the scientific and governmental society which in future can contribute to a better ecological and geological protection of the lava caves on the island.

In practice there will be a censured list for the public and an original one including details, cave names and coordinates.

The original and complete chronological numbered cave inventory is planned to be finished in 2023 and will be handed over to selected governmental authorities that are dealing with scientific work.

As archivists, patrons and conservators, these authorities will have the challenge to manage the data, store them and hopefully can use them in preserving the geological and biological heritage from today for our future world.

Special thanks to

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Bibliography

Reserva de la Biosfera, Tomo II, Habitats y Ambientes D2 2019

Vulcania 6, Gutiérrez & Fernández, Avance global del catálogo de cavidades de la isla de Lanzarote (islas Canarias) 2003

35, Subteránnea 1, el Patrimonia espeleológico de Canarias y su conservacíon, Octavio Fernández & Pedro Oromi

Table 1. *Chronological listing of caves in order of Municipality. Version 17112022, © Laurens MJ Smets*

	Code	Codigo LIG	Name	engh	ept	Municipio	Typology	Conservatio	Surveyed by
1	LZ/ACF-02		Cueva de las Rosas 2	22	5	Arrecife	Mined lava tube	bad	Speleo NL/Vulcan Vertical/Uestayaide.2021
2	LZ/ACF-03		Cueva de las Rosas 3	18	2	Arrecife	Mined lava tube	bad	Speleo NL/Vulcan Vertical/Uestayaide.2021
3	LZ/ACF-01		Cueva de las Rosas 1	10	2	Arrecife	Mined lava tube	bad	Speleo NL/Vulcan Vertical/Uestayaide.2021
4	LZ/HR-02	IC1011	*Upper Corona Lava tube System. Jameo de las Prendes - Cueva de los Verdes*	6631	173	Haría	lava tube	bad	Vigea/Speleo NL/Vulcan Vertical/ 2019
5	LZ/HR-05	IC1011	3)Túnel de la Atlántida	1968	64	Haría	lava tube	good	Tomas Abel Rivero/Vigea/Speleo NL
6	LZ/HR-03	IC1011	*Lower Corona Lava tube system:* 1)Cueva de los Siete Lagos	856	46	Haría	lava tube	bad	Tomas Abel Rivero/Vigea/Speleo NL/Vulcan Vertical. 2019
7	LZ/HR-01a		Cueva de la Atalaya (ó de Maguez, ó Las Cuevas)	773	22	Haría	lava tube	acceptable	Speleo NL/Vulcan Vertical /Craven Pothole Club.2020
8	LZ/HR-04	IC1011	2)Jameos del Agua	540		Haría	lava tube	good	Tomas Abel Rivero/Vigea /Speleo NL/Vulcan Vertical. 2019
9	LZ/HR-09		Cueva Cercado Cho Listaigua 1	191	18	Haría	Lava tube	good	Speleo NL./Craven Pothole Club 2021
10	LZ/HR-08		Cueva de Lago Né ó de Pta Prieta	154	13	Haría	lava tube, Anchialine system	good	Speleo NL 2019
11	LZ/HR-01b		Cueva de la Atalaya (ó de Maguez, ó Las Cuevas) Cueva Martin	132	11	Haría	lava tube	acceptable	Speleo NL 2020
12	LZ/HR-25		Cueva Tahoma 2	64	3	Haría	Lava tube	good	Speleo NL.2021
13	LZ/HR-01d		Cueva de la Atalaya (ó de Maguez, ó Las Cuevas) Nr.C1	60	8	Haría	lava tube	acceptable	Speleo NL/Craven PotholeClub 2020
14	LZ/HR-29		Cueva de la Araña	41	10	Haría	Lava Tube	bad	Speleo NL.2022
15	LZ/HR-11	IC1011	2)Jameo de los Molinos (ó de la Corona)	39	18	Haría	lava tube/cupula	good	Speleo NL 2019
16	LZ/HR-14		Cueva Cercado Cho Listaigua 5	37	2	Haría	Lavatube	good	Speleo NL.2022
17	LZ/HR-30		Cueva de Señor Pedro 1	37	6	Haría	Lava Tube	good	Speleo NL/ Craven Pothole Club 2021
18	LZ/HR-15		Cueva Cercado Cho Listaigua 6	36	1	Haría	Lavatube	good	Speleo NL.2022
19	LZ/HR-13	IC1011	Jameo Redondo	35	9	Haría	lava tube collapso	good	Speleo NL 2019
20	LZ/HR-17		Cueva Cercado Cho Listaigua 2	35	2	Haría	Lavatube	good	Speleo NL 2021
21	LZ/HR-18	IC1017	Sima Grieta de las Siete Lenguas	32	-13	Haría	Fumarole(?)	Good	Speleo NL/Craven Pothole Club 2021
22	LZ/HR-20		Cueva Punto del Burro 2 (Jameo del Cercado de Mariano)	31	4	Haría	lava tube	good	Speleo NL.2021
23	LZ/HR-21	IC1003/LZ02	Cueva de las Cabras	30	5	Haría	erosion, mine	bad	Speleo NL
24	LZ/HR-10	IC1011	*Corona, Jameos Arriba:* 1)Jameo de los Escaladores	27	8	Haría	lava tube/cupula	bad	Speleo NL 2019
25	LZ/HR-12	IC1011	3)Jameo de los Lajeros 2 + 3	23	12	Haría	lava tube/cupula	bad	Speleo NL 2019
26	LZ/HR-22	IC1003	Cueva de los Gracioseros	22	5	Haría	lava tube Archeological site	good	Speleo NL/Uestayaide.2020
27	LZ/HR-16		Cueva Cercado Cho Listaigua 7	17	1	Haría	Lavatube	good	Speleo NL.2022
28	LZ/HR-24		Cueva Tahoma 1	17	1	Haría	Lava tube	good	Speleo NL.2021
29	LZ/HR-23	IC1011	Cueva en La Corona	15	5	Haría	Pyroclastic	bad	Speleo NL.2020
30	LZ/HR-31		Cueva de Señor Pedro 2	13	3	Haría	Lava Tube	good	Speleo NL/ Craven Pothole Club 2021
31	LZ/HR-01c		Cueva de la Atalaya (ó de Maguez, ó Las Cuevas) Nr. B1	10	3	Haría	lava tube	acceptable	Speleo NL/Craven PotholeClub 2020
32	LZ/HR-19		Cueva Punto del Burro 1 (Jameo del Cercado de Mariano)	7	2	Haría	lava tube	good	Speleo NL.2021
33	LZ/HR-26		Cueva Tisna	5		Haría	abri	good	Speleo NL.2022
34	LZ/HR-27		Cueva de las Conchas	5		Haría	abri's	good	Speleo NL.2022
35	LZ/HR-28		Cuevas del Guanche 1- 5	5		Haría	abri's	good	Speleo NL.2022
36	LZ/HR-35		Cueva Tahoma 3	5	1	Haría		good	Speleo NL in estudio
37	LZ/HR-06		Cueva de los Valientes			Haría			
38	LZ/HR-07		Cueva de Las Tabaibitas			Haría			
39	LZ/HR-32		Cueva de la Lapa			Haría	Sea Cave		Speleo NL, En estudio
40	LZ/HR-33		Cueva Jardín de Cactus			Haría	Lava Tube		Speleo NL, En estudio
41	LZ/HR-34		Sima Risco de Famara			Haría			Speleo NL, En estudio
42	LZ/SB-03	IC1013	Cueva de Tisalaya 4	229	5	San Bartolomé	Tumulus cave	good	Speleo NL 2022
43	LZ/SB-05	IC1013	Cueva de Tisalaya 6	229	3	San Bartolomé	Tumulus cave	good	Speleo NL 2022
44	LZ/SB-02		Cueva de Ajey/ de las Cucas	175	12	San Bartolomé	lava tube	bad	Speleo NL.2022
45	LZ/SB-04	IC1013	Cueva de Tisalaya 5	70	3	San Bartolomé	lava bubble	good	Speleo NL 2022
46	LZ/SB-01		C. de San Bartolomé	13	2	San Bartolomé	lava tube	good	Speleo NL.2022
47	LZ/TG-01c	IC1013	Cuevas de Mozaga 3	250		Teguise	lava tube		G.I.E.T.
48	LZ/TG-02		Cueva Tahiche (ó del Camion)	198	21	Teguise	lava tube	bad	Speleo NL/Vulcan Vertical.2018
49	LZ/TG-19	IC1016	Tubo Don Alex	142	6	Teguise	lava tube	good	Speleo NL/Vulcan Vertical/Uestayaide.2020
50	LZ/TG-04	IC1013	Cueva de Nazaret ó del Majo	110	5	Teguise	lava tube	bad	Speleo NL/Vulcan Vertical.2019
51	LZ/TG-01b	IC1013	Cuevas de Mozaga 2	94	4	Teguise	lava tube	bad	Speleo NL/Vulcan Vertical/Uestayaide2018-2019
52	LZ/TG-01a	IC1013	Cueva de Mozaga 1	77	2	Teguise	lava tube	bad	Speleo NL/Vulcan Vertical/Uestayaide.2018-2019
53	LZ/TG-03		Cueva de la Mora	70		Teguise		bad	Benisahare LZ
54	LZ/TG-20		Cueva Paloma	46	9	Teguise	erosion, Sea cave	good	Speleo NL 2019
55	LZ/TG-07		Cueva de La Maleza 1	42		Teguise			Benisahare LZ, topo Si?
56	LZ/TG-21		Cueva del Agua, Mala	38	0	Teguise	lavatube/erosion Sea cave	good	Speleo NL 2019
57	LZ/TG-14		Cueva de las Marias	30	10	Teguise	Fumarole?	bad	Speleo NL/Vulcan Vertical/Uestayaide.2021
58	LZ/TG-16		Cueva (del Majo) de Tiagua	30	5	Teguise	lava tube/cupula	good	Speleo NL 2017
59	LZ/TG-23	IC1016	Cuevas del Jable 2	27	3	Teguise	lava tube	good	Speleo NL/Vulcan Vertical/Uestayaide.2020
60	LZ/TG-15		Cueva de Zonzamas (Cueva de los Majos)	5		Teguise		Good	Benisahare LZ
61	LZ/TG-22	IC1016	Cuevas del Jable 1	5	3	Teguise	lava tube	good	Speleo NL/Vulcan Vertical/Uestayaide.2020
62	LZ/TG-05		Cueva de Tejía			Teguise			Benisahare LZ
63	LZ/TG-06		Cueva de Las Guillenas			Teguise			Benisahare LZ
64	LZ/TG-08		Cueva de La Maleza 2			Teguise			Benisahare LZ
65	LZ/TG-09		Cueva de Los Topes 1			Teguise			Benisahare LZ
66	LZ/TG-10		Cueva de Los Topes 2			Teguise			Benisahare LZ
67	LZ/TG-11		Cueva de Los Topes 3			Teguise			Benisahare LZ
68	LZ/TG-17		Cueva del Majo de Muñique			Teguise			Benisahare LZ
69	LZ/TG-18		Cueva de Los Corrales			Teguise			Benisahare LZ
70	LZ/TG-24		Cueva de Órzola			Teguise	Sea cave		Speleo NL, En estudio
71	LZ/TG-25		Sima Vulcan de Tao			Teguise	Geysir vent?	good	Speleo NL, En estudio
72	LZ/TS-01	IC1033	Cueva de los Naturalistas(ó las Palomas)	1680	17	Tías	lava tube	acceptable	Speleo NL/Vulcan Vertical.2019/2021
73	LZ/TS-07	IC1033	Cueva encima los Naturalistas 2	281	4	Tías	lava tube	bad	Speleo NL 2022
74	LZ/TS-02	IC1013	Cueva de Tisalaya 3	250		Tías	lava tube		GES-CMB (Montoriol-Pous et al. 1991)
75	LZ/TS-03	IC1013	Gateras de Sory	80	2	Tías	lava tube	good	Speleo NL/Vulcan Vertical.2018

76	LZ/TS-04	IC1013	Cuevas (ó Gateras) de Tisalaya 1	43	3	Tías	lava tube	good	Speleo NL/Vulcan Vertical.2018
77	LZ/TS-05	IC1013	Cuevas (ó Gateras) de Tisalaya 2	21	3	Tías	lava tube	good	Speleo NL/Vulcan Vertical.2018
78	LZ/TS-06	IC1033	Cueva encima los Naturalistas 1	20	2	Tías	lava tube	good	Speleo NL 2022
79	LZ/TS-06		Cueva de Doña Juana			Tías			
80	LZ/TS-10		Cueva Higuera			Tías	Colapse	good	In estudio
81	LZ/TN-02-07	IC1040	Sima de Tinguaton (ó del Diablo)	376	101	Tinajo	Geyser Vent	good	Speleo NL/Vulcan Vertical.2020
82	LZ/TN-08	IC1038	Cueva (ó Canal) de Pico Partido	167	26	Tinajo	lava tube	good	Speleo NL 2018/2022
83	LZ/TN-09	IC1046/VC007/ TMP159	Cueva de Caldera Escondida	150		Tinajo			Unpublished (Hernandes 1998)/J.L. Martin
84	LZ/TN-27	IC1038	Cueva Amarillo 2	120	20	Tinajo	lava tube	good	Speleo NL.2022
85	LZ/TN-34	IC1038	Cueva del Paso, Pico Partido	73	16	Tinajo	explosion/vent	good	Speleo NL 2022
86	LZ/TN-14	IC1038	Fumaroles del Señalo 1	70	27	Tinajo	fumarole/chimney	good	Speleo NL 2020
87	LZ/TN-18	IC1013/IC1046/V C007	Cueva de Leti 1	69	12	Tinajo	lavatube	good	Speleo NL.2021
88	LZ/TN-33	IC1038	Cueva Sagrado	69	10	Tinajo		acceptable	Speleo NL, En estudio
89	LZ/TN-11	IC1038	Boca del Infierno	50	11	Tinajo	lava tube	good	Speleo NL 2020
90	LZ/TN-24	IC1046/IC1013	Cuevas (ó Sima) de Santa Catalina (ó de la Nueces) 3	47	15	Tinajo	Volcanic Vent/explosion holes	good	Speleo NL 2019
91	LZ/TN-20	IC1046/IC1013	Cuevas (ó Sima) de Santa Catalina (ó de la Nueces) abajo	44	4	Tinajo	Volcanic Vent/explosion holes	good	Speleo NL 2019
92	LZ/TN-21	IC1046/IC1013	Cuevas (ó Sima) de Santa Catalina (ó de la Nueces)	39	9	Tinajo	Volcanic Vent/explosion holes	good	Speleo NL/Vulcan Vertical 2019
93	LZ/TN-26	IC1038	Cueva Amarillo 1	33	6	Tinajo	Tumulus cave + lava tube	good	Speleo NL, En estudio
94	LZ/TN-15	IC1038	Fumaroles del Señalo 2	30	25	Tinajo	fumarole/chimney	good	Speleo NL 2020
95	LZ/TN-25	IC1046/VC007	Cueva de Ortiz (ó Party cave)	28	4	Tinajo	lava tube prepared for party's	bad	Speleo NL 2019
96	LZ/TN-23	IC1046/IC1013	Cuevas (ó Sima) de Santa Catalina (ó de la Nueces) 2	25	9	Tinajo	Volcanic Vent/explosion holes	good	Speleo NL 2019
97	LZ/TN-22	IC1046/IC1013	Cuevas (ó Sima) de Santa Catalina (ó de la Nueces) 1	24	12	Tinajo	Volcanic Vent/explosion holes	good	Speleo NL 2019
98	LZ/TN-31	IC1038	Cueva Rio de Lava alto	23	4	Tinajo	lava tube	good	Speleo NL 2022
99	LZ/TN-10	IC1046/VC007/ TMP159	Cueva T-23	20		Tinajo			J.L. Martin
100	LZ/TN-16	IC1038	Fumaroles del Señalo 3	17	13	Tinajo	fumarole/chimney	good	Speleo NL 2020
101	LZ/TN-17	IC1038	Fumaroles del Señalo 4	15	8	Tinajo	fumarole/chimney	good	Speleo NL 2020
102	LZ/TN-01		Cueva de Ana Viciosa	10		Tinajo	erosion, sea cave		Tremesana
103	LZ/TN-19	IC1013/IC1046/V C007	Cueva de Leti 2	10	5	Tinajo	lavatube	good	Speleo NL.2021
104	LZ/TN-12	IC1046/VC007/ TMP159	Hornito de la Tacita de Chocolate		-5	Tinajo	Hornitos		J.L. Martin
105	LZ/TN-13	IC1046/TMP158	Hornito del Manto de la Virgen		-5	Tinajo	Hornitos		J.L. Martin, Topo Si?
106	LZ/TN-28	IC1038	Fumarole de Monaña La Cazoleta 1			Tinajo			SN In estudio
107	LZ/TN-29	IC1038	Fumarole de Monaña La Cazoleta 2			Tinajo			SN In estudio
108	LZ/TN-30	IC1038	Fumarole de Monaña La Cazoleta 3			Tinajo			SN In estudio
109	LZ/TN-32	IC1038	Cueva Rio de Lava bajo			Tinajo			SN In estudio
110	LZ/TN-35		Cueva de los Piratas			Tinajo			Speleo NL, En estudio
111	LZ/TN-36		Cueva cerca de Ana Viciosa			Tinajo	lava tube		Speleo NL, En estudio
112	LZ/YZ-31	IC1046/VC007/ TMP159	Sistema Sin Nombre - Cueva de Los Pescadores	11700		Yaiza	lava tube	good	CDS74/Adventure Lanzarote
113	LZ/YZ-01		Cueva de las Breñas (ó Cueva del Sonido)	2269	42	Yaiza	lava tube	acceptable	Speleo NL/Vulcan Vertical/Craven Pothole club 2019-2022
114	LZ/YZ-45	IC1046/VC007/ TMP159	Cueva del Cangrejo	1940		Yaiza	tubo	good	CDS74/Adventure Lanzarote
115	LZ/YZ-33	IC1046/VC007/ TMP159	Cueva Escondido ó Tubo Perdido	1176		Yaiza	lava tube		J. L. Martin
116	LZ/YZ-35	IC1046/VC007/ TMP159	Cueva Choco	680		Yaiza	lava tube		Unpublished (Hernandes 1998)
117	LZ/YZ-04	IC1046/VC007/ TMP159	Cueva Esqueleto/Paso	567		Yaiza	lava tube		Titerogacat
118	LZ/YZ-32	IC1046/VC007/ TMP159	Cueva del Lago de Lava	529		Yaiza	lava tube		Unpublished (Hernandes 1998)/J.L. Martin
119	LZ/YZ-07	IC1046/VC007/ TMP159	Cueva Covón/Chifletera	517	26	Yaiza	lava tube	bad	CDS74 Haute Savoie
120	LZ/YZ-13	IC1046/VC007/ TMP159	Cueva del paso	350		Yaiza			J.L. Martin
121	LZ/YZ-34	IC1046/VC007/ TMP159	Cueva la Pedrera	320		Yaiza	lava tube		
122	LZ/YZ-06	IC1045	Cueva (ó Sima/Cupula) de Pedro Perico	201	31	Yaiza	Volcanic Vent	good	Speleo NL/Vulcan Vertical.2018
123	LZ/YZ-09	IC1046/TMP171	Cueva Montaña Rajada	168		Yaiza	lava tube		Unpublished (Hernandes 1998)/J.L. Martin
124	LZ/YZ-12	IC1046/VC007/ TMP159	C. Sendero de Mtña. Hernández	157		Yaiza			Unpublished (Hernandes 1998)/J.L. Martin
125	LZ/YZ-05	IC1046/VC007/T MP159	Cueva de Carmelo	145	16	Yaiza	Series of explosion chambers near Volcano	acceptable	Speleo NL/Craven Pothole Club 2021
126	LZ/YZ-02		Cueva de Playa Blanca (ó Rubicon)	125	21	Yaiza	lava tube	bad	Speleo NL 2018
127	LZ/YZ-16	IC1046/VC007/ TMP159	Cueva de las Plumas	86		Yaiza			J.L. Martín
128	LZ/YZ-19	IC1046/VC007/ TMP159	Cueva del Alpendre o del arriba	80		Yaiza			J.L. Martín
129	LZ/YZ-36	IC1035	Cueva Montaña Bermeja	75	12	Yaiza	lava tube + water erosion	acceptable	Speleo NL 2018
130	LZ/YZ-08	IC1046/VC007/ TMP159	Cueva T-1	60		Yaiza			J.L. Martín
131	LZ/YZ-48		Tubo Negro	58	16	Yaiza	Sea cave	good	Speleo NL 2022
132	LZ/YZ-10	IC1046/TMP171	Cueva Pequeña Montaña Rajada	50		Yaiza			J.L. Martín
133	LZ/YZ-37		Cueva de los Anillos/Cueva Grande de Playa Blanca	44	13	Yaiza	erosion, Sea cave	Good	Speleo NL 2021
134	LZ/YZ-38		Cuevas de los Lomos	44	5	Yaiza	(Mined) pyroclastic tube	good	Speleo NL 2019/2022
135	LZ/YZ-25	IC1046/VC007/ TMP159	Hornitos de las Clacas	35	14	Yaiza	Hornitos		Unpublished (Hernandes 1998)/J.L. Martin
136	LZ/YZ-27	IC1046/VC007/ TMP159	Hornito Reconstruido	35	14	Yaiza	Hornitos		J.L. Martín
137	LZ/YZ-11	IC1046/VC007/ TMP159	Cueva del Barranco del Fuego	25		Yaiza			J.L. Martín
138	LZ/YZ-39		Cueva de la Degollada (de los Majos, La Casa Honda de la Degollada)	23	2	Yaiza	lavatube	good	Speleo NL 2019
139	LZ/YZ-23	IC1046/VC007/ TMP159	Hornito Solitario	20		Yaiza	Hornitos		J.L. Martín
140	LZ/YZ-47	IC1026	Cueva de Agua	20	4	Yaiza	Sea cave	good	Speleo NL 2022
141	LZ/YZ-26	IC1046/VC007/ TMP159	Hornito de La Perola	18	21	Yaiza	Hornitos		J.L. Martín
142	LZ/YZ-40	IC1024	Cueva del Sendero 1	12	5	Yaiza	Pyroclastic, active hot/humid	good	Speleo NL.2021
143	LZ/YZ-42		Cueva Grande	9	3	Yaiza	erosion, sea cave	good	Speleo NL 2019
144	LZ/YZ-41	IC1024	Cueva del Sendero 2	7	1	Yaiza	erosion,tectonic	good	Speleo NL.2021
145	LZ/YZ-46		Cueva Segoya	5		Yaiza	abri	good	Speleo NL 2022
146	LZ/YZ-03		Cueva de Janubio			Yaiza			Benisahare LZ
147	LZ/YZ-14	IC1046/VC007/ TMP159	Cueva del Risco			Yaiza		bad	
148	LZ/YZ-15	IC1046/VC007/ TMP159	Cueva del Acantilado			Yaiza			
149	LZ/YZ-17	IC1046/VC007/ TMP159	Cueva del Ratón			Yaiza			
150	LZ/YZ-18	IC1046/VC007/ TMP159	Cueva T-24			Yaiza			
151	LZ/YZ-20	IC1046/VC007/ TMP159	Cueva del Canal Derruido			Yaiza			
152	LZ/YZ-21	IC1046/VC007/ TMP159	Hornito de los Camelleros			Yaiza	Hornitos		
153	LZ/YZ-22	IC1046/VC007/ TMP159	Hornitos de Timanfaya			Yaiza	Hornitos		
154	LZ/YZ-24	IC1046/VC007/ TMP159	Hornito Garganta del Cuervo			Yaiza	Hornitos		
155	LZ/YZ-28	IC1046/VC007/ TMP159	Hornito S-28			Yaiza	Hornitos		
156	LZ/YZ-29	IC1046/VC007/ TMP159	Hornito S-29			Yaiza	Hornitos		
157	LZ/YZ-30	IC1046/VC007/ TMP159	Hornito S-30			Yaiza	Hornitos		
158	LZ/YZ-43	IC1046/VC007/ TMP159	Cueva Chica del Mojón			Yaiza			
159	LZ/YZ-44	IC1046/VC007/ TMP159	Cueva de las Estalactitas			Yaiza			
160	LZ/YZ-49	IC1035	Cueva del colapso de Los Hervideros			Yaiza	Sea cave		Speleo NL, En estudio

The volcanic caves of Auckland, New Zealand
Part 2 – Innovative exploration, documentation and protection measures

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Abstract

New Zealand's largest city, Auckland, is built on and around more than 50 volcanoes. Some of the volcanoes produced basaltic lava and in those lava flows, more than 250 caves have been documented since the 1960s. Unfortunately, many of the caves have been damaged or destroyed as the city has grown. However, in recent years the outlook has improved through a combination of new planning regulations, close liaison between government and speleos and the use of new technologies. The result has been new cave discoveries, more rapid documentation and assessment processes and improved protection for many of the newly-discovered caves. This paper outlines the current planning and assessment environment and presents a number of case studies where use of new technologies (laser scanning, underground 3D photogrammetry, sophisticated processing software and Geographic Information Systems) have permitted rapid mapping, documentation and assessment of new caves that are discovered during building and construction works in the city.

Keywords: volcanic caves; 3D mapping technologies; cave assessment and protection.

Introduction

New Zealand is a tectonically active group of islands. It sits astride of the boundary of the Australian and Pacific tectonic plates and it is an intermittently-active volcanic area. However, it is only the Auckland area that has the right type of basalt to form caves. Within the city area there are 53 volcanic centres (Hayward, 2019). Some are explosion craters, while others have extensive lava flows topped with a scoria cone (Figure 1). The volcanoes are small, monogenetic and range in age from 200, 000 to 500 years old. The base of the cones and craters vary from sea level to about 100 metres and rise to a maximum height of some 200 metres. Many of lava flows contain typical volcanic caves, or lava caves, or pyroducts as they are sometimes known. Many of the caves lie within one or two metres of the surface. More than 250 entrances have been located. The caves are generally quite short, with the longest recorded cave found to date being 290 metres in length.

In the Early Days

The volcanic caves of Auckland have been known and used by the Maori People for countless generations. Some caves contain middens - accumulations of sea shells that are the remains of meals eaten in or close to the caves. Remnants of stone walls suggest several caves were used for habitation or defensive purposes. Other caves were used as burial sites but little evidence of this still remains.

After the arrival of Europeans, many caves and their important archaeological contents suffered badly. Some caves were used as convenient rubbish dumps, or filled in to facilitate road and building construction. Others were used for survival shelters or for commercial purposes, such as for mushroom farming.

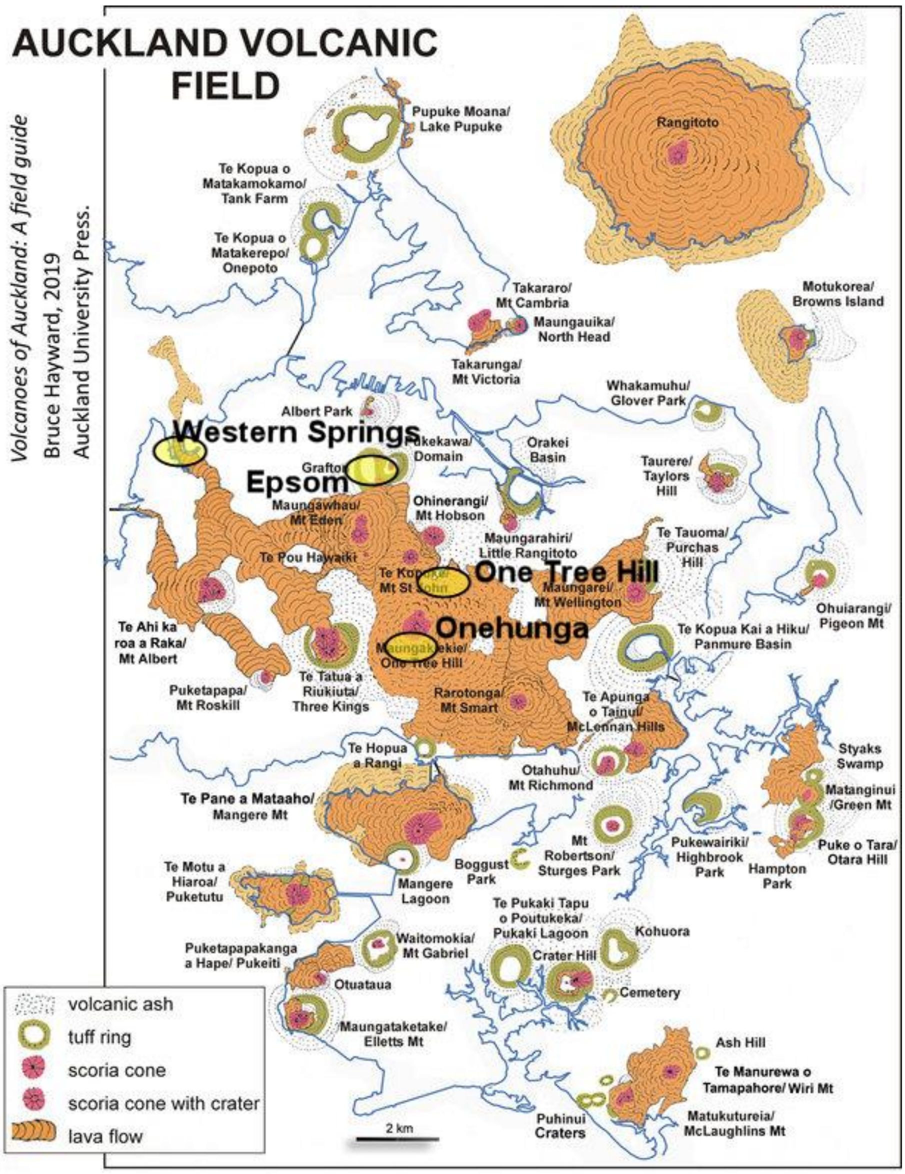


Figure 1. Auckland Volcanic field showing the four areas of the city covered by this paper (From Hayward, 2019).

By the 1960s, all the open caves had been found, but many of them were in poor condition. A local caver, Les Kermode, developed an interest in the caves. He commenced documenting them and, concerned about their state, began to talk to the Auckland Council. A few caves were put on a heritage list, including Wiri Cave (Figure 2) which eventually received protection as a scientific reserve.

Figure 2. Wiri Cave, with 290 metres of passage is the longest and one of the most impressive volcanic caves in the Auckland area and is protected within a scientific reserve.

In the 1970s, Peter Crossley commenced a project to survey all the caves he could find. He found it was difficult to accurately plot entrance locations in relation to property boundaries as, by today's standards, the property maps were primitive. The project is still continuing but the discovery and documentation tools, and also interactions with authorities, have evolved.

21st Century developments

In November 2008, a multi-agency, transdisciplinary collaborative research programme called DEVORA (**De**termining **Vo**lcanic **R**isk in **A**uckland) was established to improve assessment of volcanic hazards and risks in the Auckland metropolitan area and to develop a strategy and rationale for appropriate risk mitigation. Some years later, DEVORA extended its interests to include volcanic caves and Peter Crossley had already compiled much of the information the organisation was seeking.

In many ways, 2014 was a pivotal year for volcanic caves in the Auckland area. The New Zealand Speleological Society (NZSS) devoted a whole issue of its bulletin to the caves (Crossley, 2014), covering all known caves, along with photographs and locations. A copy was given to the Auckland Council. Peter Crossley also gave copies to interested developers. Crossley held the view that while limestone caves across the country were best protected by not revealing their locations, volcanic caves in the city were best protected from bulldozers and diggers by letting the authorities know exactly where they were.

In 2016, Auckland Council started to implement new planning regulations (*The Auckland Unitary Plan*) to replace a plethora of former regional planning policies and plans. Key elements of the new plan were to guide the use of Auckland's natural and physical resources by determining what can be built where, how to create a higher quality and more compact city while protecting rural activities and maintaining the marine environment. Implicit in the plan was an acknowledgement that the population of the city would continue to grow strongly in coming decades.

Under the Unitary Plan, it became a requirement for any accidental discovery of a void (a cave!) bigger than a metre in diameter to be reported to council. This has resulted in the reporting and subsequent documentation of many new caves.

Also in 2016, Peter Crossley featured in a short biographic film that prepared him for having a more public persona as he became the go-to source for information and comment on the caves.

As Google Earth imagery became more detailed, it became possible to superimpose cave maps on the imagery to see where caves lay in relation to streets and buildings. Geographic Information Systems (GIS) also became more widely available. For example, Auckland Council developed a comprehensive GIS site where a considerable amount of information is freely available to the public, including detailed aerial imagery, topographic cadastral maps and planning information.

In 2017, Crossley met up with Chirag Jindal, a brilliant Architecture student, who introduced Peter to LIDAR (**Li**ght **D**etection **a**nd **R**anging), or Laser scanning of volcanic caves (Figure 3) to produce highly accurate and detailed 3D maps. Chirag turned out to be a very talent artist as well, which was useful for rendering detail on the LIDAR images. Together they received a $15, 000 grant to 3D scan 10 caves. This was later followed by a further grant of $10,000 from Auckland Council to survey a further 10 caves. An exhibition in the popular city waterfront area showcased the cave maps and brought the city's caves to the attention of local residents and also enhanced Crossley's standing with Council.

Around this time, Crossley was introduced to 3D cave photogrammetry when he attended the 17th International Symposium on Vulcanospeleology in Hawaii (2016) and the International Congress of Speleology in Sydney (2017). Since then, Peter has captured 3D photogrammetry of more than 150 caves in the Auckland area.

Figure 3. Chirag Jindal with his 3D Lidar, or Laser scanning equipment, which is used to capture data that is used to produce highly accurate and detailed 3D cave maps.

In mid-2022, Devora and Auckland Council agreed to provide funds for a masters student to geo-reference all the volcanic caves in the Auckland area so that details can be added to their GIS database. This project will rely heavily on Crossley's data and is likely to require his close supervision. When the cave data is added to the Council's GIS, it will be hidden to the general public but those in the council with a need to know will be able to red flag appropriate properties.

Equipment used

In this new era of cave discovery and documentation in Auckland, a range of innovative - and also novel - tools is being used.

Cave discovery tools

a) Excavators (or backhoes) have proven to be a very useful cave discovery tool. While going about their normal business of general earthworks on building sites and digging trenches for water and other utility pipes, it is not uncommon for the machinery to break through into cave passages lying within a few metres of the ground surface.

b) A Tunnel-Boring Machine (TBM) is being used on parts of a major project to renew and expand Auckland's water supply infrastructure. The work includes a major new pipeline to the city area from storage reservoirs in the Hunua Ranges southeast of Auckland. The TBM, working at greater depths than can be reached with excavators, has intersected a number of voids in lava flows at depths of 6 to 20 metres beneath the surface.

Cave surveying and documentation tools

LIDAR (**Li**ght **D**etection **a**nd **R**anging) equipment is used for scanning volcanic caves where there is a need for detailed and highly accurate 3D maps. While the results are excellent, the laser scanning equipment is expensive ($NZ60,000) and is difficult to carry into and use in small caves.

For many caves, it has been found that 3D photogrammetry is adequate for capturing a 3D image of the cave. The equipment is compact, relatively cheap and with practice, is quick and easy to use. A small digital camera is used to take between 100 and 1000 overlapping images, ensuring that each point in the cave is photographed at least twice from different locations.

The photos are loaded into Agisoft Metashape software where the images are automatically processed in several steps:

1. Aligning the photos using pattern recognition to form a sparse 3D mosaic and it then computes where the camera positions were.
2. It then fills in the spaces and computes a point cloud of xyz coordinates and joins up the nearest points.
3. Upon command it will go back to the original photos and drape colours and detail over the mosaic.

Magnetic orientation is obtained by either using a compass, aligning the plan view of the 3D image with a standard cave map, or by surveying a section of cave or surface features such as a road, fence or a building.

Scale is determined either by placing a scale ruler in the area to be photographed, or by placing two markers in the cave a known distance apart and subsequently searching for them in the combined image. A free cartographic drawing program is then used to produce scaled and oriented views, in other words maps, of the cave.

New planning environment

As noted above, in 2016 Auckland Council commenced introducing the Auckland Unitary Plan under which it became mandatory for any accidental discovery of a void bigger than a metre in diameter to be reported to council. When this happens, it has become standard practice for council to then notify Peter Crossley.

Whenever a cave is discovered at a building or excavation site, Crossley goes there, determines the extent of the cave and does a 3D photogrammetry survey. With his simple equipment a scan can be completed in less than an hour. He then writes a report and recommends whether the cave should be saved or not.

Copies of the report are provided to heritage, environment and archaeology experts in Council and, if the cave is on private property, to the landowner or site developer. If the cave needs further surveying for building purposes, Chirag Jindal follows up with a Lidar scan to produce a 3D geo-referenced map showing both surface and underground features.

Peter does not charge developers for doing the initial survey and preparing a report, but receives recompense is in terms of exploring the new discoveries and in expanding the speleo community's knowledge of Auckland's volcanic caves.

If Council decides a cave should be protected, the ideal outcome is for a permanent entrance point to be installed, in other words an access point with a lid (a manhole). This provides ongoing access for monitoring and research purposes. Even if a decision is made not to install a permanent entrance to a cave worthy of protection, at least the precise location and extent of the cave is recorded for reference purposes and leaves open the possibility of creating an access point at a future point in time.

Case studies

The following examples cover the range of sub-surface voids that have been accidentally discovered by excavators or TBM and documented and in some cases saved, over that last several years.

<u>1. Selwyn St, Onehunga</u>

A cave on private property in Selwyn Street was discovered in 2015 when the owner was supervising shallow trenching work for a new water pipe in advance of redevelopment work. The discovery was reported to Auckland Council.

After being contacted by Council, Peter Crossley visited the cave with the property owner and his son. They soon established the cave was much longer than the 50 metres that the development surveyor had estimated. Peter later returned to the cave with Ian Mander, a fellow NZSS member, to do a compass and tape survey and to photograph the cave. The surveyed length of the cave is 122 metres, but it is probable the passage continues at the eastern end beyond a soil blockage (Figure 4). The cave is mostly 5 to 8 metres wide and 1-1.5m high, with a maximum of 3 metres (CROSSLEY, 2017).

Boreholes sunk by the developer that pierced the cave roof were used to better align the map with the surface boundaries. Two 3D laser surveys of the cave were subsequently completed in 2018-19 and the results were provided to the developer of an adjoining property, where there were plans to replace an existing house with a block of apartments. This subsequently happened (Figure 5).

Figure 4. Google Earth imagery showing the location of Selwyn Street Cave in relation to nearby buildings at the time the cave was discovered in 2015. The cave probably continues to the east beyond a soil blockage.

Figure 5. Google Earth imagery from early 2022 showing the dramatic urban redevelopment that has taken place in the vicinity of Selwyn Street Cave over the past seven years. The cave remains accessible via a permanent access point in a driveway.

The cave roof is mostly solid basalt with only occasional cracks and there is very little collapse material on the floor and there is only a small amount of mud in one area. The cave had never had an open entrance so there is no rubbish in it and the wall and ceiling features are in excellent condition (Figure 6). Some of the features are the best examples in the Auckland area.

As the rock around the break-in point was fractured during the trenching work, it was initially recommended that an alternative location should be sought for a permanent access point. The far end eastern end of the passage was selected and a rod was pushed up through cracks in the roof and through 80 cm of soil to the surface. At the time this seemed like the best location. However, with admirable foresight, the permanent entrance point was installed close to the original break-in point - and is in a concrete driveway - and the preferred location now lies beneath an apartment block. The developer of the apartments made use of the 3D survey to design foundations that avoided the cave passage.

This is a good example of a discovery on private property that was provided with a permanent access point and where co-operative liaison with property developers achieved a good outcome for the cave as well as for the city's urban renewal aspirations.

Figure 6. Passage in Selwyn Street Cave showing solid basalt floor and walls in excellent condition.

2. Ngatiawa Street, One Tree Hill

In 2015-66, construction work was underway on the Hunua 4 pipeline, which is one element of a major project to upgrade the city's water supply infrastructure to increase resilience and meet future demands. The pipeline is a 1.9 metre diameter steel pipe sunk into a 4 metre deep, 3 metre wide trench. The route through Onehunga traverses around the south eastern slopes of One Tree Hill (Maungakiekie), a prime area for volcanic caves.

Some caves were already known near the route that had been designed to avoid them, but there was always a good chance a previously unknown cave would be intersected. This occurred in Ngatiawa Street, near the junction with Rawhiti Street. Various geophysical techniques, such as seismic and ground penetrating radar surveys, were used in advance of the pipeline trench, but based on a combination of local knowledge, a hunch and a small borehole that struck a cavity, a decision was taken to excavate an exploratory hole (Figure 7).

The exploratory hole revealed a passage 1.8 metres high and 7 metres wide. Preliminary explorations revealed it to be a significant cave, so appropriate work health and safety, and confined spaces certificates had to be obtained before the cave could be properly explored, surveyed and photographed by Peter Crossley and Ian Mander. In addition, a 3D laser scan of the cave was undertaken by contractors for Watercare, the Auckland water utility.

Figure 7. The cave passage revealed by an exploratory hole dug in Ngatiawa Street after preliminary investigations suggested a high likelihood of a cavity.

The cave has a surveyed length of 65 metres (Figure 8). It has an average width of 7 metres (maximum of 12 metres) and averages about 1.6 metres in height, lowering to 0.6 m at the western end (CROSSLEY, 2015). The cave has a loose a'a floor and is in very good condition, apart from where the excavator broke through into the middle of the cave and, at the eastern end where there is recent damage from housebuilding work. This comprises a minor storm water drain and another breach that had been backfilled with basalt boulders. The roof is solid basalt, but with a few cooling joints, and shows no signs of stress under the road in spite of 60 years of traffic and recent heavy earthmovers.

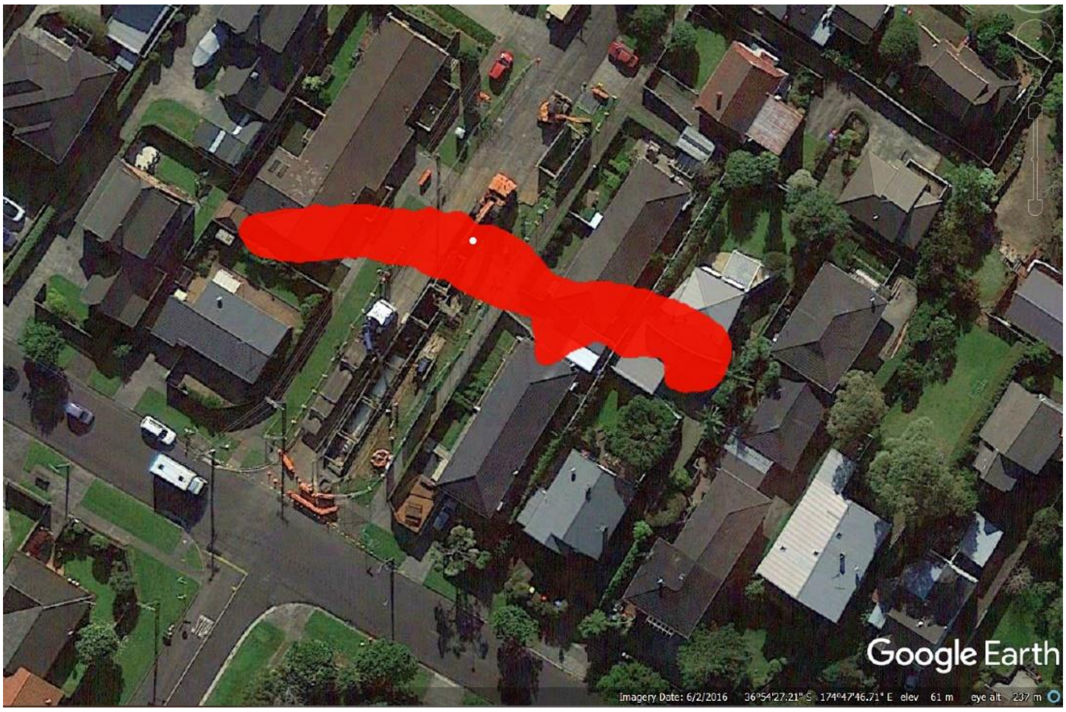


Figure 8. Google Earth Imagery taken during the construction of a water supply pipe in Ngatiawa Street, with an overlay showing the extent of the cave discovered. A permanent access point, indicated by a white dot, has been installed in the roadway.

Following recommendations to Council, a permanent access point was installed at the breakthrough point in the middle of the roadway.

3. Edgerley Avenue, Epsom and the water supply tunnel

In 2020, Peter Crossley and Chirag Jindal were called out on several occasions to inspect features discovered during construction of the long Hunua water supply tunnel.

The tunnel is being excavated by a tunnel boring machine approximately 3 metres in diameter and it is then lined with concrete pipe having an internal diameter of 2.55 metres. The concrete pipe is prefabricated on the surface in 3 metre lengths, lowered into the tunnel through access shafts, added to the tail end of the pipe and then hydraulically rammed forward towards the TBM (Figure 9).

Figure 9. View of hydraulic equipment pushing prefabricated sections of concrete pipe along a tunnel bored for the Hunua water supply pipeline project.

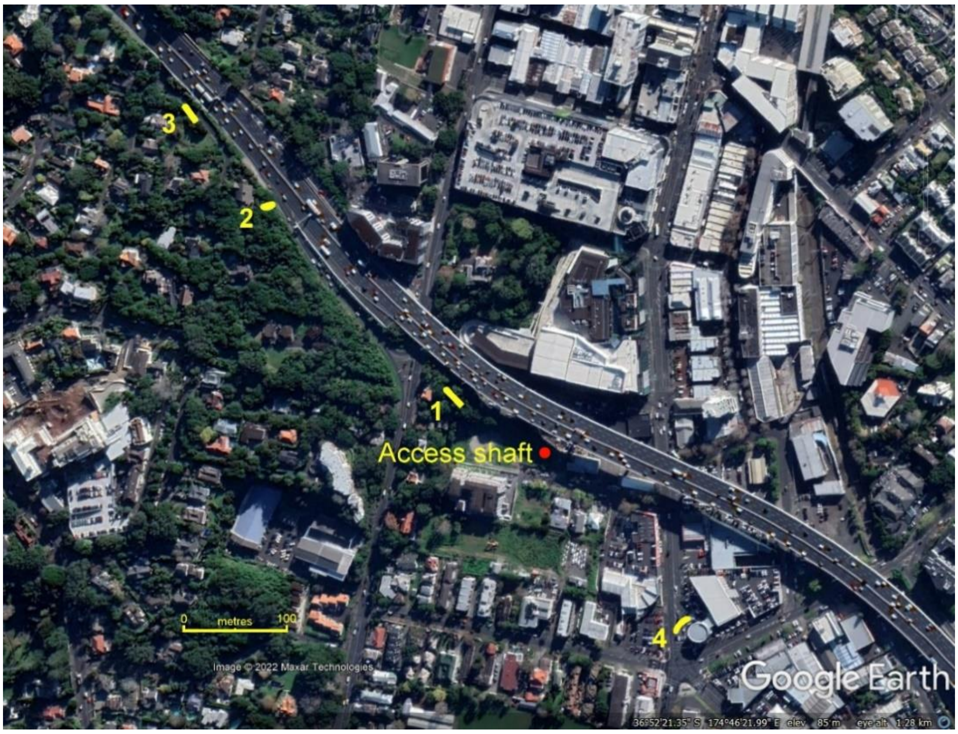
On each occasion Crossley and Jindal entered through an access shaft on Edgerley Avenue and used photogrammetry and a 3D Laser scanner to document voids at four sites along the tunnel. Safely considerations precluded them from fully exiting the tunnel to fully explore the cavities.

Three voids were in a northwesterly direction from the access shaft (Figure 10), with the most distant being some 470 metres from the access shaft. All three voids were at a depth of about 20 metres. The fourth void was in a southeasterly direction from the access shaft and was about 6 metres below the surface (CROSSLEY, 2020a).

Two voids (numbered 2 and 4 on the map) were discovered as the revolving cutting head of the TBM slowly advanced. These voids could only be studied through small (25cm square) inspection and maintenance ports in the cutting head while it was not rotating.

Void 4 was the largest cavity viewed through the cutting head (Figure 11) and it appeared to be a true lava cave with a glazed lining. The TBM intersected the passage at an angle of about 45 degrees. Crossley and Jindal pushed a camera through the inspection ports in the cutter head to determine its shape. The passage appeared to be 5-6 metres wide and 1-2 metres high. The full extent of the passage could not be seen or measured, but appeared to be at least 20 metres long.

Figure 10. Google Earth imagery showing the location of a tunnel access point on Edgerley Avenue and of four voids intersected by a Tunnel Boring Machine during construction of the Hunua pipeline tunnel.



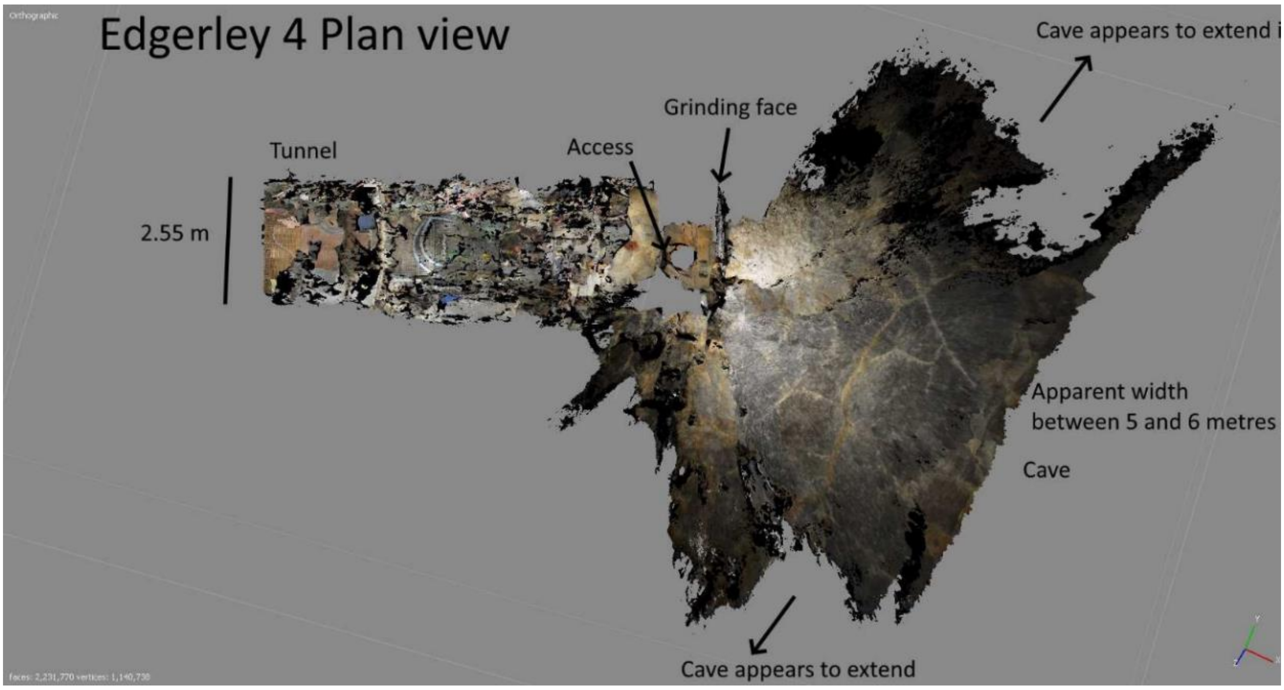


Figure 11. 3D photogrammetric image of Void 4 intersected by the TBM. The cavity appeared to be 5-6 metres wide and possibly 20 metres long.

Two of the voids (1 and 3) only become apparent after the concrete tunnel lining was breached, apparently by loose rocks that appear to have fallen onto the concrete pipe from the intersected cavities. It is hard to conceive how the thick concrete lining could have been directly breached by falling rocks. More likely, the concrete was damaged as the lining was being pushed forward and rocks became wedged between the lining and a narrowing section of tunnel – perhaps at the end of a cavity.

Crossley and Jindal could only view the cavities by poking their upper bodies and equipment up through the pipeline holes, which had been manually enlarged to facilitate closer inspection, assessment and repair (Figure 12).

Figure 12. A view from inside the damaged concrete lining of the Hunua Tunnel. The hole was created while the pipe was being pushed along the tunnel. The hole has been enlarged to facilitate inspection, assessment and repair work.

Void 1 was another lava cave with a glazed lining. It appeared to be running parallel to the direction of the tunnel.

In Void 3, the walls appeared to be semi-welded scoria and no glazed lining was observed. The cavity extended in both directions along the line of the tunnel. It was not possible to tell if the passage (Figure 13) was a real lava cave or was just an artefact of the unconsolidated rock spalling down onto the tunnel roof and being carried away by the conveyor belt as the pipe was being driven forward.

The opportunity provided by Watercare to observe and record and the voids was greatly appreciated. However given the depth below the surface, it was not feasible to provide a means for ongoing access to any of these voids.

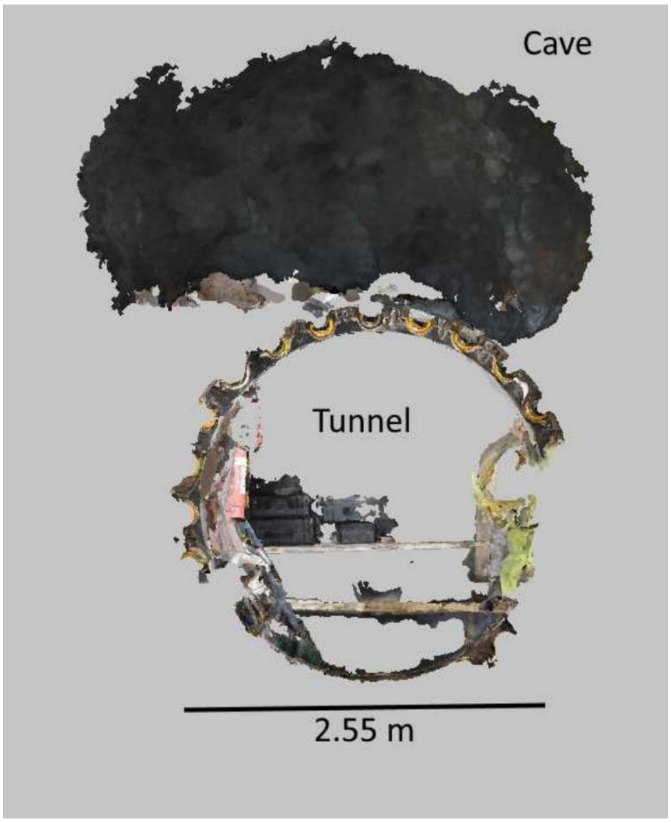


Figure 13. Composite cross sectional image showing Void 3 in relation to the tunnel position.

4. Western Springs Park

In November 2020, Peter was invited to accompany two Auckland City Council employees to inspect a cave that was discovered during construction work at a children's playground in Western Springs Park. The site is between a lake and the Auckland Zoo.

The cave is small, approximately 5 metres in diameter, and 3 metres high with a minimum roof thickness of just 0.5m (Figure 14). The walls are of solid basalt, similar to other exposed rock in the area. Large flakes of basalt had flaked off the ceiling/walls while the rock was cooling. It did not have the appearance of a lava tube and there was no sign of a glazed lining on the walls or ceiling (CROSSLEY, 2020b). The rock around the entrance was however, slightly frothy, perhaps indicating a release of pressure and suggesting the cave may have been formed from gas pressure as the lava flowed over a boggy area. It is the only cave known in the lower part of the flow.

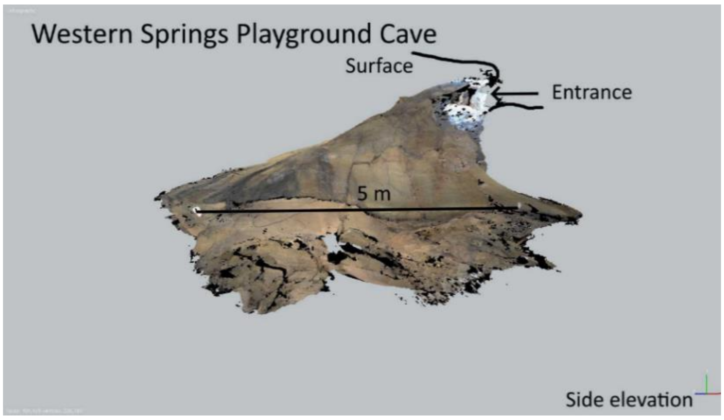


Figure 14. Photogrammetric image of Western Springs Playground Cave

Geochemical studies have indicated that the lava flow containing the cave originated at Mt St John volcano. The flow is the longest in the Auckland area and extends beyond Western Springs and into Auckland Harbour, where it is known as the Meola Reef, a feature clearly visible from aerial imagery (Figure 15).

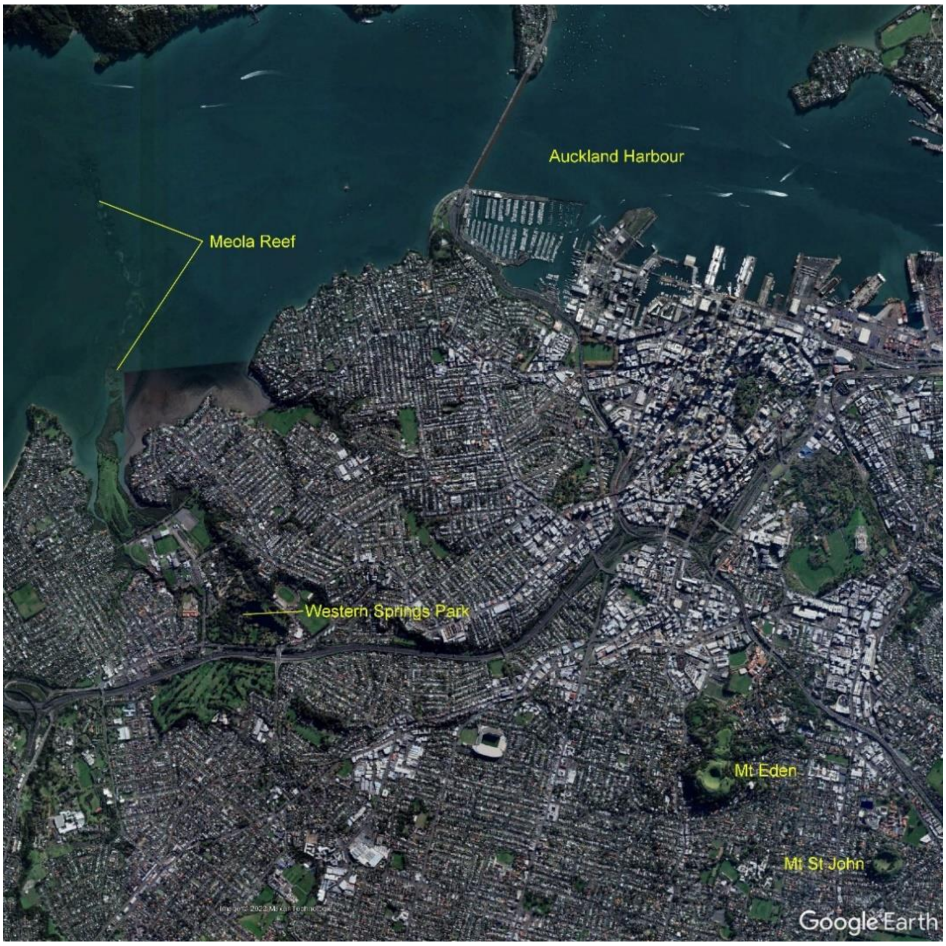


Figure 15. Google Earth Imagery showing the location of Western Springs Cave and the extent of the lave flow in which it formed. The flow originated at Mt St John and extends beyond Western Springs and into Auckland Harbour where it is known as Meola Reef.

Although the roof of the cave is very thin, it does not appear to be in danger of collapse, provided that heavy earthmoving equipment does not excavate over the top.

Because of its size, the cave has no recreational interest, but as it may be of future scientific interest, the location was recorded, the entrance covered with a steel plate and then covered with soil.

This is an example of a cave that is worthy of protection but which does not need to be readily accessible.

5. State Ave, Onehunga

In February 2022, Auckland Council invited Peter Crossley to inspect a cave that was discovered in State Ave during excavation works for a new water pipe. Peter met onsite with Council employees and after checking the entrance for safety, he entered, explored and surveyed the cave to the end. The entrance area was surveyed a few days later. The 3D survey of the cave was performed with a digital camera and processed with Agisoft Metashape software.

The was no indication the cave had ever had an entrance and hence there was no evidence of previous visitation or archaeological material.

The cave is only about 35 metres long, up to 3 metres wide and one to two metres high. It is extremely good condition and has many fine features including lava rolls along the wall/floor (Figure 16), lava drips and an unspoilt 'porridge-like' floor (CROSSLEY, 2022b). The cave starts near the footpath and curves around under the driveway by the boundary fence (Figure 17). One edge extends under the back corner of the house. There do not appear to be many cooling cracks in the roof, and it appears to be very stable.

Figure 16. Interior view of State Avenue Cave showing lava rolls.

The cave is located halfway down the southern slopes of Maungakiekie/One Tree hill, a large volcanic cone of about 60,000 years old. The area is covered by suburbia, which is presently being re-developed by infill housing.

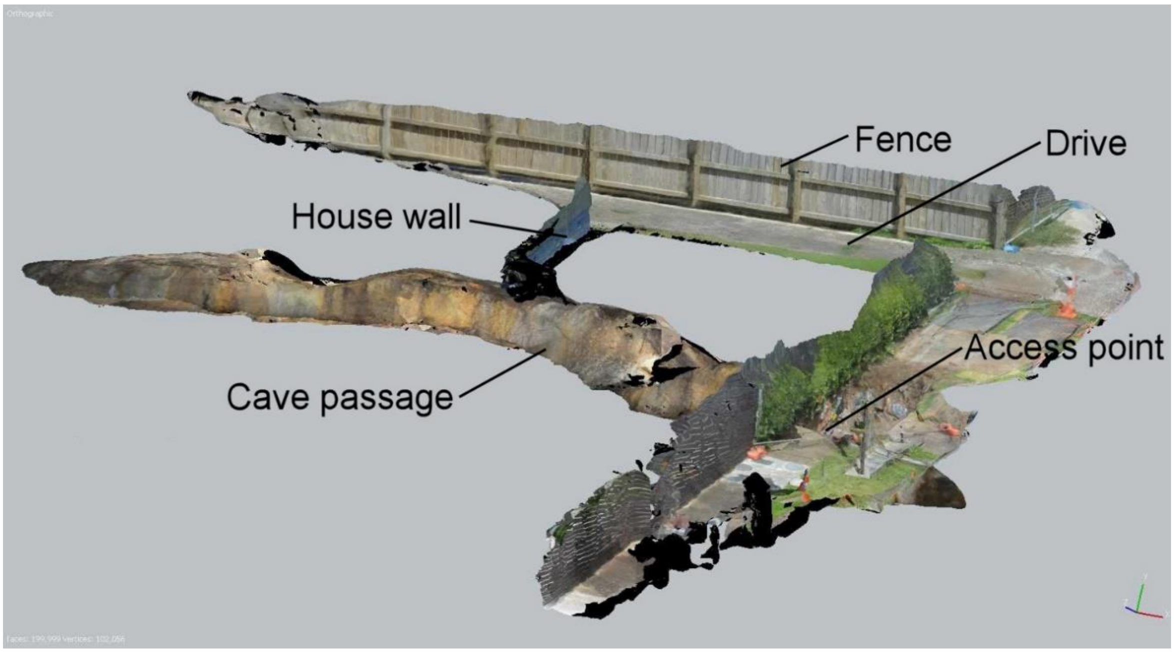


Figure 17. Composite 3D photogrammetric image showing the location of State Avenue cave in relation to the nearby house, boundary fence and other features.

This cave was assessed as being worthy of protection as it has not been damaged or despoiled, it is safe to enter and has a good range of lava cave features and the pipeline was deviated around the cave passage. In addition, it was recommended that a permanent entry point (manhole access) was installed to provide ongoing access for scientific study, for speleologists and photographers. Auckland Council has agreed to do this but at the time of writing, the access point had yet to be completed (Figure 18).

Figure 18. Google Street View image showing where the pipeline was deviated away from the cave passage. The permanent access point will be installed near the front fence of the property.

It is an excellent example of what can be discovered, documented and protected under the recently implemented Auckland Unitary Plan.

6. Roosevelt Ave, Onehunga

In mid-October 2022, a small void was encountered during trenching work for a water pipe along Roosevelt Avenue (Figure 19). The site is about 500 metres from the State Avenue site noted above.

The discovery was reported to Auckland Council and over the next few days, the site was photographed, surveyed using ground penetrating radar and photogrammetry. The cavity was about a metre in diameter and possibly as much as 5 metres long, about half of which could be accessed (CROSSLEY, 2022a). The investigations concluded the void was a collapsed lava tube lying about a metre below the surface.

The cave was assessed as being not worthy of special protection. After the investigations concluded, the trench was backfilled without installing a permanent access point to the cave

Conclusions

The volcanic cave exploration and protection scene in the Auckland area is advancing rapidly at the moment, even though all the caves with natural entrances had been discovered by the 1960s.

With cave-quality lava covering an estimated 50% of the Auckland city area, there is considerable scope for finding new caves as industry expands and as redevelopment of residential areas continues, particularly with infill housing and medium density developments.

The excavators used on construction sites are also getting larger and can dig deeper. Voids encountered by a TBM show that caves occur at deeper depths and are not restricted to within a few metres of the surface.

The use of 3D photogrammetry and Lidar scanners has dramatically changed the way cave maps are drawn and depicted and these tools have been of immense benefit in demonstrating where caves lie in relation to existing or proposed buildings and utility infrastructure.

The future looks good for Auckland's Caves, provided that developers continue to meet their legal obligations in reporting any discoveries so that they can be assessed.

Figure 19. Temporary access point to a small void discovered during pipeline work in Roosevelt Ave.

References

CROSSLEY, Peter. (2022a) Roosevelt Avenue Cave. Unpublished report, 19 October 2022.

CROSSLEY, Peter. (2022b) State Avenue Cave. Unpublished report, 20 February 2022.

CROSSLEY, Peter. (2020a). Edgerley Rd Watercare Tunnel. Unpublished report, 18 September 2020.

CROSSLEY, Peter (2020b). Western Springs Lava Cave Unpublished report, 22 November 2020.

CROSSLEY, Peter (2017). Selwyn Street Cave. Unpublished report, 5 September 2017.

CROSSLEY, Peter (2015). Ngatiawa Cave, One Tree Hill. Unpublished report, 15 December 2015.

CROSSLEY, Peter (2014). Inside Auckland Lava Caves. *Speleological Bulletin*, Vol 11,No 208 Published by the New Zealand Speleological Society Inc. 60pp.

HAYWARD, BW. (2019). *Volcanoes of Auckland: A field guide*. Auckland University Press.

Discoveries on the lava flows of north Mauna Loa, Hawaii, 2016-19

Dave Bunnell

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Abstract

This visual presentation outlines exploration in four different flows on Mauna Loa's northeast rift zone that border each other: the 1843, the 1935, the 1855, and a 5000 year-old flow that has turned red from oxidation, which we call the Big Red flow.

I've been working the 1843 flow for over 20 years and it has a couple of dozen well-decorated caves. It yielded a true gem in 2016, Dixie's Delight, a 300-foot long cave with a forest of lavacicles festooned with crystal growths. Beyond a short dig, a passage floored with unusual red dendritic pahoehoe ended in a lava sump.

In the Big Red flow, we ascended to a major rift with collapsed caves, but in the side wall an opening unexpectedly descended in a multi-hued, mineralized passage that ended after 300 feet (Brunet-Bunch Cave). In the fall of 2019 we ascended the flow to an area below the vent and surveyed Red Top Cave, also heavily mineralized.

In the 1935 flow we surveyed 265-foot-long Cocktail Cave, a large room with a short side passage where long strands of red Pele's Hair were draped over lavacicles, one over a foot long from ceiling to floor. Below it on the flow we found two significant caves and two pits to descend and survey on a future trip.

On the 1855 flow we used vertical gear to drop into a borehole that unexpectedly started dropping steeply, bypassing a large puka just downflow. An icy wind blew steadily in it. After 1700 feet a belly crawl opened stopped us for that trip. We named it Promised Land as there are no visible entrances on the surface for several miles, and a depth potential of over 2000 feet. In Fall of 2019 we returned, barely slide through the crawl, and found another thousand feet before the passage got too low to follow. On the next trip we will attempt to access the cave system from the bottom end.

Selected images from the presentation:

Crystal growths on lavacicles in Dixie's Delight Cave in a lava flow dating from 1843.

Unusual red dendritic pahoehoe floor in Dixie's Delight Cave.

Secondary mineralisation in Brunet Bunch Cave in the 5000-year-old Big Red flow (left and below).

Heavily mineralised passage in Red Top Cave, Big Red flow.

Strands of Peles Hair in Cocktail Cave, 1935 lava flow.

Passage in Promised Land Cave in the 1855 flow.

Promised Land Cave in the 1855 flow.

Caver descending Lava Ball Pit.

Inside the volcanoes

Franz Lindenmayr

Abstract

This presentation is a spin-off of a lecture at the Rotary Club in Gröbenzell in autumn 2022. The aim was to present the world of volcanoes and caves in volcanic material to a wider public.

Starting point was an exhibition at the Diözesan Museum in Freising, named "Dancing on a Vulcano", which showed many connections between man and Mt Vesuvio near Naples in Italy – from the eruption of the volcano to the destruction of Pompeii and Herculaneum over the many religious rites like praying and processions to the modern approach of measuring which began after the time of enlightenment.

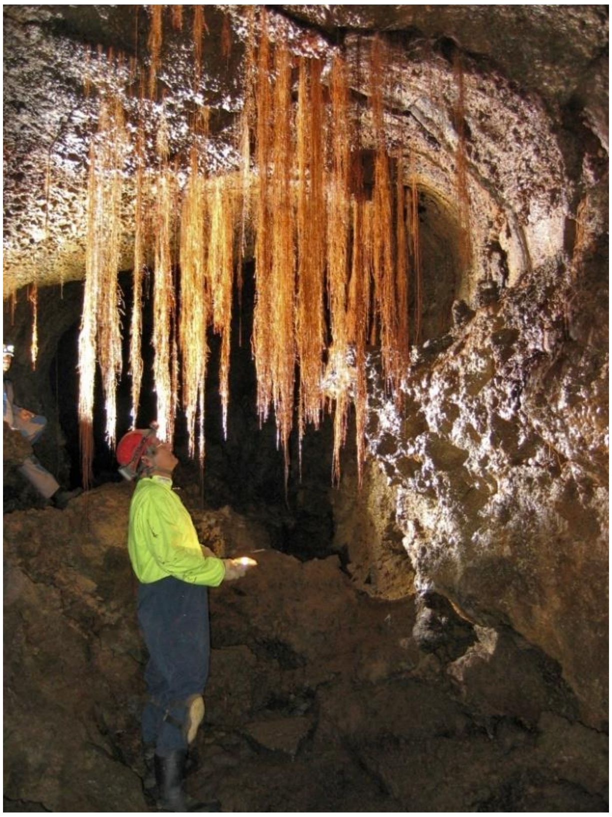
A trip round the world in about 100 photographs started with stops on many different continents and countries: Australia (Undara), New Zealand (Auckland, Mortimer's Cave), Japan (Mt. Fuji), Costa Rica (Arenal), Ecuador (Galapagos/ Triple Volcan), US (Hawaii/ Kazumura Cave), Iceland (Surtshellir, Thrihnukagigur), Germany (Parkstein), Scotland (Fingal's Cave).

Often the outside and the inside were contrasted side by side to open up new perspectives which are not possible in the so-called reality. Normally they are well separated. Here they were united to make a unique impression on a PowerPoint page.

The underworld is normally characterised by complete darkness. Modern digital cave photography makes it now possible to lighten it up in ways which have never been used before. You can often admire a cave better on a photograph than when you are there yourself. As a photographer you are sometimes surprised yourself when you have the first look at the little pictures which are more than just documentations, they become pieces of art.

Volcán Arenal, Costa Rica

Kazamura Cave, Hawai'i



Mortimers Cave, Auckland, New Zealand

Kirkjan Cave, Iceland

Buri Cave, Iceland

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VNMN

UIS Union Internationale de Spéléologie