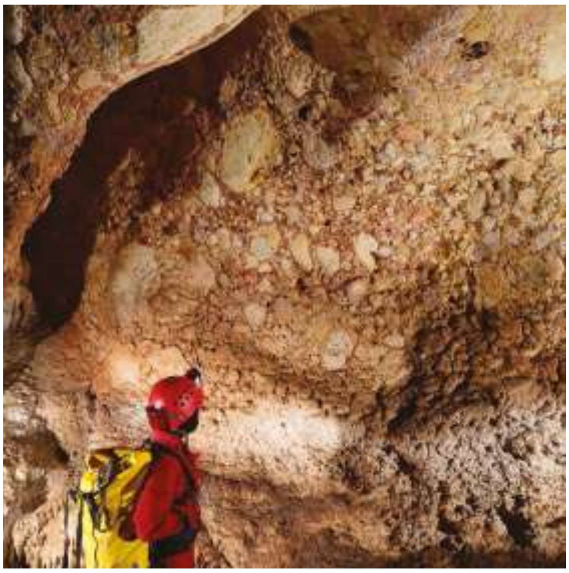
18ème congrès international de Spéléologie - 18th International Congress of Speleology

SCIENTIFIC CONFERENCE

Le Bourget-du-Lac – July 2022

PRE-PRINT 2021

SYMPOSIUM 11
Pseudokarst



Pseudokarst in igneous rock of Far West Texas, USA

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Abstract

Rising 100 meters above the floor of the Chihuahuan Desert, approximately 50 km east of the Texas city of El Paso, are 3 isolated sharp igneous hills. Covering nearly 350 hectares, they are within Hueco Tanks State Park and Historic Site. The Texas Speleological Survey and Texas Parks and Wildlife Department approved this survey of pseudokarst features at Hueco Tanks. Observed speleogenesis described here includes crevice fractures, talus voids and gravity sliding voids. Cave passage morphology is typically high, narrow canyon with frequent skylights. Subsequent chemical weathering likely plays a role in passage form and dimension. The relatively uncommon host rock is syenite porphyry which was part of an igneous intrusion dated at around 32 Ma.

Notable in the existing eroded masses are the extensive fractures of the rock and the numerous hollows (*huecos* in Spanish) that create a natural collection system for the infrequent rainwater. The availability of water in the semi-arid (precipitation < 25 cm per annum) region accounts for the presence at Hueco Tanks of significant cultural features, some of which enter into the ongoing study of the pseudokarst. For example, Cave Kiva's ceiling contains exceptional examples of the ancient pictographs for which Hueco Tanks is famous. At this writing, 3 of the 8 significant caves have been surveyed with a total length of over 500 meters.

1. Introduction

Approximately 50 km east of the west Texas city of El Paso and a like distance northeast of the international border with Mexico are 3 isolated igneous hills (Fig. 1) which rise over 100 meters above the floor of the Chihuahuan Desert, the largest desert in North America. The exposed igneous rocks cover an area of nearly 350 hectares and have been protected within the boundary of Hueco Tanks State Park and Historic Site since 1969. Based upon a 2015 volunteer agreement between Texas Parks and Wildlife Department (TPWD) and the Texas Speleological Survey, a study of the Hueco Tanks pseudokarst was initiated.

The three types of caves observed at Hueco Tanks are crevice-type fractures, talus voids and gravity sliding voids. The longest surveyed caves are developed along major fracture planes, with accompanying linear passages. Passage morphology is typically high, narrow canyon with frequent skylights. Chemical weathering of the rock likely plays a major role in ultimate passage form and dimension.

In terms of a geologic setting, the relatively uncommon rock of Hueco Tanks is a syenite porphyry which was part of an igneous pluton intruding the overlying Permian limestone around 32 Ma. Notable in the existing eroded masses are the extensive fractures in the rock and the numerous hollows (*huecos* in Spanish, Fig. 2) that create a natural collection system for the infrequent rainwater. The term "tanks" here refers to water storage. The regular availability of water in the semi-arid region (precipitation <25 cm per annum) accounts for the presence at Hueco Tanks of significant cultural features, some of which are examined in our study of the pseudokarst. Archaeological study indicates the regular occupation of the Hueco area for an estimated 10,000 years. The presence of water led to establishment of an 1850's Butterfield Overland stage station and a ranch later. Today Hueco is most renowned for thousands of indigenous pictographs on the rock walls and cave ceilings, some dating back 6,000 years to the North America Archaic Period. Also made famous as a rock climbing venue, the earliest free climb was recorded in 1839, as a Native American raiding party, trapped by militia in Kiowa Siege Cave, climbed through a skylight and escaped. Modern tensions have subsequently arisen on the recreational use of land considered sacred to some indigenous peoples.

2. Materials and methods

The initial pseudokarst survey was undertaken by members of the Mesilla Valley Grotto of the National Speleological Society using hand-held Suunto compass and laser range finder. To supplement the available manpower, park tourists were recruited from guided tours and taught the basics of cave survey. More recently, survey was conducted using the DistoX2. Given the nature of the site, there is a considerable body of literature relating to the cultural aspects of the caves. Several books have been published on the location and technique of climbing (termed bouldering) routes within Hueco Tanks. Some of the names used for climbing routes have been applied to the caves involved.

Figure 1: Hueco Tanks location & topographic map.


Figure 2: Numerous small huecos in the syenite porphyry rock. Photo K. Steiner.

3. Results

The known pseudokarst features within Hueco Tanks were prioritized for survey based upon their interpretive (from the standpoint of the park) or speleological significance. Vertical development rarely exceeds 15 m and no rope work was required in these surveys. Based on the 3 significant caves mapped to date, over 500 m of passage have been booked. It is probable that a like amount of passage remains to be surveyed.

3.1. The caves which have been mapped:

	Location	Length
Cave Kiva	upper North Mtn	45 m
Cueva de Leon	North Mtn	123 m
Kiowa Siege Cave	East Mtn	345 m

3.2. Remaining to be surveyed:

Comanche Cave	<100 m
Dragons Pen	<100 m
Kiowa Siege Cave (upper level)	<100 m
Gold Mine Cave	~100 m
Life Begins at 40	~100 m
Unnamed West Mtn. cave	~100 m

4. Discussions

4.1. Cave Kiva's ceiling contains exceptional examples of the pictographs for which Hueco Tanks is famous. This is a featured rock art venue within Hueco Tanks and contains 8 "mask" images attributed to the Jornado Mogollon (*circa* 600 CE) civilization. There are strong ties to Mesoamerican imagery and associations with water in these pictographs (Fig. 3).

The entrance to Cave Kiva is located on the sloping face of North Mountain about 50 meters above ground level. The genesis of this small cave appears to be gravity sliding with the roof moving from higher on the mountain. After crawling through the unremarkable entrance one slides about 10 m along the sloping floor of very polished rock. The polish was likely made by the passage of many visitors over more than a thousand years. The ceiling remains only about 1 m high until reaching the first bell-shaped ceiling *hueco*. The artist here placed the images along the sides of the *hueco*.

4.2. Cueva de Leon (Fig. 4) is one of the more accessible Hueco Tanks caves, as the entrance is at ground level in the only section of the park, North Mountain, allowing unsupervised public access. Formed by crevice fractures within the large Buttress cliff face, two of these meet at right angles to form the largest chamber. Daylight penetrates most of the cave through skylights at the north end. The main fauna observed during the survey are the thousands of cave crickets (Rhaphidophoridae) which densely cluster in the Harvestmen Hall side passage and make the walls of the cave there appear to be moving!

While the main passages formed by crevice fracture of the rock, their walls show little sign of breakage, but instead are relatively smooth. Likely, in Cueva de Leon, this can be attributed to chemical weathering as a film of water naturally infiltrates and moves down. Previously noted at Cave Kiva and seen elsewhere in the park, human action has worn the naturally rough rock surfaces smooth.

Figure 3: Cave Kiva mask pictographs. Image scale is slightly smaller than actual human face. Photo A. Moses.

4.3. Kiowa Siege Cave is located at the south end of Mescalero Canyon on Hueco's East Mountain. Access to this area is by guided tour. This was the first location at Hueco Tanks where modern graffiti on the rock at the ground-level entrance was removed using laser.

The north end of the cave is formed by large voids within the talus blocks. This creates a 3D maze of several levels.

Heading south from the entrance, the cave reverts to a single high, narrow canyon following the linear fracture. There are many skylights which decrease to the south.

From a historical perspective, this may be the most significant cave in Texas. Kiowa Siege Cave is named for its association with the besiegement of a Kiowa (Native American tribe) raiding party in 1839 by Mexican militia from El Paso. The pictograph panel at the head of Mescalero Canyon is interpreted as a representation of the events of the Kiowa siege. Accounts of the event vary, with the Tigua (local indigenous tribe which served as scouts for the militia) version including the dropping of burning chili peppers into the cave to smoke out the raiders. In the Kiowa account, bags of live rattlesnakes were dropped through skylights in the cave roof.

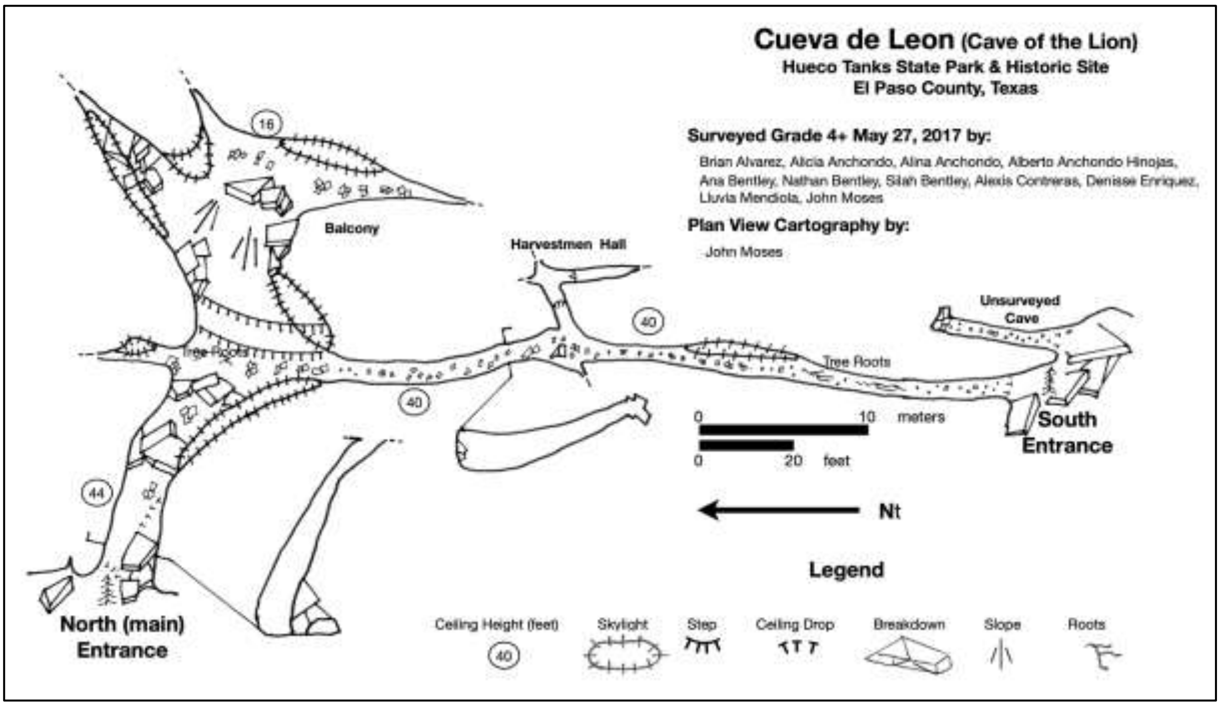

Figure 4: Plan view map of Cueva de Leon.

According to Kiowa oral tradition (related to Smithsonian ethnographer James Mooney decades later) most escaped the siege at night, following two weeks in the cave, by clinging onto juniper roots and climbing out a skylight. They took horses from the surprised militia and the survivors rode north to their home in the high plains. The cave is considered sacred by the Kiowa. During the survey, an attempt by experienced climbers to exit the cave near the back end and recreate the Kiowa event was not successful.

4.4 No geologic interpretation for the formation of the diverse and numerous *hueco*s has yet been successfully advanced

Figure 5: Ground level view of Hueco Tanks from the west. Photo K. Steiner

Acknowledgments

Texas Parks & Wildlife Department and site Superintendent Ruben Ocampo cooperated in giving access to the site.

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A cave in massive granite, with prehistoric artefacts: Grotte de la Croisière, Creuse, France

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Abstract

Grotte de la Croisière in Saint-Maurice-la-Souterraine Municipality, Creuse District, was formed at the base of a cliff in massive granite. Speleogenesis was probably initiated by stagnant water in a swampy area. Mineral leaching, mainly of feldspars, resulted in rock disaggregation and associate ionic migration generated exfoliation. Curved fissures that progressively form and propagate in granite masses initiate bowls formation. However, no bowl is currently present. Leaching, exfoliation and mineral export together resulted in cave enlargement, meanwhile thin mineral crusts deposited on squamae on the ceiling and along some parts of cave walls.

The cave fill was merely known from more than 50 years old excavations which evidenced Neolithic occupation. The author has reinterpreted these data in the light of thorough observations and observations in the cave.

This type of cave is very rare, due to its way of formation and its location in an area almost devoid of caves. The site itself is still pristine. Therefore, it should be urgently preserved as a geo-sites, among others, as it will soon be threatened by the expansion of an industrial area. It is also a prehistoric site located close to a major prehistoric pathway on topographic crest.

The paper describes the cave and discusses its genesis. It also proves its cultural value and the overall need for preservation.

Résumé

Une grotte préhistorique dans un granite massif : la grotte de La Croisière, Saint-Maurice-La-Souterraine, Creuse, France.

La grotte de La Croisière, large et basse, est située à la base d'une falaise de granite. Elle s'est probablement formée au niveau de l'eau stagnante d'une zone marécageuse. La lixiviation de minéraux, surtout des feldspaths, a initié une désagrégation de la roche et les migrations ioniques associées sont à l'origine d'une desquamation. Des fissures subhorizontales à incurvées qui s'initient et se propagent dans ces conditions précèdent la formation de boules, encore non présentes sur le site étudié. La formation de la grotte est due à l'export de matière vers l'extérieur, mais on observe aussi de minces pellicules minérales, notamment au plafond et sur le haut des parois.

La grotte de La Croisière est d'un type très rare, de par ses caractéristiques géomorphologiques et géologiques et de par son contenu préhistorique situé près d'une ligne de crête régionale. Elle mérite d'être classée, notamment comme géotope, d'autant plus que l'expansion d'une zone industrielle la menace à plus ou moins brève échéance.

1. Introduction

Grotte de La Croisière is a small cave, but it brings a lot of valuable knowledge on cave formation in granite, as it is entirely in massive rock. It is located around 42 km to the NNE of Limoges and 38 km to the west of Guéret, very close to the junction point of A 20 and RN 141 superhighways and 50 m only away from districts boundary (Fig. 1). It is also closer and closer to an expanding industrial area called "Parc d'Activités de la Croisière". It was described in a simplified way by archaeologists (CRÉDOT & DOMINIQUE, 1966 & 1967) who performed excavations and published rough sections. Subsequently, the cave was described with much more detail (MOURET, 2010) but a quantitative approach remained to be made on the cave fill poorly described in 1966 and 1967. It is presented here together with a thorough geological approach. Layers are presented in their stratigraphic order, but their numbering is the one used by archaeologists, in order to avoid confusion.

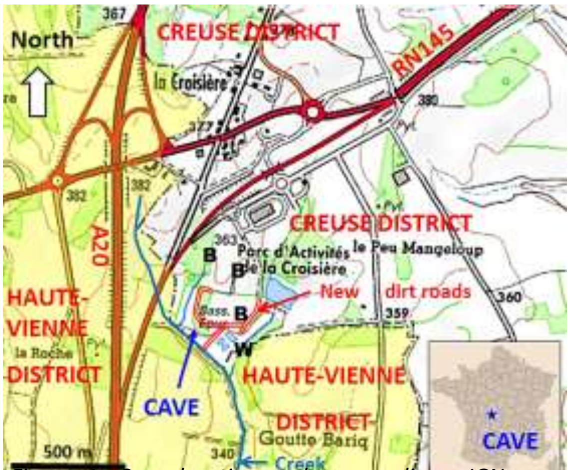

Figure 1: Cave location and surroundings. IGN map background, 1: 25 000. B: areas prepared with bulldozers; W: wastewater treatment plant.

2. Site and cave geometry

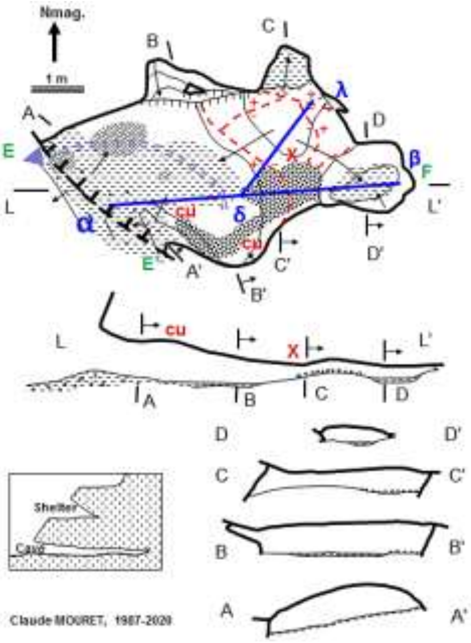

Figure 2: Cave map, longitudinal and cross-sections. Dashed red lines and marks -+ correspond to ceiling lows and highs; cu for cupolas. Solid blue line indicates cross-sections. Floor symbols: white for bedrock, dashes for earthy/clayey ground, dots for small boulders, grey frame for exfoliated floor. Dashed blue arrow indicates a low axis at cave floor level. Greek and capital letters are reference points.

The cave is broadly sub-horizontal and located at the base of a several metres high cliff of coarse-grained granite (Fig. 2 & 3). It shows a large and low opening at a little higher elevation than adjacent valley floor. It follows mainly low angle natural fractures, with local sharp dip increase.

Figures 3 and 4: Cave entrance from outside and from inside. The black box (arrow) is 10 cm high. Photos CM.

Figure 5: Northern cave wall, from entrance to cave end (F). The low cave wall is partly covered with mineral crusts (B to C). The bedrock rises up between C-C' and D-D' cross-sections then lowers down further on. Slightly tilted photo, see Fig. 1. CM.

Figure 6: Southern cave wall, between entrance (E') and end (F). Note low angle fractures dipping towards cave end (B' to C') and in the opposite direction near the entrance. CM.

Figures 5 and 6 clearly show the main sub-horizontal fracture set, which separates walls and the vault on top of them. Small boulders are present in the distal part of the cave and soft sediments closer to the entrance.
Between sections B-B' and C-C' (Fig. 2 & 5), the floor rises while the ceiling is sloping down to "X" (Fig. 2, Fig. 5, Fig. 8, Fig. 9). To the NE of this constriction, a sudden elevation of the ceiling is due to sharp variation of fracture dip (Fig. 7 & 9).

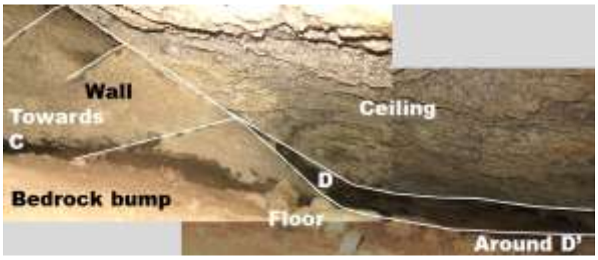

Figure 7: Subhorizontal fractures show a significant dip increase to the left. Concomitantly, the low ceiling along C'-C section shows a sudden elevation towards C. Other high angle fractures lye underneath and connect in a complex way (Fig. 9) with the main sub-horizontal fracture system from cave entrance. Photo C. Mouret.

Figure 8: The lower part (ca 40 cm) ahead of D, along C'-C.
Figure 9: The higher area in the NE tip of the cave. Ph. CM.

3. Cave fill

Figure 10: Location of long sections on Figure 10. Photo C. Mouret.

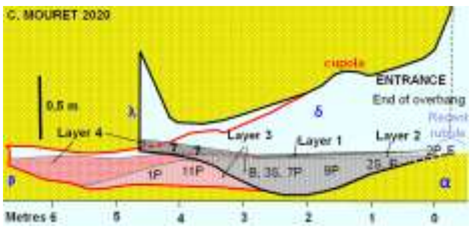

Figure 11: Longitudinal sections located on Figures 2 and 10. The longer one (red) follows archaeologists' sketchy section. Point 0 is CRÉDOT & DOMINIQUE's one. Vertical distances multiplied by 2. P: pottery; F: flintstone; B: half-ball of granite (6 cm); Fi: fireplace (at the entrance). Quantitative sections and drawing by C. Mouret (2020). Artefact location from indications by CRÉDOT & DOMINIQUE (1966).

Cave fill has been nearly entirely removed in 1966 by archaeologists who gave a minimum description of it and rather approximate location of sections. Nevertheless, crossing their data with our detailed *in situ* observations allowed us to reconstruct layer geometry, as summarised by Figure 11, and key features of their geological nature. To this end, the author performed detailed measurements of cave geometry, studied poor layer remains and made acoustic tests (high to low sounds from the rock hit by hammer blows), especially of cave floor. From bottom to top, there are four layers (numbered by archaeologists):

Layer 3: proximal in the cave and geometrically the lowest one. Not described in 1966-1967 papers. Its "lighter" colour approximately yellow brown could be granite grus, probably heterogeneous, with artefacts at unknown depth.

On Figure 11, Layer 3 is shown as the fill of a low in the rocky floor. This low has indeed to be interpreted in a 3D model, as it belongs to a channel-like low axis going from the centre of the cave towards the NW side of the cave entrance (Fig. 2), prone to grain export to the outside.

Layer 4: mostly distal, made up of pieces of granite (Fig. 5 and 6), with no grus mentioned. Layer 4 seems to overlap Layer 3; however, the almost constant total thickness of both layers strongly suggests that they are lateral equivalents. Therefore, the proximal part would have been subject to a more advanced disaggregation than the distal part, so far subject to broad granite fissuring only. It also suggests that loose granite blocks fallen from ceiling and cave walls were progressively disaggregated from cave floor to fill top and from entrance to cave end, because grus is present over a longer distance at cave bottom. Disaggregation of cave floor was probably not very active, despite exfoliation (see below). Overall, grus may have been progressively pushed toward cave entrance, and then partly transported to the outside, mainly before Neolithic times. Reworking by burrowing animals probably occurred.

Whether Layer 4 was present at the top of NE cave floor bump is questionable (see question marks on Figure 11).

Layer 2: this thin layer, probably emplaced from outside, consisted of earthy black organic matter possibly associated with a "recent" fireplace near cave entrance.

Layer 1: made up of thin particles, it probably filled a residual low ahead of Layer 4 and was likely deposited into the cave by water during heavy rains.

4. Distribution of exfoliation

Exfoliation is well visible in the proximal part of the cave. On the floor, it is present mostly near the entrance where several superimposed squamae were split apart by water and probably by frost. Further inside the cave, exfoliation is minor (Fig. 12) to non-existent on the floor. It is merely present along northern cave wall (Fig. 12 & 13), below the horizontal fracture limiting it from the vault.

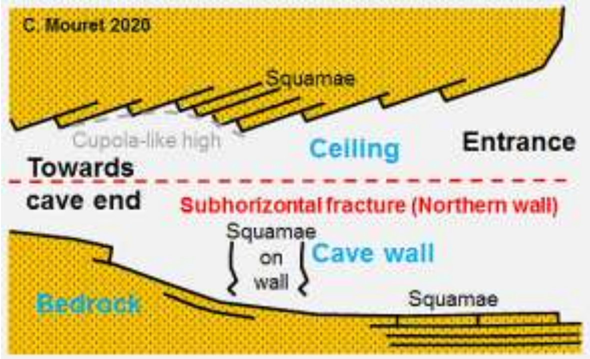

Figure 12: Exfoliation distribution in the cave (no scale).

On the ceiling, exfoliation largely contributes to the vault morphology with cupola-like highs (cu on Fig. 2), and adjacent lows (Fig. 12).

Squamae fall down once the mass of their overhang exceeds rock resistance. They are probably arenised on the cave floor and, in this sense, they might have contributed to the formation of the Layer 3.

Exfoliation supposes alternating dry and wet seasons. It is due to ionic migration in the rock, thermal variations, differences of pore pressure in the rock, also to frost.

Figure 13: Rough exfoliation along the northern cave wall, in the coarse-grained granite. The siliceous crust at the top originates from the fracture which separates the wall from the vault. Photo C. Mouret.

Figure 14: Photo ①, largely tilted: vault exfoliation near the southern cave wall (2, to the right) has generated a 180° half-cupola high (1) around which squamae are visible. There is 0.3 m from (1) to (2) and around 1.4 m from (3) to (4). Photo ②: at the contact of the half-cupola high (1) and the southern cave wall (2), a sub-horizontal fracture shows some narrow holes (3) from which water has deposited siliceous crusts, also (4). Photo ③: near the cave end, similar crusts start from similar holes. Photos C. Mouret.

5. Mineral crusts

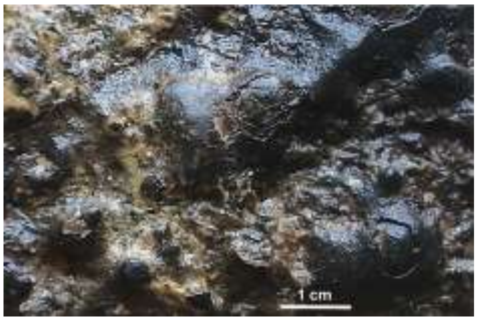

Figure 15: Black crust on the ceiling, with concentric laminae. Photo C. Mouret.

Mineral crusts show two types:

- Grey beige crusts along cave walls, connected with sub-horizontal fractures (Fig. 5; Fig. 9; Fig. 14) and narrow openings along them (Fig. 14).

- Dominantly black crusts on the ceiling, formed of parallel laminae coating granite surface (Fig. 15), but also white parts.

These deposits have been not analysed up to now, but they look to be siliceous and, anyway, they prove that mineral leaching in the granite leads to the deposition of secondary minerals. This agrees with small channelling along fractures and exfoliation processes.

6. Propagating fractures

The granite massif is crossed through by fractures related to initial cave development. Some of them locally follow elongate concentrations of larger crystals. Sub-horizontal fractures are predominant, but they may show a sudden dip angle (Fig. 7). In the NE corner of the cave, a sub-horizontal fracture with a sudden upward dip increase is relayed by a short horizontal segment with a sudden downward dip increase. Such features are interpreted as related to the strain relaxations preceding bowls formation. The steep fractures stopping along them (Fig. 7) could be slightly younger. High dip fractures are found near the north-eastern part of the cave that is closer to the massif boundary, thanks to a north-eastward backstep of the granite cliff.

In a previous study (MOURET, 2007), it was demonstrated that new fissures may be created by weathering processes, independently of exfoliation. Such fissures tend to be curved, slightly sinuous, and terminate in the granite mass. With time they obviously propagate further into the massif and so become longer. They are also precursors of granite bowls and full arenisation between them. They occur in slightly weathered rocks, as shown by beige to whitish feldspar crystals. Such fissures are observed near the entrance to Grotte de La Croisière. Also, slightly visible younger sub-horizontal fractures are present along the northern cave wall.

7. Cave formation

Grotte de La Croisière developed in relation to a set of sub-horizontal fractures with dip changes in the distal part of the cave. The passage is well limited all around, though some low enlargements (Fig. 2, section B-B’) exist on the northern side along the main sub-horizontal fracture. Vertical squamae may have helped in featuring wall verticality.

The overall notch-like sub-horizontal extension of the cave and the fact that it is located at the junction of a cliff and an alluvial valley suggests that a paleo-water level played a role in the development of cave geometry. Formation of sub-horizontal fracturing might even have been influenced by such a weathering (MOURET, 2007), but this is uncertain.

Cave formation is very likely post-glacial and obviously older than Neolithic artefacts discovered in the Layer 3. The distance from the floor to the ceiling did not exceed 0.65 m after deposition of the Layer 3, which was just enough for two or three seated persons.

I do not know what length of cave may have been removed by cliff erosion but it is probably short section.

7. Geological and cultural value of the cave: the need for a protection

Grotte de La Croisière shows several unique characteristics at regional scale:

- Occurrence at the base of a granite cliff,
- Well delimited cave with regular walls,
- Clear exfoliation showing a geometric organisation,
- Existence of enlargements along horizontal fractures,
- Existence of slightly channelised water pathways,
- Presence of well-developed secondary mineral crusts starting from channelized pathways along fractures,
- Cave use during the Neolithic period and subsequently (CRÉDOT & DOMINIQUE, 1967),
- Location near a regional topographic crest and likely long distance prehistoric trail,
- Possibility of finding more prehistoric remains in front of the cave (with associated hut?),
- Associated legends (fairies…) (CRÉDOT *et al*., 1967),
- Rocks above the cave possibly carved by Man (CRÉDOT & DOMINIQUE, 1967).

All these features together prove the patrimonial value of Grotte de La Croisière, from the geological, geomorphological, archaeological, and ethnographic points of view. Therefore, it must be seriously protected from destruction by expanding nearby industrial area, whether it is by breaking the rock or by burying the cave entrance below debris.

8. Conclusion

Despite its small size, Grotte de La Croisière is an original cave that brings a lot of knowledge on a speleogenesis in granite. It should be classified as a geotope/geo-site, especially as it is a very rare type of cave, unique in the region. The cultural elements and cave features all together show that even a small, isolated cave may bear a strong patrimonial value.

Figure 16: The entrance to the cave: notch-like, large and low, with enlarged entrance. Photo C. Mouret.

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Ibaloi mummy caves in Kabayan, Benguet Province, Philippines

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Abstract

Ibaloi tribes of the Benguet province, Philippines, used to place mummies in wooden coffins and place those in caves. The area is highly mountainous and hosts many highly secret caves, though a few are accessible under strict supervision from the authorities. Despite considerable media attention, few detailed studies are currently available. Specifically, nothing has hitherto been reported on the nature of the host rock and cave geometry. This paper briefly introduces local burial rites and then focuses on caves, which are of two main types, both of which located in andesitic formations:

- Caves in fractured or weathered parts underneath lava flows or gigantic boulders,
- Caves in the interior of gigantic andesite boulders (up to 30 m long), dipping downward towards the outside. Their circular to oval openings may be present all around the boulders, and so form an overall star-like pattern.

Human action seems to have mostly impacted the first type of cave, and only marginally the second type, for which the role of condensed water is proposed.

Résumé

Les grottes à momies Ibaloïs de Kabayan, province de Benguet, Philippines. Les tribus Ibaloï plaçaient jadis leurs morts momifiés dans des grottes. La plupart d'entre elles restent secrètes, mais quelques-unes sont ouvertes à la visite sous strict contrôle des autorités. Bien que ces grottes soient souvent citées dans les médias, très peu d'études précises et accessibles ont été menées à ce jour. En particulier, la nature de la roche et les données géométriques sur les grottes n'étaient pas connues. Nous avons observé des grottes dans les parties altérées ou déformées sous des coulées andésitiques ou des restes de coulées, ainsi que des grottes disposées en étoile autour de gigantesques blocs d'andésite. L'action de l'homme semble s'être exercée surtout pour le premier type et très marginalement pour le second, dans l'état actuel des connaissances. Un creusement par de l'eau de condensation est proposé pour les grottes dans les blocs massifs.

1. Introduction

Ibaloi mummies placed in caves in the Kabayan area have been often mentioned by media or in popular literature (DE LEON, 1976), but few extensive works have been published. Neither the geological nature of caves nor their dimensions were mentioned, except for hard-to-find Philippines publications. The city of Kabayan is 82 km from Baguio by road and 36 km to the NE as the crow flies. It is a large municipality (243 km^2, 15 260 people in 2015).

In 2019, the author made a reconnaissance there, in order to document the nature of the cave-bearing rocks and a few caves, though he had to follow a compulsory guide and had limited time. Three sites were studied. In addition, some data regarding the most famous site of mummies could be gathered, though it was closed to any visit while in the Kabayan area. The author's observations and interpretations are presented here.

2. The Ibalois, people of the Cordillera

The Ibalois are one of the main groups of traditional mountain people living in the Cordillera of Northern Luzon. This region is extremely mountainous (Fig. 1 & 2) including summits around 3000 m a.s.l. The Agno River is a major local torrent, which has deposited a several kilometer large alluvial fan at the southern foot edge of the Cordillera, in the Central Plains of Luzon.

Figure 1: the Cordillera landscape in the Kabayan region, seen eastward from the Baguio toward Bontoc road. Photo C. Mouret.

The Agno River flows at around 1150-1200 m a.s.l. in the Kabayan area (the Kabayan city is at 1180 m a.s.l.).

Ibaloi tribes have been cultivating vegetables and rice on terraces built on mountain slopes and were also warriors. They all were animists before Christianization. Due to their beliefs, they used to place their prominent dead people in wooden coffins (Fig. 3) after mummification and then brought the latter into caves. All this was heavily ritualized (as explained in detail by MOURET, 2020) and many caves were (or became) secret. The main period of mummification is unclear, often reported to range from 13th to 17th century, sometimes much older. However, a rib from caves at Mount Timbak (see below) was dated between 1785 and 1871 AD by radiocarbon (BECKET *et al.*, 2017).

Figure 2: The Kabayan area, with the location of the sites presented in this paper, centered on the Agno River. Google Earth, after © 2019 CNES/Airbus and © 2019 DigitalGlobe.

Mummy caves were "discovered" by westerners rather late. Despite an early mention of 24 coffins in 1832 and one cave in 1861, they became well known in the early 1900's and were widely mentioned by woodcutters and gold seekers. Little by little, scientists made observations and some specialized publications were issued. 50 to 80 caves are reportedly known by some elders.

The precise mummification process for the bodies is lost. Replication trials made around 1950 were unsuccessful.

Figure 3: types of coffins from Ibaloi caves, exposed in Kabayan Museum: monoxyle with one mummy; ornate, animal-like; polyxyle with several mummies. Photo C. Mouret.

3. Pongasan Cave

Figure 4: Pongasan Cave entrance underneath a large block of andesite. Photo C. Mouret.

Pongasan Cave is located at around 1900 m a.s.l. to the SSE of the small village of Bangao at 1567 m a.s.l. (Fig. 2). It is a small cave (around 4 to 5 m wide and 6 to 7 m long) packed up with six coffins (Fig. 4 and 5) and an additional one now in the Kabayan Museum (top left of Fig. 3). Self-evidently, we could not (and would not) crawl on top of the coffins to make precise observations at the cave terminus.

Figure 5: Pongasan Cave. 1: seen from the entrance. 2: from the entrance, oriented more to the right end; the monoxyle coffin is the same as the one to the left on Photo 1. 3: the open coffin is the one with pegs on Photo 1; right side of the cave. 4: right side towards the cave end; the parallelepiped open coffin is the same as on Photo 2. C.M.

The cave (Fig. 5.1 & 5.2) exhibits a westward sloping ceiling and a left (east) wall of rock, with a sharp corner then a ledge with a coffin on it, all of it hosted in massive andesite. The back wall also seems to be massive andesite; it is separated from the ledge by an open fracture. The right side (Fig. 5.3 & 5.4) includes big angular boulders and some powdery soil or crushed rock: the closing wall (Fig. 4) and the coffins hampered more detailed observation. From the outside, a mix of soil and small boulders is visible, but its relationship with the cave interior deposits is unclear. The cave floor is covered with a mix of earth and small rock fragments.

Thus, the cave was formed in a weakened part of the andesite mass, at the base of its front face. Whether the andesite mass is fully in-situ or not is questionable. However, it may have slipped a bit along the mountain slope, possibly explaining the fractures.

Humans have probably contributed to reshaping the cave, a little bit at least, for instance, by removing rock blocks.

4. Mount Timbak caves

Figure 6: Hike and a cave on Mount Timbak. Courtesy of Morgane Wermuth.

We could not reach this location as explained above. However, available photos (Fig. 6) show that there are similarities with Pongasan: on a mountain slope, an enormous block of andesite shows a tilted base making up the cave roof with a stone wall closing off the side. The tilted block dips in the direction of the slope. It is again questionable whether the rock is fully in place. Natural transport of loosened rock (small blocks or else) by weathering or from heterogeneity in the andesite (or both) is likely. Nevertheless, human action is likely required for shaping the cave adequately and, at any rate, in building walls that may help in sustaining the andesite mass.

5. Tinongshol caves

Figure 7: The Tinongshol site (arrows) is located in a tributary valley on the right bank of Agno River. On the left photo, taken from Old Kabayan, Agno River flows from right to left. The photo to the right shows the pathway to Tinongshol Rock. Photos by C. Mouret.

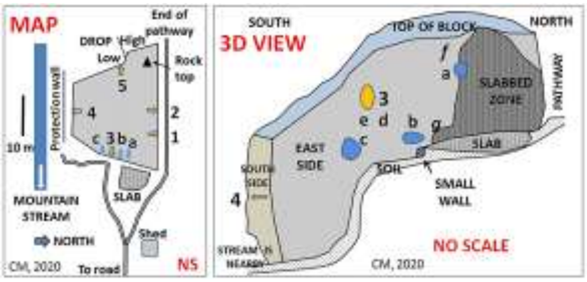

Figure 8: sketch map (NS for No Scale) and sketched side view of the Tinongshol Rock from the east.

Figure 9: Tinongshol Rock with 5 radial caves. Montage of photos seen under variable angles (due to trees). Ph. CM.

Figure 10: the five cave openings in the Tinongshol Rock, located on Figure 8. Caves 1 to 4 show coffins, which are mostly polyxyle and perpendicular to the entrance narrower than their length. Cave 5 is said to be now empty. Entrance sizes vary from 0.7 to 1.3 m. Photo C. Mouret.

The Tinongshol Rock is a gigantic block of heterogeneous massive andesite, which is protruding almost to the bottom of a tributary talweg (Fig. 7) of the Agno River. It is tilted towards the nearby mountain creek. Its horizontal dimensions and the star-like pattern of caves are sketched on Figure 8, which also shows a side view drawn from a photo montage. Figure 9 shows views in four directions.

Figure 10 presents the 5 cave openings, which are subcircular to slightly oval and in this case elongated in the vertical direction. The rock seems naturally smooth though it has been locally slightly enlarged by some hammering. Behind the entrance, the cave dips downward towards the outside. The walls and ceiling show an apparently smooth surface: it is especially visible in Cave 4 thanks to a high man-made wall culminating almost in front of it. None of the caves can be entered without moving coffins except possibly Cave 5, but no ladder is allowed there, in order to prevent further coffin degradation (graffiti) by disrespectful visitors.

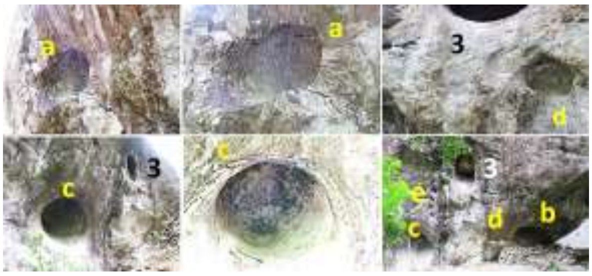

Figure 11: a, b, c are bell-shaped microcaves dipping downward to the outside, as Caves 1 to 5. Their surface is smooth, and their end clearly rounded. Photos C. Mouret.

Figure 11 illustrates what could be considered as shelters, which so far did not reach the same degree of development as Caves 1 to 5. Example "a" is clearly partly destroyed, due to the collapse of a large slab of andesite parallel to the rock wall (Fig. 9).

Figure 12 shows much less developed shelters on outer rock wall, all seen on the rock face looking eastward (towards the Old Kabayan, a coincidence? and the Agno River). There seems to be no meteorological reason that could explain more holing to the east. Some of the holes are developed along small rock fractures.

Figure 12: small holes on the eastern wall of the Tinongshol Rock. Photos C. Mouret.

A feature to be noted is the existence of colored traces starting from cave or shelter openings, and even from rock fractures. They extend below the openings along the outer wall of the Tinongshol Rock (Fig. 9 to 12). Whatever their color, reddish brown, or whitish, such linear traces along vertical or overhanging walls indicate deposits left by limited amounts of water flowing very slowly.

What is the origin of the caves and holes in Tinongshol?

First, let us consider the possible shape of caves in the Tinongshol Rock (Fig. 13, left). Behind their sloping entrance part, caves show an enlargement which is only partly visible, due to coffins packing. The cave end is nowhere visible. However, there is similarity of holes “a, b, c” (Fig. 9 & 11) and caves: regular opening, slope downward to the outside, location in the same rock. This makes it probable that caves do end in a similar way as holes. The perpendicular coffins to cave entrance prove that available space is sufficient to turn them inside (Fig. 13, left).

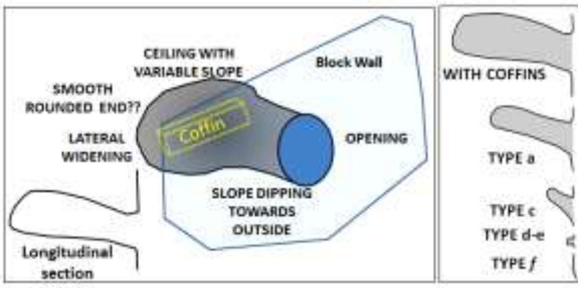

Figure 13: left: proposal on the shape of caves packed up with coffins at Tinongshol. Right: evolution from cliff scratch to cave of coffin-size.

Moreover, we observe a morphological evolution from small type f to the caves with coffins (Fig. 13, right).
Fracturing of the Tinongshol Rock is local and does not cross through most of the voids in a visible way. The traces of water coming out of openings probably originate in a limited way from fractures, that can explain neither the shape of caves nor the smoothness of their walls.
More likely, condensation water acidized by algae or other plants has driven cave development from small rock irregularities on rock walls, that subsequently enlarged and extended upward and backward. Andesite dissolution by acidized water is not uncommon. Condensation water is usually seen in the upper parts of caves and at their back wall where evaporation is far more limited than near the entrance. However, was it sufficient to generate the observed regularity?
Cave enlargement could be due also (to a very minor extent?) to rock loosening behind a crust (sometimes difficult to distinguish from the rest of the rock), due to outward ions migration as in metamorphic rocks or granite.
However, the explanation given by Ibaloi guides of caves dug by man using a corrosive plant juice cannot be accepted. First, cavities grow upward, while juice would of course flow downward. Second, the evolutive suite from type *f* hole to caves (Fig. 13, right) precludes any such formation. BALANGKOD (2018), a good botanist, wrote that caves were “specifically created for containing coffins” but neither brought a proof nor discussed it.
We need to mention that bats live in some of the caves and that we could not check at this stage whether some caves can be connected inside the Tinongshol Rock. It seems unlikely but needs checking.
Finally, it must be mentioned that some desquamation-like fissures form around the Tinongshol Rock, over large surfaces (Fig. 10.1 & 10.4). A large slab already fell to the ground on the eastern Rock side (Fig. 7 & 9) and partly destroyed a large hole (Fig. 3, hole “a”).

6. “Block” cave

On a lower terrace of Agno River, near the Tinongshol Rock (Fig. 2), a gigantic block of andesite crops out the cultivated land (Fig. 14). It shows at least one cave with coffin(s) inside. It is rather similar to Tinongshol Caves.

Figure 14: “Block” Cave near Old Kabayan. Photos C. M.

7. Conclusion

The present study is, to our knowledge, the first one to give information of Ibaloi mummy caves from geological and speleological points of view. Though not everything is so far explained (far from it!), these unusual caves have been brought to light and described as much as possible. They are certainly significant in a regional and ethnological context.
The author’s reconnaissance was a fast one, but it is a basis for further work. In particular, more caves need to be observed, in order to synthesize new facts and knowledge, despite the difficulties inherent to the human use made of them. This will also contribute to further information on burial caves in general (MOURET, 2000, 2004).

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