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Title

Mapping the Walls: high-resolution cartography applied to the analysis of prehistoric cave art in the Grotte du Mammouth (Domme, Dordogne, France)

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Abstract

The analysis of paintings and engravings on the walls of Upper Palaeolithic caves generally focuses on the images themselves, their technical or stylistic characteristics, graphical and spatial composition, and, to a lesser extent, radiometric dating. More recent studies of cave art have reinforced new interdisciplinary perspectives that address the archaeology, karstology and geomorphology of the site. This latter aspect helps place the representations in the long-term geo-morphological history of the cave itself, and thus sheds new light on its human occupation. At the Grotte du Mammouth (Domme, Dordogne, France), we developed an innovative approach to cave art that incorporates a geological and geomorphological analysis of the decorated walls combined with new mapping and digital recording techniques to produce a detailed “identity card” of the site’s features.

Keywords

cave art; karst geomorphology and deposits; high-resolution cartography; mammoth; plotting; taphonomy; Upper Palaeolithic.

Text

1. Introduction

The analysis of paintings and engravings on the walls of Upper Palaeolithic caves generally focuses on the images themselves, their technical or stylistic characteristics, graphical and spatial composition, and occasionally radiometric dating. Methods for studying cave sites have witnessed several fundamental changes since the 1970s, with researchers now routinely combining archaeological and

geological data in their research, as at the French sites of Sainte-Eulalie (Lorblanchet *et al.*, 1973) or Pech-Merle (Lorblanchet, 1981). Overlapping engravings and paintings can provide important information about the cave walls themselves, such as fissures or natural deposits, as has been shown at the sites of Villars (Delluc *et al.*, 1974), L'Aldène (Vialou, 1979), Fontanet, or Niaux (Vialou 1986). This methodology has subsequently evolved (Aujoulat, 1987), and the stages for the analysis of the figures have now become more precise (Fritz and Tosello, 2007). However, not all sediments and speleothems are included in analyses, leaving aside important geomorphological information. The pluridisciplinary approach pioneered by Michel Lorblanchet put geological studies at the forefront of rock art research (CPF congress 1981-1982). This momentum has led to innovative work, especially in the domain of paleospeleology (Rouzaud, 1978). This new research approach has been adopted at several recently discovered decorated caves, such as Chauvet (e.g. Clottes, 2001). Several recent studies have reinforced this fresh interdisciplinary perspective (Robert *et al.*, 2019) that incorporates prehistory, karstology, and geomorphology. The inclusion of these latter two disciplines have brought to light various modifications affecting caves and rockshelters (Delannoy *et al.*, 2013), including alteration processes (Lorblanchet, 1981, Kervazo *et al.*, 2010), and helped in environmental reconstructions (Delannoy *et al.*, 2001) or studies focusing on the distribution of cave art (Ferrier *et al.*, 2017, Jouteau *et al.*, 2019). Recently, important research has demonstrated the effects of biogenic corrosion in undecorated caves caused by bat guano (Audra *et al.*, 2019) that could equally have played a part in the alteration of painted and engraved cave walls (Bruxelles *et al.*, 2018).

How are geological and geomorphological data essential? First, they allow parietal art to be placed within the long-term history of the cave itself as well as revealing potential selection criteria (or lack thereof) of the prehistoric artist. Second, they shed new light on the occupation and uses of caves. The Grotte du Mammouth (Domme, Dordogne, France), discovered in 1978 (Aujoulat *et al.*, 1978), is an excellent example of this expanded, multi-disciplinary approach. Subject of a collective research programme (PCR) “Archéologie des sites ornés de Dordogne: cadre conceptuel, potentiels et réalité” (dir. C. Cretin, MNP), new research at the site has adopted an original approach placing the cave wall and its history at the core of the analysis of the prehistoric images and representations (Cretin *et al.*, 2013). Here we present a novel methodology applied to the Grotte du Mammouth that illustrates how the detailed digital mapping and plotting of natural and anthropogenic features provides new insights for the relative chronology of human activity and allows anthropogenic traces to be reliably distinguished from natural karstic features.

2. Materials and Methods

2.1 Context of the Grotte du Mammouth

The Grande Grotte de Saint Front, more commonly referred to simply as the Grotte du Mammouth, is situated upstream of the town of Domme, on the left bank of the Dordogne River (figure 1). The site forms part of a set of cavities developed along a series of sub-parallel fissures in the Coniacian sandy limestone cliffs. Its current altitude (+80 m above the Dordogne Valley) is consistent with the site being high-level Early Pleistocene or Pliocene karstic cave (Le Fillâtre, 2013) sitting on an upper level of an alluvial terrace of the Dordogne River (Karnay *et al.* 1999, Konik 1999, Salomon and Astruc, 1992).

Figure 1

The cave's current morphology results from fracturing, stratification of the sandy limestone, facies variations, and fluvial- or pseudo-karstic genesis. The very ancient history of the cave has produced overlapping exterior (e.g. truncated upstream of the karstic gallery, doline or polje, dry valley) and interior

karstic features (e.g. gallery sections, cupules, solution flutes). In the first part of the cave, relatively recent transformations have lowered the floor level, leaving the first sculpted mammoth some 4.5 m above the cave floor. The present-day floor rises towards the back of the cave, where it is obstructed by an enormous detrital cone overlying blocks from the collapse of the cave roof, approximately at the level of what would have been the Palaeolithic floor. Clandestine excavations produced a significant quantity of archaeological material that is visible on the cave floor.

One of the main characteristics of the Grotte du Mammouth is the alteration of the cave walls following the “desegregation of the limestone into sandy residues in the entrance zone and the covering of the cave walls by a thick, dry calcite layer in the deepest part” (Delluc *et al.*, 1983: 57: our translation).

Considering the complexity of the natural processes affecting the cave walls, it was necessary to understand the chronology of geological events operating both before and after the creation of the Palaeolithic engravings and sculptures. Refining the chronology of the natural and anthropic events allows us to reconstruct the wall surfaces before and after the drawings were made in order to understand how Palaeolithic groups used the different areas of the cave. Engravings overlapping geological features and deposits, as well as their destruction, can, however, complicate accurately discerning the sequence of engravings or produce natural morphologies resembling genuine rock art.

Only the most evident forms are usually represented when mapping parietal art, with attention being paid uniquely to the main characteristics of the panel and the possible use of natural relief rather than focusing on all the events recorded by cave walls.

Documenting the relationships between archaeology and geology allows a relative chronology of events to be constructed that incorporates multiple data forms and can be generalized to the same cave wall or even the entirety of the cave. Natural micro-reliefs provide a highly reliable means for establishing a relative chronology that distinguishes human modifications from geological “micro-shapes”. As these elements often lack precise definitions and remain poorly understood, developing an inventory of anthropic and geological morphologies is fundamental for documenting the genesis and subsequent alteration of the cave wall and, ultimately, the interaction of Palaeolithic groups with the cave’s geology.

2.2 Methods: integrated plotting

We developed an integrated archaeological and geomorphological approach to mapping parietal art that focuses on elements of chronology, style or/and techniques set within their geological context. This integrative method is based on a detailed geological study of the site combining evidence from karstogenesis and sedimentology in order to more reliably identify potential markers that can be used for building a relative chronology of anthropic traces. Here, we use “plot” as the best approximate translation of the French term *relevé*.

The plotting method for the Grotte de Mammouth is based on first-hand observations (Figure 2) of the decorated walls (Fritz, Tosello, 2007) designed to:

- 1) identify and record all anthropogenic traces on synthetic sketches while distinguishing them from natural formations,
- 2) produce a high-resolution photographic record of the cave walls, respecting the constraints of orthogonality, framing, resolution, and lighting (Robert *et al.*, 2016). Depending on the individual characteristics of the walls, orthophotos derived from 3D photogrammetric models either complete or replace conventional photography,
- 3) improve legibility or contrast via digital image processing; for example, RAW to TIFF format for photos using the Adobe Photoshop - Camera Raw[®] software. The processed image is subsequently printed, generally at a 1:1 scale or half-scale when restrictions are necessary,

4) produce one or several detailed layers on transparent films superposed on the photo when standing directly in front of the wall in order to carefully record Palaeolithic traces, recent marks, and the main topographic elements, and

5) digitize and graphically enhance the hand-drawn records based on comparisons with the original photographs. This final computer processing gathers all relevant graphic information for each wall, which is then associated with the geological mapping carried out at the same time.

Figure 2

In order to facilitate this process, especially the final stage, we developed a high-resolution mapping technique for the Grotte du Mammouth. The intense chemical and mechanical alteration of the cave walls since the early Plio-Pleistocene created potential confusion between human induced micro-relief and those resulting from geological processes.

The geomorphological mapping of the decorated walls used the same photographic evidence described above, complemented by additional photos, either taken from other angles or using different lighting or resolution (proxy- or macro-photography), in order to better document particular topographic features of the cave walls (diffuse karst micro-porosity, corrosion by organic matter, seepage, etc.). This process comprises multiple steps (Figure 3):

I) An initial detailed plot is made facing the cave wall using the same photographs and at the same scale as those used to document the cave art. Observations are carried out using the same analytical and interpretative elements identified by the archeological survey (stages 1 to 4 of the cave art plotting method described above).

II) A detailed computer mapping is then carried out based on digitized field documents using a CAD software (e.g. Adobe Illustrator[®] or Inkscape[®]). The shapes and elements identified in the field are integrated and generalized to all documents based color attributions. Very high-resolution zooms of the photographs (X800 to X1600), as well as the macrophotos, help to detect and record millimetric to micrometric relief. The relief or deposits identified in the cave are compared with photographic evidence (color, shade, morphology of the contours, relieves, etc.), so as to identify details that are not visible to the naked eye in the laboratory (e.g., mold) or that are highly repetitive (e.g., millimetric grooves and alterations resulting from seepage).

III) Photogrammetry is used for certain inaccessible or partially accessible entities on the cave wall. Three-dimensional models complement the plotting method by allowing access to impossible angles in the cave and to zoom in and assess the interior of the smallest karstic features.

Figure 3

A different digitized layer for each type of karst feature and deposit is generated in stage II. These layers are ordered in such a way as to allow the wall tracings to be inserted in the relative chronology of the sedimentary and geochemical deposits as well as the micro- and macro-relief. The ordering of the layers by relative chronology enables natural phenomena pre- and post-dating the figures to be distinguished and to understand which potentially altered the surface of the host rock and the representations.

The combination of these two plots and the photographic backdrop in the same CAD document is fundamental, as it creates a high-resolution workspace and makes it possible to reconstruct the chronology of natural and anthropogenic events that impacted the cave walls over the long term.

3. Results

3.1 Catalogue of karstic features

We produced a detailed catalogue of karstic features present in the Grotte du Mammouth in order to record and link the main phases of the cave network, facilitate communication between researchers, and record and describe elements of the micro-relief that are generally not found in the literature.

This catalogue describes micro-topographic features of the cave walls resulting from the underground river, chemical alterations (water flow, seepage, percolation of water in the sandstone, etc.), and mechanical alterations, including roof collapse, scree slopes, tectonic action, and freeze-thaw processes.

The fluvial-derived cave wall relief comprises simple karstic features produced by phases of flooding and mixed shapes, including diffuse karst with diffuse circulation. All of these features substantially predate the engravings and sculptures. Three main types of fluvial karstic forms can be observed in the Grotte du Mammouth: circular or ovoid dissolution features (closed base and soft shape, Figure 4A), cupules (rounded base with sharp edges, Figure 5), and jagged rocky walls associated with circular forms separated by sharp edges (Figure 4B).

Figure 4

Figure 5

The diffuse karst system is highly developed in the Grotte de Mammouth (Figure 6) and is considerably older than the engravings. Potentially reactivated during certain periods, diffuse karsts are connected to the intergranular, sponge-like pores of the cavity that sometimes form small channels following the coalescence of voids. Diffuse karst features concern facies susceptible to dissolution, including sandy zones poor in carbonates, joints, small cracks or fractures. Generally, the cave was shaped by the infiltration of rainwater into the rocky massif as well as the underground river.

Better understanding the diffuse karst system provides important information for the overall evolution of the engraved panels and helps in the identification and detection of seepage, solution flutes, and other forms of rillenkaren.

Figure 6

Among the various natural alterations, solution flutes evince sheet wash or diffuse run-off in shallow water (0 to 15 mm after Glew & Ford, 1980, Motherhead & Lucas, 2001), with a flow rate exceeding that of seepage. These heavy-altered features are rare and are found particularly on the south cave wall and in the deepest part of the cave. Due to their short decimetric shape, narrow width, semi-circular cross section and the sharp ridge separating them, they resemble pluvial flutes described by Choppy (1992), Salomon (2001), and Ginès *et al.* (2009).

Flow marks are more frequent and are characteristic of concentrated water run-off. These features develop at the outlet of pores and small diffuse karst channels, joints, or fissures during periods of substantial water infiltration (Figure 7). These relatively shallow, several centimeter wide (around 5 cm) traces are about 20 cm to 1 m long, more or less sinuous to nearly rectilinear, and are often pointed towards the base. They are deeper towards the top of the panel than at their beveled base.

Figure 7

Seepage is also frequent and takes the form of very thin threads of water that result from the same

processes as flow features. These small millimetric to micrometric V-shaped channels cut the rocky walls and generally avoid the asperities of the bedrock, such as sand grains, fossil sea shells, and other micro-relief features (Figure 8), which gives them their meandering form. When they move, they appear as the tangled strings of a ball of wool (Figure 9). Cave wall surfaces dissolved by seepage bear irregular, elongated channels that are relatively deep, rather flat and oriented along the slope.

Figure 8 and Figure 9

Sandstone alteration in the form of tabular sheets is particularly evident in the area of the first sculpted mammoth, near the entrance of the cave. These sheets follow the cave wall morphology and detach from weak zones, such as stratigraphic interfaces, fissures or anfractuosités following either gravitational stress or freeze-thaw processes. The void left by fallen sandstone fragments takes the form of a pulled-out nook with an abrupt edge, leaving clearly identifiable steps on the surface of the cave wall (Figure 10).

Figure 10

The final set of karstic features concern mechanical alterations. Tectonic stress produced several different sized fissures in the surrounding bedrock, including joints, clefts, and faults, as well as small secondary joints ranging in size from one meter to several dozen meters whose overlap form an X-shape and sometimes lapiaz¹ (Figure 11).

Figure 11

In this case, the evolution of the sandy limestone resulted in sheet-like rock strata² and relatively thin sub-vertical sandstone bars exposed by the different alteration phases and the underground river during the early Plio-Pleistocene (Figure 12). The reactivation of the diffuse karst, seepage, gravitational stress, frost or seismic activity lead to their collapse or produced decimetric to metre-sized blocks delimited by discontinuities in the bedrock, such as faults, clefts, joints, fissures, oblique stratifications. Large perforations can link parallel sheet-like strata. These features play a key role in the evolution of the engraved panels, as they direct early and present-day flows and enable water to flow between sheet-like stratum by reproducing genuine stream sink resurgence systems on the cave walls.

The “fish scale” alterations specific to Grotte du Mammouth produced large rock sheets reminiscent of fish scales. The formation of these “scales” is similar to that of the sheet-like strata and blocks (Figure 12). One edge and the top of the scale are often curved and the negative surface left by the fallen rock is arched. The scales run parallel to the cave wall and peel away along the sheet-like strata³ following fissures and joints.

Figure 12

All of these features play a role in the creation and evolution of the images and representations. The

¹ Lapiaz: centimetric to decimetric subterranean channels, furrows and cracks caused by solution on limestone, often situated on the cave ceiling.

² Sheet-like strata: this term, not part of the current geomorphology vocabulary, is used here to describe relief linked to the underground river.

identification of these micro- and macro-scale features therefore allows anthropogenic forms and shapes to be more easily differentiated from their natural counterparts and avoid confusion linked to the overlap of different morphologies and their alteration.

3.2 The contribution of geology to reading cave art: new interpretations

The identification of karstic features associated with each panel is decisive for interpreting certain graphic entities or clarifying others. Identifying the alteration of graphic entities is only possible by observing and determining geomorphological features. Here, we define a graphic entity as “one or several interconnected prehistoric anthropogenic traces forming an abstract or figurative drawing, painting or engraving that is clearly identifiable and can be delineated. Graphic entities can take the form of an animal figure or a simple isolated engraved or painted line” (Petrognani *et al.*, 2014: 428, our translation). In other words, the clear anthropogenic nature of the drawings is identifiable even if it is impossible to identify the specific object, form, animal or graphic representation.

Our approach to the Grotte du Mammouth provides important information for three aspects of the site’s parietal art: understanding choices influencing the location and preservation of the graphic entities, identifying one new figure as anthropogenic, and eliminating another as a natural, geological feature.

3.2.1 A strategic position for the sculpted mammoth

The first representation analyzed using our dual plotting method is graphic entity n°1, a large sculpted mammoth on the north cave wall near the entrance to the cavity. Its silhouette comprises a trunk, tusk and a cervico-dorsal line (Figure 13), an essential element confirming the mammoth species represented (*Mammuthus primigenius*). A hump in the front part of the animal’s back precedes the slump of the cervico-dorsal line at the level of the thoracolumbar region, typical of this proboscidean (Garutt, 1964, Kubiak, 1982).

Figure 13

The undeniable presence of a nuchal cavity, trunk, and a tusk beginning just below the eye in the figure’s silhouette reinforces this interpretation. The mammoth was sculpted on a massive bar of relatively soft, cross-bedded sandy limestone. It is framed by moonmilk-covered dripstones, which predate the sculpture and potentially influenced the choice of location. In addition, the relief of the sculpted area was more prominent than in the surrounding areas, which is another possible element underlying the selection of location (Figure 14). As is likely case for Palaeolithic parietal art in other sites, the sculpted area of the cave was not chosen because it naturally resembled a mammoth but as it probably offered a space conducive to creating a very imposing sculpture.

Figure 14

Notably, erased solution flutes are evident above the neck and beginning of the back (Figure 15). Truncated by modifications to the surface of the bas-relief, these karstic features are less well developed compared to those lower down in the cave. Diffuse karst is very clearly present along this cave wall, as in most of the rest of the cave. Unlike this natural karstic relief, others (i.e. flow marks) postdate the sculpture and altered its shape and probably its volume.

Today, focusing on micro-relief produces a better understanding of the Palaeolithic artists’ intentions compared to a previous emphasis on macro-shapes such as the ceiling pocket and the initial convexity of mammoth n°1’s cave wall. Ultimately, both morphologies contribute to the creation of the bas-relief

sculpture.

Figure 15

First, the mammoth's body is covered by numerous small negatives of fallen sandstone slabs (Figures 9 and 10). The sculpting of the figure likely led to the more intense natural alteration of the humanly modified surface of the cave wall compared to the hollows.

Localized dissolution features are evident over nearly the entire surface of the mammoth and result from circulating water, chemical reactions between the air and substratum, or earlier alterations of more ancient cupules and other fluvial features. Some of these features can resemble altered traces of pitting, particularly around the head, where they co-occur with impact traces.

Seepage is evident across the whole figure in the form of a thin calcite layer overlain by organic matter, exfoliated sandstone platelets, and altered dripstones anterior to the sculpting of the mammoth. These tend to reduce the volume of the bas-relief and erase previous shapes and deposits while encouraging the development of mold, concretions, or the destruction of calcite layers.

Organic matter is also present on the cave wall, which potentially results from biological activity in a zone initially exposed to daylight. The presence of thin calcite layers is also very significant, currently concentrated between the legs and trunk of the mammoth. Calcite deposits initially covered a large part of mammoth's body, of which several traces and thin calcite plates remain.

During the geomorphological survey (Figure 16), natural formations and the mammoth sculpture were plotted according to their relative chronology in order to distinguish phenomena pre- and post-dating its creation. As the thin calcite layer obscures much of the cave wall, they appear slightly transparent (70%), such that the entire contour of the figure remains perceptible and the overlapping zones are still identifiable. Finally, it is important to note the presence of the grain-by-grain alteration of the sandy limestone, as in the others sectors of the cave, which is linked to the integrity of the sandstone, water infiltrating the surrounding rock, and by air humidity in the cave. The alteration of the sandstone reduced the volume of the bas-relief and partially obliterated technical elements of the mammoth figure in a more subtle way compared to the exfoliation of the sandstone walls and local dissolutions.

Figure 16

Ultimately, the geomorphological analysis enhanced our understanding of the natural processes that influenced the location and evolution of the mammoth sculpture. It equally revealed the previous presence of micro- and macro-relief that potentially guided the choice of location for the figure. The rounded morphology of the cave wall where the bas-relief was sculpted, the framing of the mammoth sculpture by ancient dripstones covered by moonmilk, and nearby ceiling pockets could have been mobilized to create a sense of volume while several stratification planes accented by the porosity of the diffuse karst potentially guided the line of the animal's back.

The volume of the mammoth and part of its silhouette were clearly attenuated by the calcite deposits in the hollows, with seepage and granular weathering of the sandstone forming the figure's body. This being the case, it was necessary to map a large surface around the engraved panel. This analysis of the first mammoth in the Grotte du Mammouth illustrates a form of 'long-term' reconstitution that includes the evolution of the figure since its creation.

3.2.2 A genuine horse head or geological illusion?

A figure discovered in the deepest part of the cave was analyzed using the same approach (Robert *et al.*, 2017). This figure is located near an anfractuosity opposite the north wall in the final part of the cavity. It occurs on an overhanging indurated limestone bar to the right of a block with ripple-marks and exhibits

similar formal characteristics to that of a neighboring graphic entity.

Figure 17

The placement of the engraving suggests a search for volume through the creation of wide V-shaped section (Figure 17). The beginning of the carving is clearly perceptible in the top of the furrow, and curves towards the base before rising again to the right to form what appears to be an animal's head, probably a horse, with a rectangular forehead and rounded muzzle (Robert *et al.*, 2017).

The representation covers a 26.5 cm wide by 17 cm high area, 1.4 m above the present-day cave floor. Immediately to the right of the forehead, lies another sub-horizontal furrow suggestive of a mane and the beginning of the animal's back (Figure 18).

Figure 18

This previously unpublished engraving initially appears rather "crude"; however, a detailed mapping of the cave wall allowed us to separate the genuine contour of the figure from natural processes.

The panel is located on a small 25-cm thick bar of cross-bedded carbonated sandstone below the thick yellow massive sandstones of the cave ceiling. Several of the sedimentary deposits were laid down before the engraving. These deposits are potentially very old (Figure 19) and therefore cannot be used to build a relative chronology of the graphic entities, other than the fact that they pre-date their creation and thus influenced the nature of the surface worked by the prehistoric artist.

For this figure, the risk of uncertainty stems from the possible confusion between genuine engravings, cross-bedded deposits, and rectilinear or sinuous seepage marks depending on the composition of the surrounding rock or/and surface morphology (plane, curved, with or without asperities), to which can be added mold and organic matter covering the surface of the panel.

Figure 19

The orientation of the engraved furrows contrasts sharply with the stratification planes and the orientation of the little rivulets of seepage. The sandstone stratifications appear oblique to the vertical or sub-vertical engravings and it is clear that the lines are not natural features. The curve at the base of the furrow forming the relief intersects several stratification planes. In addition, the very deep hollowing and the width of the line are incompatible with the fine cross-bedded sandstones.

Seepage altered numerous zones of the engraved panel and, in places, dissolved the sandstone carbonates protruding out of the quartz grains, creating small, several centimeter long, elongated hollows with flat bottoms reminiscent of flow traces. These alterations affected the wall surface and decreased the volume of the figure, in particular around the cheek and mane of the animal. This also confirms the engraved horse figure to be anterior to these geological alterations.

3.2.3 A bovid or a natural shape produced by geological phenomena?

Similar to demonstrating non-geological aspects of traces inside the cave, our detailed mapping approach also invalidated a graphic entity previously thought to be anthropogenic. The feature is located on the north wall in a 85 cm by 65 cm high rectangular area more than 2 m above the present-day floor. The figure was previously described simply as a sculpted bovid (Delluc *et al.*, 1983) due to the heavily altered cave wall, recent human activity and calcite deposits covering the lower part of the panel.

In the original description, the dorsal line and upper contour of the head were considered as being formed by a joint with an abrupt edge without any traces of human intervention. A line marks the lower side of the

head, the neck and the chest, and forms the limit of a significantly lowered area that extends over about 20 cm to the left, designed to emphasize the figure's body. The line of the belly, beginning of the fore and hind limbs as well as the external side of the tail reflect the same process. The two adjoining forelimbs as well as the hindquarters and tail are independent (Figure 20).

Figure 20

Our analysis identified no anthropogenic modifications (pitting, scraping, etc.) or lines described by Delluc *et al.* (1983) as delimiting the forequarters, hindquarters and tail.

Instead, we observed two important elements:

- modern traces (pickaxe blows and metal tool marks) within and surrounding these volumes, especially in the lower part,
- highly active geological phenomena identified during the geomorphological plot. Tectonic activity induced fissures in the cave wall that are covered with numerous pores of the diffuse karst and traces of mechanical and chemical alterations. Large juxtaposed scales were detached from the sheets at the interface between joints, fissures and stratifications (Figure 21). The subsequent manifestations result from small water flows and flow flowing across the diffuse karst channels and voids.

Figure 21

These observations demonstrate the morphology of the reported graphic entity to exclusively result from ancient geological phenomena (Figure 22). This holds true for all four "strategic" zones described as forming the animal's body:

- The space separating the "tail" from the "hind-quarters" is, in fact, a natural alignment of cupules and pores along a scale. In addition, the shape of the "hindquarters" is, in reality, formed by the negative surface left by the detachment of a "fish scale shaped stone" fragment, while the external edge of the "tail" is associated with sheet-like strata.
- The distinction between "the chest" and "front leg" equally results from a similar alignment of cupules and pores secondarily induced by flows at the limit of E1 (Figure 22).
- The volume described as distinguishing the animal's belly follows an oblique stratification plane with small millimetric channels carved by seepage. Water flowing along this bedding plane precipitated the removal of small fragments of the calcite layer and rock, accentuating the effect of volume.
- Finally, the relief of the "chest" is the consequence of the junction of two scales (E1 and E7 in Figure 22) and the limit of the sandy limestone strata.

In addition, the marks evoking pitting traces correspond to a high concentration of millimetric pores of the diffuse karst observable nearby on the same cave wall.

Figure 22

Ultimately, all the elements contributing to the volume result uniquely from geological phenomena. Subsequently, a thin calcite layer was deposited over this relief, in association with brown sediments, organic matter, and calcium carbonates partly destroyed by recent flows. Numerous rivulets of seepage led to dissolution across the entire surface of the panel. While these deposits and limited water flow could have altered possible traces of limited anthropic modifications, we did not identify any such changes on the cave wall where this "entity" is located. Observations of the cave wall around this entity also support these conclusions. First, the "fish scale-shaped stone" system on the north cave wall is similar in volume

and size to that of the panel with entity n° 4, in particular, the natural line of the back (Figure 23).

Figure 23

Second, the same type of clearly natural perforations can be observed on the same wall to left of the theoretical neck, associating diffuse karst and pores formed by the underground river, sometimes mixed with pitting (Figure 24).

Figure 24

The mapping of this entity confirmed our initial observations, namely the absence of anthropogenic traces, including small technical marks within or at the edge of the furrows that could be considered as engraved. Moreover, the observable geological phenomena responsible for the volume identified as a bovid are also present in the immediate vicinity of the panel. Taken together, this demonstrates the 'figure' to be entirely natural.

Several doubts still persist in terms of the potential "limbs", as a thin, altered calcite layer overlies these sectors, including the inside of the "thigh". The fact that the part underlying the figure clearly bears traces of recent pitting presents an additional difficulty, as they may have obliterated any traces of engravings or the creation of a volume at the end of the possible "limbs".

As all the elements previously considered to reflect human intervention (engraving, flattening or installation of a volume) have been shown to be a consequence of geological processes, the hypothesis of an anthropogenic graphic entity appears impossible to maintain.

4. Discussion

Combining archaeology with geomorphology: a long-term history of Paleolithic art in the Grotte du Mammouth

Our results for the Grotte du Mammouth demonstrate that by combining geological and archaeological data with plots and analyses using high-resolution photography (x 1,200 and x 1,600) or photogrammetry make it possible to reconstruct the chronology of most of the natural cave wall phenomena and anthropogenic representations (Figure 25). At the very least, this method shows how it is possible to identify and distinguish natural processes from the production of anthropogenic images on cave walls.

Figure 25

During the karstogenesis of the cave and several early Plio-Pleistocene flooding events, the underground river generated ceiling pockets, cupules, jagged rocky walls and circular shapes. On the other hand, flow marks and solution flutes only appeared after the disappearance of flooded regime flows but before the prehistoric artists visited the site.

The thin calcite layers are more difficult to place in the site's relative chronology; however, at least one generation of calcite crust formed after the sculptures were made (e.g. mammoth n° 1, Figure 16).

Similarly, the visible traces of seepage and alteration zones postdate the cave art and formed at the same time or before the thin calcite layers, which probably appeared with warmer postglacial climatic conditions. To a large extent, these fine rivulets of water, the grain-by-grain alteration and the formation of alteration planes are responsible for the deterioration of engravings and the development of the early natural shapes. Documenting the evolution of the cave wall also makes it possible to anticipate how best to conserve the graphic entities (active and inactive areas).

The shape of the cave wall guided the choice of location for the engravings, as shown by the position of

the first mammoth and other graphic entities, such as the equid head (Entity 9), which is materialized in the wall's natural relief (Aujoulat *et al.*, 1989) and completed by a circular line for the eye and several additional micro-traces identified by mapping the cave wall. Geological processes also complicate "reading" the walls to such an extent that certain morphologies formerly attributed to human intervention turned out to be totally or partially natural, such as "bovid" n°4. Other traces, on the other hand, can be clearly distinguished from deep engraved lines, such as the newly documented animal head in the back of the cave (entity 13) (Figure 25).

The detailed recording of the walls' morphology can also indicate the time that elapsed between two artworks and can help identify more recent human activity when micro-relief are intercalated with microgrooves due to water seepage. A further example is entity n° 9 (Figure 25), where the engraved circle is separated from modern pickaxe traces by several calcite and moonmilk layers as well as seepage microgrooves. Furthermore, the spatial and chronological organization of these small, more recent furrows compared to ancient and modern tools marks, fingerprints, and scuff marks demonstrate that most of the cave walls dried only recently, perhaps following modern climatic warming. Finally, tracing the evolution of the cave walls also provides insights on other aspects (environmental conditions, state of preservation, etc.) of the site that none of the previous graphic plotting methods had discussed because it takes into account all elements of the wall, especially the importance of micro-relief.

5. Conclusion

The cave wall mapping developed at the Grotte du Mammouth open up new research opportunities, including reconstructing the original volume of the sculptures, use-wear analysis, relative dating, climate studies, and aspects of conservation. It also offers a more reliable means of interpreting doubtful traces on cave walls damaged by various forms of alteration and where traces of different human activities are intercalated with natural features. The method outlined here makes it possible to approach marks, traces, and styles of cave art with more confidence and differentiate natural alterations, geological formations, cave wall topography (both before and after any human activity) and intentional human-made images, engravings or sculptures.

Perhaps for the first time, a set of new analytical and inferential methods that did not strictly rely on stratigraphy and speleothems made it possible to establish a relative chronology of natural processes in relation to cave art. Our approach places parietal art in its cultural and geological chronology, resulting in a more rigorous and detailed analysis. This complementary approach to the study of decorated caves, some overlooked due to the poor preservation of certain parts of the cave art, provides an enhanced vision of prehistoric art within its geological context.

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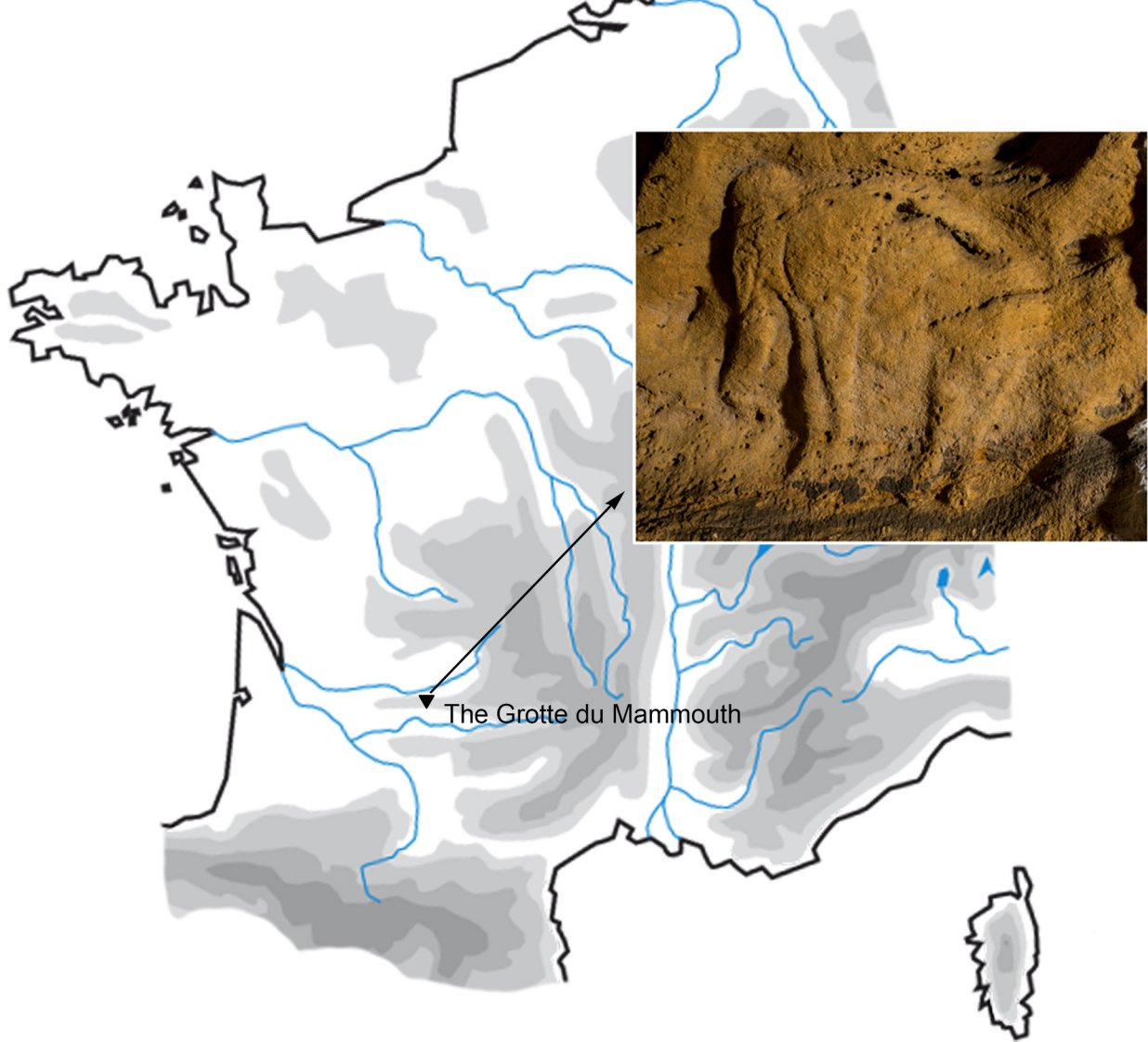
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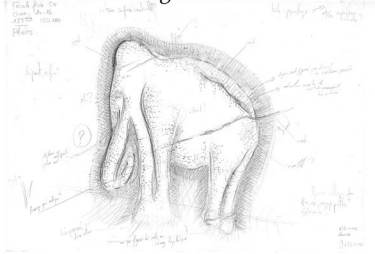
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The Grotte du Mammouth

Survey's process of a graphic entity - Grotte du Mammouth - Entity 1

Reading sketch



High-resolution photography



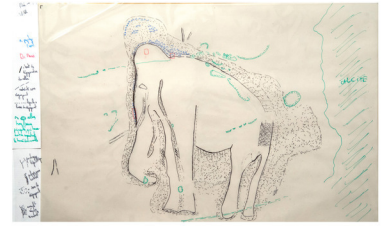
Detailed layer - natural formations



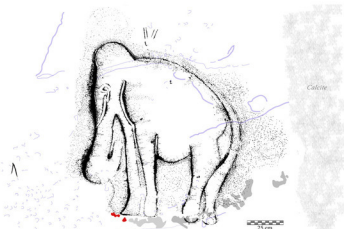
Detailed layer - Anthropogenic lines



Detailed layer - Technical informations



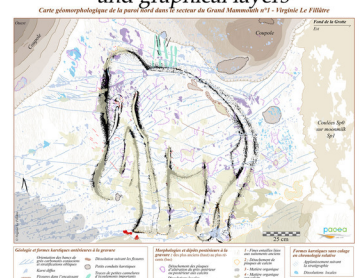
Analytic final plot



Infographic final plot

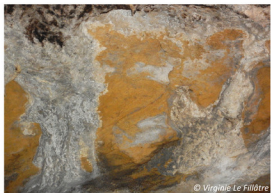


Plotting geomorphological and graphical layers



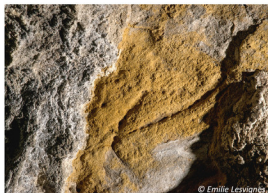
The work inside the cave

The wall cave without photographic and data processing



© Virginie Le Fildras

High-resolution photography in order to highlight rock art

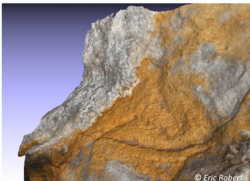


© Emilie Lesvigny

Transfer of the geology on a tracing paper overlaying the photography

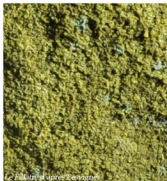


Photogrammetry : to do the sights the cave walls shapes from varied angles



© Eric Robert

Microreliefs on high-resolution photography zoom X800 à X1600



© Emilie Lesvigny

Macrophotography



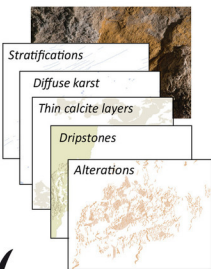
CAD Software

Photography and layers inside CAD software

Several layers based on the type and the relative chronology of reliefs and deposits

Key on-screen editing in form of relative chronology

Complet final results Geomorphological map of cave wall



- 1 - Natural shapes and microreliefs
- 2 - Sediments deposits
- 3 - Chemical deposits
- 4 - Organisms and biological deposits
- 5 - Non-geological traces : vandalisme, animal scratches, unspecified strokes...

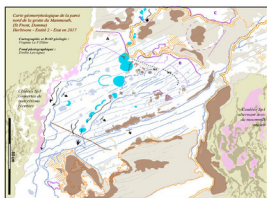
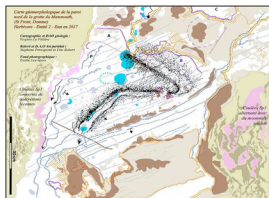


The utilisation of results

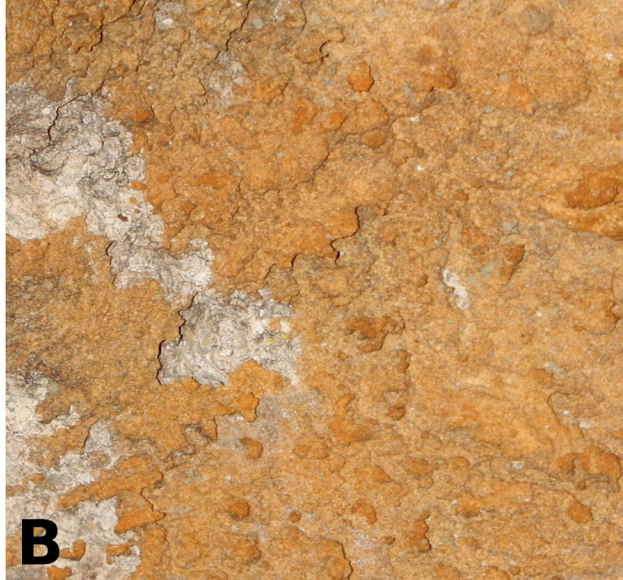
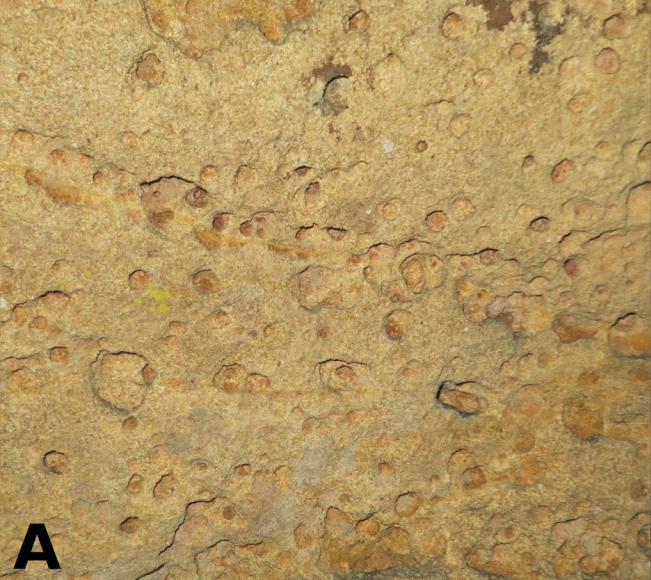
The archeologist work

Geological data vs archeological data

Data selection by archeologist from the CAD software



- 1 - Differentiation of geological reliefs and anthropic shapes deteriorated by chemical and mechanical alterations and sometimes by human activities.
- 2 - Understanding of the cave walls evolution
- 3 - Relative chronology of deposits, natural shapes, and rock art.
- 4 - Utilisation of the walls cave by the actual and prehistoric men.
- 5 - Anthropic shapes selection to compare with the other rock engravings and bas-reliefs.
- 6 - Preservation : definitions and origins of the cave walls active and damaged zones.
- 7 - Datations by the method of speleothems phases (C14, U/Th).















negative pattern by alteration

*Secondary X-shaped joints,
beginning of lapiaz*



Fault
→



Entity 8

Entity 7

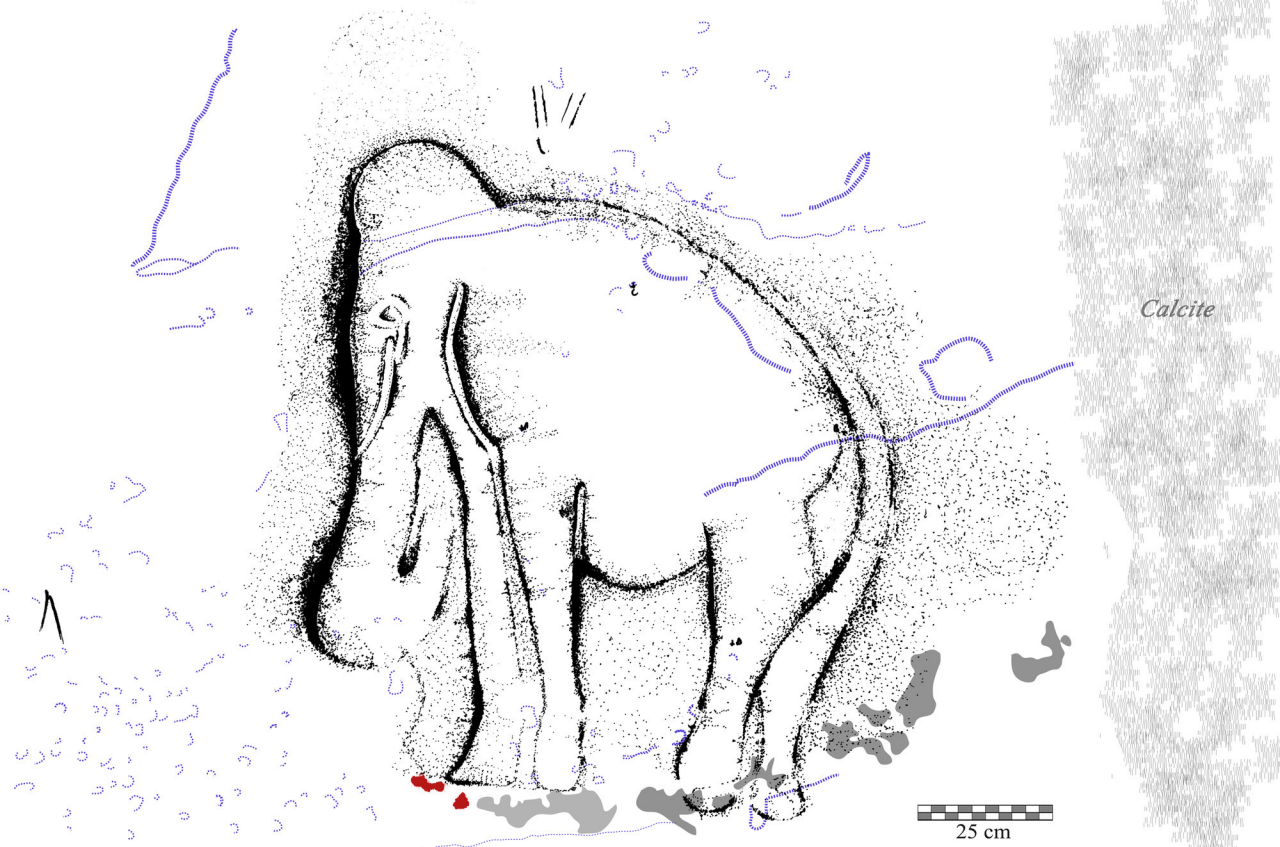


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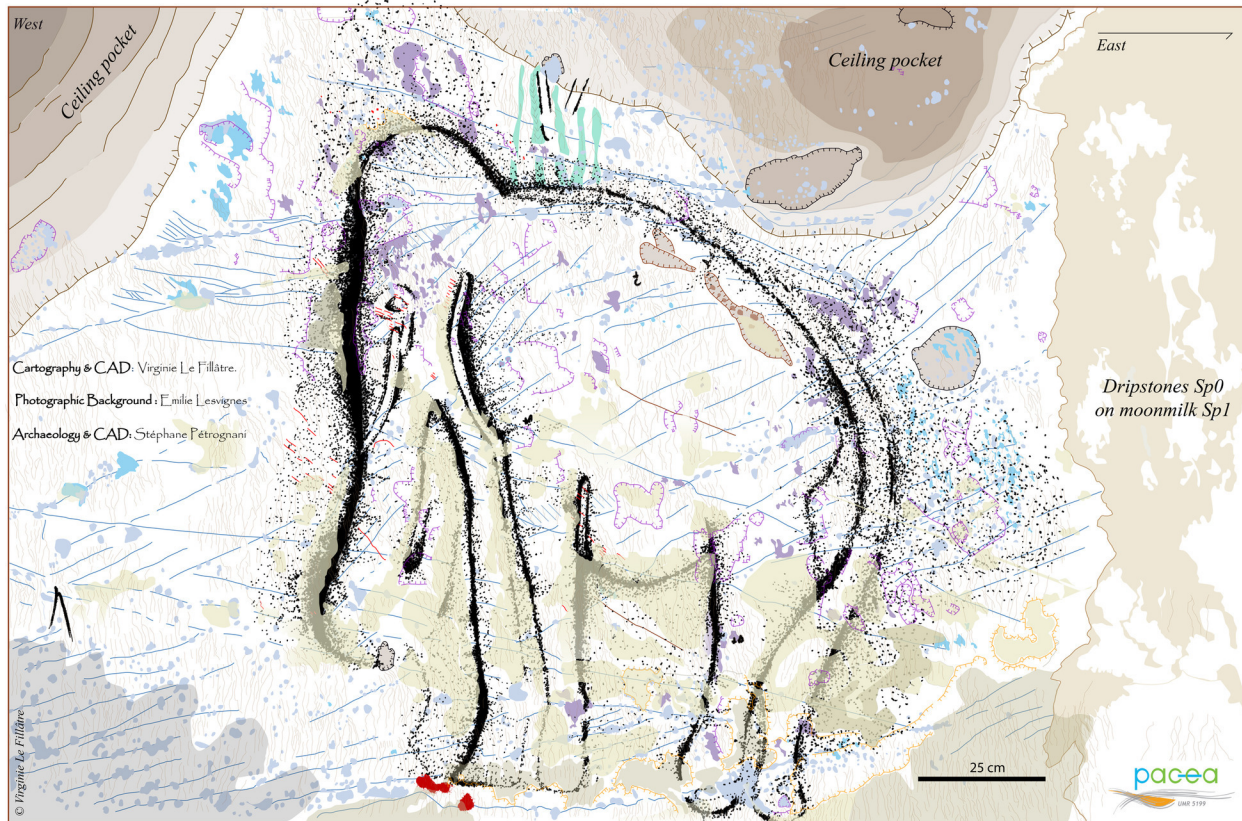
Calcite

25 cm





Geomorphological mapping of the north cave wall - Graphic entity n°1 - Great Mammoth



Geology and karstic morphologies anterior to engravings

- Orientation of coniacian sandstone et their cross stratifications
- Dissolution along fissures
- Diffuse karst
- Little karstic channels
- Fissures in the bedrock
- Solution flutes or significant flow marks destroyed by palaeolithic artists

Morphologies and deposits subsequent to engravings ranked from oldest to youngest

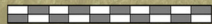
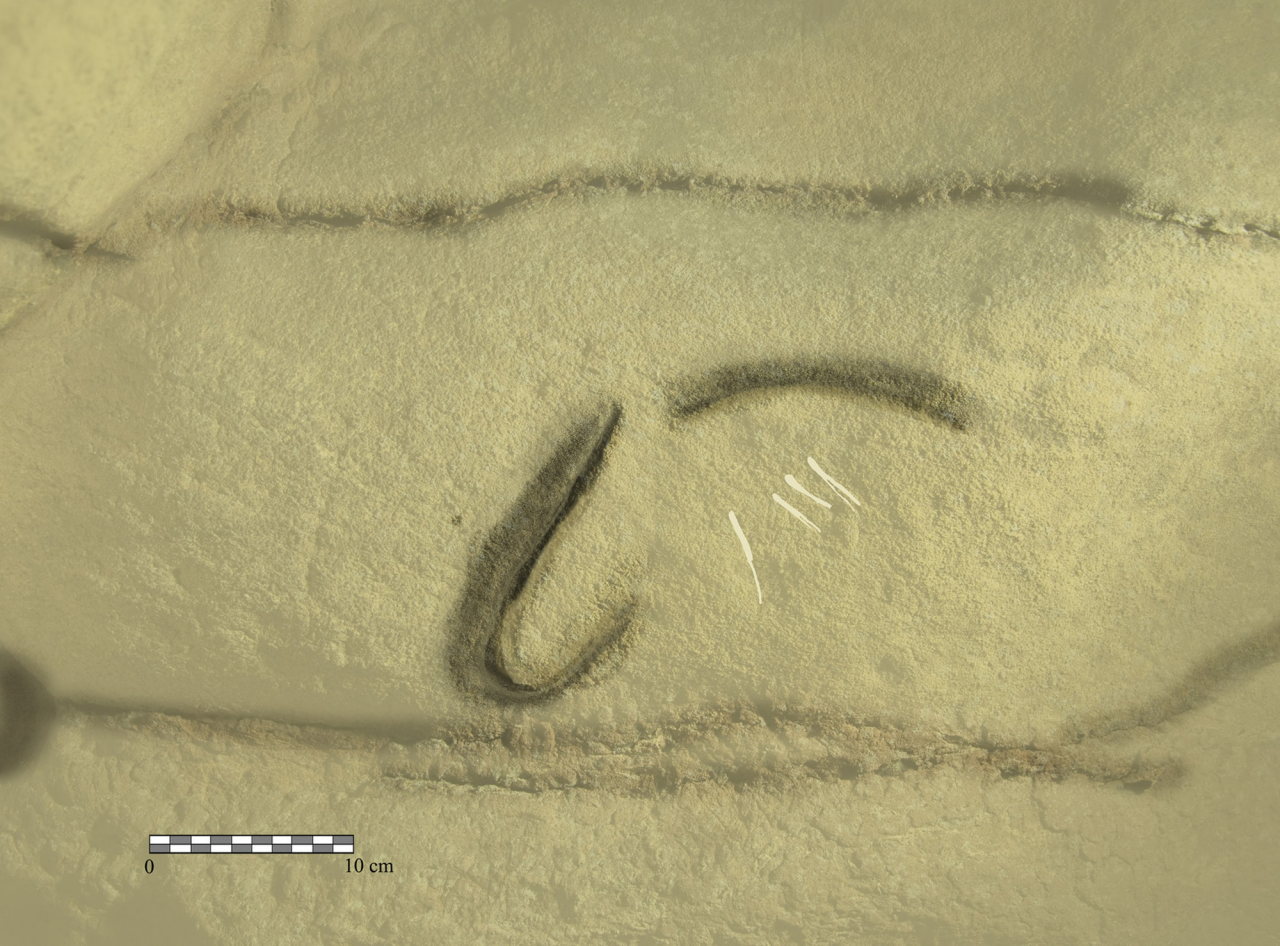
- Marks of fallen alteration plates after or before calcins genesis
- Local dissolutions
- 1 - Little V-shaped furrows associated to old seepages
- 2 - Marks of fallen calcite crust plates
- 3 - Organic matter
- 4 - Organic matter destroyed by palaeolithic artists
- 5 - Calcins, calcite crust

Karstic morphologies without relative chronological rank

- Flattening by alteration along to stratifications
- Local dissolutions



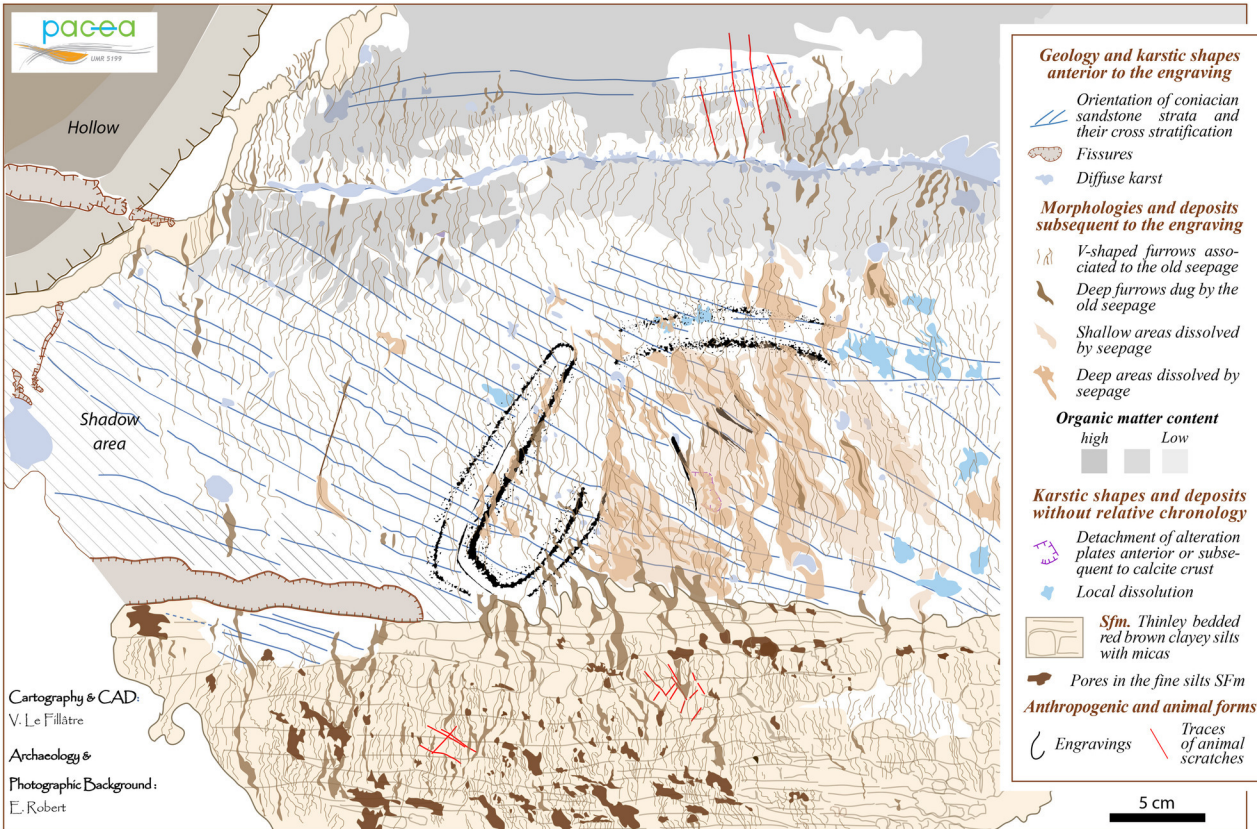


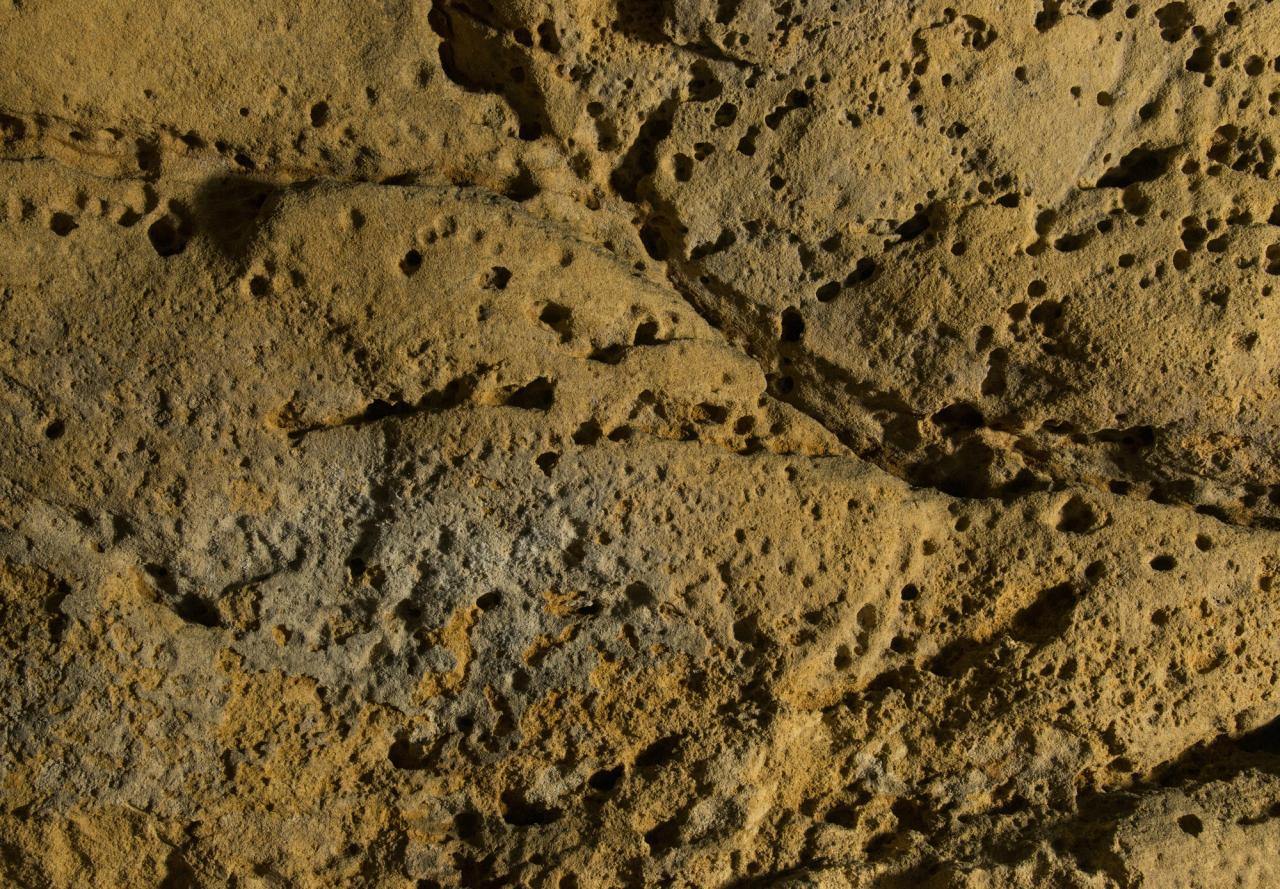


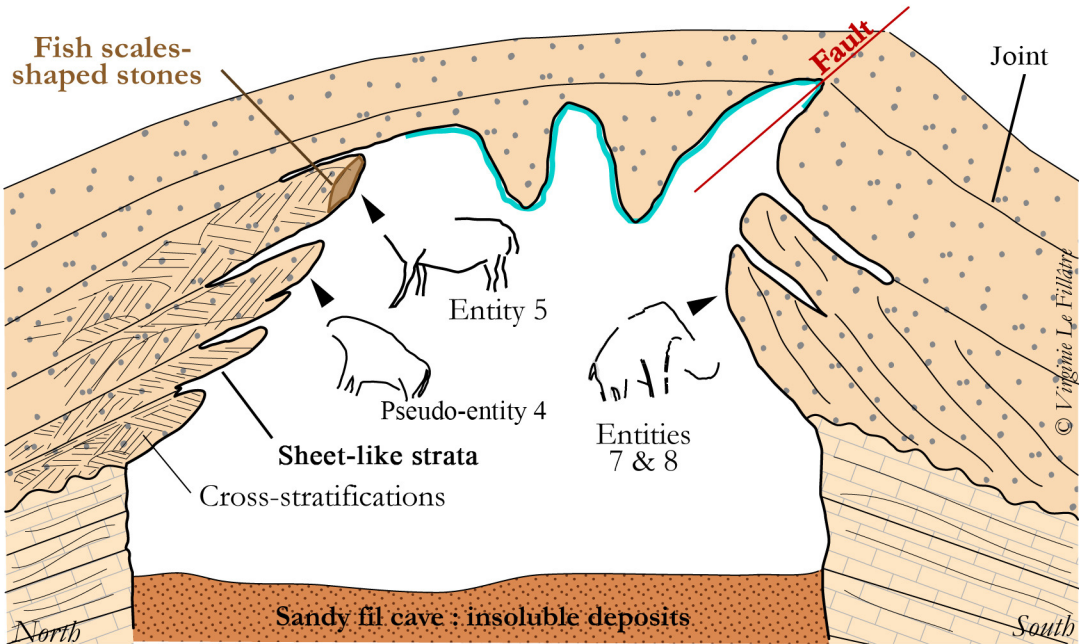
0

10 cm

Geomorphological mapping of the wall - graphic entity 13







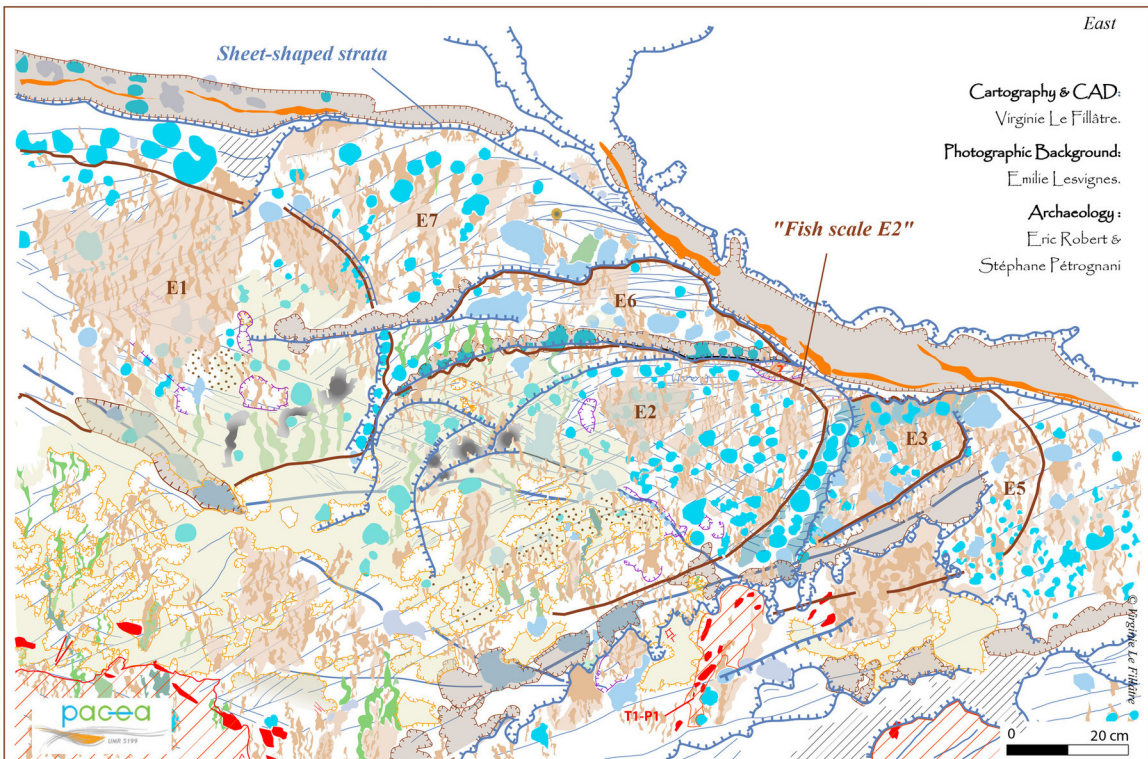
Geomorphological mapping of the north cave wall - Graphic entity n°4

East

Cartography & CAD:
Virginie Le Fillâtre.

Photographic Background:
Emilie Lesvignes.

Archaeology:
Eric Robert &
Stéphane Pétrogiani



Geology and ancient karstic morphologies

- Orientation of coniacian sandstones and their cross-stratifications
- Dissolution along a fissure or a stratum
- Significant flow marks anterior to the thin calcite layer (calcin)
- Diffuse karst
- Underground river traces during the early Plio-Pleistocène (cupules, pores, ...)

Strata boundaries and their infill

- Boundaries of overhanging strata
- Iron oxides between strata (limonite or goethite)

"Fish-scale" alteration system (old phase)

- E1 à 6** Number of "fish scale" broken away the cave wall from the sheet-shaped strata

Geology and deposits after the ancient phase

- Shallow areas of the calcareous sandstone dissolved by seepage : pattern of dots, protruding of quartz sand grains, destruction of carbonates
- Deep areas dissolved by seepage
- Significant flow marks subsequent to the calcite layer formation
- A melting of organic matter, sediments, and calcite
- Calcite crust or thin calcite layer (calcin)
- Traces of fallen calcite crust on the rocky wall
- Unstudied sectors

Deposits and karstic shapes without relative chronology

- Detachment of alteration plates anterior or subsequent to calcins
- Local dissolution traces
- Significant flow marks

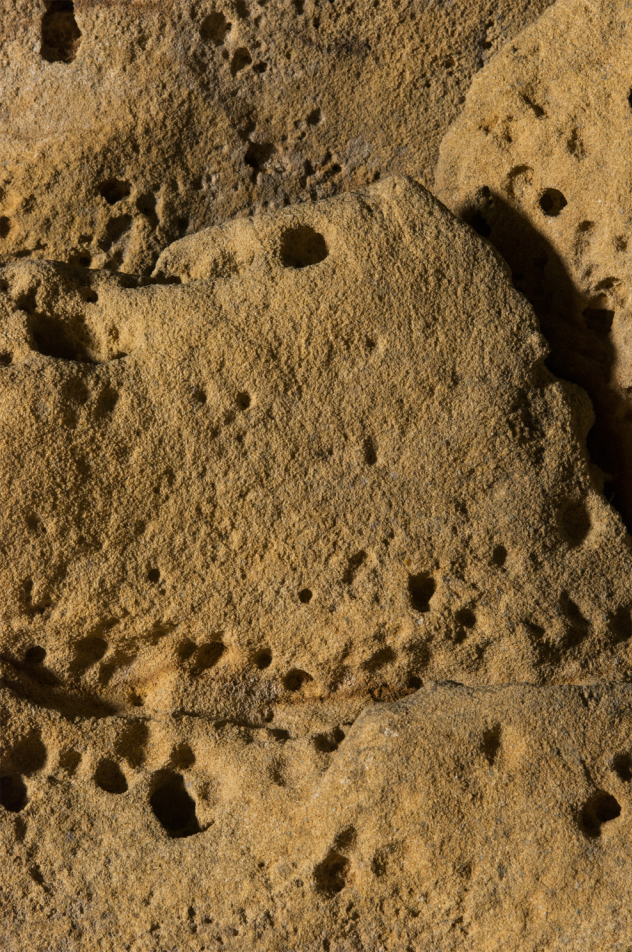
Actual organisms






- Lichens
- Mould

Anthropic elements

- Recent anthropic destructions (modern history or Middle Ages...)
- Recent traces of tool
- T1-P1** Number of tool marks
- Unidentified origin of fallen stone plates traces on the cave wall





Entities	Reliefs and deposits prior to rock art	Reliefs and deposits subsequent to rock art	Geological results related to rock art	The cave walls State of preservation
Entity 1, "Tall Mammoth"				
	<p>1 – Cambered surface of panel 2 – Ceiling pockets 2 & 3 - Cupules 2 & 3 – Jagged rocky walls 2 & 3 & 4 – Diffuse karst 2 or 3 or 4 – Solution flutes 4 or 5 – Altered speleothems (Sp1) with moonmilk surrounding the mammoth</p>	<p>1 – Calcite thin layer 2 – The altered stones and calcite thin layers came away cave walls 3 – Actual dripstones (Sp0) surrounding the mammoth 1 & 2 & 3 - Seepages</p>	<p>■ Morphologies and reliefs prior to rock art determine the use of cave wall; ■ No Misunderstanding between geological and human macro-reliefs but traceology is often impossible because of the bedrock alteration except for the back of mammoth, its belly, the front and the end of its trunk.</p>	<p>■ Bad preservation state of Mammoth's legs and feet and the bottom of panel because of organic matter and seepages. ■ Good state of preservation everywhere else.</p>
Entity 2, "herbivorous head"				
	<p>1 – Ancient reliefs of Pliocene or lower Pleistocene : cupules + diffuse karst 2 – Sheet shaped strata 3 – Inverted relief and falling blocks 4 – Dripstones (Sp1) 5 – Moonmilk (Moon 1)</p>	<p>1 – Seepages and alteration processes 2 – Perhaps thin calcite layer.</p>	<p>■ Morphologies existing before rock art have determined the use of the wall cave. ■ The head crosses the geological reliefs. No misunderstanding between geological and human shapes. ■ The animal neck is delimited by a sheet shaped strata and an alignment of cupules and diffuse karst voids. ■ The relief situated above the herbivorous muzzle is damaged by seepages and alterations. Consequence: a ticker nose that could influence the determination of the beast order (equid or cervid).</p>	<p>■ Very altered wall cave, but no actual known seepages.</p>
Entity 4, "Bovid"				
	<p>1 - Polished cave walls 1 - Cupules 1 – Sheet-shaped strata forming 1 & 2 - Diffuse karst 3 – Breakdowns of fish scales-shaped stones.</p>	<p>? – Little flows marks on the cave walls 1 – Thin calcite layers 2 - Seepages</p>	<p>■ The shape of the bull is defined by cleft, joints and strata, fluvial reliefs and the alteration system forming fish scales-shaped stones. The bull is not an anthropic morphology. ■ An uncertainty there on the bull's legs.</p>	<p>■ A few microbiological deteriorations in spite of mould. ■ The thin calcite layers and little altered stones come away the "bull tail".</p>
Entity 9, circle or "horse eye"				
	<p>1 – X-shaped joints 2 – Polished and rounded shape of the horse's head due to the subterranean river. 3 – Splitting of cross-stratifications.</p>	<p>1 – Actual calcite dripstone covered by recent moonmilk around and on the circle (the horse's eye). 2 – Fall of the thin calcite layer fragments and sandy calcareous stones 3 – Seepages. 1 & 2 & 3 - Splitting of cross-stratifications.</p>	<p>■ The underground stream has drawn the shape of the horse's head. ■ The ring around the centimetric knoll and stokes have not a geological origin.</p>	<p>■ Few damages resulting from seepages ■ Perhaps biological alterations : golden lichens and moonmilk</p>
Entity 13, "animal head"				
	<p>1 – Cross-stratifications 2 - Joints 3 – Diffuse karst</p>	<p>■ Many dissolutions marks connected to seepages.</p>	<p>■ The distinction between the engraved strokes of the animal's nose and the traces of stratifications and seepages is simple by reason of their orientations. ■ Some strokes not belonging to the entity 13 haven't a geological origin.</p>	<p>Many moulds.</p>