Origin of the asymmetry of certain fossil galleries: the major role of biocorrosion as exemplified in the Roquette cave (Gard, France)

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Abstract

Some portions of fossil caves show asymmetrical gallery sections and these morphologies can be associated with biocorrosion. When the highest point of the gallery is not situated in the middle axis, we can observe, just below, an inclined to subvertical flat surface where the rock is strongly weathered and cut out by karrens and pots. At the foot of the opposite wall of the gallery, a well-marked basal notch is common. Above the notch, a succession of hollow shapes (conches) intersecting both limestone and calcite is present. The above features, as well as the presence of hydroxyapatite crusts, indicate significant occupation by bats and represent morphologies formed through ancient biocorrosive processes. The inclined wall, situated under the living areas of the bats, is transformed into a “biogenic lapiaz” formed under a layer of guano. The notches located at the base of the opposite wall correspond to the distal end of the guano heap, the acidity of which, released by mineralization, corrodes laterally. Above the notch, the hollow shapes, which we will call "biogenic conches", result from the upward circulation of gases and acid aerosols generated by the convection resulting from the degradation of guano. This process of differential alteration tends to increase the initial asymmetry of the gallery whose two walls have a very different morphology and texture.

1. Introduction

Geomorphological studies of caves in tropical areas have shown that the presence of large colonies of bats has an impact on the morphological evolution of galleries (MC FARLANE *et al.*, 1995; LUNDBERG & MC FARLANE, 2012). Biocorrosion can result in occasional alterations, such as bell holes on the ceiling or pot holes on the ground. They develop around bat nesting areas or under piles of guano but it appears that biocorrosion can also be responsible for larger features manifested on the scale of the entire gallery (Fig. 1). These morphologies are often more difficult to identify, requiring consideration of a whole series of features that are still relatively unknown, the association of which reveals not only the different impacts of biocorrosion, but also the extent of biogenic reshaping. In certain cavities such as the Roquette cave (Gard, France), biocorrosion has erased the initial speleogenic features and radically modified the general section of the gallery.

Figure 1: Overview of an asymmetrical gallery marked by biocorrosion. The biogenic lapiaz on the right faces a smooth wall hollowed out with biogenic conches on the left that overlies a notch visible at the foot of the walls. The soil is made up of a thick layer of phosphates from guano mineralization (photo: P. Crochet).

2. Materials and methods

For the study of these forms, we have chosen to take the cave of La Roquette (Gard, France) as a case study where substantial evidence of biocorrosion has recently been identified (BRUXELLES *et al.*, 2022). Located about thirty meters above the Vidourle river, this cave consists of a large gallery almost 500 m long with two entrances, a 15 m sinkhole to the northwest and a prehistoric entrance, leading to the side of the valley, to the southeast (DU CAILAR & COUDERC, 1947). With the exception of the entrance sinkhole, the cavity is horizontal and corresponds to an old local base level linked to deepening of a large polje. Locally, abundant speleothem partially clogs the gallery. This cave is known since prehistory and has yielded archaeological material dating back to the Middle Palaeolithic (JEANJEAN, 1871; DE JOLY, 1938; MEIGNEN & COULAROU, 1981). Thus, it appears that this cavity has been connected to the surface at least since the Middle Pleistocene, meaning that it has therefore been able to shelter colonies of bats at least since this time.

The Roquette cave shows features of spectacular biocorrosion over almost its entire length (BRUXELLES *et al.*, 2022). It was necessary to characterize these features as carefully as possible in order to establish a typology of the different forms of evidence along the cavity. In addition to the photographs specifically dedicated to these features, we took photos and videos by drone in the cave. This allowed us to obtain novel perspectives and better highlight the particular morphologies caused by biocorrosion. Finally, two episodes of 3D scans utilising lasergrammetry were conducted using a Faro Focus 3D 360 short-range phase shift scanner (Edytem laboratory). The acquisitions were conducted with a density of about seven million points per scene, every 2-3 m. In total, 227 scan scenes were acquired over the entire network, making it possible to model the whole cave and then to generate numerous gallery sections in order to conduct morphometric analyses in particular sectors where the asymmetry is the most marked (Fig. 2).

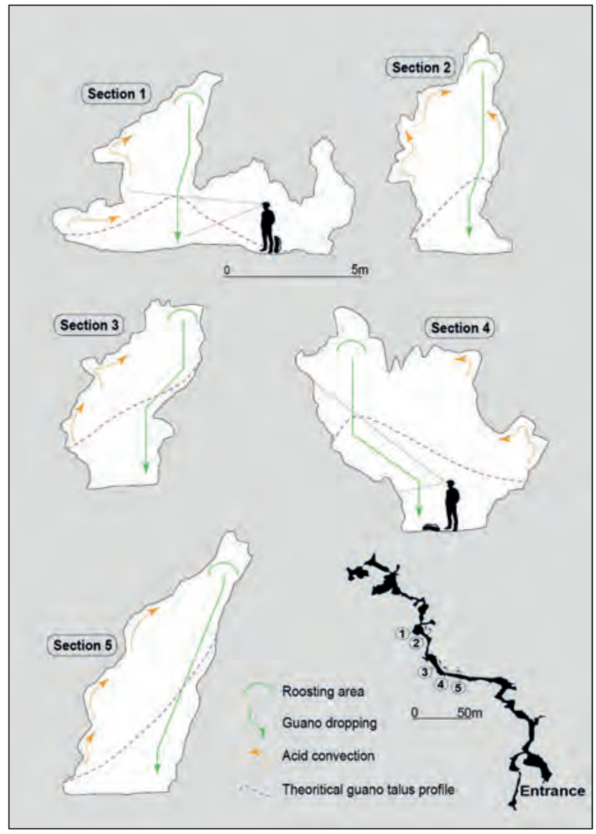

Figure 2: Some sections of galleries in the Roquette cave. The green arrow indicates the arrival of guano from the bat nesting area. The orange arrow materializes the convective phenomena responsible for the expansion of the gallery. The purple dotted lines give an idea of the geometry of the piles of guano, keeping in mind that their size is very variable over time (3D scan and drawing by S. Jaillet).

3. Results

Among all the biocorrosion features identified, some may be genetically associated. The most significant and the most characteristic feature is the asymmetrical galleries because it includes a whole suite of features deriving from several processes working together. This multifaceted feature represents a complex biogeochemical system (Fig. 2) that includes the following forms:

- ***At the vault***, bats occupy the highest part, often at the top of phreatic cupolas. Bell holes (biogenic cupolas) are superimposed in these forms. In these high parts, the rock is altered in a differential way by the condensation-corrosion enriched in CO_2 resulting from the respiration of bats. This results in a rough texture leaving the less soluble parts in relief and resulting in an “elephant skin” appearance (Fig. 3).

- ***When the high point of the gallery*** is not exactly in the center of the gallery but rather eccentric, the urine and the guano flows along a wall and a film of guano can persist if the wall is not too vertical. On contact with them, the surrounding rock is altered and the limestone is replaced by a layer of hydroxyapatite type phosphate. Here, the alteration of the rock takes place in a differential way and results in the formation of a biogenic lapiaz covered with a dark layer of phosphate (Fig. 4).

- ***On the ground***, the guano forms a heap leaning against one of the walls and flowing to the other wall (Fig. 2, sections 2-5). Its mineralization leads to the release of sulphuric and nitric acids and the formation of various types of phosphates.

Figure 3: "Elephant skin" appearance of the rock around the bat nesting areas. Here the rock is differentially altered by corrosion condensation made slightly more aggressive thanks to the CO_2 released by bats (photo: J.-Y. Bigot).

- ***At the base of the opposite wall***, the distal part of the pile of guano causes the formation of a notch, by the leaching of fermentation juices (whose pH can reach 2-3). This develops several decimetres to more than one meter into the limestone (Fig. 2, sections 1 to 5).

- ***Above the pile of guano***, fermentation causes a rise in temperature and convection processes raise acidic gases and aerosols. Above, at the contact with the cooler wall, which overhangs the guano, the gases condense and form a veil of acidic water that actively dissolves the limestone. Vertically organised dissolution features develop along these updrafts routes. These biogenic conches, similar in form to large wall cupolas, range in size from the decimetric to metric (left wall in Fig. 1). Here, the rock is perfectly smooth and these forms affect the limestone or calcite concretions equally, a sign of sufficient potency to overcome the difference in crystal size (micrite vs sparite) in particular.

Figure 4: Biogenic lapiaz formed by cryptocorrosion under a guano film. The dark parts (to the left of the personage) correspond to hydroxyapatite crusts (photo: P. Crochet).

Figure 5: Facing a biogenic lapiaz (on the back of the personage), the limestone wall shows the forms of successive upwelling waves. They cannot be attributed to paragenetic benches and correspond to a stage in the evolution of biogenic conches formed by the convection of acid gases resulting from the fermentation of guano (photo: J.-Y. Bigot).

4. Discussions

The association of features and the implied succession of processes are visible all along the cavity. Of course, the asymmetry changes axis depending on the initial position of the top point of the gallery, where the bats have settled (Fig. 2). The wall located under the droppings undergoes a direct alteration, but the guano film and the hydroxyapatite crusts protect it from the acid flows resulting from the fermentation of the main pile of guano (Fig. 4). On this wall, we therefore only observe forms of cryptocorrosion (biogenic lapiaz), sometimes pierced with pot holes and the retreat of the wall is moderate. The opposite wall, however, is constantly subjected to the action of acid fluxes resulting from the fermentation of guano. The development of notches at the foot of the opposing walls allows this phenomenon to extend laterally, altering the wall's morphology and accentuating the asymmetry of the gallery.

Above these notches, a series of biogenic conches are organized vertically and cause the progressive retreat of the wall (fig. 2 and 5).

They even sometimes result in a very particular morphology that resembles upwelling waves, illustrating the role of acid convection in their formation. Here the retreat of the wall is much more marked because it is constantly exposed to weathering, the limestone being always bare and exposed. This wall therefore moves back faster, increasing the initial asymmetry of the section (Fig. 1).

Of course, depending on the initial geometry of the gallery, all scenarios are possible and all of these manifestations are not always present. For example, if the high point of the gallery is located right in the center or if the walls are vertical or overlooking, we will not find any biogenic lapiaz. We will rather have a system with a double lateral notch overlain by facing biogenic conches (Fig. 2, section 1).

5. Conclusion

It is accepted that biocorrosion has an impact on the walls (i. e. LUNDBERG & MC FARLANE, 2012; AUDRA *et al*., 2016 & 2019) to such an extent that in some caves, the initial section of the conduit has sometimes been expanded by twice its original size (BARRIQUAND et al., 2021). This expansion is not homogeneous along the cavity but also on the scale of the section of the galleries. Depending on the initial geometry of the gallery, but also on the position of the bat nesting area and the density of the colonies, we observe a differential evolution of the walls, which can lead to the accentuation of the initial asymmetry of the conduit. This aspect is only one example of the many impacts of biocorrosion in caves, many forms of which have yet to be identified and described. It is important to know how to identify them because they testify to a post-speleogenic evolution, the impact of which on underground volumes and their organization constitutes a new perspective for karstologists and archaeologists. Indeed, this remodelling erases the initial speleogenic features of the cavity and the traces of art, if there were any before the arrival of the bats (BRUXELLES *et al*., 2016). This type of analysis, in decorated or partially decorated cavities, therefore becomes essential to the study of the integrity and preservation of the cave rock art.

Acknowledgments

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