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Ghost rocks and hypogene mineralization: Questions raised by the Grande Vernissière mine complex (Gard, France).

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Abstract

In cavities inherited from ghost rock weathering networks, the alterite is rarely observed as most of it has been removed by erosion and the galleries are largely reshaped. So, we looked for old mines to search for *in situ* ghost rocks artificially recut. The Grande Vernissière mine complex was dug in the 19th and 20th centuries, in particular for the exploitation of lead and zinc. We found very clear examples of ghost rocks but also extensive hypogene mineralization (fluorite, barite). This assemblage is very interesting as it raises the question of the links between this case of ghost rock weathering and hypogene mineralization dating from the Eocene. Does this ghost rock have an hypogene origin or does it correspond to another stage of weathering, depending on hydrogeological, geological or geomorphological evolution?

Résumé

Roches fantômes et minéralisations hypogènes : Questions soulevées par le complexe minier de la Grande Vernissière (Gard, France). Il est très rare de retrouver l'altérite initiale dans les grottes que l'on suppose avoir initiées par un processus de fantômisation. La plupart du temps le fantôme, très fragile, a été entièrement emporté par la poursuite du processus de karstification qui a largement remodelé les conduits. La mine de la Grande Vernissière a été creusée durant le 19e et le 20e siècle pour l'exploitation du plomb et du zinc. Dans ces cavités artificielles, nous avons trouvé des exemples de fantômes très bien préservés ainsi que des indices de minéralisations d'origine hypogène (fluorite, barite). L'association entre les fantômes de roches et ces minéralisations incite à se poser la question de leurs liens génétiques. Est-ce que ces altérations se sont formées lors de la mise en place de ces minéralisations, à l'Eocène, ou est-ce qu'elles répondent de conditions plus tardives, en fonction d'un nouveau contexte géologique, géomorphologique et hydrogéologique ?

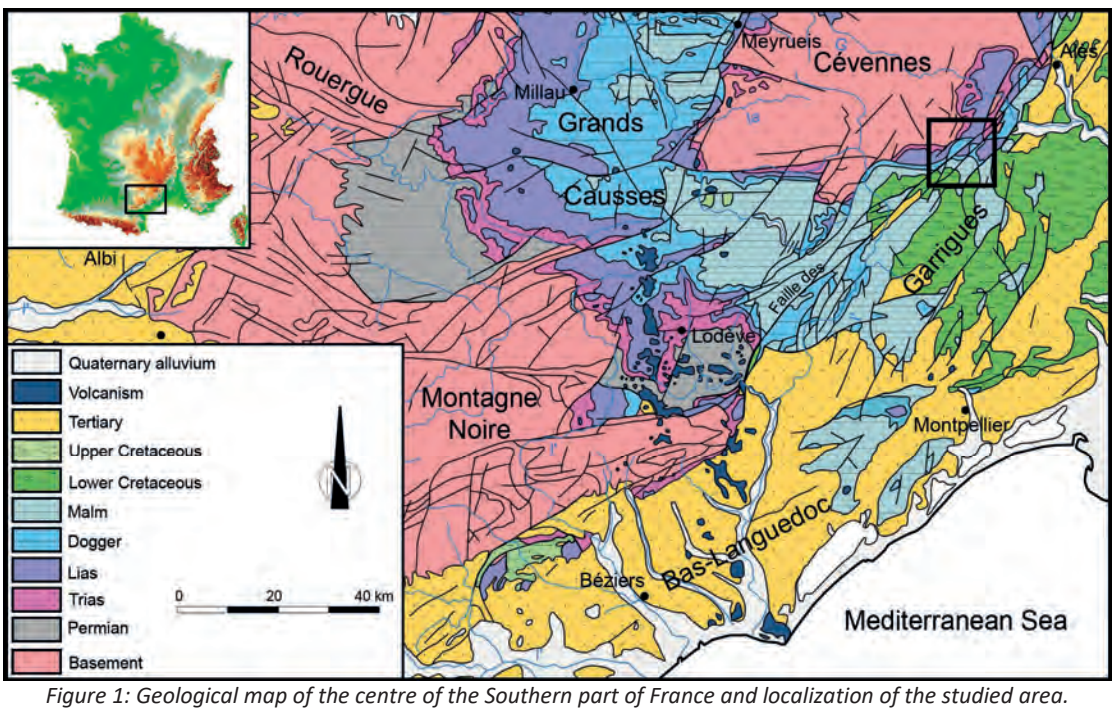

Figure 1: Geological map of the centre of the Southern part of France and localization of the studied area.

1. Introduction

Our work along the Cévennes border has shown that part of the caves originates from ghost rocks formation (BRUXELLES & BRUXELLES, 2002; BRUXELLES, 2010). That means that their formation was initiated by an isovolume alteration phenomenon developed in a context of low hydraulic gradient allowing the alterite to remain *in situ* (VERGARI, 1998; QUINIF, 1999, 2010; QUINIF & BRUXELLES, 2011; DUBOIS *et a*l., 2014). The extremely porous residual alterite is then evacuated by karstic water flows when a sufficient gradient appears. The voids are then reshaped by phreatic, epiphreatic and vadose evolution and thus, it is rare to find any remains of the initial ghost rock in these caves.

Like the Belgian quarries, where this phenomenon has been widely studied (e. g. VERGARI, 1998; QUINIF, 1999 and 2010), we looked for artificial structures likely to intersect nicely preserved ghost rocks. All along the Cévennes border, on the southern edge of the Massif Central, lead, zinc and silver mines have been exploited since at least Antiquity. They were dug in the limestone and dolomite of the Lias (early Jurassic). The idea was therefore to look for signs of ghost rocks in mines, as they have not undergone an evolution as complex as natural karst cavities, and thus, it should be possible to find residual alterite there.

2. Materials and methods

The Grande Vernissière mine, located in the town of Fressac (Gard, Occitanie, France) was exploited during Antiquity, Medieval times and then in the 19th and 20th century. It is several hundred meters long and formed in the same lithological context as the nearby 10 km Trabuc cave (BRUXELLES, 2003).

This mine is located in the Cévennes border (Fig. 1), a fairly tectonized strip located between the crystalline Cévennes and the Jurassic and Cretaceous limestones plateaus (*Garrigues*). It is part of a set of mineralized deposits that affects a quadrangular bulge located between the main sections of the Cévennes fault (PERISSOL, 1990). The mine galleries were dug in the limestones and dolomites of the Sinemurian, which are locally clayey and include frequent siliceous cherts.

Mineralization mainly affects these bedded limestones, creating various facies. They are Mississippi Valley type mineralizations, consisting mainly of calcite, dolomite, with fluorite including galena and sphalerite. Their origin has been debated for nearly fifty years, but recent studies has confirmed the role of hypogenic ascending flows (ROUVIER *et al*., 2001; JOST *et al*., 2004). The hypogene processes were dated from the Lower to Middle Eocene, and are believed to be due to gravity hydrogeological loops linked to the uplift of the Pyrenees. The mineralizing fluids were brought up along the Cévennes border, following the fractures and the most porous rocks.

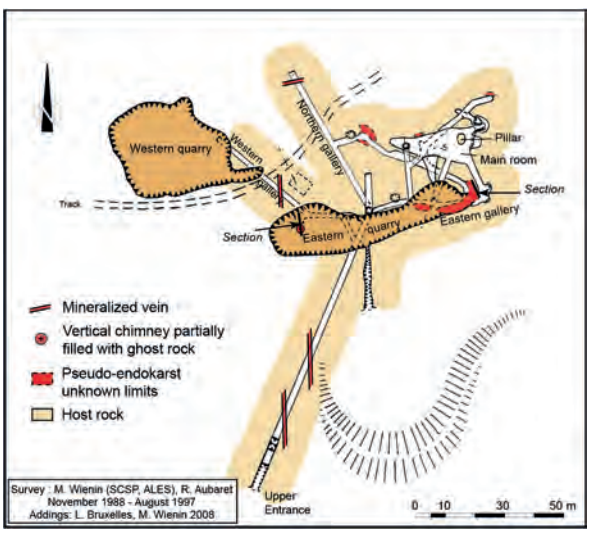

Figure 2: Map of La Grande Vernissière Mine showing the main ghost rocks occurrence.

3. Results

During the survey of the mine, more than thirty rock ghosts were identified and plotted on the map (Fig. 2). A typology of these ghost rocks can be proposed:

- Several mineralized veins are associated with a loose altered fringe. Vertical or inclined a few degrees, they do not exceed a few tens of cm in thickness. When these veins intersect the limestones, the weathered walls are clayey and orange. In contrast, in dolomite, the alterite is sandy and grey.
- Locally, vertical chimneys have been crossed by the mine galleries. Several meters wide, they are in the process of being emptied but mostly choked by the *in situ* alterite. They are more than 20 m in height and the process of collapse of the alterite is ongoing.
- Large amounts of ghost rocks also developed under a well-lithified limestone vault (Fig. 3). Mining works have sometimes cross them and we can easily recognize the pseudo-endokarsts therein (VERGARI, 1998; QUINIF, 1999). Here, the ghost rock developed horizontally, following the lithological contrasts exploited by the slow water flow. In the *in situ* alterite, one can recognize the continuous beds of cherts but we also the initial nature of the rock, depending on whether it consists of orange clay or dolomitic sand (Fig. 4 and 5).

Figure 3: Example of in situ ghost rock (light) preserved on a hard roof. Removed alterite is accumulating at the bottom of the wall.

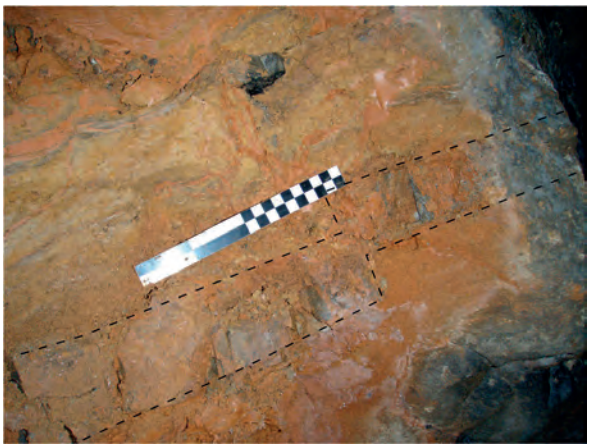

Figure 4: Contact between the ghost rock and the limestone wall. Deformed cherts layers can be followed from the host rock to within the alterite, with the same tilt.

4. Discussion

It is interesting to note that whenever the galleries have intersected a ghost rock, it is associated with mineralization. On the other hand, not all mineralization is accompanied by ghost rocks. It is therefore difficult to genetically associate these two phenomena. In fact, some mineralization forms geodes or veins within the alterite (Fig 5). They are unlikely to have settled in the ghost rock without permeating it more diffusely due to its porosity. It is more logical to think that the ghost rock weathering occurred as a second step, not necessarily affecting all the mineralized zones.

Thus, two hypotheses can be proposed for ghost rock development:

- It occurs just after the mineralization period, while the hypogenic fluids still travel through the discontinuities. It could happen at the end of the mineralization process with probably a different chemistry although one still aggressive towards the carbonates.
- It occurs much later than mineralization and arises *per descensum* water flow. The hydrothermal feed is gone and the water, of epigenic origin, slowly flows into the carbonates, exploiting the discontinuities and parts of the mineralized veins that encompass the alterite.

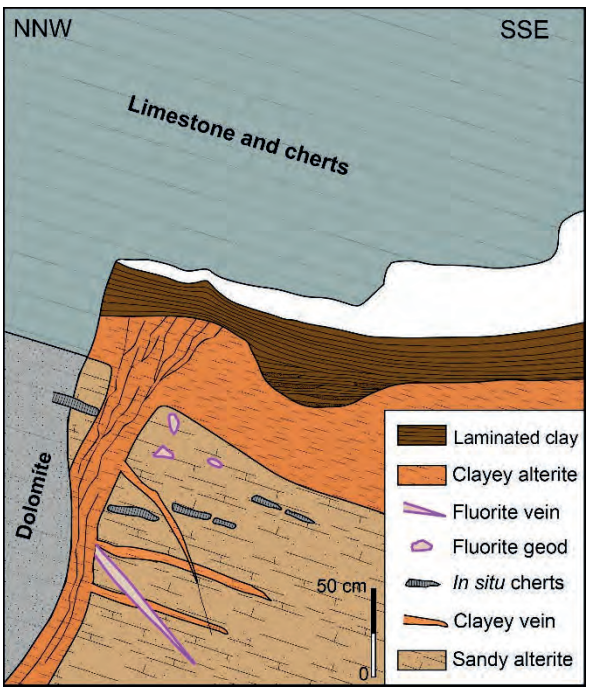

Figure 5: Section of the dead end of the northern gallery (see Fig. 2) where we can see the edge of a large ghost rock developed at the contact between dolomite and limestone.

5. Conclusion

At this stage, it is not possible to separate the two processes that gave rise to these ghost rocks, but other mines exist in this area, which may provide additional information to help discriminate the origin of the waters responsible for the formation of these ghost rocks.
A geochemical approach is also to be considered and could provide additional information.
In any case, the existence of hypogenic ghost rocks is theoretically quite possible. If the chemical conditions are met but the flow doesn't have sufficient competence to export the insoluble residues, this will lead, as for the *per descensum* ghost rocks, to the development of loose volume of alterite within the carbonates. Later, when the base level drops, these discontinuities will be exploited by more dynamic circulations and results in the formation of cavities. The beginning of this process can be observed at the top of the ghost rocks in this mine where bedded clays lie in a gully cut in the alterites (Fig. 5).

Since the cessation of mining, successive collapses have formed in weathered chimneys, contributing to the ghost emptying, a fast process. Furthermore, on a geological time

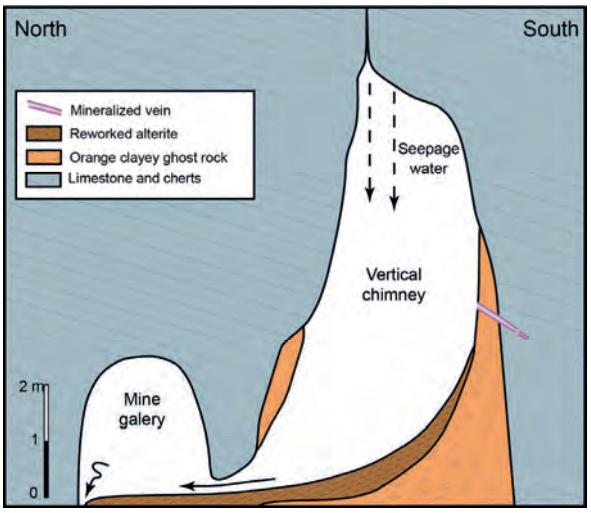

Figure 6: Vertical chimney created by the natural removal of the ghost rock after the abandonment of the mine.

scale, as large vertical chimneys were already emptied from the bottom after mine abandonment, only small amounts of seepage water come from the surface through cracks (Fig. 6).

In any case, the numerous ghost rocks found in this mine significantly show how these limestones are deeply weathered. It allows us to observe, for the first time, very demonstrative examples of pseudo-endokarst that are very rare (Fig. 7) and confirms the origin of maze caves like Trabuc cave in comparable contexts.

Figure 7: This dead-end of the northern gallery of the mine terminates on in situ pseudo-endokarst ghost rock. The section represented in Fig. 5 is located behind the caver.

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