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# Ghost-rock karstification in Gironde (France) Highlighting in quarries and drillings

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## Abstract

The alteration of the Rupelian limestone in Gironde, by the process of ghost-rock karstification, was studied on the Entre-deux-Mers low plateau, into surface and underground quarries. Several types of morphologies were brought out: 1) *in situ* subhorizontal haloes; 2) subhorizontal recessing areas with vault pendants; 3) irregularly recessed weathered areas; 4) pseudoendokarst in the form of large multi-metric porches. Pleistocene palaeokarst exploiting ancient ghost-rock areas have also been identified. Some boreholes on the left bank of the Garonne River show a total loss during mud injection into the Rupelian limestone, between 15 and 35 m depth. Because of the induced decrease of the water table, pumping can lead to collapses. This highlighting of the phenomenon of ghost-rock karstification allows us to better understand the speleogenesis of the Gironde caves, either in non-phreatic zone (Entre-Deux-Mers) or in phreatic zone (porous reservoirs of the Graves area). Paleogeographic studies suggest that the alteration process first occurred during the platform's emersion at the end of the Rupelian, and probably in the Upper Miocene during the second emersion.

## Résumé

**Fantômisement des calcaires oligocènes en Gironde (SW France) - Mise en évidence dans les carrières et forages.**

L'altération du calcaire rupélien de Gironde, de type « fantômisement », a été étudiée dans des carrières de surface et souterraines du bas-plateau de l'Entre-Deux-Mers. Plusieurs types de morphologies sont mis en évidence : 1) des auréoles subhorizontales en place ; 2) des zones subhorizontales en voie d'évidement avec pendants de voûte ; 3) des zones altérées irrégulières ± évidées ; 4) des pseudoendokarsts en forme de grands porches plurimétriques. Des paléokarsts pléistocènes exploitant d'anciennes zones fantômisées ont aussi été identifiés. Certains forages en rive gauche de la Garonne montrent une perte d'injection dans le calcaire rupélien sur 15 à 35 m d'épaisseur. Cette mise en évidence du phénomène de fantômisement permet de mieux comprendre la spéléogénèse des cavités de la région, soit en zone dénoyée (Entre-Deux-Mers), soit en zone noyée (réservoirs poreux des Graves). A cause du rabattement de la nappe phréatique, les pompages peuvent induire des effondrements. L'étude paléogéographique suggère que la fantômisement s'est produite d'abord lors de l'émergence de la plate-forme à la fin du Rupélien et probablement au Miocène supérieur lors de la seconde émergence.

## 1. Introduction

Following discoveries made in Belgium (VERGARI, 1996; QUINIF, 2010), the phenomenon of ghost-rock in Gironde was first highlighted in an underground quarry of the Médoc (COURRÈGES, 1996; COURRÈGES & MAIRE, 2014). Other discoveries were subsequently made in the Entre-deux-Mers (LANS *et al.*, 2006; DUBOIS *et al.*, 2011). This phenomenon was better identified in the quarries of Frontenac and Jugazan. There are several types of morphologies: 1) the subhorizontal ghost-rock halo in place; 2) the subhorizontal altered areas being hollowed out, showing the weathered rock, an allogenic laminated clay

deposit, a summit void, and small arch pendants; 3) irregularly altered areas more or less hollowed out; 4) pseudo-endokarsts representing large multi-metric porches showing classical succession: ghost-rock, massive brown laminated clay, summit void and roof affected by domes and pendants. Moreover, Pleistocene palaeokarsts situated in ancient, altered areas have been identified in "Bernat" former quarry near Jugazan: some pockets of Pleistocene fauna and a gallery fossilized by sediments and speleothems, one of which was dated by U/Th.

## 2. Highlighting the ghost-rock alteration of Oligocene limestones in quarries

### 2.1 The phenomena of ghost-rock alteration in "Piquepoche" quarry (Frontenac)

The "Piquepoche" quarry is located in Frontenac, in the

Entre-deux-Mers plateau. It was used to extract yellow and yellow-white limestone named locally "Calcaire à Astéries". This quarry shows several typical shapes.

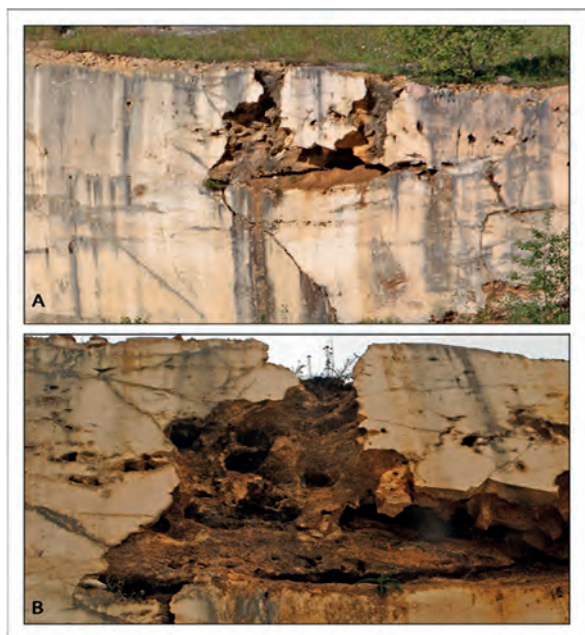


Figure 1: 3 m long cavity with very irregular morphology, related to the emptying of the alterite. A. Overview. B. Zoom on the cavity with typical vault pendants.

#### Subhorizontal ghost-rock not hollowed out

The faces show ghost-rock altered areas in the form of subhorizontal halos with irregular rounded contours. They are 10 to 30 m long by 1 to 2 m high and indicate an alteration without direct influence of lithology and joints. These morphologies can be observed in three dimensions thanks to the cuttings of the faces into perpendicular sections. We also observe vertical ghost-rocks, more or less hollowed out, sometimes intersecting the subhorizontal halos. The contours of the altered areas suggest that alteration ceased when the biochemical process stopped at the time of the uplift of the carbonated platform.

#### Subhorizontal or irregular ghost-rock hollowed out

There are many examples showing various forms of caves: irregular or rounded porches similar to classical caves.

#### Irregular caves with anastomosis

A typical example was observed in the form of an irregular cave; it is about 3 m wide by 2 m high and has a flared opening upwards. There are characteristic vault pendants related to the flushing of the alterite.

#### Corbelled levels

These are the most remarkable morphologies in terms of hollowing out of ghost-rock areas, which generally present, from bottom to top:

- a ghost-rock in place, infiltrated by green and brown clays
- a brown clay filling (20 - 30 cm thick) showing thin laminae attesting total decantation
- thin levels of reworked ghost-rock within brown clays
- a flat or corrugated roof.

This succession suggests a complex ancient evolution. Ghost-rock was partially evacuated and collapsed. Then the void was filled by green and brown clays.

#### Porches of pseudo-caves

These are major phenomena intersected by the exploitation of the quarry and similar to porches of classic caves. We observe here the presence of remarkable pseudo-endokarsts, in the form of galleries, whose interior is largely made up of rock altered in place, but whose top has been hollowed out and/or compacted.

The existence of green and brown clay deposits at the top of a compacted and/or partially emptied ghost-rock suggests a first stage of karstification with the existence of a cavity and a lacustrine type filling evoking two stages. The first supposes a frank emersion, the second evokes a return to submerged phreatic context with sedimentation of clay material from the external deposits. Examination of the sandy fraction makes it possible to specify the nature of the filling and its origin. Brown clay is of great interest because it is found in a generalized way in many clogged voids associated with ghost-rocks. These are deposits of total settling corresponding to recurrent floods, carrying fine silts, clays, and a small sandy fraction. Locally we can observe coarser levels with micrograins of ghost-rock (calcite dust) transported by floods and/or the rise of the piezometric level.

### 2.2 The Middle Pleistocene palaeokarsts of “Bernat” quarry (Jugazan)

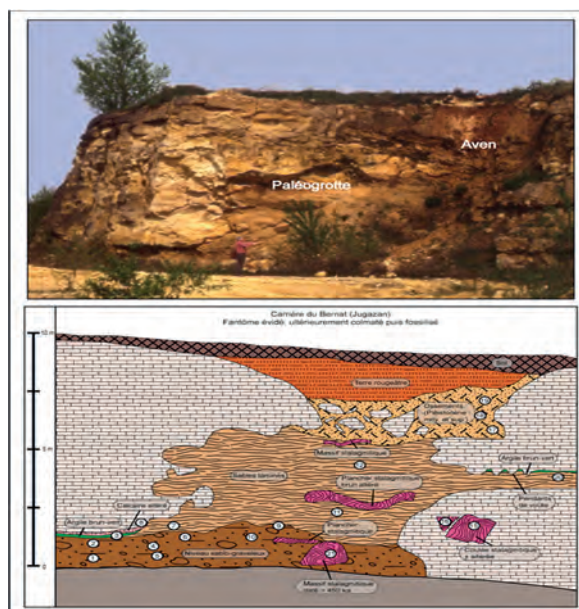


Figure 2: A. Fossilised palaeocave of the “Bernat” quarry (R. Maire). B. section with location of stratigraphic units and samples. The bottom is dated to more than 0.45 Ma per U/Th on a large stalagmitic massif.

The palaeokarst intersected by the ancient quarry of Jugazan is a fundamental milestone in the chronology of the caves of Gironde. It is indeed the only palaeocave, currently fossilised by sediments, which is dated at least to the Middle Pleistocene, first by the fauna studied in pockets located nearby (FERRIER and LEBLANC, 1990), then by U/Th dating. In addition, the analysis of surface states and parietal forms shows that it is an ancient ghost-rock later exploited by karstification. It is the incision of the adjacent valley

(Engranne) during the Pleistocene base-level rise that is responsible for the formation of the cave and its subsequent fossilisation by sediments. A stalagmitic sample was dated (B. Ghaleb, UQAM, Montréal). Micromorphological analysis shows a clean, not very porous calcite. Geochemical analyses in TIMS confirm the very low level of detrital

thorium. As the U/Th ratio is at equilibrium, the calculation indicates an age greater than 450,000 years BP, which places the genesis of the cave probably at the beginning of the Middle Pleistocene or, even earlier.

### 3. Alteration of limestone on the Garonne left bank

#### 3.1 Alteration observed in drillings

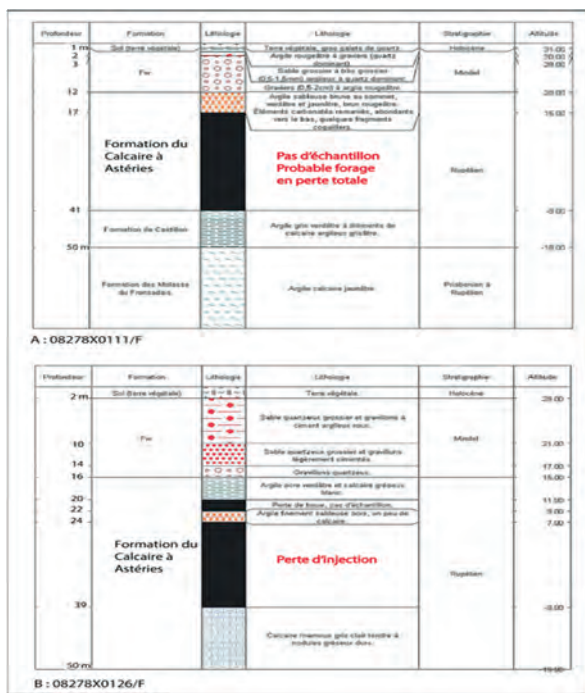


Figure 3: Drillings of Virelade area (BRGM - BSS, 2020). A: Arbanats, limestones altered significantly over 24 m thickness. B: Portets, very altered over 16 m thickness.

The drillings carried out on the left bank of the Garonne are of the utmost interest because they confirm field observations. The stratigraphic log of the Arbanats borehole (BRGM, log n°08278X0111/F) highlights a total drilling

(BRGM, log n°08278X0126/F); the stratigraphic log loss of about 24 m thickness, attesting to the presence of a very porous limestone, with low mechanical cohesion and drowned by groundwater. The same applies to the Portets, indicating a loss of about 16 m thickness, still related to the very strong alteration of the “Calcaire à Astéries”. Such mechanical fragility of these highly altered levels is favourable to the formation of large voids, 10 to 15 m high, such as that revealed by the Virelade collapse sinkhole. There is therefore an excellent concordance between field observations and drilling data.

#### 3.2 Micromorphological analysis

Micromorphological analysis of altered limestone situated at the top of sinkholes reveals a high porosity. We thus observe many altered fossils and bioclasts presenting vacuoles at the level of round or elongated lodges. Inter-lodge micrite is also altered. Elsewhere, it is the sparitic calcite that is widely perforated. There is a strong contribution of the activity of sidero-bacteria, or even mangano-bacteria. There are also remarkable hematite microspherules (4 to 10 µm).

At the bottom of the sinkhole’s level, micromorphological analysis of the altered limestone shows a bioclastic structure with many pores. The analysis highlights the importance and very irregular morphology of corrosion vacuoles in microsparite cement between bioclasts. The pores vary from 50-100 µm to 1 mm or more. The micritic calcite inside the microfossils is altered by the partial passage from ferrous iron to ferric iron.

## 4. Discussion

#### 4.1 First dated signs of alteration: Rupelian

GAYET (1980) showed that an early emersion phase occurred before the end of the sedimentation of “Calcaire à Astéries”. This period is attested by an altered carbonate layer that resembles a palaeokarst. It is only an alteration surface that does not penetrate the mass of the limestone due to too short a time to allow a first ghost-rock alteration. Then this karstified surface is sealed by a new carbonate sedimentation (thin layer).

#### 4.2 Main phase of ghost-rock alteration: end of Rupelian

The study of the phenomenon of ghost-rock in surface and underground quarries makes it possible to propose a minimum age for the period of alteration of “Calcaire à Astéries”. The condition for the ghost-rock process is the elevation of the water table: it must be located at a shallow

depth so that there is no hydrodynamic potential, except for slow circulation of the aquifer linked to water loops essential to evacuate the dissolved CaCO<sub>3</sub>. Stratigraphic and palaeogeographical studies make it possible to situate the main ghost-rock alteration phase at the period of emersion (end of Rupelian), thus before the detritic phase of the “Molasses de l’Agenais”. It is a phase of slight emersion but long enough to erode-corrode the roof and penetrate the carbonate mass. The question of the role of the salt bevel is raised due to the proximity of the coastline and the stratiform altered morphologies.

#### 4.3 Another phase of ghost-rock alteration: Miocene

The alteration of the limestones from the Lower Miocene of the Aquitanian is observed on residual mounds (Castelviel). The period of alteration is probably during the definitive emersion that occurred in the Late Miocene. Due to the long

duration of this period of low-altitude emersion (Miocene), it is possible that the water table may have crossed the series of "Molasses de l'Agenais" to affect the underlying limestone during the Plio-Pleistocene uplift.

#### 4.4 Genesis of the first caves: Early Pleistocene

The example of Bernat highlights an ancient caving phase related to the first base-level rise phase. The latter allows the appearance of a hydrodynamic potential and the emptying of the alterite and the genesis of the first caves. In addition to the U/Th dating, another chronological clue is provided by the origin of quartz gravel from the material of the high terrace of Sadirac dated from the Early Pleistocene. The organisation of systems on the left bank of the Garonne allows the establishment of a first chronology. All the characteristics indicate a young karst system, without well-individualised conduits, but probably a network of voids in the form of "ancillary systems", separated by narrow stretches or very porous areas. The large collapse of Virelade shows there is a progression of karstification inwards. The presence of collapses around Virelade village shows that the downstream part is also subject to this type of karstification. There are two types of underground erosion: one from upstream to losses; the other coming from downstream by regressive erosion from a young outlet that may have changed due to the evolution of the base level.

## 5. Conclusion

The highlighting of the process of ghost-rock in the quarries of the Entre-deux-Mers is the essential condition for studying the speleogenesis of the actual caves of the region. The original and exceptional example of the fossilised palaeocave of Bernat has also made it possible to prove that cavities, probably equivalent to those we know today, were formed at least 500,000 years ago, or even well before. In the semi-karstic zone of Graves located on the left bank of the Garonne, the Virelade aquifer system is therefore like a

#### 4.5 Probable evolution since Late Pleistocene

The example of the Virelade system is more complex than the Entre-deux-Mers systems located in a free flow zone. The sinkhole-aven of Virelade shows the existence of large voids that can measure 20 to 30 m in diameter. This complexity of evolution must consider the evolution of the water-table level during the Pleistocene, especially since the Graves zone was raised allowing a flow of the aquifer to the north towards the Garonne.

It is also necessary to integrate the level of the water table during the last cold phases, especially during isotopic stages 6, 4 and 2. As seen on boreholes carried out in the axis of the Garonne, there is a clear ante-Holocene incision, with a deposit corresponding to the periods when the sea level was 100 m lower, causing a noticeable linear incision.

During the cold phases, it can be assumed that the underground flow emerged 10 m lower due to the lowering of the water table. Today these ancient emergences have been covered by Holocene alluvium. The karst formed at that time, in a cold context, functioned mainly during summer. In addition, it is possible that the pumping, responsible for a strong drop of the water table under the 0 NGF, drew the permanent reserves located in the partly karstified aquifer and generated during the cold phases.

karstic system in the process of formation in a drowned or even epiphreatic zone in the upstream part. These two examples differ in an opposite hydrodynamic context, one in the vadose phase, the other in the drowned phase, which supposes a theoretically faster evolution for the Entre-deux-Mers systems. However, the losses on the left bank compensate the weakness of the slope by a large volume absorbed during the floods. The lowering of the water table during the last glaciation is a direction of research to be explored further because this parameter played a more important role here than in the Entre-deux-Mers.

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