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THE SALITRE CAVE KARST IN THE QUARTZITE ROCKS OF DIAMANTINA, MINAS GERAIS, BRAZIL

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Abstract This work presents the main morphological characteristics of the Salitre Cave, located in the municipal district of Diamantina - MG and formed in quartzite rocks of the Espinhaço Supergroup, Sopa-Brumadinho Formation as an example of a well-developed karst system. This system now supported by two to three independent small seasonal rivers and displays well-developed dissolution and breakdown structures, as a result of intense intemperance activity. This karst formed, probably before the beginning of Quaternary taking advantage of a system of fractures, normal and thrust faults caused by Espinhaço and Brasiliano events in the Middle to Late-Cambrian. This work attempts at presenting an integrated view of the investigated area and at emphasizing its importance for the understanding of the processes, which occurred in the in carbonatic, quartzitic and silico-carbonatic rocks of Rio San Francisco and Rio Jequitinhonha Basins among the chain of the Espinhaço Range on east and the river valley of San Francisco on the west.

Keywords: Noncarbonatic karst, Salitre Cave, Espinhaço Range, Diamantina-MG

1. Introduction

The study of karsts in non-carbonate environments corresponds to a recent theme in the world of karstological sciences, which make it possible to understand weathering processes in silicate regions in the same way as in carbonate terrains. Therefore, it is important to emphasize that the study of the karstic processes "in situ" are in the center of the speleological discussions.

In this context, debates are included also for the revision of the concept of "pseudo-karsts" and its exclusion from use due to its morphologic significance, which ignores of dynamic facet of the processes involved, such as the physiographic characteristics and the dissolution process.

Several studies carried out in countries of Africa, Venezuela and others demonstrate the existence of karsts morphologies in non-carbonate lithologies and show that the genesis in these environments corresponds to the same processes taking place in carbonate rocks. Those works show the fingerprints of dissolution of the rock and features which are observed in carbonate substrates. This demonstrates that the karsts morphologies originated by the dissolution processes should not be considered "pseudo karsts".

In Brazil, the studies of the non-carbonate karsts are more recent and the main references are Borghi & Moreira (2002), Hardt (2009), Auler (2004), Willems et al. (2008), and Rodet et al. (2009).

These studies investigate mainly karsts developed in sandstones and quartzites in São Paulo, Tocantins, Mato Grosso, Minas Gerais, and Rio Grande do Sul and Roraima States. These works contributed to an increased knowledge in non-carbonate karst environment research and to an enlarged speleological heritage. The justification of the present study is that the massif of Salitre is a well-defined body of silicate clastic rocks showing all features of an evolving karst. The research is been carried out together with European experts, within a multinational and interdisciplinary context. This study also has the objective to present the main characteristics of the karst morphology of the Salitre Cave, located in the municipal district of Diamantina - MG, developed in silicatic rocks of Espinhaço Supergroup, Sopa-Brumadinho Formation.

2. Location and physiographic characterization of the studied area

The municipal district of Diamantina is located in it is upper Jequitinhonha Valley, approximately 292 km from Belo Horizonte - MG. The access to the region is made by the federal highways BR-259 and BR-367. The Massif of the Salitre Cave is located 9 km southeast of the city of Diamantina - MG, between the coordinates UTM 0687393E and 7962317S (Fig. 1). The access to the site is made by a local secondary road.

3. Geological context

The cave is situated in the units of the Espinhaço Supergroup, especially in the Sopa-Brumadinho formation, southeast of Diamantina, near Extração (Fig. 2). The geological profile of the whole supergroup with a zoom of the cave situated part of the Sopa-Brumadinho Formation, is given in Fig. 3.

This is the most important part of the whole Espinhaço Supergroup, due to its widespread distribution and the content of diamond placers. The typical sequence is found northern of the city of Guinda, where the formation has three members: Datas, Caldeirões e Campo Sampaio (Almeida-Abreu, 1993) consisting of metapelites, a wide variety of quartzites, polymictic metaconglomerates, with local intercalations of volcano-sediments, basic volcanites and levels of hematite phyllites.

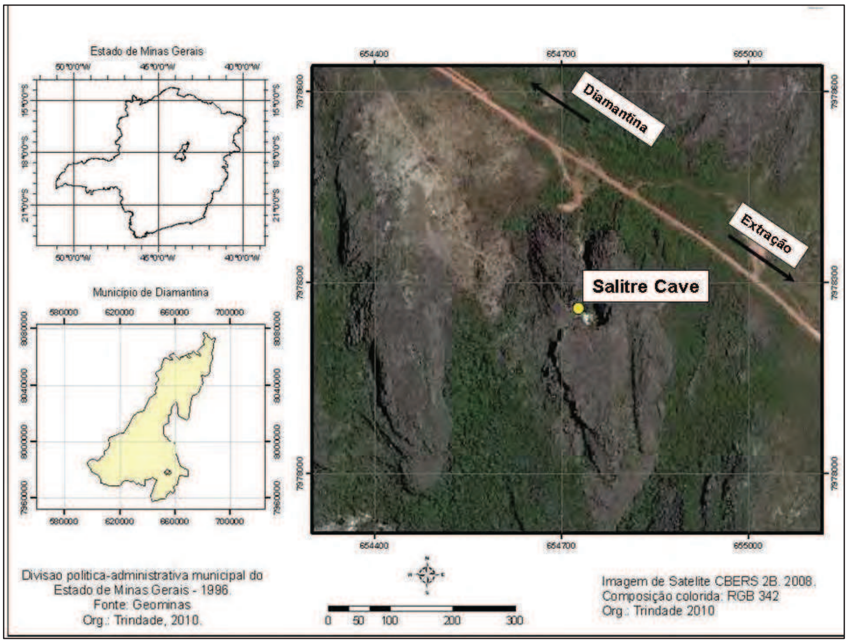

Fig. 1. Location of the Massif of the Salitre Cave (Gruta do Salitre) between Diamantina and Extração (Souza et al. 2010, modified). The cave is part of a lixiviated fracture system situated in a N-S direction on the both side of the road, which cut the figure from E to W (Souza et al. 2010).

3.1. Stratigraphy

The investigated region encompasses only the middle part of Espnhaço Supergroup, the Sopa-Brumadinho Formation, together with younger sedimentary covers (Fig. 2).

Datas Member: The base of the formation is formed by a 30-40m stack of quartzites, phyllite and mica rich quartzites with fluvial structures, cross beddings, laminations and a wide variety of facies, suggesting a sedimentation in low energy environments like subsident flat platforms (Schöll, 1980; Garcia & Uhlein, 1987).

Caldeirões Member: This is the more developed unit with 100-200m of an extreme variety of sediments, hosting the Salitre Cave. This unit is predominately formed by quartzites, discontinuous mono- or polymictic metaconglomerates, with a N-S trend (Schöll, 1980). In the mining area, the formation is dominated by medium of fine-grained quartzites, sometimes with microconglomeratic aspect and very rich in iron oxides (hematite) or mica matrix, accompanied by mono- to polymictic conglomerates, hematite-phyllite and dykes of grey and green schists and centimetric m to metric levels with rare fragments from the basement. These sediments suggest marine-coastal ore continental-close environments and are abundant in tabular, channel- and cross-bedding structures (Schöll, 1980).

Campo Sampaio Member: This upper unit of normally 2-3m up to 50m can be observed in the western part of the map (Fig. 2) and show N-S orientation (Fogaça & Almeida-Abreu, 1982). This unit is formed principally by metapelites (phyllites and siltites) and some fine grained quartzites at the top, close to the erosive contact with the overlaying units. This unit has a very high content of iron oxides and contains intercalated polymictic breccias formed by angular quartz and hematite fragments, with numerous typical lacustrine to shallow water and coastal sediment structures, such flaser, channels, cross layering, fishbone-structures and wave and ripple marks.

3.2 Structural geology

The area is characterized by important fault-zones with mainly N-S orientation, accompanied by an open W-vergent fold system. In the studied area, the fault zones are well-expressed and cross-cut earlier folds. The important direction of foliation S_n is between N5°W and N10°E diving to E (~70°) and intersected by another West vergent fold system S_{n+1} with centimetric to metric amplitudes and by a final system S_{n+2}, responsible for the formation of anticlines and synclines such as the one containing the Salitre Cave (Fig. 4). An opening of the fracture system by tensional forces and the erosion of the overlain sediments is clearly visible in the composition of all the quartzites of all formations of the Supergroup. The structural evidences suggests a evolution with one compression maxima N10°E and N20°E, plans (N10°E and N20°E) and another one of N60-70°W orientation, all diving nearly to E.

4. Geomorphological context

The Espinhaço Range is the hydrographic divisor between the São Francisco basin on the West and Jequitinhonha basin on the East. The Espinhaço Range is characterized by a sequence of plateaus oriented N-S. According to Saadi (1995), the denomination "range" obscures, however, the physiographic reality and would be better defined by the term "highlands". The Espinhaço Range is built up by the compartments of a median and a western range with a general SSE-NNW and SSW-NNE orientation separated by a well-expressed NW-SE depression area originating in the same tectonic processes, but lithologically differentiated. The southern compartment, which includes the study area, starts in the East near the springs of the Cipó river, close to Belo Horizonte and extends to the city of Couto of Magalhães. The average altitude varies around 1200 m , with Itambé Mountain summit at about 2062 m.

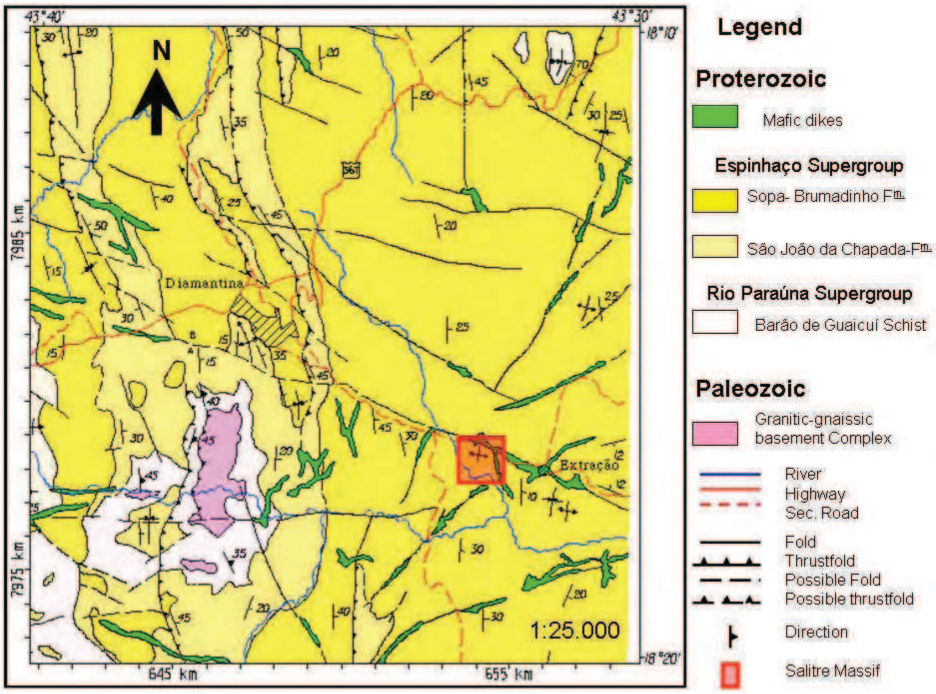

Fig. 2. Geological map of the investigated area. The Salitre Cave is situated in the red quadrangle, between two small rivers. (Fogaça, 1997).

The southern Espinhaço Range is mainly characterized by the absolute predominance of quartzites that, over the whole extension of the area, describe a rigid covering, but intensively fractured and sheared. The relief is formed by crests, scarps and deep valleys as a result of fluvial dissection, oriented in the most part, by old tectonic directions. It is to restate, that the geomorphological evolution of the Espinhaço Range was exclusively determined by structural, morpho-structural, morpho-tectonic patterns and subordinately, by climatic factors. The leveled paleo-surfaces are represented by plateaus with crest alignments and with the presence of quartzite "monadnocks".

5. The quartzite Karst of the Salitre Cave

The Salitre Cave is a natural cavity, developed in the quartzite rocks of the Sopa-Brumadinho Formation and oriented NW-SE. Fig. 2 shows the main morphological and evolutional compartments of this cave.

The canyon allows access to the Poljé of the Salitre Cave, to the Halls and to smaller cavities. The canyon of the Salitre Cave is an important structural feature and possesses beside the geological, geomorphological and biological importance, a historical relevance, because rebelling slaves used the canyon to take refuge among the rocky mazes. The canyon of the Salitre Cave is formed in the direction of a brittle N-S fault, with an extension of approximately 125m in length and 10 to 15 m in width. The scarps of the canyon show tectonic structures like folds and faults, locally reaching 50m in height. Horizontal and vertical systems of "karrens" may also be observed (Hardt et al. 2010). The canyon of the

Salitre Cave does not have a specific superficial drainage; however, the exuberant arboreal and herbaceous vegetation demonstrates the existence of a active subsurface hydrological system, formed by two to three small sectional rivers.

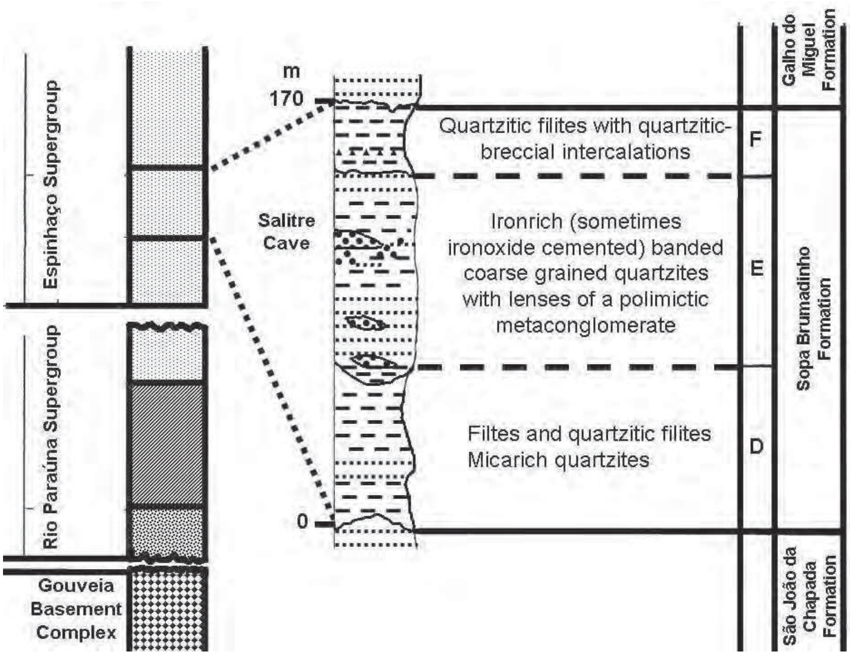

Fig. 3. Simplified geological profile of the Espinhaço Supergroup. The right side details the Sopa-Brumadinho formation. The middle part shows the host formation of the cave (after Fogaça, 1997). D: Datas; E: Caldeirões; F: Campo Sampaio.

Fig. 4. Satellite image of Salitre Cave region. Some structures are indicated: 1. The canyon and 2. Poljé (red dashed line); First halls (red dotted line); Inner hall (brown dotted line); Traverse (green ring); the continuation (yellow dotted line); The blue arrows show he supposed water directions from the regional rivers. Picture from www.googleearth.com.br, modified.

The tectonic evolution of the Salitre canyon is linked directly to the Espinhaço Rift System, whose sedimentation began in the late Paleo-Proterozoic (± 1,75 Ga), lasting till the Meso-Proterozoic (± 1,4 Ga) and the Brasiliano Event at the limit between the Pre-Cambrian and the Mesozoic. The middle part of this canyon is covered by blocks and sand and hosts one important water system.

6. The Poljé of the Salitre Cave

The Poljé of the Salitre Cave is directly connected to the canyon and it is characterized by a semicircular form, which appears as a closed depression. The floor of the depression is locally formed by scarce white medium to coarse-grained sand and by a wide variety of quartzite blocks from the breakdown of the walls and roofs. In the areas close to the rocky blooming, however, the floor is covered by a layer of clay from desilicification processes. The walls of the Poljé are more than 80m high and are intersected by several planes and groups of fractures, sometimes of significant dimensions (from cm to meters) and developing in a variety of directions controlled by old tectonic processes.

In the right corner of the Poljé, when looking from the canyon to the outer halls of the cave, a well-expressed fault of 40 to 100cm of width and 18m of length, may be observed. The fault was opened by the breakdown of a giant block. Fig. 4 displays a part of this fault and of the fracture system visible here. The wall rocks are characterized by systems of alveoli of various dimensions, which may be directly related to the karst genesis (Rodet & al. 2009) which is also responsible for the forming of halls and other cavities, using faults, fractures, and heterogeneities of the massif. The Salitre Cave Saltpeter possesses two external main halls and three internal ones, located at different paleo-levels. The presence of those paleo-levels is a consequence of the change in the local base-level which also modified the dynamics of rock dissolution. The paleo-level 1 includes the external main hall, which is easily accessible; the paleo-level 2 is less accessible and corresponds to the secondary external hall connected to a deeper and smaller hall by passages between irregular blocks.

The upper main hall (1) of the Salitre Cave has is funnel shaped with front semicircular opening. The main access of this cavity is N-E oriented and has an angular profile of oval-semicircular form with a W-E extension of 120-30m and 70m depth. Several microspeleological features on the floor and the roof demonstrate that the genesis of the Salitre Cave is mainly a result of the dissolution process in the quartzite rock often along heterogeneities with subsequent breakdown of rock blocks.

The floor is dominated by deposits formed in a collapsed block, with clastic sediments and karst microfeatures that are concentrated in less accessible areas, thus fortunately inhibiting any human intervention.

The roof is covered in a thin mineral film, described by Willems (2008) as pyrolusite (MnO_2). is the coating is concentrated mainly on the left area of the hall (looking the entrance) and hosts also various iron minerals (e.g. Fe_2O_3; $FeO(OH)_2$), nitrates and organophosphate compounds.

The entrance of the secondary lower hall is located on the right deeper side of the entrance of the upper main hall. The access is difficult due to the inclination, steep slopes and a high amount of depressed blocks. The traverse part of the entrance to the secondary hall is very irregular, and is 2m wide and 1.5m high. The interior of the hall has an elliptic form with its inner part enlarged to 25m wide and 15m long (Fig. 5). The hall is characterized by the presence of oxidic and argillitic deposits up to 10cm, several speleological micro features that also prove the process of dissolution of the quartzite rocks. "Tafoni" in different stages of evolution can be seen in all parts of the cave and in the host rock. Various speleothems are still visible in the more internal parts of the cave, probably due to the difficult access. The hall continues down with a small tubular syphon and with the W-E passage of a small river.

Fig. 5. The upper, first main hall of the Salitre Cave with blocky material on the ground and microstructures located in its roof. The red material is composed by argillites, iron oxides and a slightly violet phosphate of organic origin (guano). Dissolution effects are visible on the roof and on the collapsed blocks.

The karst is still active and there are underground drainages at the bottom of the two internal halls located close to the hall floor. The first drainage begins in the canyon and occupies the lower part of the first internal hall; the second comes from the opposite direction and flow into the most internal hall. During the dry periods, the first drainage reaches 0.5m wide and 0.5m deep; the water is clear and the flow is fast. A thick pyrolusite layer is visible inside the drainage. The second drainage seems to be smaller, it lacks pyrolusite but shows instead, cave clay and gravel.

The floor is ornamented by several karst microstructures, formed on the white fine sand and in the areas of influence of the river where red sediments develop. The walls and the roof of the internal halls are covered by variously colored microfeatures: with ash-grey, white, yellow and red tones standing out. The presence of coral structures indicates the interception of groundwater level and indicates active karst processes. From this hall, a small passage goes down to the South leading to a small fracture.

7. Final considerations

The Salitre Cave is a natural cavity developed in quartzite rocks. Its genesis is the result of the same physico-chemical processes developed in carbonate rocks, and is in this way related to the dissolution process, which occur along fissures, fractures and layers. This karst system is segmented in three main physiographic units: the canyons, the Poljés and underground drainages represented by the halls and floors.

The speleological characteristics in the quartzite system suggest the actuation of dissolution process all over the Salitre Massif, but concentrated along old tectonic structures. This is supported by the existence of a group of features that are typical to karst environments formed by dissolution, e.g. the horizontal and vertical "karren"; the benches or warts; the towers; the alveoli; the coral type hairs, the interconnected halls, the canyons and the Poljés and various types of microspeleothems on the roofs and floors. The peculiarity of the form and surface of the wall rocks of the halls together with secondary drainage systems show that this is still an active karst system.

During its evolution, the energy level has lowered at least two times thus leading to the formation of halls in distinct levels and collapsed forms in the inner hall. All this pleads for a more detailed speleological study aiming at the creation of a Conservation Unit (UC) that will secure the preservation of this area.

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