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VOLUME V

Session 11: Artificial Caves
Session 12: Pseudokarst and Non-Traditional Karst
Session 13: Volcanic Caves
Session 14: Climatology and Monitoring
Session 15: Special Topics

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Silicilcastic cave or diamond mine? The case of Canal da Fumaça, Igatu Village, Chapada Diamantina - Bahia, Brazil

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Abstract

The Igatu Village is a remanescent of the diamond mining period that covered the Chapada Diamantina, center of Bahia state, northeast of Brazil, during the XIX and XX centuries. Caves and other geological features, developed in Mesoproterozoic siliciclastic rocks, acted as traps for diamond-bearing sediments and, therefore, were severely impacted by mine activity. The Canal da Fumaça Cave, probably the first and richest mine in Igatu, was so modified that raises the doubt: is it trully a cave or an artificial diamond mine? Aiming to answer this question, we developed speleological and geological analysis, in order to recognize natural and anthropogenic factor that may have influenced the system development.

Résumé

A Vila de Igatu é remanescente do período de mineração de diamantes que recobriu a Chapada Diamantina, região central do estado da Bahia, nordeste do Brasil, durante os séculos XIX e XX. Cavernas e outras feições geológicas, desenvolvidas em rochas siliciclasticas mesoproterozoicas, agiram como armadilhas para os sedimentos diamantíferos e, assim, foram severamente impactadas pela atividad mineira. O Canal da Fumaça, possivelmente o primeiro e mais rico garimpo em Igatu, foi tão modificado que levanta a dúvida: se trata realmente de uma caverna ou de uma mina artificial de diamante? Para responder a essa pergunta, foram desenvolvidas análises espeleológicas e geológicas, visando reconhecer os fatores naturais e antropogênicos que podem ter influenciado no desenvolvimento desse sistema.

1. Introduction

The diamond rush in Chapada Diamantina (Bahia, Brazil) during the XIX and XX centuries, attracted thousands of people in search for wealth, leading to a populational boom followed by profound social and ambiental issues. The Igatu Village, at the east part, emerged during this period and, today, preserves the building and living history of the mining era.

The Canal da Fumaça was the richest and, possibly, the first mine site in Igatu (PEREIRA, 1937). Together with eleven other cavities (according to national databases, such as the CANIE and CNC), it composes the knowed subterranean heritage of Igatu. Significant cave occurrences were recognized in the last years, involving one of the longest caves of South America in siliciclastic lithologies (AULER & SAURO, 2019), and other systems with a great diversity of chemical and clastic deposits (PARRA et al., 2023a, 2023b). The rich subterranean biodiversity is also highlighted and the area is considered a biodiversity´s hotspot (GALLÃO, BICHUETTE, 2015).

This karst features are hosted in Mesoproterozoic rocks of Tombador Formation, Chapada Diamatina Group. They are constituted by metasandstones and metaconglomerates, mainly (BONFIM & PEDREIRA, 1990; PEDREIRA, 1994). Those resistent lithologies result in a montainous relief, knowed as Sincorá Ridge (LIMA & NOLASCO, 2015).

Diamond deposits come from the conglomerates erosion, whose sandy to pebbly sediments are deposited as colluvium and alluvium, often filling fractures or ‘’channels’’, as called by miners (NOLASCO et al., 2001), and in some cases, inside the caves.

Due to it, caves were significant targets to miners prospect, leading to heavily mischaracterization of this environments. In this context, the Canal da Fumaça was one of the most affected cavities, raising doubts even whether it is a natural cave, or an artificial mine. In order to answer this question, this study introduces geological and speleological data, aiming to identify the main natural or anthropogenic processes that led to its development.

2. Materials and methods

Work development involved field campaigns and laboratory analysis. Cave survey and geological assesment were carried out. Morphological aspects were described inside the cave and surroundings, looking for identify and diferentiate natural features, crated by karst processes, from those artificials, resulted of human impact during mining activity. Host rock and clastic deposits were described, searching for structural, lithological, and stratigraphic guidances of cave development. Structural measurements of fractures and bedding planes were carried, following strike-dip notation.

Fresh and weathered rock were collected (samples A34, A35, A36, A37, A38, and A40) and sent to laboratory analysis. Thin and polished sections were prepared, aiming the microscopic assessment. Weathered samples were impregnated with a hardener resin and blue dye, allowing the observation of the porosity evolution at optical microscope. Furthermore, polished and carbon-metalized sections were described at scanning electronic microscope (SEM), equipped with a detector for energy dispersive X-ray spectroscopy (EDS). Whole rock chemical compositions – mayor and minor elements – were obtained by X-ray fluorescence (XRF).

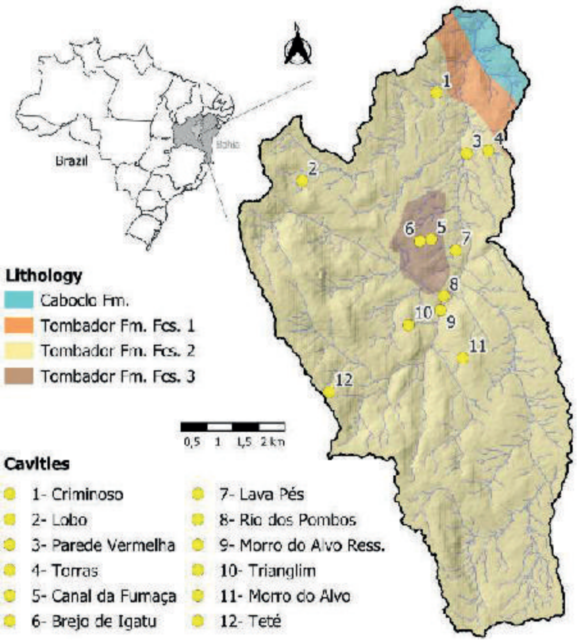

***Figure 1:** Lithological map of the Coisa Boa River basin and location of caves registered in Igatu Village.*

3. Results

Cave survey covered, to date, 644m in linear development and 624m in horizontal projection, such as 29m in vertical range. However, mapping was not completed yet, and this values must increase, specially for secondary conduits. With the speleometry data, distance between extremes was measured as 172m and the overall slope calculated as 17% or 9.6º, with dip from SSW to NNE. Conduits are straight and main elongations follow the NNE-SSW, ENE-WSW and NNW-SSE directions. Passage connectivity is high (around 90 connections), resulting in a network pattern at floor plan map (Fig. 2A).

The structural measurement indicates a close correlation between cave morphology and structures (see diagrams in Fig. 2A). Subvertical fracture planes occur parallel both to the primary (NNE-SSW) and secondaries (ENE-WSW and NNW-SSE) orientations of cave elongation. This planes occur in some cases as dense fracturing zones with cataclastic aspect, guiding the block falling from the ceiling and contributing to larger galleries development (Fig. 2B). Sub-horizontal fractures were also identified, at times, filled by quartz veins.

At the surface relief, fracture planes mark fissures and channels that reach up to 15m in depth and 8m wide, creating a ruiniform relief (Fig. 2C) and, in some cases, connecting the surface with underground conduits (Fig. 2D). Bedding planes show N dip trend, with gentle angles close to 10º, conducting water flow in that direction.

The predominant lithology of host rock is sandy, composed by quartz and rare feldspar grains at an advanced level of alteration. Textural maturity is low and the grains are surrounded by a phyllosillicate matrix (pyrophyllite and kaolinite), which occurs as fine-grained aggregates in the cave rock facies (sample A34, Fig. 3A) and as brownish masses of well-crystalized pyrophyllite in upper cave strata. Quartz grains often occur corroded at the boundaries and, in some cases, in the whole grain, where they appear replaced by pyrophyllite. XRF analysis indicate, to samples A36, A37 and A38, the predominance of silica (80-87%), and aluminum (12-18%), varying according to grain/matrix proportion (Table 1).

A clayey layer was also identified (sample A35), with a thickness varying from 10 to 20 cm (Fig. 2E). XRF pointed to higher amounts of aluminum and potassium, indicating the presence of clay minerals (e.g. kaolinite, illite). This stratum occurs boundaring a lower fresh rock sandy facies (A34) and an upper weathered one (A36).

wt%	SiO_2	Al_2O_3	K_2O	TiO_2	Fe_2O_3	CaO	P_2O_5	Na_2O	MgO	MnO
A35	70.01	24.72	3.77	0.65	0.40	0.00	0.20	0.02	0.06	[illegible]
A36	86.97	12.01	0.22	[illegible]	[illegible]	0.01	[illegible]	0.00	0.00	0.00
A37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
A38	80.97	18.53	[illegible]	[illegible]	[illegible]	0.00	0.20	0.01	0.06	[illegible]

***Table 1:** Whole-rock chemical compositions (mayor and minor elements) obtained by XRF analysis.*

Fresh rocks are cohesive and low porous, while weathered rock assume friable aspect, has depositional structures partial or tottaly effaced, and the porosity increased comparing to fresh one. Thin section of sample A36 impregnated with hardener resin and blue dye, showed the intra and intergranular secondary porosity enhancing (Fig. 3B). Intergranular pores are spread through the matrix and, in some cases, at the quartz grain contacts or overgrowth cement.

SEM images highlight the corrosion and crack of quartz grains boundaries, such as the presence of pyrophyllite filling the voids between grains (Fig. 3C). Frequently, this pyrophyllite occur replaced by kaolinite with booklet pattern (Fig. 3D).

Clastic deposits are rarely preserved inside the cavity. They constitute coarse-grained sediments, with pebble levels and discordances with the host rock, in some cases preserving the paleoconduit morphologies (Fig. 4A).

Cave passages and galleries morphology varies from natural to anthropogenic origin, predominanting the artificial ones (Fig. 4B). The floor is smoothed, possibly due to high energy floods wear, although often carved by a linear perennial water flow. On the other hand, passages in weathered and friable rock seems to be excavated, sometimes in a low arch format and, in other times, rectified from fractures and bedding planes (Fig. 4C). Fresh rock were also impacted, with marks of gunpowder detonations (Fig. 4D). Stone buildings, walls and pillars are present all over the cavity.

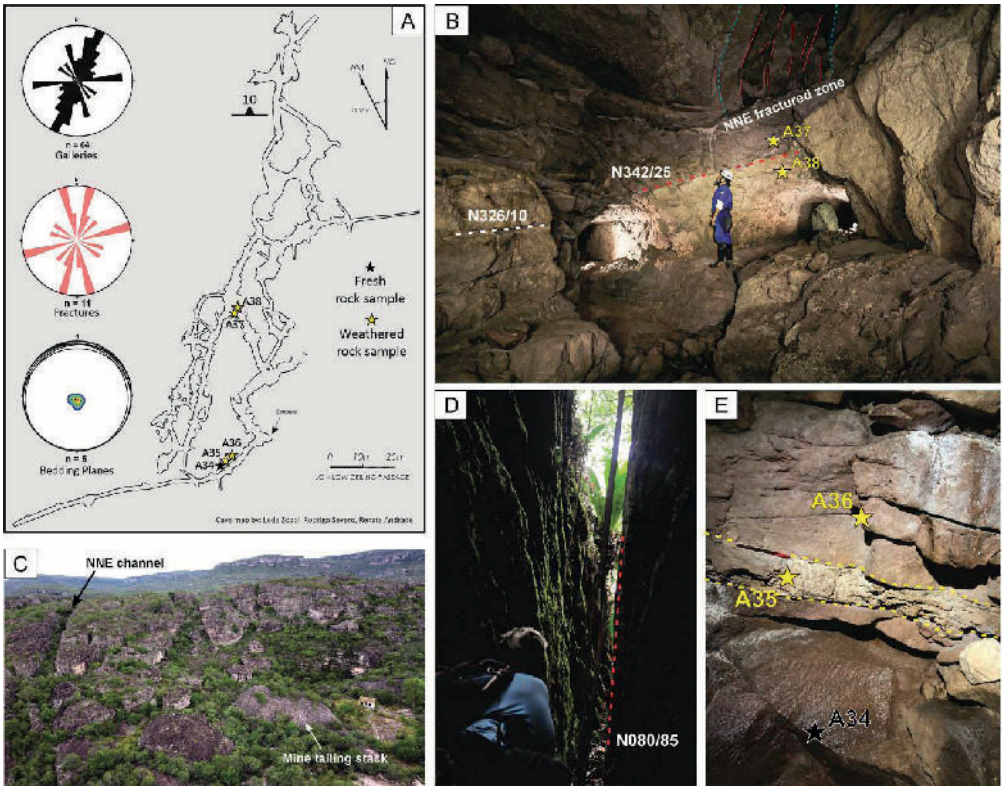

Figure 2: A) Floor plan map of the Canal da Fumaça positioning the rock samples collected and rose diagrams of galleries, fractures and bedding dip direction. B) Largest gallery of the cavity, where subvertical fractures planes guide the block falling. C) Ruiniform relief above the cavity. D) Deep fissures (channels) that connect surface to underground. E) Clay layer limiting upper altered and lower fresh metasandstone strata. Stars represents the rock samples collected, yellow for weathered rock and black for fresh rock.

4. Discussion

The correlation between structures measured in the field and the elongation direction of the cave conduits suggests the structural as a important factor guiding its development. Subvertical fractures planes were recognized setting the water percolation and block falling, evidencing that they act as weathering and mechanical erosion fronts, similiar with described by MELO et al. (2007) and SAURO (2014).

As the meteoric waters infiltrate mainly through this planes, minerals are more exposed to chemical weathering, leading to a higher rock alteration, which is notable by the friable rocks at the fractures walls.

Furthermore, bedding planes dip conducts the water flow to N, contributing to the cave N to NNE-SSW elongation. Water flows along the bedding dip tend to be fast (AULER et al., 2020), which increases the erosion potential and, thus, the enlargement of galleries and channels. Similarity between bedding inclination (~10o) and overall calculated cave slope (9,6o) reinforce this correlation.

Lithology was also identified as a guiding factor for the cave formation. The presence of the clayey layer limiting an upper altered sandy facies from a lower unweathered one (Fig. 2E), suggests that this impermeable stratum could play a sealant role, holding the percolation of meteoric water and, thus, retaining weathering in superficial levels.

In turn, constrast in matrix crystallization degree can also contribute to limit stratigraphic development of the cave. Low-crystalline pyrophillite of the cave facies (A34) are more susceptible to weathering in comparision to well crystallized pyrophyllite of cave upper strata (A40).

Petrographic analysis demonstrated that the occurrence of pyrophyllite is due to the regional anchi-metamorphism that affected the east Chapada Diamantina (VARAJÃO & GOMES, 1997; BATTILANI et al., 1999; SOUZA, 2017). Therefore, lithology can be defined as metasandstone. Phyrophyllite formation is given by the anchi-metamorphism reaction of deposicional kaolinite and quartz, through the HEMLEY et al. (1980) equation:

$$Al_2Si_2O_5(OH)_4 + 2SiO_2 = Al_2Si_4O_{10}(OH)_2 + H_2O$$

This reaction explains the quartz corrosion and cracks (Fig. 3A and 3D). Although these features are not products of weathering processes, this minerals weakness sites increase the microporosity and act as starting points for chemical attack.

On the other hand, the pyrophyllite shows alteration stains, where neoformed kaolinite occurs, interpreted as a product of recent chemical weathering. Incongruent dissolution of pyrophyllite and neoformation of kaolinte is ruled by the hydroxylation-desilication reaction, described by HEMLEY et al. (1980) and HURST & KUNKLE (1985):

$$Al_2Si_4O_{10}(OH)_2 + 5H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2H_4SiO_4$$

Thus, it suggests that weathering transformation that affect the rock occurs mainly on aluminous phyllosilicate matrix, instead of quartz grains. The acid water pH (4-5), common in the study area (AULER et al., 2020), corroborates with this hypothesis, once aluminousilicates have considerably higher solubility than quartz in acid medium.

This chemical attack over the metasandstone matrix dissociates the quartz grains and reduces the rock strength. This process can be classified as phantomization, and represents an important mechanism to siliciclastic rocks karstification (QUINIF, 2010; HARDT, 2011; WRAY & SAURO, 2017). With the cohesion decrease, grains are susceptible to mechanical erosion, which takes place through water flow, in piping process, leading to the conduit opening.

On the other hand, several anthropogenic modifications are notable in the cave interior. In search of diamonds, miners removed most of the clastic deposits, emptying the galleries once filled by them. In addition, due to friable aspect of the predominant rocks in the cave, miners were allowed to excavate, enlarging existing conduits and creating new ones. This process possibly obliterated natural features of the cave, such as speleogens and speleothems, and certainly increase considerably the conduits area and volume.

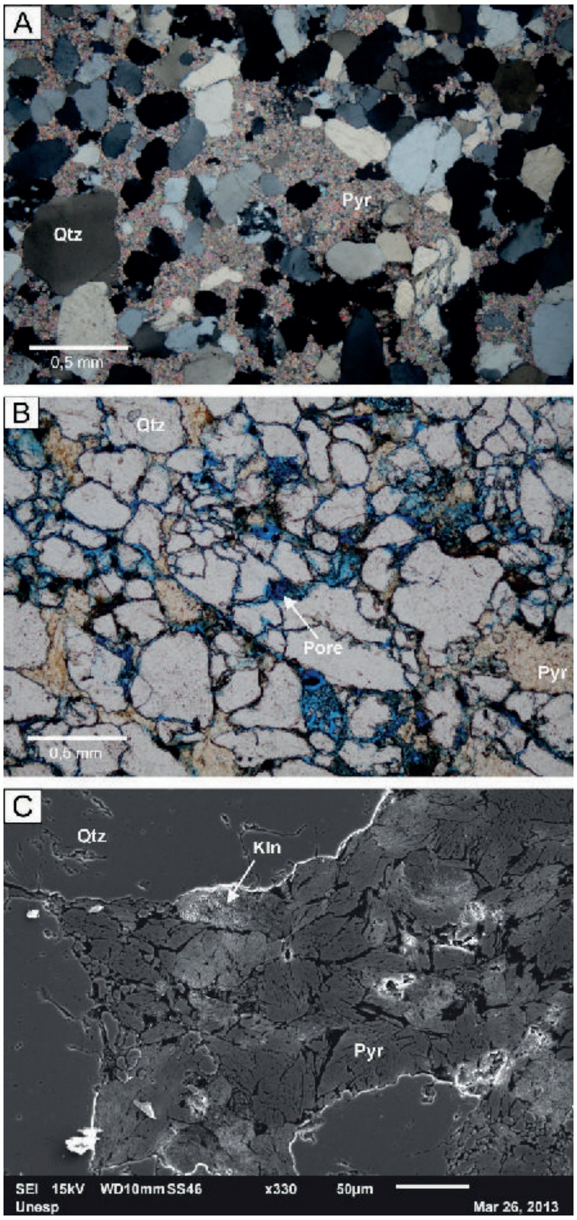

Figure 3: *A) Thin section (at crossed nicols) of fresh sample A34, evidencing the imature texture, with the fine-grained phyllosilicate matrix surrounding poor sorted grains, some of then corroded by anchi-metamorphism reaction. B) Thin section (at parallel nicols) of weathered rock sample A36 impregnated with resin and dye, highlighting intra and intergranular porosity. Cracks and corrosions increase the microporosity, and the metamorphic reaction sites act as preferential weathering targets. C) SEM image from sample A40, showing pyrophyllite matrix and consumed quartz grains boudaries. Neoformed kaolinite with booklet pattern occurs replacing initial weathered pyrophyllite, increasing the porosity where the reaction is advanced.*

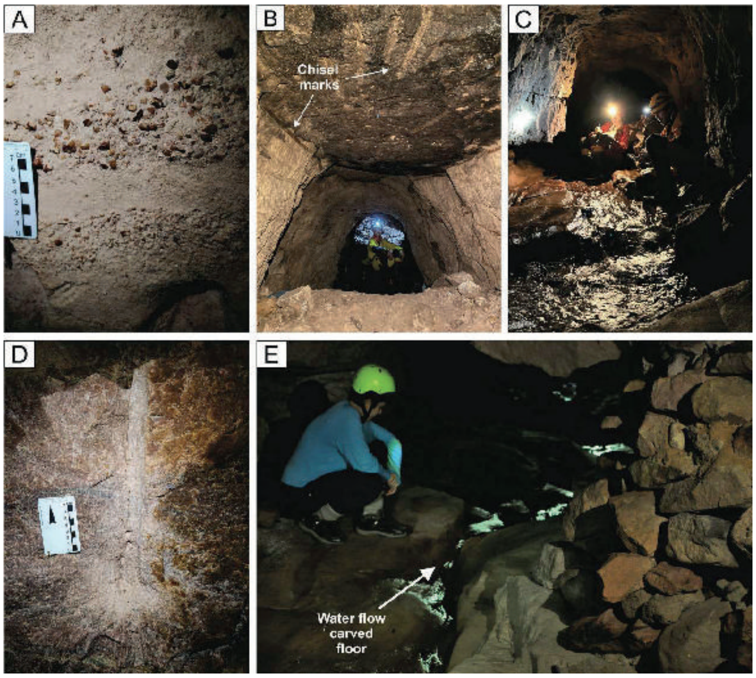

Figure 4: *A) Clastic diamond-bearing gravel explored by the miners. B) Excavated passage, with morphology varying from straight to arch. Note the chisel marks. C) Contrast between water eroded floor and excavated ceiling and walls. D) Gunpowder detonation in fresh rock. E) Water flow carved floor and stonewall built inside cave gallery.*

5. Conclusion

This work aimed to present and discuss studies developed at the Canal da Fumaça Cave, a siliciclastic karst system hosted in metasandstone rocks of the Tombador Formation, which was strongly affected by diamond miner activity that ruled the Chapada Diamantina during 19th and 20th centuries.

Natural processes of karstification were recognized, which are in consonance with those consolidated in literature. Structural and lithology are important factors guiding the cave development, conditioning the chemical weathering that leads to the metasandstone matrix dissolution, in a process of phantomization. Thus, mechanical piping removed loose grains and enlarged voids, creating conduits, channels and galleries. Later, fluvial sedimentation processes filled the cave conduits with diamond-rich deposits.

Contrasting with these natural processes, anthropogenic modifications by mine activity took place and left several marks in the cave system. Existing conduits were enlarged, new galleries were excavated in weathered rocks, fresh rocks were detonated with gunpowder, and most of clastic sediments were removed. Main impact of the modifications were the increase of the conduits area and volume.

Thus, the Canal da Fumaça were originally a cave and then transformed in a mine. So, it can be classified as a mined cave, in consonance with the descriptions of Onac (2019).

This research can be a contribution both to karst system in non-carbonate rocks literature and to the study of mined caves, which are common in the Chapada Diamantina and other regions of the Espinhaço Ridge. Future studies at this system must evolve water analysis, aiming to better understand the mobility of elements. Furthermore, researches should be expanded to other cave systems in Igatu Village, providing a complete view of this speleological and historical region and also supporting advances in the implementation of the Serra do Sincorá Geopark Project as a UNESCO territory.

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