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Session 08 : Cave and Karst Protection and Management

08.1 : Audio and Video Productions

08.2 : Cave and Karst Tourism

08.3 : Environmental Education

08.4 : Legislation





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# Karst terrains in carbonate rocks in the state of Bahia - Brazil: a regional approach

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## Abstract

In order to group the karstic terrains in State of Bahia with a regional focus, in light of the Decree 6.640/2008 and normative instructions MMA n° 2/2017, this project utilizes the conceptual model Province District System of KARMANN & SANCHEZ (1979). In the State of Bahia, the karst provinces are mainly located in stratigraphic groups of Neoproterozoic ages, in addition to minor occurrences of Mesoproterozoic and Cenozoic. For the regional focus it was utilized the taxa Espeleological District, arriving in 26 districts clusters formed by the analyses of diverse physiographic parameters such as geomorphology, watershed, stratigraphy, structural geology, tectonics, karst typology and distribution.

## 1. Introduction

Karst terrains in carbonate rocks consist of environmentally sensitive areas protected by Brazilian law, through a set of legal instruments, due to their peculiarities, importance and vulnerabilities. On the other hand, carbonate rocks have diverse economic importance, once used as soil correctives, ornamental rocks, raw material in cement manufacturing and, sometimes, as gravel or aggregates in civil construction. Therefore, conflict scenarios are commonly installed, encompassing cases of environmental and/or geotechnical risk, due to the widespread ignorance in relation to the particularities of the karst.

Thus, resolving these conflicts begins with identifying and mapping areas where relevant cave occurs. The maps of Figure 1 highlights, for the state of Bahia - the largest in area in northeast region of Brazil - the contrast between economic use, represented by ore exploration (A) and environmental protected areas (B) with main carbonate terrains and cave occurrences.

This paper aims to present the methodology and the current progress of a project focused on the regionalization and compartmentalization of karstic areas in carbonate rocks in the state of Bahia, based on approaches established in environmental laws and the scientific literature.

### Conceptual Framework

In Brazil, some researches have focused the topic of regionalization of areas with cave occurrence almost half a century ago. KARMANN & SANCHEZ (1979) were the first to discuss about and introduce the concepts of speleological provinces and districts. For these authors, a speleological province corresponds to a region within a carbonate geological unit susceptible to karstification, while the districts are sec-

tors of greater local or regional incidence of caves within the province, attesting the discontinuity and anisotropy of karstic processes along the same carbonate unit.

Later, other studies improved these concepts of province and districts (KARMANN & SANCHEZ, 1986), also adding the system as an analysis unit (SANCHEZ, 1992) and, so, defining and summarizing the main areas of cave occurrence in the country (SALLUN FILHO & KARMANN, 2012; RUBBIOLI et al., 2019).

In turn, the environmental laws, such as the Federal Decree 6.640/2008 and the Normative Instruction 02/2017, important milestones in Brazilian speleological legislation, introduce the concepts of regional and local focus to the analysis of karst terrains. The regional focus is delimited by the speleological unit, which is understood as the area with physiographic homogeneity, associated with the presence of soluble rocks and including various forms of karstic relief, such as dolines, sinkholes, ressurgences, blind valleys, lapies, and caves. The local focus is defined by the continuous geomorphological unit, such as mountain ranges, hills, or karst systems, whichever is more restrictive in terms of area, contemplating the influence area of the cave.

From these conceptual definitions, it can be established a correlation between the concept of speleological district, defined by KARMANN & SANCHEZ (1979; 1986) and the regional approach defined by the NI 02/2017, once both represent areas with particular physiographic features, controlled by geological, geomorphological and hidrological features guiding the speleogenesis. Thus, they will be used as synonyms in this paper.

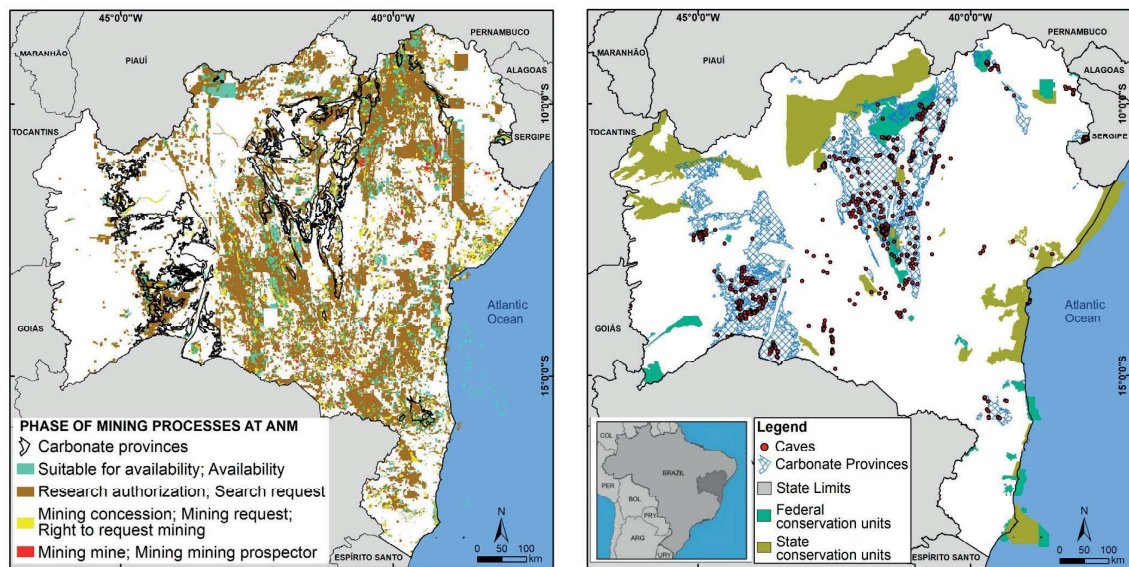


Figure 1 : A) Correlation between the mineral exploration project areas in the State of Bahia and the location of the speleological provinces in the state's carbonate terrains. B) Bahia's protected areas and the location of caves and speleological provinces in the carbonate terrains of the state.

## 2. Materials and methods

Between January, 2021 and December, 2022 a systematic literature review and fieldwork were conducted by the team of researches of the project "Characterization and regionalization of karst terrain in carbonate rocks in the state of Bahia", aiming to establish the coverage areas and subdivisions of karst provinces in carbonate rocks in this state, aiming to provide criteria for definition of the regional approaches for the karst terrains, in carbonate rocks, as established in the Federal Decree 6.640/2008.

The field campaigns were carried out after an inventory of the knowledge and information available on these terrains, generating detailed maps of these provinces. And using the geomorphology, watersheds, stratigraphy, structural geology, tectonics and karst typology, a method for this regionalization was elaborated. These information were the basic criteria for the subdivision of known karstic provinces in regions.

## 3. Results

The subdivision of each province has different weights for the physiographic variables and other adopted criteria, depending on the relevance on speleogenesis control and relief evolution. The geomorphological expression was the most remarkable aspect and considered. However, it was also necessary to consider watershed, stratigraphic, structural, tec-

tonic aspects, cave typology, and other intrinsic characteristics observed in the karst districts found in the field. The regions established for each province is presented in Figure 2. The characteristics of each province and the names for each proposed region are presented at Figure 3.

It was assumed the proposal of KARMANN & SANCHEZ (1979) for the speleological districts, as 'sectors of greater local or regional incidence of caves within a province, attesting the discontinuity and anisotropy of karstic processes along the same carbonate unit', and this concept was considered as the basis for the establishment of each region.

On geospatial databases were also plotted data collected during field surveys which characterizes the karst systems in each proposed region. These procedures, in addition to the inventory and analysis of relevant literature were the basis for the subdivisions that will be presented herein.

At the end of the research, at least 10,500 km were travelled by researchers and 26 regions were defined for the 6 speleological provinces, in carbonate rocks, which occur in Bahia.

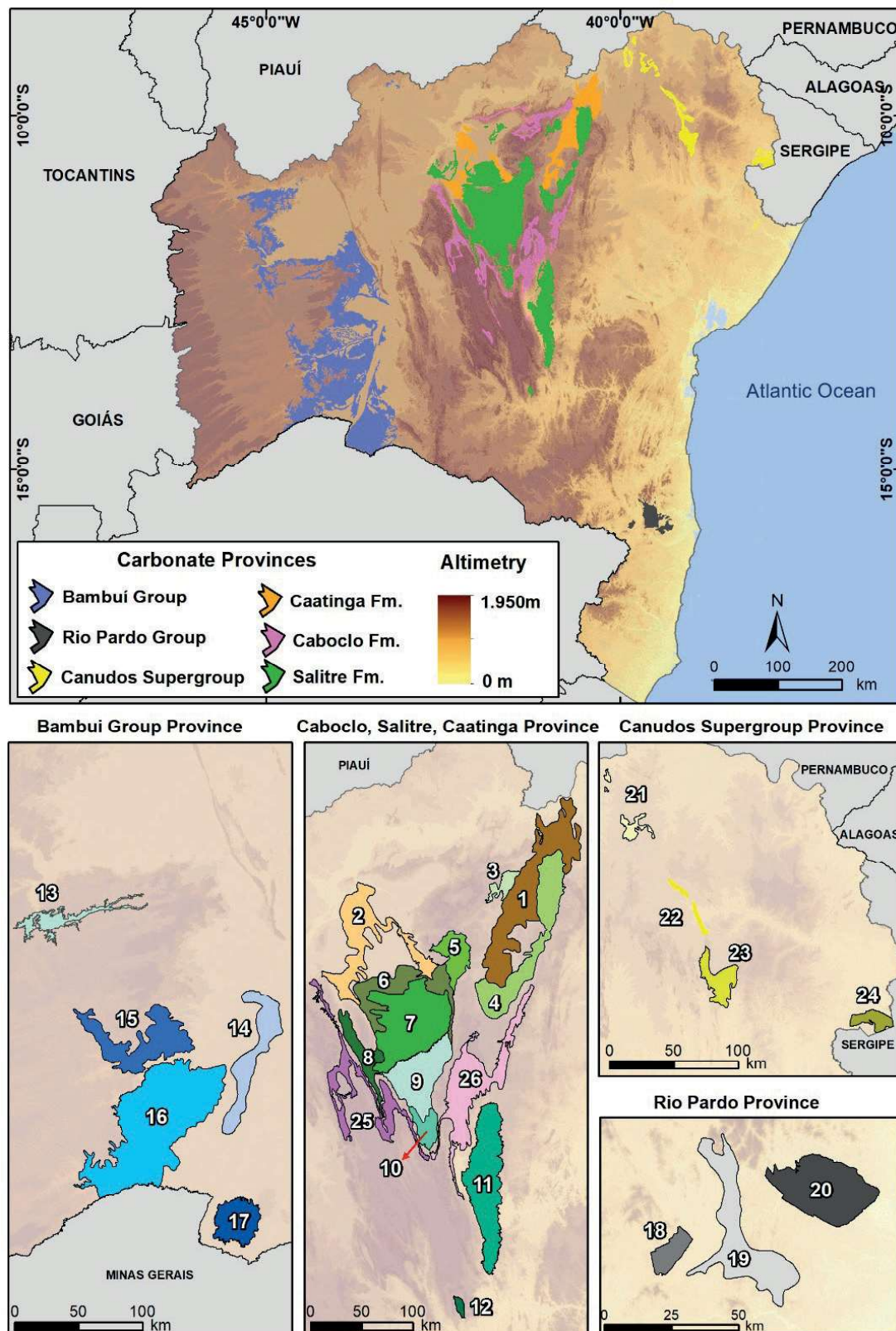


Figure 2 : Maps of carbonatic espeleological provinces and proposed karstic regions, for the carbonate terrains in the State of Bahia. The name of each region is presented at chart 1.

| Eon             | Provinces          | Regions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Characteristics                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-----------------|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Cenozoic        | Caatinga Formation | 1. Northwest Morro do Chapéu, North/Northeast São Gabriel, North Jussara, Southwest Sento Sé & Itaguaçu da Bahia<br>2. South Juazeiro, Center Campo Formoso, West Mirangaba, West Jacobina, East Umburanas & East Ourolândia                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Carbonate Breccia and calcretes, associated with flat relief areas.                                                                                                                                                                                                                                                                                                                                                             |
| Neoproterozoic  | Salitre Formation  | Campinas Sub-basin:<br>3. West Campo Formoso<br>4. South Juazeiro, East Campo Formoso, Center Mirangaba, Center West Jacobina, Center West Várzea Nova, Northeast Morro do Chapéu & South Ourolândia<br>Irecê Basin<br>5. Southwest Umburanas, West Ourolândia & North Morro do Chapéu<br>6. North/Northeast Morro do Chapéu, East América Dourada, East João Dourado, Northeast São Gabriel, Center Jussara, Southeast Itaguaçu da Bahia & Center-North Central<br>7. West América Dourada, Southwest João Dourado, South/Southwest São Gabriel, South Jussara, Southeast Central, East Uibaí, Presidente Dutra, Ibititá, South Ibipeba, East Barra do Mendes, Irecê e Lapão<br>8. Center-East Barra do Mendes & Ibipeba<br>9. Barro Alto, Canarana, Cafarnaum, West Morro do Chapéu, West Mulungu do Morro, North Souto Soares & North Iraquara<br>10. South Souto Soares, East Seabra, North Palmeiras & South Iraquara<br>Una-Utinga Basin<br>11. Utinga, Ruy Barbosa, Wagner, Lajedinho, Ibiquera, Boa Vista do Tupim, Andaraí, Nova Redenção, Itaetê e Iramaia<br>Ituaçu Sub-basin<br>12. Ituaçu | Diverse scenarios, mostly with dark gray and fine limestones or dolomites, associated with flat relief areas, but also sometimes with hilly areas. The structure also can vary from horizontal layers - more common in Una-Utinga Basin and parts of the Irecê Basin or also in the Campinas sub-basin, to folded and fractured carbonate rocks, which can be found in the Ituaçu Sub-basin and other parts of the Irecê Basin. |
|                 | Bambuí Group       | 13. São Desidério<br>14. Bom Jesus da Lapa & Northeast Serra do Ramalho<br>15. Santana, Santa Maria da Vitória & Canápolis<br>16. Cocos, Feira da Mata, Carinhanha, Coribe, São Félix do Coribe & Southwest Serra do Ramalho<br>17. Iuiú                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Mostly dark gray and fine limestones or dolomites, with intercalations of clay layers, associated with flat relief areas, sometimes in the top of plateaus, which outcrops along the São Francisco River valley and are grouped into two formations, as follows: Lagoa do Jacaré & Sete Lagoas. The structure is mostly of horizontal layers, cutted by spaced vertical fractures.                                              |
|                 | Rio Pardo Group    | 18. West Potiraguá<br>19. Pau-Brasil, East Potiraguá, Itapebi & South Mascote<br>20. Santa Luzia, Camacã & North Mascote                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Hilly reliefs with various types of carbonate rocks, which are separated into two formations: Serra do Paraíso – folded and highly metamorphosed and Salobro – fractured and not metamorphosed.                                                                                                                                                                                                                                 |
|                 | Canudos Supergroup | 21. Curacá<br>22. Uauá & North Canudos<br>23. Euclides da Cunha & South Canudos<br>24. Paripiranga                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Light gray or whitish and medium to coarse marbles, which are grouped into two formations: Olhos d'Água and Acauã. These rocks are associated with different types of reliefs areas, which can vary from plainlands to sierras, and are highly folded and/or with faults and thrust belts.                                                                                                                                      |
| Mesoproterozoic | Caboclo Formation  | 25. Xique - Xique, Gentio do Ouro, Ibipeba, Center Barra do Mendes, Ipupiara, Brotas de Macaúbas, North Seabra, West Souto Soares & Northwest Palmeiras<br>26. Jacobina, Miguel Calmon, Southeast Morro do Chapéu, West Tapiramutá, Bonito, Wagner, West Utinga, East Mulungu do Morro & Lençóis                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Highly silicified carbonate rocks, but mostly with preserved sedimentary structures, sometimes associated with siliciclastic layers, always related with hilly reliefs                                                                                                                                                                                                                                                          |

Figure 3 : Table of carbonatic espeleological provinces and proposed karstic regions, with their defining characteristics.

## 4. Discussion

The stratigraphy, structural and faciological variations, associated with changes caused by the paleoclimatic and tectonic past, condition both the typology of caves and karst and the topographic compartmentalization, resulting in marked differences in types, concentration and distribution of karst features. For each province, their main characteristics differentiate the weights of aspects considered for each subdivision that was shown in the results presented in the previous section.

The definition of these regions represents an instrument for karst management in the state of Bahia. During this research it was also calculated that karst systems, in carbonate terrains, represents almost 15% of Bahia's territory. These terrains are mostly present in a semiarid region, and only the Rio Pardo Group Province, which is situated at the rainforest biome, is outside this climatic condition.

It must be highlighted that the speleological heritage of Bahia occupies a prominent place in Brazil, as it is the state with the longest cave in South America and also has regions with one of the highest concentrations of caves in the country. In the other hand it lacks an efficient management of its karst systems, increasing the vulnerability of this heritage and missing out on opportunities in speleotourism (Figure 4) in underserved regions as discussed in Carvalho et al. (2023).

To fill this gap, an atlas was created with a detailed description of each of the regions proposed here. This Atlas is now in the final stages of editing and will contribute to increasing knowledge about Bahia's speleological heritage, representing an important instrument for the management of the state's karst terrains.

In order to promote scientific outreach and the popularization of knowledge related to the karst lands of Bahia, an e-book was also produced (JESUS ET AL, 2023), informative in nature and focusing on the population living in these areas, which is available at the link: <https://editora.iabs.org.br/site/index.php/portfolio-items/cavernas-carste-rochas-carbonaticas-na-bahia/>.

It is understood that the regionalization proposal presented here for karst terrains, in carbonate rocks, in the State of Bahia should serve as an important support for the licensing of activities in these locations, although through the use of detailed scale work it is still possible to

improve some of the limits established here. In any case, it is understood that the methods used here can be implemented in other states, promoting advances in the management of the speleological heritage and Brazilian karst areas.

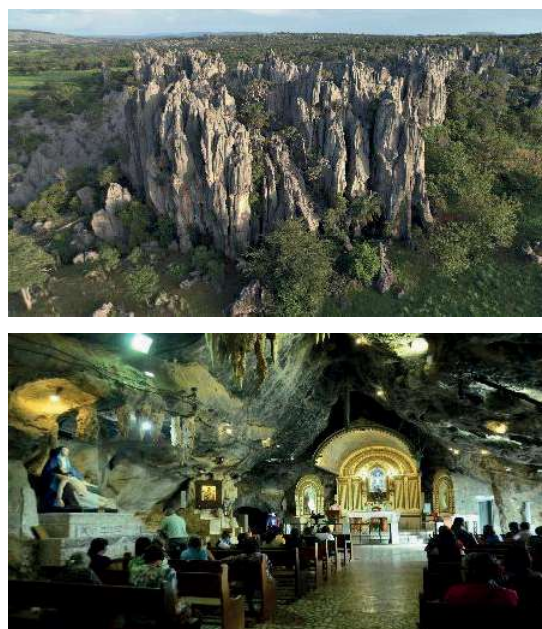


**Figure 4 :** Lapias with maze caves, in the southernmost part of the Ramalho's Sierra, nearby the municipality of Cocos, in the Bambuí's Group Province. Despite its outstanding features, this site is mostly unknown in the country. In the other hand, the caves in the municipality of Bom Jesus da Lapa, also located in the Bambuí's Group Province, house one of the largest religious pilgrimages in Brazil.

## 5. Conclusion

The results provided information on a more detailed scale about the karst terrains, in carbonate rocks, in the state of Bahia. These results will contribute to further studies in a wide variety of areas, including the vulnerability and/or potentialities of karst in carbonate rocks in Bahia, as well as serving as a framework for licensing, environmental management and conservation of speleological heritage in the state. The fieldwork also allowed the construction of an educational collection of carbonate rocks and karst in the state, which is being improved to be used as outreach of the knowledge about karst systems in Brazil.

In order to support the application of the regional approach, proposed at the Decree 6.640, published in 2008 by the Brazilian government, geological parameters such as watersheds, stratigraphic, geomorphological and geological structure data, beside field work, were used to define 26

karstic regions in carbonate terrains, in the State of Bahia. To reach this objective, it was herein assumed that the definition of speleological district, proposed by KARMANN & SANCHEZ (1979), could be used as a synonym of the regional approach.

The compilation and analysis of existing information, for each of the Bahia's speleological provinces, and the summary description of these lands and their respective geological-geographical contexts, already represent a unique product in Brazil, prepared on a state scale, having diverse applications, whether in the prevention of conflicts or risk scenarios, or in territorial planning and management. The method can also be a model to be adopted in other states, improving the karst management in the country.

## Acknowledgments

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signed between Vale S.A. and the Chico Mendes Institute for Biodiversity Conservation (ICMBio), with operational management carried out by the Brazilian Institute for Development and Sustainability (IABS).

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