

PS Hypogenic Karst Dissolution in Carbonate Rocks has Implications for Karstified Carbonate Reservoirs*

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Abstract

Dissolution along zones of preferential flow enhances anisotropy in geological media and increases its complexity. Many karst models tend to be descriptive and fail to predict localization and structure of karst systems. Conduit architecture is difficult to derive from borehole data, and it can be hardly mapped even with the advent of 3D seismic techniques. Therefore, analysis of the geometry of karst conduit systems remains elusive where direct access to karst conduits is not possible. The present study investigates the relationship between lithofacies, tectonics and karstification in the Neoproterozoic Salitre Formation, located in the central-eastern Brazil. This unit comprises several systems of caves including the Toca da Boa Vista and da Barriguda hypogenic caves, the largest in South America, and focus of this study. We focused on cave mapping and morphogenetic analysis, determination of petrophysical properties, thin-section description, micro-tomography, and isotopic analysis. The Salitre Fm, deposited in an epicontinental sea, comprises mud/wackestones, grainstones, microbial facies, and fine siliciclastic rocks. The caves comprise 3D mazes with a network/spongework pattern. Passages occur in several levels within ca. 60 m thick cave-forming section, limited at the top by lithofacies with low permeability and fractures. Cave development occurred in phreatic sluggish-flow environment with overall upwelling flow. It rose via cross-formational fractures and distributed laterally within the cave-forming section using geological heterogeneities to eventually discharge up through outlets breaching across the upper confining beds. Cave formations include an assemblage indicating a period of water table conditions. Sediment fill includes deposits of dolomitic sand originated from in situ weathering of cave walls and ceiling. Caves show no relationship with the surface. Our data indicate several events of porosity evolution, such as subaerial exposure, folds and fractures, hydrothermal events (exotic minerals assemblage), sulfuric acid dissolution, dissolution at the water table, condensation corrosion, and faults and fractures reactivation. The major enhancement of secondary porosity was due to hypogene speleogenesis. Hypogene karst process may have implications to carbonate reservoirs not only through porosity enhancement, but also through their influence on regional flow systems, cross-formational communication, and migration of hydrocarbons

Reference Cited

Mazzullo, S.J., and P.M. Harris, 2009, An Overview of Dissolution Porosity Development in the Deep-Burial Environment, With Examples from Carbonate Reservoirs in the Permian Basin: Search and Discovery Article #60028, Web Accessed April 9, 2016, http://www.searchanddiscovery.com/documents/2009/60028mazzullo/ndx_mazzullo.pdf

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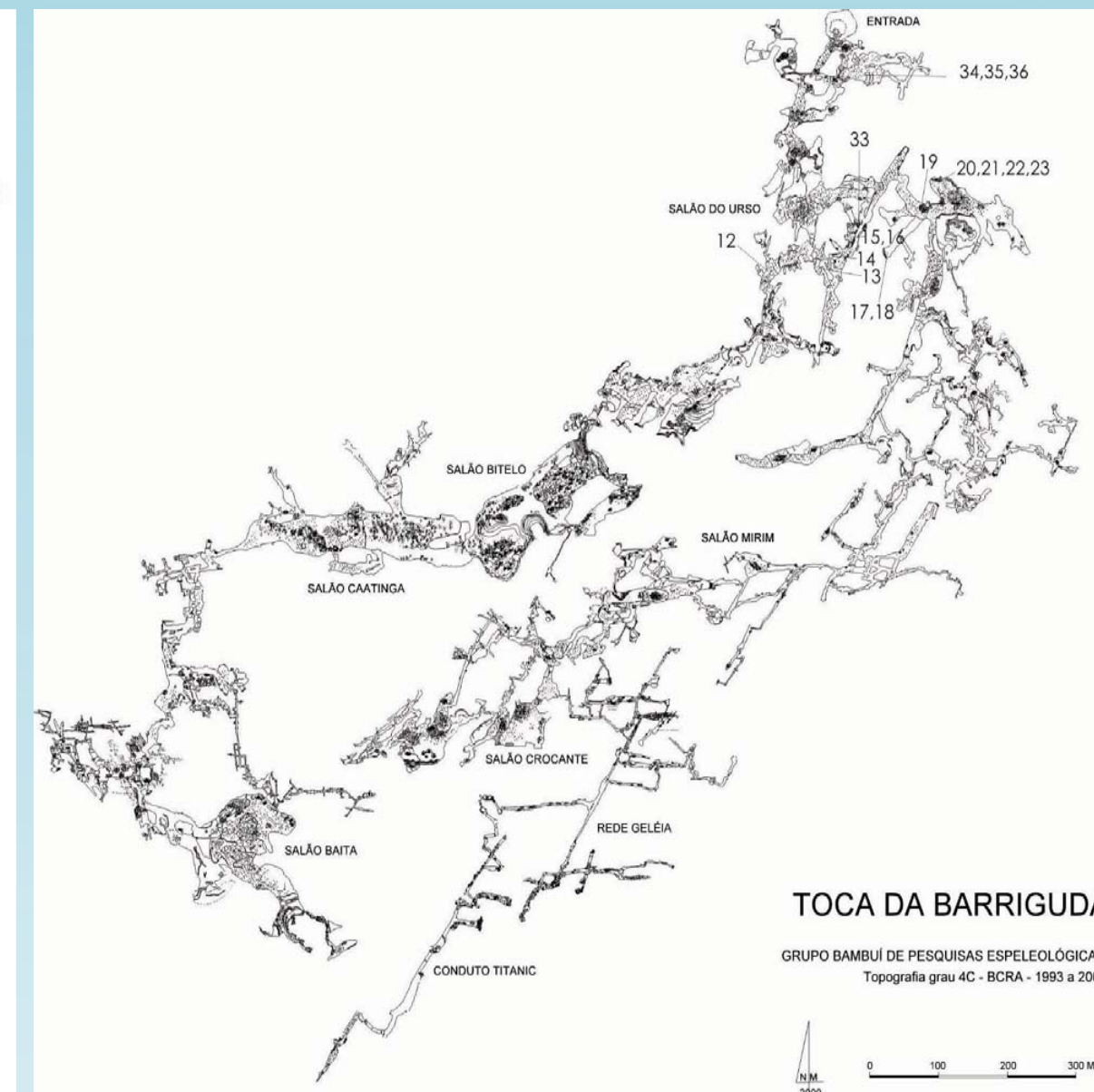
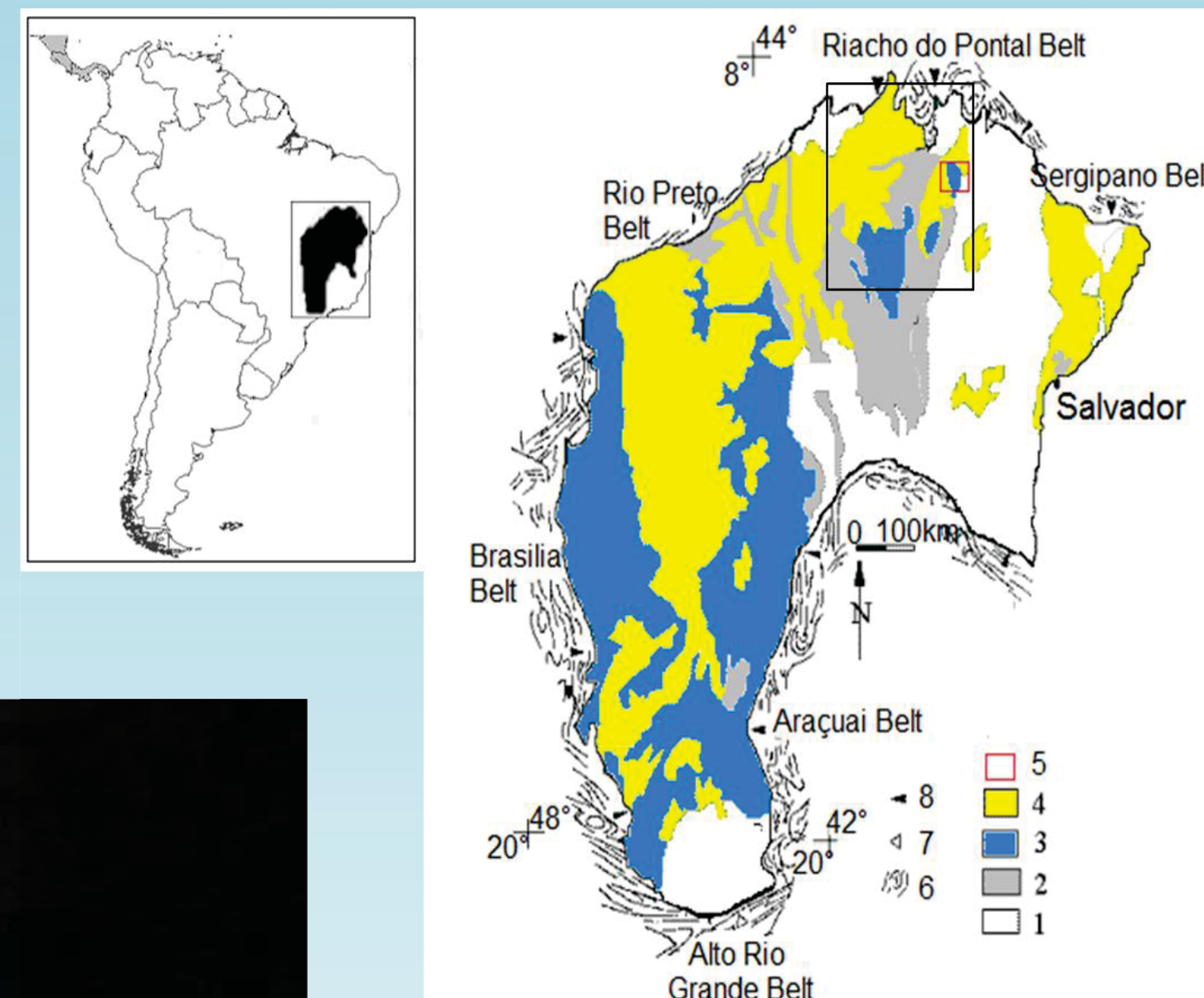
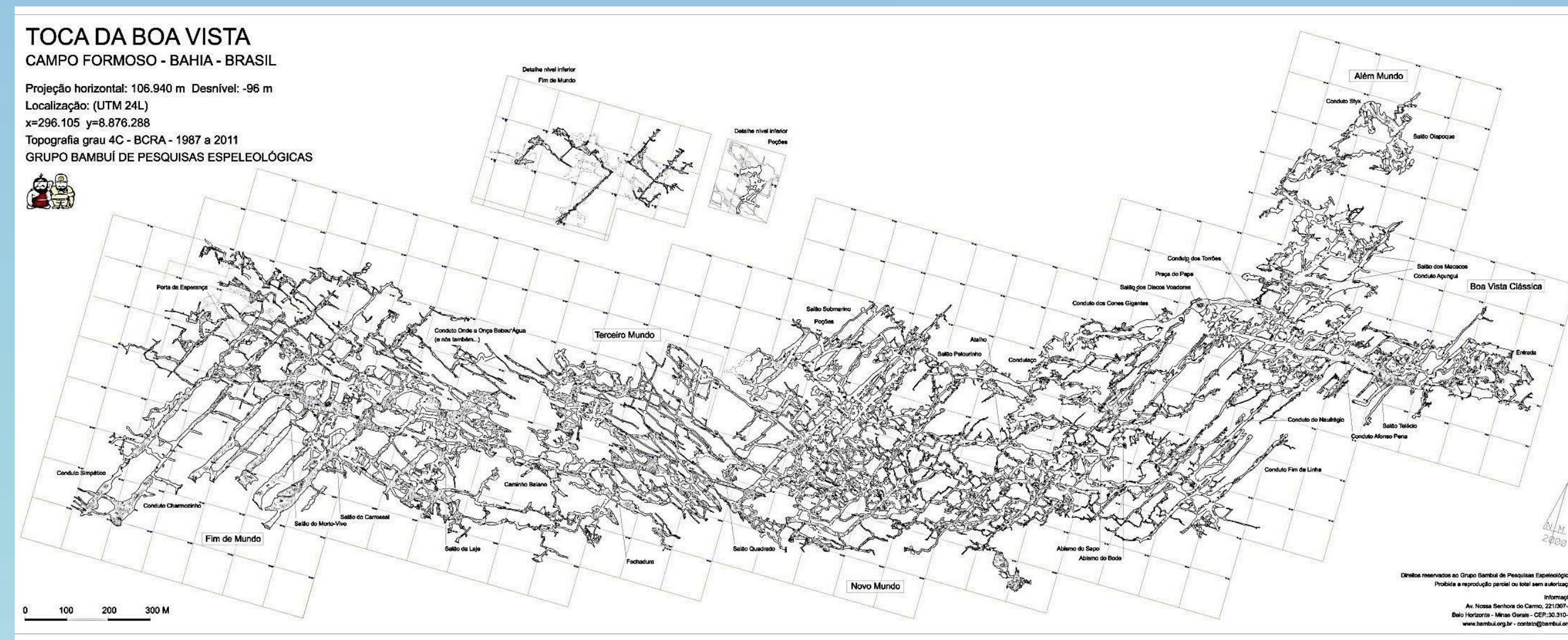
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Introduction

- Hypogenic karst systems have some differences from epigenic. Commonly, they are at great depth, recharge is due to some soluble formation above and formed by rising fluids
- Dissolution along zones of preferential flow enhances anisotropy in geological media and increases its complexity. Many karst models tend to be descriptive and fail to predict localization and structure of karst systems.
- Conduit architecture is difficult to derive from borehole data, and it can be hardly mapped even with the advent of 3D seismic techniques. Therefore, analysis of the geometry of karst conduit systems remains elusive where direct access to karst conduits is not possible.
- The present study investigates the relationship between lithofacies, tectonics and karstification in the Neoproterozoic Salitre Formation, located in the central-eastern Brazil.

Study Area/Methods

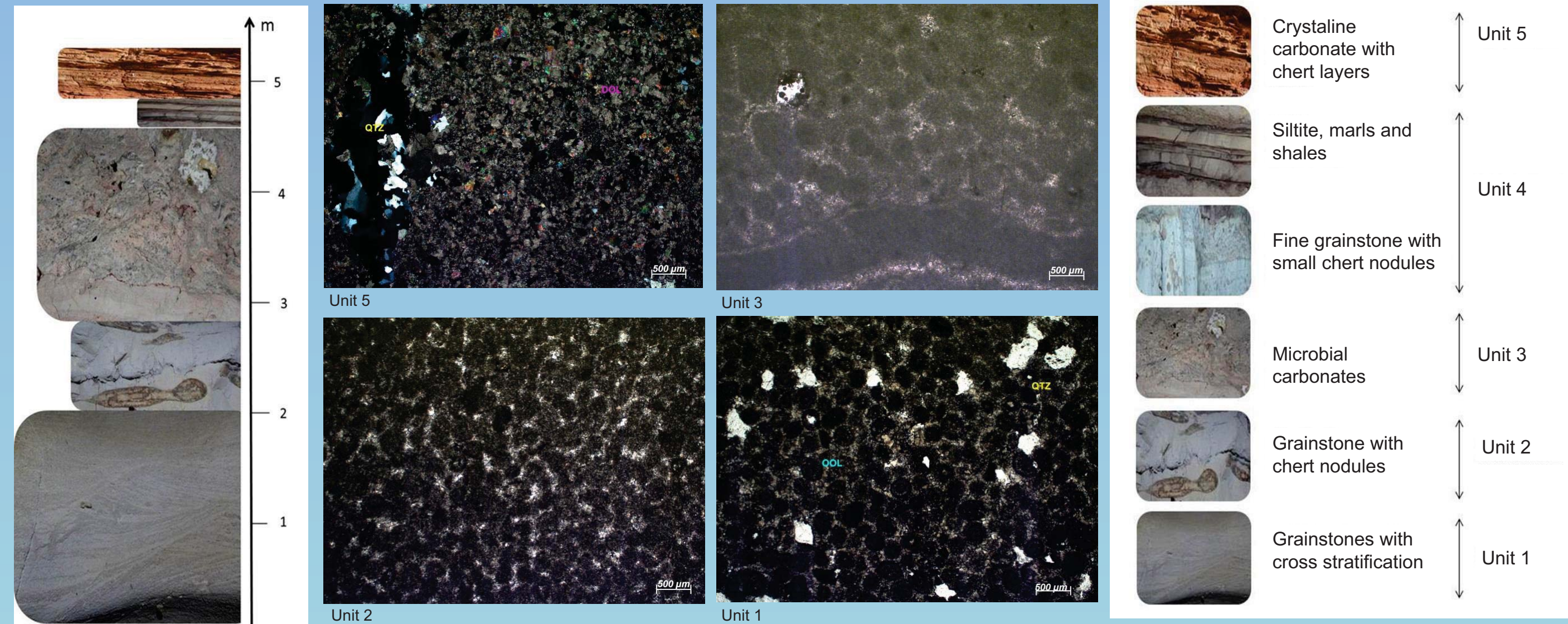
- The Hypogenic Complex in the Salitre Formation comprises several systems of caves including the **Toca da Boa Vista** and **Toca da Barriguda** caves, the largest in South America, and focus of this study.
- We focused on cave mapping and morphogenetic analysis, determination of petrophysical properties, thin-section description, micro-tomography, and isotopic analysis.
- The Salitre Fm, deposited in a epicontinental sea, comprises mud/wakestones, grainstones, microbial facies, and fine siliciclastic rocks.



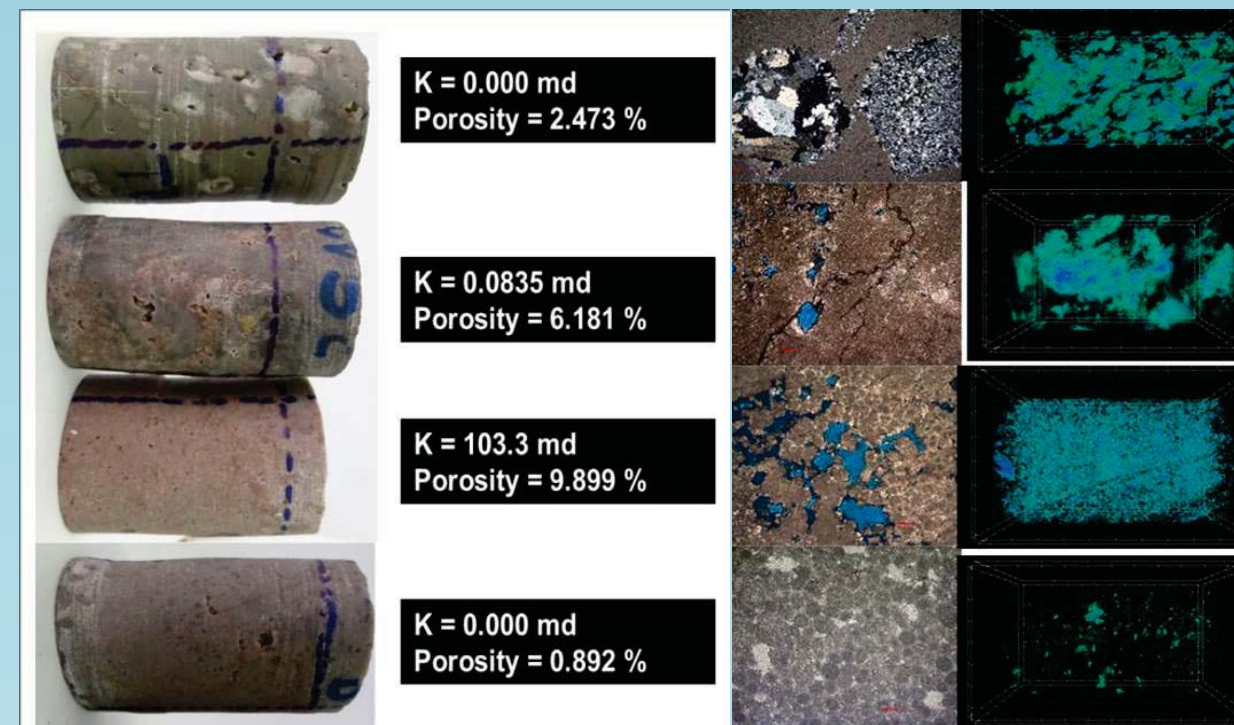
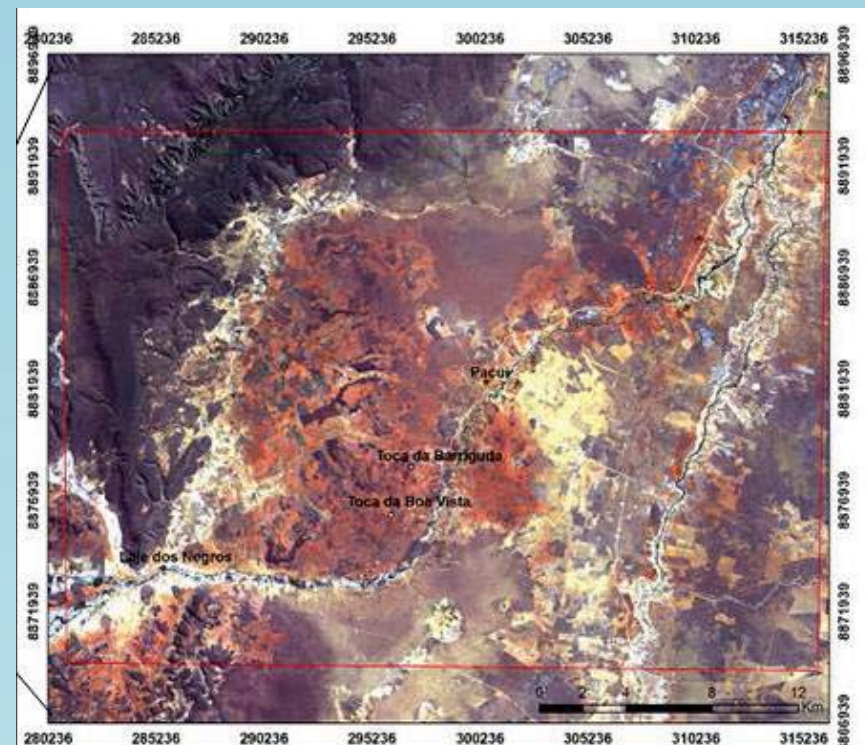
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Results

- The caves comprise 3D mazes with a network/spongework pattern.
- Structural controls in Toca da Boa Vista and Toca da Barriguda are folds, joints and faults (frequently no alignment is observed between structures and conduits or morphological features).
- Passages occur in levels within ca. 60 m thick cave-forming section, limited at the top by lithofacies with low permeability and fractures.
- Cave development occurred in phreatic sluggish-flow environment with overall upwelling flow. It rose via cross-formational fractures and distributed laterally within the cave-forming section using geological heterogeneities to eventually discharge up through outlets breaching across the upper confining beds.
- Caves show no relationship with the surface.



Litostratigraphy in TBV-TBR System..

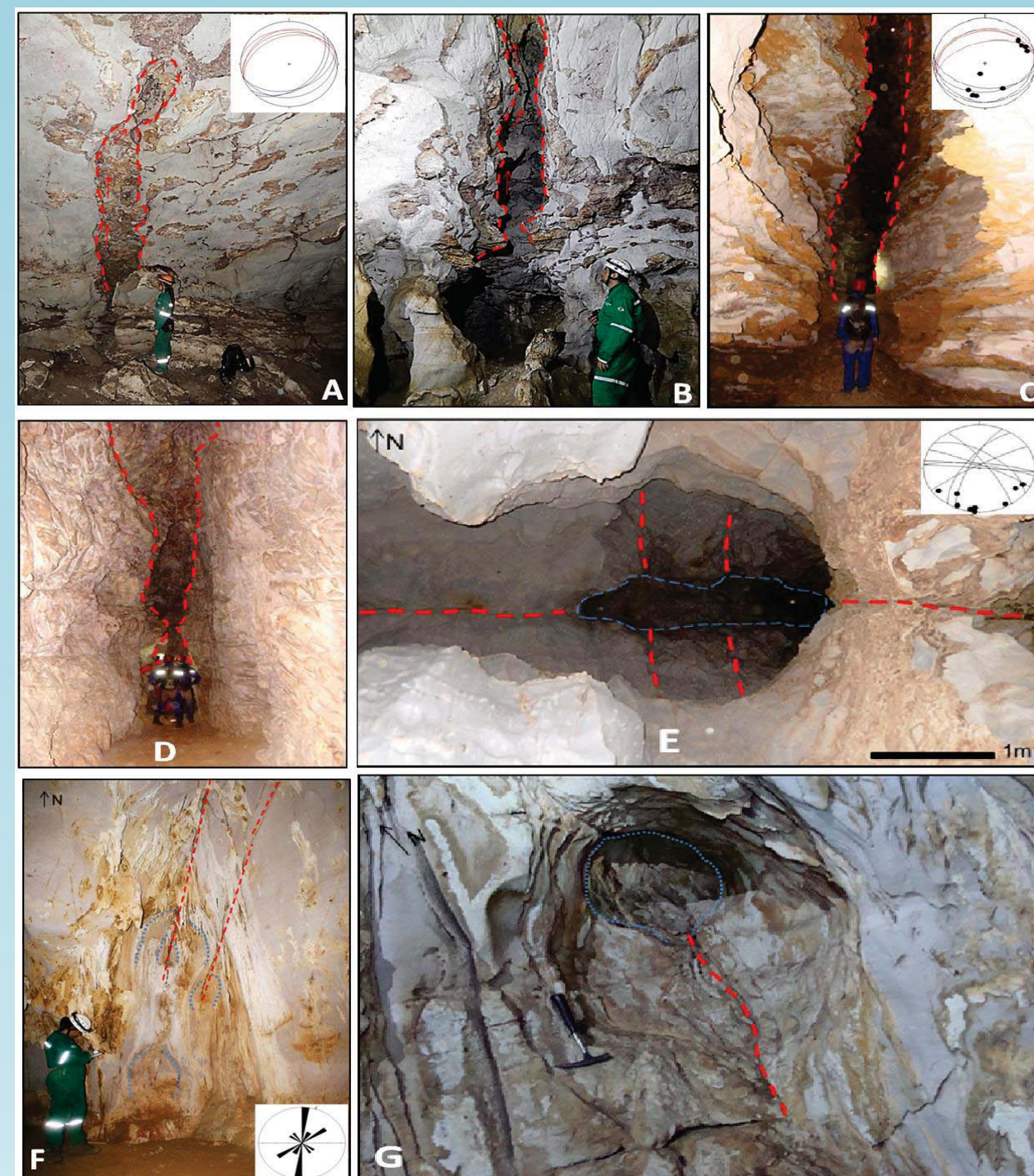


Unit 1 - Grainstone

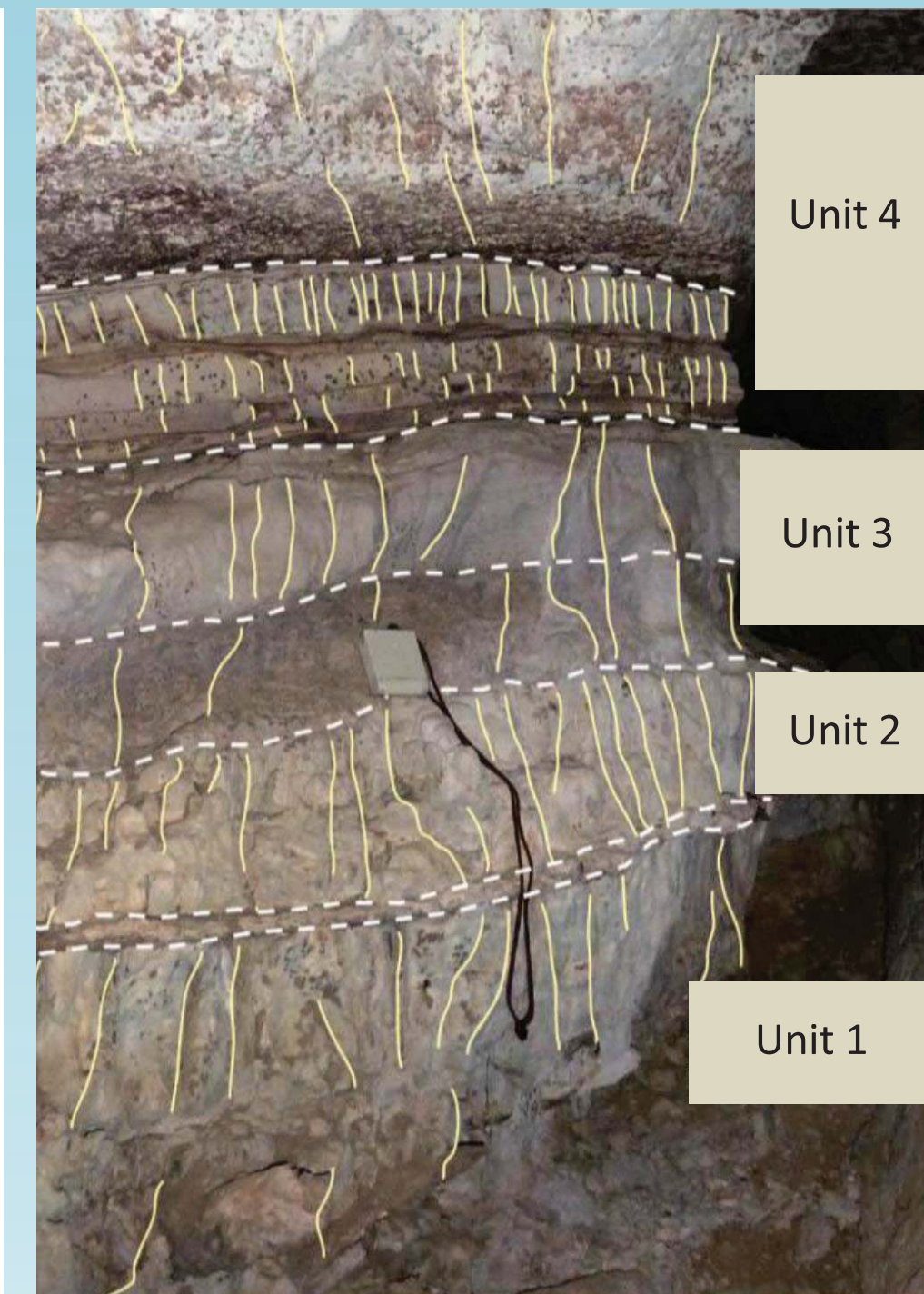
Unit 3 - Stromatolite

Unit 3 - Laminite

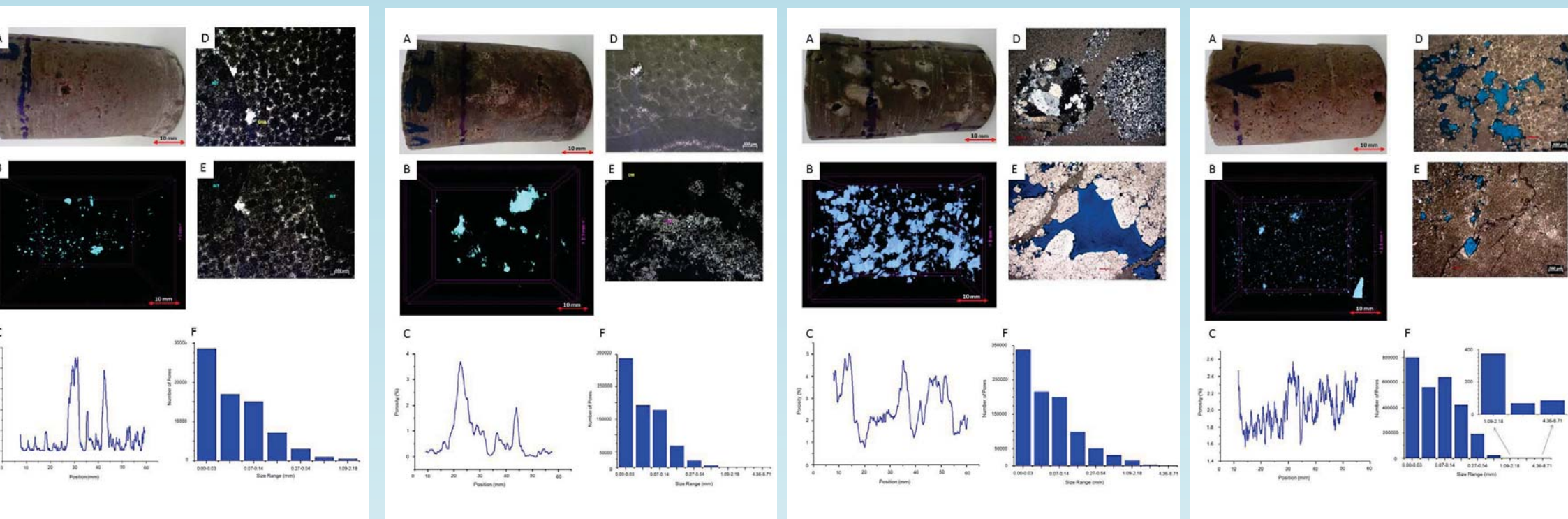
Unit 3 - Thrombolite



Morphology of Toca da Boa Vista and Toca da Barriguda karst system. A e B are feeders (NNE-SSW direction) ; C and D are rift-like passages (NNE-SSW direction); E is an outlet developed in the intersection of N-S and E-W fractures; F is cupolas developed along E-W fracture, and, G is a cupola.



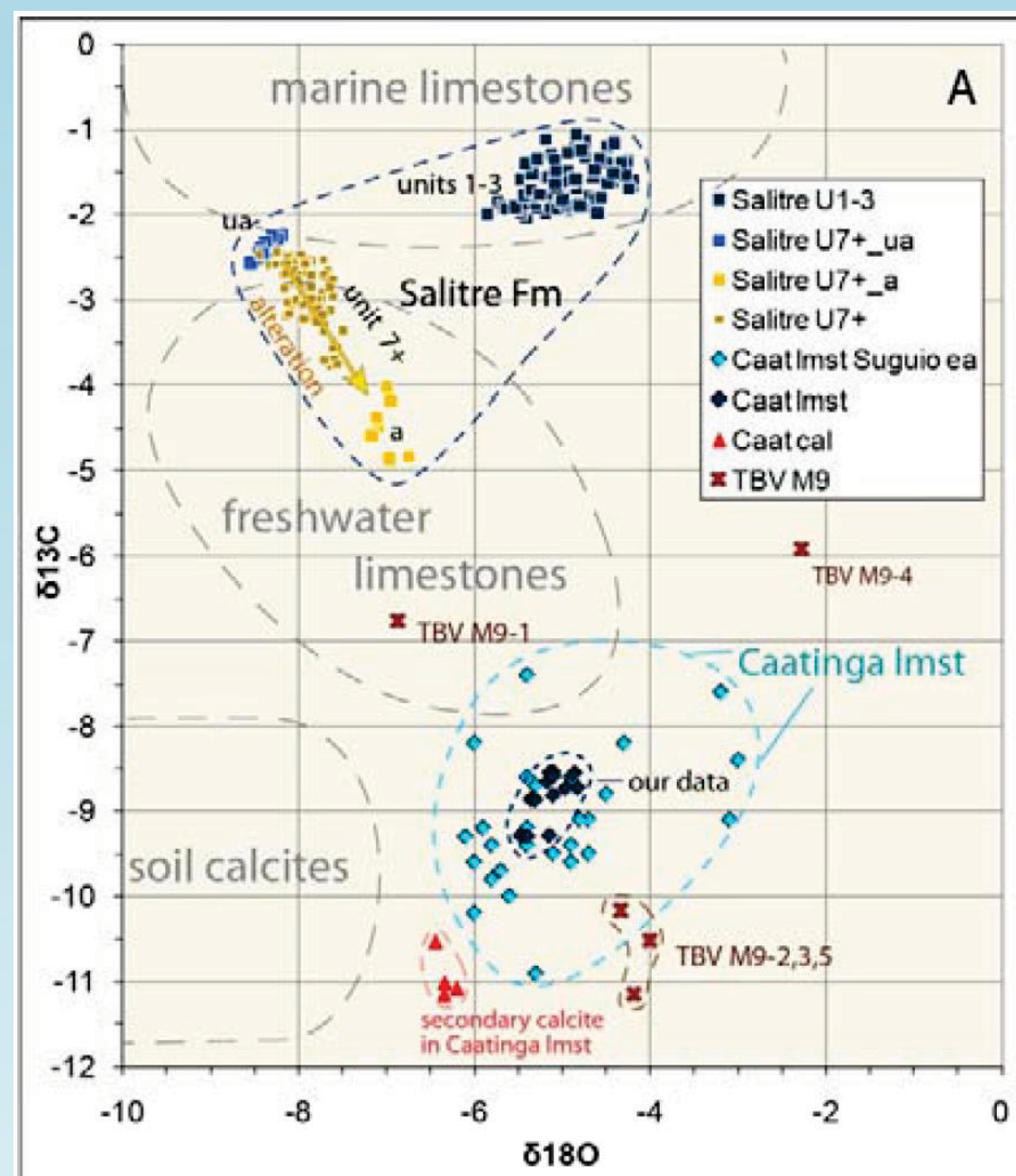
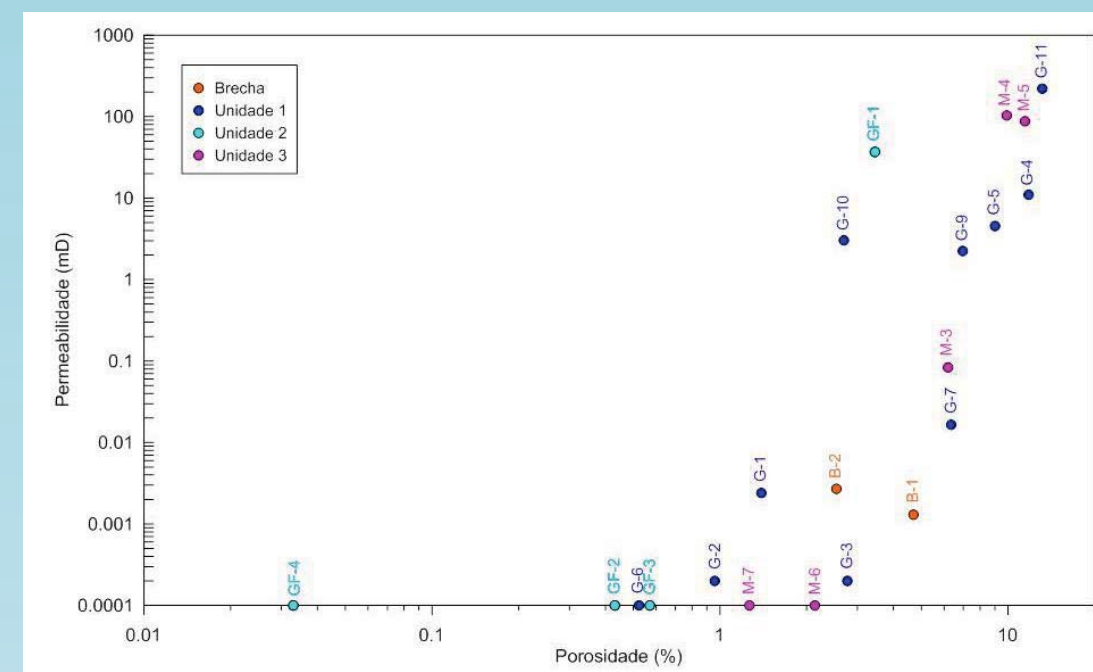
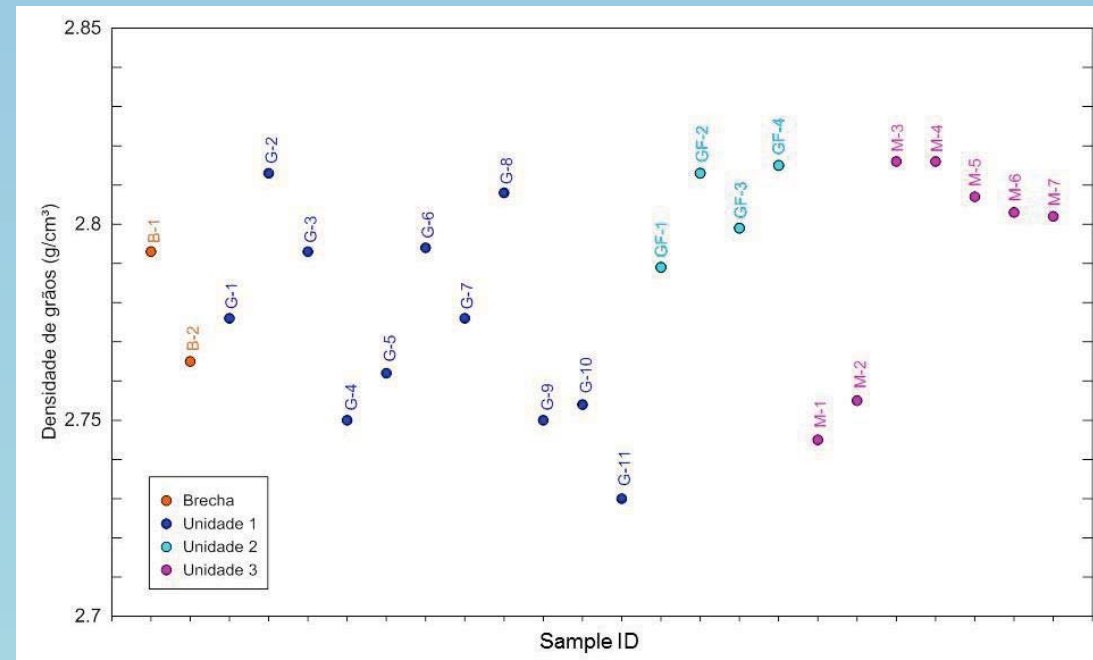
Mechanical stratigraphy on karst dissolution.



Microfacies and microtomography: (A) horizontal sample; (B) 3D pore reconstruction, (C) porosity profile along sample, (D) (E) photomicrography; (F) pore size distribution.

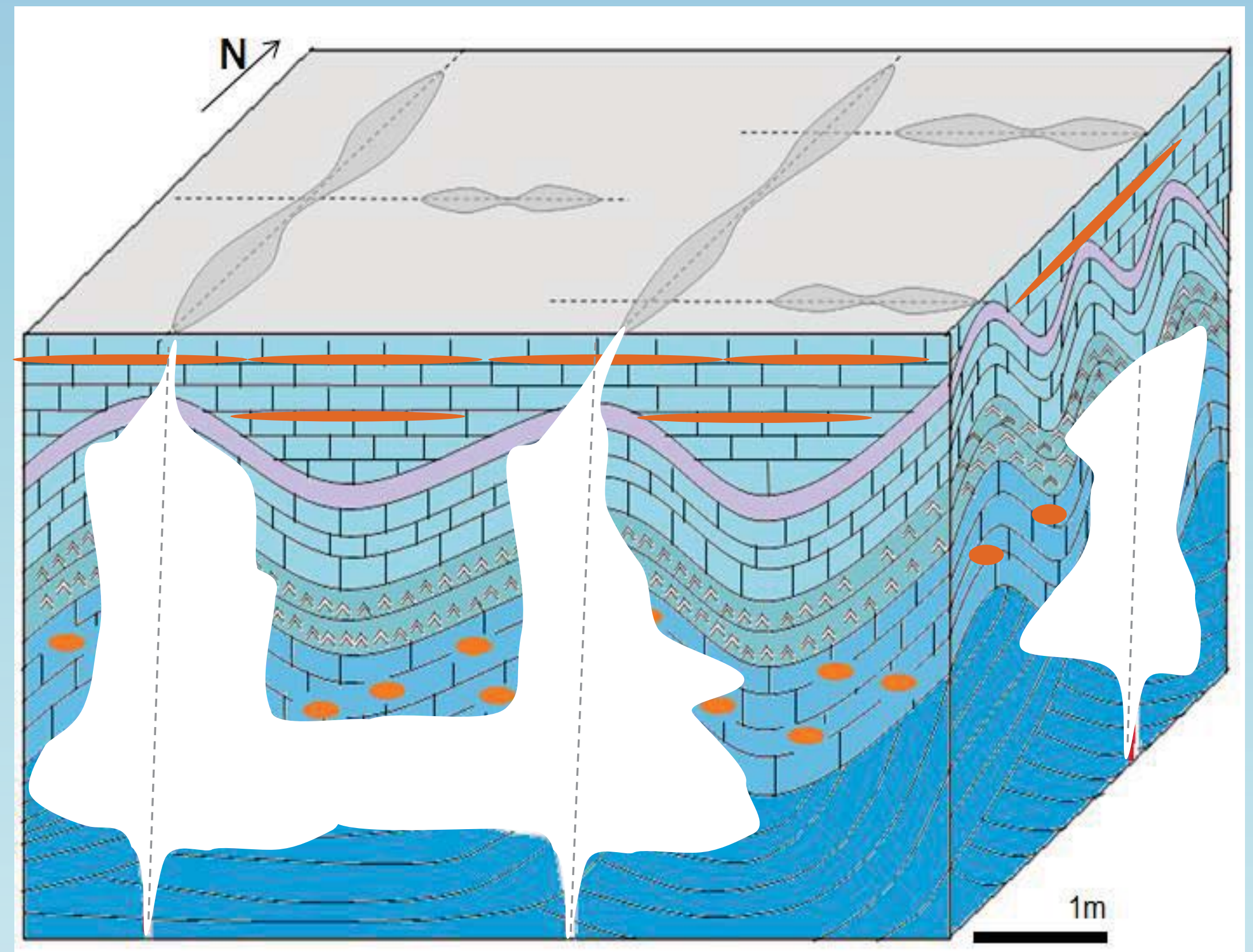
- Grain density ranges from 2.73 g/cm³ to 2.82 g/cm³ are consistent with dolomitized lithologies.
- Silica content in a few samples reduces grain-density values.
- The occurrence of microbial intraclasts reduces grain density values.
- The major enhancement of secondary porosity was due to hypogene speleogenesis.
- Micro-CT shows pore geometry. However, with image resolution, this technique does not indicate the full rock porosity. This corroborates with the lab porosity, which is also low.
- Overall, distribution of cavities/conduits through the rock succession is mainly controlled by fracture porosity, i.e. by distribution and the connectivity of fractures within the lithostratigraphic framework.

Sample ID	Unit	Sample Length (cm)	Kair (md)	Dry Weight (gm)	Grain Volume (cc)	Grain Density (gm/cc)	Lab Porosity (%)	micro-CT Porosity (%)
B-1	Breccia	5.432	0.0013	144.76	518.355	2.793	4.696	3.160
B-2	Breccia	4.976	0.0027	133.9	484.282	2.765	2.538	
G-1	1	4.644	0.0024	124.76	449.451	2.776	1.391	1.640
G-2	1	5.313	0.0002	146.92	522.296	2.813	0.959	0.120
G-3	1	5.699	0.0002	150.93	540.467	2.793	2.767	
G-4	1	5.245	11.0	129.27	470.135	2.75	11.794	
G-5	1	5.332	4.54	138.35	500.982	2.762	9.012	
G-6	1	4.979	0.0001	138.62	49.606	2.794	0.523	
G-7	1	5.660	0.0165	146.97	529.399	2.776	6.349	
G-9	1	2.902	2.24	73.46	267.101	2.75	6.960	
G-8	1	5.610	0.0000	155.41	553.371	2.808	0.892	0.100
G-10	1	4.961	3.03	133.04	48.304	2.754	2.693	
G-11	1	4.810	220.2	114.63	419.818	2.73	13.145	
GF-1	2	5.194	36.8	139.98	501.956	2.789	3.453	
GF-2	2	3.775	0.0001	104.73	372.254	2.813	0.431	
GF-3	2	4.355	0.0001	118.63	423.782	2.799	0.570	
GF-4	2	4.935	0.0001	138.24	491.057	2.815	0.033	
M-1	3	5.705	0.0000	150.37	547.842	2.745	2.473	2.660
M-2	3	5.567	0.0000	147.9	536.789	2.755	1.528	
M-3	3	5.509	0.0835	145.3	516.039	2.816	6.185	0.750
M-4	3	5.095	103.3	130.05	461.758	2.816	9.899	2.050
M-5	3	3.464	87.7	86.63	308.657	2.807	11.447	
M-6	3	4.590	0.0001	122.38	436.637	2.803	2.134	0.500
M-7	3	4.717	0.0001	129.22	461.238	2.802	1.265	



Discussion/Conclusion

- Mesodiagenesis is a basin-wide scale process, which may include dissolution.
- Mazzullo and Harris (2009) have shown that mesodiagenetic dissolution in carbonate reservoirs occurs at burial depths ranging from 200 m to 9150 m.
- Our studies in the TBV-TBR cave system identified various mesodiagenetic processes in the five stratigraphic units of the Salitre Formation, in which the cave system is developed. We also observed pervasive hydrothermal dolomitization, which have an influence on matrix porosity and permeability. These features indicate that the Salitre Formation has undergone deep-seated burial and experienced respective mesodiagenetic processes, including dissolution.



Toca da Boa Vista and Toca da Barriguda karst system.

- Isotope profiles for all cores are essentially flat – there is no gradient toward the walls. This means that (1) there was no isotope alteration by conduit-forming fluids (the most likely option, especially considering that the limestones are very old and diagenetically mature), or (2) an alteration zone was once formed but later removed by dissolution during one of subsequent speleogenetic phases.
- Yet another interpretation could be that the studied cores are parts of a wider alteration halo.

