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ORIGINAL ARTICLE

Stromatolites in Caves in Southeastern Brazil and their Importance to Geoconservation

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Abstract
This article presents a detailed description of stromatolites formed simultaneously with caves' bedrock, within karstic areas in Southeastern Brazil. We discuss the importance of such fossils for geoconservation and their legal preservation under the Brazilian law. Six caves are described with occurrences of *Conophyton*-type stromatolites. All those caves are located in the State of Minas Gerais, one of which in the Arcos-Pains-Doresópolis Karst (Bambuí Group) and the others in the Vazante-Paracatu-Unaí Karst (Vazante Group). In general, the stromatolite columns are not exquisitely preserved, yet conspicuously exposed in cross section and lateral view. The stromatolite caves are easily accessed, making them suitable for scientific and educational activities to both academic and non-specialized public. Yet, such activities should rely on the implementation of a management plan for monitoring potential damage due to anthropic interference. Given the rarity of caves with fossils embedded in their host rocks, these structures should be treated with the status of maximum importance for conservation, according to the Brazilian legislation, thereby ensuring their permanent protection, with the support of the public entities for environment and nature.

Keywords Fossil · Paleontology · Limestone cave · Minas Gerais · Precambrian

Introduction

Caves are unique environments. Their specific conditions, including, for instance, the reduced natural light and low variation of temperature and humidity, create conditions for a peculiar biodiversity (Barton and Northup 2007; Ribera et al. 2014). Not only from a biological standpoint, their geological structures, which are the result of long periods of water flow and percolation, tectonic movements, and the action of biological and chemical agents, among other factors (Gillieson 1996), can match some criteria for geoconservation (Gillieson 1996; Cigna and Forti 2013; Stephens et al. 2013). Cave environment is also widely used for tourism and religious activities,

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confirming their esthetic and cultural value (Moyes 1998; Healy 2007; Stephens et al. 2013).

Caves are also recognized for their potential for fossil preservation. The most important fossil records in such environments are the remains of Quaternary vertebrates incorporated to the caves at a time subsequent to their connection with the surface realm (Santucci et al. 2001; Jass and George 2010). On the other hand, fossils preserved as primary structures within the enveloping rock, i.e., those which have been preserved in the rock in which the caves are formed, are less well-known and frequently underestimated in terms of their scientific and esthetic value (DuChene 2000; Santucci et al. 2001; Vasconcelos and Bittencourt 2018).

This article aims to describe the occurrence of fossil stromatolites embedded in the host rock of caves and also to discuss the importance of those fossils to the geoconservation of caves, and their management under the specificities of the Brazilian law.

Stromatolite Occurrences in Caves

Stromatolites are laminated structures produced by microbial activity in aquatic environments (marine, lagoon, and lacustrine), occurring since the Precambrian up to the present (Hofmann 1973; Srivastava 2002). Although the stromatolites display considerable morphological variation, the most common types are easily recognizable by the cylindrical shape and the internal laminae with the convexity upward (in lateral view) or concentric in cross section (Walter et al., 1976; Dardenne, 2005; Sallun Filho and Fairchild 2005).

In addition to their paleoenvironmental and stratigraphic importance, stromatolites are also of biological significance, because they are the oldest traces of life in the fossil record (Schopfa et al., 2007). Furthermore, in South America, they are of great historical importance as they were the first Precambrian fossils ever to be described for the continent (Almeida 1944). Such fossils are mainly associated to carbonate rocks and can be found in several regions of the country (for a review see Fairchild and Sanchez 2015). Yet, there are relatively few studies about stromatolites in Brazil (Marchese 1974; Dardenne, 1972; Cloud and Dardenne 1973; Dardenne and Campos Neto 1975; Srivastava 1982; Zaine 1991; Nogueira and Dardenne 1992; Guimarães et al. 2002; Sallun Filho and Fairchild 2004; Dardenne, 2005; Fraga et al. 2013).

Most sites where fossil stromatolites have been described in Brazil refer to surface outcrops, some of them exposed due to quarries and highway cuttings. Some stromatolites have been reported in the host rock of caves; however, these still lack detailed description (Vasconcelos et al. 2016; Vasconcelos and Bittencourt 2018).

There are several studies describing Quaternary stromatolite-like structures in caves, and those structures have been referred to as bio-speleothems, speleo-stromatolites or simply classified as stromatolites (Gomes 1985; Braithwaite and Whitton 1987; Cox et al. 1989a; Gradzinski et al. 1995; Leveille et al. 2000, 2002; Northup et al. 2000; Jones 2001; Melin et al. 2001; Baskar et al. 2007; Barton and Northup 2007; Baskar et al. 2016; Bontognali et al. 2016). They can be found in caves formed in different lithologies, and they show considerable morphological variation (Cox et al., 1989a, b; Cacchio et al. 2004; Cañaveras et al. 2006; Baskar et al. 2007; Lozano and Rossi 2012; Bontognali et al. 2016). Fossil stromatolites, however, are restricted to carbonate caves (Vasconcelos et al. 2016; Vasconcelos and Bittencourt 2018).

Caves provide a unique opportunity to observe the internal structures of stromatolites embedded in the bedrock, especially in areas covered by soils or where there are no well-preserved surface outcrops. Depending on the cave morphology and their quality of preservation, it may be possible to determine the general characteristics of the stromatolites preserved within it.

Study Areas

Until now, four areas with stromatolitic caves have been identified in Brazil, but only one of them has been described, even if partially (CECAV 2019; Vasconcelos and Bittencourt 2018). Two areas will be described here, both located in the state of Minas Gerais (Table 1). One of the caves is located in the Arcos-Pains-Doresópolis Karst and the other five in the Vazante-Paracatu-Unaí Karst (Fig. 1). All of the caves are in areas of privately-owned land. These areas were elected for study due to easy accessibility, granted land-owner permission, abundance of the stromatolites, and their conspicuous occurrence.

Geological Context of the Areas

Arcos-Pains-Doresópolis Karst

The *Teto Estromatolítico* cave have developed in the limestones of the Bambuí Group (Fig. 2). The sedimentary and metasedimentary rocks of that geological unit occupy an area of more than 200,000 km^2 (Alkmim and Martins Neto 2001), spreading across the western portion of the Brasília Fold Belt and overlaying the gneissic-granitic rocks of the São Francisco Craton (Sial et al. 2009; Hasui 2012). It was formed during the Neoproterozoic, on a continental platform of a foreland basin, within repeated marine transgression-regression cycles (Dardenne 1978).

Stratigraphically, the Bambuí Group is the top unit of the São Francisco Supergroup (Alkmim and Martins Neto 2001; Sial et al. 2009; Hasui 2012). Its rocks are composed of a pelite-carbonate sequence (limestone, slate, and phyllite rocks) capped by a sequence of sediments from 600- to 800-m thick deposited on a continental crust (Shinzato, 1998). Those rocks

Table 1 Location of the studied caves

Area	Cave	Coordinates
Arcos-Pains-Doresópolis Karst	*Teto Estromatolítico*	20° 24′ 08.1″ S and 45° 34′ 46.3″ W
Vazante-Paracatu-Unaí Karst	VT-004	17° 43′ 21.4″ S and 46° 45′ 17.2″ W
	VT-047	18° 11′ 58.5″ S and 46° 51′ 45.6″ W
	VT-051	18° 08′ 30.4″ S and 46° 53′ 04.8″ W
	VT-197	17° 43′ 22.9″ S and 46° 45′ 17.8″ W
	Gruta da Fendinha	16° 25′ 08.3″ S and 47° 03′ 45.9″ W

are divided into five formations (from base to top): Sete Lagoas, Serra de Santa Helena, Lagoa do Jacaré, Serra da Saudade, and Três Marias (Dardenne 1978; Vieira et al., 2007).

In the studied area, the exposed carbonates are assigned to the Sete Lagoas Formation. They are characterized by pinkish and greenish calcipelites at the base, and dark gray limestones at the top. The calcipelites of the basal unit are correlated with the Pedro Leopoldo Member and the dark gray limestones of the top with the Lagoa Santa Member (Ribeiro et al. 2008).

The stromatolites in the Arcos-Pains-Doresópolis area are readily recognized (Fig. 3a–c). They include structures with varied morphologies such as nodular forms, erect and decumbent columns, sub-planar and pseudo-columnar constructions, with convex, and sub-rectangular lamination (Lopes 1995). The stromatolites also vary in other aspects such as height, the presence of bifurcate or multifurcate branching and round or irregular elliptical form in transverse section (Bittencourt et al. 2015).

Vazante-Paracatu-Unaí Karst

The caves in the Vazante-Paracatu-Unaí Karst area have formed in the limestones of Vazante Group (Figs. 1 and 2). This group consists of Mesoproterozoic carbonates (limestones, dolomitic breccias and bioherms) and pelites (phyllite and slates; Dardenne and Walde, 1979). Stratigraphically, it is divided into seven formations: Retiro, Rocinha, Lagamar, Serra do Garrote, Serra do Poço Verde, Morro do Calcário, and Serra da Lapa, not all of them bearing microbialites. In the Vazante-Paracatu-Unaí Karst, the

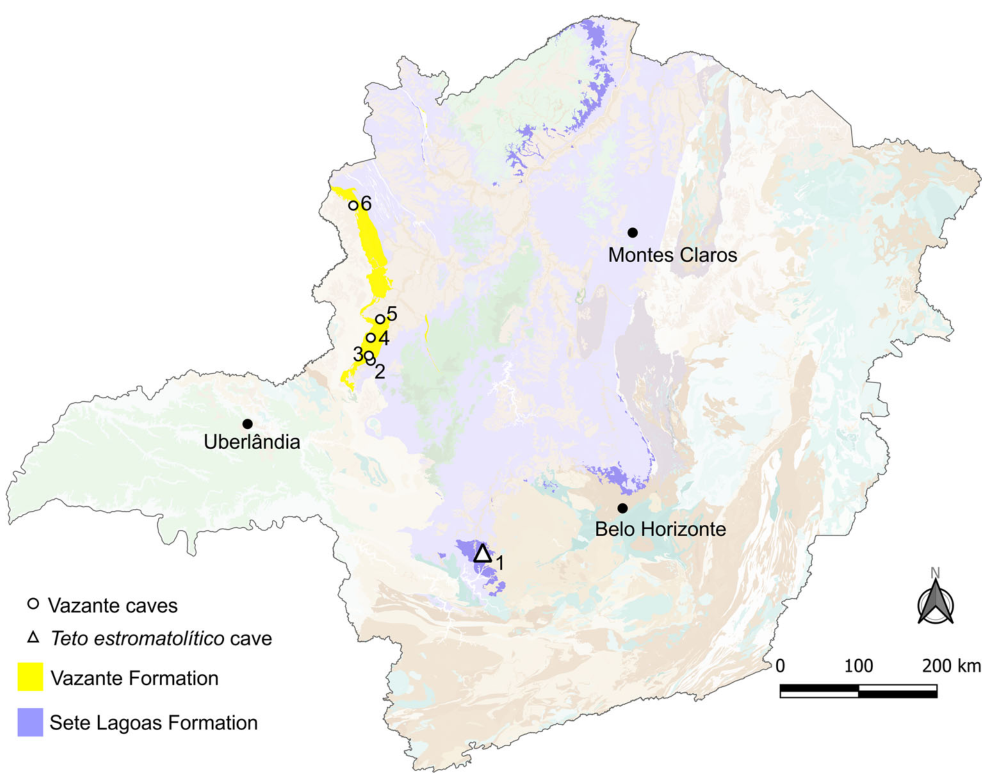

Fig. 1 Location of the studied caves: the Arcos-Pains Doresópolis Karst (triangle, one cave) and the Vazante-Paracatu-Unaí Karst (circle, four caves). (1) *Teto Estromatolítico*, (2) VT-047, (3) VT-051, (4) VT-004, (5) VT-197, and (6) *Gruta da Fendinha. Map modified from* CPRM-CODEMIG (2014)

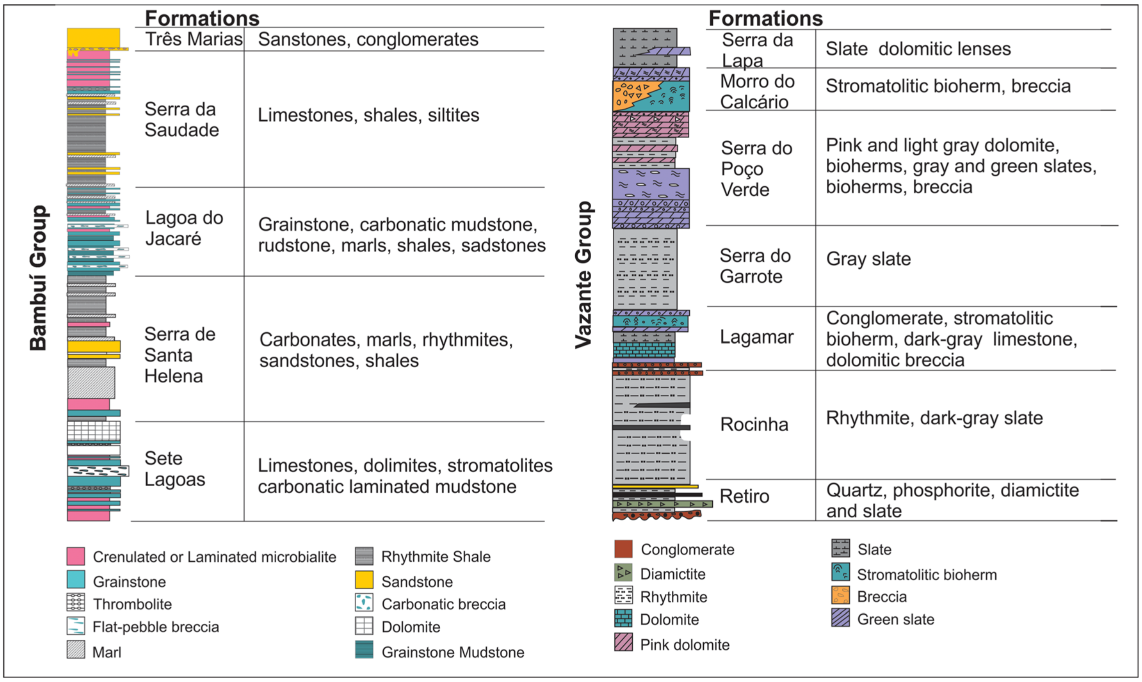

Fig. 2 Simplified lithostratigraphic chart of the studies areas. Modified from Fairchild et al. (2015) for the Vazante Group, and Uhlein et al. (2017) for the Bambuí Group

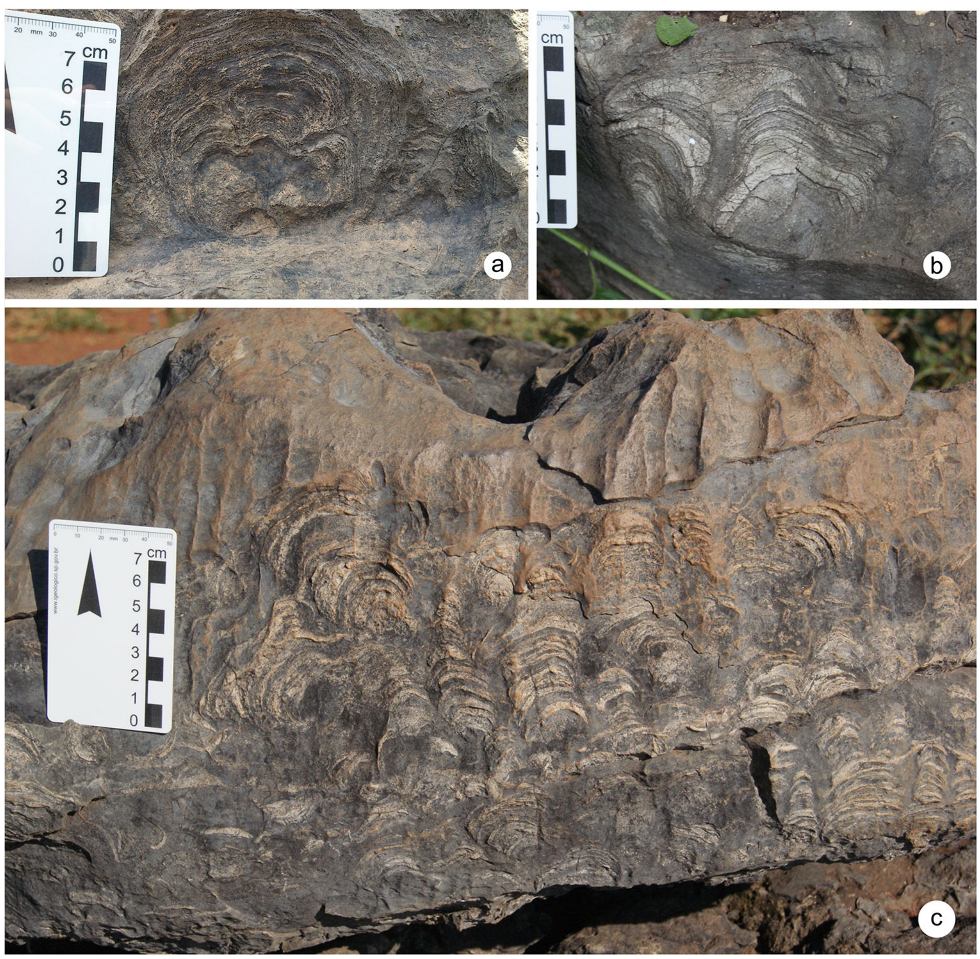

Fig. 3 Different lamina shapes of stromatolites at Arcos-Pains-Doresópolis Karst, in lateral view, their profiles can be steeply convex (**a**), rhomboidal (**b**), or gently convex (**c**)

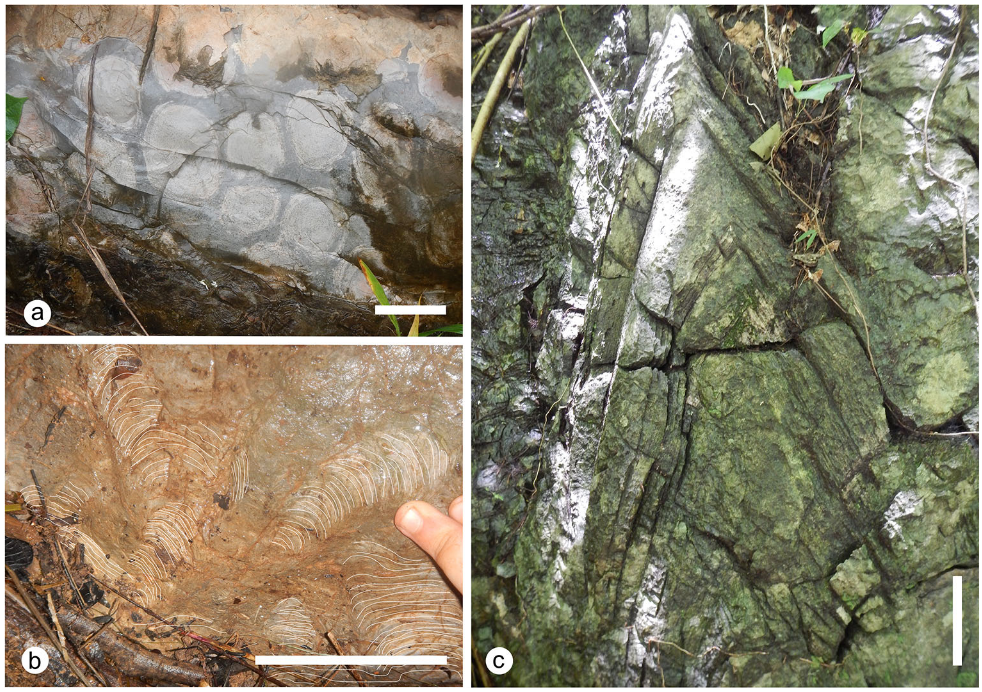

Fig. 4 Stromatolite outcrops at Vazante-Paracatu-Unaí Karst: **a** multifurcate branching style (view in cross section), **b** recumbent attitude, and **c** conical shape. Scale bar 10 cm

stromatolites (Fig. 4) are recorded as *Baicalia* and *Conophyton metula* Kirichenko (Dardenne, 2005) in the Lagamar Formation; *Conophyton cylindricum* Maslov (Dardenne and Walde, 1979, Dardenne, 2005; Campos Neto 1984) in the Poço Verde and Morro do Calcário Formations; and *Conophyton cylindricum* and *C. metulum* in the Morro do Calcário Formation (Moeri 1972; Cloud and Dardenne 1973). In addition to those, oncolites and algal mats also have been noticed (Nogueira and Dardenne 1992; Dardenne 2009; Dardenne et al. 2009).

Description of the Caves and Stromatolites

Arcos-Pains-Doresópolis Karst

The *Teto Estromatolítico* cave is located in a blind valley in the Arcos-Pains-Doresópolis Karst. The cave is ca. 49-m long and located at an altitude of 860 m. It is divided into two main chambers, and the height of the passages varies from 40 to 450 cm. Stromatolites are only found in the first chamber, and they compose most of the ceiling, as well as on a small part of the cave eastern wall (Fig. 5). In the ceiling, they are exposed in elliptical cross section, and their diameters vary from 10 to 20 cm. Most of the stromatolite columns are preserved in high relief (Fig. 6a). The light gray limestone matrix supporting the stromatolites is homogeneous. Longitudinal displays of stromatolites on the cave wall are not well preserved, hindering detailed descriptions (Fig. 6b).

Where columns are vertically exposed, they are connected at the base and branched at the top, reaching a maximum height of 15 cm (Fig. 6b) in the samples studied for this paper. The lowest parts of the columns are straight, but the upper ones are recumbent/prostrate (i.e., angle of < 45° with the base line). The columns are contiguous, nearly contacting each other. The laminae are gently convex, with only one order of curvature, i.e., a simple curve. At the edge of the structure, the laminae are inflected, not covering the underlying ones. The lamina stacking is moderately regular and asymmetrical. No alternation of columnar and stratiform parts or microscopic irregularities, ramifications and lateral projections have been observed.

Another chamber deep within the cave bears carbonatic structures of inorganic origin consisting of concentric circles. Because of their close resemblance to stromatolites, they are known as pseudo-stromatolites (Awramik and Grey, 2005; for detail see below, Fig. 14).

Vazante-Paracatu-Unaí Karst

The *Vazante-Paracatu-Unaí* Karst has been subject to paleontological studies since the 1970s. Outcrops with stromatolites and other structures of microbial origin were recognized in various localities, including the caves described in the present study (Moeri 1972; Dardenne 2009; Dardenne et al. 2009; Vasconcelos and Bittencourt, 2018). A recent speleological study of the area (Souza et al., 2018) identified 181 caves in the Vazante-Paracatu-Unaí Karst, most of which situated at the bases of isolated residual massifs covered with dry forest vegetation and surrounded by pastureland. More specifically, the five caves that have stromatolites are, on average, 330 m long and located at altitudes ranging from 500 to 840 m.

All the visited caves (namely *Gruta da Fendinha*, VT-004, VT-047, VT-051, and VT-197) have preserved *Conophyton*-

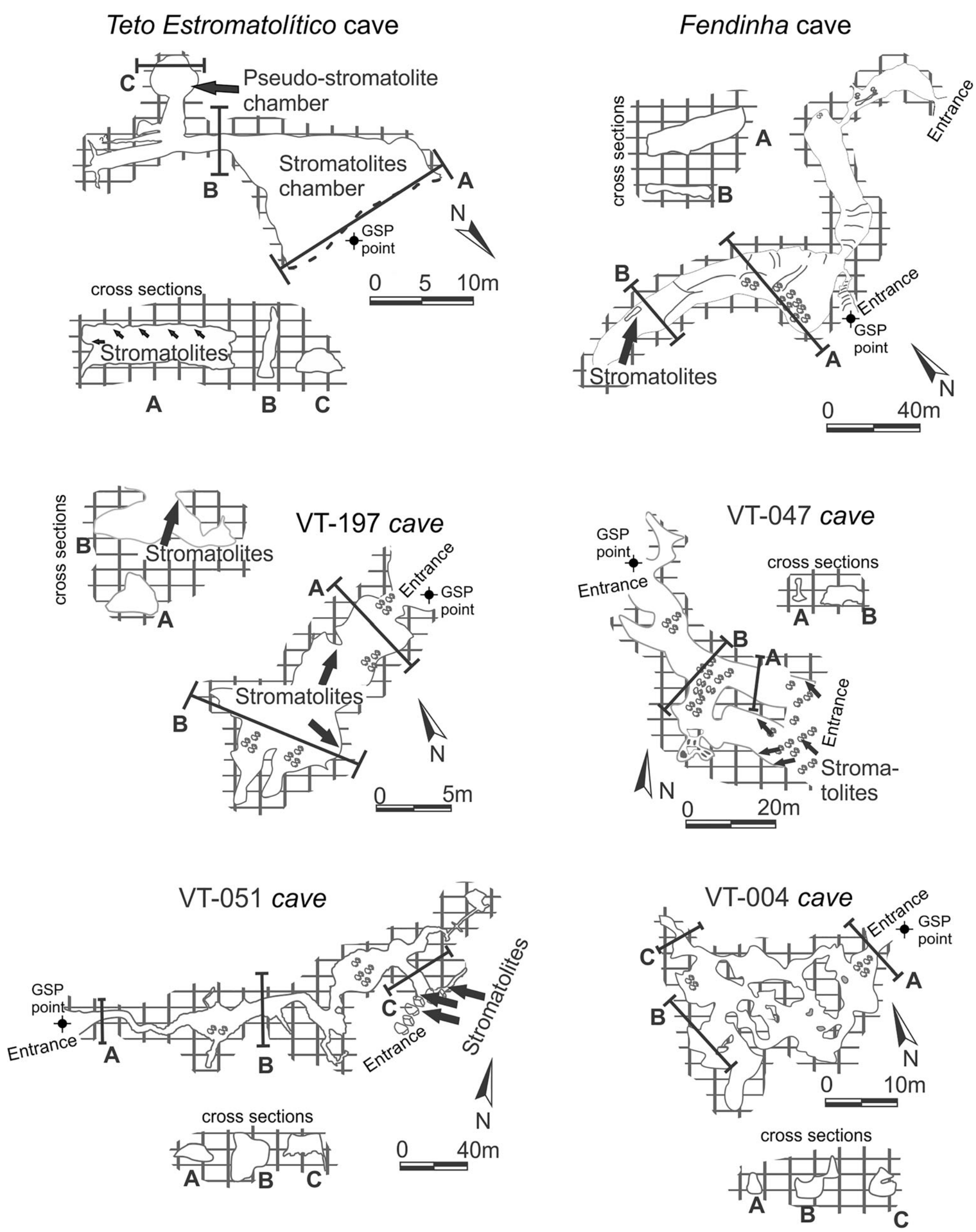

Fig. 5 Cave maps with stromatolite and pseudofossil locations indicated by arrows. Source: *Carste Ciência e Meio Ambiente* database (modified)

type stromatolites, presenting a variety of sizes, colors, textures and states of conservation (Figs. 7a–d). They occur on cave walls, ceilings and fallen blocks. In VT-004 and VT-197, the stromatolites are widespread within the cavities, albeit in varying densities, whereas in VT-047, VT-051, and *Gruta da Fendinha*, they occurrence are more restricted. The stromatolites and their bearing rocks are colored with varied shades of gray, but in VT-004 and VT-047, the sedimentary matrices are respectively beige and reddish (Figs. 7a-d).

VT-004

The VT-004 cave, located at an altitude of 601 m, extends horizontally for 220 m (Souza et al., 2018). Its morphological pattern is reticulate (Fig. 5) and its passageways vary from 100 to 330 cm high.

The stromatolites in cave VT-004 are well preserved and most of them are exposed in cross section, many of them in high relief (Figs. 8a–c). Some of these are associated with cupules in the ceiling (Fig. 9, see also Auler and Souza 2018), a feature not observed in the remaining studied caves. The surface of the limestone is weathered, and as a result the stromatolites are fragile. Some stromatolite columns are exposed in lateral view at the cave entrance. Those are 90 cm high, with rectilinear growth axis, conical form, and smooth walls (Fig. 8c). Its laminar form is angular with just a single curve. The arrangement of the laminae along the column axis is symmetrical. The laminae inflect intensely, each of them covering the preceding one considerably.

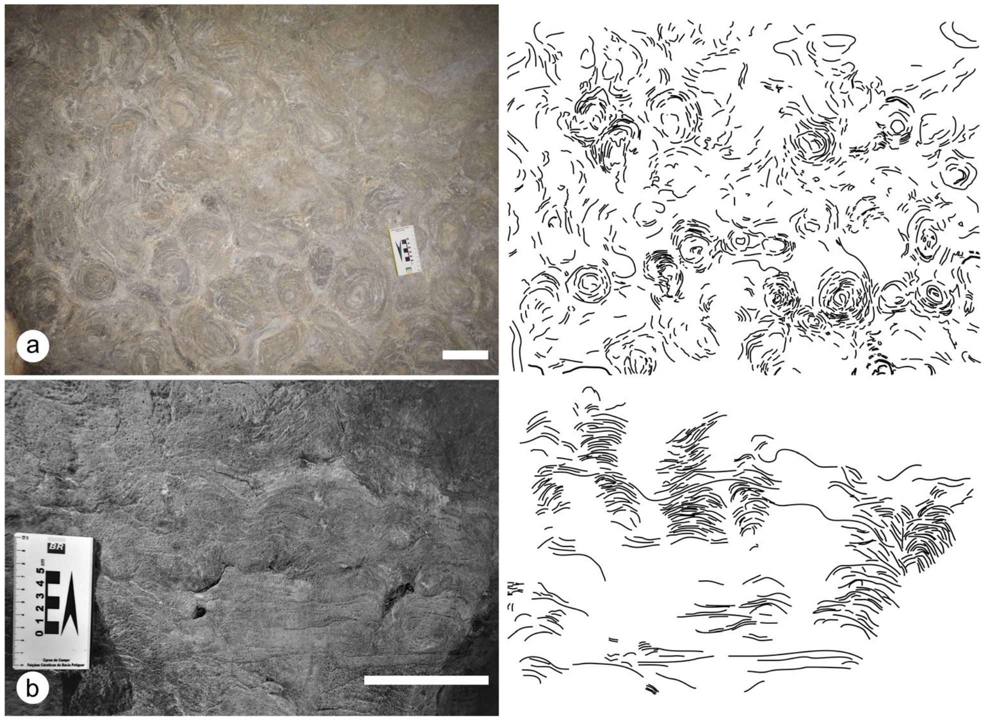

Fig. 6 Stromatolite columns are preserved in high relief on the *Teto Estromatolítico* cave celling (**a**) and on its eastern wall (**b**). Scale bar 10 cm

No branching columns, lateral projections or microscopic irregularities occur within the laminae.

In cross section, the columns are ellipsoid. The average length of the stromatolite columns is 65 cm. These structures are very close together, and some of them are in contact (Fig. 8b).

VT-047

Cave VT-047 has a rectilinear and reticulate layout (Fig. 5) extending horizontally for about 380 m, and it is situated at an altitude of 712 m (Souza et al., 2018). Some of its passages are over 6-m high. The stromatolites in this cave are well

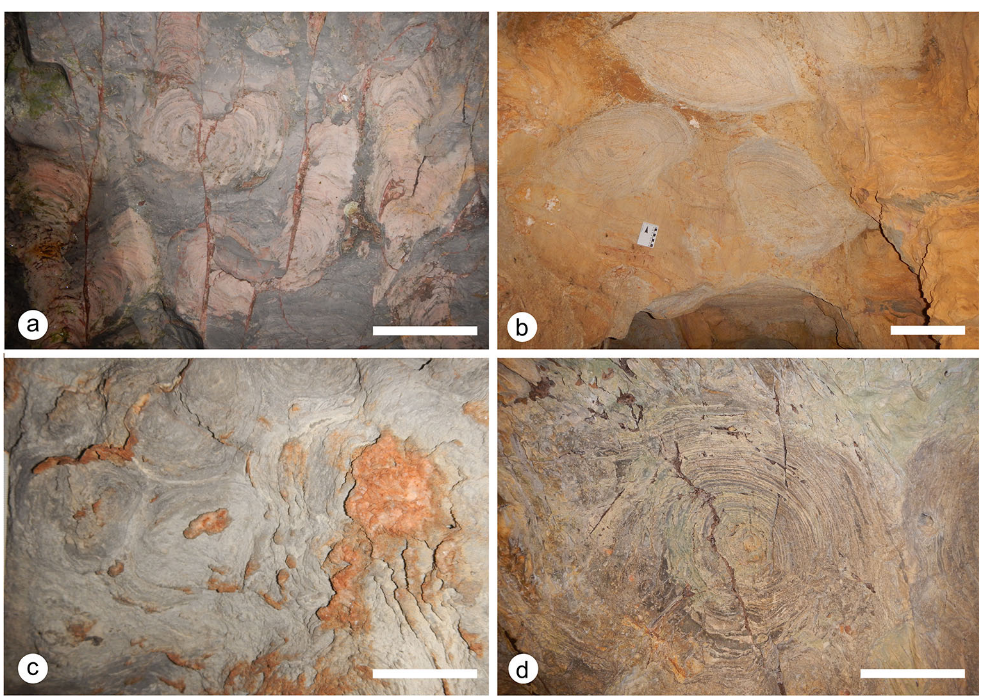

Fig. 7 *Conophyton* stromatolites inside the VT-047 (**a**), VT-004 (**b**), *Gruta da Fendinha* (**c**), and VT-197 (**d**) caves. Scale bar 3 cm (**a**, **c**), ~ 25 cm (**b**), 20 cm (**d**)

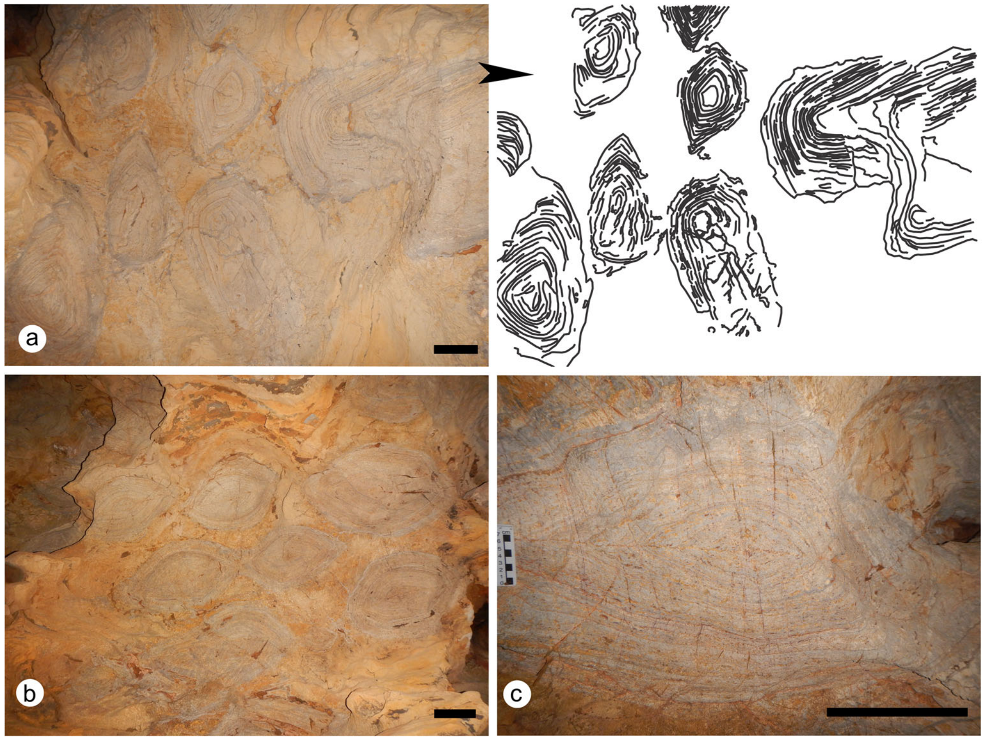

Fig. 8 The stromatolites in cave VT-004 are well preserved and most of them are in plan view and in high relief. Scale bar 20 cm

preserved. Some of them are exposed in high relief, whereas others are highly polished due to the action of water (Figs. 10a, b). The stromatolite colors are variable, with pinkish or light gray laminae. In both cases, the carbonate matrix is dark gray (Figs. 10a, b). The stromatolite columns vary from 6 to 15 cm in diameter, reaching 100 cm tall.

The stromatolites have cylindrical, sinuous, or recumbent columns. The laminae are tall and symmetrical, inflecting at their edges, partially covering the ones beneath them. As in VT-004, there are no branching columns, bundles, lateral projections or microscopic irregularities within the laminae.

The columns are close to each other, some of them connected by outgrowth bridges (Fig. 10b). The columns are branched and also thicker immediately below the point where the branches diverge at angles of less than 20°. The edges of the columns are smooth and do not present a laminated covering. In cross section, the morphology of the columns varies as round, elliptical or oblong with rounded edges. Slightly undulating gray-colored microbial mats were also observed. Apparently, they form the bases for the stromatolite columns.

VT-051

The morphology of the VT-051 cave is rectilinear with a horizontal extension of 660 m. It is located at an altitude of 694 m (Souza et al., 2018). Its passages can be as high as 8 m. Stromatolites only occur in a small part of this cave, and they are preserved in high relief. The columns are pinkish within a dark gray carbonate rock matrix. The stromatolite columns are 10 cm in diameter, but their height, as well as the lamination morphology, cannot be assessed due to poor preservation (Fig. 11a). The columns are cylindrical, with rectilinear growth and not in contact with each other (Fig. 11b).

In the best preserved structures, no branching columns, bundles, lateral projections, or microscopic irregularities within the laminae are seen. The edges of the columns are smooth, and there is no lamination of the column cover. In cross section, the columns are rounded. Some domes of microbial mats can be seen in lateral aspect within the VT-051 cave.

VT-197

The VT-197 cave consists of a large chamber minimally 5-m high and with a horizontal extension of ca. 34 m. It is located at an altitude of 598 m (Souza et al., 2018). The stromatolites are well preserved in high relief and show a similar light gray color as the surrounding carbonate rock (Figs. 12a–c). The stromatolite columns are around 25 cm in diameter and minimally 50-cm high. The partial exposition of the columns hampers the exact assessments of their dimensions (Fig. 12a). The stromatolites are cylindrical in shape with a rectilinear growth pattern. The laminae are cone-shaped, maintaining the symmetry throughout the stack. They inflect at the edge, each lamina partially covering the one beneath it. There are no bundles, lateral projections, or microscopic irregularities within the laminae.

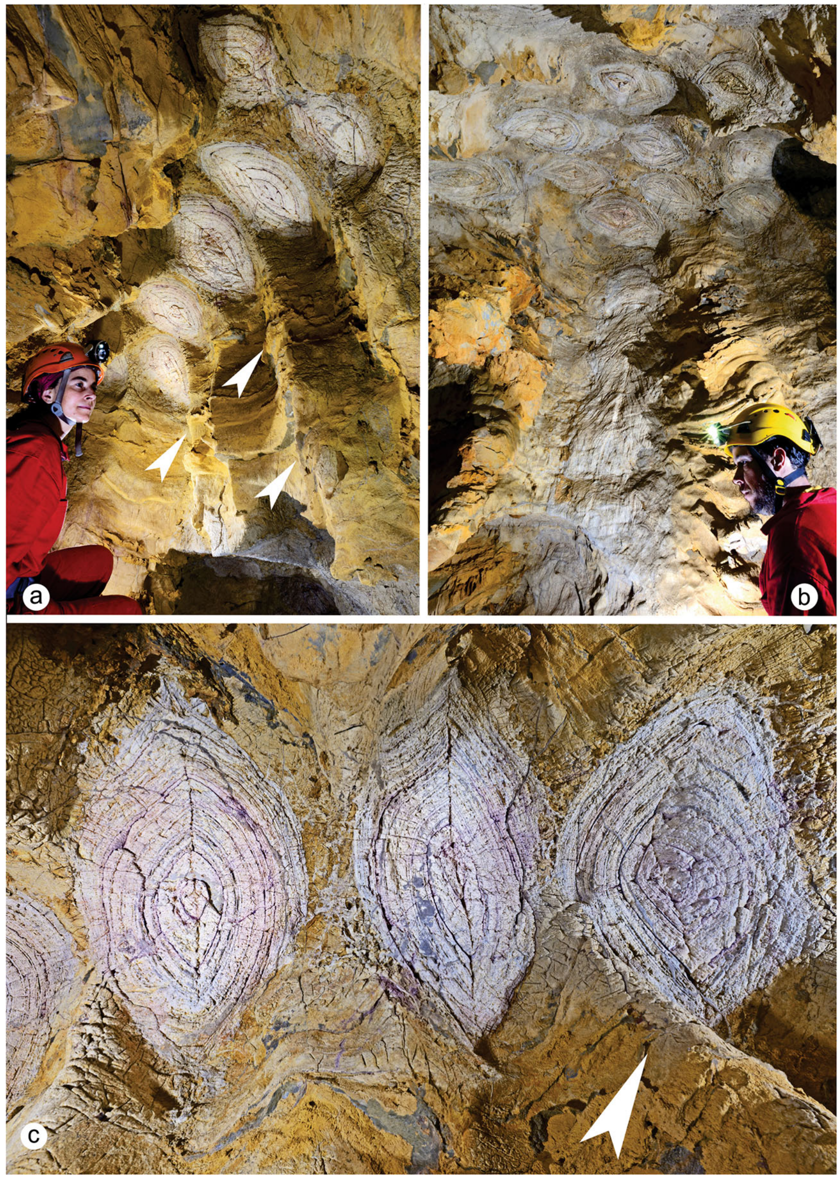

Fig. 9 Stromatolites cupules in the ceiling of VT-004 cave. The arrows indicate the walls that divide the domes. Photos: L. Alt and V. Moura (2018)

The stromatolites appear as clusters of columns. Within clusters, the columns are close to each other, or even in contact. Across groups, they are well separated. The edges of the columns are smooth, and there is no lamination of the column cover. In cross section, the columns are rounded (Figs. 12a, c). In this cave, many stromatolites are covered by speleothems (e.g., coraloids; Fig. 12c).

Gruta da Fendinha

The *Gruta da Fendinha* cave is located at the base of an isolated massif in the municipality of Unaí. The cave extends horizontally for ca. 390 m, and it is situated at an altitude of 812 m (Souza et al., 2018). Its layout is rectilinear and the height of its conducts varies from 40 cm to ca. 600 cm. Here, the stromatolites are well-preserved and exposed in high relief (Fig. 13). The columns and laminae are whitish, against the light gray background of the surrounding the carbonate matrix, in which milimetric intraclasts occur. The cylindrical stromatolite columns are approximately 10 cm in diameter and over 30 cm high, with sinuous and recumbent growth axis (Fig. 13).

The laminae are conical and disposed symmetrically along the column axis. They inflect at the edges, each one partially covering the preceding lamina. Columns are close together and commonly contact each other. The columns may bifurcate or multifurcate, with small divergence of the branches, not widening prior to the branching. There are no lateral projections of the columns or microscopic irregularities within the laminae. The edges of the columns are rounded, varying from round to lanceolate in cross section (Fig. 13).

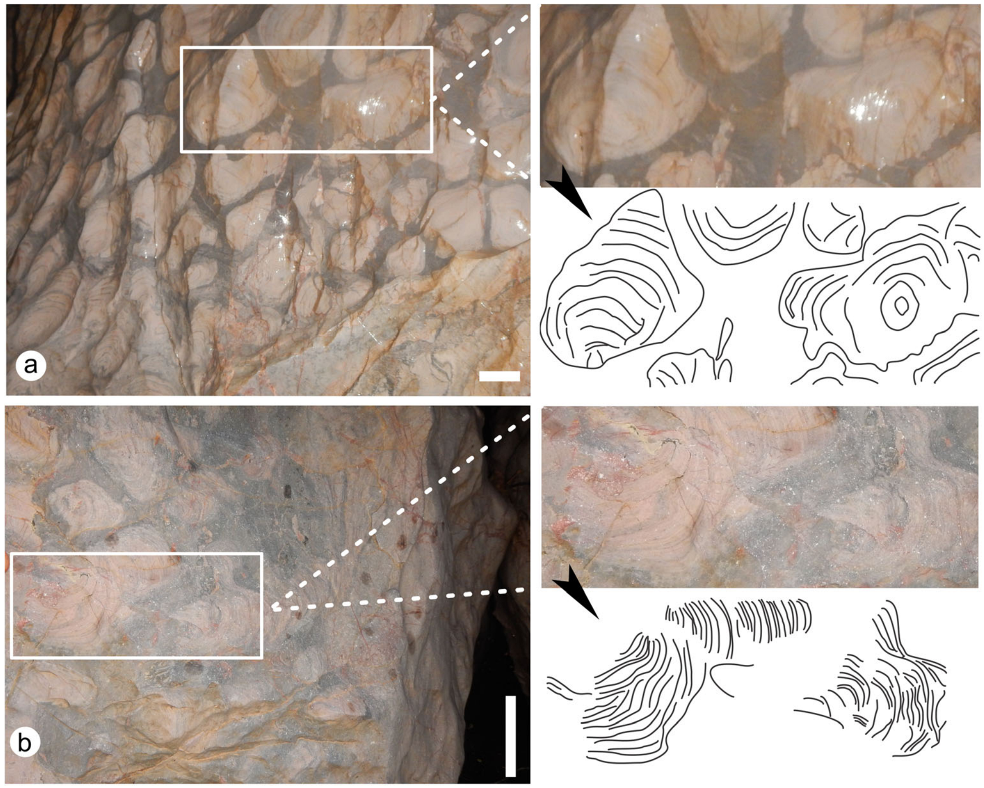

Fig. 10 Stromatolites in VT-047 cave are well preserved and most of them are highly polished due to the action of water. Scale bar 20 cm

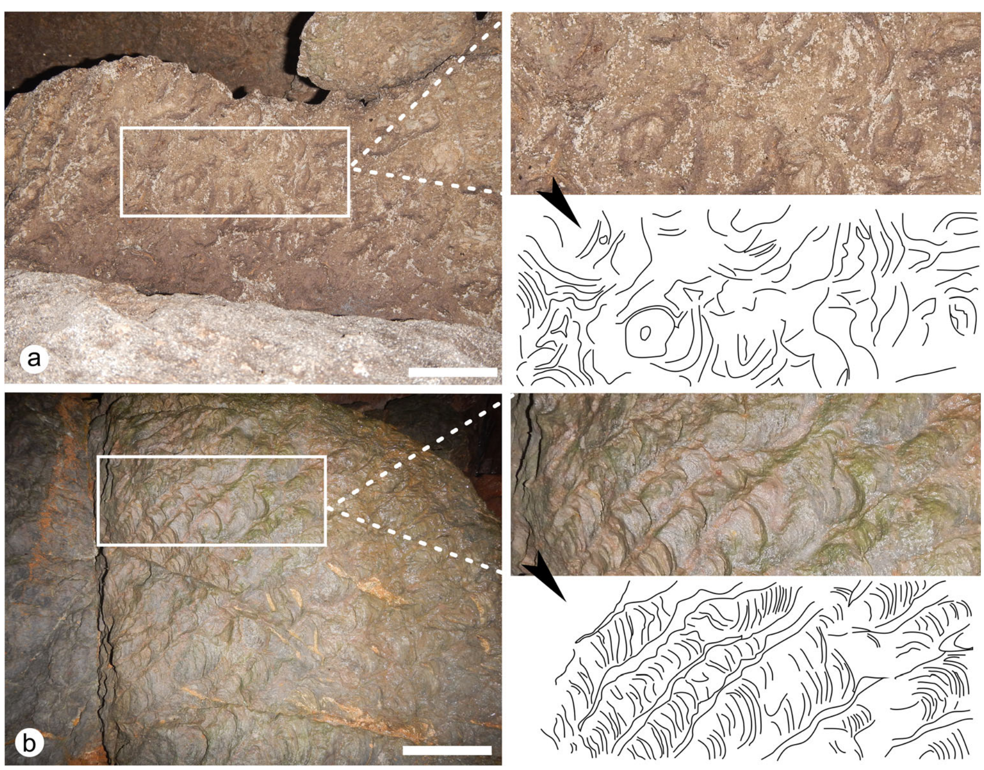

Fig. 11 Stromatolites in VT-051 cave. They occur in a limited portion of the cave, embedded on a dark gray carbonate rock matrix. Scale bar 2.5 cm

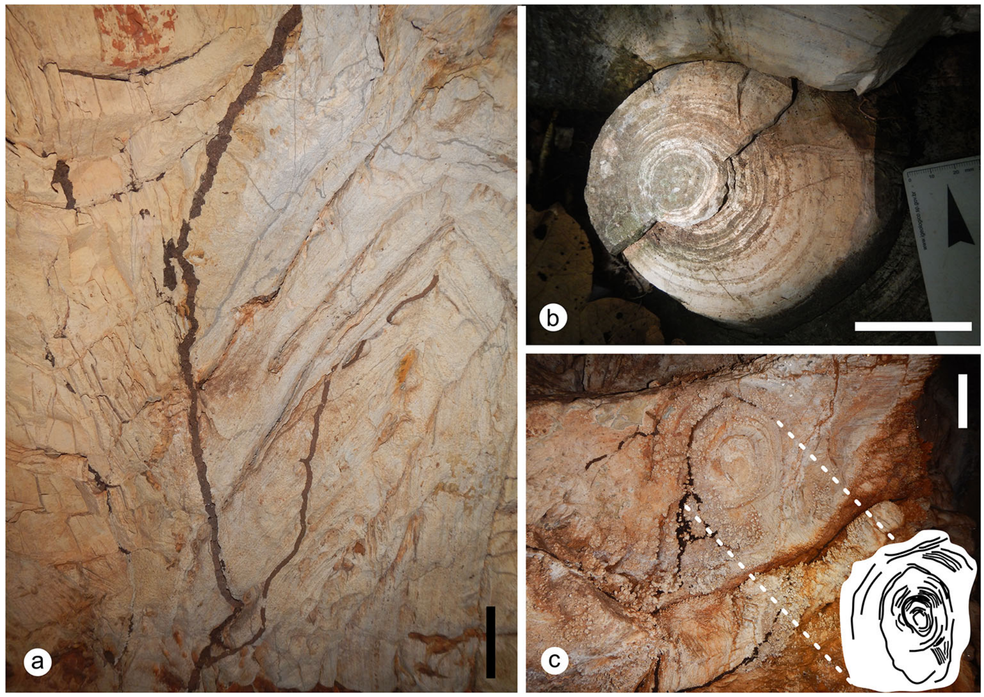

Fig. 12 The well-preserved stromatolites in VT-197 cave are preserved in high relief (**a**–**c**) and many of them are covered by coraloids (**c**). Scale bar ~ 10 cm (**a** and **c**) and 50 mm (**b**)

Pseudofossils

Pseudofossils are inorganic structures or traces that can easily be mistaken for real fossils (Awramik and Grey, 2005). In both studied areas, such structures are found in the caves. Two processes produced them: chemical precipitations on gravels (Fig. 14a, b) or weathering of chemical covers (Fig. 14c, d).

In the second chamber of the *Teto Estromatolítico* cave (Arcos-Pains-Doresópolis Karst), speleothems formed by the precipitation of carbonates around a gravel core occur as concentrically laminated structures, roughly similar to stromatolites in cross section. Yet, differences among these structures and stromatolites are conspicuous: the speleothems are highly variable and irregular in size and shape, do not bear not true columnar laminae, and are nucleated by a rock fragment.

In VT-014 and VT-167, there are marks in the flowstone, which are caused by weathering (Figs. 14c, d).

Structures resembling stromatolites have also been observed in other karstic areas in Brazil such as cave A204 (14° 23′ 12.2″ S 44° 15′ 40.4″ W) in Montalvânia/Juvenilia, municipalities located in the northern part of Minas Gerais state (Vasconcelos 2016).

Other Occurrences

There are approximately 19,300 officially registered caves in Brazil (CECAV, 2019). They are found in all regions of the country and are inserted in a variety of different lithologies including quartzite, arenite, and granite but especially in carbonate rocks and ferriferous contexts (Fig. 15; Auler and Farrant 1996; Rubbioli et al. 2019).

The occurrence of stromatolites, however, is more restricted, and they have only been registered in carbonate rock formations. They occur most commonly in Brazil's central and southern regions including the São Francisco Craton, the Brasília Belt, and the Paraná Basin (Fig. 15). However, there are some

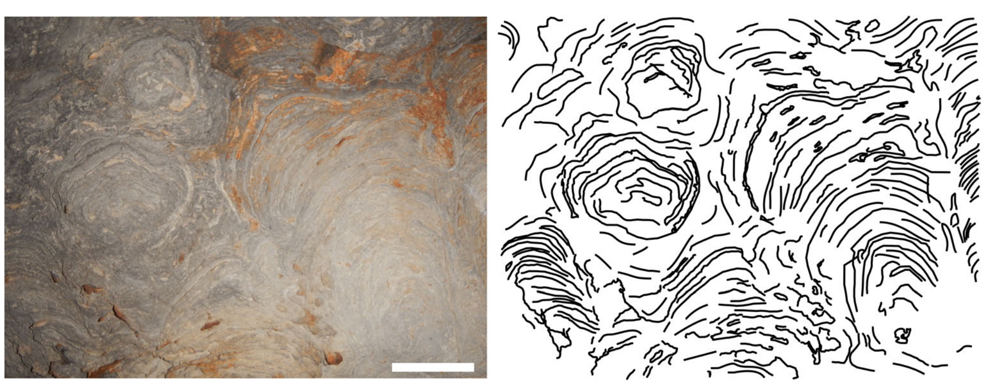

Fig. 13 Stromatolites in profile view into *Gruta da Fendinha* cave. Scale bar 4 cm

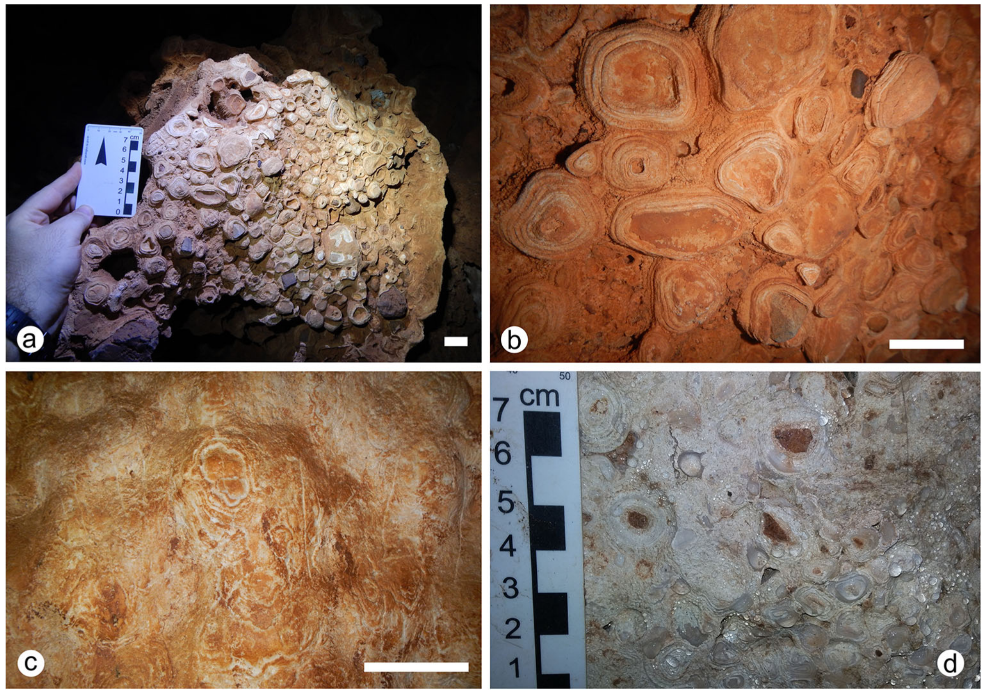

Fig. 14 Pseudo-fossils preserved inside the *Teto Estromatolítico* cave (**a** and **b**) and the VT-167 cave. Scale 2 cm (**a**, **b**) and 10 cm (**c**)

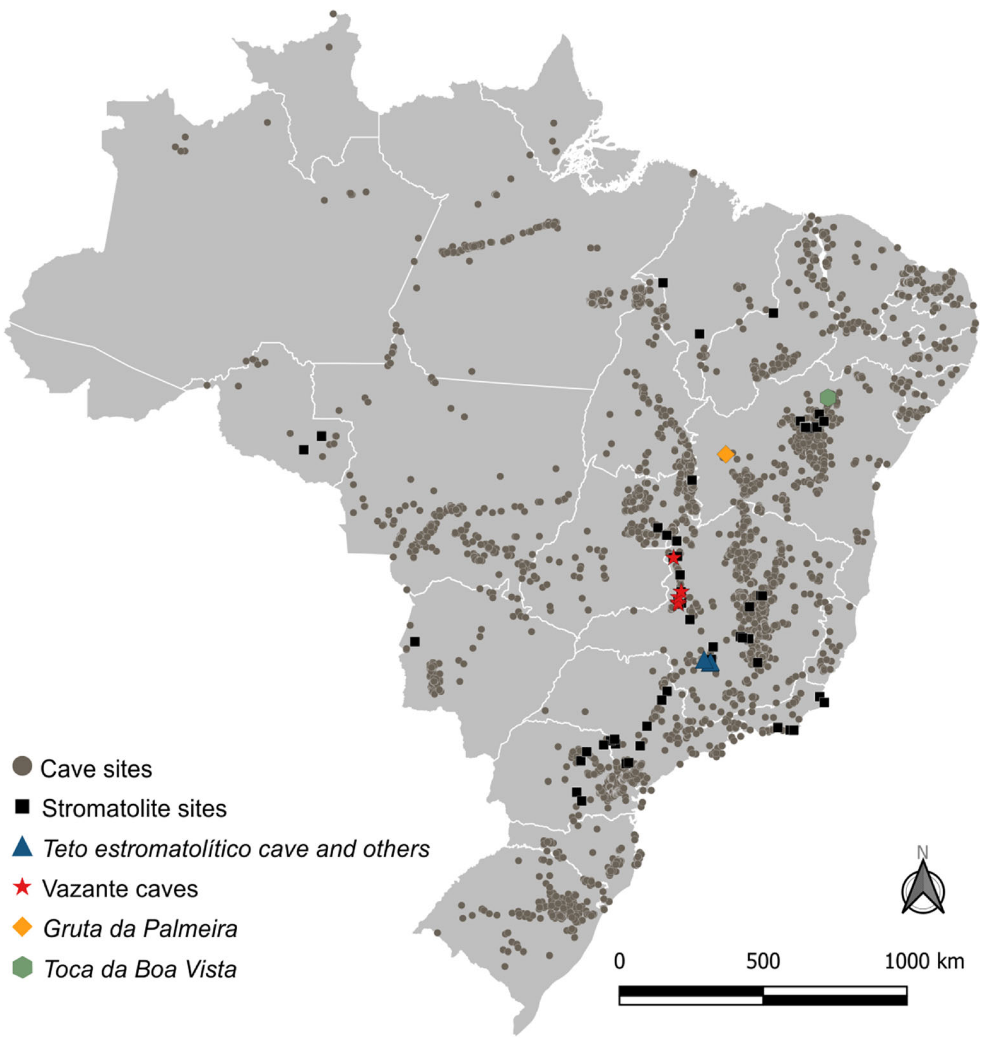

Fig. 15 Cave distribution and stromatolite locations in Brazil. Based on Fairchild and Sanchez (2015), CECAV (2019), and Vasconcelos and Bittencourt (2018)

scattered occurrences in the northern and northeastern regions of the country (for a review, see Fairchild and Sanchez 2015).

Stromatolites in surface outcrops are frequently easy to locate when they occur in cuttings for highways, stone quarries, or natural rock outcrops (Cloud and Moeri 1973; Marchese 1974; Nogueira and Dardenne 1992; Lopes 1995; Srivastava and Rocha 2002a, b; Sallun Filho and Fairchild, 2005; Fraga et al. 2013). Although there are caves in the same regions where such occurrences of stromatolites have been identified, there are very few reports associating those occurrences to caves (e.g., Reis et al. 2019). In addition to the caves presented here, there are reports of stromatolites in caves in the São Desidério and Campo Formoso regions, both in the state of Bahia (Klimchouk et al. 2016; Cazarin et al. 2019). In the database of the CECAV (2019), there are records of stromatolites in caves near to the *Teto Estromatolítico* cave, but they have not been formally described (Table 2, Fig. 15). Also, the existence of five additional caves with the presence of stromatolites has been reported for Coromandel region (Reis et al. 2019) and the Vazante-Paracatu-Unaí Karst (Auler and Souza 2018).

Cave and Stromatolite Protection in Brazil

The different degrees of protection rendered to caves vary across countries (for a review see Auler et al. 2017). In some countries of Europe and North America, different measures are taken to protect caves from vandalism and degradation, including the creation of protected areas (see, for example, US Congress 1988; British Columbia 1994, 2003; Slovenia 2003; Williams 2008; Lipps 2009; Skrbinšek 2009; Cigna and Forti 2013; Maggio et al., 2012; FSE 2013). Brazil has specific laws to address the protection of caves (Brasil, 2008; MMA 2017). These laws have been designed to ensure the conservation of caves which contain significant physical (e.g., size) or biological (e.g., rare species) features. Accordingly, once a series of studies is undertaken, a cave may be classified in one out of four levels of significance: maximum, high, medium, or low (Brasil 2008; for a review see Auler and Piló 2015; Auler et al. 2017; Ribeiro et al. 2019).

The presence of fossils in a cave enhances its significance and helps to support its conservation. Yet, the only fossils mentioned in the Brazilian legislation for cave protection are those inserted in caves after their formation, including here the remains of Quaternary mammals. There is no mention to biogenic structures that were formed simultaneously in the rocks where the cave developed (Minas Gerais 2005; Brasil 2008; MMA 2017). The conservation of caves would benefit from and update of the Brazilian legislation, as to enforce more meticulous prospection for fossils and their collecting. Also, there should be more detailed criteria to evaluate the fossil occurrences, including those native to the cave bedrock (e.g., microbialites), rather than simple “presence or absence of fossils”. However, for those other parameters to

Table 2 Caves with records of preserved stromatolites embedded in the host rock in Brazil

Cave	Coordinates	Area	Reference
Gruta da Palmeira	12° 22′ 50.77″ S and 44° 57′ 51.23″ W	São Desidério—BA	This study
Toca da Boa Vista	10° 9′ 37.69″ S and 40° 51′ 40.25″ W	Campo Formoso—BA	Klimchouk et al., (2016), Cazarin et al., (2019)
Caverna do Estromatólito	20° 22′ 42.89″ S and 45° 34′ 30.71″ W	Arcos—MG	CECAV (2019)
Gruta Estromatolítica	20° 24′ 17.15″ S and 45° 35′ 56.57″ W	Pains—MG	CECAV (2019)
Gruta do Brega	20° 25′ 4.20″ S and 45° 46′ 20.14″ W	Pains—MG	CECAV (2019)
Rede de Estromatólitos	20° 17′ 23.24″ S and 45° 50′ 11.14″ W	Doresópolis—MG	CECAV (2019)
VT-006 Cave	17° 43′ 34.40″ S and 46° 45′ 31.16″ W	Vazante - MG	Auler et al. (2018)
VT-007 Cave	18° 11′ 59.99″ S and 46° 51′ 38.85″ W	Vazante—MG	Auler et al. (2018)
VT-014 Cave	17° 46′ 9.46″ S and 46° 43′ 35.04″ W	Vazante—MG	Auler et al. (2018)
VT-188 Cave	18° 4′ 52.06″ S and 46° 56′ 13.38″ W	Vazante—MG	Auler et al. (2018)
VT-195 Cave	18° 2′ 12.33″ S and 46° 55′ 50.96″ W	Vazante—MG	Auler et al. (2018)
Ronan I Cave	18° 22′ 58.58″ S and 47° 9′ 49.80″ W	Coromandel—MG	CECAV (2019), Reis et al. 2019

be analyzed and described correctly in technical reports, they must be included in the Brazilian legislation and mentioned as a criterion for evaluating paleontological potential. Thus, the Brazilian laws and norms should be updated. All features of paleontological interest should be clearly included in any official document concerning cave value assessment (i.e., laws, norms, instructions), including the fossils preserved in the docking rocks.

Those legal documents should also contain the a standard methodology to be used by professionals in the efforts of characterizing and evaluating caves and their fossil content. If this does not occur, it is risky that caves that have only these types of fossils are not properly protected or are still destroyed due to the development of anthropic activities.

In this case, the rarity of stromatolites within caves would automatically render maximal protection, which would also be supported by their obvious scientific, touristic, and esthetic value (Table 3; Minas Gerais 2005; MMA 2017). In other instances where organic remains entered the cave and eventually fossilized, the quality of the preservation should also be a criteria for assessing the cave value, rather than just the abovementioned "presence or absence of fossil".

Geoconservation of Caves in Brazil

Many areas in Brazil have a rich geological heritage due to their geomorphological, paleoclimatic, historical, geological, or speleological importance. Currently, there are many endeavors in progress to foster the creation of conservation areas based on geological features. Specially one of those, the publications of the Brazilian Committee for Geological and Paleontological Sites (SIGEP, which stands for *Sítios Geológicos e Paleontológicos*; see Schobbenhaus et al. 2002; Winge et al. 2009, 2013), is worth mentioning. Among the candidates assessed by SIGEP for geoconservation, the proposals number 9 and 37 refer to caves and paleontological sites, respectively, and other six candidates concern stromatolites (Schobbenhaus et al. 2002; Srivastava 2002, Srivastava and Rocha, 2002a, b; Boggiani et al. 2009; Dardenne 2005, 2009; Winge et al. 2009, 2013). However, only one SIGEP proposal refers specifically to the creation of a geopark in an area of cave development (the Lago Azul cave, in the state of Mato Grosso do Sul; Boggiani et al. 2009).

Reported alterations to cave environments in Brazil, other than natural weathering, include littering, vandalism of speleothems, graffiti, and soil removal or alteration (Auler and Smart 2002; Berbert-Born 2002; Berbert-Born and Karmann 2002; Cajaiba 2014; Auler 2016). The major threat to the *Teto Estromatolítico* cave, for instance, is the explosions carried out by a nearby (ca. 200 m) quarry, which could easily lead to the total or partial collapse of the cave. Another threat is uncontrolled visitation, which is revealed by the presence of litter, the compacting of the soil and the depredation of the cave features (Fig. 16). In caves in the Vazante-Paracatu-Unaí Karst, the original vegetation has been removed and the land converted into pastures, indicating anthropic activity close to the cave localities.

Potential for Visitation and Management of Caves

The caves in the Arcos-Pains-Dorésópolis Karst, as is common in karstic areas in Brazil, are visited for different purposes, including technical and scientific studies, sportive speleology (restrict to speleological organizations) and religious practice (e.g., Gruta do Santuário cave). No cavity there is open to mass-tourist activities. In the Vazante-Paracatu-Unaí Karst, one cave is open for visitation (Lapa Nova II), and several of them are used for religious practice (Lapa Velha and Gruta Lagoa Rica; Alt and Moura 2018).

Among the caves described here, VT051, VT-047, and Fendinha are attractive for public visitation, due to amount and variability of speleothem, clastic deposits, and stromatolites. The other cavities (Teto Estromatolítico, VT-004, VT-

Table 3 Possible criteria to determine cave importance that could be applied to stromatolites in caves in keeping with the Brazilian legislation (Brasil 2008; MMA 2017)

Criterion	Explanation/description
Scientific and/or teaching importance; educational use; Geological structures of scientific interest	Stromatolites in caves can be used to paleoenvironmental interpretation and stratigraphic correlation. In the case of the cave studied herein, the stromatolites is also useful for educational purposes.
Scenic beauty; esthetic and scenic values; scenic value; public visitation	In most cases, the beauty of caves is associated with speleothems. Stromatolites can improve the scenic aspect of the caves. In such cases, if a cave is identified for non-suppression, the owner of the property (or government) should implement a management plan that could include the cave as a tourist attraction
Unique morphology (cave VT-004)	Stromatolites associated with the formation of ceiling cupules.

Fig. 16 Environmental damage observed in the *Teto Estromatolítico* cave. **a** Presence of litter, feces, and compacting of the soil. **b** and **c** rock surface flaking off due to weathering

047, and VT-197) are attractive to a more specific public, including scientists, educators, technical people, and sportive speleology practitioners (Table 4). VT-004 is especially relevant here, due to the occurrence narrow passages and stromatolitic cupules. Educational visiting could use the stromatolite occurrences within caves to approach scientific themes as the origin of life, Precambrian oxygenation event, paleogeography, and plate tectonics (e.g., Klein et al. 1987; Kusky and Vanyo 1991; Bosak et al. 2013; Schirrmeister et al. 2015).

Yet, opening those caves to public visitation should rely on previous preparation, encompassing minimally improvements to accessibility and safety, with construction of roads or trails leading to caves, cave floor leveling, and installation of stairs, platforms, and artificial illumination. A visitation plan could be created in order to select the most relevant points for visitation of the caves, isolating the areas not suitable for it. It would be of public interest to involve the local people in such implementation. They could be employed in the tourism infrastructure, including the management of cave visitation (e.g., Cigna 2011, 2016; Okonkwo et al. 2017; Leung et al. 2018).

On the other hand, all the caves mentioned here are located in private land and are not part of legal conservation areas. These are the greatest obstacles for implementing public visitation, mainly due to the high costs of the preparations mentioned above and maintenance. In addition to accessibility and safety improvements, tourism activities should also rely on a management plan including studies for impact evaluation, technical preparation of the staff, divulging, maintenance, and conservation. In general, tourist activities are not economically attractive to land owners. One possible solution could be provided by governmental funding, but unfortunately, it is scarce in Brazil (Alt and Moura 2018).

Table 4 Features with tourist, educational, and scientific potential of caves

Cave	Tourism		Features
	Diversified	Educational/ scientific	
Teto Estromatolítico		x	Stromatolites and pseudofossils
VT-004		x	Stromatolite cupules, morphologically varied conducts
VT-047	x	x	Speleothems, wide chambers, clastic deposits, underground river
VT051	x	x	Speleothems, wide chambers, clastic deposits, two (lower and upper) levels
VT-197		x	Stromatolites
Gruta da Fendinha	x	x	Speleothems, stromatolites, wide chambers, clastic deposits

Final Considerations

We described six caves that have stromatolites (*Conophyton*) on their ceilings, walls, and collapsed blocks. All of them are located in the state of Minas Gerais, one in the Arcos-Pains-Doresópolis Karst and the other five in the Vazante-Paracatu-Unaí Karst. The stromatolites are in good state of preservation and well exposed in both lateral view and cross section.

Caves with fossils preserved in their bedrock are suitable candidates for geoconservation, in close alignment with the Brazilian legislation. Given the rarity of that association in Brazil, it is recommended that caves with fossils embedded in their bedrocks receive the status of maximum importance that would ensure their permanent protection with the support of the respective public environmental entities.

Despite some obstacles concerning its implementation, we conclude that some of the caves described herein (e.g., *Teto Estromatolítico*, VT-197, and *Gruta da Fendinha*) can be used for controlled public visitation, if executed with adequate physical infrastructure and management plan. This would serve the purpose of geoconservation, assuring the continuation of the scientific research and cultural practices, ultimately improving the life quality of the local population.

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References

Alkmim FF, Martins-Neto MA (2001) A Bacia Intracratônica do São Francisco: Arcabouço estrutural e cenários evolutivos. In: Pinto CP, Martins-Neto MA (eds) Bacia do São Francisco. Geologia e Recursos Naturais. Sociedade Brasileira de Geologia/Núcleo de Minas Gerais, Belo Horizonte, pp 9–30

Almeida FFM (1944) *Collenia itapevensis* sp n: um fóssil pré-cambriano do estado de São Paulo. Bol. Fac Filos Cienc Letras Univ São Paulo Geologia 01:89–106

Alt LR, Moura V (2018) Áreas Prioritárias Para Conservação do Patrimônio Espeleológico, Arqueológico e Paleontológico: Principais Desafios e Recomendações. In: Souza TAR, Auler AS (eds) O Carste de Vazante-Paracatu-Unaí: Revelando Importâncias, Recomendando Refúgios. Carste Ciência e Meio Ambiente, Belo Horizonte, pp 238–271

Auler AS (2016) Cave protection as a karst conservation tool in the environmentally sensitive Lagoa Santa karst, Southeast Brazil. Act Carsolog 45(01):131–145. https://doi.org/10.3986/ac.v45i2.4429

Auler AS, Farrant AR (1996) A brief introduction to karst and caves in Brazil. Proc Univ Bristol Spelaeol Soc 20(03):187–200

Auler AS, Piló LB (2015) Caves and mining in Brazil: the dilemma of cave preservation within a mining context. In: Andreo B, Carrasco F, Durán JJ, Jiménez P, Lamoreaux JW (eds) Hydrogeological and environmental investigations in karst systems, 1rd edn. Springer, Heildelberg, pp 487–496

Auler AS, Smart PL (2002) Toca da Boa Vista, Campo Formoso, BA: a maior caverna do hemisfério sul. In: Schobbenhaus C, Campos DA, Queiroz ET, Winge M, Berbert-Born M (eds) Sítios geológicos e paleontológicos do Brasil. CPRM, Brasília, pp 443–452

Auler AS, Souza TAR (2018) Gênese de cavernas no Grupo Vazante. In: Auler A, Souza T (eds) O Carste de Vazante-Paracatu-Unaí: Revelando Importâncias. Recomendando Refúgios. Carste Ciência e Meio Ambiente, Belo Horizonte, pp 149–175

Auler AS, Souza TAR, Sé DC, Soares GA (2017) A review and statistical assessment of the criteria for determining cave significance. Geol Soc Sp Pub 466:443–459. https://doi.org/10.1144/SP466.8

Awramik SM, Grey K (2005) In: Hoover RB, Levin GV, Rozanov AY, Gladstone GR (eds) presented at the Optics & Photonics san Diego, CaliforniaStromatolites: biogenicity, biosignatures, and bioconfusion, vol 5906, pp 59060P1–59060P2. https://doi.org/10.1117/12.625556

Barton HA, Northup DE (2007) Geomicrobiology in cave environments: past, current and future perspectives. J Cave Karst Stud 69(01):163–178 10.1.1.546.5834

Baskar S, Baskar R, Kaushik A (2007) Evidences for microbial involvement in the genesis of speleothem carbonates, Borra Caves, Visakhapatnam, India. Curr Sci 92(03):350–355

Baskar S, Routh J, Baskar R, Kumar A, Miettinen H, Itävaara M (2016) Evidences for microbial precipitation of calcite in speleothems from Krem Syndai in Jaintia Hills, Meghalaya, India. Geomicrobiol J 33: 906–933. https://doi.org/10.1080/01490451.2015.1127447

Berbert-Born M (2002) Carste de Lagoa Santa: berço da paleontologia e da espeleologia brasileira. In: Schobbenhaus C, Campos DA, Queiroz ET, Winge M, Berbert-Born M (eds) Sítios Geológicos e Paleontológicos do Brasil (SIGEP), vol 01. CPRM, Brasília, pp 415–430

Berbert-Born M, Karmann I (2002) Lapa dos Brejões: Vereda Romão Gramacho, Chapada Diamantina, BA: gigantesca caverna e vale cárstico com rico depósito de fósseis do Quaternário. In: Schobbenhaus C, Campos DA, Queiroz ET, Winge M, Berbert-Born M (eds) Sítios geológicos e paleontológicos do Brasil. CPRM, Brasília, pp 469–479

Bittencourt JS, Kuchenbecker M, Vasconcelos AG, Meyer KEB (2015) O registro fóssil das coberturas sedimentares do Cráton do São Francisco em Minas Gerais. Geonomos 23:39–62 https://10.18285/geonomos.v23i2.710

Boggiani PC, Sallun Filho W, Karmann I, Gesicki ALD, Philadelphi, NM, Philadelphi M (2009) Gruta do Lago Azul, Bonito, MS: onde a luz do sol se torna azul. In: Schobbenhaus C, Campos DA, Queiroz ET, Winge M, Berbert-Born M (eds) Sítios geológicos e paleontológicos do Brasil. CPRM, Brasília, pp 57–68

Bontognali TRR, D'Angeli IM, Tisato N, Vasconcelos C, Bernasconi SM, Gonzales ERG, De Waele J (2016) Mushroom speleothems: stromatolites that formed in the absence of phototrophs. Front Earth Sci 4:49. https://doi.org/10.3389/feart.2016.00049

Bosak T, Knoll AH, Petroff AP (2013) The meaning of stromatolites. Ann Rev Earth and Planetary Sciences 41:21–44

Braithwaite CJR, Whitton BA (1987) Gypsum and halite associated with the cyanobacterium Entophysalis. Geomicrobiol J 05(01):43–55. https://doi.org/10.1080/01490458709385956

Brasil (2008) Decreto Federal 6.640. Presidência da República. http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2008/Decreto/D6640.htm. Accessed 15 September 2017

British Columbia Ministry of Forests (1994) Cave/karst management handbook for the Vancouver forest region. In: cave management guidebook. Prov BC, Victoria, BC 13:1–11

British Columbia Ministry of Forests (2003) Karst management handbook for British Columbia. For BC Min For, Victoria, BC. https://www.for.gov.bc.ca/hfp/publications/00189/Karst-Mgmt-Handbook-web.pdf. Accessed 30 August 2019

Cacchio P, Contento R, Ercole C, Cappuccio G, Martinez ML, Lepidi A (2004) Involvement of microorganisms in the formation of carbonate speleothems in the Cervo Cave, L'Aquila-Italy. Geomicrobiol J 21:497–509. https://doi.org/10.1080/01490450490888109

Cajaiba RL (2014) Diagnóstico dos impactos ambientais causados por ações antrópicas em cavernas no município de Uruará, PA. Rev Meio Amb Sustentab 06(03):490–507

Campos Neto MC (1984) Litoestratigrafia, relações estratigráficas e evolução paleogeográfica dos Grupos Canastra e Paranoá (região de Vazante-Lagamar, MG). Rev Bras Geoc 14(2):81–91

Cañaveras JC, Cuezva S, Sanchez-Moral S, Lario J, Laiz L, Gonzalez JM, Saiz-Jimenez C (2006) On the origin of fiber calcite crystals in moonmilk deposits. Naturwis 293(1):27–32. https://doi.org/10.1007/s00114-005-0052-3

Cazarin CL, Bezerra FHR, Borghi L, Santos RV, Favoreto J, Brod JA, Auler AS, Srivastava NK (2019) The conduit-seal system of hypogene karst in neoproterozoic carbonates in northeastern Brazil. Mar Pet Geol 101:90–107. https://doi.org/10.1016/j.marpetgeo.2018.11.046

CECAV (2019) Cadastro Nacional de Informações Espeleológicas. CANIE, ICMBIO

Cigna A (2011) Show cave development with special references to active caves. Tour Karst Areas 4:7–16

Cigna A (2016) Tourism and show caves. Zeits für Geomorp 60(Supplem Issues):217–233. https://doi.org/10.1127/zfg_suppl/2016/00305

Cigna AA, Forti P (2013) Caves: the most important geotouristic feature in the world. Tour Karst Ar 6(1):9–26

Cloud P, Dardenne MA (1973) Proterozoic age of the Bambuí group in Brazil. Geol Soc Am Bull 84:673–1676. https://doi.org/10.1130/0016-7606(1973)84<1673:PAOTBG>2.0.CO;2

Cloud P, Moeri E (1973) Conophyton in the Bambuí Group: What form and age? Geol 01(3):127. https://doi.org/10.1130/0091-7613(1973)1<127:CITBGW>2.0.CO;2

Cox G, James JM, Amstrong RAL, Leggett KEA (1989b) Stromatolitic crayfish-like stalagmites. Proc Univ Bristol Spelaeol Soc 18(03):339–358

Cox G, James JM, Leggett KEA, Amstrong RAL (1989a) Cyanobacterially deposited speleothems: subaerial stromatolites. Geomicrobiol J 07(04):245–252. https://doi.org/10.1080/01490458909377870

CPRM-CODEMIG (2014) Mapa Geológico do Estado de Minas Gerais. CPRM/CODEMIG. Available at < http://www.portalgeologia.com.br>

Dardenne MA (1972) Os recifes algais da região de Vazante (Minas Gerais, Brasil). In: SBG (ed.), Boletim de Resumos do 26° Congresso Brasileiro de Geologia, Belém, SBG, pp 247–248

Dardenne MA (1978) Síntese sobre a estratigrafia do Grupo Bambuí no Brasil Central. In: SBG (ed.), Boletim de Resumos do 30° Congresso Brasileiro de Geologia, Recife, pp 597–610

Dardenne MA (2005) Conophytons de Cabeludo, Grupo Vazante, MG - Construções dolomíticas por cianobactérias no Proterozóico. In: Winge M, Schobbenhaus C, Berbert-Born M, Queiroz ET, Campos DA, Souza CRG, Fernandes ACS (eds) Sítios geológicos e paleontológicos do Brasil. CPRM, Brasília, pp 303–310

Dardenne MA (2009) Conophyton de Cabeludo, Grupo Vazante, MG: construções dolomíticas por cianobactérias no Proterozóico. In: Winge M, Schobbenhaus C, Berbert-Born M, Queiroz ET, Campos DA, Souza CRG, Fernandes ACS (eds) Sítios geológicos e paleontológicos do Brasil. CPRM, Brasília, pp 303–310

Dardenne MA, Campos JEG, Campos Neto M (2009) Estromatólitos Colunares no Sumidouro do Córrego Carrapato, Lagamar, MG. In: Winge M, Schobbenhaus C, Souza CRG, Fernandes ACS, Berbert-Born M, Queiroz ET, Campos DA (eds) Sítios geológicos e paleontológicos do Brasil. CPRM, Brasília, pp 311–320

Dardenne MA, Campos Neto M (1975) Ocorrência de Estromatólitos colunares na Série Minas (MG). Rev Bras Geoc 3(3):160–180

Dardenne MA, Walde DHG (1979) A estratigrafia dos Grupos Bambuí e Macaúbas no Brasil Central. In: SBG (ed.), Atas do l° Simpósio de Geologia de Minas Gerais, SBG, Diamantina, pp 43–53

DuChene HR (2000) Bedrock features of Lechuguilla Cave, Guadalupe Mountains, New Mexico. J Cave Karst Stud 62(2):109–119

Fairchild TR, Rohn R, Dardenne MA, Alvarenga CJ, Guimarães EM (2015) Microbialitos dos Grupos Paranoá (Mesoproterozoico) e Vazante (Neoproterozoico), Distrito Federal, Goiás e Minas Gerais. In: Fairchild TR, Rohn R, Dimas-Brito D (eds) Microbialitos do Brasil do Pré-cambriano ao Recente: um Atlas, 1rd edn. UNESP-IGCE-UNESPetro, São Paulo, pp 90–151

Fairchild TR, Sanchez EAM (2015) Microbialitos no Brasil: panorâmica de ocorrências e guia de caracterização morfológica. In: Fairchild TR, Rohn R, Dimas-Brito D (eds) Microbialitos do Brasil do Pré-cambriano ao Recente: um Atlas, 1rd edn. UNESP-IGCE-UNESPetro, São Paulo, pp 22–41

Fraga LMS, Neves SC, Pires GLP, Tibães A, Uhlein A (2013) Estromatólitos colunares na base do Grupo Macaúbas, nordeste da Serra do Espinhaço, MG: paleontologia e ambiente de sedimentação. Geonomos 21(01):34–43. https://doi.org/10.18285/geonomos.v21i1.254

FSE (2013) European Speleological Federation. All Rights Reserved. ISSN 1817-0684http://www.eurospeleo.eu/en/?option=com_content&view=article&id=15&Itemid=22. Acessed 15 June 2018

Gillieson DS (1996) Caves, processes, development, management. Blackwell publishers, Malden

Gomes NANC (1985) Modern stromatolites in a karst structure from the Malmani subgroup, Transvaal sequence, South Africa. Trans Geol Soc S Afr 88:01–09

Gradzinski M, Banas M, Uchman A (1995) Biogenic origin of manganese flowstones from Jaskinia Czarna Cave, Tatra Mts., Western Carpathians. Ann Soc Geol Pol 65:19–27

Guimarães SB, Reis Neto JM, Siqueira RBL (2002) Caracterização dos estromatólitos da Formação Capiru (Proterozoico) nas regiões de Morro Azul e Morro Grande. Bol Paran Geoc 51:77–88

Hasui Y (2012) O Cráton São Francisco. In: Hasui Y, Carneiro CDR, Almeida FFM, Bartorelli A (eds) Geologia do Brasil. Ed Beca, São Paulo, pp 200–227

Healy PF (2007) The anthropology of mesoamerican caves. In: Brady JE, Keith MP (eds) In the Maw of the Earth Monster: mesoamerican ritual cave use, Rev Anthrop, vol 36, pp 245–278

Hofmann HJ (1973) Stromatolites: characteristics and utility. Earth-Sci Rev 09:339–373. https://doi.org/10.1016/0012-8252(73)90002-0

Jass CN, George CO (2010) An assessment of the contribution of fossil cave deposits to the quaternary paleontological record. Quat Int 217:105–116. https://doi.org/10.1016/j.quaint.2009.11.008

Jones B (2001) Microbial activity in cave: a geological perspective. Geomicrobiol J 18:345–357. https://doi.org/10.1080/01490450152467831

Klein C, Beukes NJ, Schopf JW (1987) Filamentous microfossils in the early proterozoic transvaal supergroup: their morphology, significance, and paleoenvironmental setting. Precambrian Res 36:81–94. https://doi.org/10.1016/0301-9268(87)90018-0

Klimchouk A, Auler AS, Bezerra FHR, Cazarin CL, Balsamo F, Dublyansky Y (2016) Hypogenic origin, geologic controls and functional organization of a giant cave system in Precambrian carbonates, Brazil. Geomorp (Amst) 253:385–405. https://doi.org/10.1016/j.geomorph.2015.11.002

Kusky TM, Vanyo JP (1991) Plate reconstructions using stromatolite heliotropism: principles and applications. J Geol 99:321–335

Leung Y-F, Spenceley A, Hvenegaard G, Buckley R (2018) Tourism and visitor management in protected areas: guidelines for sustainability. International Union for Conservation of Nature, Switzerland

Leveille RJ, Fyfe WS, Longstaffe FJ (2000) Geomicrobiology of carbonate-silicate microbialites from Hawaiian basaltic sea caves. Chem Geol 169:339–355. https://doi.org/10.1016/S0009-2541(00)00213-8

Leveille RJ, Fyfe WS, Longstaffe FJ (2002) Kerolite in carbonate-rich speleothems and microbial deposits from basaltic caves, Kauai, Hawaii. Clays Clay Min 50(04):514–524. https://doi.org/10.1346/000986002320514235

Lipps JH (2009) PaleoParks: our paleontological heritage protected and conserved in the field worldwide. In: Lipps JH, Granier BRC (eds) PaleoParks: the protection and conservation of fossil sites worldwide, vol 03(01). Carnets Géo/Noteb Geo, Brest, pp 01–10

Lopes JN (1995) Faciologia e gênese dos carbonatos do Grupo Bambuí na região de Arcos, estado de Minas Gerais. Universidade de São Paulo, Dissertation

Lozano RP, Rossi C (2012) Exceptional preservation of Mn-oxidizing microbes in cave stromatolites, El Soplao, Spain. Sediment Geol 255-256:42–55. https://doi.org/10.1016/j.sedgeo.2012.02.003

Maggio CD, Madonia G, Parise M, Vattano M (2012) Karst of Sicily and its conservation. J Cave Karst Stud 74(02):157–172. https://doi.org/10.4311/2011JCKS0209

Marchese HG (1974) Estromatolitos "gymnosolenidos" en el lado oriental de Minas Gerais, Brasil. Rev Bras Geoc 04:257–271

Melin LA, Shinglman KM, Boston PJ (2001) Evidence for microbial involvement in pool finger precipitation, hidden cave, New Mexico. Geomicrobiol J 18(03):311–329. https://doi.org/10.1080/01490450152467813

Minas Gerais (2005) Fundação Estadual do Meio Ambiente: Termo de referência para elaboração de estudos de impacto ambiental para atividades minerárias em áreas cársticas no estado de Minas Gerais, 28 pp

MMA (2017) Instrução Normativa N. 2. Ministério do Meio Ambiente, <http://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/19272154>. Accessed 13 February 2018

Moeri E (1972) On a columnar stromatolite in the Precambrian Bambui Group of Central Brazil. Eclogae Geol Helv 65:185–195

Moyes H (1998) The cave as a cosmogram: function and meaning of Maya speleothem use. In: Colas PR, Delvendahl K, Kuhnert M, Schubart A (eds.), the sacred and the profane architecture and identity in the Maya lowlands, 3rd edn. Eur Maya Conf Univ Hamburg. Acta Mesoam 10:137–148

Nogueira GMS, Dardenne MA (1992) Caracterização dos dolomitos biohermais estromatolíticos da Região de Lagamar. In: SBG (ed.), Boletim de Resumos do 37° Congresso Brasileiro de Geologia, SBG, São Paulo, pp 70–71

Northup DE, Dahm CN, Melim LA, Spilde MN, Crossey LJ, Lavoie KH, Mallory LM, Boston PJ, Cunningham KI, Barns SM (2000) Evidence for geomicrobiological interactions in Guadalupe caves. J Cave Karst Studies 62(2):80–90

Okonkwo EE, Afoma E, Martha I (2017) Cave tourism and its implications to tourism development in Nigeria: a case study of Agu-Owuru cave in Ezeagu. Int J Res Tour Hosp 3(3):16–24. https://doi.org/10.20431/2455-0043.0303003

Reis PVM, Rodrigues RR, Ferreira AC, Ibrahim L, Quaglio F (2019) Classificação do grau de dificuldade da Gruta Ronan I, Coromandel, MG. In: Zampaulo RA (ed) Boletim de resumos do Congresso brasileiro de espeleologia. SBE, Bonito, pp 214–216

Ribeiro A, Paciullo FVP, Senra AS, Valeriano CM, Trouw RAJ (2008) Nota explicativa da Folha Piumhi (SF.23-V-B-II), Minas Gerais. UFRJ/CPRM, Rio de Janeiro

Ribeiro AA, Reino JCR, Cruz JB (2019) Histórico e fundamentação legal. In Cruz JB Piló LB (2019)

Ribera C, Elverici M, Kunt KB, Özkütük RS (2014) Typhlonesticus gocmeni sp n, a new cave-dwelling blind spider species from the Aegean region of Turkey (Araneae, Nesticidae). ZooKeys 419:87–102. https://doi.org/10.3897/zookeys.419.5739

Rubbioli EL, Auler AS, Menin D, Brandi R (2019) Cavernas. Atlas do Brasil Subterrâneo, 1rd edn. IABS, Brasília

Sallun Filho W, Fairchild TR (2004) Os estromatólitos do Grupo Itaiacoca ao sul de Itapeva, São Paulo. Rev Bras Paleo 7(3):359–370

Sallun Filho W, Fairchild TR (2005) Estudo comparativo entre estromatólitos do tipo *Conophyton* das faixas Ribeira e Brasília. Rev Inst Geo 26:1–18

Santucci VL, Kenworthy J, Kerbo R (2001) An inventory of paleontological resources associated with national park service caves. U.S. depart Int, Nat Park Serv, GRD technical report NPS/NRGRD/GRDTR-01/02 (NPS publication D-2231)

Schirrmeister BE, Gugger M, Donoghue PCJ (2015) Cyanobacteria and the great oxidation event: evidence from genes and fossils. Palaeontology 58:769–785. https://doi.org/10.1111/pala.12178

Schobbenhaus C, Campos DA, Queiroz ET, Winge M, Berbert-Born M (2002) Sítios geológicos e paleontológicos do Brasil. CPRM, Brasília

Schopfa JW, Kudryavtsevb AB, Czajac AD, Tripathic AB (2007) Evidence of Archean life: stromatolites and microfossils. Precambrian Res 158(2007):141–155. https://doi.org/10.1016/j.precamres.2007.04.009

Shinzato E (1998) O carste da área de proteção ambiental de Lagoa Santa (MG) e sua influência na formação dos solos. Dissertation, Universidade Estadual do Norte Fluminense

Sial A, Dardenne MA, Misi A, Pedreira A, Ferreira VP, Silva Filho MA, Uhlein A, Pedrosa-Soares AC, Santos RV, Egydio-Silva M, Babinski M, Alvarenga CJ, Pimentel MM (2009) The São Francisco Paleocontinent. In: Gaucher C, Sial A, Halverson G, Frimmel H (eds) Neoproterozoic-Cambrian tectonics, global change and evolution: a focus on outhwestern Gondwana. Elsevier, London, pp 31–69

Skrbinšek AM (2009) Report on the implementation of the Bern Convention in Sloveni: convention on the conservation of European wildlife and natural habitats, 29th meeting. T-PVS Inf (14):01–21

Souza TAR, Franca L, Auler AS (2018) O Carste - Importância e Fragilidade. In: Souza TAR, Auler AS (eds) O Carste de Vazante-Paracatu-Unaí: Revelando Importâncias. Recomendando Refúgios. Carste Ciência e Meio Ambiente, Belo Horizonte, pp 19–43

Srivastava NK (1982) Algumas observações sobre os estromatólitos dos Grupos Una (Bahia) e Vaza Barris (Sergipe), Nordeste do Brasil. Ciên Terra 03:07–11

Srivastava NK (2002) Lagoa Salgada, RJ - Estromatólitos recentes. In: Schobbenhaus C, Campos DA, Queiroz ET, Winge M, Berbert-Born M (eds) Sítios geológicos e paleontológicos do Brasil. CPRM, Brasília, pp 203–209

Srivastava NK, Rocha AJD (2002a) Fazenda Arrecife (Bahia): Estromatólitos Neoproterozóicos. In: Schobbenhaus C, Campos DA, Queiroz ET, Winge M, Bebert-Born M (eds) Sítios geológicos e paleontológicos do Brasil. CPRM, Brasília, pp 95–100

Srivastava NK, Rocha AJD (2002b) Fazenda Cristal (Bahia): Estromatólitos Mesoproterozoícos. In: Schobbenhaus C, Campos DA, Queiroz ET, Winge M, Bebert-Born M (eds.), Sítios geológicos e paleontológicos do Brasil, CPRM, Brasília, pp 95–10087-94

Stephens M, Hodge S, Paquette J (2013) Geoconservation of Volivoli Cave, Fiji: a prehistoric heritage site of national significance. Geoherit 05:123–136. https://doi.org/10.1007/s12371-013-0075-7

Uhlein GJ, Uhlein A, Stevenson R, Halverson GP, Caxito FA, Cox G (2017) Early to late Ediacaran conglomeratic wedges from a complete foreland basin cycle in the southwest São Francisco Craton, Bambuí Group, Brazil. Precam Res 299:101–116

United States Congress (1988) Federal Cave Resources Protection Act 1988 (FCRPA) 16 U.S.C. 4301– 4310

Vasconcelos AG (2016) Levantamento do Potencial Paleontológico das Cavidades Inseridas no Município de Montalvânia, Minas Gerais. Relatório técnico. 66p

Vasconcelos AG, Bittencourt J (2018) Desenterrando a vida do passado. Potencial paleontológico em cavernas. In: Souza TAR, Auler AS (eds) O Carste de Vazante-Paracatu-Unaí: Revelando Importâncias, Recomendando Refúgios. Carste Ciência e Meio Ambiente, Belo Horizonte, pp 215–237

Vasconcelos AG, Eliziario NT, Bittencourt J (2016) Estromatólitos como ferramenta para valoração de cavidades naturais. In: SBP (ed.), Anais do 48° Congresso Brasileiro de Paleontologia, SBP, Porto Alegre, pp 5932

Vieira LC, Almeida RP, Trindade RIF, Nogueira ACR, Janikian L (2007) A Formação Sete Lagoas em sua área-tipo: fácies, estratigrafia e sistemas deposicionais. Rev Bras Geoc 37(4):2–14

Walter MR, Bauld J, Brock TD (1976) Microbiology and morphogenesis of columnar stromatolite (Conophyton, Vaccarella) from Hot Springs in Yellowstone National Park. In: Walter MR (ed) Developments in sedimentology, vol 6.2. Elsevier, Amsterdam, pp 273–310

Williams PW (2008) World heritage caves and karst: a thematic study. World heritage Conv. IUCN Programme on protected areas, WCPA, IUCN, International Union for Conservation of nature, gland https://www.iucn.org/sites/dev/files/import/downloads/cavesandkarstwh.pdf. Accessed 30 August 2019

Winge M, Schobbenhaus C, Souza CRG, Fernandes ACS, Berbert-Born MLC, Queiroz ET, Campos DA (2009) Sítios geológicos e paleontológicos do Brasil. CPRM, Brasília

Winge M, Schobbenhaus C, Souza CRG, Fernandes ACS, Berbert-Born MLC, Sallun Filho W, Queiroz ET (2013) Sítios geológicos e paleontológicos do Brasil. CPRM, Brasília

Zaine MF (1991) Análise dos fósseis de parte da Faixa Paraguai (MS, MT) e seu contexto temporal e paleoambiental. Dissertation, Universidade de São Paulo