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Distribution and Growth Morphology of the Recent Microbialites: the Case of Lagoa Salgada, Rio de Janeiro - Brazil

Distribuição e Morfologia de Crescimento de Microbialitos Recentes: o Caso de Lagoa Salgada, Estado do Rio de Janeiro, Brasil

Douglas Rosa da Silva; Kátia Leite Mansur & Leonardo Fonseca Borghi de Almeida

Universidade Federal do Rio de Janeiro, Instituto de Geociências, Departamento de Geologia, Av. Athos da Silveira Ramos 274, 21941-916, Cidade Universitária, Rio de Janeiro, RJ, Brasil
E-mails: douglasrosageo@gmail.com; katia@geologia.ufrj.br; lborghi@geologia.ufrj.br.
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Abstract

Organosedimentary deposits formed by interaction of carbonate and terrigenous sediments are commonly found in the Lagoa Salgada, a holocenic environment located on the north of Rio de Janeiro state which records environmental and biological information of their evolution. Microbial mats are widespread however stromatolites are very prominent and exposed nowadays in the lagoon. Microbial mats were distinguished into two main morphologies, colloform and polygonal mats. It is interesting to note that the colloform ones are not lithified unlike the polygonal ones. Related to stromatolites three main morphologies were defined and classified based on their external morphology and internal structure. Internal structure was further analyzed by sample cutting and thin section study to confirm field classification. Stromatolites are mostly bioherms dome-like and vary from 10 to 40cm high. Morphologically stromatolites are columnar or branched to columnar and coalescence among them are very common resulting in stratiform morphologies. Stromatolitic domal-like bioherms though showing similar internal structure were separated in small and large according to their size; the differences in size are clearly observed and have different areal distribution, which possibly reflects changes in the lagoon paleogeography during the geological time. Also, the identification of differences in the internal structure of stromatolites allows the formulation of hypothesis supporting environmental changes in the Lagoa Salgada.
Keywords: Stromatolite; Microbial mats; Recent stromatolite

Resumo

Depósitos organosedimentares são formados por interação de sedimentos carbonáticos e terrígenos. Estes são comumente encontrados na Lagoa Salgada, norte do estado do Rio de Janeiro, formada em um ambiente holocênico do qual registra informações sobre a evolução ambiental e biológica. Esteiras microbiais são amplamente observadas na lagoa, bem como estromatólito aflorantes. As esteiras microbiais foram distinguidas em duas morfologias, coloformes e poligonais. É importante ressaltar que as esteiras do tipo coloforme não apresentam litificação, diferentemente das poligonais. Foram caracterizados três tipos de morfologias principais para os estromatólitos, definidas e classificadas em relação a forma externa e estrutura interna. As estruturas internas foram analisadas a partir do corte das amostras e em lâminas delgadas, confirmando as classificações de campo. Em geral os estromatólitos apresentam formas domais, variando de 10 a 40cm de altura. Morfologicamente os estromatólitos apresentam-se como montes estratiformes coalescentes, colunares ou colunares ramificados, resultando em morfologias estratiformes. Os estromatólitos do tipo domal apresentam estrutura interna similar, foram separados em maiores e menores à depender do tamanho de sua estrutura externa; as variações de tamanho são claramente observadas em campo e possuem diferentes áreas de ocorrência, da qual possivelmente são reflexos das modificações decorridas na paleogeografia da lagoa com o passar do tempo. Além disto, a identificação das diferentes estruturas internas estromatolíticas permitem a formulação de hipóteses em relação as variações ambientais na Lagoa Salgada.
Palavras-chave: Estromatólito; Esteiras microbiais; Estromatólitos recentes.

1 Introduction

According to Burne & Moore (1987) organosedimentary deposits formed from interaction between benthic microbial communities and detrital or chemical sediments are named Microbialites. Depending of their inner structure or morphology, microbialites are classified as stromatolites, thrombolites, oncolites, spherulites and cryptic, that can be lithified or not (Burne & Moore, 1987; Riding, 1999). The term stromatolites was proposed by Kalkowsky (1908) meaning layered rocks for lacustrine exemplars of lower Triassic in north of Germany (Riding, 2000).

Hofmann (1973) suggests that stromatolites are known in all continents, including Antarctica, and in all geological ages, dating back the Archean. The holocenic examples are observed mainly in Australia, Gulf of Mexico, Bahamas, Persian Gulf, India and Brazil (Hofmann, 1973; Srivastava, 2002). In Brazil there are two occurrence areas of stromatolites in hypersaline lagoons and swamps on Rio de Janeiro state. They have gained visibility due to possible analogies of their genesis and possible related processes at the formation of pre-salt reservoir of the Brazilian marginal basins (Estrella *et al*., 2009; Mansur *et al*., 2012).

These lagoons and swamps share similarities, such as the quality of water (brackish or hypersaline) and presence of microbialites. The main studies conducted at the regions and the different microbialite deposits observed are listed at Table 1. The Lagoa Salgada (Salty Lagoon), localized at the extreme northeast of Rio de Janeiro state, has stromatolites, microbial mats, thrombolites and oncolites. It has geological and paleontological relevance globally, given the rarity of the bioconstructions (Srivastava, 2002; Silva e Silva *et al*., 2007c; Iespa *et al*., 2012). Stromatolites can be observed in other lagoons (Table 1), in Sistema Lagunar de Araruama (Araruama Lagoon System).

The Lagoa Salgada (Figure 1) is located on the north coast of Rio de Janeiro (41°00’30” W and 21°54’10” S), southeast of Brazil, near the Cabo de São Tomé region, between the counties of Campos dos Goytacazes and São João da Barra (Srivastava,

Lagoons/ Swamps		Microbial mats	Stromatolite	Thrombolite	Oncolite	Authors
Araruama Lagoon System	Pitanguinha	X	X	X	X	Damazio et al. 2005; Damazio-Iespa *et al.* 2007, e 2008;
	Vermelha	X	X		X	Vasconcelos *et al.* 1997; Silva e Silva *et al.* 2004a e 2007c; Alves, 2007; Sampaio *et al.* 2015;
	Pernanbuca	X	X	X	X	Silva e Silva *et al.* 2004b, 2006; Iespa *et al.* 2006
	Brejo do Espinho	X	X			Silva e Silva *et al.* 2007a e 2013; Delfino, 2009; Feder *et al*., 2013; Rocha & Borghi, 2017
	Brejo do Pau Fincado	X				Lopes, 2009; Silva e Silva *et al.* 2007b
Lagoa Salgada		X	X	X	X	Lemos 1996; Srivastava, 2002; Silva e Silva *et al.*, 2007c; Iespa *et al*., 2012; Silva e Silva, 2002; Birgel *et al.*, 2015

Table 1 List of references and microbialites described at the north region of Rio de Janeiro State.

2002). This lagoon is inserted at the coastal plain of the Paraíba do Sul river delta, which corresponds to the emerged portion of Campos Basin (Winter *et al*., 2007). It was formed mainly in the late Holocene marine regression (Martin *et al.,* 1993).

It is a lagoon with approximately six square kilometers, low dissolved oxygen rate and water circulation. Its water is brackish to hypersaline and can be alkaline depending to rainfall index or directly from the anthropic action (Lemos, 1996; Silva e Silva *et al*., 2013). It has had a strong marine influence during its evolution showing it has been an open system with direct link to the open sea until its closing occurred (Iespa *et al*., 2012). Its feeding is possibly aided by advance of the salt wedge or anthropic factors interacting with the nearby Lagoa do Açu (Açu Lagoon). High evaporation makes hypersalinity conditions (Iespa *et al*., 2012; Birgel *et al*., 2015).

Although many workers had already published about this lagoon, still no one has ever

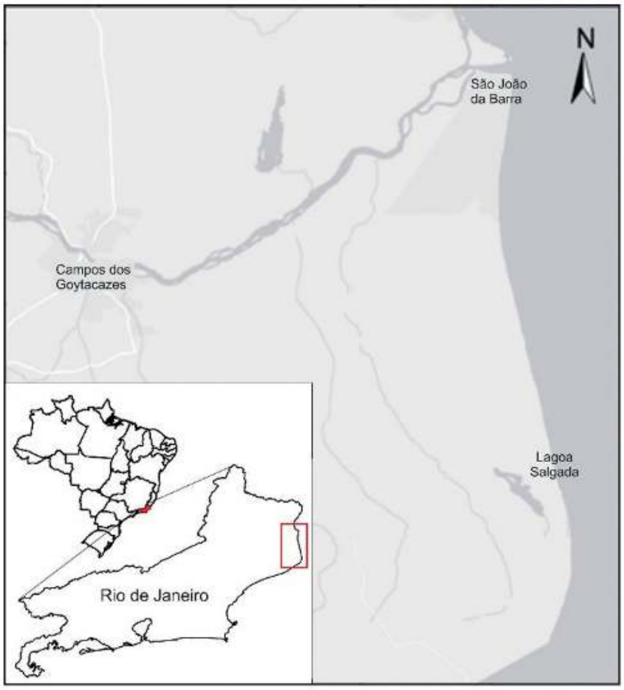

Figure 1 Location map of the Lagoa Salgada.

made a microbial distribution map on Lagoa Salgada. In this sense, the present paper aim is characterizing the different microbialites exposed in this Lagoon, distinguished by morphology and texture observable in the field (mesoscale), fabric and components (microscale).

2 Material and Methods

Field trips were made in December 2016 (summer) and June 2017 (autumn). In both periods the lagoon was dry allowing to cover the entire area and to identify stromatolites and microbial mats occurrence. It was requested authorization from INEA (Instituto Estadual do Ambiente) for development of the field work in Lagoa Salgada, because this institution manages of the Protected Area (Parque Estadual da Lagoa do Açu) where Lagoa Salgada is partially inserted.

The different bioconstructions were distinguished in field by size (height and width) and morphology (external configuration). Photographic register and sample collection were made for thin sections. From two stromatolites collected, was confectioned three thin sections, two of stromatolite base and top and encompass the whole stromatolite. These were added to the acquis Laboratório de Geologia Sedimentar – LaGeSed/UFRJ, totalizing for this work three macroscope samples and 14 thin sections of stromatolites from Lagoa Salgada.

The softwares ArcGIS (version 10.4) and the Open Street Map online database, were used to elaborate the bioconstructions occurrence map. The areas were mapped considering yet the quantity and the best exposure of relevant microbialites.

At the laboratory two bioconstructions collected were cut and described with use of stereomicroscope (ZEISS Discovery V12), for better delimitation and characterization of these structures (internal microbial growth and layer distinction), fabric (elements organization), pores and bioclasts types and other components (siliciclastic). Photographic register was made as well. The thin sections were described in petrographic microscope (ZEISS AxioimagerA2m), for better characterization of the microscopic features and possible similarities observed on samples. For better visualization, synthesis and data correlation, the descriptions were inserted in tables. The porosity was classified using the terms proposed by Choquette & Pray (1970).

3 Results

3.1 Microbialites of the Lagoa Salgada

Three types of stromatolite buildups were identified according to their external morphology: large and small domal forms, and branched / columnar stromatolite, both made bioherms and the columnar can made biostromes. These types made up of three main morphologies: stratiform, columnar and branched / columnar stromatolite. Stromatolite buildups developed over the base made up mixed carbonate-terrigenous sediments. The segmentation observed in mesoscale was confirmed in thin sections. Besides, two microbial mats types were described. From field data were delimited (Figure 2) the occurrence areas of the microbialites and where the better expositions of each microbialite type were emphasized.

3.2 Large Domal Stromatolite

Morphologically the buildups exhibited domal forms forming rounded heads or mounds, whi-

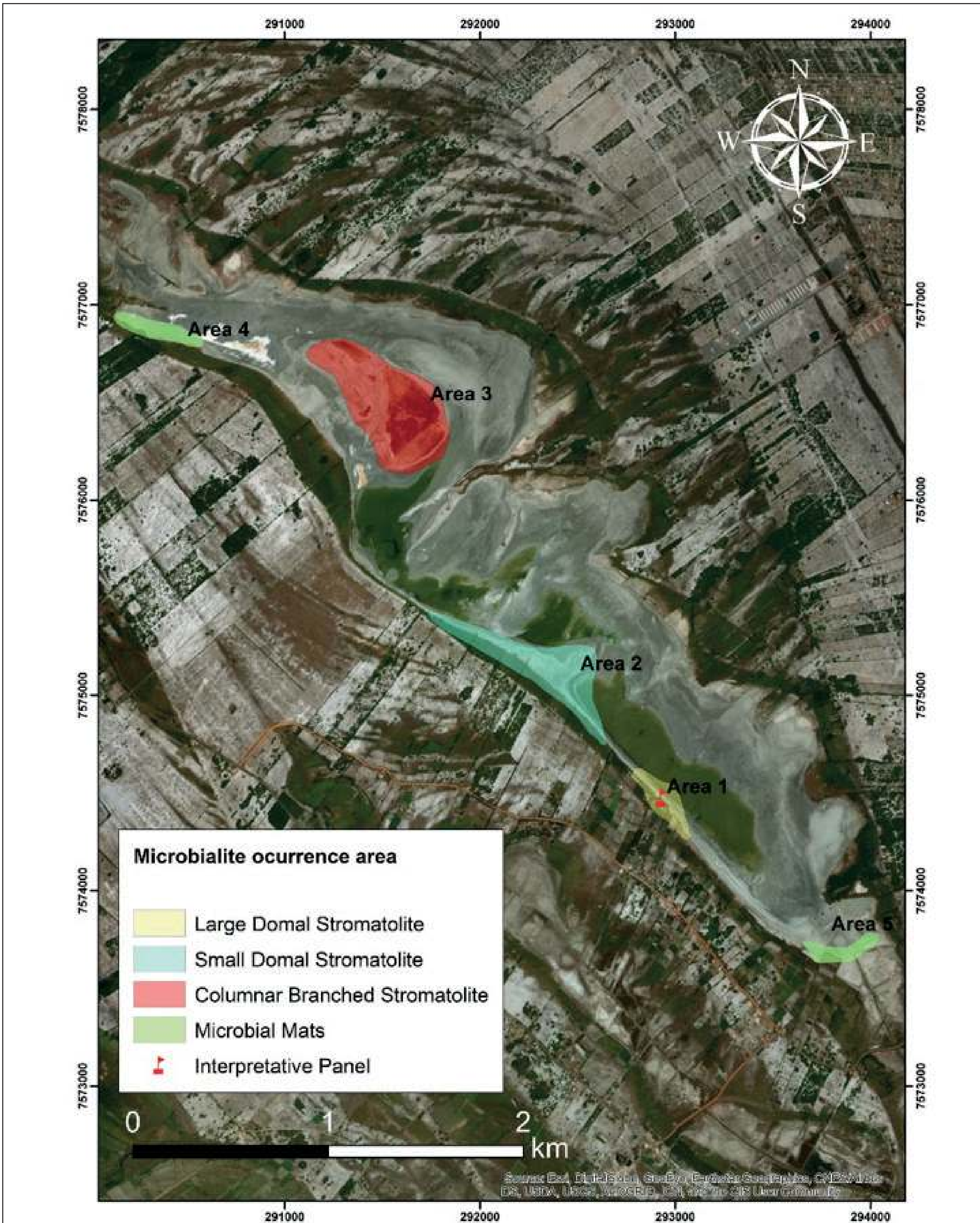

Figure 2 Map delimiting microbial occurrence areas of stromatolites, microbial mats and the interpretative panel.

ch can reach more than 30 centimeters in height and 40 centimeters for diameter (Figure 3). The bioherm (Figure 4) can be differentiate in base (lower and upper) portion, intermediate (lower and upper) and top (lower and upper).

The lower portion of the base (Figure 4 B-1) presents thick lamination and continuous, wavy or ripple marks and it is cemented, with large amount of siliciclasts (quartz) and bioclasts (bivalves and gastropods). The upper base part (Figure 4 B-2) is bioturbed (serpulid tubes), presents irregular layers, discontinues and high porosity. Were observed large porous spaces (vug), siliciclasts and gastropods. The lower intermediate portion (Figure 4 B-3) presents thin and continuous lamination and massive aspect by cement. It is observed bioturbation, bioclasts decrease regarding the lower portion, and there is increase of siliciclasts. In this part are observed ripple marks, in the top of layer. The upper intermediate portion (Figure 4 B-5) is formed by less continuous layers, irregular, cemented, bioturbed (serpulid tubes) and with development of columnar forms. Gastropods and few siliciclasts are observed. Between the layers (lower and upper) there is thick porous region that presents significant number of bivalves (Figure 4 B-4). At the top (Figure 4 B-6) there are little continuous and irregular layers, forming thin columns. This part is bioturbated (serpulid tubes) and porous. There are gastropods and few siliciclasts amount. The more external portion of the sample (Figure 4 B-7) is formed by continuous, porous and regular layers. The thin section descriptions of the large domal stromatolite were inserted in Table 2 and the more representative images are highlighted in Figure 5.

3.3 Small Domal Stromatolite

These stromatolite buildups also present domal forms and rounded heads or mounds. In general, they not exceed few height centimeters (~10 cm) but can reach more than 20 centimeters. Laterally they don't reach more than 25 centimeters, except when ramified (compound stromatolite) with two or more heads (Figure 6). The bioherm (Figure 7) can be subdivide in internal parts, which was base, porous portion, intermediate (upper and lower) and top (upper and lower).

Figure 3 A. Large domal stromatolite outcrop in the Lagoa Salgada, can be observed an example in situ of this type of stromatolite, their morphology external and size; B and C. Can be observed remobilized and stacked stromatolites by anthropic action, for construction of walls and surrounded.

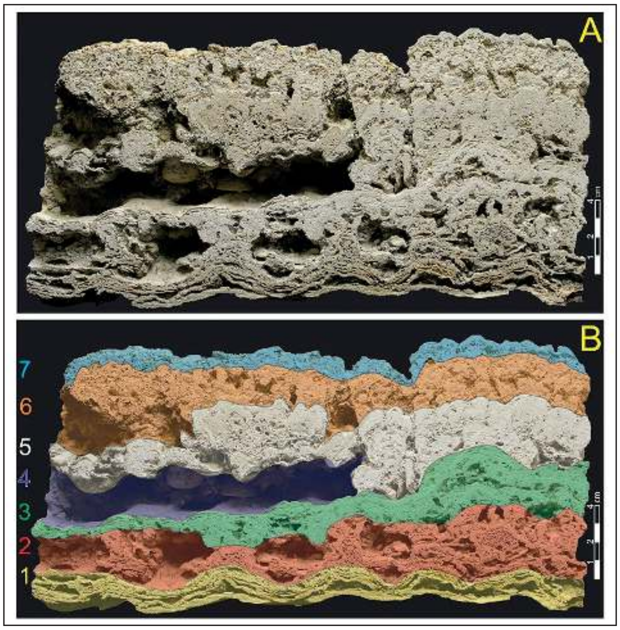

Figure 4 A. Large domal stromatolite sample; B. Sample highlights the different layers that can be macroscopic distinguished, using color for each layers, being respectively from the bottom to the top: lower (1) and upper (2) base, lower (3) and upper (5) intermediate portion, porous region (4), lower (5) and upper (6) of the top.

The base (Figure 7 B-1) presents thin, continuous and wavy (ripple marks) lamination, great siliciclasts (quartz) amount, bioclasts (gastropods and bivalves) and it is cemented. Above this there is a porous region (Figure 7 B-2), a thick portion without layer deposition. The lower intermediate portion (Figure 7 B-3) presents discontinuous and irregular layers, strongly bioturbation (serpulids tubes), high porosity, siliciclasts grains and bioclasts are present. The upper intermediate (Figure 7 B-4) is relatively continuous (more than the lower), is friable with dissolution, probably by weathering, described with transitional layer between intermediate and upper portion. The lower top (Figure 7 B-5) of stromatolite sample, exhibit columnar morphology as well as small-branched columns, rarely isolated. In contrast, the upper region (Figure 7 B-6) shows laterally continuous lamination characterizing stratiform morphology. The thin section descriptions of the small domal stromatolite were inserted in Table 3 and the more representative images are highlighted in Figure 8.

3.4 Columnar / Branched Stromatolite

These stromatolites exhibit columnar forms, isolated and/or branched (Figure 9). In general, the thickness varies from 12 to 16 centimeters, and the diameter is variable. When isolated and inside of a same bioherm the diameter not except centimeters (Figure 9- C), however, can made biostromes of columnar stromatolite slabs that can reach metrics extensions (Figure 9- A e B). It is important to emphasize that these bioconstructions can present ramifications or no, forming isolated columns. For this reason, we used the term “columnar / branched” to classify them. Its structure presents two morphological portions: the base and the bioherm or the biostromes.

Thick and continuous layers, with white and reddish carbonate grains, great quantity of siliciclasts grains and bioclasts (gastropods and bivalves), form the base (Figure 10 B-1). The bioherm presents columnar, branched or isolated layers (Figure 10 B-5). It can be vertically continuous or no, presents packages with great material detrital quantity imprisoned, formed by siliciclasts grains, bivalves and gastropods. The thickness is centimetric (Figure 10-A and 10-B 2).

However, the samples may present bioturbed portions, dissolved, porous and sometimes it is cemented. For this reason, the structure was segmented in lower intermediate portions (Figure 10 B-2) porously, bioturbed and with great bioclasts quantity; upper intermediate (Figure 10 B-3) less porous and more cemented; and the top, that is porous, dissolved, has less siliciclastic grains and bioclastic (shell and gastropods fragments) than the lower positions (Figure 10 B- 4). The thin section descriptions of the columnar / branched stromatolite were inserted in Table 4 and the more representative images are highlighted in Figure 11.

3.5 Colloform mats

Present botryoidal and rounded forms (Figures 12 and 13), forming laminated mounts with positive relief and wrinkle features in the water absence (Figure 9). It presents size of 15 centimeters of thickness, and from five to 20 centimeters of length and width.

Thin section	Sample region in stromatolite	Mineralogy and debris	Bioclasts/ allochemical	Cement	Bioconstructions
TS-1	Top	Quartz, feld-spars and peloids.	Shell fragments, gastropods.	Micrite and isopachous cement.	Upper: small columnar heads, irregular and continuous layers; ooids can be in different portions of the thin section. Intermediate: irregular stromatolites (columnar?), discontinuous, porous, with dissolved portions and observed filamentous bacteria. Lower: bigger heads, irregular, continuous and preserved (Fig.5-C).
TS-2	Upper interme-diate	Quartz and peloids.	Shell fragments, gastropods and ostracods.	Micrite	Microbial growth in stratiform stromatolites, make heads, oncoids and ooids (symmetrical) (Fig. 5-D).
TS-3	Lower interme-diate	Quartz, feld-spars, mus-covite, zircon, phosphate and peloids.	Shell fragments, gastropods, ostracods and foraminifera.	Micrite and isopachous	Microbial growth irregular, observed small oncoids and ooids (symmetrical).
TS-4	Base	Quartz, feld-spars, horn-blende, chlorite, muscovite, zir-con, phosphate and peloids.	Shell fragments, gastropods, ostracods and foraminifera	Micrite and isopachous cement	Microbial growth irregular, observed small oncoids and ooids (symmetrical).
Tr-1	Upper top	Quartz and peloids.	Shell fragments, gastropods and ostracods.	Micrite	Upper: discontinuous and porous layers, and dissolved; Intermediate: continuous layers and few porous; Lower: porous and bioturbed layers. Ooids can be observed in different portions of the thin section.
Tr-2	Lower top	Quartz and peloids.	Shell fragments, gastropods and ostracods.	Micrite and isopachous cement and meniscus.	Upper: discontinuous layers, porous and bioturbed; Intermediate: continuous layers, with great bioclasts quantity; Lower: porous, bioturbed, with incipient layers. Ooids observed in differ-ent thin section portions.
Tr-3	Upper interme-diate	Quartz, feld-spars, horn-blende, phos-phate, iron oxide and peloids.	Shell fragments, gastropods and ostracods.	Micrite	Upper: small heads, irregular and continuous; Intermediate: columnar stromatolites, irregular, discontinuous, porous, partially dissolved and observed filamentous bacteria (Fig. 5-A and B); Lower: continuous and stratiform heads, could be irregular in some parts. Ooids observed in different thin section portions.
Tr-4	Lower interme-diate	Quartz, feld-spars, musco-vite, hornblende and peloids.	Shell fragments, gastropods, ostracods and foraminifera.	Micrite and isopachous cement.	Irregular columnar stromatolite growth and in some portions stratiform (continuous) growth. Observed ooids.
Tr-5	Base	Quartz, feld-spars, musco-vite, hornblende and peloids.	Shell fragments, gastropods and ostracods.	Microespatic, micrite and isopachous cement.	Discontinuous, irregular and bioturbed. Microbial growth few defined.

Table 2 Microscope description synthesis of the large domal stromatolite.

3.6 Polygonal mats

When under water have polygonal shapes. They exhibit rectilinear (straight) edges limited by cracks (Figure 14). When exposed to air, they are wrinkled (Figure 15). They may be a few centimeters thick (~ 3cm) and varied in diameter, from 10 to 30 centimeters, but may present larger shapes.

4 Discussion

As shown in the map (Figure 2) the best exposures for large (area 1) and small (area 2) domal stromatolites are on the west margin, south limit of the lagoon. The columnar / branched stromatolites (area 3) occur in the northern portion of the water body. Microbial mats (areas 4 and 5) with positive

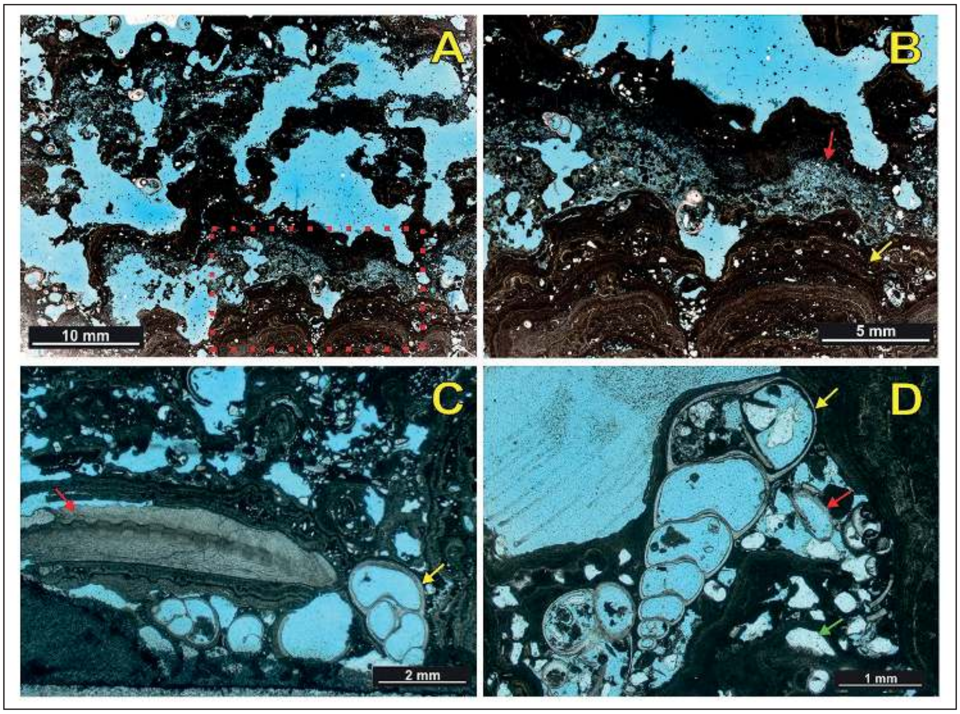

Figure 5 Photomicrography of large domal stromatolite, all the pictures are presented in parallel nicols. A. Thin section TR-3, displaying heads growth in the base and columnar forms in top. Observe regions more or less altered/dissolved; B. Image "A" detail, in lower portion, displaying less altered (red arrow), continuous growth microbial, and altered/dissolved layers (yellow arrow), porous and micritized; C. Thin section TS-1 detail, displaying shell fragment (red arrow), gastropods (yellow arrow), quartz grains and others, with microbial growth rounded these; D. thin section TS-2 detail, observed gastropods (yellow arrow), ostracods (red arrow) and quartz grains (green arrow).

Figure 6 A. Small domal stromatolite outcrop in the Lagoa Salgada, observed great quantity still in life position, preserved and few remobilized; B and C. Image "A" detail that can be observed the morphology and different types of grow, being isolated or branching, in this case two or more heads grow close and can join.

relief are generally found in the northern and southern limits of the Lagoa Salgada but can also be found elsewhere. However, these small exposures do not have considerable thicknesses, such as those highlighted on the map.

The three stromatolites types present base made of stratiform stromatolite, from which they grow with their morphologies. Both typologies of domal stromatolite demonstrate differences in size (width, length and height). However, they have simi-

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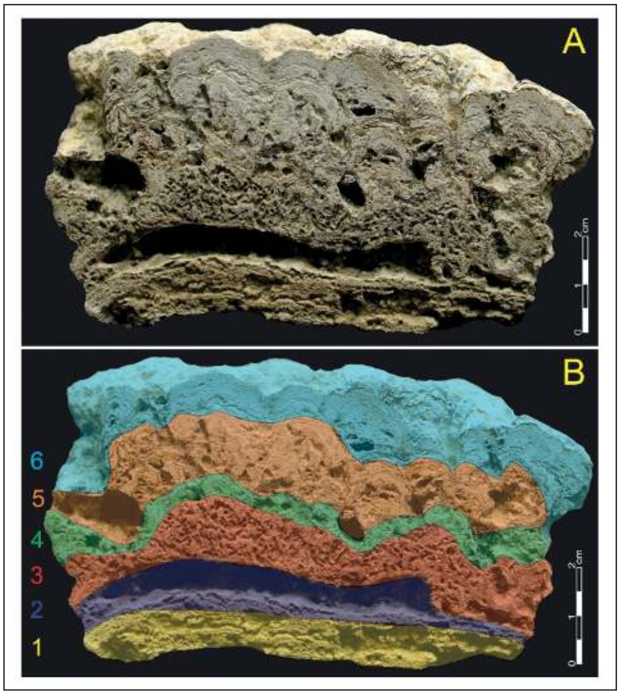

Figure 7 A. Small domal stromatolite sample; B. Sample highlights demonstrating the different layers that can be macroscopic distinguished, using different color for each layers being respectively from the bottom to the top: base (1), porous region (2), lower (3) and upper (4) of the intermediate portion, lower (5) and upper (6) of the top.

larities in the development of the inner layers, conferring morphological similarities that may suggest concomitant moments of growth. Unlike these, the columnar stromatolites have differentiated growth in relation to the development of the domal stromatolite, evident by its different internal pattern.

Iespa *et al*. (2012) characterized five microfacies for the large domal stromatolite, constituting the "stromatolite, thrombolite and oncoid plex (STOP)". For these authors the base (microfacies 1 and 2) representing the marine phase, the intermediate portion (microfacies 3) evidences the beginning of the lagoon formation, the portion above (microfacies 4) marks the end of the lagoon closure and isolation from the sea. The top (microfacies 5) represents the current conditions of the Lagoa Salgada, similar subdivision was observed in both domal stromatolites (Table 5).

However, for the columnar stromatolites this segmentation is not possible. Their internal and external morphology is different from the other bioconstructions, except for the base, which is common to all stromatolites. Iespa *et al*. (2012) suggests that the morphologies domal and columnar are associa-

Thin section	Sample region in stromatolite	Mineralogy and debris	Bioclasts/ allochemical	Cement	Bioconstructions
Y-1	Full	Quartz, feldspar, zircon, muscovite, hornblende, phosphates, intraclasts and peloids.	Shell fragments, gastropods and ostracods.	Meniscus, isopachous cement, micrite.	Upper: continuous layers, develop heats on the top (Fig. 8-A and B)
					Intermediate: columnar stromatolites;
					Lower: microbial growth of discontinuous and irregular layers that filled the base, for separate columns.
Y-2	Full	Quartz, feldspar, zircon, muscovite, hornblende, phosphates, tourmaline, chlorite, intraclasts and peloids.	Shell fragments, gastropods and foraminifera.	Isopachous cement growth rounded grains and porous, micrite.	Upper: developed stromatolite layers (Fig. 8-C and D).
					Intermediate: irregular and bioturbed layers;
					Lower: Discontinuous and irregular microbial growth, with many siliciclastic. Oncoids developed, being concentric forming ooids, these grains can be in different portions of the thin section;
EST-1-LS	Full	Quartz, zircon peloids, hornblende, tourmaline and intraclastos. Only in intermediate part of the thin section are observed feldspar and muscovite.	Shell fragments, gastropods and ostracods.	Meniscus and isopachous cement. In base is thin and in intermediate portion is thicker.	Upper: developed stromatolite layers, forming heats on the top;
					Intermediate: irregular (columns) and bioturbed layers,
					Lower: continuous and irregular microbial growth; oncolites developed, being concentric (ooids), which may be in different portions of the thin section;

Table 3 Microscope description synthesis of the Small domal stromatolite.

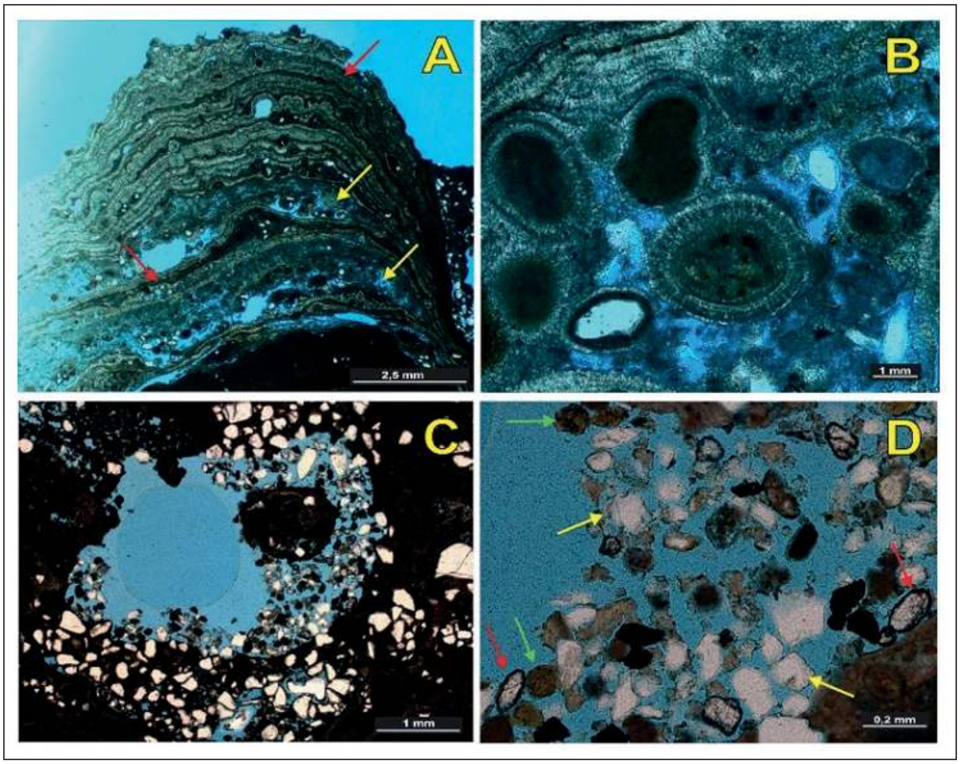

Figure 8 Photomicrography of small domal stromatolite, all the pictures are presented in parallel nicols. A. Detail of thin section EST-1-LS, when can be observed preserved layer successions (red arrow) and others altered (yellow arrow), with formation of micrite and porous; B. Image A detail, with different sizes of oncoids; C. Vug porous, in thin section Y-2, being observed concentration of detritic grains, like a quartz, peloids, hornblende and zircon in great quantity, more than observed in others thin section; D. Image C detail when can be observed zircons (red arrow), quartz (yellow arrow) and hornblende (green arrow).

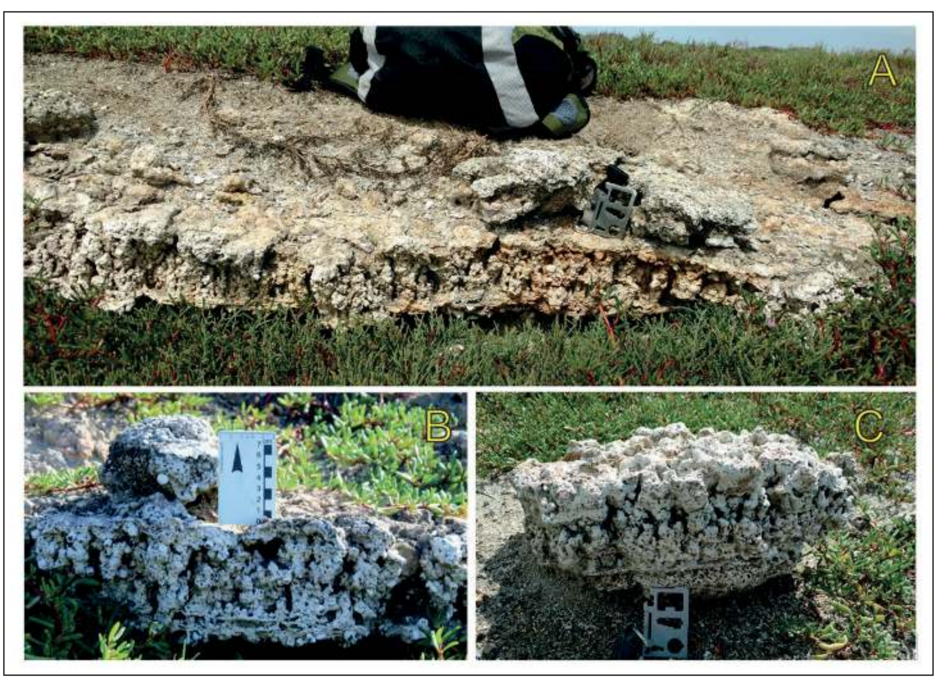

Figure 9 A. Columnar / branched stromatolite outcrops, biostrome forming a slab, exhibiting columnar grow, that can be branched; B. Detail of the image “A”, showing the columnar structures; C. Bioherm columnar stromatolite outcrop.

ted, respectively, with the low or high energy related to the water flow, with physical erosion.

Macroscopic and microscopic analyzes suggest that the Lagoa Salgada underwent different periods of flooding and drought. Associated to this, are interpreted moments with interruption in the growth of bioconstructions and intense alteration (dissolution and recrystallization). In addition, the upper analyzed portion is altered (dissolved), possibly by subaerial exposure and meteoric water interaction.

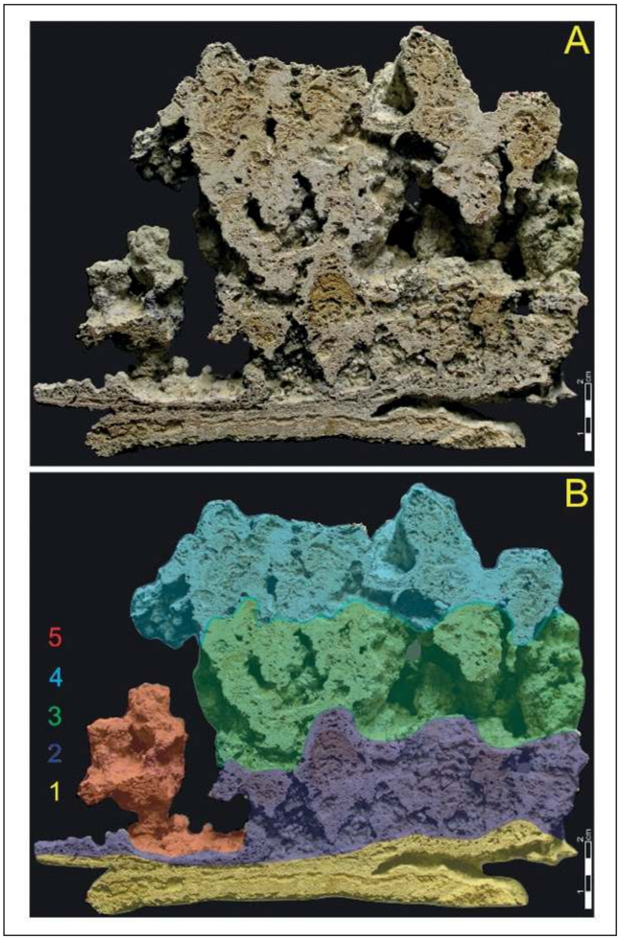

Figure 10 A. Columnar / branched stromatolite sample; B. Sample highlights, demonstrating the different layers macroscopically distinguished, using different color for each layer, being respectively from the bottom to the top: base (1), lower (2) and upper (3) intermediate and top (4). Beside this, distinguished the isolated column (5).

Coimbra *et al*. (2000) suggest climatic fluctuations during the lagoon evolution, indicated by the pore arrangement found in the stromatolites sample. The data denote salinity and body water depth variations during the stromatolite growth. This hypothesis was confirmed by the dating of the stromatolite base, which presents ages of 2260 ± 80 years, coinciding with dry period, and the top with 290 ± 80 years, in humid period. On the other hand, there are gastropods in upper muddy part of layers, whose feeding inhibited bioconstruction growth. Birgel *et al*. (2015) presented similar ages, conferring 2000 years for the base and 260 years for the top. They propose that the microbial growth of the Lagoa Salgada occurs in episodic events, with gaps bigger than material record. These authors suggest that the correlation with sea level variations is not simple, and may indicate entrance of water in different moments on the lagoon and different ways.

These affirmations can be observed in large domal stromatolites. The ripple marks presence in intermediate portion suggests that the bioconstructions growth was interrupted by subaerial exposition. Subsequently, the development of the hydrodynamic features occurred, allowing the formation of the one new bivalve-based substrate, from which the microbialites continued to grow. The high dissolution and recrystallization observed in thin section reveal that the stromatolites were exposed to the environmental variations. These conditions are also reflected in the pore arrangement and in effective porosity of the rock (Table 5) that is high and may be found in different forms (primary and secondary).

In this sense, it is believed that the evolution of the lagoon and its stromatolites is more complex

Thin section	Sample region in stromatolite	Mineralogy and debris	Bioclasts/ allochemical	Cement	Bioconstructions
C-1	Upper	Quartz, intraclasts, peloids.	Shell fragments, gastropods, ostracods and foraminifera.	Micrite and isopachous cement growth rounded grains, may be recrystallized or micritized	Discontinues and irregular layers, in columns and some stratiform portions, altered (dissolved) and porous, with others less. Are observed also oncoids and filamentous bacteria preserved or no, showing moldic porous. (Fig. 11-A, B, C and D)
C-2	Lower	Quartz, feldspar, intraclasts, peloids.	Shell fragments, gastropods, ostracods and foraminifera.	Micrite, meniscous, isopachous cement growth rounded grains and porous, may be recrystallized or micritized	Upper: columnar microbial growth, intercalating layers more, or less altered (dissolved). Are observed also oncoids and filamentous bacteria. In general, this portion is recrystallized (Fig. 11-E)
					Lower: less continuous, irregular and porous layers

Table 4 Microscope description synthesis of the Columnar / branched stromatolite

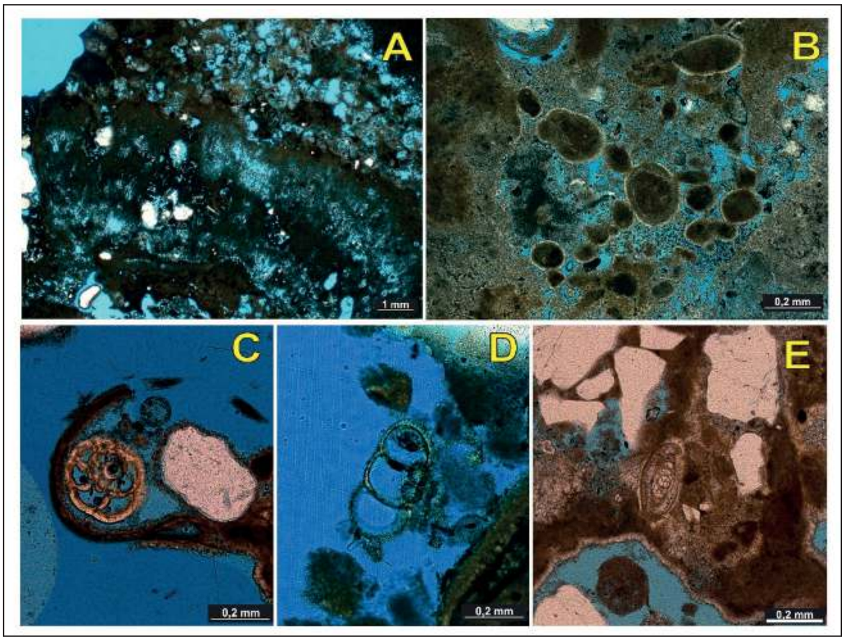

Figure 11 Photomicrography of the Columnar stromatolite, all the pictures in parallel nicols. A. Thin section C-1 detail, showing porous molds of filamentous bacteria, within micritic cement; B. Oncoids in different sizes fold in thin section C-1, shows thin isopachous fringe around ooids and then micrita partly filling the intergranular porosity, the micrite may be part a cement; C and D. (thin section C-1); and E. (Thin section C-2): different foraminifera types, fold in columnar stromatolite. The foraminifera observed in D is the same also fold in thin sections of large and small domal stromatolites.

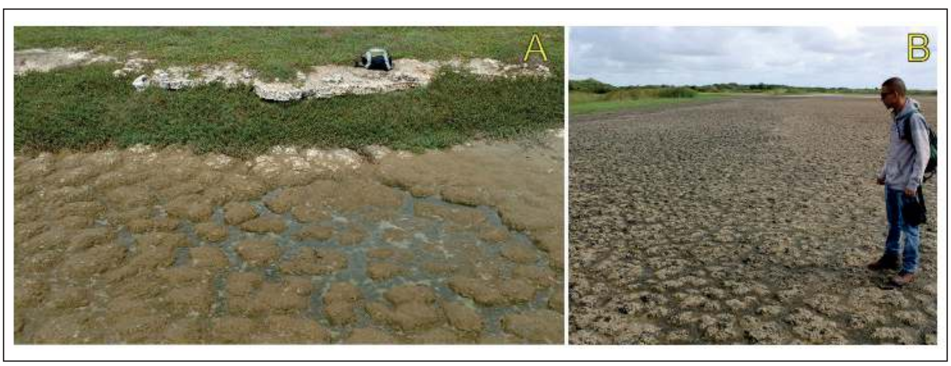

Figure 12 Colloform mats observed in the Lagoa Salgada. A. Colloform mats, observed in inner portion of the lagoon, with domal forms, in dry period but yet with water. To observe in the upper portion of the image the slab outcrop of the columnar/branched stromatolite; B. Big area with outcrop of the colloform mats, in southeast portion of the lagoon, without water but showing same rounded forms.

Figure 13 Colloform mats, showing positive relief, observed in the Lagoa Salgada, southeast portion of the lagoon. A. Area with outcrop of the colloform mats; B. Detail of the image "A", with wrinkle shapes; C. Colloform mats of top view.

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Figure 14 Polygonal mats observed in south portion of the Lagoa Salgada. A. Polygonal mats yet underwater, showing fracturing and straight edges; B. Polygonal mats that had been recently exposed, near position of the outcrop of the image "A".

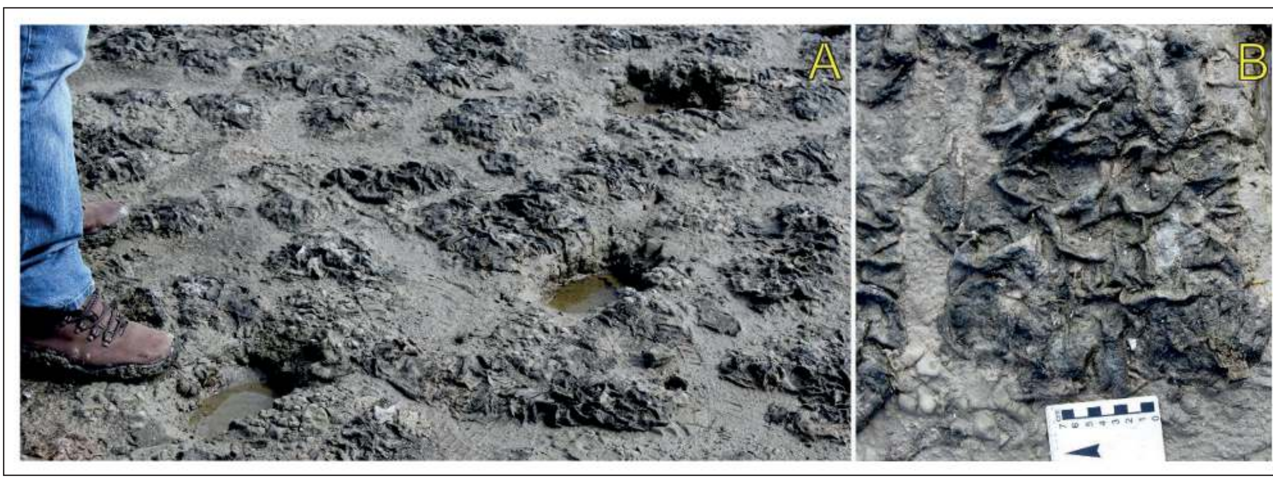

Figure 15 Polygonal mats observed in north portion of the Lagoa Salgada. A. Polygonal mats that had been recently exposed, showing with wrinkle shapes; B. Detail of the image "A", of top view.

Thin Section	BIOCONSTRUCTION				POROSITY				
					Fabric-selective				
	Stratiform / heath stromat-olites	Columnar stro-matolite	Ooids	Foraminifera	Interparti-cle (prima-ry)	Intraparti-cle (prima-ry)	Intercrystal (second-ary)	Not Fabric-se-lective	Fabric-selective or not
TS-1	X	X	X		X	X	X	X	X
TS-2	X		X		X	X	X	X	X
TS-3	X		X	X	X	X	X	X	X
TS-4	X		X	X	X	X	X	X	X
Tr-1	X		X		X	X	X	X	X
Tr-2	X		X		X	X	X	X	X
Tr-3	X	X	X		X	X	X	X	X
Tr-4	X	X	X	X	X	X	X	X	X
Tr-5	X		X		X	X	X	X	X
Y-1	X	X			X	X	X	X	X
Y2	X		X	X	X	X	X	X	X
EST-1-LS	X	X	X		X	X	X	X	X
C-1	X	X	X	X	X	X	X	X	X
C-2		X	X	X	X	X	X	X	X

Table 5 Synthesis of the bioconstructions and porosity observed in thin sections

than previously suggested. There are times when the lagoon had direct connection with the ocean (or with the Açu Lagoon), as well as there are records of the absence of water in periods of drought. At different times, stromatolites were exposed to weathering and erosive agents, followed by full submersion, which also probably conferred variations in porosity.

Srivastava (2002) and Silva e Silva *et al*. (2007c) described the occurrence of thrombolites and oncoids in the Lagoa Salgada. However, these were not found in the present study. It is believed that parts of these microbialites is buried, remobilized and/or stacked in the marginal portions of the lagoon. Iespa *et al*. (2012) describes the occurrence of thrombolytic layers, also evidenced in this work in very bioturbated layers.

The microbial mats are observed in all lagoon extension, mainly of that polygonal type. However, we chose to stand out the two with better expositions and more expressive positive relief. Rocha & Borghi (2017) suggest that coloform mats are found in full body water phase and residually in dry phase, being this a transitional morphology to polygonal mats. Then, as the water depth decrease and other factors rise, such as aridity, there is an increase of the hypersalinity and underwater dehydration (syneresis). Factor precursors of the crack that is intensified for expose subaerial, as well as these the composition of the mats represent the controlling factors of the morphology.

Silva e Silva *et al*. (2013) suggested that at least 31 cyanobacteria species tolerant to intense variations of salinity and temperature are associated to stromatolites and microbial mats of the Lagoa Salgada. The filamentous cyanobacteria and flat type mats, tufted, polygonal and in bubble are the major producers of stromatolites. These factors can help in the formation of distinct stromatolite morphologies; however, those authors do not suggest that has been sampling in columnar stromatolites like in this work.

5 Conclusions

The different microbialites exposed currently in *Lagoa Salgada*, were morphologically classified in columnar/branched, large and small domal stromatolites, and this distinction was confirmed in microscale. The colloform and polygonal microbial mats were classified in field and can be found in different parts of the lagoon. Each stromatolite type presents a growth with different layers. However, the two domal forms share growth similarities showed in macroscopic and microscopic samples. The columnar/branched stromatolite doesn't have their growth associated with the domal stromatolites. Possibly, these morphologies may be associated with different depths of water and energy flow. The map of bioconstructions occurrences demonstrates the portions where it is better exposed, as well as the regions of concentration by type, following the discrimination of this work. The data showed in this paper point the discovery and/or confirmation of different structures present in the lagoon, opening new possibilities of investigation about the presence of different microbialites from Lagoa Salgada and marginal lagoons in the north of the Rio de Janeiro.

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