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Cyanobacterial and sedimentary composition in polygonal microbial mats from Pernambuco lagoon, Rio de Janeiro, Brazil

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ABSTRACT
The Pernambuco Lagoon is a hypersaline water body located in the Massambaba barrier-island, coastal plain of Rio de Janeiro State, southeastern Brazil. Its marginal environments are characterized by the development of microbial mats resulting from the organic activity produced by sediment trapping and binding in the matrix. The aim of this study is to characterize the cyanobacterial and sedimentary composition of these mats, mainly those with polygonal morphology, where a porous compact structure limits and forms polygonal fissures and cracks. The MEV and SED analysis show a calcitic and sodium chlorate composition and dominance of filamentous cyanobacteria *Microcoleus chthonoplastes* (Thuret) Gomont 1892 in the polygonal microbial mats. The disposition of filamentous forms on the surface level and the spherical ones in the deeper layers results in a stratification of the mats. These observations are useful in the identification of similar organic generated deposits in the fossil record.

Key words: cyanobacteria, polygonal microbial mats, calcite, Pernambuco Lagoon.

RESUMO
CIANOBACTÉRIAS E COMPOSIÇÃO SEDIMENTAR DAS ESTEIRAS MICROBIANAS NA LAGOA PERNAMBUCO, RIO DE JANEIRO, BRASIL. A lagoa Pernambuco é um corpo de água hipersalino localizado na ilha de barreira da Massambaba, constituindo parte do sistema lagunar de Araruama, costa do Rio de Janeiro, sudeste do Brasil. As esteiras microbianas formadas em suas bordas são resultado da atividade de cianobactérias e resultam do aprisionamento de sedimentos por sua matriz orgânica. O objetivo deste estudo é caracterizar sua composição, em especial daquelas de caráter poligonal, formadas por uma estrutura compacta porosa em torno das fissuras de gretas de contração. Os grãos analisados por MEV e EDS demonstraram a presença de calcita e cloreto de sódio e da cianobactéria filamentosa *Microcoleus chthonoplastes* (Thuret) Gomont 1892 como elemento principal na formação das esteiras. O domínio das cianobactérias filamentosas nos estratos superficiais e das esféricas nas camadas mais profundas são a causa da estratificação das esteiras. Estes dados possuem uma importante aplicação no estudo de esteiras microbianas de constituição e deposição similar no registro fóssil.

Palavras-chave: cianobactéria, esteira microbiana poligonal, calcita, lagoa Pernambuco.

INTRODUCTION

Microbialites are the organosedimentary deposits formed mainly by the activity of cyanobacteria, which involve algal mats, stromatolites, thrombolites and oncoids/oncolites, among many other geological registers, since the Archean until the present (Reitner *et al*., 1995).

Their study can focus either on the interaction between microbial organisms and their environment, particularly the geochemical mobility of elements and mineral formation (Geomicrobiology) (Ehrlich, 2002), or the sedimentary particles and rocks derived from the microbial activity (Biosedimentology, a Comparative Sedimentology branch) (Selley *et al*., 2004).

Also, their study addresses geological problems like the origin and evolution of early life, the origin of expressive iron formations, and the search for extraterrestrial life (Toporsky *et al*., 2003).

Microbial mats (algal mats) are the oldest of all known ecosystems. They fringed all continents and shallow waters of the Earth as early as 3,500 million years ago. Their lithified remains originated the geological structures known as stromatolites (Knoll, 1989). Marine data show that microbial carbonates episodically declined during the Phanerozoic Eon, with a peak at 500 Myr ago (Riding and Liang, 2005).

Stromatolites are examples of an interactive system involving radiate accretive growth of microbial mats (Dupraz *et al*., 2006). Most of these microbial mats are formed by horizontally stratified, multicolored and cohesive thin layers of several functional groups of microorganisms (Van Gemerden, 1993). Microbial mats develop in time as the result of microbial growth and activity, sediment trapping and binding in the organic matrix, and sedimentation (Margulis *et al*., 1980).

The microbial mats vary from dark to dark greenish, composed of a succession of very thin (0.5-1 mm thick), dark (rich in organic matter) and light grey, calcareous layers, occasionally dispersed with microgastropods, ostracods and palinomophs (Srivastava and Almeida, 2000). Their description is rather comprehensive: smooth, film, pustular, polygonal, tufted, gelatinous and coloform (Hoffman, 1976; Gerdes *et al*., 2000).

In the associated sediment the presence of calcite, aragonite, micrite and Mg-calcite is very common (Srivastava and Almeida, 2000; Arp *et al*., 2002) and the microbial mats could be formed on siliciclastic sands as well as on fine-grained siliciclastic substrates (Schieber, 1998).

The layers are formed mostly by cyanobacteria (mainly of the genera *Microcoleus*, *Lyngbya*, *Spirulina* and *Phormidium*) and diatoms. There are usually different populations of anaerobic phototrophic bacteria: purple sulfur bacteria (Chromatiaceae), green sulfur bacteria (Chlorobiaceae) and green non-sulfur bacteria, like *Chloroflexus* sp. (Guerrero *et al*., 1993). Microbial mats develop at the water-sediment interface in shallow environments such as estuaries, sheltered sandy beaches, or hypersaline salterns (Caumette *et al*., 1994).

The diversity of cyanobacteria results from the distinct environments where they grow. In these terms specially call the attention those living in extreme conditions, such as deserts, soils, hypersaline microbial mats, cold environments, freshwater lakes and hydrothermal vents with temperature nearly 85 °C (Raven *et al*., 2002; Abed *et al*., 2003; Knauth, 2005).

Through biochemical process the cyanobacteria could dissolve the carbonate substrates and shell fragments, extending microborers and holes already existing and generating bioerosion (Perry and Macdonald, 2002; Bottjer, 2005).

Extracellular polymeric secretions (EPS) that are produced by cyanobacteria represent potential structural agents in the formation of microbial mats (Decho *et al*., 2005). The EPS matrix is a key structural component in the microbial mats (Decho, 1990), and it could influence a number of biological and geochemical processes that are critical to microbial mat formation. These include: (i) physically stabilizing microbial cells and calcium carbonate ooids against the high-energy environments, *e.g.*, waves, tidal currents, in which these structures commonly occur (Reid *et al*., 1995); (ii) Ca^{++} buffer, that perhaps prevent the $CaCO_3$ precipitation (Arp *et al*., 1999a; Reitner *et al*., 2000); (iii) $CaCO_3$ inducing precipitation (Reitner *et al*., 2000); and (iv) a chemically protective microenvironment for cells (Decho, 1990; Arp *et al*., 1999b).

So the calcification of the microbial mats is dependent on ambient water chemistry and its growth is influenced by the competition with other organisms, such as metazoans (Riding and Liang, 2005).

The filamentous cyanobacteria are responsible for the union and imprisonment of sediment to form the layers in the mats. These cyanobacteria are responsible for $CaCO_3$ precipitation and for the lamination structure, according to observing by Gerdes *et al*. (2000).

In the lamine of the microbial mats the precipitation of calcite was due to the cyanobacteria activity; inorganic chemical precipitation of $CaCO_3$; decomposition of organic substances composed primarily of $CaCO_3$; plant assimilation and cyanobacteria activity resulted in the precipitation of $CaCO_3$; submicroscopic cyanobacteria fragments of $CaCO_3$; disintegration of $CaCO_3$ hard part invertebrates and borings of endolithic cyanobacteria and invertebrates into calcareous exoskeletons similar with the results of Welle *et al*. (2004).

The objectives of the present study are to characterize the polygonal microbial mats and their cyanobacterial and sedimentary composition in the Pernambuco Lagoon.

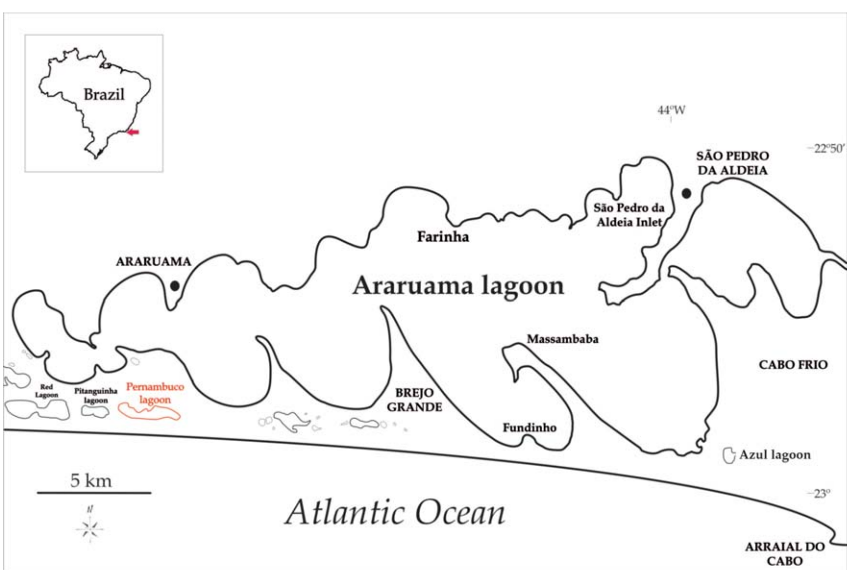

Figure 1. Map of the Araruama system of lagoons, Lagos region, northeast of Rio de Janeiro State, Brazil, and the location of Pernambuco Lagoon (in red).

STUDIED AREA

The Pernambuco Lagoon (22°55'42" - 22°56'00"S; 42°20'45" - 42°21'30"W) is a hypersaline water body located in the Massambaba barrier-island. Compound part of the more expressive Araruama lagoon system, in the coastal plain of Rio de Janeiro state, southeastern Brazil (Figures 1-2) and it was formed during the regressive and transgressive events that result from the end of Pleistocene and Holocene climatic changes (Silva e Silva *et al*., 2004).

The average salinity is 67.4 ‰ and the average pH 8.6 (Iespa, 2006). The air temperature varies from 19ºC to 31ºC and the annual pluviometric rate is of 900 mm, with an evaporation of 1,400 mm (Iespa, 2006). The semi-arid climate, with a great precipitation/evaporation deficit ratio makes the region excellent for salt extraction (Iespa and Silva e Silva, 2005; Silva e Silva *et al*., 2006).

MATERIAL AND METHODS

The study in the region was based on a monthly sampling made in the intertidal and supratidal portions of the marginal region of the lagoon, during March and December of 2007. The material was selected in agreement with the integrity, size and color.

To verify the presence of cyanobacteria was applied H_2O_2 at 20% over the samples. Taxonomic analysis involved the production of permanent, semi-permanent and fresh slides (Silva e Silva, 2002) and the cyanobacteria identification were based in Prescott (1975), Anagnostidis and Komárek (1988) and Komárek and Anagnostidis (1999).

The grains of microbial mats were analyzed by SEM and EDS at TRO/CENPES/PETROBRAS.

Petrographic slides were prepared to analyze the micro-stratification and the cyclic succession of the stromatolitic structure (Iespa, 2006).

RESULTS

The polygonal microbial mats here analyzed show three principal broad strata distinguished by their colors: the superficial one green, the interior red and the basal, deep brown. Below the brown stratum, a layer composed by shells of the bivalve *Anomalocardia brasiliana* Gmelin 1791 and the gastropod *Heleobia australis* d' Orbigny 1835 are detected. Skeletal remains, distributed between bivalves, gastropods, foraminifers and ostracods from the genera *Cyprideis* Jones 1857 are also found in the interior layers of the mats, associated with organic matter, subangulate and subrounded quartz grains with fine to medium sand sizes, and many white laminations of calcium carbonate.

On the surface exists a polygonal and porous structure (Figure 3), with its limits marked by fissures and cracks (Figure 4). This layer is dominated by filamentous forms of bacteria, while the deeper ones are characterized by spherical ones.

The grains of microbial mats analyzed by SEM and EDS are composed by calcite and sodium chloride.

The taxonomic analysis allows to the identification of 49 distinct species of cyanobacteria (Table 1), represented by 51% of Cyanophyceae and 49% of Hormogonae.

The most representative family is Phormidiaceae Anagnostidis and Komárek 1988, representing 30.6% of the assemblage. It is followed by Synechococcaceae Komárek and Anagnostidis 1995 (24.5%); Chroococcaceae Nägeli 1849 (22.5%); Oscillatoriaceae Gomont 1892 (8.2%); Pseudanabaenaceae Anagnostidis and Komárek (4.1%); Schizothricaceae Elenkin 1934 (4.1%); Entophysalidaceae Geitler 1925 (2%); Merismopediaceae Elenkin 1933 (2%) and Nostocaceae Bourrelly 1970 (2%).

The filamentous cyanobacteria *Microcoleus chthonoplastes* (Thuret) Gomont 1892 (Figure 5) are the common species in the polygonal microbial mat.

Figure 2. Panoramic view of a marginal area of Pernambuco Lagoon.

Figure 3. Polygonal microbial mats developed at Pernambuco Lagoon.

Table 1. Cyanobacterial distribution in the polygonal mats.

	Green layer	Red layer	Brown layer
Aphanothece castagnei	X	X	X
Aphanothece clathrata	X	X	
Aphanothece halophytica		X	X
Aphanothece marina	X	X	X
Aphanothece pallida	X	X	X
Aphanothece salina	X	X	X
Aphanothece saxicola		X	
Aphanothece stagnina	X		X
Chroococcus dispersus	X	X	X
Chroococcus giganteus	X		
Chroococcus membraninus	X	X	X
Chroococcus microscopicus	X	X	X
Chroococcus minimus	X	X	X
Chroococcus minor	X	X	X
Chroococcus minutus	X		
Chroococcus obliterates		X	
Chroococcus quaternarius		X	X
Chroococcus turgidus	X	X	X
Cyanosarcina thalassia	X	X	X
Entophysalis granulosa		X	X
Gomphosphaeria aponina	X	X	
Gloeothece confluens		X	X
Gloeothece linearis	X	X	
Johanesbaptistia pellucida	X	X	
Kyrtuthrix maculans	X	X	
Leptolyngbya komarovii	X		
Leptolynbya tenuis	X	X	X
Lyngbya aestuarii	X	X	X
Lyngbya fragilis	X		
Microcoleus chthonoplastes	X	X	X
Microcoleus tenerrimus	X		
Microcoleus vaginatus	X	X	X
Oscillatoria limnetica	X	X	
Oscillatoria subbrevis	X		X
Phormodium acuminatum		X	
Phormidium acutum	X		X
Phormidium breve	X	X	
Phormidium formosum	X		
Phormidium hamelli	X	X	
Phormidium hormoides	X		X
Phormidium hypolimneticum	X		
Phormidium minesotense	X		
Phormidium okenii	X	X	X
Phormidium terebriforme	X		
Phormidium willei	X	X	X
Schizothrix arenaria	X		
Schizothrix friesii	X	X	X
Spirulina subtilissima	X	X	X
Synechococcus elogantus		X	X
PARTIAL TOTAL	**41**	**35**	**28**
TOTAL SPECIES		**49**	

The purple sulfur bacteria *Chromatium* Perty 1852; the diatom *Navicula* Bory 1822; the *Chlorophyta* macroalgae *Enteromorpha* Link 1820 were also observed in the polygonal mats.

Both shells of *Anomalocardia brasiliana* Gmelin 1791 (Figure 6) and quartz grains (Figure 7) show perforations caused by the cyanobacteria.

DISCUSSION

The main organic component of the polygonal microbial mats is *Microcoleus chthonoplastes.* Its presence, also common in hypersaline waters from China (Zhang and Hoffman, 1992), approximates the microbial mats here studied from that growing in the proximal area of the Pitanguinha Lagoon (Damazio, 2004) and those developed in Shark Bay, Australia (Hoffmann, 1974; Hoffman, 1976), leading to conclude that *M. chthonoplastes* is the main element in the composition and structure of polygonal mats.

Together with *Chroococcus* Nägeli 1849; *Leptolyngbya* Anagnostidis and Komárek 1988; *Oscillatoria* (Vaucher) Gomont 1892 and *Phormidium* (Kützing) Gomont 1892 were registered also in microbial mats from France by Fourçans *et al.* (2004).

In Laguna Mormona, Mexico, Horodyski *et al.* (1977) found *M. chthonoplastes*, *Lyngbya aestuarii* (Liebman) Gomont 1892; the genera *Lyngbya* (Agardh) Gomont 1892; *Entophysalis* Kützing 1843 and *Oscillatoria* (Vaucher) Gomont 1892.

In French Polynesia, Défarge *et al.* (1994) and Abed *et al.* (2003) identified *Aphanocapsa* Nägeli 1849; *Phormidium* (Kützing) Gomont 1892; *Entophysalis* Kützing 1843; the species *Chroococcus membraninus* (Meneghini) Nägeli 1849; *C. minutus* (Kützing) Nägeli 1849; *C. turgidus* (Kützing) Nägeli 1849; *Johanesbaptistia pelucida* (Dickie) Taylor and Drouet 1938; *Lyngbya aestuarii*, *Microcoleus chthonoplastes*, *Phormidium breve* (Gomont) Anagnostidis and Komárek 1988 and *Spirulina subtilissima* Kützing, 1843.

In Ebro Delta, Spain, *Lyngbya aestuarii* and *Microcoleus chthonoplastes* already characterized the microbial mats (Martinez-Alonso *et al*., 2004), the same forms identified in the Salgada and Pitanguinha lagoons, in Rio de Janeiro, Brazil, with *Schizothrix friesii* (Agardh) Gomont 1892 (Silva e Silva, 2002; Damazio, 2004).

According to Baeta Neves and Casarin (1990), *M. chthonoplastes* and *Aphanothece stagnina* (Sprengel) A. Braun 1863 (Figure 8) are tolerant species to the hypersaline environments. The same is observed by Damazio *et al*. (2005) in Pitanguinha Lagoon where the cyanobacterial dominance is justified through its high morphologic adaptations that ensure its survival in many environments, including the hypersaline ones.

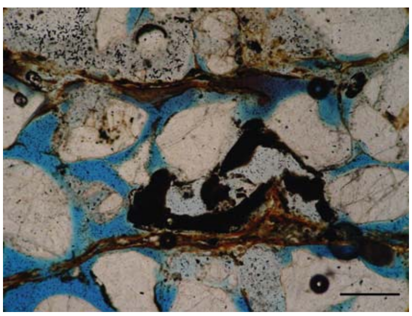

Figure 4. Photomicrography of the microbial mat showing a transversal lamination and the disposition of quartz grains. Scale bar = 1 mm.

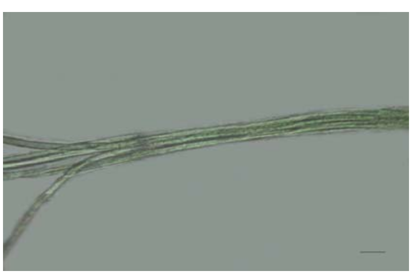

Figure 5. *Microcoleus chthonoplastes* (Thuret) Gomont 1892. Scale bar = 10 µm.

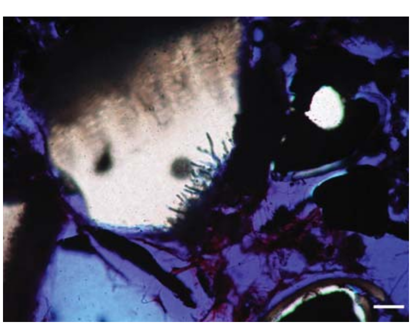

Figure 6. Perforations in shell fragments of *Anomalocardia brasiliana* Gmelin 1791 made by cyanobacteria filaments. Scale bar = 0.1 mm.

Draganits and Noffke (2004) proposed that silicified lamination of the polygonal microbial mats led a strong support to the mats, that becomes more stable. And according to Giralt *et al*. (2001), the presence of calcite is also common in its composition.

Silva e Silva *et al*. (2004) showed that the skeleton remains of mollusks, foraminifers and ostracods are the source of calcium carbonate to construct the structure of the mats.

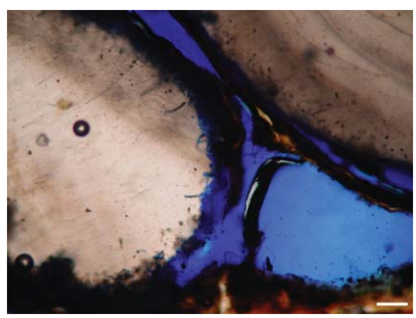

Figure 7. Perforations in quartz grains by filamentous cyanobacteria. Scale bar = 0.1 mm.

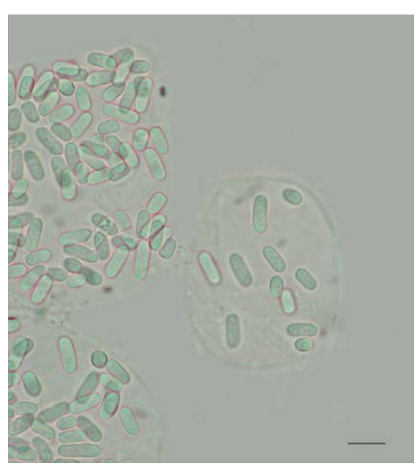

Figure 8. *Aphanothece stagnina* (Sprengel) A. Braun 1863. Scale bar = 10 µm.

The purple sulfur bacteria *Chromatium* here detected also forms the microbial mats in Vermelha Lagoon (Vasconcelos, 1988) and Ebro Delta (Guerrero *et al*., 2003), and it is responsible for sulfur degradation. For otherwise, the diatom *Navicula*, destroys the organic matter and was also previously registered in Pitanguinha (Damazio, 2004) and Mormona Lagoons (Horodyski *et al*., 1977) and in Ebro Delta (Urmeneta and Navarrete, 2000). To the first area are associated with the chlorophyta *Enteromorpha* (Damazio, 2004).

Finally, the perforations in quartz grains and shell fragments caused by microorganisms and biofilms were also observed by Brehm *et al*. (2005).

CONCLUSION

Polygonal microbial mats are common in aquatic environments characterized by the presence of mineral salts, good light incidence and absence of predation. In these conditions the organic construction is controlled by tides, wind regime, rainy seasons, water table level, water chemistry and by their own microbiocenosis. The filamentous cyanobacteria are responsible for the union and imprisonment of sediment grains to form the layers in the microbial mats. They are capable of causing the disintegration of minerals and producing biochemical dissolution of carbonate structure and shell fragment from molluscs, foraminifers and ostracods that compound the structure of the mat.

Their stratification is the result of the disposition of filamentous forms on the surface level and the spherical ones in the deeper layers, and the dominance of cyanobacteria is justified by its great capacity to survive in severe environmental conditions, like hypersalines water bodies.

The observation and study of these biofilms and organic induced deposits are of large application in similarly generated deposits in the fossil record.

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REFERENCES

ABED, R.M.M.; GOLUBIC, S.; GARCIA-PICHEL, F.; CAMOIN, G.F.; SPRACHTA S. 2003. Characterization of microbialite-forming cyanobacteria in a tropical lagoon: Tikehau Atoll, Tuamotu, French Polynesia. *Journal Phycology*, **39**:862-873.

ANAGNOSTIDIS, K.; KOMÁREK, J. 1988. Modern Approach to the classification system of cyanophytes 3 – Oscillatoriales. *Archiv für Hydrobyologie Algological Studies*, **80**(1-4):327-472.

ARP, G.; REIMER, A.; REITNER, J. 1999a. Calcification in cyanobacterial biofilms of alkaline salt lakes. *Europe Journal Phycology*, **34**:393-403.

ARP, G.; THIEL, V.; REIMER, A.; MICHAELIS, W; REITNER, J. 1999b. Biofilm exopolymers control microbialite formation at thermal springs discharging into the alkaline Pyramid Lake, Nevada, USA. *Sedimentary Geolology*, **126**:159-176.

ARP, G.; REIMER, A.; REITNER, J. 2002. Calcification of cyanobacterial filaments: *Girvaneila* and the origin of lower paleozoic lime mud: Comment and reply. *Geology*, **30**(6):579-580.

BAETA NEVES, M.H.C.; CASARIN, A.J. 1990. As cianofíceas das salinas de Cabo Frio - Brasil. *Acta Biologica Leopoldensia*, **12**(1):99-123.

BOTTJER, D.J. 2005. Geobiology and the fossil record: eukaryotes, microbes and their interactions. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **219**(1-2):5-21.

BREHM, U.; GORBUSHINA, A.; MOTTERSHEAD, P. 2005. The role microorganisms and biofilms in the breakdown and dissolution of quartz and glass. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **219**(1-2):117-129.

CAUMETTE, P.; MATHERON, R.; RAYMOND, N.; RELEXANS, J.C. 1994. Microbial mats in the hypersaline ponds of Mediterranean salterns (Salins-de-Giraud, France). *FEMS Microbiology Ecology,* **13**:273-286.

DAMAZIO, C.M. 2004. *Tipificação e bioestratificação cianobactériana das esteiras microbianas da borda noroeste da Lagoa Pitanguinha, Holoceno do Rio de Janeiro, Brasil*. Rio de Janeiro, UNIRIO, Monografia de Bacharelado, 171 p.

DAMAZIO, C.M.; SILVA e SILVA, L.H.; IESPA, A.A.C.; SENRA, M.C.E 2005. Correlações entre cianobactérias endolíticas e esteiras microbianas hipersalinas da Lagoa Pitanguinha, Neoquaternário do Rio de Janeiro, Brasil. *Revista Universidade Guarulhos Geociências*, **10**(6):11-16.

DECHO, A.W. 1990. Microbial exopolymer secretions in ocean environments: their role(s) in food webs and marine processes. *Oceanografic Marine Biological Annual,* **28**:73-154.

DECHO, A.W.; VISSCHE, P.T.; REID, R.P. 2005. Production and cycling of natural microbial exopolymers (EPS) within a marine stromatolite. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **219**:71-86.

DÉFARGE, C.; TRICHET, J.; MAURIN, A.; HUCHER, M. 1994. Kopara in Polynesian atolls: early stages of formation of calcareous stromatolites. *Sedimentary Geology*, **89**:9-23.

DRAGANITS, E.; NOFFKE, N. 2004. Siliciclastic stromatolites and other microbially induced sedimentary structures in an early Devonian Barrier-Island environment (Muth Formation, NW Himalayas). *Journal Sedimentary Research*, **74**(2):191-202.

DUPRAZ, C.; PATTISINA, R.; VERRECCHIA, E.P. 2006. Translation of energy into morphology: Simulation of stromatolite morphospace using a stochastic model. *Sedimentary Geology,* **185**:185-203.

EHRLICH, H.L. 2002. *Geomicrobiology*. 4th ed., New York, Marcel Dekker, 768 p.

FOURÇANS, A.; OTEUZA, T.G.; WIELAND, SOLÉ, A.; DIESTRA, E.; BLEIJSWIJK, J.; GRIMALT, J.O; KÜHL, M.; ESTEVE, I.; MUYZER,G.; CAUMETTE, P.; DURAN, R. 2004. Caracterization of functional bacterial groups in a hypersaline microbial mat community (Salins-de-Giraud, Camargue, France). *Microbiology Ecology*, **51**:55-70.

GERDES, G.; KLENKE, T.; NOFFKE, N. 2000. Microbial signatures in peritidal siliciclastic sediments: a catalogue. *Sedimentology*, **47**:279-308.

GIRALT, S.; JULIA, R.; KLERKX, J. 2001. Microbial biscuit of Vaterite in Lake Issyk -Kul (Republic of Kyrgyzstan). *Journal of Sedimentary Research,* **71**(3):430-435.

GUERRERO, R.; PIQUERAS, M.; BERLANGA, M. 2003. Microbial mats and the search for mineral ecosystems. *International Microbiology*, **5**:177-188.

GUERRERO, R.; URMENETA, J.; RAMPONE, G. 1993. Distribution of types of microbial mats at the Ebro Delta, Spain. *BioSystems*, **31**:135-144.

HOFFMAN, P. 1976. Stromatolite morphogenesis in Shark Bay, Western Australia. *In*: M.R. WATER (ed.), *Stromatolites*. *Developments in sedimentogy*. New York, Elsevier Scientific Publishing Company, p. 261-271.

HOFFMANN, P.F. 1974. Shallow and deepwater stromatolites in Lower Proterozoic platform-to-basin facies change, Great Slave Lake, Canada. *American Association of Petroleum Geologists Bulletin,* **58**:856-867.

HORODYSKI, R.J.; BLOESER, B.; HAAR, S.V. 1977. Laminated algal mats from a coastal lagoon, Laguna Mormona, Baja California, Mexico. *Journal of Sedimentary Petrology*, **47**(2):680-696.

IESPA, A.A.C. 2006. *Estudo geomicrobiológico da Lagoa Pernambuco, Região dos Lagos (Estado do Rio de Janeiro)*. Rio de Janeiro, UFRJ, Dissertação de Mestrado, 116 p.

IESPA, A.A.C.; SILVA e SILVA, L.H. 2005. Laminitos microbianos e cianobactérias na Lagoa Pernambuco, Neogeno do Rio de Janeiro, Brasil. *Revista Universidade Guarulhos Geociências*, **10**(6):5-10.

KNAUTH, L.D. 2005. Temperature and salinity history of the Precambrian ocean: implications for the course of microbial evolution. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **219**(1-2):53-69.

KNOLL, A.H. 1989. The paleomicrobiological information in proterozoic rocks. *In*: Y. COHEN; Y. ROSENBERG (eds.), *Microbial mats: Physiological ecology of benthic microbial communities*. Washington, American Society for Microbiology, p. 469-484.

KOMÁREK, J.; ANAGNOSTIDIS, K. 1999. *Süßwasserflora von mitteleuropa band 19/1: Cyanoprocaryota 1. Teil: Chroococcales.* Stuttgart, Gustav Fisher, 548 p.

MARGULIS, L.; BARGHOORN, E.S.; ASHENDORF, D.; BANERJEE, S.; CHASE, D.; FRANCIS, S.; GIOVANNONI, S.; STOLZ, J. 1980. The microbial community in the layered sediments at Laguna Figueroa, Baja California, Mexico: does it have Precambrian analogues? *Precambrian Research*, **1**:93-123.

MARTINEZ-ALONSO, M.; MIR, J.; CAUMETTE, P.; GAJU, N.; GUERRERO, R.; ESTEVE, I. 2004. Distribution of phototrofic populations and primary production in a microbial mat from the Ebro Delta, Spain. *International Microbiology*, **7**:19-25.

PERRY, C.T.; MACDONALD, I.A. 2002. Impacts of light penetration on the bathymetry of reef microboring communities: implications for the development of microendolithic trace assemblages. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **186**:101-113.

PRESCOTT, G.W. 1975. *Algae of western great lakes area*. Iowa, W.M.C. Broun Company Publishers, 997 p.

RAVEN, J.A.; JOHNSTON, A.M.; KÜBLER, J.E.; KORB, R.; MCINRAY, S.G.; HANDLEY, L.L.; SCRIMGEOUR, C.M.; WALTER, D.I.; BEARDALL, J.; CLAYTON, M.N.; VANDERKLIFT, M.; FREDRIKSEN, S.; DUNTON, K.H. 2002. Seaweeds in cold seas. Evolution and carbon acquisition. *Annals of Botany*, **90**:525-536.

REID, R.P.; MACINTYRE, I.G.; STENECK, R.S.; BROWNE, K.M.; MILL, T.E. 1995. Stromatolites in the Exuma Cays, Bahamas: Uncommonly common. *Facies*, **33**:1-18.

REITNER, J.; GAUTRET, P.; MARIN, F.; NEUWEILER, F. 1995. Automicrites in modern marine microbialite. Formation model via organic matrices (Lizard Island, Great Barrier Reef, Australia). *Bulletin Institute Oceanographique Monaco*, **14**:237-264.

REITNER, J.; THIEL, V.; ZANKL, H.; MICHAELIS, W.; WORHEIDE, G.; PGAUTRET, P. 2000. Organic and biogeochemical patterns in cryptic microbialites. *In*: R.E. RIDING; S.M. AWRAMIK (eds.), *Microbial Sediments*. Berlin, Springer-Verlag, p. 149-160.

RIDING, R.E.; LIANG, L. 2005. Geobiology of microbial carbonates: metazoan and seawater saturation state influences on secular trends during the Phanerozoic. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **219**:101-115.

SCHIEBER, J. 1998. Possible indicators of microbial mat deposits in shales and sandstones: examples from the Mid-Proterozoic Belt Supergroup, Montana, USA. *Sedimentary Geology*, **120**:105-124.

SELLEY, R.C.; COCKS, L.R.M.; PLIMER, I.R. 2004. *Encyclopedia of Geology.* Amsterdam, Elsevier, 594 p.

SILVA e SILVA, L.H. 2002. *Contribuição ao conhecimento da composição microbiana e química das estruturas estromatolíticas da Lagoa Salgada, Quaternário do Rio de Janeiro, Brasil*. Rio de Janeiro, UFRJ, Tese de Doutorado, 176 p.

SILVA e SILVA L.H.; IESPA, A.A.C.; DAMAZIO, C.M. 2006. Trombólitos e cianobactérias da Lagoa Pernambuco, Holoceno do Rio de Janeiro, Brasil. *Revista de Biologia e Ciências da Terra*, **6**(2):243-250.

SILVA e SILVA L.H.; SENRA, M.C.E.; FARUOLO, T.C.L.M.; CARVALHAL, S.B.V.; ALVES, S.A.P.M.N.; DAMAZIO, C.M.; SHIMIZU, V.T.A.; SANTOS, R.C.; IESPA, A.A.C. 2004. Estruturas microbianas recentes da Lagoa Pernambuco, Estado do Rio de Janeiro, Brasil. *Revista Brasileira de Paleontologia*, **7**(2):189-192.

SRIVASTAVA, N.K.; ALMEIDA, L.B. 2000. Lagoa Salgada (Rio de Janeiro): recent stromatolites. *In*: INTERNATIONAL GEOLOGICAL CONGRESS*,* 31, Rio de Janeiro, *Field Trip Guide*, UFRJ, 10 p.

TOPORSKY, J.; STEELE, A.; MCKAY, D.S.; WESTFALL, F. 2003. Bacterial biofilms in astrobiology the importance of life detection. *In*: W.E. KRUMBEIN; D.M. PATERSON; G.A. ZAVARZIN (eds.), *Fossil and recent biofilms a nature history of life Earth*. Boston, Kluwer, p.430-445.

URMENETA, J.; NAVARRETE, A. 2000. Mineralogical composition and biomass studies of the microbial mats sediments from the Ebro Delta, Spain. *International Microbiology*, **3**:97-101.

VAN GEMERDEN, H. 1993. Microbial mats: A joint venture. *Marine Geology*, **113**:3-25.

VASCONCELOS, C.O. 1988. *Sedimentologia e geoquímica da Lagoa Vermelha – um Exemplo de formação e diagênese de carbonatos.* Niterói, UFF, Dissertação de Mestrado, 63 p.

WELLE, B.A.; HIRSCH, A.C.; DAVIS, L.E.; JOHNSON, A.C.; HUNT, G.J.; EVES, R.L. 2004. Origin of calcareous sediments in the Holocene Pigeon Creek tidal lagoon and tidal delta, San Salvador Island Bahamas. *American Journal of Undergraduate Research,* **3**(1):1-8.

ZHANG, Y.; HOFFMANN, L. 1992. Blue-green algal mat of the salinas in San-ya, Hai-nan Island (China): structure taxonomic composition and implications for the interpretation of precambrian stromatolites. *Precambrian Research,* **56**:275-290.

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