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Acritarchs of the Ediacaran Frecheirinha Formation, Ubajara Group, Northeastern Brazil

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ABSTRACT

We report for the first time the occurrence of organic-walled microfossils in Ediacaran limestones and marls of the Frecheirinha Formation, Ubajara Group, and the first Precambrian acritarchs so far reported for northeastern Brazil. The assemblage of the Frecheirinha Formation represents a low-diversity microflora comprising *Leiosphaeridia*, *Lophosphaeridium* and subordinated *Bavlinella* (=*Sphaerocongregus*). Their thermal alteration index (TAI) between 4+ and 5, suggests metamorphic temperatures exceeding 200-250°C. Higher temperatures are probably related to intruding granitic plutons (Meruoca, Mucambo). Reported $\delta^{13}C$ values of carbonates of −3.5 ‰ VPDB (Vienna-Peedee Belemnite) at the base, passing up section into a positive plateau of up to +3.7 ‰, and corresponding $^{87}Sr/^{86}Sr$ values between 0.7075 and 0.7080 suggest an Ediacaran age. The acritarch assemblage is comparable to the Late Ediacaran Leiosphere Palynoflora (LELP) or Kotlin-Rovno assemblage, in broad agreement with chemostratigraphic data. Macrofossils belonging to the Ediacara fauna were reported from the overlying Jaibaras Group, which would constrain even further the depositional age of the Frecheirinha Formation to within ca. 575-555 Ma. A more comprehensive palynological study of the Frecheirinha Formation is necessary to confirm this age assignment.

Key words: Acritarchs, Ediacaran, Neoproterozoic, northeastern Brazil.

INTRODUCTION

The Neoproterozoic is characterized by extreme climate change, oscillations in oceanic geochemistry, a significant oxygenation event, and the diversification of the marine biota (Hoffman and Schrag 2002, Willman et al. 2006, Frei et al. 2009, Halverson et al. 2010). Several near-global glacial events ocurred between 740 and 580 Ma, considered as a bottleneck for marine biota evolution (Kaufman and Knoll 1995, Moczydłowska 2008).

Neoproterozoic body fossils have been described for a few successions in Brazil, the most diverse being the assemblage preserved in the late Ediacaran Corumbá Group, Mato Grosso do Sul (e.g. Beurlen

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and Sommer 1957, Zaine and Fairchild 1985, Gaucher et al. 2003, Fairchild et al. 2012 Warren et al. 2012).

Until recently, no Neoproterozoic body fossils were known from northeastern Brazil. Soft-bodied macrofossils typical of the Ediacara Fauna, which can be assigned to the White Sea assemblage (Narbonne 2005), were recently described from the Jaibaras Group, Ceará (Barroso et al. 2014, Figs. 1-2). The Jaibaras Group overlies the Ubajara Group (Fig. 2), which comprises thick carbonates rocks of the Frecheirinha Formation, with an erosional unconformity between the two groups. The Ubajara Group represents a proximal platform sequence, composed, from base to top, of the following formations (Fig. 2a): (a) Trapiá (quartz conglomerate), (b) Caiçara (ferruginous siltstones), (c) Frecheirinha (limestones and subordinate marls) and (d) Coreaú (sandstone and greywacke) located in the Médio Coreaú Domain, Borborema Province. This Domain is characterized by graben and horst structures controlled by NE-trending shear zones, and is bounded to the northeast by the Transbrasiliano Lineament, which separates it from the Ceará Central Domain (Caby et al. 1991, Santos et al. 2008). The age of the carbonate rocks of the Frecheirinha Formation is poorly constrained by C− and Sr-chemostratigraphy and radiometric ages as late Neoproterozoic (Sial et al. 2000, 2003, Chiglino 2013).

In the present work, we describe organic-walled microfossils (acritarchs) from the Frecheirinha Formation, which contribute towards our understanding of the depositional environments, age and thermal overprint of the Ubajara Group. These are the first Precambrian acritarchs reported, so far, from northeastern Brazil.

Lithostratigraphy and Age

The Ubajara Group represents a proximal platform sequence (Costa et al. 1979, Hackspacher et al. 1988), the type area is located along the road BR 222 between Aprazível and Saco towns, roughly 300 km from the city of Fortaleza (state of Ceará; Fig. 1). This sedimentary succession reaches 3000 m in thickness and is composed, from base to top, by:

(a) Trapiá Formation sandstones.
(b) Caiçaras Formation, fine-grained sandstones which pass into red, finely laminated siltstones up section.
(c) Frecheirinha Formation, pink and dark gray limestones and subordinated marls at the base and gray limestones with microbial lamination at the top.
(d) Coreaú Formation, sandstones and graywackes.

The contact between the base of the Ubajara Group and the basement is not exposed, and at the top it is overlain by the Jaibaras Group with erosional unconformity (Oliveira 2000, Santos et al. 2008).

The Frecheirinha Formation is a carbonate unit about 500 m in thickness, the type area is located near the Frecheirinha town and the best exposures are observed at the quarry of the Companhia Cearense de Cemento Portland (CCCP), north of Aprazível. The strata exhibit intense ductile deformation recorded by folds with axes oriented NE-SW and, locally, low grade metamorphism.

Carbonates are characterized by limestones and marly rythmites in the lower part, which pass into dark gray to gray, fine, laminated, stromatolitic limestones at the top. In the Araticum area (Fig. 1), carbonates are composed of fine-grained, calcitic mudstones (grain size: 10 μm; Figs. 3a-b) intercalated with organic-rich marls (Fig. 3a), in which microfossils are preserved. On the other hand, in the Angustura farm region recrystallization of carbonates is evident, and the occurrence of tremolite in the limestones (Figs. 3c-d) indicates that they reached low-grade metamorphic conditions. This metamorphism was probably caused by the nearby Mucambo Granite (Fig. 1) and is not regional in nature.

The Araticum profile, located between the Frecheirinha and the Ubajara village (Fig.1), was

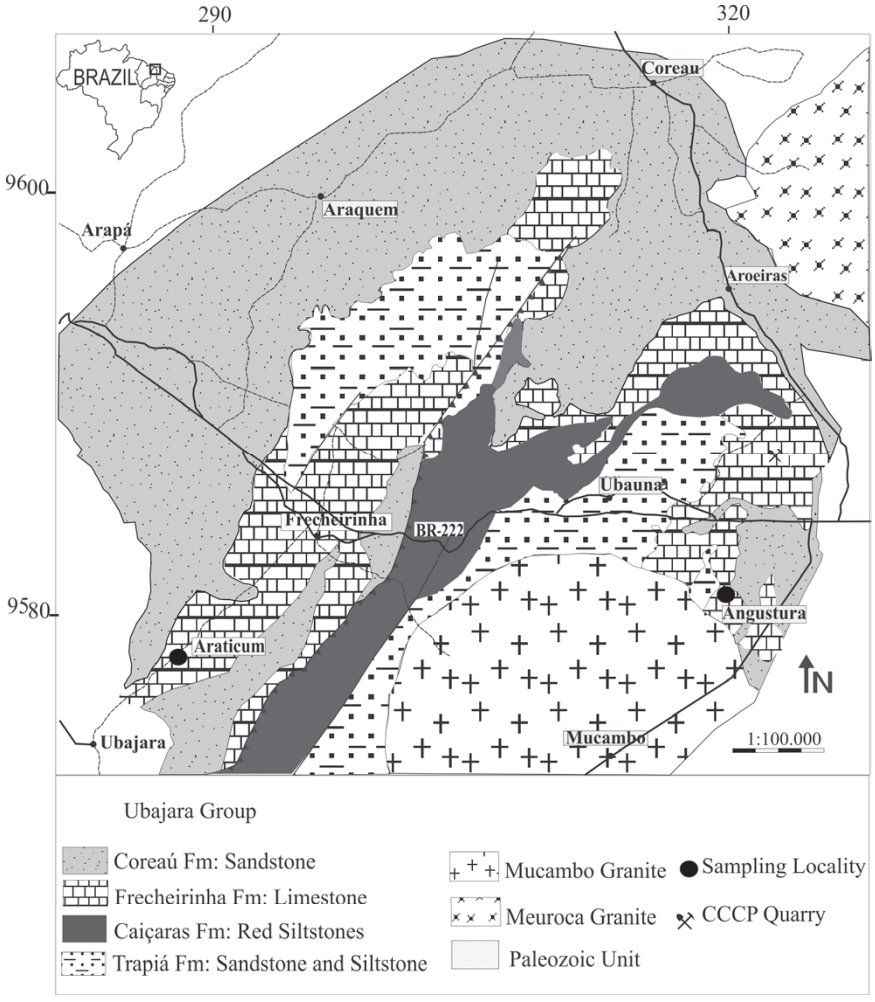

Fig. 1 - Geological map of the studied area, showing the Ubajara Group and sampled outcrops of the Frecheirinha Formation (Araticum Section).

selected for the palynological study because of the lower thermal overprint. There, limestone-marl rhythmites occur at the base, which grade into dark gray to black, finely laminated, organic-rich limestones at the top (Fig. 2).

Barroso et al. (2014) reported the occurrence of probable soft-bodied Ediacaran macrofossils in the overlying Jaibaras Group, similar to the White Sea assemblage, which justify an Ediacaran age for this unit (560-542 Ma: Narbonne 2005, Fedonkin et al. 2007). These biostratigraphic relationships may provide a minimum late Ediacaran age constraint for the Frecheirinha Formation, but it needs a more detailed study to explore the paleontological affinity of the macrofossils described by Barroso et al. (2014) and their relationship to the Ediacara fauna.

The age of the Ubajara Group is still uncertain due to the lack of reliable radiometric ages. The minimum age is constrained by the following ages:

(a) a Rb-Sr age of 562 ± 19 Ma determined for the Coreaú dike swarm, which crosscuts the sequence (Sial and Long 1987),

(b) the Mucambo Granite intrudes the Ubajara Group (Fig. 1) and yielded a U-Pb crystallization age of 532 ± 7 Ma (Santos et al. 2008), and

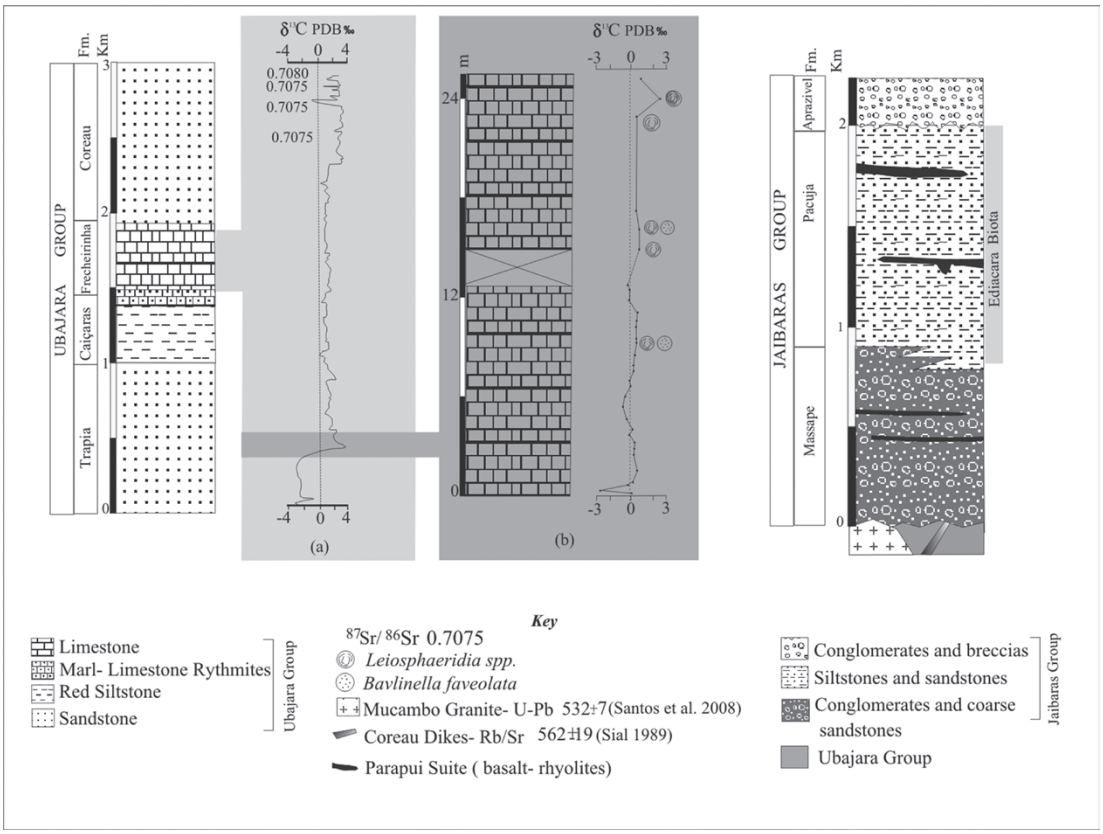

Fig. 2 - Lithostratigraphy of the Ubajara and Jaibaras groups, showing stratigraphic range of fossils occurring in these units. a-Chemostratigraphy ($\delta^{13}C$ and $^{87}Sr/^{86}Sr$) of the entire Frecheirinha Formation (Sial et al. 2003, Chiglino 2013). b-Detail of the stratigraphic interval sampled in this work.

(c) a Rb-Sr age of 540 ± 24 Ma, a U-Pb age of 532 ± 24 Ma (Fetter et al. 2003) and a U-Pb SHRIMP age of 541 ± 5 Ma (Santos et al. 2013) for the Meruoca Granite, which intrudes the group and develops an important contact aureole. The U-Pb SHRIMP age of 541 Ma is considered the best age estimate for the crystallization of the pluton.

Chemostratigraphic data presented by Chiglino (2013, Fig. 2 a and b) show negative $\delta^{13}C$ values of −3.5‰ VPDB at the base, passing up section into a positive excursion with maximum values of +3.7‰. Corresponding $^{87}Sr/^{86}Sr$ values range between 0.7075 and 0.7080 (Sial et al. 2003). Especially the Sr isotope ratios, which were obtained from high-Sr limestones (Sr concentration up to 3500 ppm: Chiglino 2013), favor a latest Cryogenian to Ediacaran depositional age (e.g. Jacobsen and Kaufman 1999, Melezhik et al. 2001, Halverson et al. 2007). However, late Cryogenian successions are often characterized by elevated $\delta^{13}C$ values of up to +8‰ VPDB which drop to negative values before the end-Cryogenian glaciation (Halverson et al. 2005). This pattern is not observed in the Frecheirinha Formation. Instead, a plateau around +3‰ VPDB characterizes most of the unit and post-dates a negative excursion, similar to that observed for the late Ediacaran Nama and Corumbá groups (Grotzinger et al. 1995, Boggiani et al. 2010; Table I). Likewise, a negative excursion followed by moderately positive values is also observed in the late Ediacaran upper Polanco Formation (Arroyo del Soldado Group, Uruguay),

TABLE I

Table showing key correlation features for several Neoproterozoic units dominated by Bavlinella and/or *Leiosphaeridia*. Features shown include radiochronometric constraints (mainly U-Pb), $\delta^{13}C$, $^{87}Sr/^{86}Sr$ and relative. Sources of data: 1: Chiglino 2013 and this work. 2: Germs et al. (1986), Grotzinger et al. (1995). 3: Gaucher (2000), Gaucher and Poiré (2009), Gaucher et al. (2009), Blanco et al. (2009). 4: Gaucher et al. (2003), Boggiani et al. (2010). 5: Mallmann et al. (2007), Gaucher et al. (2008), Oyhantçabal et al. (2009). 6: Grey (2005), Walter et al. (2000), Kendall et al. (2006). 7: Yin and Yuan (2007), Zhang et al. (2008). 8: Germs et al. (2009), Halverson et al. (2005), Hoffman et al. (1996), Hoffmann et al. (2004). 9: Nagy et al. (2009), Karlstrom et al. (2000).

Unit	Absolute ages (Ma)	$\delta^{13}C$carb ‰ V-PDB	$^{87}Sr/^{86}Sr$	Thin-walled Leiosphaeridia	Thick-walled Leiosphaeridia	Bavlinella	Remarks
Frecheirinha Fm.1	>560 Ma	-3.5 to +3.7	0.7075-0.7080	Dominant	Present	Subordinate	
Lower Nama Group2	549-543	-4 to +5	0.7085	Dominant	Common	Subordinate	*Cloudina*
Lower Arroyo del Soldado Group3	<566, >532	-4.5 to +5.5	0.7070-0.7085	Dominant to common	0	Dominant to common	*Cloudina*
Corumbá Group4	>543	-4.5 to +5.5	0.7084-0.7086	Subordinate	0	Dominant	*Cloudina*
Las Ventanas Formation5	590-573	-------	--------	Dominant	0	0	
Lower Pertatataka Formation6	<657 Ma	-3 to +2.5	0.7075-0.7080	Common	Dominant	0	
Datangpo Formation7	663-654	--------	--------	Subordinate	Common	Dominant	
Auros Fm., Otavi Group8	746-636	-6 to +8	0.7072	Present	0	Dominant	
Upper Chuar Group9	>742	--------	--------	Common	Present	Dominant	*Valeria lophostriata, Cerebrosphaera buickii*

which is also associated to $^{87}Sr/^{86}Sr$ values between 0.7070 and 0.7082 (Gaucher et al. 2009, Frei et al. 2011). Thus, the chemostratigraphic data suggest an Ediacaran age as the most probable depositional age of the Frecheirinha Formation, but so far do not allow a more refined geochronology.

MATERIALS AND METHODS

Palynological macerations of carbonates were prepared at the Micropaleontology Laboratory of the Departamento de Geología, Facultad de Ciencias (Montevideo). The method does not use centrifugation or ultrasonic bath to avoid breakage of fragile specimens (e.g. Gaucher et al. 2008). Following crushing and digestion of samples with concentrated HCl, 72% HF was applied for 24h. After neutralization, boiling HCl was applied to remove fluorides formed in the previous step. The remaining solution was diluted with water and the supernatant discarded after allowing at least 30 min for particle settling. The organic residues were recovered by means of a 5 µm sieve, stored in glass flasks and mounted with glycerin-gelatine on standard glass slides. Microfossils were determined under a Leica DM LP polarizing microscope, using both transmitted and reflected light (Pflug and Reitz 1992).

Twelve samples of carbonates and marls of the Frecheirinha Formation at the Araticum section were analyzed. Acritarch preservation was quite poor, mainly due to advanced carbonization, corrosion and fragmentation. Despite the advanced thermal alteration of acritarchs, they could still be classified using reflected light techniques described by Pflug and Reitz (1992).

RESULTS

Preservation and Thermal Alteration

Although entire, fairly well-preserved specimens are common, most of the organic remains are fragmentary and/or corroded to some degree. Moreover, acritarchs exhibit advanced carbonization, showing colors from dark gray to black (Figs. 4-6). Corresponding Thermal Alteration Index (TAI) ranges from 4+ to 5, suggesting metamorphic temperatures exceeding 200-250°C (Teichmüller et al. 1998). It is not yet clear if this metamorphic overprint is of a regional nature or enhanced by the voluminous granitic intrusions affecting the succesion, such as the Meruoca and Mucambo granites (Fig. 1). As we have shown in Figs. 3c-d, contact metamorphism is evident in the Angustrura section near the Mucambo Granite (Fig. 1), but it is uncertain as to how far away from the pluton's edge this thermal overprint reaches.

Although the advanced carbonization of acritarchs hinders, to some extent, their identification, the use of reflected light techniques allows overcoming this dificculties. Thus, the low diversity observed in the Frecheirinha microflora is considered as a primary feature, and not the result of a taphonomic bias.

Systematic Palaeontology

Repository. All palynological slides, containing specimens described here, are kept in the Precambrian collection of the Departamento de Paleontología, Facultad de Ciencias (Montevideo, Uruguay). The position of specimens on the slides are clearly marked on corresponding duplicates.

Incertae sedis

Group Acritarcha Evitt (1963)

Genus *Leiosphaeridia* Eisenack (1958), emend. Downie and Sarjeant (1963), emend. Turner (1984).

Type species: *Leiosphaeridia baltica* Eisenack (1958)

Leiosphaeridia tenuissima Eisenack (1958)

Figs. 4 a-c

1958 *Leiosphaeridia tenuissima* Eisenack: pl. 1.2-1.3

1994 *Leiosphaeridia tenuissima* Butterfield et al.: fig. 16I

1996 *Leiosphaeridia tenuissima* Hofmann and Jackson: figs. 12E

1998 *Leiosphaeridia tenuissima* Gaucher et al.: fig. 4.6

2000 *Leiosphaeridia tenuissima* Gaucher: pl. 11.5

2004b *Leiosphaeridia tenuissima* Gaucher et al.: fig. 4D

2005a *Leiosphaeridia tenuissima* Gaucher et al.: fig. 8g-h

2006 *Leiosphaeridia tenuissima* Gaucher and Germs: figs. 7 d, f-g; 8 b-f

2008 *Leiosphaeridia tenuissima* Gaucher et al.: figs. 3B-I

Material. Slides Arat 29A-1, Arat 29E-7 and Arat 29E-9. Ten fairly well-preserved specimens and fragments in macerations of carbonates, Frecheirinha Formation.

Description. Thin-walled, psilate, originally spheroidal vesicles with common folds. Diameter ranging between 70 and 100 μm (mean=84 μm; N=5). Two different patterns of folding of the walls were observed in the vesicles: (a) simple, psilate sphaeromorphs with mainly concentric folds (Fig. 4.a); and (b) vesicles with a microplicate wall (Figs. 4.b, c).

Remarks. *L. tenuissima* is the most frequent species in the black limestones of the Araticum section, and represents the base of the Frecherinha Formation. Two different wall structures are included here under *L. tenuissima*: one with a thin,

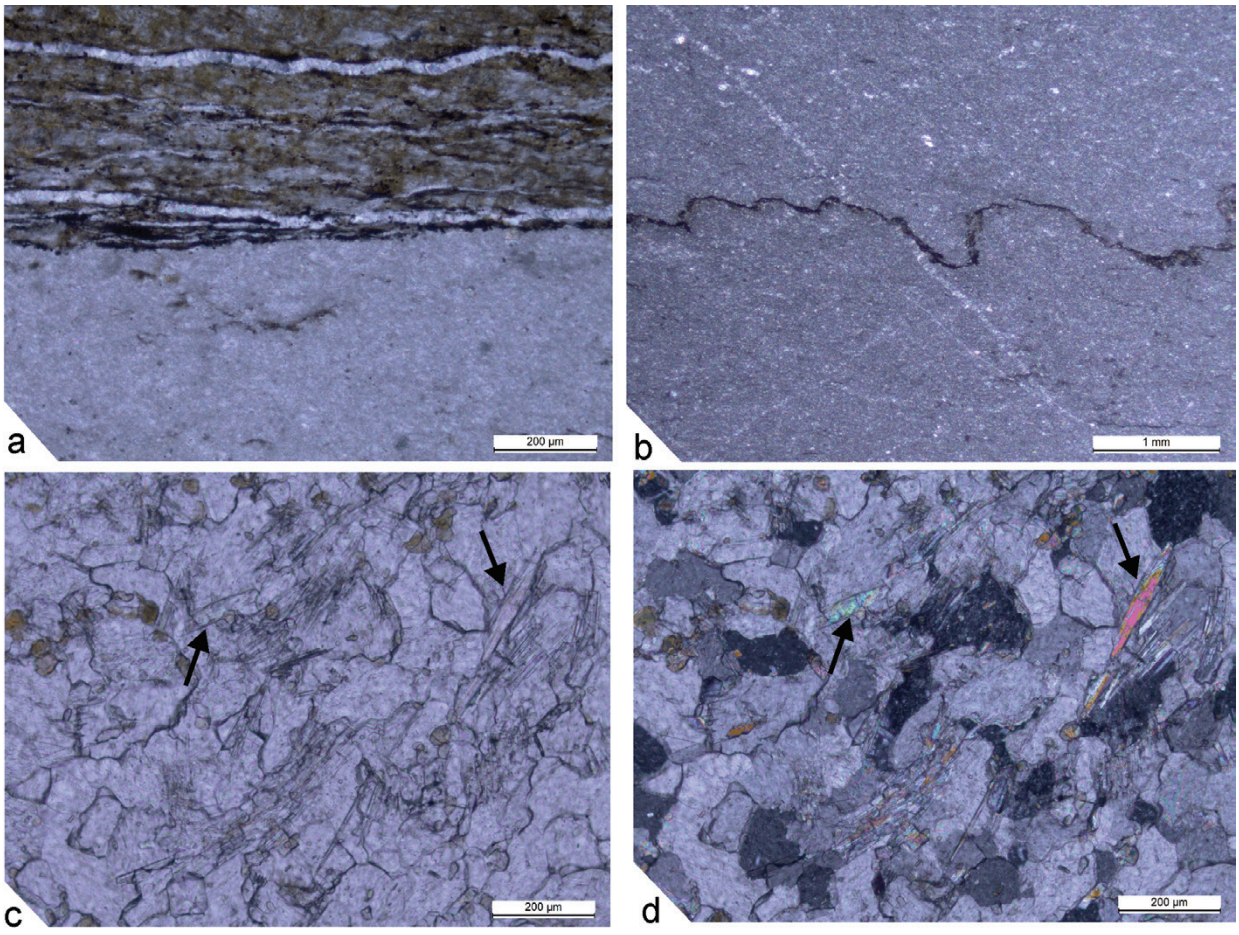

Fig. 3 - Microphotographs of thin sections of carbonates of the Frecheirinha Formation. a-Contact between calcitic mudstone (below) and organic-rich marl, Araticum section, crossed nicols. b-Stylolite in fine-grained limestone (Araticum section), plane-polarized light. c-Recrystallized limestone (marble) from the Angustura section, plane-polarized light. Note tremolite crystals. d-Same as previous, crossed nicols.

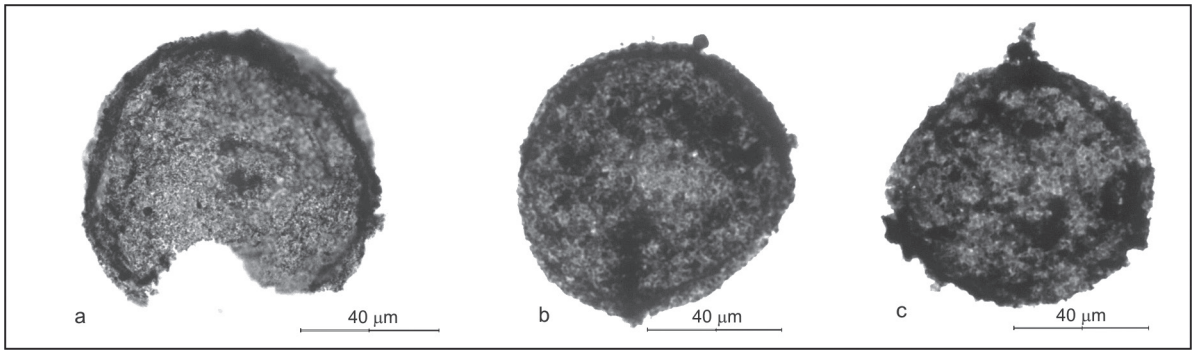

Fig. 4 - Sphaeromorphs of the Frecheirinha Formation recovered from limestones (Araticum Section) by means of standard palynological maceration. a- *Leiosphaeridia tenuissima* Eisenack (1958), specimen Arat 29A-1, b-*L. tenuissima* Eisenack (1958), specimen Arat 29E-9, c-*L. tenuissima* Eisenack (1958), specimen Arat 29E-7.

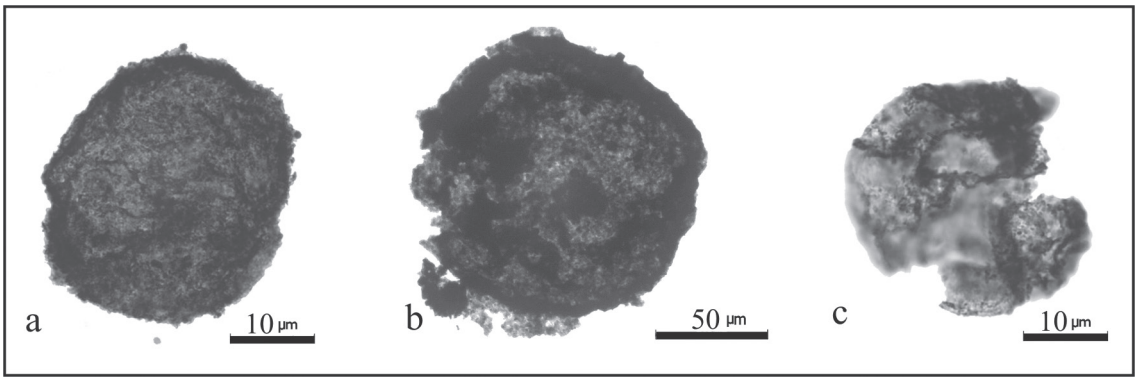

Fig. 5 - a- *Leiosphaeridia minutissima* Naumova (1949), specimen Arat 29A-5, b- *Leiosphaeridia jacutica* (Timofeev 1966), specimen ARAT 29E-8, c- *Lophosphaeridium* sp, specimen 110227/2B-2.

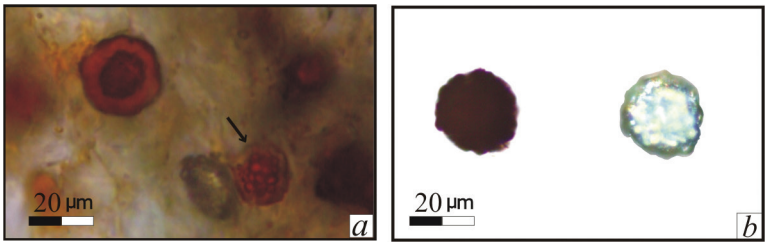

Fig. 6 - a-Thin section of limestone (Araticum section) showing hematized *Bavlinella faveolata* (Schepeleva) Vidal (1976), specimen ARAT 30 (arrowed), b-*Bavlinella faveolata* from a palynological maceration of black limestone, specimen ARAT 29C-8 in transmitted light (left) and in combined reflected-transmitted light (right), showing individual microspheres.

but still competent wall, the other with a very thin, pliable membrane. The same wall structure has been observed in specimens from other Ediacaran units in South America: Las Ventanas Formation of Uruguay (Gaucher et al. 2008), and the Sierras Bayas Group of Argentina (Gaucher et al. 2005b).

Leiosphaeridia minutissima Naumova (1949), emend. Jankauskas et al. (1989)
Fig. 5a

1992 *Leiosphaeridia minutissima* Butterfield and Chandler: figs. 3A-3I
1996 *Leiosphaeridia minutissima* Hofmann and Jackson: figs. 15.9-15.15, 15.16
1996 *Leiosphaeridia minutissima* Hofmann and Jackson: figs. 12A-C
2000 *Leiosphaeridia minutissima* Gaucher: p. 66
2008 *Leiosphaeridia minutissima* Gaucher et al.: fig. 3A

Material. Slides ARAT 20B, 29A-5, 29B, 34A and 35A, few specimens and vesicle-fragments in palynological macerations of carbonates, Frecheirinha Formation.

Description. Thin-walled and psilate, originally spheroidal vesicles with common, irregular to concentric folds. Diameter ranging from 40 to 70 µm (mean= 57 µm; N=3; Fig. 4.a).

Remarks. The specimens show irregular folds on the wall which appear as darker patches and soft waves. Here we applied the criteria established by Jankauskas et al. (1989) for the classification of leiospherids. This taxon occurs as a subordinate component of the microbiota of Frecheirinha Formation.

Leiosphaeridia jacutica (Timofeev 1966) emend. Mikhaylova and Yankauskas in Jankauskas et al. 1989
Fig. 5b

1989 *Leiosphaeridia jacutica* Mikhaylova and Jankauskas (in Jankauskas et al. 1989): fig 3a,b,7,9
1994 *Leiosphaeridia jacutica* Butterfield et al.: fig. 16H

Material. Four carbonized specimens in palynological macerations, Araticum Section (sample ARAT 29).
Description. Several thick-walled, spheroidal vesicles, characteized by a rough surface, concentric folds and diameter roughly between 100 and 200 µm. Most specimens are opaque in transmitted light, and only a few are translucent (Fig. 5b).

Remarks. The thicker walls compared to *L. tenuissima* cause the opaqueness of the vesicles. The species is a common constituent of Neoproterozoic microbiotas worldwide.

Genus *Lophosphaeridium* Timofeev (1959), ex Downie (1963), emend. Lister (1970)
Lophosphaeridium sp.
Fig. 5c

Material. Poorly preserved and few specimens in palynological maceration 110227/2B-2 of carbonates in the Araticum Section.

Description. Robust-walled vesicles with verrucate, plicated surface. Verrucae are less than 1 µm in diameter. Folds are prominent and the diameter of the only complete specimen observed is 46 µm. (Fig. 5.c)

Remarks. These sphaeromorphs are left in open nomenclature because of the small number of specimens observed and due to their poor preservation. Although we cannot totally rule out that these are degraded (corroded) *Leiosphaeridia* specimens, the regularity of the verrucae suggests that they are original structures and not taphonomic artifacts. The microfossils described under this taxon are similar to those reported by Gaucher et al. (2008) under *Lophosphaeridium* sp. for the Las Ventanas Formation (Uruguay).

Kingdom Eubacteria Woese and Fox (1977)
Phyllum Cyanobacteria Stanier et al. (1978)
Classis, Ordo et Fam. indet.

Genus *Bavlinella* (Schepeleva) Vidal (1976)
Type species. *Bavlinella faveolata* (Schepeleva) Vidal (1976)

Bavlinella faveolata (Schepeleva) Vidal (1976)
Fig. 6

1974 *Sphaerocongregus variabilis* Moorman: pls. 1-3
1976 *Bavlinella faveolata* Vidal : figs. 7A-C
1992 *Bavlinella faveolata* Schopf : pl. 54-J
2000 *Bavlinella faveolata* Gaucher: pl. 9, pl. 18.1-18.2
2003 *Bavlinella faveolata* Gaucher et al.: figs. 5C-H, 6F
2005a *Bavlinella faveolata* Gaucher et al.: figs. 6a-i
2006 *Bavlinella faveolata* Gaucher and Germs: figs. 6a-o, 7a-c
2009 *Sphaerocongregus variabilis* Nagy et al., figs. 1m-n

Type specimen. German et al. (1989) designated a lectotype for the species from the Kotlin Formation of the former USSR. This lectotype has also been illustrated by Schopf (1992: pl. 54-J). Therefore, the valid designation of a lectotype supersedes any previous restriction of the application of the name of the genus and species *Bavlinella faveolata*. *Sphaerocongregus variabilis* Moorman (1974) is thus to be considered as a junior synonym (Vidal 1976, Gaucher et al. 2003).

Material. Seven specimens occur both in thin section ARAT 30 and palynological macerations (ARAT 20, 29C and 35B) of carbonates from the Frecheirinha Formation

Description. The observed specimens were mainly single spheroidal vesicles made up of tens of tightly-packed, micron-sized (1-2 µm) microspheres (Fig. 6.a), thus corresponding to the endosporangia morphotype of Moorman (1974). Two types of preservation were observed: carbonized remains,

mainly occurring in macerations, and hematized specimens (only in thin sections). Both types of preservation are common for the species (e.g. Gaucher 2000, Gaucher et al. 2003, Gaucher and Germs 2006). Diameter of vesicles ranges between 5 and 20 μm (mean=12 μm, N=17).

Remarks. *B. faveolata* is a subordinate component in the acritarch assemblage, which is clearly dominated by leiosphaerids. However, a few organic-rich marl layers preserve mass occurrences of *B. faveolata*, which is a common feature of the species (Moorman 1974, Gaucher and Germs 2006, Nagy et al. 2009).

DISCUSSION

The low-diversity fossil assemblage of the Frecheirinha Formation comprises *Leiosphaeridia, Lophosphaeridium and* subordinated *Bavlinella faveolata (=Sphaerocongregus variabilis)*. Both *Leiosphaeridia* and *Bavlinella* are long-ranging microfossils, but occur as an assemblage (Table I) in the Cryogenian (e.g. Knoll et al. 1981, Nagy et al. 2009, Yin and Yuan 2007) early and late Ediacaran successions, worldwide (e.g. Germs et al. 1986, Gaucher et al. 2003, 2008, Gaucher and Germs 2006, Grey et al. 2003).

The Cryogenian occurrences are usually characterized by a strong dominance of *Bavlinella faveolata* in almost monospecific assemblages. Examples in North America are the Mineral Fork Formation from Utah, USA (Knoll et al. 1981) and its correlative Uinta Mountain Group in the same region (Nagy and Porter 2005), and the upper Chuar Group (Nagy et al. 2009). All these units are constrained to the lower Cryogenian, between 770 Ma and 740 Ma (Table I, Nagy et al. 2009, Link and Christie-Blick 2011). Similar, *Bavlinella*-dominated assemblages occur just prior to the end-Cryogenian glaciation (Table I) in the Otavi Group in Namibia (Germs et al. 2009) and in the Datangpo Formation in South China (Yin and Yuan 2007). Again in these cases, *Bavlinella faveolata* strongly dominates the assemblages, unlike the Frecheirinha assemblage, in which *Bavlinella* is a subordinated component. Furthermore, vase-shaped microfossils (VSM's) and other acritarchs occur in the Cryogenian assemblages (Nagy and Porter 2005, Huntley et al. 2006, Nagy et al. 2009), such as *Cerebrosphaera*, *Valeria* and *Trachysphaeridium*, none of which occur in the Frecheirinha Formation.

The evolution of acritarchs in the Ediacaran (ca. 635-541 Ma) can be divided into three phases (Gaucher and Sprechmann 2009, and references therein):

The Ediacaran Leiosphere Palynoflora (ELP; Grey 2005), re-named as Early Ediacaran Leiosphere Palynoflora (EELP: Gaucher and Sprechmann 2009), which is characterized by *Leiosphaeridia*-dominated assemblages, typically with large acritarchs >200 μm in diameter, and with abundance of the thick-walled *Leiosphaeridia crassa* (Grey 2005). *Bavlinella faveolata* –if present at all- is a subordinated component and acanthomorphs are absent. This assemblage occurs in successions deposited after the end-Cryogenian glacial event (635 Ma), and before the Gaskiers glacial event at ca. 580 Ma (Liu et al. 2013).

The Ediacaran Complex Acanthomorph Palynoflora (ECAP: Grey et al. 2003, Grey 2005), best represented in China and Australia (Zang and Walter 1992), but also known from other sections (e.g. Sergeev et al. 2011, Moczydlowska and Konstantin 2012) is made up of a diverse assemblage of spiny acritarchs (acanthomorphs). It has been recently divided into a lower *Tianzhushania spinosa*-assemblage, only represented in the lower Doushantuo Formation, and an upper, more widespread *Tanarium anozos-Tanarium conoideum* assemblage (Liu et al. 2013). The stratigraphic distribution of the ECAP is narrow, possibly representing between 5 and 15 Myr (Grey 2005).

The Late Ediacaran Leiosphere Palynoflora (LELP; Gaucher and Sprechmann 2009) or Kotlin-Rovno assemblage of Vidal and Moczydlowska-Vidal

(1997), marks a late Ediacaran crisis, represented by a low-diversity assemblage, characterized mainly by thin-walled Leiosphaeridia spp., more or less abundant Bavllinela faveolata, colonial microfossils of the genus Soldadophycus and small acanthomorphs of the genus Asteridium. Soft-bodied and skeletal metazoans co-occur with the depauperate acritarch assemblage. This assemblage spans the period between ca. 575-560 Ma and the Neoproterozoic-Cambrian boundary at 541 Ma (Gaucher and Sprechmann 2009).

Two Ediacaran acritarch assemblages resemble the Frecheirinha microflora, namely the EELP and LELP. The abundance of thin-walled *Leiosphaeridia* spp., less abundance of *Bavlinella* and complete absence of ECAP acanthomorphic acritarchs suggest an assignment of our fossil material to the Late Ediacaran Leiosphere Palynoflora (LELP). On the other hand, there are similarities with the Early Ediacaran Leiosphere Palynoflora (EELP). However, the absence of *Leiosphaeridia crassa*, the main taxon of the EELP (Grey 2005), and the common occurrence of *Bavlinella* militate against an assignment of the Frecheirinha microflora to the EELP. The closest counterparts of the Frecheirinha acritarchs are assemblages from (Table I) the Corumbá Group in the southern Paraguay Belt, Brazil (Gaucher et al. 2003), the Arroyo del Soldado Group in Uruguay (Gaucher 2000, Gaucher and Poiré 2009) and the Nama Group in southern Africa (Germs et al. 1986), all of which are younger than 565 Ma. They represent impoverished acritarch assemblages dominated by thin-walled *Leiosphaeridia* with occurrence of *Bavlinella faveolata*. Furthermore, all the mentioned units share similar C and Sr isotope composition of carbonates with the Frecheirinha Formation (Table I).

The apparent absence in the Ubajara Group of clear glacial deposits and sedimentary features typical of post-glacial cap carbonates (Hoffman and Schrag 2002) do not allow us to relate the Frecheirinha Formation to any glacial event, which fits a late Ediacaran age. Sedimentological evidence of such an event is so far lacking. Chemostratigraphic studies of the carbonates (Sial et al. 2003, Chiglino 2013) reported negative $\delta^{13}C$ values (−3.5 ‰) at the base of the unit that may be related to periods of low plankton bioproductivity or sea level fluctuations (Gaucher et al. 2004a, Frei et al. 2011). The dark gray to black, laminated limestones of the Araticum section, start with a negative $\delta^{13}C$ excursion (−3 ‰), followed by positive values up to +3 ‰ for the rest of the unit, and the samples analyzed in this study come from the interval with positive $\delta^{13}C$ values.

CONCLUSIONS

The low-diversity microflora comprising *Leiosphaeridia, Lophospheridium* and subordinated *Bavlinella*, found in carbonates of the Frecheirinha Formation, is here assigned to the Late Ediacaran Leiosphere Palynoflora (LELP), and suggests a depositional age between ca. 575 and 541 Ma. These are the first Precambrian acritarchs, reported so far, from northeastern Brazil. Their thermal alteration index (TAI) between 4+ and 5, suggests metamorphic temperatures exceeding 200-250°C. Even higher temperatures, recorded at the Angustura section, are probably related to contact metamorphism of the nearby Mucambo pluton. $\delta^{13}C$ values of carbonates of −3.5 ‰ VPDB at the base, passing up section into a positive plateau of up to +3.7 ‰, and $^{87}Sr/^{86}Sr$ values between 0.7075 and 0.7080 (Chiglino 2013) are in broad agreement with a late Ediacaran age for the Frecheirinha Formation. Given the intruding Meruoca Granite that yielded an U-Pb SHRIMP age of 541 ± 5 Ma (Santos et al. 2013) and the reported occurrence of macrofossils of the Ediacara Fauna in the overlying Jaibaras Group (Barroso et al. 2014), the depositional age of the Frecheirinha Formation may be further constrained to between 575-555 Ma. A more comprehensive palynological study of the Frecheirinha Formation is necessary to confirm this age assignment.

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RESUMO

São descritos neste estudo, pela primeira vez, a ocorrêcia de microfósseis de parede orgânica e primeiros acritarcos do Nordeste do Brasil em calcáreos e margas Edicaranos da Formação Frecheirinha, Grupo Ubajara. A assembleia fóssil da Formação Frecheirinha representa uma microflora de baixa diversidade, englobando *Leiosphaeridia*, *Lophosphaeridium* e *Bavlinella* (=*Sphaerocongregus*) subordinada. O índice de alteração térmica (TAI) entre 4+ e 5, sugere temperaturas metamórficas superiores a 200-250°C. Temperaturas mais altas provavelmente estão relacionadas à intrusão dos plútons graníticos (Meruoca, Mucambo). Valores negativos de $\delta^{13}C$ de -3,5 ‰ VPDB (Vienna-Peedee Belemnite) nos carbonatos da base, um patamar de valores positivos de +3,5 ‰ nos carbonatos da base, um patamar de valores positivos de +3,5 ‰ nas seções do topo e os correspondentes valores de $^{87}Sr/^{86}Sr$ entre 0,7075 e 0,7080 foram reportados sugerindo idade Ediacarana. A assembleia de acritarcos é comparável a denominada Late Ediacaran Leiosphere Palynoflora (LELP) ou assembleia Kotlin-Rovno em concordância com os dados quimioestratigráficos. Macrofósseis pertencentes à Fauna Ediacara foram relatados no sobrejacente Grupo Jaibaras, que limitaria ainda mais a idade de deposição da Formação Frecheirinha entre ca, 575-555 Ma. Estudos palinológicos mais abrangentes da Formação Frecheirinha são necessários para confirmar a idade atribuída.

Palavras-chave: Acritarcos, Ediacarano, Neoproterozóico, nordeste do Brasil.

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