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Calcareous algae from Upper Albian – Cenomanian strata of the Potiguar basin (NE Brazil)

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ABSTRACT

Calcareous Albian-Cenomanian strata in the Potiguar basin yield a number of microfossils, among which are calcareous algae (Dasycladales and Corallinales). This data, together with an inventory of previous discoveries, enabled the discussion of their biogeography. These benthic organisms probably came from the early Central Atlantic Ocean through its northwestern neck between Africa and South America and thus reached the early South Atlantic platforms.

Keywords: calcareous algae, Albian, Cenomanian, Potiguar Basin, Brasil, biogeography

1. INTRODUCTION

Calcareous algal remains are common components of mid-Cretaceous shallow-water carbonate rocks in Brazilian sedimentary basins. However, here, as in the other basins of the southern hemisphere, they are poorly documented. This study focuses on the fossil algae found in an offshore well of the Potiguar Basin, north of Macau (Fig. 1). The cursory inventory of the fossil algal assemblage in this area is supplemented by a discussion of earlier published records regarding the early South Atlantic Ocean.

2. GEOLOGIC AND STRATIGRAPHIC SETTINGS

Cretaceous outcrops of shallow-water marine carbonates are known only from northeastern Brazil, (*e.g.*, the Sergipe, Pernambuco-Paraiba, Araripe, and Potiguar basins). In the subsurface, these carbonate successions, attaining hundreds of metres in thickness, were identified from seismic and well-logging data. This is also the case offshore on the continental margin between latitudes 28° and 2° S, where they are of Albian age in southern, southeastern and eastern tracts (*i.e.*, the Santos, Campos, Espírito Santo, and Jequitinhonha basins), and of Albian to Campanian age in northeastern and equatorial areas (*e.g.*, the basins listed above plus the Barreirinhas Basin).

The studied material comes from a Petrobrás exploration well (Fig. 1) drilled through the Albian-Cenomanian carbonate sequence of the Ponta do Mel Formation (TIBANA & TERRA, 1981). According to DIAS-BRITO (1985), the upper part of the lower Ponta do Mel Formation, of Early to Middle Albian age, represents low-energy "deep-water" mud-dominated fabrics: mudstone and wackestone facies with planktonic foraminifera (hedbergellids and *Favusella washitensis*) and pithonellids. The upper Ponta do Mel, Late Albian to Cenomanian in age, displays mainly high-energy "shallow-water" grain-dominated fabrics: ooid-oncoidal grainstone and packstone facies commonly with red algae (and a few benthic foraminifera: *Andersenolina* sp. and lituolids), and locally with algal (rhodalgal) biolithites (TIBANA & TERRA, 1981; TERRA, 1990; TERRA & LEMOS, 1999). The boundary between these sub-units of the

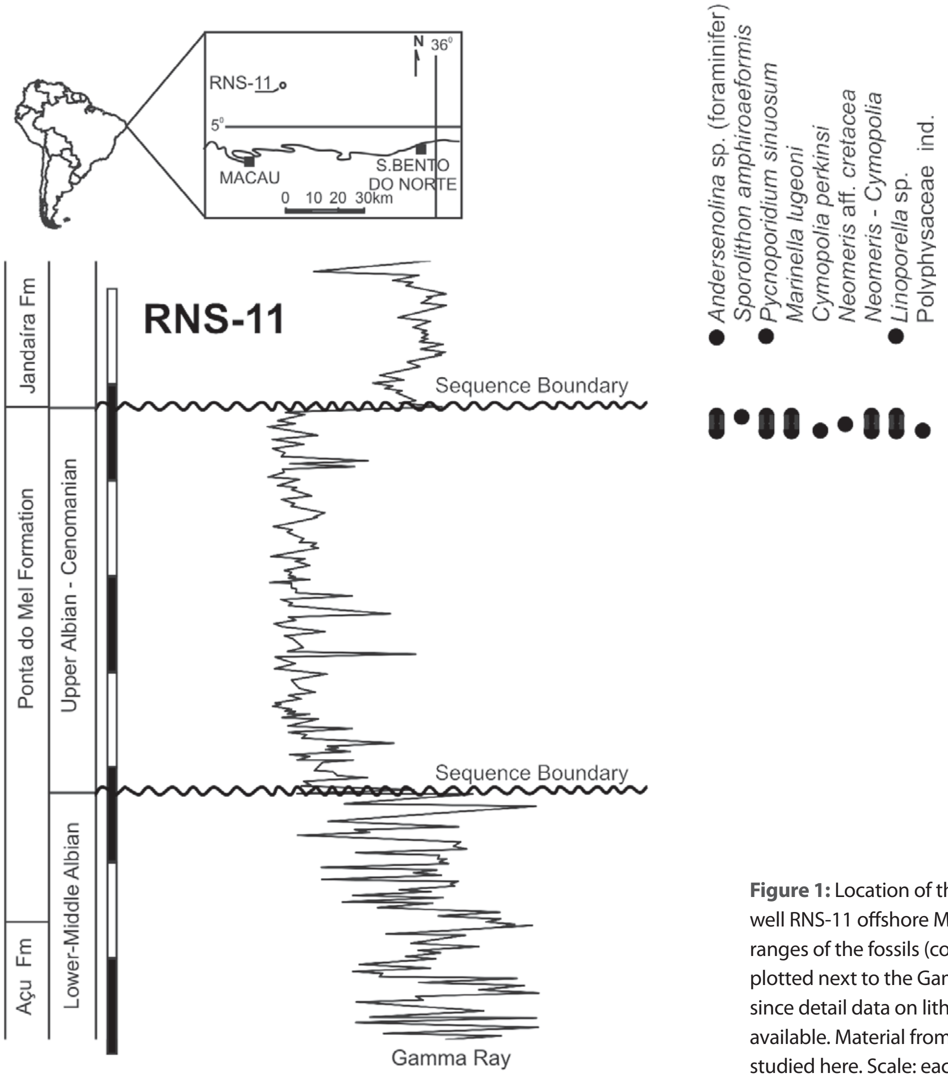


Figure 1: Location of the studied exploration well RNS-11 offshore Macau. The observed ranges of the fossils (cored interval only) are plotted next to the Gamma-Ray well log, since detail data on lithology are not available. Material from İandaira Fm. is not studied here. Scale: each interval = 100 m.

Ponta do Mel Formation appears to record a rapid lowering of sea level, that is a forced regression; it is therefore interpreted as being a major sequence boundary.

The studied material consists of 31 thin sections that were cut from cores taken in the uppermost part of the Ponta do Mel Formation (Fig. 1); consequently it is possible that the fossils described are all of Cenomanian age.

3. PRELIMINARY INVENTORY OF THE BRAZILIAN MID-CRETACEOUS ALGAE

Division Chlorophyta
Class Chlorophyceae KÜTZING, 1843
Order Dasycladales PASCHER, 1931
Family Triploporellaceae (PIA, 1920)
Tribe Triploporelleae (PIA, 1920)
Sub-Tribe Linoporellinae PIA, 1927
Genus *Linoporella* STEINMANN, 1899
***Linoporella* sp.**
(Pl. 1, Figs. B & E)

The type species *L. capriotica* (OPPENHEIM, 1899) was recently revised by BARATTOLO & ROMANO (2005). Our specimens present affinities with the named species: a rather short and thin primary, rather long and thin secondary's, and tertiaries that are rather short and thin. This material is very fragmentary and does not allow more precise identification.

Tribe Salpingoporelleae BASSOULLET et al., 1979
Sub-Tribe Salpingoporellinae BASSOULLET et al., 1979
Genus *Holosporella* PIA, 1930
***Holosporella nkossaensis* P. MASSE, 1995**
(Pl. 2, Fig. F)

As in the type-specimens of this poorly known form, calcification in our material is rather weak and the structures are in part masked by micritization.

Family Dasycladaceae KÜTZING, 1843
Tribe Dasycladeae PIA, 1920
Sub-Tribe Cymopoliinae
Genus *Cymopolia* J.V. LAMOUROUX, 1816
***Cymopolia perkinsi* JOHNSON, 1968**
(Pl. 1, Fig. C)

First described from Texas, this species was probably illustrated from the Congo as "*Dasycladacea* ind." in P. MASSE (1995; pers. comm., 2008). It has strong calcification along the main axis and on the outer end of the laterals (around the fertile ampulla and the surrounding sterile secondaries).

Remarks: Specimens illustrated by TERRA (1990: Fotos 18–19) and ascribed to *Actinoporella* should not be referred to that genus but are representatives of *Cymopolia*.

Sub-Tribe Neomeriineae
Genus *Neomeris* J.V. LAMOUROUX, 1816

Neomeris is very common in our material and presents two patterns for the position of the fertile ampulla: it is either set between two sterile secondaries, as in the sub-genus *Neomeris*, or both sterile secondaries are below the associated ampulla, as in the sub-genus *Larvaria*. Their identification at the species level is barely feasible in thin section, (the most complete delineations were obtained from washed samples of unconsolidated Cenozoic sediments).

Neomeris (*Neomeris*) sp.
(Pl. 1, Fig. A; Pl. 2, Fig. I)

Neomeris cretacea which was revised by BARATTOLO (1990) is in this first group. It was not discovered in the Potiguar basin, but it is known from the neighbouring Sergipe basin (GRANIER et al., 1991a, 1991b).

Neomeris (*Larvaria*) sp.
(Pl. 2, Fig. H)

Some representatives of this sub-genus are found in the Potiguar basin.

Family Polyphysaceae KÜTZING, 1843
Indeterminate Polyphysaceae
(Pl. 1, Figs. D, F)

The available material is poorly calcified and suffered micritization which partly masks the structures.

Division Rhodophyta
Class Rhodophyceae RABENHORST, 1863
Order Corallinales SILVA & JOHANSEN, 1986
Family Sporolithaceae VERHEIJ
Genus *Sporolithon* HEYDRICH, 1897
Sporolithon sp.
(Pl. 2, Fig. C)

Occurrences and records of the genus are rare in the South American scientific literature. TERRA (1990) illustrated a form (*op. cit.:* "Foto 9") from the Ponta do Mel Formation of the Potiguar basin that he ascribed to the "coralináceas" and which we find to be is a genuine *Sporolithon* (the photomicrograph clearly documents the existence of sori). SRIVASTAVA (1982a; figs. 23–24) illustrated *Archaeolithothamnium*, a synonym for *Sporolithon*; but his specimens are younger for they were discovered in the Jandaíra Formation. Similarly a specimen illustrated by BERTHOU & BENGSTON (1983, pl. 3, fig. 3–4) from the Cotinguiba Formation in the Sergipe-Alagoas Basin is of Coniacian age. The occurrence of sori in some poorly preserved specimens allows us to ascribe them to this genus.

Sporolithon amphiroaeformis (ROTHPLETZ,1891)
(Pl. 2, Figs. D, G)

The material includes a non-geniculate (= unarticulated) encrusting coralline. Its thallus has fructicose branches, for most sections cut through finger-like protuberances. Some sections display unisporangial conceptacles (sori), a reproductive feature known only from the Family Sporolithaceae. However, regarding the internal structure, the monomerous thallus displays core cells with a coaxial arrangement (*i.e.* core cells arranged in tiers). This growth pattern is rather rare in the genus *Sporolithon* as most representatives have central cores of non-coaxial filaments (WOELKERLING, 1988). There are few records of coaxial growth: for instance, TOWNSEND et al., (1995; WOELKERLING, pers. comm. 2008) reported that both coaxial and non-coaxial growths occur in *Sporolithon durum* (FOSLIE).

To confirm our identification of the species, the material was compared with topotypic material, from "la Cadière, dans le bassin du Beausset", Var, France, available from the collections of Mme P. LEMOINE (1917) and J. PFENDER (1926).

Family Hapalidiaceae J.E. GRAY, 1864
Subfamily Melobesioideae BIZZOZERO, 1885
Genus *Lithothamnion* HEYDRICH, 1897

We did not find representatives of this genus in the Potiguar basin, but they are known from the neighbouring Sergipe basin. Most specimens ascribed to *Lithothamnium angolense* ROMANES, 1916, in the study of the Sergipe basin by GRANIER et al. (1991b), represent an undetermined species of *Lithothamnion* but cannot be ascribed expressly to *L. angolense* (which is a synonym for *Marinella lugeoni* PFENDER, 1926). Some illustrated sections (*op. cit.*: pl. 2, figs. 1, 3, 5–6; pl. 3, fig.1) exhibit the multiporate conceptacles that are known to host asexual reproductive organs, a characteristic feature of the Family Hapalidiaceae.

Family Solenoporaceae PIA, 1927

The current taxonomic knowledge of the other fossil Rhodophytes requires a major revision which is beyond the scope of the present study. The re-study of the type-material of species ascribed to the genera *Solenopora*, *Parasolenopora*, *Pseudosolenopora*, *Parachaetetes*, will probably reveal a number of erroneous generic ascriptions as well as a number of synonyms. However, there are three discrete species that were easy to identify.

Genus *Elianella* PFENDER & BASSE, 1947
Elianella elegans PFENDER & BASSE, 1947
(Pl. 2, Fig. E)

Elianella consists of more or less stacked files of cells, transverse sections of which are polygonal or circular depending on the degree of amalgamation. Within a filament, individual cells are barrel-shaped and the wall between two successive cells looks like a watch glass, *i.e.* it is curved outward (in the direction of growth). Cells of discrete filaments may be arranged in regular rows.

Genus *Pycnoporidium* YABE & TOYAMA, 1928
Pycnoporidium sinuosum JOHNSON & KONISHI, 1960
(Pl. 2, Fig. B)

Pycnoporidium is characterized by stacked sinuous (*vide* specific name) files of cells. It is a major contributor to limestone sedimentation.

PLATE 1

A *Neomeris* (*Neomeris*) sp.: oblique section.

B, E *Linoporella* sp.: oblique section.

C *Cymopolia perkinsi*: oblique section.

D–**F** Polyphysaceae ind., D: subaxial section, F: subtransverse section.

Figures A & C are at the same scale –500 µm; Figures B & D–F are at another scale –500 µm.

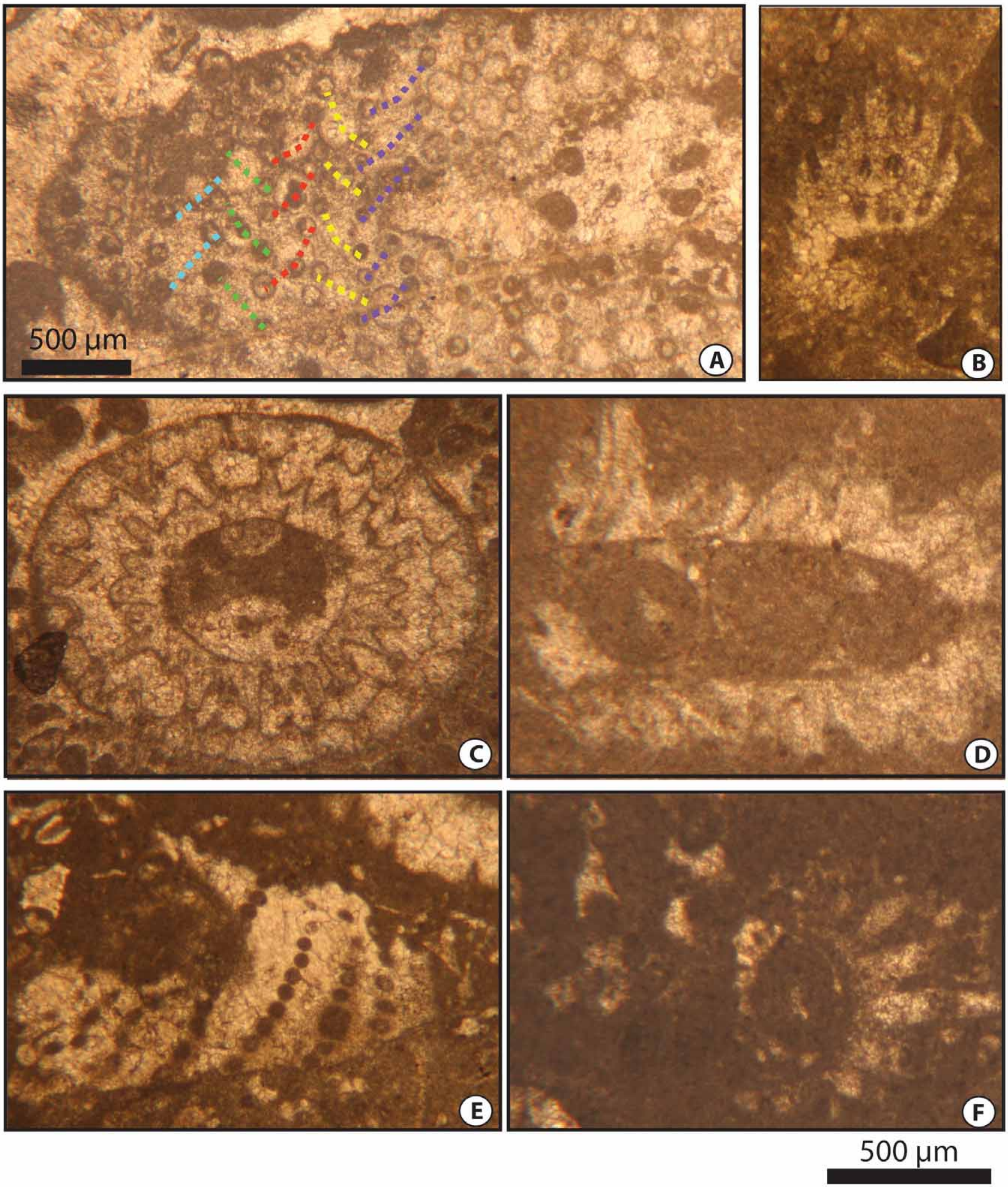

500 µm
A
B
C
D
E
F
500 µm

PLATE 2

A *Marinella lugeoni* ("bouffées de pipe").

B *Pycnoporidium sinuosum*.

C *Sporolithon* sp. (with typical sori).

D *Sporolithon amphiroaeformis* (left) and *Andersenolina* sp. (right).

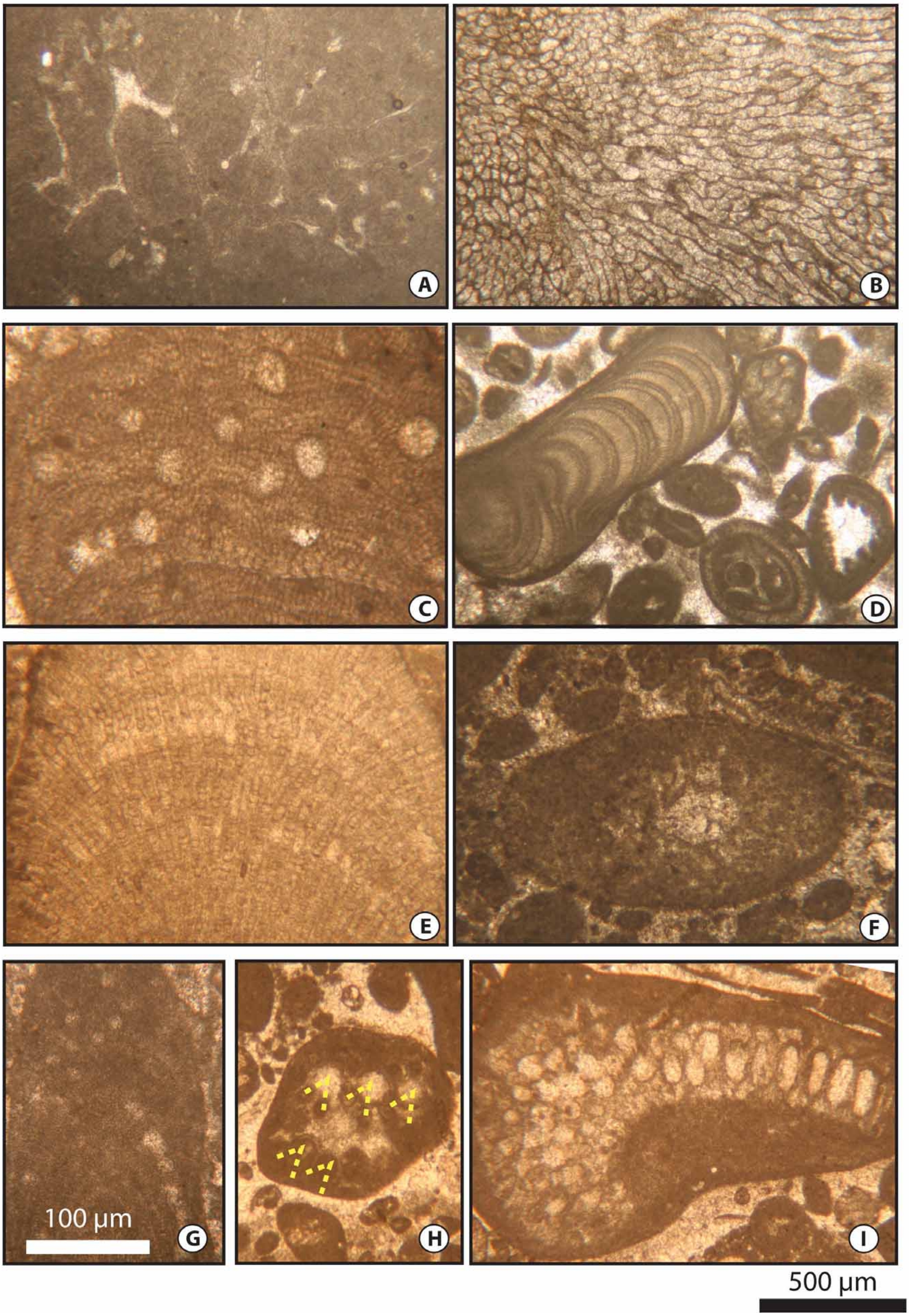
E *Elianella elegans;* **F)** *Holosporella nkossaensis*: oblique section.

G *Sporolithon amphiroaeformis* (with typical sori).

H *Neomeris* (*Larvaria*) sp.: tangential section.

I another *Neomeris* (*Neomeris*) sp.: oblique section.

All figures, except G – 100 µm, are at the same scale –500 µm.


A
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100 µm
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Genus *Marinella* PFENDER, 1939
Marinella lugeoni PFENDER, 1939
(Pl. 2, Fig. A)

The filaments are narrower and they display constrictions at regular intervals (without true walls as illustrated by BARATOLLO & DEL RE, 1985). The typical shape of the thallus is that of a puff of pipe smoke (*"bouffée de pipe"*).

4. DISCUSSION OF THE BIOGEOGRAPHIC RESULTS

Though the assemblage contains representatives of many algal families (Triploporellaceae, Dasycladaceae, Polyphysaceae, Sporolithaceae, Hapalidiaceae, and Solenoporaceae), its diversity is very low, each family being represented by one or rarely two genera or species. But we remain very cautious about coming to any definite conclusion on the diversity issue for some well-known species, such as *Polystrata alba* (PFENDER, 1926), a Gigartinale which occurs in both Congo and Nigeria, were not identified in the Potiguar basin. Their absence may only be because of the sparseness of adequate sampling.

In addition, in South America, with the exception of the Potiguar basin, there are very few data available on palaeophycological occurrences. Also, some records are erroneous: for instance, the Dasycladales illustrated by LEGUIZAMON et al. (1993) are bryozoans. However a synthesis of earlier discoveries and the results of this preliminary inventory, provides some keys to an understanding of the observed patterns.

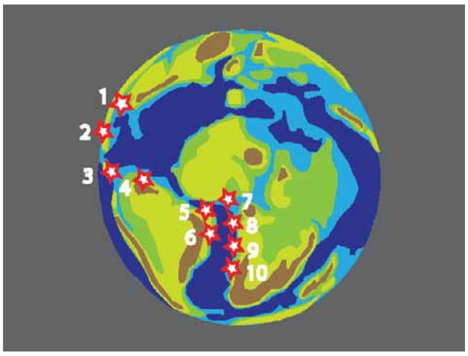

Figure 2: Palaeogeographic reconstruction used to locate fossil localities for the Albian-Cenomanian interval (map at – 100 Ma based on Scotese's Paleomap Project, http://www.scotese.com/). 1: Arizona and Texas, JOHNSON, 1954, 1965, 1968; KONISHI & EPIS, 1962; 2: Mexico, BARATTOLO, 1983, 1990; 3: Guatemala, JOHNSON & KONISHI, 1960; JOHNSON & KASKA, 1965; 4: Venezuela, JOHNSON, 1965; 5–6: Brazil, 5: Potiguar, SRIVASTAVA, 1982a, 1982b, 1984, 6: Sergipe, BERTHOU & BENGSTON, 1988; GRANIER et al., 1991a, 1991b; 7: Nigeria, POIGNANT & LOBITZER, 1982; 8: Gabon, ROUSSELOT, 1995; 9: Congo, MASSE, 1995; 10: Angola, ROMANES, 1916.

For instance, earlier occurrences from other localities in both Central and South America (Guatemala: JOHNSON & KONISHI, 1960; JOHNSON & KASKA, 1965; Venezuela: JOHNSON, 1965; Brazil: SRIVASTAVA, 1982a, 1982b, 1984; BERTHOU & BENGSTON, 1988; GRANIER et al., 1991a, 1991b), as well as from the opposite side of the South Atlantic Ocean (Nigeria: POIGNANT & LOBITZER, 1982; Gabon: ROUSSELOT, 1995; Congo: P. MASSE, 1995; Angola: ROMANES, 1916), suggest that during mid-Cretaceous times the diversity of these algal associations was low on both sides of the South Atlantic Ocean. The new discoveries do not contradict this hypothesis, in contrast they appear to add to its strength.

Table 1: Albian-Turonian occurrences of calcareous algae recorded in Western Africa and Central and South America, originally determined as: (a) *Neomeris budaense* n.sp. (JOHNSON, 1968); (b) *Heteroporella potiguarensis* n.sp. (SRIVASTAVA, 1982a); (c) Dasycladacea ind. (P. MASSE, 1995); (d) *Permocalculus budaensis* n.sp. (JOHNSON, 1968); (e) *Trinocladus norteriograndensis* n.sp. (SRIVASTAVA, 1982b); (f) both *Marinella lugeoni* and *Lithothamnium primitiva* (JOHNSON & KASKA, 1965, USNM n° P 042547A); (g) *Lithophyllum*? *venezuelaensis* (JOHNSON, 1965, USNM n° P 042467); (h) *Lithothamnium regonis* n.sp. (HAUG *in* MAURY, 1937); (i) *Lithothamnium angolense* n.sp. (ROMANES, 1916); (j) *Parachaetetes keitheiti* (POIGNANT *in* GRANIER *et al*., 1991b); (k) *Parachaetetes* sp. (TERRA & LEMOS, 1999); no fig. (Poignant's collection).

	1 Arizona and Texas	2 Mexico	3 Guatemala	4 Venezuela	5-6 Brazil		7 Nigeria	8 Gabon	9 Congo	10 Angola
					5-Potiguar	6-Sergipe				
Heteroporella lepina	■ (a)	■			■ (b)	■		■		
Holosporella nkossaensis					■				■	
Cymopolia perkinsi	■				■				■ (c)	
Neomeris cretacea		■				■				
Genotella pfenderae	■					■	■ no Fig.			
Trinocladus sp.	■ (d)	■			■ (e)					
Marinella lugeoni			■ (f)	■ (g)	■	■ (h)	■ no Fig.			■ (i)
Pycnoporidium sinuosum			■		■	■ (j)	■			
Sporolithon amphiroaeformis					■					
Lithothamnion sp.						■				
Elianella elegans					■ (k)	■	■		■	
Ethelia alba							■ no Fig.		■	

Furthermore,this preliminary inventory provides supplementary information and data concerning the origin of these algae (and the associated benthic foraminifers):

4.1. Did the algae come from the South?

The paleolatitudinal location of the southern ends of the African and South American continents near the South-Polar realm (see the extension of the mid-Cretaceous Tethyan Realm, *i.e*. the Megatethys, on Fig. 22 in DIAS-BRITO, 2000 or on Fig. 2 in BELLIER & VRIELYNCK, 2007) precludes a southern origin for these temperature-sensitive organisms.

4.2. Did they come from the Tethyan realm through the trans-Saharan Seaway?

According to MOULLADE & GUÉRIN (1982) who discuss the patterns of foraminiferal distribution, this hypothesis has not been thoroughly documented for the oldest part of the interval: "*le passage 'transsaharien' n'a jamais été documenté sérieusement pour cette période*". For the youngest part of the interval we consider that the environments (siliciclastic-rich facies and associated water-turbidity) along this pathway were probably unfavourable to algal growth and their subsequent dissemination.

4.3. Did they come from the Tethyan realm through the north-western neck of the South Atlantic Ocean?

It is possible that these benthic organisms reached the early South Atlantic Ocean through a channel formed by the set of rifts and transform faults that existed between the shoulders of both continents and connected it to the early Central Atlantic Ocean. There are some similarities between the South Atlantic algal assemblages and those in Texas, Mexico, Guatemala and Venezuela (though here again the Albian-Cenomanian series are poorly documented). These similarities support this interpretation.

However, we should consider that colonization of the South Atlantic shorelines by Dasycladales and Corallinales did not occur in the same way. Rhodophytes are common in most shallow-water marine palaeoenvironments where they occasionally build up small knolls ("reefs"), but they are not confined to the sublittoral zone for they are also found in slightly cooler or deeper marine palaeoenvironments. Consequently the relative abundance of these wide-spread opportunist forms on the early South Atlantic ramps is not surprising.

It is a different story for the Chlorophytes. Modern Dasycladales are either choristosporate or umbrellosporate and their Albian-Cenomanian relatives appear to have pioneered in the early South Atlantic ocean: Dasycladaceae (choristosporate forms), such as *Neomeris* (*N.*), *Neomeris* (*L.*), *Genotella* and *Cymopolia*, are common in the study area; Polyphysaceae (umbrellosporate forms) are also abundant. As this was a time of change in the evolution of the Dasycladales, (near the end of the range of the Family Triploporellaceae), it is probable that this distribution is related to the peculiar pattern of their reproductive organs that gave them an "evolutionary advantage" rather than to a control only by the then-existing latitudes.

Though calcareous algae provide a unique tool to investigate the palaeobiogeography of the early South Atlantic Ocean, one should not overlook other (non-algal) groups or the overall fossil assemblage. There is no doubt that planktonic organisms used a route from the Central to the South Atlantic, possibly as early as Late Aptian times (see DIAS-BRITO & FERRÉ, 2001; BELLIER & VRIELYNCK, 2007). Some benthic foraminifera followed the same route, but at a later date (see MOULLADE & GUÉRIN, 1982). We think that organisms that lived with photosynthetic symbionts: foraminifera like the orbitolinids (apparently absent on the South Atlantic ramps) but also macrofossils like the rudists and corals, (for which the fossil record is scanty) are potentially excellent case studies. In any case, we are required to supplement our current database on both the South American and African continents, to add validity to our hypothesis.

5. CONCLUSION

This preliminary study adds to the palaeophycological inventory of the South Atlantic basins. The list of taxa encountered is still short, thus suggesting that diversity was low. The benthic green and red calcareous algae probably originated in from the Central Atlantic Ocean and reached the early South Atlantic Ocean through a north-western passageway between Western African and South America. Their paucity is possibly related to the degree of capability of each algal group (at the family or even the genus levels) to colonize new coasts, an hypothesis that will require further investigation.

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