

## End of a modern geological myth: there are no rudists in Brazil! Paleobiogeographic implications

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**Abstract:** Out of the few records of rudists from the Cretaceous strata of the South Atlantic coastal basins only two refer to Brazilian localities. However, petrographic analyses demonstrate that these shells should be assigned to Ostreids or to Pycnodontids rather than to Rudistids. More specifically, the domain considered herein, north of the Río Grande Rise - Walvis Ridge barrier, was part of the warm-water "tropical" realm, but it was not part of the Mesogean domain because both Rudistids and Orbitolinas are missing. In addition, the scarcity of corals leads us to ascribe the taphonomic assemblage to the Chloralgal facies. Neither generalized hypersalinity or extreme sea-water temperatures seem to account for these biotic peculiarities. Instead, our alternative hypothesis favors the driving role played by oceanic circulation in the dispersal of the benthic organisms.

**Key Words:** Rudists; Ostreids; Pycnodontids; corals; Orbitolinids; calcareous algae; Cretaceous; Albian; Cenomanian; South Atlantic; Tethys; Mesogea; Chloralgal; paleobiogeography.

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**Résumé :** *Fin d'un mythe géologique moderne : il n'y a pas de rudistes au Brésil ! et ses implications paléobiogéographiques.*- Parmi les quelques signalements de rudistes dans les séries crétacées des bassins côtiers de l'Océan Atlantique Sud, deux seulement correspondent à des sites brésiliens. Toutefois, les analyses pétrographiques montrent que ces coquilles ne sauraient être attribuées à des rudistes mais plutôt à des Ostréidés ou à des Pycnodontidés. Plus spécifiquement, les régions situées au N de la barrière Rio Grande Rise-Walvis appartenaient au domaine à eaux "tropicales" chaudes, mais pas au domaine mésogéen parce que rudistes et orbitolines y font défaut. De plus, la rareté des coraux nous a conduit à attribuer l'association taphonomique au faciès Chloralgal. Ni une hypersalinité généralisée, ni des températures particulièrement élevées de l'eau de mer ne semblent rendre compte de ces particularités biotiques. Au lieu de cela, notre hypothèse alternative favorise le rôle moteur joué par la circulation océanique dans la dispersion des organismes benthiques.

**Mots-clefs :** Rudistes ; Ostréidés ; Pycnodontidés ; coraux ; Orbitolinidés ; algues calcaires ; Crétacé ; Albien ; Cénomaniens ; Atlantique Sud ; Téthys ; Mésogée ; Chloralgal ; paléobiogéographie.

### 1. Introduction

The presence or absence of rudists in mid- and Upper Cretaceous limestones of the Brazilian coastal basins is an episodic issue, recurrent since the 1970's. The myth of Brazilian rudists probably began with the international diffusion of "ready-made" sedimentological models for Cretaceous carbonate environments commonly referred to in the oil industry.

In the present publication, we examine some large bioclasts, which were eventually ascribed to rudists, including few that are not even molluscan shells as demonstrated by "quick-look" petrographic analyses. We also take advantage of the opportunity in this review to address paleobiogeographic considerations regarding mid-Cretaceous tropical assemblages.

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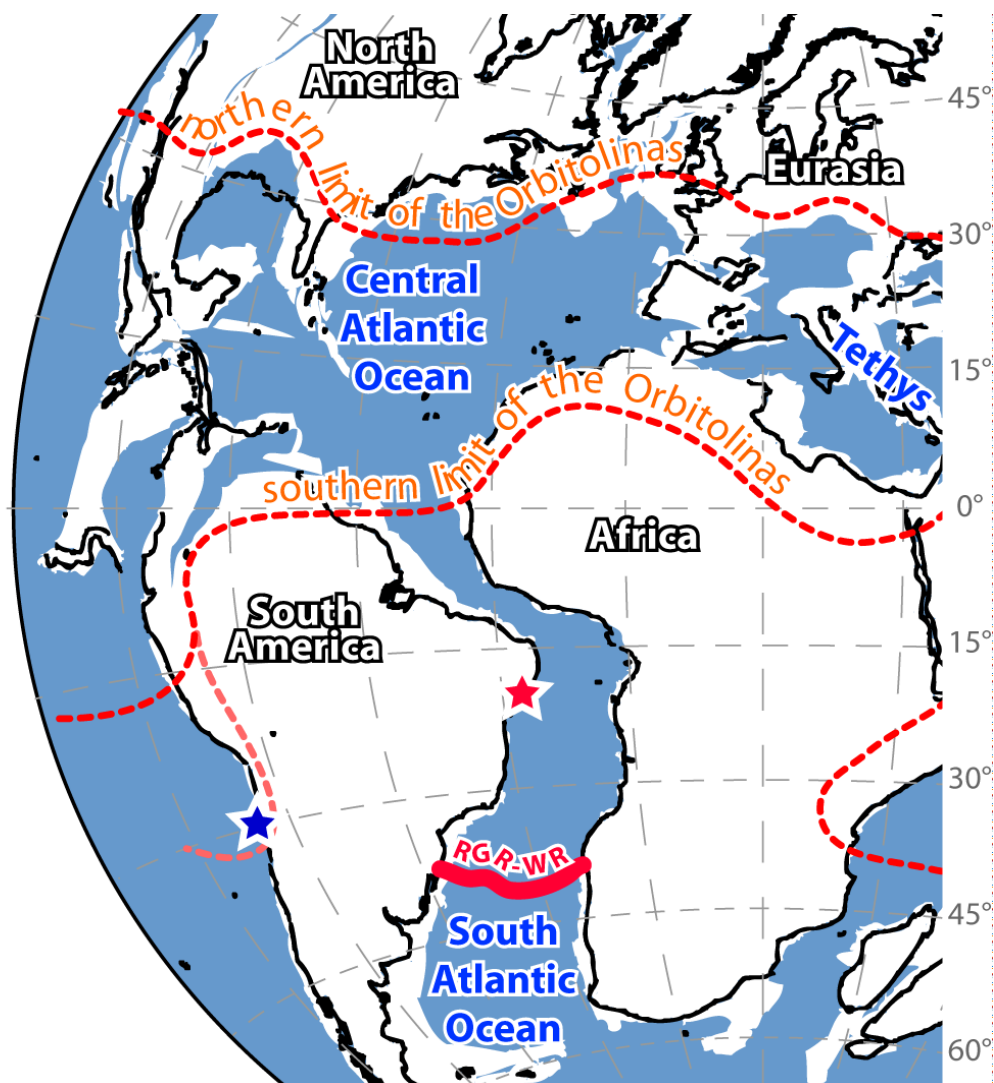
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**Figure 1:** Maximum extension of the Orbitolinas on a LAMBERT Azimuthal map projection with reconstruction of continents for the mid-Cretaceous (circa 100Ma). The red star is for Fazenda Cafuz, Sergipe, Brazil; the blue star is for ORBIGNY's forgotten rudists from the Chañarillo (Atacama) Basin, Chile. Plate fragments as at 100Ma: grey; present-day shorelines: black; approximate position of the Río Grande Rise - Walvis Ridge barrier (RGR-WR): red. The same base map was used in WOELKERLING *et al.* (2014). It was initially generated using the ODSN (Ocean Drilling Stratigraphic Network) Plate Tectonic Reconstruction Service established by GEOMAR, Research Center for Marine Geosciences at Kiel and the Geological Institute of the University of Bremen (URL: <http://www.odsn.de/odsn/services/paleomap/paleomap.html>). Parameters used to generate base map were as follows: cartographic projection: Lambert Azimuthal; move plates relative to: Magnetic Ref. Frame; guideline interval 15°; annotation interval 15°; reconstruction age: 100 Ma; map boundaries: 90° North, -120° West, 90° East, 90° South; frame type: thin lines.

## 2. Brazilian Cretaceous shells

### 2.a. The 1980's reports

It is almost impossible to track back the exact date of the first reference to models with the so-called "rudist shoal banks or reefs" in Brazil because this source of further quotes (*e.g.*, the recent HART *et al.*, 2007) is probably to be found in a confidential and proprietary report of a petroleum company. However, as early as the 80's, authors started publishing papers reporting rudists in Brazil. For instance, FALKENHEIN *et al.* (1981) report "rudistids, bryozoans, corals" in their "microfacies 50" of the

Macaé Formation (Macaé Group, Quissamã Formation, Albian, as nowadays considered) of the Campos basin, ... however their illustrations do not provide indisputable rudistid shells. Also a number of paleobiogeographic maps show rudists in the Sergipe Basin (*e.g.*, LLOYD, 1982: Fig. 6 \*; SOHL, 1987: Fig. 1; STÖSSEL, 1999: Fig. 1.1).

\* There is an ambiguity here because the letter R on the map corresponds to "Lower and mid-Cretaceous warm-water faunas, including rudist bivalves, hermatypic corals, Orbitolina and keeled globotruncanid foraminifera" (op. cit., p. 408).



**Figure 2:** Ostreid shells not rudists on the outcrop at Fazenda Cafuz, Sergipe Basin, Brazil; Riachuelo Formation, ?Lower-Middle Albian.

### 2.b. The myth gains credibility in the 1990's

Bruno GRANIER (the first author of the present paper), the late Pierre-Yves BERTHOU and the late Alain François POIGNANT (1991b) stated that "*L'affleurement des calcaires à Rudistes et des marnes de la Fazenda Cafuz [?Lower-Middle Albian, Riachuelo Formation, Sergipe Basin] est (...) l'unique gisement de Rudistes connu dans les bassins atlantiques de la marge brésilienne*" [the outcrop with rudistid limestones and marls at Fazenda Cafuz (Fig. 1, red star) is the sole locality with rudists known in the Brazilian basins sited on the South Atlantic margin].

There was a concern as regards this singular occurrence and the uniqueness of this outcrop and a need to re-examine Pierre-Yves BERTHOU's material: unfortunately, this material was lost. Luckily, Paulo TIBANA had some specimens from the exact same locality (Fig. 2). At first sight, sections of the shells visible on polished slabs (Fig. 3.A) evoke sections of rudists. They display foils (3.A) that look similar to the curved septa observed in some Caprinid rudists (Fig. 3.B-C), for example. Petrographic thin sections should contribute to the analysis and solve the case.

The shells of the rudists, which are exclusively known from the fossil record, consist of 2 layers: a calcitic outer layer and an aragonitic inner layer. Some families -- mostly post-Ceno-

manian -- include calcite-dominated taxa whereas others -- mostly pre-Turonian -- group aragonite-dominated taxa (STEUER, 2002: Fig. 3); the remaining families consist of taxa with no dominance of calcite over aragonite. In calcite-dominated shells, aragonite was always present, never scarce as in an ostreid shell (STEUER, 2002: Fig. 2). In contrast, calcite might be almost non-preserved in aragonite-dominated shells, as in the *Offneria* specimens from Lebanon (J.-P. MASSE *et al.*, 2015a) illustrated here (Fig. 3.B-C).

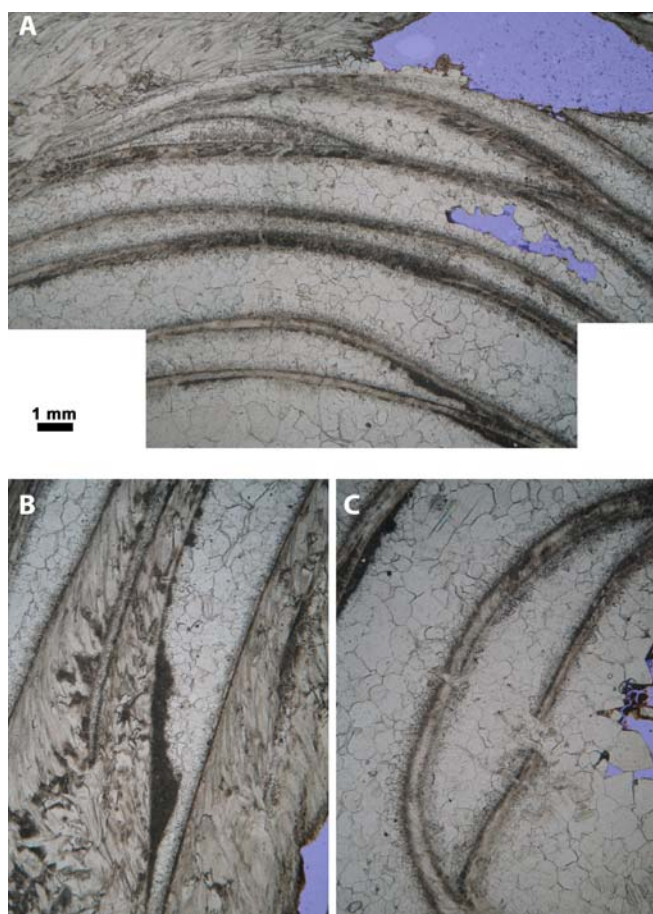
For its part, the shell of the modern *Ostrea* consists of 4 discrete layers:

- the outer layer, *i.e.*, the periostracum, made of conchiolin, an organic material that is not preserved most fossil specimens;
- a calcitic prismatic layer;
- a calcitic ostracum, which makes up the major part of the shell;
- a thin inner layer, *i.e.*, the aragonitic hypostracum. To summarize the *Ostrea* shell is deemed to be composed almost entirely of calcite (see BOUILLON, 1958, for instance).

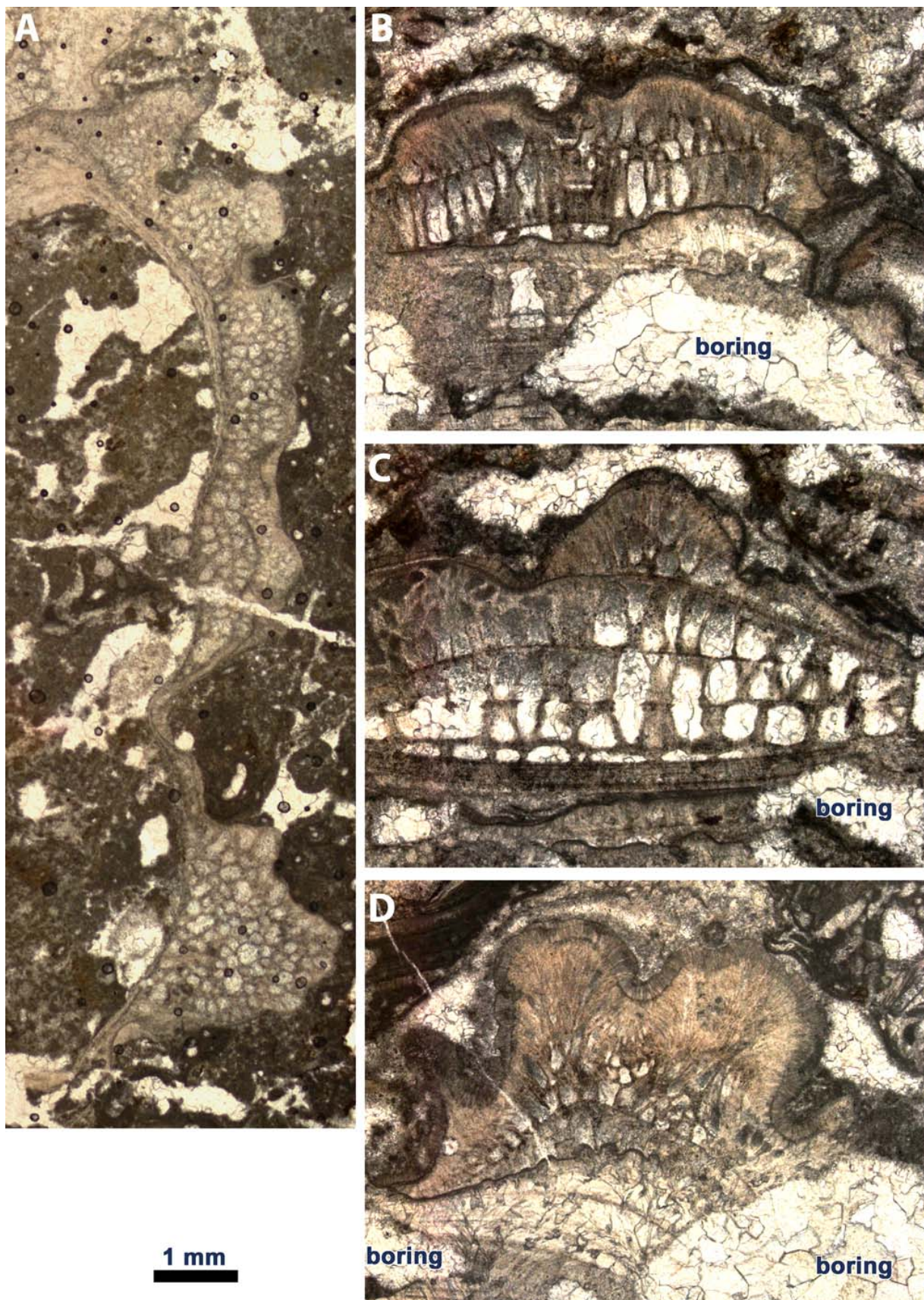
Our so-called rudist shells (Figs. 2, 3.A & 4.A-C) are valves of an Ostreid similar to those illustrated by MAJEWSKE (1969: Pl. 72, fig. 2, to compare with our Fig. 4.A-C) showing the "*loosely fabricated latticework of foliated layers forming 'chambers' in the shell*".



◀ **Figure 3:** A) Polished slab with a few large calcite-dominated shells. Fazenda Cafuz, Sergipe Basin, Brazil; Riachuelo Formation, ?Lower-Middle Albian. B-C) *Offneria* specimens from Lebanon. These aragonite-dominated shells were leached and the cavity was later filled by calcitic or dolomitic cements. Beit Mery, Matn District, Lebanon; Jezzian, lowermost Aptian (lower Bedoulian); B) see J.-P. MASSE *et al.*, 2015a: Fig. 2B & Pl. 1, fig. I; C) see J.-P. MASSE *et al.*, 2015a: Pl. 1, fig. G.



▶ **Figure 4:** A-C) As noted by MAJEWSKE (1969), the "loosely fabricated latticework of foliated layers" form "chambers" in this *Ostrea* shell. The early marine dull cement and the thin micritic "microbial" crusts on the shell fibrous laminae fill original void spaces and were not leached aragonitic parts. The interspaces are now partly or fully filled by drusy calcitic cement (crystals centripetally increasing in dimensions). Fazenda Cafuz, Sergipe Basin, Brazil; Riachuelo Formation, ?Lower-Middle Albian.



**Figure 5:** A-D) *Pycnodonte* shells with vesicular layer, commonly bored.- Sergipe Basin, Brazil; Riachuelo Formation, ?Lower-Middle Albian. A) UPAFSE\_0052; B-D) UPAFSE\_0129. The thin inner aragonitic layer was replaced by a mosaic of calcite (nearly equant crystals, with ghosts of organic linings); organic pores and borings are filled by drusy calcitic cement (crystals centripetally increasing in dimensions).

### 2.c. The last reports in the 2010's

More recently, TERRA *et al.* (2010) reported new "*Ocorrência de rudistas em amostras de testemunho do Albiano inferior da Bacia de Campos*" [occurrence of rudists in core samples from Lower Albian strata of the Campos Basin]. In this case, the illustrated material seems to be valves of *Pycnodonte* (Fig. 5.A-C), comparable with those illustrated by MAJEWSKE (1969: Pl. 72, fig. 1), with vesicular portions. Additional sections illustrating the skeletal microstructure of Pycnodontid pelecypods are found in HOROWITZ and POTTER (1971: Pl. 35, figs. 1-4). *Pycnodonte vesiculosa* (SOWERBY, 1822) is a species well known from Brazil (SEELING & BENGTON, 1999, inter alia) but also from Angola (where it is coined either as "*Ostrea*" or "*Gryphea*" by CHOFFAT, 1888a: p. 18; 1888b: p. 91-92, Pl. V, figs. 15-17).

### 2.d. Some more shells

Folded shells are commonly observed in Cretaceous limestones of Brazil (*e.g.*, SEELING & BENGTON, 1999) and are usually referred to *Lopha*-type shells (Fig. 6.A-F). J.H. JOHNSON (1968: p. 55, Pl. 12, fig. 1) illustrated similar structures from the Comanche Peak Formation, Albian of Texas. However, he erroneously ascribed them to the algal genus *Clypeina* (MICHELIN). The first author (B.G.) got the opportunity to examine JOHNSON's material (GRANIER *et al.*, 2013c) and more specifically the thin section Shell BFP-6459, USNM 42772 (Fig. 6.G-H). The calcitic nature of these "fragments" most definitively disqualifies them to be ascribed to algae; conversely, the foliated structure of their folded calcitic layers as observed in thin sections is typically that found in mollusc shells.

Some reported rudist shells may actually be serpulid tubes, which consist of 2 layers: an aragonitic inner layer and a calcitic outer layer (Fig. 7.A). The outer layer may be alveolar (Fig. 7.A-C) as in *Pyrgopolon* MONTFORT, 1808, for instance. For example, the Radiolitidae shells from the Upper Aptian-Lower Albian of Provence (France) illustrated by P. MASSE (1988: Pl. VI, figs. 1-9) may well be serpulid tubes.

## 3. Paleobiogeographic discussion

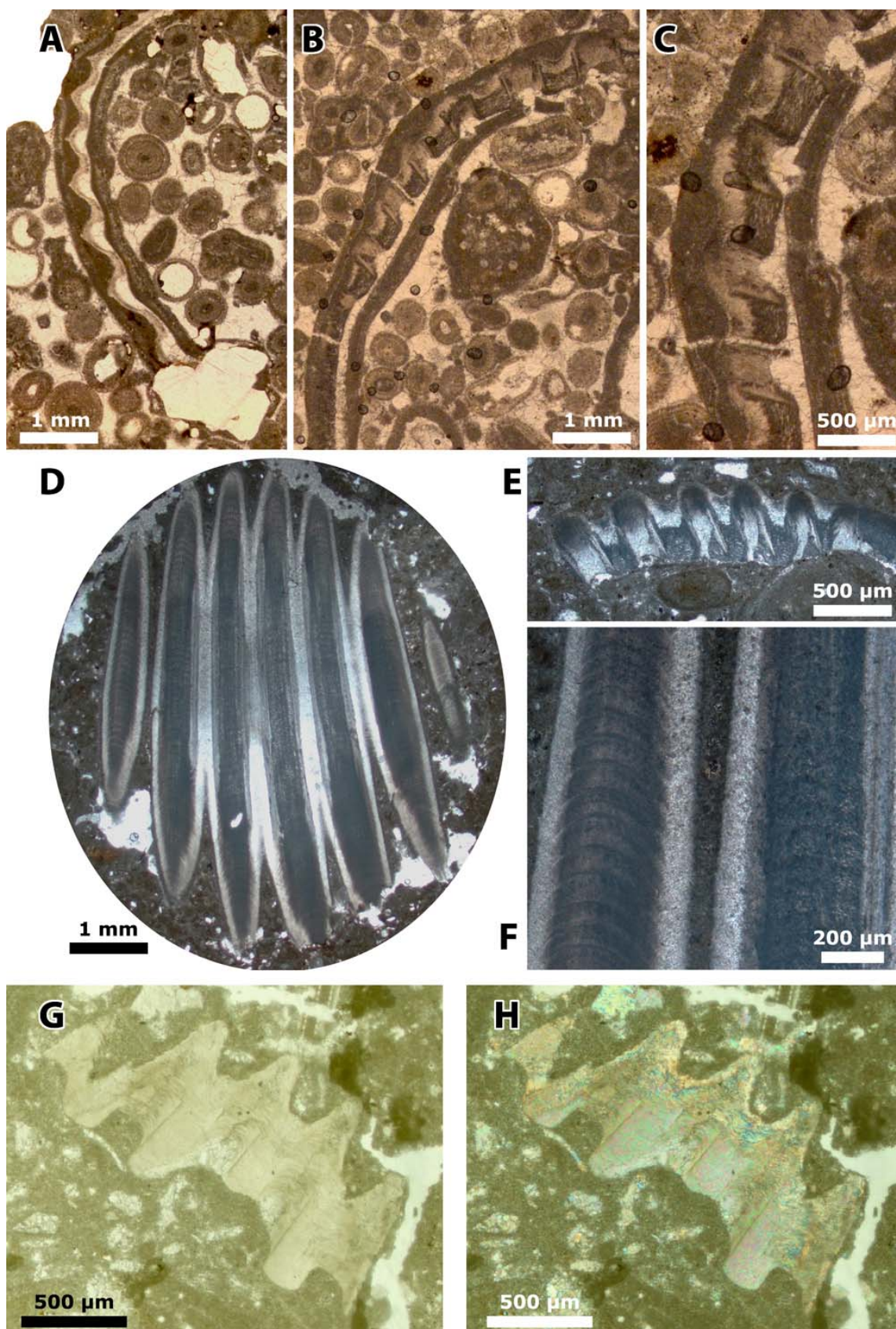
In terms of paleoceanography, though the Tethys Ocean, which opened from East to West, was connected to the northern segment of the young South Atlantic Ocean [we shall use the acronym NYSAO], the latter opened at an angle with respect to the first and, in terms of geodynamics, and NYSAO cannot be considered a branch of the Tethys. However, considering the ecological factors, the question of the scarcity or total absence of some benthic

"Tethyan" biota in the proto-South Atlantic Ocean during the "middle" and Late Cretaceous time should be addressed:

- Against the views shared by several authors (*e.g.*, according to KAUFFMAN, 1973: "The South Atlantic Subprovince" was part of "the South Temperate Realm") who considered the NYSAO as a temperate zone, DIAS-BRITO (1995) pointed out that, during the Late Aptian-Albian, it rather was a tropical zone, on the basis of the occurrence of pelagic "Tethyan" biota (*e.g.*, colomiellids, pithonellids, favusellids, nanoconids, roveacrinids) in the open-sea carbonates of many Brazilian coastal basins;
- DIAS-BRITO (2000) is emphatic regarding the absence of "coral and rudistid reefs" in the Brazilian Albian-Cenomanian coastal basins. Because microbial structures (oncooids, ...) dominate in shallow-water carbonate facies, he suggested that: "*In these shallow waters, high temperatures and hypersalinity excluded coral and rudistid reefs, as well as large foraminifera such as orbitolinids (...) and alveolinids*" (DIAS-BRITO, 2000);
- SEELING & BENGTON (2002) advocated other possibilities: "*The absence of rudists and allied organisms from the Sergipe Basin can probably be explained by the general decrease of diversity, combined with morphological and palaeogeographical characteristics of the Sergipe Basin as a homoclinal ramp in the incipient South Atlantic Ocean, which at this time was connected to the Tethys by a narrow and only temporarily open seaway*";
- GRANIER *et al.* (2014) conclude that "*some taxa or fossil groups known in the Tethyan realm are probably missing along the South Atlantic coasts only because they or their ancestors did not find a route to the South.*"

Not only the rudists (as documented above) but also some large benthic foraminifers such as the Orbitolinas *sensu lato* are missing in Brazil (DIAS-BRITO, 2000; GRANIER & DIAS-BRITO, 2013). In addition, other groups such as the hermatypic corals are not missing but rather scarcely represented (Fig. 7.D); alcyonarians (Fig. 7.E-G) are rare. The situation is almost identical on the eastern side of the NYSAO. Only two very early records documented rudists from Angola:

- a) CHOFFAT (1886: p. 155) who described oolitic limestones with rolled pieces of corals and "*fragments d'un grand bivalve rappelant le genre Pachyrisma*" [fragments of a large bivalve mollusc close to the genus *Pachyrisma*];



**Figure 6:** A-C) *Lophia*-like shells.- UPAFSE\_015c and UPAFSE\_016, Sergipe Basin; Riachuelo Formation, ?Lower-Middle Albian; D-F) *Lophia*-like shells.- Santos Basin; G-H) *Lophia*-like shell, identified as "*Clypeina* species" in JOHNSON (1968: Pl. 12, fig. 1). G: conventional transmitted light, H: cross polarized light.- USNM\_42772, Comanche Peak Formation, Texas (U.S.A.). In A-C, E and F-G, the aragonitic layer was leached and the moldic vug was later filled by drusy calcitic cement (crystals centripetally increasing in dimensions).

b) CHOFFAT (1888a, p. 25) who reports questionable remains of *Pachyrisma* and two of *Requienia* (sometimes called *Toucasia* in old publications). However, we have to be very cautious as such rare finds have never been confirmed since then. Actually there were no records either of rudists or of Orbitolinas from Gabon, Congo-Brazzaville (e.g., P. MASSE, 1995), Congo-Kinshasa and Angola where mid-Cretaceous strata have been intensively drilled and cored in the search for post-salt oil and gas reservoirs.

Based on our current knowledge we shall examine what are the possibilities to resolve this paleobiogeographic dilemma.

1) The **first approach** is based on the analysis of selected elements of the biotic content.

That was the approach of RAT and PASCAL (1982) who focused on the Early Cretaceous Urgonian (Late Hauterivian-Bedoulian) platforms. These authors assumed that "*les éléments les plus caractéristiques en ont été les Rudistes non constructeurs (Requienies, Monopleuridés) et les Orbitolinidés*" [their most characteristic features were rudists that do not form framework structures (Requienids, Monopleurids) and orbitolinids].

Similarly, for the "middle" Cretaceous (Aptian-Cenomanian), DILLEY (1971: Fig. 3) mapped the extension of the Orbitolinas -- among other foraminifers --; on the other hand, GORDON (1973: Fig. 3) combined rudists and Orbitolinas while COATES (1973: Fig. 1), SOHL (1987: Fig. 1), KAUFFMAN & JOHNSON (1988: Fig. 1) and SIMO *et al.* (1993: Fig. 2) used rudists or hermatypic corals. In addition, other groups of organisms were eventually considered to produce similar maps (e.g., actaeonellid gastropods by SOHL, 1971, 1987). However, the most frequent combination remains that of rudists and Orbitolinas.

The original idea of using this combination dates back to 1900 and is to be attributed to Henri DOUVILLÉ with the definition of the Mesogean domain:

"Grâce à la considération de ce double élément, Rudistes et Orbitolines (...), il devient relativement facile de tracer sur une carte l'aire où ces animaux ont vécu aux diverses époques géologiques; ces aires d'habitat ont naturellement varié d'une époque à une autre et leurs variations indiquent les modifications successives éprouvées par le rivage des mers, mais ces modifications sont ordinairement assez faibles." (H. DOUVILLÉ, 1900: p. 222) [The consideration of these two components, rudists and Orbitolinas (...), makes it relatively easy to map the area where these animals lived at various times in the geological past; these habitat areas have, of course, changed from one period to another and these changes

witness to successive shifts of the shoreline, but these changes are usually quite low].

"*Ces divers fossiles se trouvent répartis sur une bande régulière que l'on peut suivre d'une manière continue depuis le Mexique et la mer des Antilles à l'ouest jusqu'aux îles de la Sonde à l'est: elle correspond à ce que l'on appelle d'habitude la zone méditerranéenne. Cette dénomination prête un peu à confusion avec les environs immédiats de la Méditerranée elle-même, et nous proposerons de la remplacer par zone Mésogéenne ou Mésogée.*" (op. cit.: p. 223) [These various fossils are distributed in a regular realm that can be traced continuously from Mexico and the Caribbean Sea in the West all the way to the Indonesian Sunda Islands in the East; it corresponds to the so-called Mediterranean domain. The name itself leads to confusion with the immediate vicinity of the Mediterranean Sea; thus, we suggest using Mesogean domain or Mesogea instead].

"*C'est l'existence de cette mer tropicale continue qui donne à la période crétacée son caractère particulier.*" (op. cit.: p. 223) [The existence of this contiguous tropical sea determines the unique character of the Cretaceous Period].

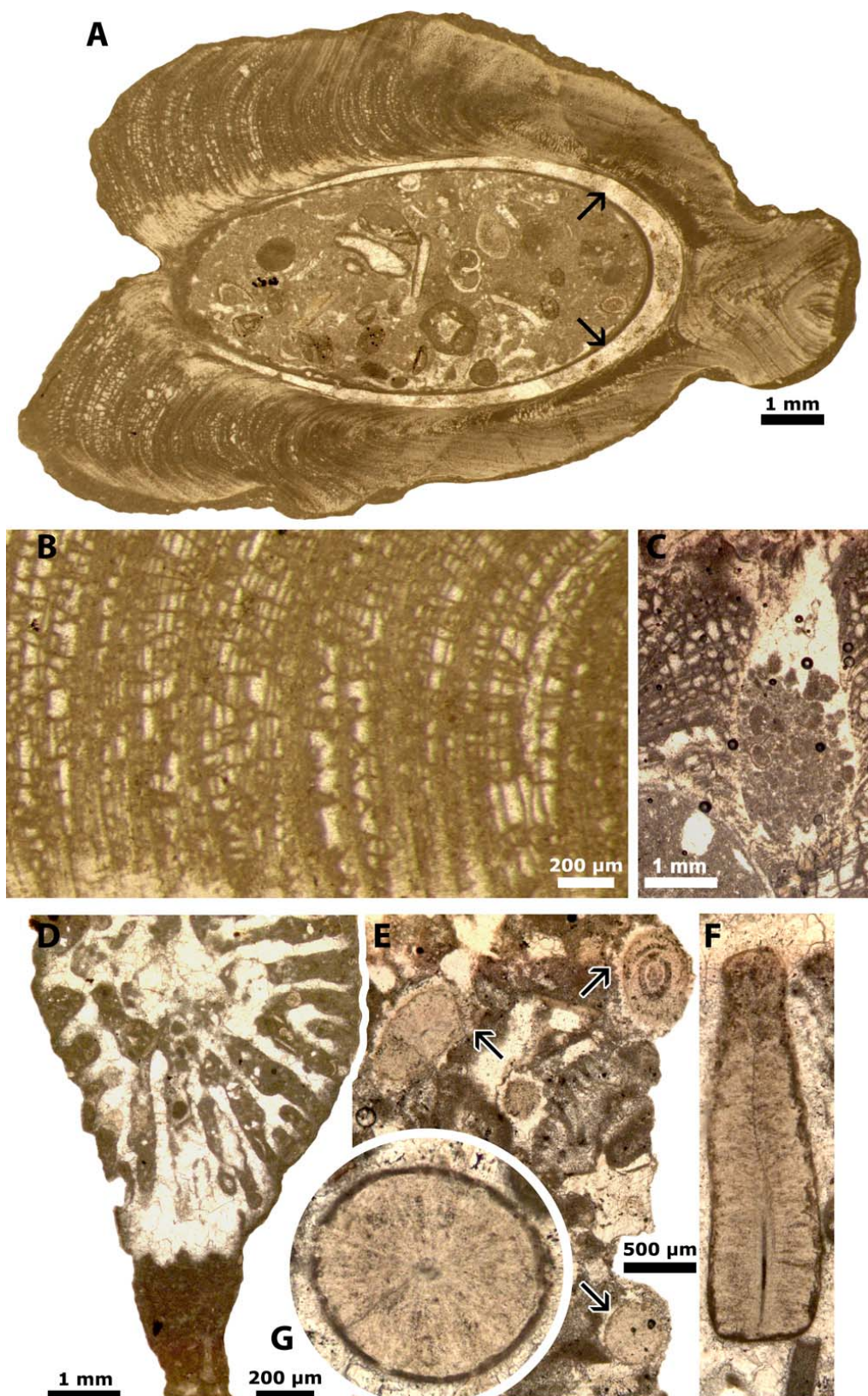
"*La Mésogée correspond à une phase particulière (...) de la Téthys de SUSS; c'est uniquement la mer dans laquelle les Rudistes ont vécu et se sont développés.*" (op. cit.: footnote 2, p. 223) [The Mesogea is a special phase (...) of the Tethys *sensu* SUSS; it is only this sea where the rudists have lived and developed].

Actually plotting on a world map either the rudists or the Orbitolinas or both produces almost the same outcomes (Fig. 1). Some earlier authors plotted Orbitolinas -- but not the rudists -- on today's world map: e.g., DILLEY (1971: Fig. 1) combined MAYNC's (1959: Fig. 3) and DOUGLAS' (1960: Fig. 20) datasets. Note that MAYNC was the only one of the three who referred to DOUVILLÉ's concept of the Mesogea. Slightly later RAT and PASCAL (1982: Fig. 3) who started plotting rudistid facies as well as Orbitolina localities on palinspastic world maps (actually on a "mid"-Cretaceous palinspastic world maps for Early Cretaceous fossils) concluded that it quite consistently constrains the maximal extension of the Early Cretaceous "Mesogean phenomenon".

On our map of the "middle" Cretaceous (Fig. 1), we drew the maximum northern and southern extent of Orbitolinas, *i.e.*, roughly the maximum extension of the Mesogean domain:

- In North and Central Atlantic Ocean, the northernmost occurrences of Orbitolinas are from the Grand Banks and Flemish Cap in America (SCHROEDER & CHERCHI, 1979, Bedoulian) and from S England in Europe





**Figure 7:** A-C) Serpulid tube.- A) the thin aragonitic inner layer was replaced by mosaic calcite (nearly equant crystals); the thicker calcitic outer layer is locally alveolar; B) in the grid pattern curved rows come to the fore; A-B) 1649.40m, RNS11, Potiguar Basin; C) bored serpulid tube.- UPAFSE\_035, Sergipe Basin, Brazil; Riachuelo Formation, ?Lower-Middle Albian; D) Coral bioclast in an oolitic facies.- TIBANA, 566, Barreirinhas Basin; E) arrows point to alcyonarian sclerites (*Pieninia*, see GRANIER, 1986).- TIBANA, Eo-1+4, Barreirinhas Basin; F-G) alcyonarian sclerites (*Pieninia*).- TIBANA, 282, Barreirinhas Basin.

(e.g., HART *et al.*, 1979, Cenomanian). At the eastern margin of the Eurasia, in the Panthalassa Ocean, the northern occurrence of *Orbitolinas* is from Hokkaidô, Japan (YABE & HANSAWA, 1926, Bedoulian).

- The southern occurrences of *Orbitolinas* in Africa are in Senegal (reported from oil exploration wells, see GRANIER, 1992, Albian) and Tanzania (DIETRICH, 1925; PEYBERNÈS & FORSTER, 1987, Bedoulian) for its Atlantic and Pacific coasts respectively. In Tanzania, the *Orbitolinas* are associated with rudists (PEYBERNÈS & FORSTER, 1987), which are not illustrated here.
- In the Americas, *Orbitolinas* are known from Cuba, Trinidad and Tobago, Venezuela (HODSON, 1926), Peru, Colombia, Honduras, Guatemala, Mexico, and U.S.A.: Texas, New Mexico and Arizona (DOUGLAS, 1960), but not Brazil. We would have obtained similar results if we had considered the rudists. A better constrained mapping of the "middle" Cretaceous Mesogean domain should include Chile with the forgotten "*Hippurites chilense*" (the blue star on Fig. 1) of A. d'ORBIGNY (1842: p. 107), now resurrected from oblivion thanks to MOURGUES *et al.* (2010) and J.-P. MASSE *et al.* (2015b).

This Mesogean domain should not be confused with the Tethys: the Mesogea corresponds to the warm-water biotic province of both the Tethys and the Panthalassa, based upon the sole distribution of distinctive assemblages of organisms (*i.e.*, rudists and *Orbitolinas* for the Early-"middle" Cretaceous). The NYSAO, which is devoid of both rudists and *Orbitolinas*, is by definition not part of it.

2) The **second approach** is still based solely on the analysis of biotic content, but includes calcareous green algae.

Apart from the rudists and *Orbitolinas* (*i.e.*, the criteria to identify the Mesogean area) we could have considered the hermatypic (= reef-builder) corals and the calcareous green algae (CGA *sensu* GRANIER, 2012). That was the approach of J.-P. MASSE (1992: Fig. 4) and also that of LEES and BULLER (1972) when discussing the factors that control the distribution of modern carbonate platforms. Their starting point is that "hermatypic corals and calcareous green algae live only in warm seas" (*op. cit.*). LEES and BULLER (1972) call "Chlorozoan" (**Chlorophyta** + **Zoantharia** with their symbiotic zooxanthellae) the association of skeletal grains derived from photo-autotrophic organisms. Nowadays annual minimum surface water temperature (of at least 14°C) and annual mean temperature (of at least 23°C) are the major physical factors controlling the Chlorozoan distribution (LEES & BULLER, 1972).

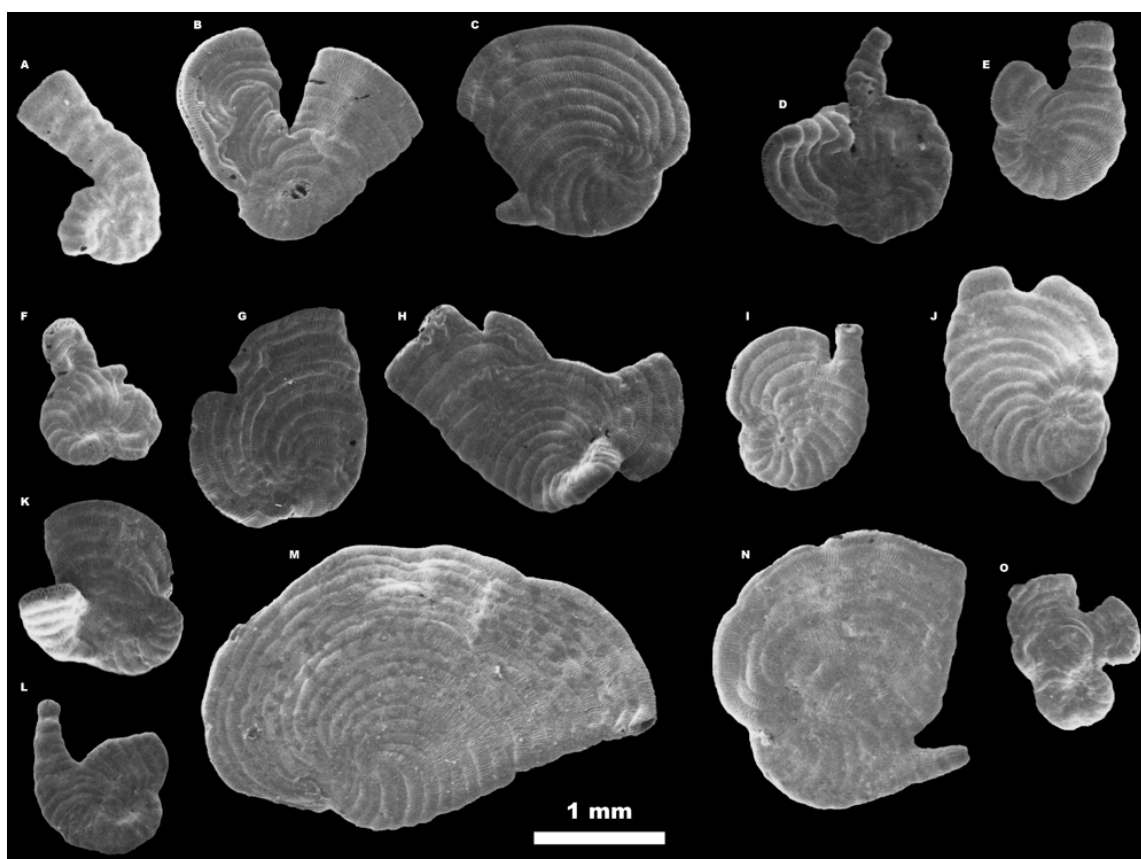
As already mentioned earlier by GRANIER &

DIAS-BRITO (2013), hermatypic corals are rather scarcely represented in Brazilian and West-African mid-Cretaceous series, but CGA are quite common and diverse (Brazil: GRANIER *et al.*, 1991a, 1991b, 2008, 2013a, 2013b, 2014; GRANIER, 2015; Congo: P. MASSE, 1995). The maximum extension of the mid-Cretaceous Chlorozoan association, characterized by the presence of CGA bioclasts, corresponds roughly to a marine warm-water realm with latitudes ranging between circa 35 degrees North and circa 35 degrees South (Fig. 1). During this time the NYSAO, which was not part of the Mesogean domain, was part of the warm-water, *i.e.*, tropical, realm as herein defined.

3) The **third approach** is also based on the analysis of biotic content, but incorporates some non-skeletal grains, *i.e.*, ooids and grain aggregates. LEES and BULLER (1972) pointed out that ooids and aggregates are restricted to their Chlorozoan associations but do not necessarily occur in all of them. LEES (1975) advocated that the Chlorozoan association should be split in two: the Chlorozoan *sensu stricto* and the Chloralgal. The latter "*accommodates those sediments containing calcareous green algae but no corals*", a definition that fits quite well that of the margins of the NYSAO.

To summarize, the NYSAO, which was not a branch of the Tethys in terms of geodynamics, was located in the southern half of the mid-Cretaceous warm-water realm, *i.e.*, the warm-water realm for the southern hemisphere. It did not belong to the tropical Mesogean domain because it lacked the typical biota, *i.e.*, rudists and *Orbitolinas*. It was characterized by its Chloralgal, not Chlorozoan *sensu* LEES (1975), tropical assemblage.

LEES (1975) used a STAR diagram (Salinity Temperature Annual Ranges) to distinguish biofacies. Chlorozoan assemblages are related to a 'normal' salinity of seawater (30 - 40 ‰) and Chloralgal to hypersaline (>40 ‰) or brackish (<30 ‰) environments. In addition, based on our current understanding of coral bleaching phenomenon, extremely warm seawater temperature is one of the causative factors of the dissociation of algal symbionts and their hosts (corals, rudists, large benthic foraminifers). On the basis of a microfacies analysis of lower-middle Albian carbonate rocks from the Campos Basin, *i.e.*, in the southern part of the NYSAO, DIAS-BRITO (1987) suggested that the low foraminiferal diversity could result from high temperatures and hypersalinity. Eight years later, he pointed out that environmental conditions might have been more favorable in Brazilian basins from the northern part of the NYSAO (DIAS-BRITO, 1995). But, another five years later, he applied the scenario of "*high temperatures and hypersalinity*" to the whole NYSAO (DIAS-BRITO, 2000).



**Figure 8:** Deformed tests of *Peneroplis planatus* (FICHEL & MOLL, 1798) from Mussafah channel section, Abu Dhabi, United Arab Emirates.

Today, we can rule out the generalized hypersalinity hypothesis for the entire shallow water Late Aptian-Albian NYSAO (because, for instance, we have never observed teratologic specimens of foraminifera like those from the hypersaline Abu Dhabi coastal lagoons and marshes: Fig. 8). In addition, apart from the corals -- which are rare (but not totally absent in Brazil, nor in West Africa) --, we have also detected in the mid- and Upper Cretaceous limestones of Brazil some benthic elements known from the Tethyan realm, such as the foraminifera *Coscinoconus* (with an aragonitic test, formerly quoted as *Trocholina*), *Rhapydionina liburnica* (with a porcelaneous test) and *Nezzazatinella picardi* (with an agglutinated test), as well as a great diversity of calcareous algae (either green or red: see GRANIER *et al.*, 1991a, 1991b, 2008, 2013a, 2013b, 2014; GRANIER & DIAS-BRITO, 2013; WOELKERLING *et al.*, 2014; GRANIER, 2015). This assemblage would not be consistent with the high-temperature hypothesis (for the Late Aptian-Albian interval, see DIAS-BRITO, 2000), nor with that of "narrow and temporarily [*sic*] connections" with the Tethys (see SEELING & BENGTON, 2002). In addition, these supposed narrow and temporary connections never prevented planktonic foraminifera from entering the NYSAO (DIAS-BRITO, 2000). The remaining hypothesis is still valid: some Mesogean biota was not distributed

southward because of unfavorable ocean currents (GRANIER *et al.*, 2014).

#### 4. Conclusions

Rudists are not present in Brazilian basins. References found in the literature point either to Ostreids (GRANIER *et al.*, 1991b) or to Pycnodontids (TERRA *et al.*, 2010).

The NYSAO (the young South Atlantic Ocean north of the Río Grande Rise - Walvis Ridge barrier), which was not a branch of the Tethys in terms of geodynamics, belonged to a warm-water / tropical realm, but not to the Mesogean domain (Fig. 1). Its biotic / taphonomic assemblages are typically Chloralgal, not Chlorozoan, but the lack or scarcity of corals, rudists and some large benthic foraminifera (mostly these hosts of algal symbionts) does not look related to hypersalinity or extreme seawater temperature. The most probable hypothesis is that, in mid- and even in Late Cretaceous time, marine currents did not help either (most) coral and (any) rudist larvae, or the flagellate gametes of some foraminifera (during their brief phase of free and pelagic life) to penetrate the pathway to the NYSAO.

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