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# PALYNOLOGICAL CHARACTERIZATION AND DATING OF THE TIANGUÁ FORMATION, SERRA GRANDE GROUP, NORTHERN BRAZIL

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## ABSTRACT

This study is based on the palynological investigation of core samples from four PETROBRAS wells penetrating the Tianguá Formation of the Serra Grande Group, in the Parnaíba Basin, northern Brazil : 1-GI-1-PA, core 3; 1-BJ-1-PA, cores 49 and 52; 2-SL-1-MA, core 77 and 1-MA-1-PI, core 113. The organic residues are dominated by marine-palynomorphs with abundant acritarchs, chlorophycean algae and chitinozoans, but only few miospores (trilete spores and cryptospores). Open marine conditions prevailed with intermittent inlfux from fluvial discharges. The chitinozoan assemblages contains diagnostic elements of the the *Conochitina elongata* Zone and upper part of the *Conochitina proboscifera* - *Desmochitina* cf. *densa* Subzone characteristic from late Aeronian to early-middle Telychian. The acritarch assemblages contain several species in common with contemporaneous assemblages from Western Sahara, Libya and Saudi Arabia, implying quite good correlations from west to east on the northern Gondwanan margin, and indicate an early to middle Telychian age. The few spores and cryptospores recorded are also consistent with an Aeronian to early Telychian age. Eight new acritarch species are described herein: *Cymbosphaeridium armatum, Divetipellis tianguaense, Eupoikilofusa striatospinata, Michrystridium celsum, Multiplicisphaeridium apparatum, Oppilatala biscula, Pteroverricatus granomarginata* and *Villosacapsula herinacea*.

## INTRODUCTION

The Parnaíba Basin extends over 600,000 km$^2$ in northern Brazil, occupying parts of the states of Piauí, Maranhão, Tocantins, Pará, Ceará and Bahia. Four of the PETROBRAS wells studied herein (Fig. 1), 2-SL-1-MA and 1-MA-1-PI, are located in that basin. The other two, 1-BJ-1-PA and 1-GI-1-PA, are located in the adjoining Marajó Basin. This is a Mesozoic rift basin that still preserves erosional remnants of a former westward extension of Paleozoic sediments of the Parnaíba Basin.

The Tianguá Formation is one of the consistuent rock units of the Serra Grande Group in the Parnaíba Basin (Fig. 2), which comprises sediments from Late Ordovician(?) through Silurian and possibly earliest Devonian age. The Serra Grande Group was first described as a series by Small (1914), and then regarded as a formation for several years. Finally it was raised to the Group rank by Carozzi *et al.* (1975), who included in it the Mirador, Ipu, Tianguá and Itaim Formations. Caputo & Lima (1984) and Góes *et al*. (1992) redefined the group, suggesting that it was unconformably overlain by the Canindé Group (Devonian-Mississipian), and composed only by the Ipu, Tianguá and Jaicós Formations. Góes & Feijó (1994) further reinforced this subdivision. The same stratigraphic framework is presented herein in Figure 2, but modified on the basis of palynological datings concerning both the Serra Grande Group (Grahn, 1992 and this paper) and the overlying Canindé Group (Grahn, 1992; Loboziak *et al.,* 1992, 1993, 1994 and 2000 ; Melo & Loboziak, 2000).

## PREVIOUS DATINGS AND OBJECTIVES

The Silurian of the Parnaíba Basin has been studied by several palynologists (Müller 1962; Brito 1967, 1971, 1979; Quadros 1982; Grahn, 1992), and some of their results are contradictory. Müller (1962) attributed the Serra Grande Formation to the Lower Devonian, whereas Brito (1979) extended the unit's age range from Silurian to Devonian. Quadros (1982), based on chitinozoan-acritarch studies, dated the Tianguá Formation as Gedinnian (~Lochkovian), contrasting with Grahn's (1992) Llandovery dating of the same unit using chitinozoans. Independent graptolite dating of the Tianguá Formation, based on the identification of *Climacograptus* cf. *scalaris scalaris* from core 52 of well 1-BJ-1-PA (H. Jaeger, writ. com. to J.H.G. Melo in March 1992), suggests an age span within the middle or earliest late Llandovery for this section. In terms of the international Silurian graptolite biozonation (generalized zonation of Koren *et al.*, 1996 and Silurian Subcommission), this would correlate with a portion of the broad interval ranging from the middle Aeronian to middle Telychian, i.e from *Demirastrites convolutus* to about *Monoclimacis crenulata* - *Monoclimacis griestoniensis* Zones. In this study selected samples from the Tianguá Formation (Fig. 1), previously dated as Silurian (Grahn 1992), have been investigated independently by palynologists specialized on different fossil groups, in order to clarify doubts still persisting on the accurate age of this rock unit.

## ACRITARCHS

In the material studied acritarchs and related forms (*e.g*. prasinophycean phycomata) display a remarkable

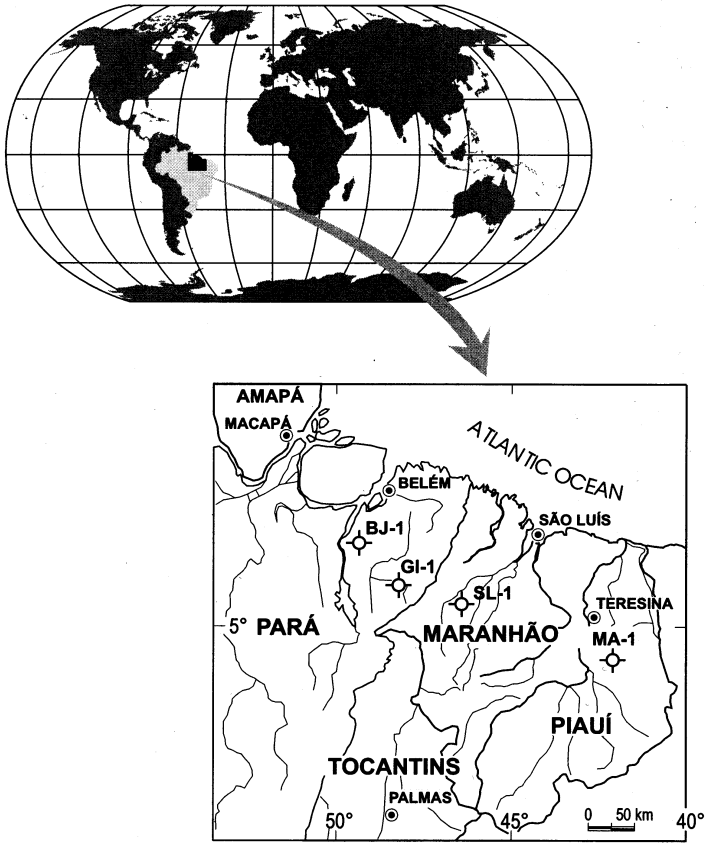


Fig. 1. Location map of studied wells in northern Brazil.

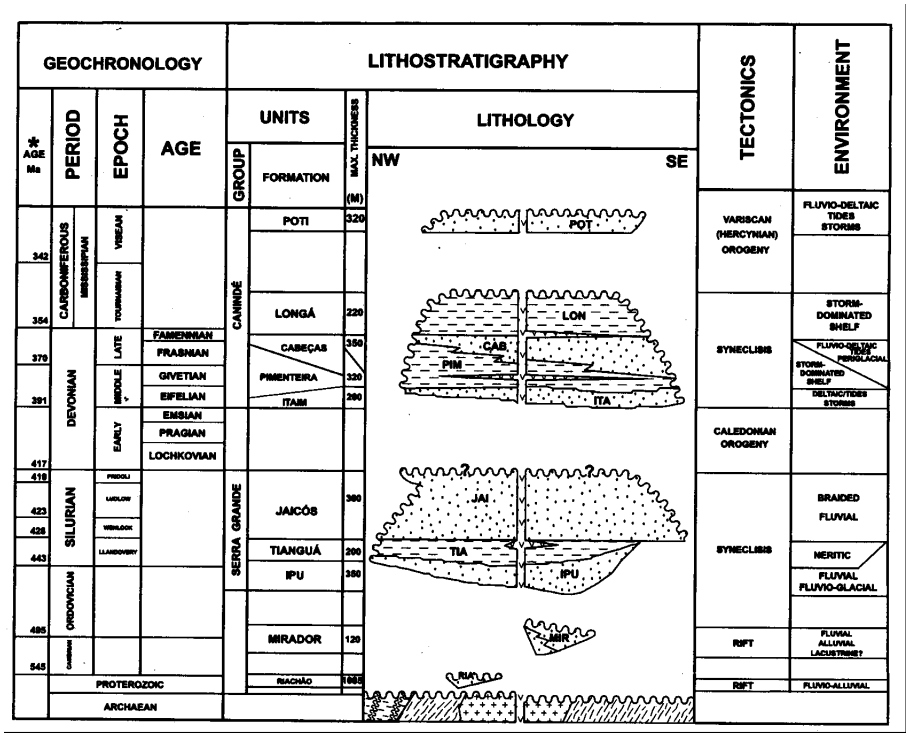


Fig. 2. Parnaíba basin stratigraphic chart (modified from Góes & Feijó, 1994; chronostratigraphic scale after Gradstein & Ogg, 1996).

diversity with more than 100 species encountered. The assemblages also demonstrate great originality, and several new species have been identified. This increased diversity is a typical trend in the Telychian

(Kaljo *et al.*, 1995), that can be related to the major transgression during this time interval, with oceanographic and climatic conditions that favored cyst production. The evolution of relative abundances of various categories of acritarchs and chlorophyta (prasinophycean phycomata and other microalgal remains) permits to interpret the paleoenvironmental conditions of these Silurian strata.

Preliminary results issued from the few samples studied are very interesting. They point out to the need for additional sampling and continued investigations of the Tianguá Formation with the following objectives:
1. a more detailed systematic study, taking account of the high diversity and polymorphism of certain groups such as the multiplicisphaerids, veryhachids and netromorphs (e.g. *Dactylofusa maranhensis*). The excellent state of preservation of this material could be a good advantage for this study. Several species recorded here can be regarded as new.
2. a study of the significance of certain species (or morphologies) documented in the Tianguá Formation with regard to paleoclimatic and paleoenvironmental conditions (paleosalinity, sediment input, etc.).
3. in addition to their importance for paleogeographical purposes, acritarchs and related forms can also help to improve the stratigraphical resolution of the Silurian. The results presented here are useful in recalibrating the Silurian acritarch evolution and zonation, and permit more accurate correlation of the latter with the global Silurian chitinozoan biozonation (Verniers *et al.*, 1995).

Table 1 shows the distribution of the most relevant species. The assemblages contains 26 species that occur elsewhere and are more or less cosmopolitan. Taking account of the literature (but with some necessary readjustments), they have a known age distribution within the late Aeronian to early Wenlock span. However, a better resolution is possible considering the association of certain taxa and their relative abundance. The following discussion is based on the most important ones.

*Beromia rexroadii* for example, first described and illustrated by Wood (1996), is considered as a significant index fossil for correlations of upper Llandovery strata (basal Telychian stages C4 to C5) of the eastern North American platform (Red Mountain Formation of Alabama and Georgia, Lulbegrud Shale Member of the Noland Formation, Crab Orchad Group of Kentucky, and the Lower Sodus Shale of New York State). It should be noted that in more recent papers, the Lubegrud Shale Member and the Lower Sodus Shale are restricted to the Aeronian-Telychian boundary, C2-C3 boundary (Brett *et al.*, 1998). The species is also recorded from the Brabant Massif in Belgium in a core dated late Aeronian to Telychian (Wauthoz, 1997).

The group of *Crassiangulina* cf. *tessellita* and *Crassiangulina grotesca* n. comb. is also well represented in all samples studied. These two taxa provide a good possibilty of comparison with assemblages described elsewhere in different areas of the North Gondwanan margin, and also in Baltica. The two species occur in the Qusaiba Member of the Qualibah Formation in Saudi Arabia. *C. tessellita* is a diagnostic element of Biozone 6, of late Llandovery to (?)early Wenlock age, defined in Kahf.1. However the association of the two species (*C.* cf. *tessellita* + *C. grotesca*) seems to be restricted to the transition between Biozones 5 and 6, i.e., the early to middle Telychian transition (Le Hérissé, 2000; Ruwaili, oral communication and new data). *Crassiangulina* (as *Antruejadina*) *grotesca* is also a component of Zone JS.3 defined in the Silurian of the Hashemite Kingdom of Jordan, which is attributed to the Llandovery (Keegan *et al*., 1990). In addition, *Crassiangulina* cf. *tesellita* has been found (unpublished data) in subsurface sediments of Algeria (Tindouf basin) and Libya (Murzuk basin) ranging from near the Llandovery/ Wenlock boundary up to the early Wenlock (equivalent of the *Margachitina margaritana* chitinozoan Biozone). In Baltica, *C*. cf. *tessellita* has been reported from the upper Aeronian in the Llandovery Type Area (specimens described as *Veryhachium* sp.1 in Hill 1974), and up to the Llandovery/Wenlock in the Upper Visby beds of the Gotland succession ( Le Hérissé, 1989, undescribed). Recently, abundant representatives of this species, identified by Wauthoz & Dorning (2001) as *Avalonella*

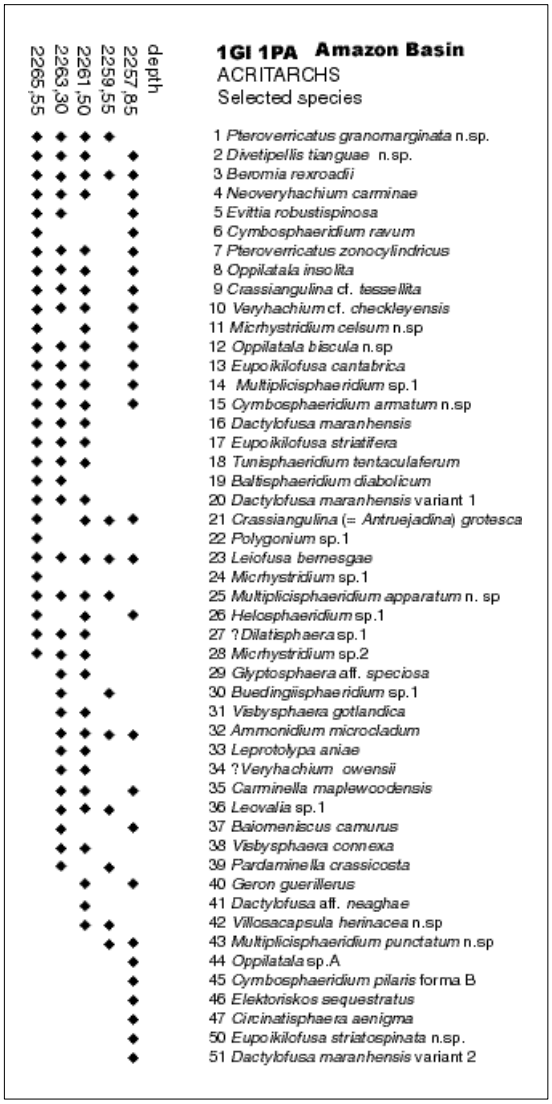


Table 1. Range chart of selected acritarchs in the interval 2265.55-2257.85 m in well 1GI 1PA .

*variacornuta* n. gen., n.sp., were reported from the Telychian of Great Britain and Brabant Massif, Belgium (interval equivalent to *crispus-crenulata* Zones).

In terms of paleobiology and paleoecology, it should be noted an interesting restricted distribution of the *Crassiangulina* Group. Thus, following this Silurian record (Aeronian - early Wenlock) it is not until the Devonian-Carboniferous boundary that the genus reappears with *Crassiangulina tessellita*, the type species, described in the Famennian-Strunian of the Sahara (Jardiné *et al*., 1972). This long absence in the fossil record is not surprising. It does not illustrate recycling or contamination but may be interpreted as a Lazarus phenomenon, presumably related to environmental controls.

The sound question is: what is the real significance of this group? It does not seem to be an indicator of regressive tendency, but could be associated with the flooding of continental margins, and/or be also related to possible climatic changes.

*Dactylofusa maranhensis*, *Baiomeniscus camurus* and *Dactylofusa* aff. *neaghae* are well represented in the samples. *Baiomeniscus camurus* was first described from the Mapplewood Shale of central New York, assigned to the Middle Silurian by Loeblich (1970). Nevertheless, the Mapplewood Shale is now regarded as late Aeronian (Brett *et al*., 1998). *D. neaghae* is known from the Late Llandovery (Cramer, 1970, Keegan *et al*., 1990) to the earliest Wenlock (Dorning, 1983). The total known range of *D. maranhensis* is late Aeronian to early Wenlock, but the species is particularly abundant from late Aeronian to earliest Telychian. In the systematic part of this work we discuss the striking morphological disparity of the specimens recorded. *D. maranhensis* is essentially found in different high latitudes sites of the North Gondwanan margin. For example, the species is well represented in the Elmina sandstone of SW Ghana (Bär & Riegel, 1980), the Tindouf Basin of Algeria and the Silurian of Jordan and Saudi Arabia towards the East .

Additional similarities with the Qusaiba Member of the Qualibah Formation in Saudi Arabia can be underlined. They concern *Baltisphaeridium diabolicum*, *Circinatisphaera aenigma*, *Eupoikilofusa striatospinata*, *Pardaminella crassicosta* and the particular form ?*Veryhachium owensii* Al Ruwaili, 2000 (2261.50-2263.30 m in 1-GI-1-PA), all encountered in the upper Llandovery of Saudi Arabia, some of which restricted to the Qusaiba member of the Qualibah Formation (Al Ruwaili, 2000; Le Hérissé, 2000). *Pardaminella crassicosta* is a lenticular form that was originally described from the Ludlow of Spain. The species seems to disappear temporarily during the Wenlock (Lazarus phenomenon).

The presence of *Leprotolypa aniae* (not illustrated) is recorded at depths 2261.50 m and 2263.30 m in 1-GI-1-PA. This species has been documented in middle to possibly late Llandovery strata of the Algerian Sahara (Jardiné *et al*., 1974).

Another important feature of Tianguá assemblages is the good representativity of large veryhachids assigned to *Veryhachium* cf. *checkleyensis*. The type specimens are from early Wenlock assemblages in Great Britain (Dorning, 1981). However, *V. checkleyensis* is represented also in the Telychian of the Gotland succession (Le Hérissé, 1989) and also in the upper Llandovery of Saudi Arabia.

**Systematics**

Group **Chlorophyta**
Probable **Hydrodictyacean** algae

Genus *Carminella* Cramer, 1968
Type species *Carminella maplewoodensis* Cramer 1968

*Carminella maplewoodensis* Cramer 1968
Plate 1, fig. 4
Remarks: *C. maplewoodensis* is a complex form composed of a spherical central body inside an open-ended, very thin-walled, cylindrical skirt. The central body is attached to the outer cylinder by filaments that are expanded at the two poles. In the material examined two specimens have been found in quite close position suggesting the possibility of connection and therefore of coenobial mode of life (cf. Fig. 3), with several cells attached by the filaments in the poles and forming a ring (or *verticillum*). This arrangement could be equivalent to the circular arrangement described for the Silurian coenobium *Deflandrastum* Combaz 1962 or better *Kahfia arabica* Le Hérissé *et al*., 1995, where the link of the different cells is maintained by means of filaments. The sporadic occurrence of *Carminella maplewoodensis* in the lower and middle Silurian can be paleoecologically significant. The presence of this species seems to be coherent with shallow near-shore depositional settings (usual conditions of a low-stand system tract) or brackish environment. It would be very interesting to confirm a freshwater origin for this taxon.

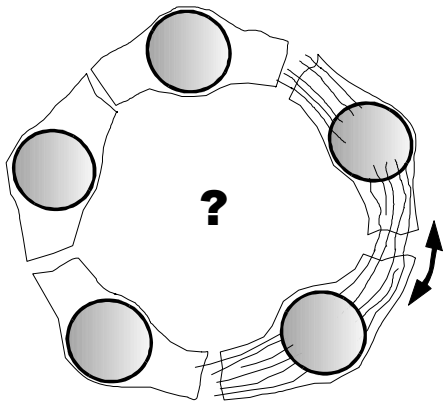


Fig. 3. Hypothetic verticillate organisation for *Carminella maplewoodensis*

Group **Acritarcha**

Genus *Baltisphaeridium* (Eisenack 1958) Eisenack, 1969
Type species : *Baltisphaeridium longispinosum* (Eisenack 1931) Eisenack 1969

*Baltisphaeridium diabolicum* Le Hérissé, Al Tayyar & Van der Eem, 1995
Plate 1, fig. 2

Remark: the Brazilian specimens referred here to *B. diabolicum*, a species originally described from the upper Llandovery of Saudi Arabia (Le Hérissé *et al.*, 1995), have similarly some heteromorph processes. The vesicle surface is granulate.

Genus *Cymbosphaeridium*
Type species *Cymbosphaeridium bikidium* Lister, 1970

*Cymbosphaeridium armatum* nov. sp.
Plate 1, fig. 8
Holotype : 1-GI-1-PA; 2259.55m, slide 9707101, England Finder coordinate X27.3.
Locus typicus : well 1-GI-1-PA, northern Brazil.
Stratum typicum : Tianguá Fm., Serra Grande Group, upper Llandovery.
Derivatio nominis : from the Latin name armatus, armed.
Material : abundant.
Diagnosis : vesicle subspherical, hollow, double-walled, bearing a limited number of processes (4 to 6) that do not communicate with the vesicle interior. The processes are finely striate and also bear sparse denticulate ornaments. The terminations are manate or digitate. The vesicle wall is relatively thick, commonly forming a little plug under the processes.
Remarks and comparisons : this is a quite large form as compared to the other acritarch species encountered in this material. With respect of the double-walled vesicle and presence of denticulate ornaments on the processes, the Brazilian specimens are very close to forms illustrated by Cramer (1970), plate XI, figs. 160, 166 as *Baltisphaeridium denticulatum* with internal cyst. The concept of internal cyst introduced by Cramer is not followed here. As for dinoflagellates we can distinguish some simple cysts or cavate forms with double-walled central body. A material similar to that observed here has been also found in the subsurface of the Algerian Sahara (unpublished data). At this time this form seems to be restricted to Gondwanan regions.
Dimensions : Central body 28 to 31µm, thickness of the wall 1.5µm, process length 31 to 45µm, process width 5-7µm.

Genus *Dactylofusa* (Brito and Santos, 1965)
Type species *Dactylofusa maranhensis* Brito & Santos 1965

*Dactylofusa maranhensis* Brito & Santos 1965
Plate 1, fig. 9
Remark: Brito and Santos (1965), in their original description and illustration of the species, took account of some morphological variation. We came to a similar conclusion for our material, so we decided to distinguish different variants (Plate 1, figs. 10,11) based on their extreme variability, particularly in size and number of clavate elements. We have separated some specimens that are closer to *D. neaghae* (Plate 1, fig. 12) because the ornamentation on the striations is composed of spines (sometimes digitate) and not clavae. We keep using *Baiomeniscus camurus* (Plate 1, fig. 1) for granulate forms, even though the position of *Baiomeniscus* in relation to *Dactylofusa* or *Eupoikilofusa* remains unclear in the literature. In fact a review of all fusiform acritarchs will be necessary in order to clarify their taxonomical situation.

Genus *Divetipellis* Wicander, 1974
Type species *Divetipellis robusta* Wicander, 1974

*Divetipellis tianguaense* nov. sp.
Plate 1, fig. 13
Holotype: 1-GI-1-PA; 2265.55m, Slide 9707104, England Finder coordinate C38.
Locus typicus: well 1-GI-1-PA, northern Brazil.
Stratum typicum: Tianguá Fm.Serra Grande Group, upper Llandovery.
Derivatio nominis: from the Tianguá Formation
Material: more than 25 specimens
Diagnosis: a species of *Divetipellis*, ovate, double-walled and cavate, with a very thin, diaphanous outer wall frequently folded, and a thick, darker inner wall. The inner body can be decentralized. The two wall layers are psilate.
Dimensions: central body 20 to 25µm, total diameter of the external body 40 to 45 µm.
Remarks: the species is referred to *Divetipellis* and not *Pterospermopsis* because the external membrane completely encloses the central body and is not limited to the equatorial part only.

Genus *Eupoikilofusa* Cramer, 1970
Type species: *Eupoikilofusa striatifera* (Cramer, 1964) Cramer, 1970

*Eupoikilofusa striatospinata* nov.sp.
Plate 1, fig. 14
Holotype: 1-GI-1-PA; 2257.85m, slide 9707100, England Finder coordinate W25.
Locus typicus: borehole 1-GI-1-PA, northern Brazil.
Stratum typicum: Tianguá Fm., Serra Grande Group, upper Llandovery.
Derivatio nominis: from the combined spinose and striate ornamentation on the vesicle.
Material: 3 specimens.
Diagnosis: central body fusiform in outline, finely striate on the longitudinal axis, and bearing spinose (hair-like) ornaments on the striae, with long terminal polar processes; vesicle and process wall thin, less than 1µm in thickness.
Dimensions: central body 15 x 24µm in average, process length 50 to 60µm.
Remarks and comparisons: the new species differs from other species attributed to *Eupoikilofusa* by the special ornamentations of fine, bristle-like spinae on the striae, and also the polar processes which are quite long in comparison to the size of the vesicle. It is worth mentioning that a similar material is recorded in the Lower Silurian of Saudi Arabia (A. Le Hérissé, unpublished data).

Genus *Micrhystridium* (Deflandre, 1937) Downie & Sarjeant, 1963

Type species : *Micrhystridium inconspicuum* Deflandre, 1937

*Micrhystridium celsum* nov sp.
Plate 2, figs. 17,18

Holotype : 1-GI-1-PA; 2261.50m; slide 9707102, England Finder coordinate M24.
Locus typicus : well 1-GI-1-PA, northern Brazil.
Stratum typicum : Tianguá Fm., Serra Grande Group, upper Llandovery.
Derivatio nominis : from the Latin name celsus, proud, superb.
Material : abundant.
Diagnosis : vesicle circular in outline, relatively thick-walled, bearing generally 40 to 50 filiform processes with flexible tips, well differentiated from the central body. The interior of the processes freely communicates with the vesicle interior.
Variability : very numerous specimens have been observed, demonstrating a great variability in the number of processes, as stated in the diagnosis. There is an inverse relationship between the number of the processes and their length.
Dimensions : central body 17 to 25µm, process length 17 to 22µm.
Comparisons : *B. capillatum* Jardiné *et al*., 1974, differs from *M. celsum* in the smaller size of processes and a granulate to rugulate vesicle surface.

Genus *Multiplicisphaeridium* Staplin, 1961, restricted by Staplin, 7Jansonius and Pocock, 1965, emend Lister, 1970.
Type species *Multiplicisphaeridium ramispinosum* Staplin, 1961

*Multiplicisphaeridium apparatum* nov sp.
Plate 2, fig. 19
? *Baltisphaeridium* cf. *ramusculosum* Cramer 1970, Pl. VII fig.112.
Holotype: 1-GI-1-PA; 2265.55m, slide 9707104, England Finder coordinate T-16.
Locus typicus: well 1-GI-1-PA, northern Brazil.
Stratum typicum: Tianguá Fm., Serra Grande Group, upper Llandovery.
Derivatio nominis: from the Latin name apparatus, armed, equipped.
Material: only 3 specimens, but very characteristic.
Diagnosis: vesicle subspherical, thin-walled and scabrate, bearing 5 to 6 heteromorphic processes freely communicating with the vesicle interior, ramified up to the 3rd order in their distal part. No excystment structure observed.
Dimensions : central body 18-22µm, processes length 15-17µm, processes width at base about 4µm.
Comparisons : We propose a possible synonymy of a specimen illustrated by Cramer (1970) as *B*. cf. *ramusculosum* with the new species *M. apparatum*, because the morphology of processes in both taxa is very similar. In spite of the limited number of specimens encountered we have erected a new species because we have found similar material in the Lower Silurian of Saudi Arabia (A. Le Hérissé, unpublished data). This provides additional evidence of the close relationships between Early Silurian assemblages of the two regions.

Genus *Oppilatala* Loeblich & Wicander, 1976
Type species : *Oppilatala vulgaris* Loeblich & Wicander, 1976

*Oppilatala biscula* nov. sp.
Plate 2, fig. 20
Holotype : 1-GI-1-PA; 2257.85m, England Finder coordinate R32.3.
Locus typicus : well 1-GI-1-PA, northern Brazil.
Stratum typicum : Tianguá Fm., Serra Grande Group, upper Llandovery.
Derivatio nominis : from the Latin name bisculus, forked.
Material : very abundant specimens.
Diagnosis : vesicle spherical, with a thick wall, smooth or finely granulate. The processes are numerous, uniformly distributed and homomorphous. They have a cylindrical base and are divided at about one third of their total length or near their tip into two long, filose and flexible branches, sometimes secondarily divided into two smaller branches. The processes are plugged at the base and do not communicate with the vesicle interior. Their wall is thin and smooth.
Dimensions : Diameter of central body 27-29µm ; length of processes 20-24.5µm.
Comparisons : as concerns the density of processes and the thickness of the vesicle wall, *Oppilatalla biscula* shows some similarities to *Baltisphaeridium areolatum laevigatum* Jardiné *et al*., 1974. However, here the processes are homomorphic and their bases are not underlined by an areola. *Baltisphaeridium illinoii* Cramer and Diez, 1972 presents some simple and flexible processes quite comparable to the processes of *O. biscula*, but they are irregulalry branched and freely communicate with the vesicle interior.

Genus *Pteroverricatus* Al Ameri, 1984
Type species *Pteroverricatus pequantus* Al Ameri, 1984

*Pteroverricatus granomarginata* nov. sp.
Plate 2, fig. 25
Holotype : 1-GI-1-PA; 2265.55m; slide 9707104, England Finder coordinate D38.3.
Locus typicus : well 1-GI-1-PA, northern Brazil.
Stratum typicum : Tianguá Fm., Serra Grande Group, upper Llandovery.
Derivatio nominis: with reference to the ornamentation of grana circumscribed around the margin of the central body.
Material: 5 specimens.
Diagnosis : Central body circular in outline, dorsoventrally compressed, with an ornamentation of coarse grana on the periphery; the central body is surrounded by an equatorial membrane very thin and transparent, poorly developed, not exceeding 1/5 of the vesicle diameter.
Dimensions : central body 35 to 45µm, flange 5-7µm wide.
Comparison : this species can be distinguished from *P. pequantus* or *P. zonocylindricus* (see Al Ameri, 1984) by the localization of the verrucate ornamentation, which is restricted to the equatorial border of the central body, and disposed as a ring.

Genus *Villosacapsula*
Type species *Villosacapsula setosapellicula* Loeblich & Tappan, 1976

*Villosacapsula herinacea* nov. sp.
Holotype : 1-GI-1-PA; 2257.85m; slide 9707100, England Finder coordinate U24.1.
Locus typicus : well 1-GI-1-PA, northern Brazil.

Stratum typicum : Tianguá Fm., Serra Grande Group, upper Llandovery.
Derivatio nominis : from the Latin name herinaceus, hedgehog.
Material : about 15 specimens.
Diagnosis : vesicle subspherical bearing 4 long and fine processes that freely communicate with the vesicle interior; the surface is densely covered with echinate to baculate ornaments.
Dimensions : central body 13.5µm, process length 24 to 26µm.
process width 1.5µm.
Comparison : this morphotype is differentiated from other congeneric species by the length of the processes compared to the vesicle diameter, as well as by the outline of the vesicle which is subcircular and not subtriangular.

## CHITINOZOANS

Chitinozoans have been recovered in samples from 1-GI-1-PA core 3; 1-BJ-1-PA cores 49 and 52; 2-SL-1-MA core 77; and 1-MA-1-PI core 113. Their preservation is generally poor, and the abundance and diversity low as compared to coeval chitinozoan faunas of the Amazon and Paraná Basins.

The Tianguá chitinozoan assemblages show similarities to those of Llandovery age in the two aforementioned basins (author´s own observations; Grahn & Paris, 1992, Grahn *et al*., 2000). The lack of late Telychian species (e.g. *Salopochitina monterrosae, Angochitina* sp. A *sensu* Grahn & Paris 1992, *Margachitina margaritana* etc.) that commonly occur in the Amazon and Paraná Basins, and absence of species diagnostic for the Rhuddanian (e.g., *Belonechitina postrobusta*) and early Aeronian (*Spinachitina wolfarti, Conochitina* cf. *iklaensis,* etc.), restrict the probable age of the Tianguá shales to the late Aeronian – early-middle Telychian interval. A characteristic Llandovery species, *Sphaerochitina* sp. B *sensu* Paris 1985 (in Hill *et al.,* 1985), has been found in cuttings from the Tianguá Formation shales in well 2-SL-1-MA. Basal Jaicós strata overlying the Tianguá Formation in well 1-BJ-1-PA (core 49) contain *Spinachitina* cf. *harringtoni, Cingulochitina* cf. *serrata* and *Angochitina* sp. (Fig. 4). The former is a species restricted to the Aeronian in the Paraná Basin (Grahn *et al.,* 2000), and *Cingulochitina* cf. *serrata* is characteristic for the late Aeronian and Aeronian - Telychian transition beds in the Paraná Basin (Wood & Miller, 1997, Grahn *et al*., 2000). It is also known from the Amazon Basin, where it occurs together with *Lagenochitina* n.sp. aff. *navicula* (Grahn & Paris, 1992), a species that also appears in core 3 of well 1-GI-1-PA. Lange (1967) reported specimens similar to *Angochitina* n.sp. A in the lower part (late Telychian) of the Pitinga Formation, together with *Salopochitina monterrosae* and *Angochitina* sp. A sensu Grahn & Paris 1992. *Spinachitina* n.sp. A is another common species in the Tianguá Formation, as well as in the lower part of the Pitinga Formation (author's own observations).

The chitinozoan species documented in the Tianguá Formation and their occurrences in the investigated samples are shown in Fig. 4. Selected characteristic species are illustrated in Plate 3. Noteworthy is the absence of the genera *Conochitina* and *Cyathochitina*, which are very common in contemporary beds of the Amazon and Paraná Basins.

| AGE AND CHITINOZOAN ZONES | CHITINOZOAN SPECIES by Grahn, Y. | CORE SAMPLES | | | | |
|---|---|---|---|---|---|---|
| | | 1-BJ-1-PA c.49 | 1-BJ-1-PA c.52 | 1-GI-1-PA c.3 | 2-SL-MA c.77 | 1-MA-1-PI c.113 |
| LATE AERONIAN TO THE AERONIAN-TELYCHIAN TRANSITION / Conochitina elongata Zone / Lower C. proboscifera - D. cf. densa Subzone/ C. proboscifera - S. harringtoni Subzone | **Ancyrochitina ancyrea** | | | ● | | |
| | **Angochitina** n. sp. A | | ● | ● | ● | |
| | **Angochitina** sp. B | | | ● | | |
| | **Angochitina** sp. | ● | | | | |
| | **Cingulochitina** cf. **serrata** | ● | | | | |
| | **Lagenochitina** n. sp. aff. **navicula** | | | ● | | |
| | **Linochitina** n. sp. A | | ● | | | |
| | **Plectochitina** n. sp. A | | | | ● | |
| | **Plectochitina** sp. | | | ● | | |
| | **Sphaerochitina** sp. B* | | | | ● | |
| | **Spinachitina** cf. **harringtoni** | ● | | | | |
| | **Spinachitina** n. sp. A | ● | ● | ● | ● | ● |

Fig. 4. Age and distribution of the chitinozoan species present in the investigated cores. *Specimen found in cuttings from the Tianguá Formation in well 2-SL-1-MA.

The chitinozoans present in the Tianguá shales suggest that these rocks probably range in age from late Aeronian through the early to middle Telychian transition. Thus they correspond to the *Conochitina proboscifera - Spinachitina harringtoni* concurrent range Subzone (late Aeronian) and the lower part of the *Conochitina proboscifera - Desmochitina* cf. *densa* concurrent range Subzone (early Telychian s.l.) as defined in eastern Paraguay by Grahn *et al*. (2000).

## TRILETE SPORES AND CRYPTOSPORES FROM THE TIANGUÁ FORMATION, NORTHERN BRAZIL

Miospore assemblages have been reported previously from Llandovery layers elsewhere in Brazil, e.g. from outcrops of the Vila Maria Formation on the northern rim of the Paraná Basin, State of Goias (Gray *et al.,* 1985 ; Melo, 1997), and from exposures of the Trombetas Group on the northern border of the Amazon Basin near Presidente Figueiredo, north of Manaus (Melo & Steemans, 1997).

Few cryptospores were observed in two of the studied samples from the Tianguá Formation (core 3 of well 1-GI-1-PA, and core 52 of well 1-BJ-1-PA). In both, the assemblages are similar and consist of the following taxa: *Dyadospora murusdensa* Strother & Traverse 1979, *Tetrahedraletes medinensis* Strother & Traverse 1979, *Segestrespora rugosa* (Johnson) Burgess 1991, *S. laevigata* Burgess 1991, *S. burgessii* Steemans *et al*. 1996, *Velatitetras retimembrana* (Miller & Eames) Steemans *et al*. 1996, *V. laevigata* Burgess 1991, *V. rugosa* (Strother & Traverse) Steemans *et al*. 1996, *V. anatoliensis* Steemans *et al.* 1996, *Laevolancis divellomedia* (Chibrikova) Burgess & Richardson 1991, *Rugosphaera rugosa* Miller & Eames 1982, *Rimosotetras problematica* Burgess 1991,

*Imperfectotriletes vavrdovae* (Richardson) Steemans *et al.*, 2000, *Hoegisphaera* sp. A *in* Gao 1987. Only two specimens of a true trilete spore have been observed. Both belong to the morphon *Ambitisporites avitus-dilutus sensu* Steemans *et al*. (1996).

The studied material also includes rare tetrads (from sample 1-GI-1-PA) showing an ornamentation similar to that of *Hispanaediscus*? *irregularis* Wellman & Richardson 1996, a species found near the Silurian-Devonian boundary. Unfortunately the Parnaíba specimens (shown in Plates 4-5) are too poorly preserved to allow proper identification, and therefore have only been referred to as "tetrads n. g. n. sp.". The *incertae sedis Hoegisphaera* sp. A (from core 3 of 1-GI-1-PA) has been previously recorded only in Wenlock to Lochkovian rocks of Saudi Arabia (Steemans, 1995) and in the Lower Devonian of China (Gao & Ye, 1987). This species is not sufficiently known to have any stratigraphic value.

Most of the cryptospore species identified in the Tianguá samples are typical for the interval ranging from Caradoc to Llandovery (Burgess, 1991; Richardson, 1988; Steemans *et al*., 1996, 1999, 2000; Steemans, 1999, 2000; Wang *et al*., 1997; Wellman, 1996). The miospore biostratigraphy across the Ordovician-Silurian boundary has been recently revised by Steemans *et al.* (2000).

The relative abundance of cryptospores enclosed in a membrane, the scarcity of trilete miospores, the presence of *Laevolancis divellomedia* and the absence of characteritic species belonging to the *chulus-nanus* Biozone (Richardson & McGregor, 1986), altogether suggest that the Tianguá assemblage belongs to *divellomedia* subzone, dated Rhuddanian to lower Telychian in Saudi Arabia (Steemans *et al*., 2000).

On the other hand, regional first occurrences of the earliest trilete spores (*Ambitisporites*) seem to be diachronous within the latest Ordovician through Llandovery time span. Indeed, the age of the oldest trilete spores is Hirnantian in Turkey (Steemans *et al*., 2000), late Aeronian in Libya (Richardson, 1988), and latest Aeronian in UK (Burgess, 1991). In Paraguay (western margin of the Paraná Basin), the first trilete spores (*Ambitisporites*) appear in the Aeronian (Steemans and Pereira, 2000, 2001) as dated by chitinozoans (Grahn *et al.*, 2000). Therefore, the diachronous first appearances of trilete spores in the Llandovery require the use local biozonations. In addition, the first appearance of *Archaeozonotreiletes* is within the Telychian in Paraguay (Steemans & Perieira, 2000, 2001). On the basis of results from Paraguay, the Tianguá miospores would be Aeronian to early Telychian in age. But, because of the insufficient observations and poor quality of the Paraguayan material, this stratigraphic evaluation has to be taken with caution.

Except minor changes, the composition of Tianguá miospore assemblages is very similar to that of other Caradoc-Llandovery palynofloras elsewhere in the world.

Surprisingly, such assemblages remain unchanged in composition while ranging from the Silurian paleoequatorial belt to high latitude areas in the Southern Hemisphere (Brazil and Paraguay). These data suggest that the plants which produced those sporomorphs were rather cosmopolitan and could survive under varied climates. This is perhaps the reason why there is no coarse impoverishment in palynomorph biodiversity during the Hirnantian glaciation (Caputo, 1998), to the contrary of many other fossil groups which underwent severe biotic crisis at that same time.

## CONCLUSIONS

The material studied for the Tianguá Formation contains a marine-dominated palynmorph assemblage consisting of acritarchs, chlorophyta and chitinozoans, but only few miospores. Acritarchs are particulalry diversified and point out to optimal conditions for productivity, consistent globally with oligotrophic environments found in marine platforms of a transgressive system. The occurrence of chlorophyta of possible fresh-water origin or near-shore settings could result from floodings of the continental margin or erosion related to periods of increased fluvial discharge. Acritarch assemblages have species in common with other regions of the North Gondwanan margin, testifying to close relationships from West to East across Brazil, Guinea, Western Sahara, Libya, Jordan and Saudi Arabia. Microphytoplankton-based correlations allow to propose a late Aeronian to early-middle Telychian age range for Tianguá palynomorph assemblages, which is also consistent with evidence issued from chitinozoan and miospore studies. The cosmopolitan character of the oldest trilete spores and cryptospores seems to indicate a remarkable climatic tolerance of early land plants during that time interval.

The results provided by the analysis of the various palynomorph groups permit to better define the paleoenvironmental conditions and stratigraphy of the Tianguá Formation. These constraints are of major importance for the exploration prospects involving the Silurian of northern Brazil.

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**CAPTION FOR PLATES 1-5**

**Acritarchs**

**Plate 1**

Fig. 1 - *Baiomeniscus camurus* : vesicle 56x20µm. 1-GI-1-PA; 2257.85m (E14), slide 9707100.

Fig. 2 - *Baltisphaeridium diabolicum* : central body 30µm, process length 29µm, plug at base 7µm, N=6. 1-GI-1-PA; 2265.55m (F17), slide 9707104.

Fig. 3 - *Beromia rexroadii*: Central body 24.5µm, process length 33µm, process width at base 9µm. 1-GI-1-PA; 2257.85m (F16) slide 9707100.

Fig. 4 - *Carminella maplewoodensis* : Dimensions 72x36µm, 1-GI-1-PA; 2257.85m (L31.4), slide 9707100.
Fig. 5 - *Circinatisphaera aenigma* : central body 27µm, process width 2,5-3µm, 1-GI-1-PA; 2257/85m (N83), slide 9707100.
Figs. 6 - *Crassiangulina grotesca* : Central body 31µm, process length 4,5µm ; 1-GI-1-PA; 2259.55m (Z25), slide 9707101.
Fig. 7 - *Crassiangulina grotesca* : Central body 31µm, process length 4,5µm ;1-GI-1-PA; 2261.50m (G34.1), slide 9707102
Fig. 8 - *Cymbosphaeridium armatum* nov. sp. central body 28µm, LP 31-33µm, process width 3-4,5µm, 1-GI-1-PA; 2259.55m (X27.3), slide 9707101. Holotype.
Fig. 9 - *Dactylofusa maranhensis*, with tiny clavate processes 1,5µm high and wide : total length 67µm, total width 18µm. 1-GI-1-PA; 2261.50m (D33), slide 9707102.
Fig. 10 - *Dactylofusa maranhensis* variant 1, a specimen close to the type material: LT 80µm, Vesicle width 22µm, polar spine 8-9µm, clavate ornaments 3,5µm high.1-GI-1-PA; 2257.85m (028), slide 9707100.
Fig. 11 - *Dactylofusa maranhensis* variant 2 : total length 75µm, width 22µm, ornaments 9-11µm high. 1-GI-1-PA; 2257.85m (U32.3), slide 9707100
Fig. 12 - *Dactylofusa* aff. *neaghae* : total length 83µm, width 17µm, ornaments 7-11µm, 1-GI-1-PA; 2261.50m (S30.2), slide 9707102.
Fig. 13 - *Divetipellis tianguaense* nov. sp. : central body 23µm, flange 11µm, total diameter 43µm ; 1-GI-1-PA, 2265.55m (C38), slide 9707104. Holotype.
Fig. 14 - *Eupoikilofusa striatospinata* nov.sp., central body 24,5x15,5µm, LP 59µm. 1-GI-1-PA, 2257.85m (W25), slide 9707100. Holotype.
Fig. 15 - *Evittia robustispinosa* : central body 31µm, process length 14.5µm, process width 4µm ; 1-GI-1-PA; 2257.85m (O19),slide 9707100.

**Plate 2**

Fig. 16 - *Helosphaeridium* sp.1. : Central body 24µm, length of ornaments 1µm ; 1-GI-1-PA, 2265.55m (W26.1), slide 9707104.
Figs. 17 - *Micrhystridium celsum* nov. sp. : central body 25µm, LP 22µm, N=40. 1-GI-1-PA; 2261.50 (M24), slide 9707102. Holotype.
Fig. 18 - *Micrhystridium celsum* nov. sp. : central body 26µm, LP 18µm, N=50. 1-GI-1-PA; 2265.55 (M38.2), slide 9707104. Paratype.
Fig. 19 - *Multiplicisphaeridium apparatum* nov.sp. : central body 20µm, process length 17 µm, process width 4µm, N = 6, 1-GI-1-PA 2265.55 m (T16), slide 9707104. Holotype.
Fig. 20 - *Oppilatala biscula* nov. sp. : central body 27 µm, process length 20µm, N = 35. 1-GI-1-PA, 2257.85m (R32.3) , slide 9707100. Holotype.
Fig. 21 - *Oppilatala* aff. *insolita compacta* : central body 18µm, LP 22µm, process width 3,5µm,1GI-1-PA; 2261.50m (D33), slide 9707102.
Fig. 22 - *Oppilatala* sp. : central body 33µm, LP 45-55µm,1GI-1-PA; 2257.85m (O28), slide 9707100.
Fig. 23 - *Oppilatala* sp.A. : an odd morphotype with 6 main, heteromorphic processes, and several accessory processes of smaller size. 1-GI-1-PA; 2257.85m (M33), slide 9707100.
Fig. 24 - *Pardaminella crassicosta* : total diameter 54µm; 1-GI-1-PA 2259.55m (W29), slide 9707101.
Fig. 25 - *Pteroverricatus granomarginata* nov. sp. : central body 40µm, flange 7µm, total diameter 52µm; 1-GI-1-PA, 2265.55m (D38.3) slide 9707104. Holotype.
Fig. 26 - *Pteroverricatus zonocylindricus* : central body 67µm, flange 25µm, total diameter 135µm ; 1-GI-1-PA, 2265.55m (H42), slide 9707104.
Fig. 27 - *Veryhachium* cf. *checkleyensis* : Central body 25µm process length 61µm,process width 1,5µm ; 1-GI-1-PA; 2265.55m (D35), slide 9707104.
Fig. 28 - *Villosacapsula herinacea* nov sp. : Central body 13.5µm, process length 24.5µm, process width at base 1,5µm ; 1-GI-1-PA; 2257.85m (U24.1), slide 9707100. Holotype.

**Chitinozoa**

**Plate 3**

Selected chitinozoans from the Tianguá Formation in the Parnaíba Basin. The bar represents 100 µm.
All illustrations in plate 1, except n°. 9, were made available to me by Dr. Florentin Paris and Daniéle Bernard (Rennes, France). My sincere thanks to both.
1. *Angochitina* n.sp. A, 1-GI-1-PA core 3.
2. *Angochitina* n.sp. A, 2-SL-1-PA core 77.
3. *Angochitina* n.sp. B, 1-GI-1-PA core 3.
4. *Cingulochitina* cf. serrata, 1-BJ-1-PA core 49.
5. *Lagenochitina* n.sp. aff. navicula, 1-GI-1-PA core 3.
6. *Linochitina* n.sp. A, 1-BJ-1-PA core 52.
7. *Plectochitina* n.sp. A, 2-SL-1-PA core 77.
8. *Plectochitina* sp., 1-GI-1-PA core 3.
9. *Sphaerochitina* sp. B, 2-SL-1-PA cuttings in Tianguá Formation.
10. *Spinachitina* cf. *harringtoni*, 1-BJ-1-PA core 49.
11. *Spinachitina* n.sp. A, 2-SL-1-PA core 77.
12. *Spinachitina* n.sp. A, 1-GI-1-PA core 3.

All representatives of new species will be housed at UERJ.

**Spores-Cryptospores**

**Plate 4**

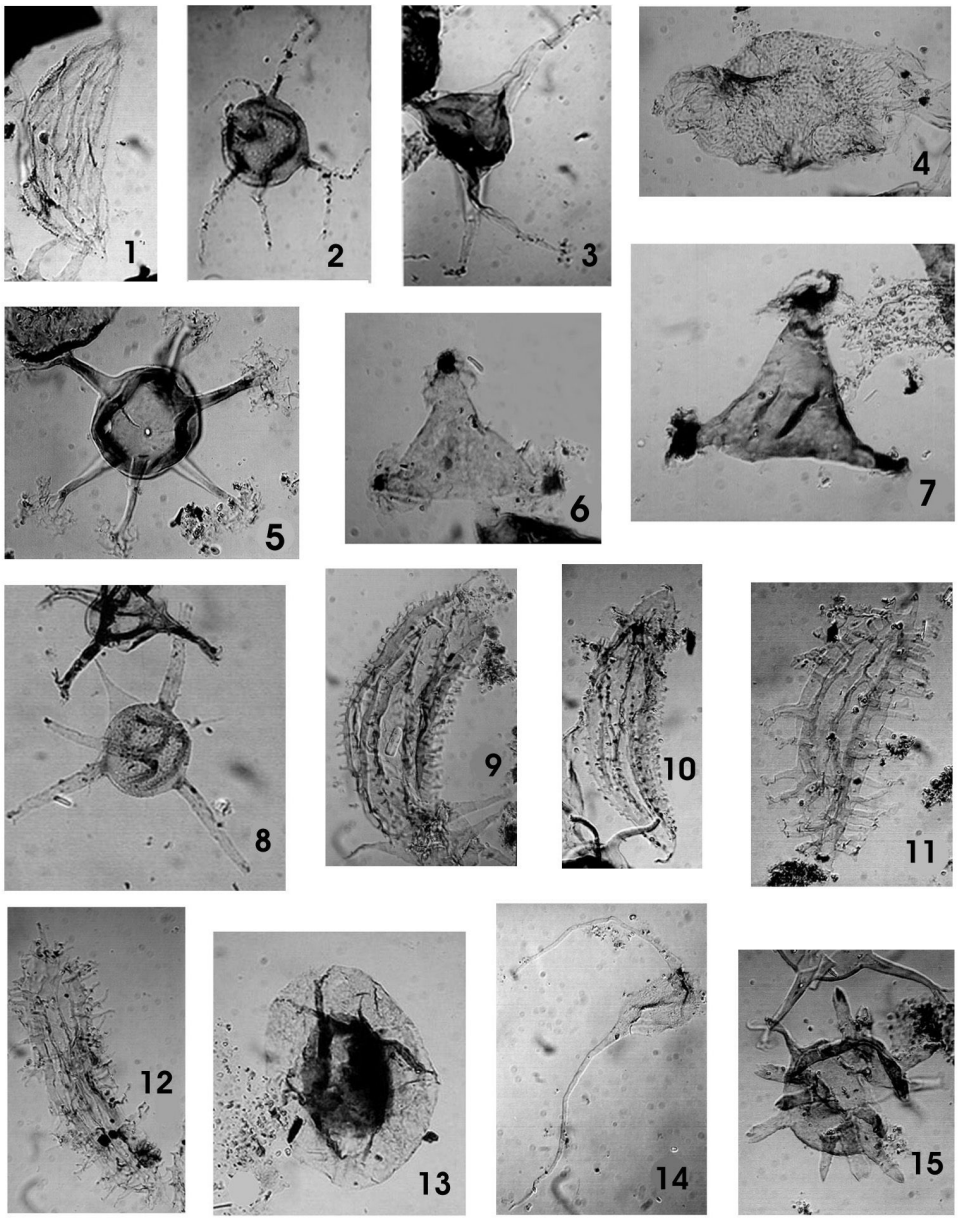
Fig. 1 - *Ambitisporites avitus* Hoffmeister 1959, 1-BJ-1-PA, core 52/ L53/1.
Fig. 2 – *Imperfectotriletes vavrdovae (*Richardson) Steemans *et al.*, 2000, 1-GI-1-PA, core3/ R30/0.
Fig. 3 - *Hoegisphaera* sp. A, 1-GI-1-PA, core3/ D31/1.
Fig. 4 - *Laeovolancis divellomedia* (Chibrikova) Burgess & Richardson 1961, 1-GI-1-PA, core 3/ P42.
Fig. 5 - *Laeovolancis divellomedia* (Chibrikova) Burgess & Richardson 1961, 1-GI-1-PA, core3/ R30/4.
Fig. 6 - *Rugosphaera cerebra* Miller & Eames 1982, 1-BJ-1-PA, core 52/ D22/0.
Fig. 7 - *Rimosotetras problematica* Burgess 1991, 1-GI-1-PA, core 52/ X28/1.
Fig. 8 - *Rimosotetras problematica* Burgess 1991, 1-GI-1-PA, core 3/ W27/0.

Fig. 9 - *Rugosphaera cerebra* Miller & Eames 1982, 1-GI-1-PA, core 52 / U43/1.
Fig. 10 - *Segestrespora laevigata* Burgess 1991, 1-BJ-1-PA, core 52/ R40/1.
Fig. 11 - *Segestrespora burgesii* Steemans, Le Hérissé & Bozdogan 1996, 1-BJ-1-PA, core 52 / V22/4.
Fig. 12 - *Segestrespora rugosa* (Johnson) Burgess 1991, 1-GI-1-PA, core 3/ V44/3.

**Plate 5**

Fig. 13 - Ornamented tetrad with coarse verrucae, 1-GI-1-PA, core 3/ T39/1.
Fig. 14 - Ornamented tetrad with coarse verrucae, 1-GI-1-PA, core 3/ P58/2.
Fig. 15 - *Tetrahedraletes medinensis*,Strother & Traverse 1979 *emend*. Wellman & Richardson 1993, 1-BJ-1-PA, core 52/ O19/0.
Fig. 16 - Trilete spore, 1-BJ-1-PA, core 52, EF 020/3.
Fig. 17 - *Velatitetras laevigata* Burgess 1991, 1-GI-1-PA, 3/ C40/4.
Fig. 18 - *Velatitetras laevigata* Burgess 1991, 1-GI-1-PA, core 3/ V32/1.
Fig. 19 - *Velatitetras retimembrana*(Miller & Eames) Steemans, Le Hérissé & Bozdogan 1996, 1-GI-1-PA, core 3/ S37/2.
Fig. 20 - *Velatitetras* sp., 1-BJ-1-PA, core 52 / U41/3.
Fig.21.–*Velatitetras* (*Nodospora*) *rugosa* (Strother & Traverse) Steemans, Le Hérissé & Bozdogan 1996, 1-BJ-1-PA, core 52 / L21/4.
Fig. 22 - *Velatitetras anatoliensis* Steemans, Le Hérissé & Bozdogan 1996, 1-GI-1-PA, core 3/ Q57/2.

# PLATE 1



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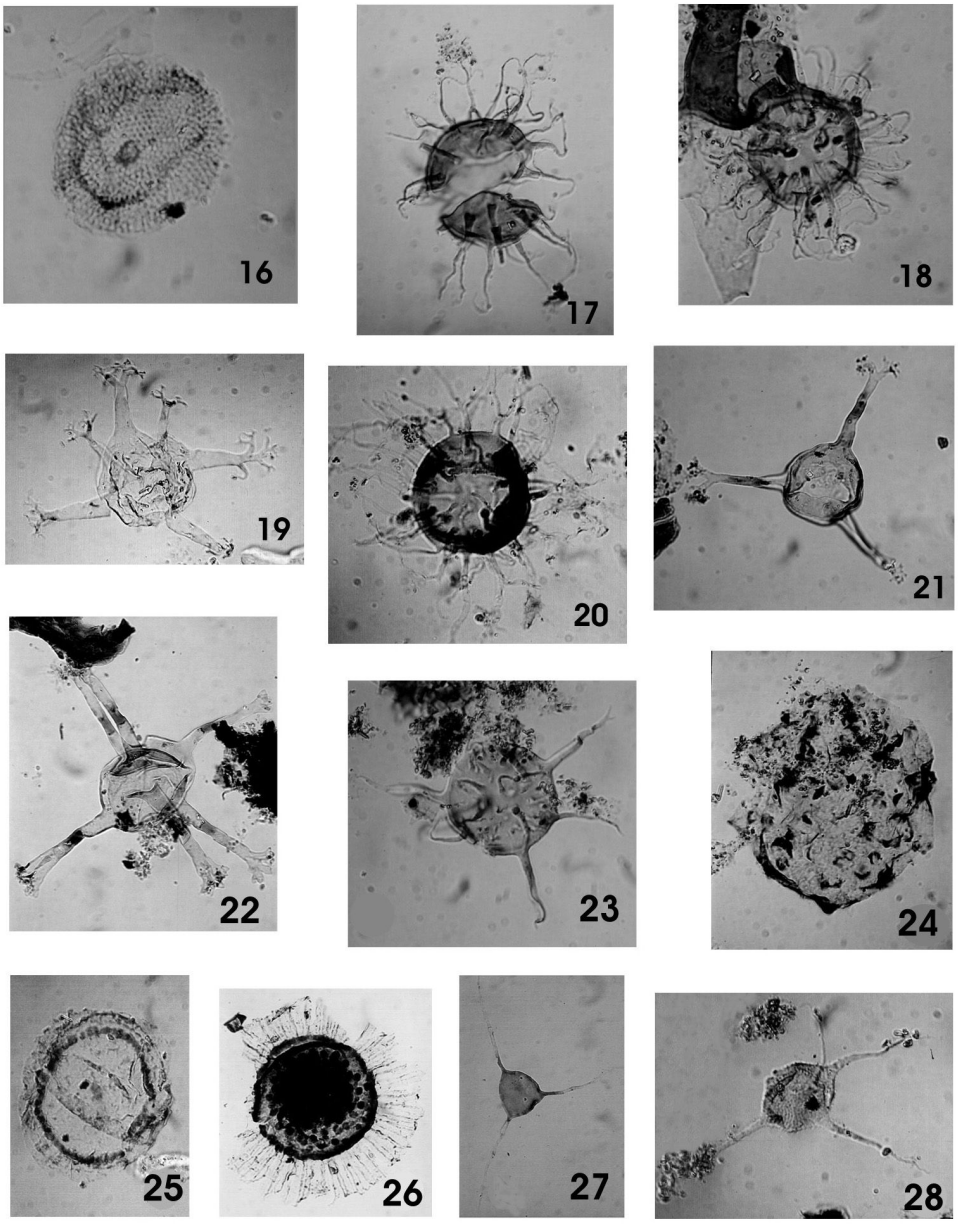

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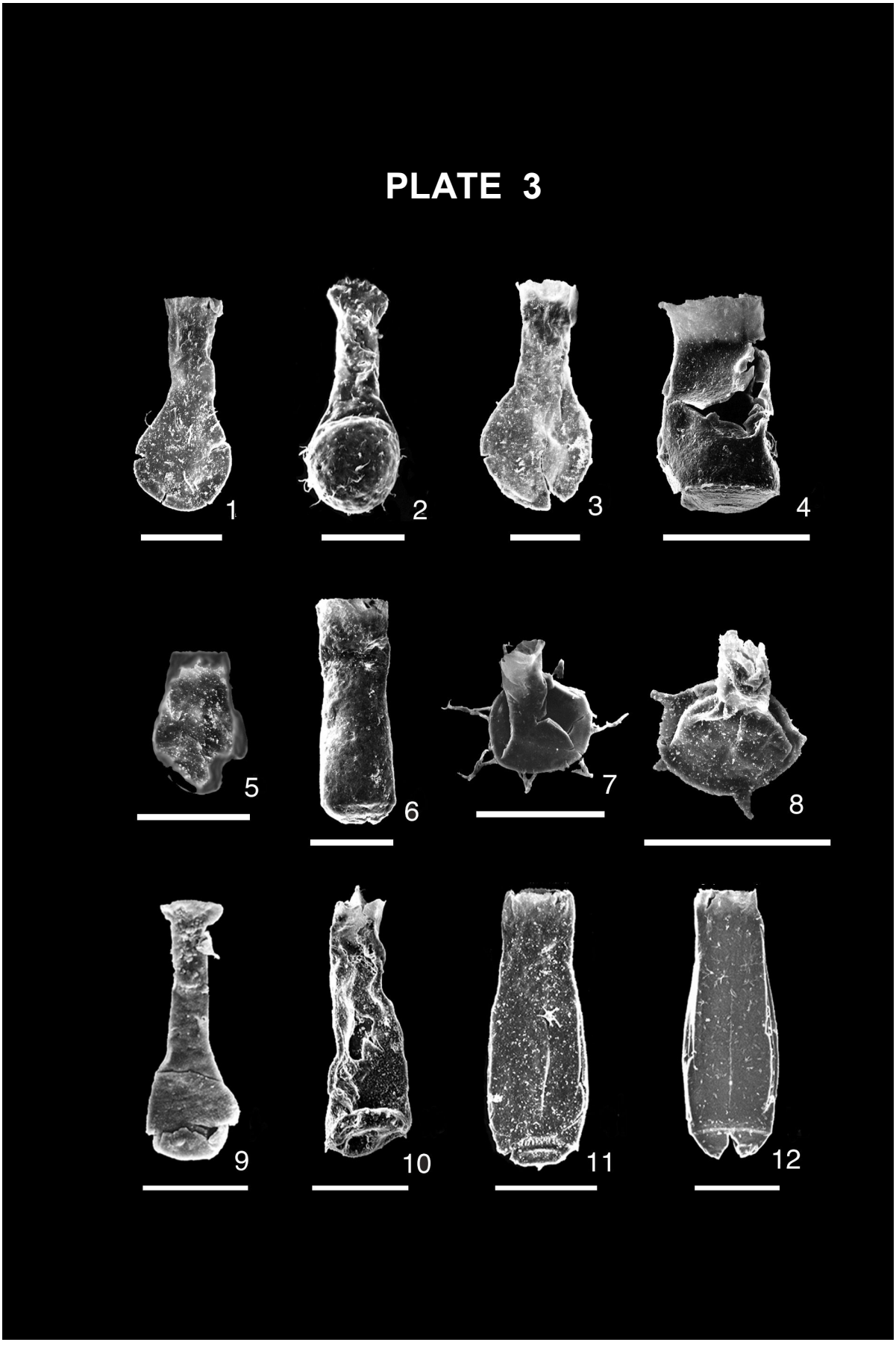
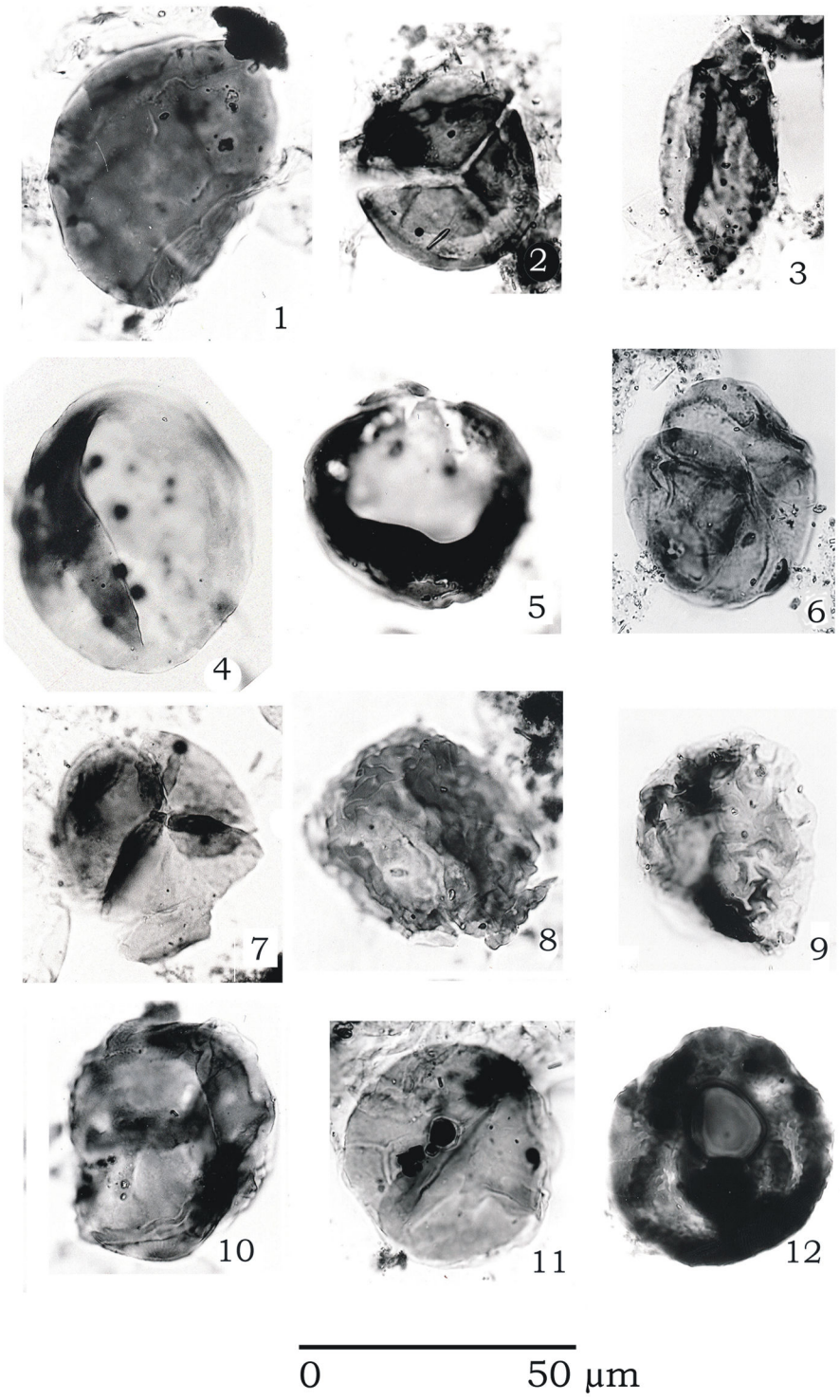
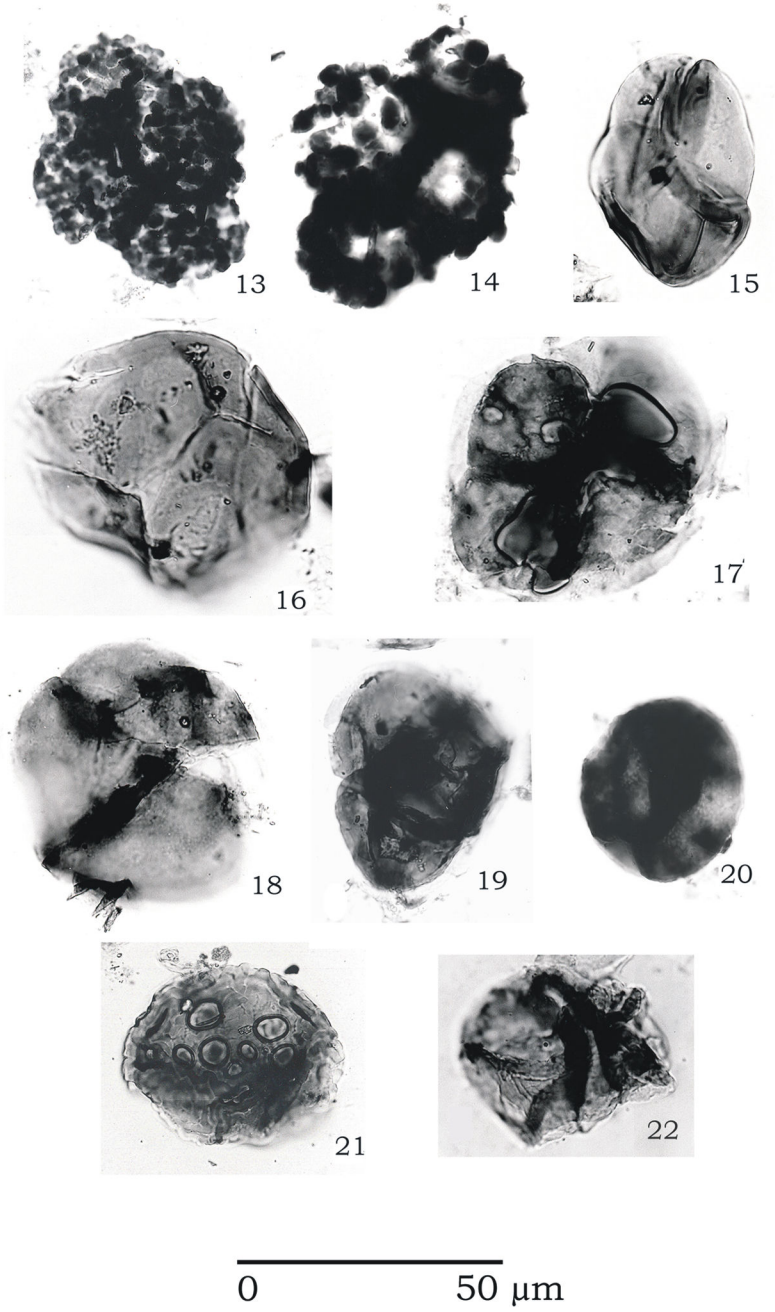


# PLATE 4



# PLATE 5