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Marine diatom study and stratigraphy of Cenozoic sediments in the coastal plain between Morro da Juréia and Barra do Una, State of São Paulo, Brazil

ABSTRACT

Samples of sediments obtained from cores of four wells drilled by Nuclebrás, in the coastal plain of State of Sao Paulo, have been here studied from the viewpoint of diatom flora.

The irregular surface of the crystalline pre-Cambrian basement rocks is locally covered by the Pliocene Pariquera-Açu Formation - like deposits, whose contact with the Quaternary sediments is flat, being situated about 40 m below the present sea-level. The contact between the Holocene Santos Formation and the probable Pleistocene Cananéia Formation is very difficult to be recognized. It has been tentatively established based on two radiocarbon ages (Bah. 1138: 8,220 +/- 310 years B.P. and Bah. 1139: older than 30,000 years B.P., obtained from carbonaceous plant debris sampled respectively from wells F-003 and F-004). Dominantly clayey-silty intervals from the wells F-004 and F-006, probably related to the Cananéia Formation, have been selectively sampled and studied for definition of their diatom flora assemblage. According to these studies, there are littoral marine, estuarine and freshwater sediments, suggesting several phases of sea-level fluctuations. On the other hand, the most abundant species (Raphoneis fatula) is an extinct form and, until now, it had not been reported in sediments more recent than the Pliocene.

RESUMO

Amostras de sedimentos obtidas de testemunhos de quatro sondagens realizadas pela Nuclebrás, na planície costeira do Estado de São Paulo, foram aqui estudadas quanto ao seu conteúdo em diatomáceas.

A superfície irregular de rochas do embasamento cristalino pré-cambriano acha-se localmente coberta por sedimentos do tipo Formacao Pariquera Açu, de idade pliocênica, cujo contato com os sedimentos quaternários é plano, estando situado cerca de 40 m abaixo do nivel do mar atual. O contato entre a Formaçao Santos, de idade holocênica, e a provável Formaçao Cananéia, de idade pleistocênica, é muito dificil de ser reconhecido. Ele foi tentativamente estabelecido com base em duas datações ao radiocarbono (Bah. 1138 : 8.220 +/- 310 anos A.P. e Bah. 1139: > 30.000 anos A.P., obtidas de restos vegetais carbonizados amostrados respectivamente dos poços F-003 e F-004).

Intervalos predominantemente síltico-argilosos dos poços F-003 e F-004, provavelmente relacionados a Formaçao Cananéia, foram seletivamente amostrados e estudados para determinação da assembléia de diatomáceas. De acordo com esses estudos, existem sedimentos marinhos litorâneos, estuarinos e de água doce, sugerindo várias fases de flutuações do nível marinho. Por outro lado, a espécie mais abundante (Raphoneis fatula) é uma forma extinta e, até agora, não foi registrada em sedimentos mais novos do que o Plioceno.

INTRODUCTION

The sedimentary deposits here studied occur at the northeastern extremity of the Cananéia-Iguape coastal plain (Figure 1) defined by Suguío and Martin (1978).

During the climax of the Cananéia transgression, about 120,000 years B.P., the sea reached the foot of the Serra do Mar coastal ranges. This episode is characterized by shore-face clayey-sandy deposits followed by foreshore sands, both covering the continental Pariquera Açu Formation, which has been assumed as Pliocene in age (Sundaram & Suguio, 1983). The retreat of the sea was accompanied by the deposition of beach

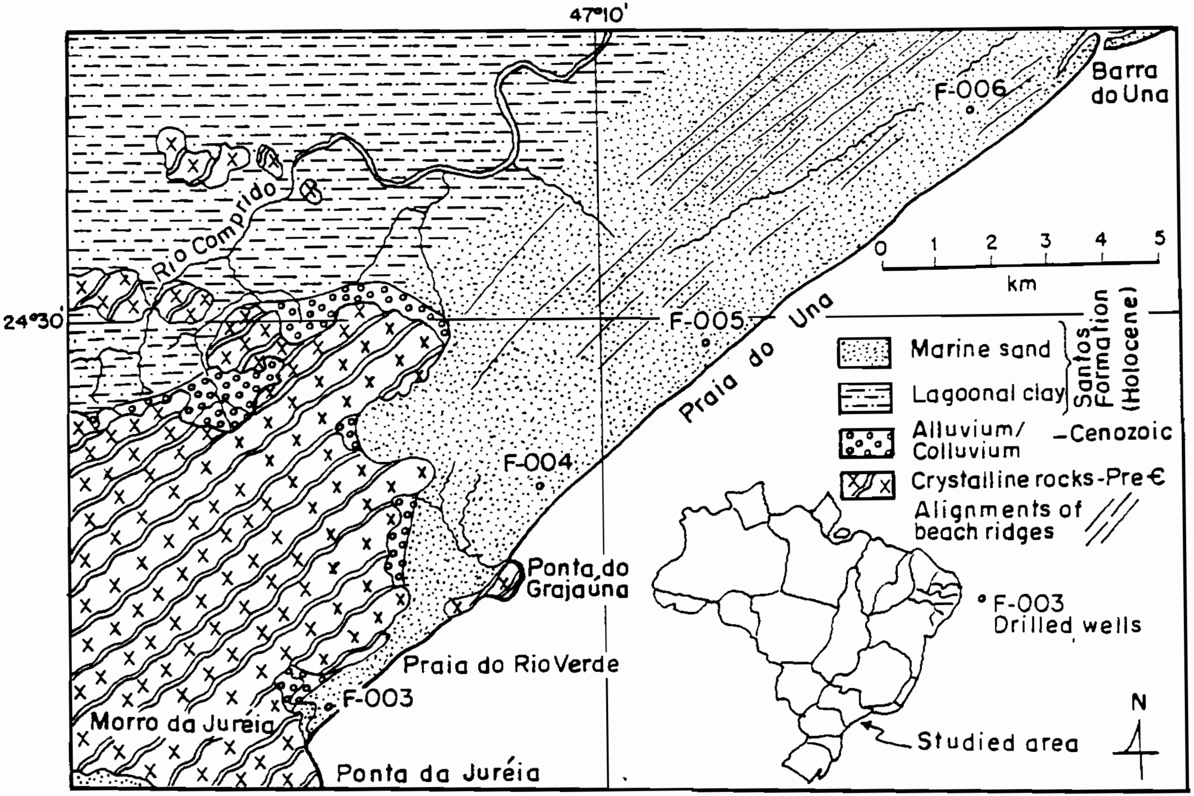

Figure 1. Geologic map showing the locations of drilling sites.

ridges overlying the transgressive sands. During the northern hemisphere Würm glacial stade, the sea-level dropped until more than 100 m below the present level, when the Cananéia Formation surface was strongly dissected by a drainage net. Until this point, the evolutionary history of this coastal plain is quite similar to that of its southern portion.

The Santos transgressive sea deeply encroached the more inland portions between Morro da Juréia (Juréia hill) and Barra do Una (Una outlet). This fact is demonstrated by the occurrence of several shell-middens, dominantly composed of Anomalocardia brasiliana, which normally lives within muddy bay-bottom sediments (Suguío and Martin, 1978). A barrier-island, probably developed soon after the 5,100 years B.P. maximum of the Santos transgression, separated the bay from the open-sea, which has been transformed successively into a lagoonal area, freshwater coastal lake and finally to a swampy lowland. A shell-midden situated at the Rio das Pedras headwaters, with 3,800 years B.P. radiocarbon age (Suguío & Martin, 1978) is indicating the presence of the sea at least until that time. Then, the communication of this lagoonal area with the open-sea has been interrupted only after the second Holocene maximum sea-level, which occurred about 3,400 years B.P.

The four drilling wells, here studied, belong to a Nuclebrás geological investigation program performed for the geotechnical characterization of the future site for thermonuclear power plants (Hassano et. al., 1984).

DRILLED LITHOSTRATIGRAPHIC UNITS

Six rotary drilling wells, with a disposition parallel to the present shoreline, were perforated by the Nuclebrás in the studied area, whose depths changed between 80 m and more than 150 m. Only the drilling wells F-003, F-004, F-005 and F-006 (Figure 1 and 2), with more clayey-sandy beds and organic plant debris, have been sampled, respectively, for diatom studies and radiocarbon datings.

The local pre-cambrian crystalline basement is represented by the Brasiliana Age Complexo Costeiro (Coastal Complex), composed of migmatitic-granitic rocks grading to schists, which is characterized by a very irregular paleo-relief, as demonstrated by the wells that reach the substrate. Meanwhile the substrate is about 50 m deep in some places, like at the sites of the wells F-003 and F-004, the well F-005, distant only 4,1 km from F-004, does not reach the substrate until its final depth of 150 m. These depressions could be explained as paleo-valleys excavated by the drainage net, during the periods of lower sea-levels, as well as by possible faults trending parallel to those of Rio Verde area (Morro da Juréia), oriented according to N 32 oW to 87 oW directions, and probably related to the Guapiara alignment (Hassano et al., 1984).

The crystalline rocks are overlain by continental deposits of the Pariquera Açu Formation, probably Pliocene in age, whose thickness is very changeable according to the substrate's paleo-topography. Its basal portion is characterized by coarse sands and gravels grading upward to reddish-coloured conglomeratic layers alternated with sandy beds and clayey-silty matrix.

Apparently, the top of the Pariquera Açu Formation is flat and is situated about 40 m below the present sea-level, exhibiting a very sharp contact with the superimposed sedimentary deposits. It is very difficult to distinguish the Pleistocene Cananéia Formation from the Holocene Santos Formation, but certainly both are present in the area, as suggested by radiocarbon ages obtained from carbonized plant debris sampled from the wells F-003 (Bah. 1138 : 8,220 +/- 310 years B.P.) and F-004 (Bah. 1139 > 30,000 years B.P.). The first age is clearly indicative of Holocene age and the second one is related to a minimum age. The limit between the Pleistocene and the Holocene formations has been tentatively established in the studied drilling wells (Figure 2), which indicated a thickness variable between 14 and 27 m for the Cananéia Formation, and between 13 and 30 m for the Santos Formation. Inlandwards in the lagoonal area, northwestward from the area of the Figure 1, the top of the Cananéia Formation mapped by Suguío and Martin (1978) is situated about 10 m above the present sea-level, where its thickness could be more than 50 m.

As in the type-locality of Cananéia, the homonymous formation in this area is more clayey-sandy in its basal part, becoming more sandy (fine to very fine sands) on the top. The Santos

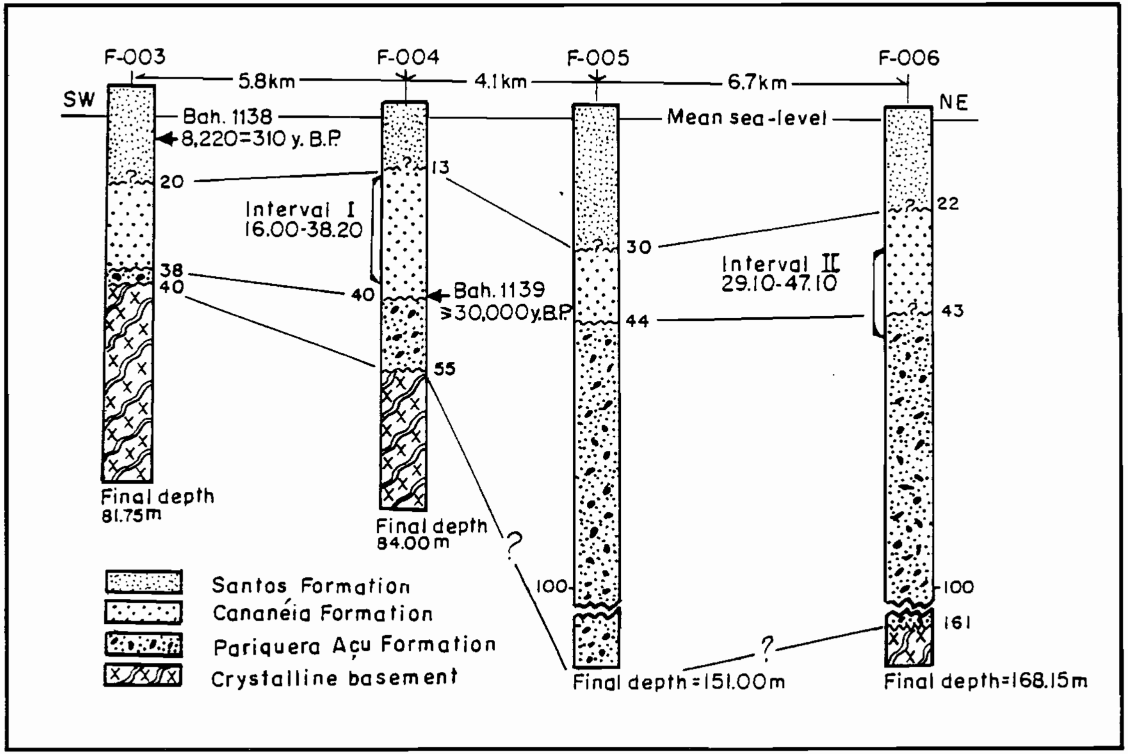

Figure 2. Columnar sections of four wells drilled by Nuclebrás with indications of radiocarbon ages and studied intervals.

Formation comprises, besides shallow marine sands, fluvial, lacustrine and mangrove deposits.

DIATOM BIOSTRATIGRAPHY

Samples for diatom study have been taken from two cores of the wells F-004 and F-006 (Figure 2). In the first one (F-004), seven samples have been analyzed, but only three of them contain a very rich diatom flora. In the second one (F-006), also seven samples have been analyzed, however only three of them contain a poor diatom flora. Assemblages of both cores are similar; a detailed systematic study has been done only in the richest samples F-004/4 and F-004/7 (Table 1).

1 VARIATIONS OF THE DIATOM ASSEMBLAGES ALONG THE CORES FROM THE WELL F-004

The sample 4/1 from about 12 m below the present sea-level in the Holocene Santos Formation does not contain any diatom; this lack of diatoms is perhaps due to the sandy nature of the sediment.

Between 13 and 40 m, six samples have been taken from the Pleistocene Cananéia Formation. Only three of these samples contain diatom; samples 4/4 and 4/7 show a true littoral marine assemblage whereas sample 4/6 contains a freshwater to slightly saline water diatom flora.

The sample 4/2 from about 16 m below the present sea-level is the uppermost sample of the Cananéia Formation. It contains some broken frustules of Synedra **ulna** and **Melosira arenaria**. Both are freshwater species, probably related to a lower sea-level period.

The sample 4/3 from 20.80 m of depth does not contain diatoms.

The sample 4/4, from 24.15 m of depth, is the most interesting sample due to the good preservation of the frustules and to the greatest specific diversity. The diatom assemblage is characterized by true marine species, **Raphoneis fatula** (37%) (Figure 3) and **Paralia sulcata** (32%) (Figure 4) being dominant.

The sample 4/5, from 31.45 m of depth, does not also contain any diatom.

The sample 4/6, from 34.65 m of depth, showed the diatom flora distributed within a very thin (1

Table 1. Frequency of the diatom species in some samples from the wells F-004 and F-006, with ecological information.

Species / Samples	4/2	4/4	4/6	4/7	6/2	6/3	6/5	Ecology
Actinocyclus tenellus	0	1	0	0	0	0	0	M.W.
Actinoptychus kusnetzkianus	0	0	0	1	0	0	0	M.*
Actinoptychus senarius	0	4	0	0	1	1	0	M.C.
Actinoptychus splendens	0	2	0	2	1	1	0	M.W.
Actinoptychus undulatus var. *tamanicus*	0	1	0	2	0	0	0	M.*
Actinoptychus vulgaris	0	0	0	2	0	0	0	M.E.
Biddulphia reticulata	0	2	0	0	0	0	0	M.W.
Cerataulus smithii	0	1	0	1	0	0	0	M.W.
Coscinodiscus concavus var. *minor*	0	0	0	1	0	0	0	M.*
Coscinodiscus divisus	0	0	0	4	0	0	0	M.
Coscinodiscus perforatus	0	2	0	0	0	0	0	M.C.
Delphineis surirella	0	0	0	1	0	0	0	M.C.
Diploneis bombus	0	2	0	1	1	0	0	M.
Endictya japonica	0	1	0	0	0	0	0	M.*
Melosira arenaria	2	0	0	0	0	0	0	F.
Navicula cincta	0	0	4	0	0	0	0	B.
Navicula directa	0	0	2	0	0	0	0	M.
Nitzschia granulata	0	0	0	1	2	0	0	M.B.
Nitzschia tryblionella var. *victoriae*	0	0	0	1	1	0	0	M.B.
Paralia sulcata	0	4	0	1	2	2	1	M.B.
Pinnularia microstauron	0	0	4	0	0	0	0	F.
Podosira stelligera	0	3	0	0	0	1	0	M.W.
Raphoneis fatula	0	4	0	1	2	0	0	M.*
Stauroneis amphioxys	0	0	1	0	0	0	0	M.B.
Synedra ulna	1	0	0	0	0	0	0	F.
Thalassiosira eccentrica	0	0	0	3	0	0	0	M.
Thalassiosira nodulolineata	0	2	0	3	0	0	0	M.
Xanthiopyxis sp.	0	0	0	2	0	0	0	M.*

M.= Marine, B.= Brackish, F.= Freshwater, W.= Warm, C.= Cold, E.= Eurythermal, O = Absent, 1 = Very rare, 2 = Rare, 3 = Abundant, 4 = Very abundant and * = Only reported as fossil.

mm thick) yellow silty lamina overlying a very hard and black sediment without diatoms. This sample contains a lacustrine slightly saline water diatom assemblage. The dominant species is Pinnularia microstauron (Fig. 6: 45), which is oligahalobious. Navicula cincta (Fig. 6: 46) oligo-mesohalobious and Stauroneis amphioxys (Fig. 6: 49) mesohalobious species are rare. There are also few marine species, e.g., Navicula directa. This assemblage indicates a lagoonal freshwater or slightly saline water environment, probably related to a short period of sea-level drop.

The sample 4/7, from 38.20 m of depth, contains a rich and well-preserved diatom flora. All the species are marine, most of them are composed of still living species, except for Coscinodiscus concavus (Fig. 4: 24) and

Xanthiopyxis. The Pennatophycideae are represented by the following marine species: Nitzschia tryblionella var. victoriae (Fig. 6: 50), Diploneis bombus (Fig. 5: 37), Nitzschia granulata (Fig. 3: 7), Delphineis surirella (Fig. 6: 48), all these species widespread in ancient deposits and still living today. According to Andrews (1981 a, b) Delphineis surirella indicates shallow marine brackish waters along coasts of cool to temperate climate.

2 VARIATIONS OF THE DIATOM ASSEMBLAGES ALONG THE CORES FROM THE WELL F-006

When compared with the cores of the well F-004, the frequence of the frustules as well as its diversity are lower. Seven samples have been taken from 21.80 to 130.50 m of depth.

The sample 6/1, from a depth of 21.80 m, does not contain any diatom. The sample 6/2, from a depth of 29.10 m, contains some Paralia sulcáta, Actinoptychus splendens, Raphoneis fatula and Nitzschia granulata. The sample 6/3, from a depth of 33 m, contains some Podosira stelligera, Paralia sulcata and Actinoptychus sp. The sample 6/4, from a depth of 43.40 m, does not contain any diatom. The sample 6/5, from a depth of 77.10 m, contains some Paralia sulcata. The samples 6/6 (130.50 m) and 6/7 (130.50 m) do not contain any diatom.

DIATOM TAXONOMY AND GEOLOGY

1. Actinocyclus tenellus (Breb.) Andrews

Description - Diameter = 26 µm. The Brazilian form is quite similar to that one illustrated by Abbott and Andrews (1979) in their plate 1:9, except by the presence of six sectors instead of five. The single radial rows delimiting the sectors are composed of big areolae (8 in 10 µm), the areolae filling the sectors are smaller (10 in 10 µm), arranged in radial irregular rows. The margin is occupied by very small areolae. Marginal labiate processes are located at the end of the single radial rows of bigger areolae.

Geological range - Miocene to Recent.

Ecology - Navarro (1982:12) found this species in warm waters, and Hendey (1964:84) in the neritic zone.

2. Actinoptychus kusnetzkianus Pantocsek (Fig. 5: 36)

Description - Diameter = 30µm. The surface of circular valve is divided into six sectors. When compared with A. senarius, the valve is flatter, the differences between raised and depressed sectors are slight, the pores are smaller, and the reticulate network is less apparent. Three of six setors are bordered by a hyaline area near the margin as it occurs in A. vulgaris. A labiate process is located at the middle of the margin of each sector. The Brazilian form looks quite similar to Pantocsedk´s drawing in Tafel XXVI, Figure 383, band III. Another species, A. punctulatus illustrated in Schmidt´s Atlas, Tafel 109, seems to be a close species.

Geological range - Never has been reported after Pantocsek (1886), who found it in marine Kusnetzk deposits of Tertiary age from USSR.

3. Actinoptychus senarius (Ehrenberg) Ehrenberg (Fig. 5: 29-35).

Description - Diameter = 25 to 40 µm. It is divided into six sectors. In internal view, the three depressed sectors bear a labiate process near the margin, the pores are fine and arranged in irregular, linear rows, the three elevated sectors do not bear labiate processes, the pores are bigger, and arranged in irregular rows (Fig. 5: 32-34). The mantle contains seven rows of small pores arranged in a quincuncial pattern (Fig. 5: 35). In external view, a reticulate network clearly appears under LM (Fig. 5: 29). The external openings of the labiate processes are short, broad tubes, located near the margin of the valve (Fig. 5: 31).

Geological range - Cretaceous to Recent. Common in Neogene deposits.

Ecology - It is common in cool waters of modern seas, being able to tolerate considerable changes of salinity (G.W. Andrews, personal communication). It is a north-temperate species, frequently found in the plankton of deep waters (Wornardt, 1967:44).

3. Actinoptychus splendens (Shadbolt) Ralfs (Fig. 6: 39-41).

Description - Two different morphological types can be distinguished, separated by their size and some different features. The first one groups the big specimens (diameter = 70 µm) with eighteen alternating raised and depressed sectors, which fit the type species (Fig. 6: 39). The second one groups the small specimens (diameter = 30 µm), characterized by only twelve sectors, a stellate central hyaline area (Fig. 6: 41), and a coarse reticulate network, but the strongest difference appears in the elevation of the raised sectors. In the first type, the elevation is the same along the sector from the margin to the center. In the second type, the elevation is highest near the margin, this restricted part of the raised sectors appears out of focus in valve view (Fig. 6: 40, arrow), the labiate process is located in this zone. This same peculiar feature appears on Actinoptychus aequalis (Andrews & Abbot, 1985), plate 11, and on Polymyxus coronalis - L.W. Bailey (Syn. Actinoptychus) from the Pará river in the slide no490 of the Tempere and Peragallo Collection, illustrated by Schmidt, Tafel 132.

Perhaps it will be necessary to separate within the Actinoptychus genus, species with regular raised sectors and species with irregular raised sectors, and not to attribute these small Actinoptychus to species splendens, as for the big ones.

Geological range - Late Miocene to Recent (Andrews, 1980).

Ecology - According to Hendey's opinions (1964:95), it is a common littoral form, frequent in the English channel. For Navarro (1982), it is a sublittoral form of warm waters, and John (1983) found it in the summer within planktonic and benthic samples.

5. Actinoptychus undulatus var. tamanicus, Jousé (Fig. 6: 42-44).

Description - Length = 60 µm and width = 45 µm. It is an oval diatom with two very elevated sectors (Fig. 6: 43), and two slightly elevated sectors (Fig. 6: 44), bearing a labiate process each one (see schematic drawing), separated by narrow depressed sectors. The pores are round and arranged in regular parallel rows.

A form similar to that of Tempere and Peragallo collection (2nd edition, n° 182) was found in the Middle-Late Miocene Richmond Formation of Virginia. However, in the plate n o 18 of the Ehrengerg Mikrogeologie (1838), concerning to this formation, this form is not illustrated, and it is missing too in Andrews' recent work on the same formation published in 1986. This form is illustrated only in "the diatoms of USSR" edited by Glezer et al.

(1979), under the name A. undulatus var. tamanicus (Plate 40:13).

Probably, Actinoptychus undulatus var. tamanicus can be considered as synonymous of Polymyxus coronalis, because of the areolae arrangement on the valve face and the restricted elevation near the margin of the raised sectors, although it has a lower number of sectors.

Geological range - Miocene of the Richmond Formation, according to Tempere and Peragallo. Marine Miocene deposit of Kuriles Islands, according to Glezer et al. (1979:178), where it is associated with true Miocene assemblage characterized by Stenphanopyxis inermis, Thalassiosira zabelinae, Denticula kamtschatica, but also with Paleogene species, like Pseudopodosira hyalina, Coscinodiscus payeri var. payeri and Hemiaulus elegans.

6. Actinoptychus vulgaris A. Schmidt (Fig. 6: 38).

Description - It is a very peculiar species with only eight sectors and a characteristic pattern. There is no reticulate network, pores are big in regular linear rows, with the same disposition and number in the depressed and elevated sectors. In external view, the elevated sectors are delimited by a hyaline area near the margin. The closest form was illustrated by John (1983, Plate X, Figure 10). A nice specimen was found in Tempere and Peragallo Collection (2nd edition, no 622, from the Malacca detroit, China).

Ecology - It is a benthic and planktonic form, pH around 8, and temperature between 13 o and 35oC (John, 1983).

7. Biddulphia reticulata, Ropper (Fig. 3: 6).

Description - Length = 45 µm and width = 30 um. Five hexagonal areolae in the center and eight at the extremities. There are no peculiar remarks about the morphological features of this species.

Ecology - It presently lives in sublittoral marine environments, predominantly in warm waters (Navarro, 1982:14).

8. Cerataulus smithii, Ralfs (Fig. 3: 8-9).

Description - Diameter = 30 µm. Circular valve with two small triangular elevations, round areolae inside, with external velum consisting of volae, 8 in 10 µm (Fig. 3: 9).

Ecology - According to Navarro (1982:17), it is a sublittoral to supralittoral species, common throughout the year. For Hendey (1964:106) it is common and widespread littoral species along all North Sea coasts. Also widespread in the eastern Mediterranean sea during the Early Holocene, where was replaced by **Paralia sulcata** during the Late Holocene (Sneh et al., 1986).

9. Coscinodiscus concavus var. minor, Grove (Fig. 4: 24).

Description - Diameter = 30 µm. Circular valve, not flat. Focus cannot be done on the entire valve at the same time. In one half part of the valve the areolae (7 in 10 um) appear round bordered by a thick rim; this image corresponds to the internal morphology of the areolae, meanwhile, on the other half, the areolae appear hexagonal, each angle marked by a siliceous round point clearly seen under LM (outside morphology of the areolae).

Similar forms have been found in the slides no 569 and 570 of the Tempère and Peragallo Collection from Miocene Otago Oamaru Formation of New Zealand; quite identical to the brazilian specimen.

Geological range - Until now, only reported in Miocene deposits.

10. Coscinodiscus divisus, Grunow (Fig. 4: 25,26).

Description - Diameter = 52 µm. Circular valve containing seven polygonal areolae in 10 µm, with external velum visible under LM. Valve fasciculate, divided into twelve sectors. This form is morphologically very similar to the specimen illustrated by Abbott and Andrews (1979, Plate 2, Figure 3, p.236), and was identified as **C. divisus** by Andrews (written communication).

Geological range and ecology - According to these authors: "previously reported from rocks of Pliocene age to Holocene in a widespread modern littoral and neritic environments".

11. Coscinodiscus perforatus, Ehrenberg (Fig. 3: 10).

Description - Diameter = 46 µm. Circular valve with rounded areolae, bigger in the center of the valve (5 in 10 µm) than near the margin. The marginal strutted processes are regularly spaced every 2 µm (Fig. 3: 10, arrows) there are five central strutted processes irregularly spaced, located at about midway between the center and the margin.

Geological range - Miocene to Recent.

Ecology - It is frequent in the plankton of the North Sea (Hendey, 1964:77).

12.Endictya japonica, Kanaya (Fig. 4: 23).

Description - Diameter = 18 µm. It is a small circular species. The areolae are loculate, and covered by an hexagonal cellulation (5 in 10 µm in the center), smaller near the margin of the valve.

Geological range - It has been described by Kanaya (1959) in the Middle Miocene of deposit Onnagawa Formation in Japan and by Hendey (1981) in the uppermost part of core 10, site 278, leg 29, in the Subantarctic Southwest Pacific.

13. Paralia sulcata (Ehrenberg) Cleve (Fig. 4: 11-19).

Description - It constitutes about 32% of the assemblage observed in the sample no
4/4 of the well F-004. Its greatest interest is due to the morphological features. Widely studied by Crawford (1979), SEM observations on Brazilian material supplied with additional information, which are very useful to better understand the valve structure of this complicated species. A detailed description will be given at the end of this chapter.

Geological range - Throughout the Tertiary to Recent. Widespread in Miocene deposits; it is common in the Richmond Formation, Virginia (Ehrenberg, 1838, Mikrogeologie, Plate 18). This formation has been recently studied by Andrews (1986, Plate 7:12-14).

Ecology - This species is very important for paleoecological reconstructions. According to Andrews, this species is common in modern shallow marine coastal waters; to Hendey (1964:73) and
John (1983:16) in shallow marine environments and to Navarro (1982) in sublittoral zone.

14. Podosira stelligera (Bailey) Mann (Fig. 4: 20,21).

Description - Diameter = 15 to 50 µm. Strongly convex circular valve, whose central portion presents sparse areolae, marginal area fasciculate with radiate fine rows of areolae.

Ecology - For Hendey (1964:90), it is a tychopelagic species; for Andrews (1980:32), it is a common planktonic form in Recent marine and coastal waters. Navarro (1982:11) found it in sublittoral zone with a temperature of 17
oC.

15.Raphoneis fatula, Lohman (Fig. 3: 1 to 5).

Description - Length = 40 to 60 µm and width = 8 to 10 µm. Flat, lanceolate, more or less rounded valve, with transversal rows of puncta (7 in 10 µm), longitudinal rows of puncta (7 - 8 in 10 µm). Very thin axial area. Specimens very changeable in shape and morphology, which have been firstly related to several species, but according to Andrews, these morphological variations cannot be considered as specific differences, thus they have been reported as a single species R. fatula, Lohman.

Geological range - R. fatula has been described by Lohman (1938) from the Pliocene San Joaquin Formation, east flank of North Dome, Kettleman Hills, Kings Country, California. It has not yet been reported in modern environments. Very abundant in the well F-004, its presence in this level makes questionable the problem of attribution to the Pleistocene of the Cananéia Formation. Alternatively, the sediments assumed to be of Cananéia Formation could be older than this formation, because 14C dating supplied only with its minimum age.

Ecology - The habitat of the genus is shallow marine environment.

16. Thalassiosira eccentrica (Ehrenberg) Cleve (Fig. 4: 27,28).

Description - Diameter = 35 to 45 µm. Circular valve with rounded areolae inside and hexagonal outside, arranged in tangential rows with large sectors not very clearly marked in some specimens (8 in 10 um). Many strutted processes are scattered throughout the valve, a strong labiate process can be observed under LM (Fig. 4: 27), marginal strutted processes appear in Figure 4: 28.

Geological range - Lower Miocene to Recent.

Ecology - This species is found in neritic plankton (Andrews & Abbott, 1985). It is a common planktonic diatom found in large numbers at the lower stations during the summer in Australia (John, 1983:19).

17. Thalassiosira nodulolineata (Hendey) Hasle & Fryxell (Fig. 4: 22).

Description - Diameter = 25 µm. Circular valve with hexagonal loculate areolae (6 in 10 µm) in linear rows. Marginal processes can be observed under LM, but they are not visible on Fig. 4: 22. Six small central strutted processes are arranged in a small sub-circular rim.

Geological range - Unknown to Recent.

Ecology - Marine.

18. Genus **Xanthiopyxis**

This genus only appears in the sample n° 4/7 of the well F-004. There are few specimens, three different dominant forms should possibly related to X. lacera, Forti (Late Miocene to Early Pliocene), X. diaphana, Forti (Middle Miocene to Early Pliocene), X. new sp., Wornardt (Early Pliocene).

MORPHOLOGICAL REMARKS ON THE SPECIES **PARALIA SULCATA**

Paralia sulcata is a very interesting species from different points of view: complexity in its structure, abundance in modern environments and its great geographical-geological distribution in ancient sediments. It has been illustrated by previous authors under different names, for example, by Schmidt (Tafel 175, 176, 177). The last more detailed study on this species is due to Crawford (1979).

In the Brazilian material this species is abundant. Detailed SEM observations allowed us to clarify some yet problematic aspects concerning the ultrastructure of the valve face, essentially the relation existing between the different images appearing under LM and the location in the chain of the different images of the valve face.

Crawford (1979) has shown that the structures formerly attributed to Paralia **sulcata** and to P. **sulcata var. coronata** represent the same species, since they occur together in the same chain. It is a case of heteromorphy, named by this author as Paralia sulcata structure, Type 2, and Paralia sulcata var. coronata, Type 1.

In the Brazilian material, both structures can be observed in big specimens (diameter = 50 µm), as well as in small ones (diameter = 12µm). Type 2 is more complex than type 1. Under Lm three different morphologies (or images) can be distinguished and described; they depend on the location within the chain of the observed valve, and the side through which they are charged. Figure 7 illustrates the following different possibilities:

a) Sub-type 2A (Crawford, 1979: Figure 6, 17). From the margin to the center it is possible to observe: 1) the spines, 2) a rim of big pores, 3) a rim of stellate radiating markings, and 4) a central circular hyaline area. This image corresponds to the external view of the linking cells (Figure 7: 4).

b)Sub-type 2B (Crawford, 1979. Figure 9) (Fig. 4: 13, 15, this paper). Under LM, it is composed of: 1) the spines, 2) a rim of big pores, 3) a rim of fine striae at the same level, 4) a rim of stellate radiating markings and 5) a central circular hyaline area. This image corresponds to the internal view of the linking cell (Figure 7). Under SEM, this internal view appears very simple (Fig. 4: 11-13) and according to Crawford (1979: Figure 28) it is composed of: 1) a ring of fine striae near the margin of the valve, the rimoportulae are located near the mantle edge, and 2) a hyaline circular central area.

The stellate radiating markings and the rim of big pores are not visible because they are strouded by an internal lamina (Fig. 4: 13) composed, from the center to the margin, of a hyaline lamina covering the radiating markings, and a rim of fine striae covering the big pores. When by chance this internal lamina is broken (Fig. 4: 15 and Crawford, 1979: Figure 20), it is possible to see the big pores and the radiating markings which are below it.

So, the two different images (sub-types 2A and 2B) observed under LM, represent the same kind of valve face, regarded in internal or external view respectively (Figure 7:4 and 3).

c) Sub-type 2C. The third image of the valve face (Fig. 4:19) is quite difficult to interpret. It is composed of: 1) the spines, 2) the rim of big pores, 3) the stellate radiating markings, 4) the rim of fine striae, and 5) a rim of short wedge-shaped markings.

The presence at the same time of the radiating markings of the linking cells and the wedge-shaped markings of the separation cell can only be explained, if we admit that we observe the internal view of the last linking valve, located just before the separation valve (Figure 7:2). The wedge-shaped markings appear by transparency under LM. This case is not so common, that is normal because the number the last linking cell linked with the separation cell, is smaller compared with the number of the linking cells in the chains.

EXPLANATION OF THE PLATES

Figure 3: 1-10

LM: Scale bar = 10 µm

1 - 5: Raphoneis fatula, Lohman
  1 - Same specimen under different focus.
  2 - Dyssymmetrical form
  3 - Quadrate pattern of ornamentation
  4 - Interior of valve
  5 - Detail of the same specimen, showing the external valve.
6: Biddulphia reticula, Ropper
7: Nitzschia granulata
8 - 9: Cerataulus smithii, Ralfs
  8 - LM at different magnifications.
  9 - SEM view of the internal valve.
10: Coscinodiscus perforatus, Ehrenberg
  Internal valve at different magnifications.
  Arrowhead:
  Marginal strutted process. Arrow: Central strutted process.

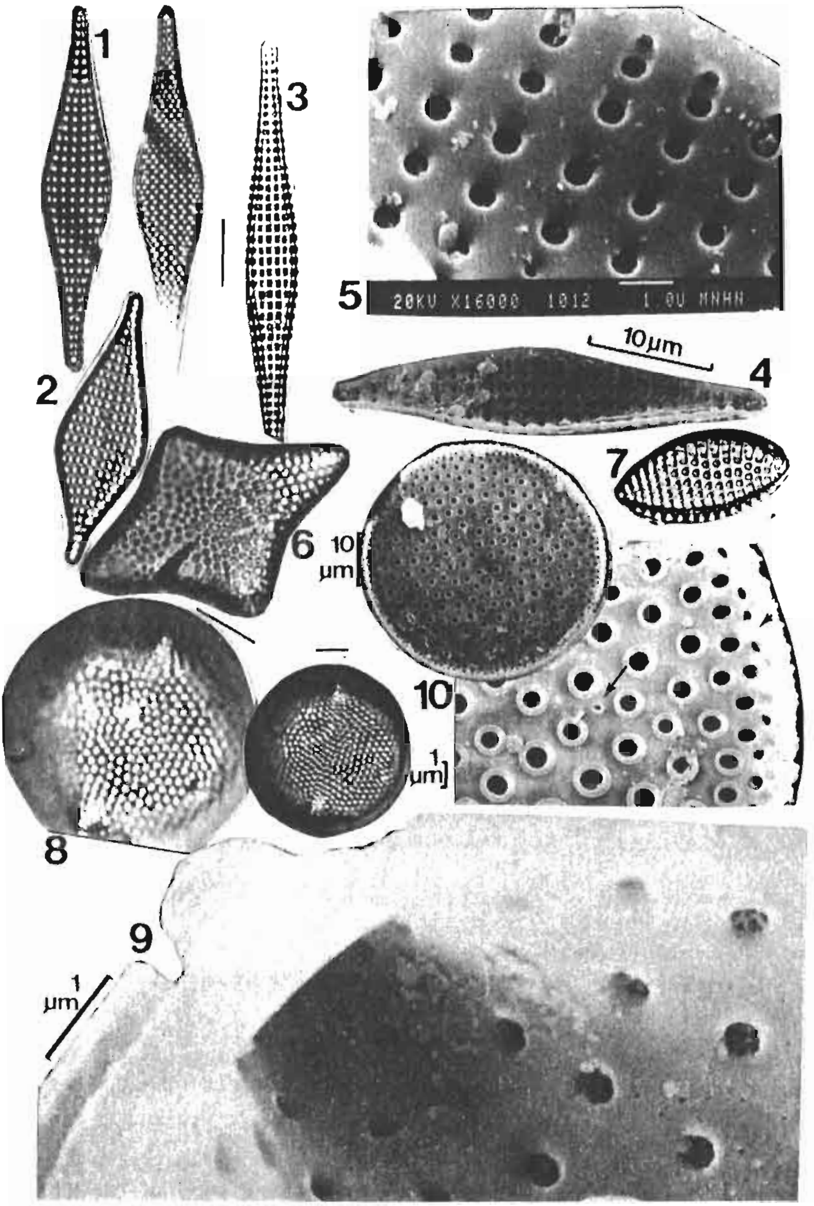

Figure 3: 1-10

Figure 4: 11-28

LM: Scale bar = 10 um

11 - 19: Paralia sulcata (Ehrenberg) Cleve
- 11 - SEM: Lateral and internal views of one valve of linking cell.
- 12 - LM: Lateral view of a chain of three linking cells.
- 13 - SEM: Internal view of a valve of linking cell or of the hypovalve of a separation cell.
- 14 - LM: Internal view of a linking cell. Image corresponding to sub-type 2B (See Fig. 7:3).
- 15 - SEM: Internal view of a valve of linking cell, similar to 13, but with an internal broken lamina (arrowhead), which allows to see the radiating markings and the big pores.
- 16 - LM: Chain of Paralia including a complete separation cell (arrow), a complete last linking cell (double arrows) and the hypovalve of another linking cell.
- 17 - LM: Internal view of the epivalve of separation cell. (See Fig. 7:1b - Type 1).
- 18 - SEM: External view of the epivalve of a separation valve (See Fig. 7:1a - Type 1).
- 19 - Internal view of the epivalve of the last linking cell, including the internal view of the epivalve of the separation valve (See Fig. 7:2 - Type 2C).

20 - 21: Podosira stelligera (Bailey) Mann
Two specimens of different sizes.

22: Thalassiosira nodulolineata (Hendey) Hasle & Fryxell.

23: Endictya japonica, Kanaya.

24: Coscinodiscus concavus var. minor, Grove.

25 - 26: Coscinodiscus divisus, Grunow.

27 - 28: Thalassiosira eccentrica, (Ehrenberg) Cleve.

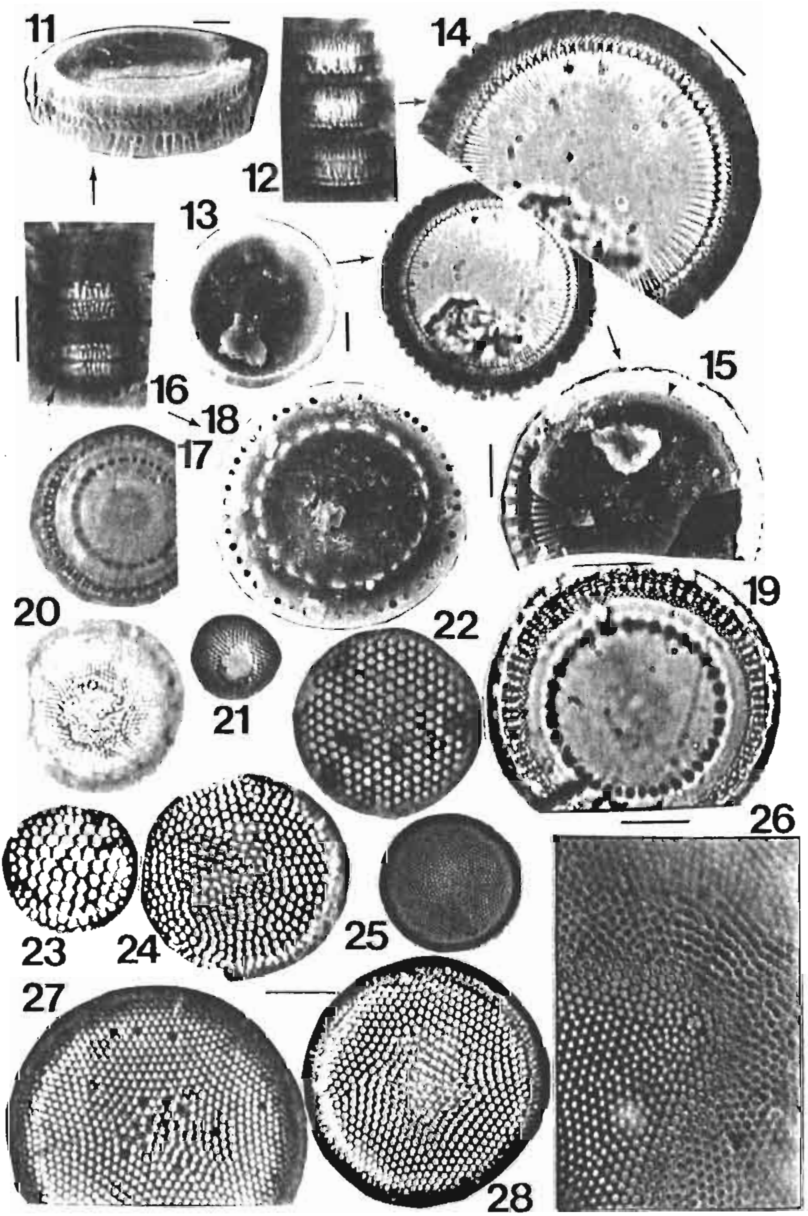

Figure 4: 11-28

Figure 5: 29-37

LM: Scale bar = 10 um

29 - 35: **Actinoptychus senarius** (Ehrenberg) Ehrenberg.
- 29 - LM: (a) Focus on raised sectors, (b) Focus on depressed sectors.
- 30 - SEM: External valve.
- 31 - Detail on the external reticulate system and the external foramen of labiate process.
- 32 - SEM: Internal valve.
- 33 - SEM: Detail on depressed sector, with irregular rows of pores on a raised sector, bearing a labiate process.
- 34 - SEM: Detail of the labiate process.
- 35 - SEM: Rows of small pores on the mantle arranged in quincuncial pattern.

36: **Actinoptychus kusnetzkianus**, Pantocsek.

37: **Diploneis bombus**, (Ehrenberg) Cleve.

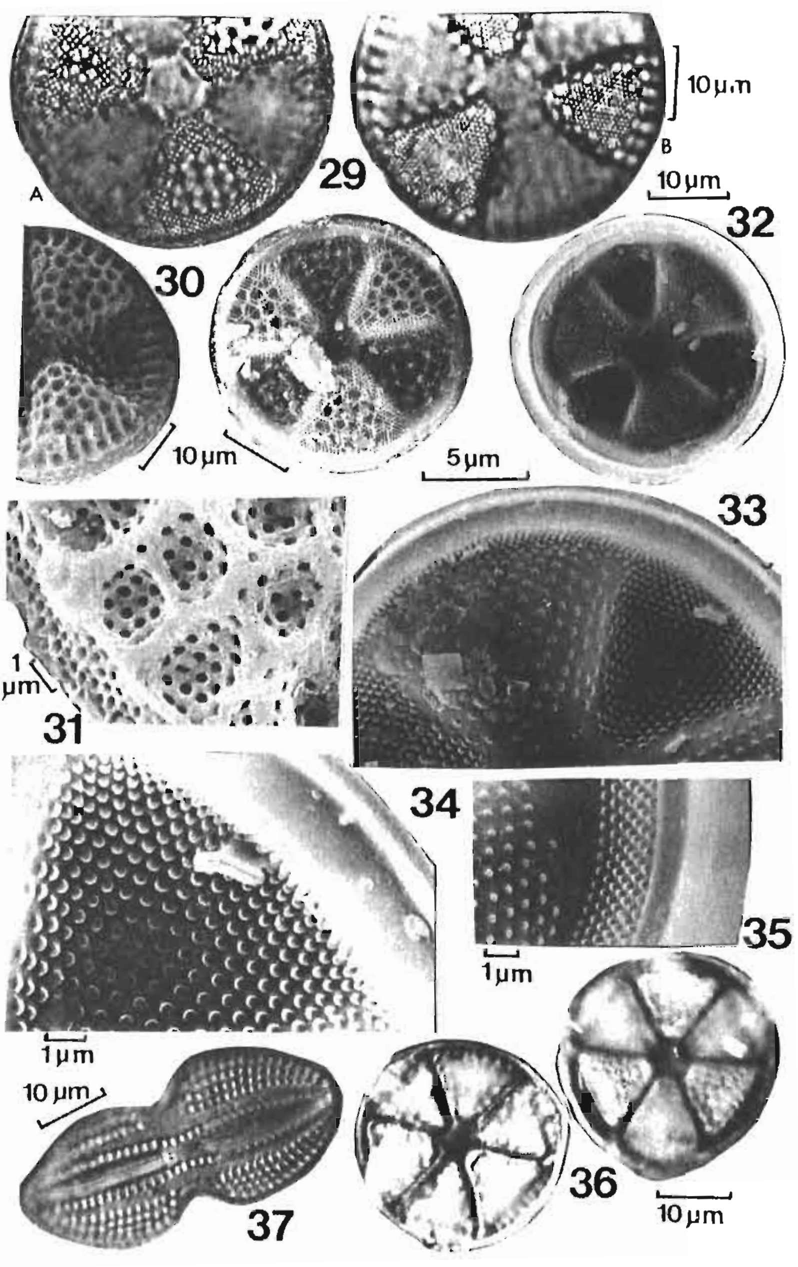

Figure 5: 29-37

Figure 6: 38-50

LM: Scale bar = 10 um

38: Actinoptychus vulgaris, A. Schmidt
a = Focus on raised sectors, b = Focus on depressed sectors.
39: Actinoptychus splendens, (Shadbolt) Ralfs
40 - 41: Actinoptychus splendens, (Shadbolt) Ralfs
40 - Stellate central area (See localized great elevation near the margin in the raised sectors, appearing out of focus and bearing the labiate process).
41 - Detail of the central area.
42 - 44: Actinoptychus undulatus var. tamanicus, Jousé.
42 - Entire valve.
43 - Detail of raised terminal sectors.
44 - Detail of intercalated raised sectors.
45: Pinnularia microstauron, (Ehrenberg) Cleve.
46: Navicula cincta, (Ehrenberg) Kutzing
47: Nitzschia punctata, (W. Smith) Grunow
48: Delphineis surirella, (Ehrenberg) Andrews
49: Stauroneis amphioxys, Gregory
50: Nitzschia tryblionella var. victoriae, Grunow

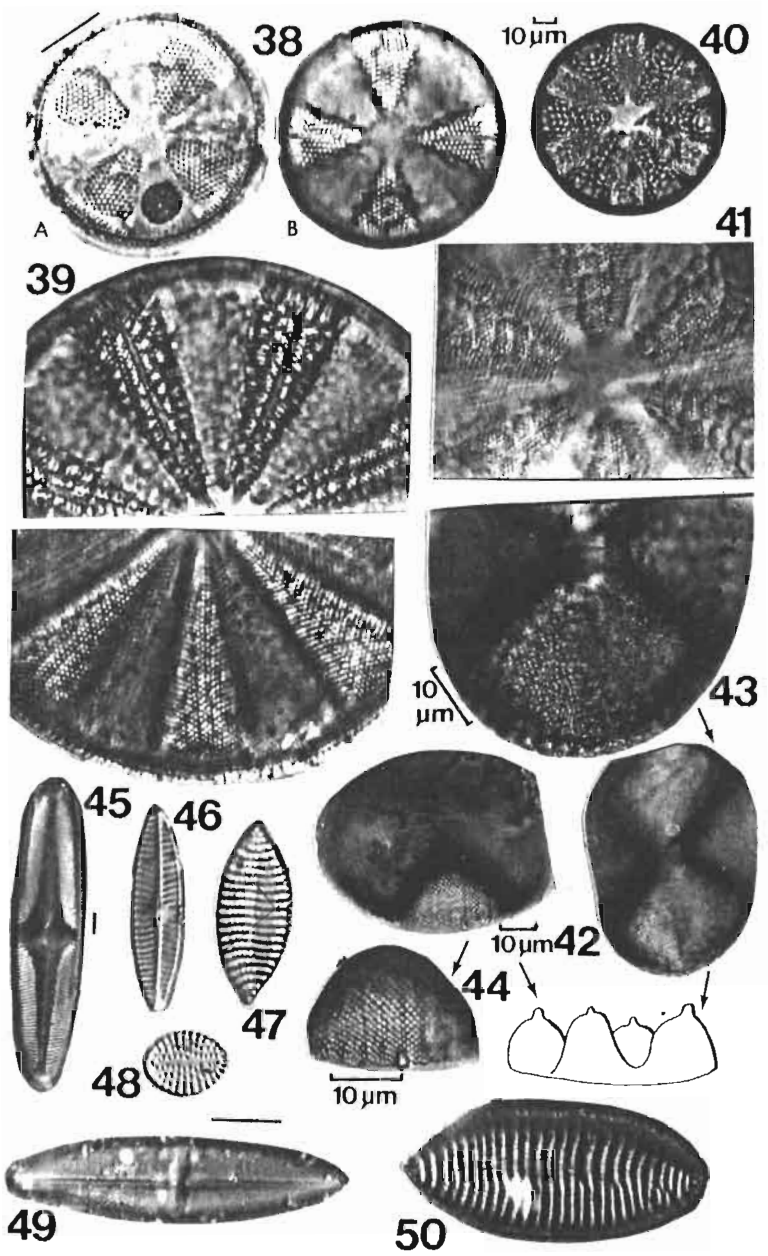

Figure 6: 38-50

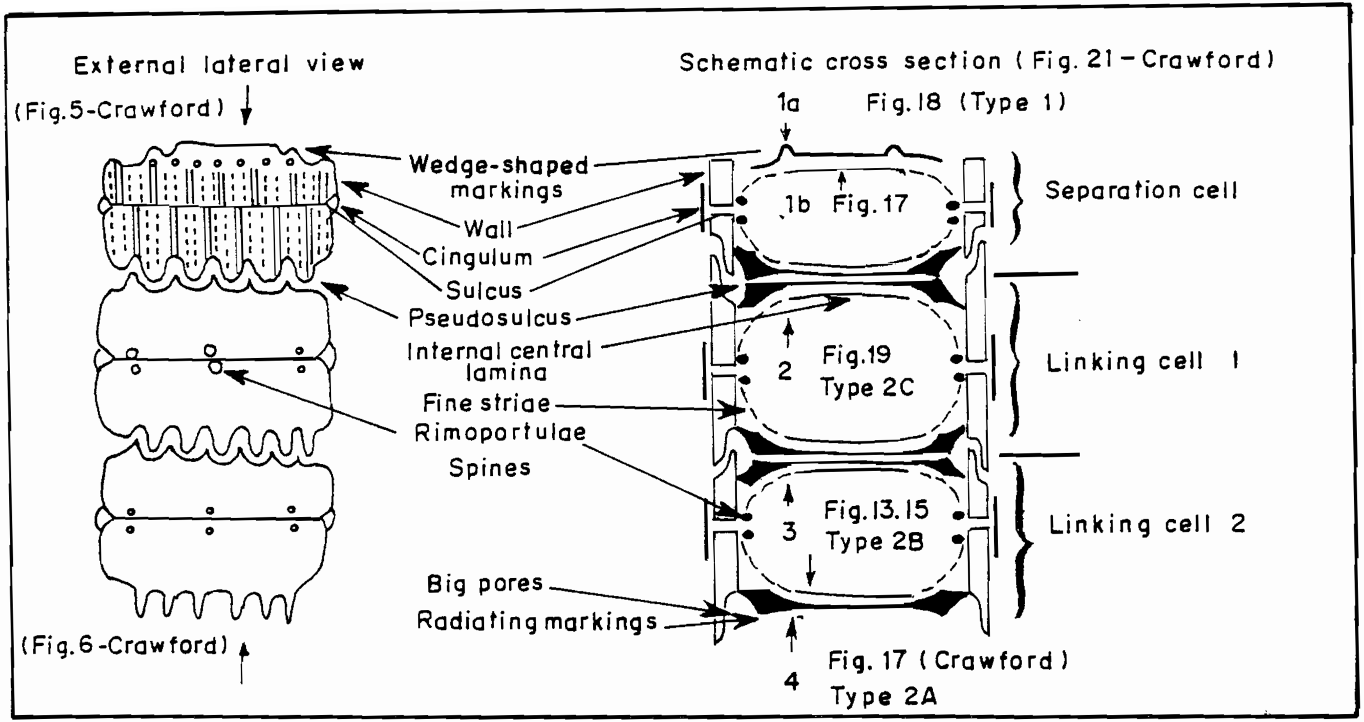

Figure 7: Morphological remarks on the species Paralia sulcata

d) Type 1 (Fig. 4: 18). It corresponds to the view of the epivalve of the separation cells, formerly called Paralia sulcata var. coronata. It is composed of: 1) a rim of big pores and 2) a rim of wedge-shaped markings (If it is regarded from the outside - Figure 7: 1a and Crawford, 1979: Figure 15:5. If it is regarded from the inside - Figure 7:1b, the big pores are recovered by a rim of fine striae corresponding to the marginal structure of the internal lamina). The internal view of the hypovalve of the separation cells presents the same image as the valves of the linking cells and can be assigned to sub-type 2B.

In summary, the variability in the structure of the valve face of P. sulcata, which induced the former authors to create many different varieties, can be understood taking into account the internal and external views of the two different types of cells (separation and linking cells) and the different types of valves (epi and hypovalve of the separation cells) in the same chain.

FINAL CONSIDERATIONS

Four wells drilled in the coastal plain, between Morro da Juréia and Barra do Una (State of São Paulo, Brazil), reached the Pre-cambrian crystalline basement, cutting before the continental Pliocene Pariquera Açu Formation, and shallow marine Cananéia and Santos formations, both of Quaternary age. The Cananéia Formation, according to the contained diatom flora, was deposited within a littoral marine environment with interbedded level of lacustrine diatoms indicating phases of sea-level drop. The analyzed samples from the Holocene Santos Formation do not contain diatom.

The Cananéia Formation exhibited a rich and well preserved diatom flora, most of the species constituted by living forms, but six of them are extinct, and the most abundant one (**Raphoneis** fatula) has not been reported until now in sediments more recent than Pliocene. The presence of these extinct species raises the problem of the age of the Cananéia Formation. Alternatively, the sediments assumed to be of this formation could belong to older deposits.

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