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## Biochronostratigraphy and paleoenvironment analysis of Neogene deposits from the Pelotas Basin (well 2-TG-96-RS), Southernmost Brazil

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### ABSTRACT

This paper presents the integration of micropaleontological (palynology and foraminifera) and isotopic ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) analysis of a selected interval from the well 2-TG-96-RS, drilled on the onshore portion of the Pelotas Basin, Rio Grande do Sul, Brazil. A total of eight samples of the section between 140.20 and 73.50 m in depth was selected for palynological analysis, revealing diversified and abundant palynomorph associations. Species of spores, pollen grains and dinoflagellate cysts are the most common palynomorphs found. Planktic and benthic calcareous foraminifera were recovered from the lowest two levels of the section (140.20 and 134.30 m). Based on the stratigraphic range of the species of dinoflagellate cysts and sporomorphs, a span age from Late Miocene to Early Pliocene is assigned. The relative age obtained from the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio in shells of calcareous foraminifera indicates a Late Miocene (Messinian) correspondence, corroborating the biostratigraphic positioning performed with palynomorphs. Paleoenvironmental interpretations based on the quantitative distribution of organic components (palynomorphs, phytoclasts and amorphous organic matter) throughout the section and on foraminiferal associations indicate a shallow marine depositional environment for the section. Two palynological intervals were recognized based on palynofacies analysis, related to middle to outer shelf (140.20 to 128.90 m) and inner shelf (115.75 to 73.50 m) conditions.

**Key words:** Micropaleontology, Biostratigraphy, Neogene, Pelotas Basin.

### INTRODUCTION

The Pelotas Basin is situated in the southernmost portion of the Brazilian continental margin and was developed as a result of the Gondwana break-up, which originated the South Atlantic Ocean. The stratigraphical evolution of this basin has been

intensively studied in recent years (Fontana 1990, Villwock and Tomazelli 1995, Castillo et al. 2009, Contreras et al. 2010, Stica et al. 2014).

Additionally, several paleontological studies have been published, mainly focused on taxonomic and paleoenvironmental analysis of foraminifera (e.g., Closs 1967, 1970, Thiesen 1977) and ostracods (e.g., Sanguinetti 1980, Carreño et al.

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1997) as well as certain biostratigraphic studies based on foraminifera and calcareous nannofossils (Gomide 1989, Anjos and Carreño 2004, Coimbra et al. 2009, Guerra et al. 2012). Few palynological contributions have been made in pre-Quaternary deposits of this basin (Arai et al. 2006, Premaor et al. 2010, Silva et al. 2011, Fischer et al. 2013). These papers represent recent investigations from subsurface sampling, focusing on age assignments and paleoenvironmental analysis. Dinoflagellate cysts and spore-pollen taxa are the most common palynomorphs recorded by those authors. However, a palynostratigraphical framework of this basin is still needed.

A general biostratigraphic analysis on the Cenozoic strata of the Pelotas Basin was presented by Anjos-Zerfass et al. (2008), which also included  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopes data, as a tool for chronostratigraphic purposes. The use of a strontium isotopes stratigraphic framework is a significant resource to calibrate the dates obtained by biostratigraphy, improving the integrated stratigraphic framework of the basin.

This paper presents the results of high-resolution biostratigraphical analysis based on microfossils (palynology and foraminifera) and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios for a Neogene section of this basin, in samples from well 2-TG-96-RS, drilled by the Companhia de Pesquisa de Recursos Minerais (CPRM). Additionally, a palynofacies characterization is presented, as a guide to the paleoenvironmental interpretations.

## GEOLOGICAL AND PALEONTOLOGICAL SETTING

### GEOLOGY

The Pelotas Basin, located on the South America continental margin between 28°40' S and 34° S (**Fig. 1a, b**), is bounded to the North by the Florianópolis High in Brazil and to the South by the Polonio High in Uruguay (Kowsmann et al. 1974). The Florianópolis High, of volcanic origin, is related to the South Atlantic superplume, that was active

during the Cretaceous. The Polonio High is an older feature of the Precambrian Uruguayan Shield basement. Similar to other Brazilian Eastern Margin basins, the Pelotas Basin resulted from the Gondwana break-up and South Atlantic opening since the Aptian (Ojeda 1981, Asmus and Baisch 1983, Conceição et al. 1988, Chang et al. 1992, Cainelli and Mohriak 1999).

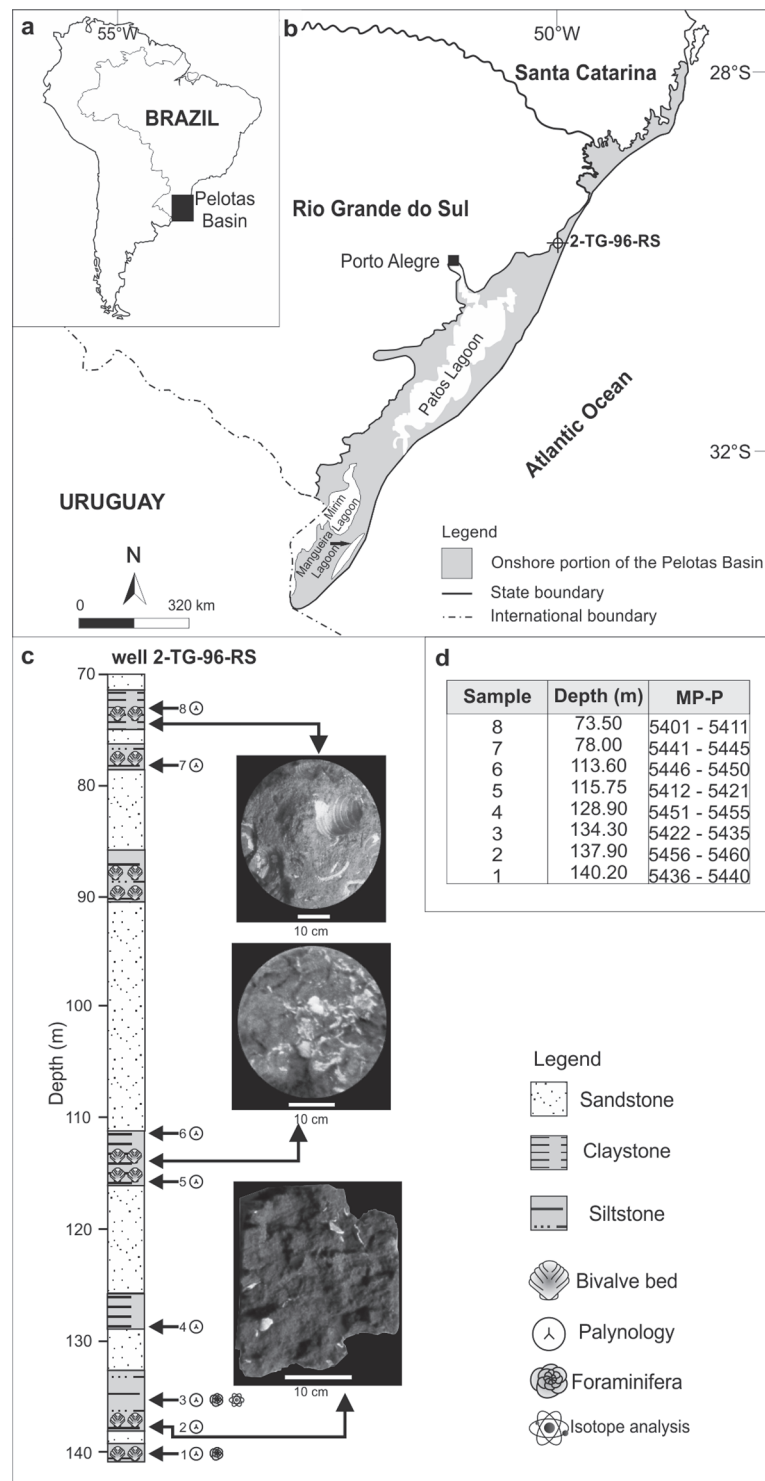
The basin area is approximately 210.000 km<sup>2</sup>, of which 40.000 km<sup>2</sup> is onshore. Although the entire section includes sedimentary rocks from the Aptian to the Holocene, on the onshore portion of the basin only deposits of the Quaternary outcropping (**Fig. 1a, b**). The maximum thickness of the total sedimentary section reaches 12.000 m (Fontana 1994).

Since the opening of the South Atlantic, the Pelotas Basin received clastic sedimentation as a result of the denudation of adjacent highlands (Villwock 1984). Successive sea-level cycles caused the accumulation of a clastic wedge, which was affected only by incipient post-depositional deformation, represented by tilted blocks with strata dipping seaward (Villwock 1984). In general, the entire stratigraphic succession includes a basic transgressive and an upper regressive interval, from the Aptian to Holocene strata (Bueno et al. 2007).

The studied interval is part of the major Paleocene-Holocene regressive supercycle that is composed of proximal siltstones and sandstones assigned to the Cidreira Formation, as well as distal mudstones with some intercalated turbiditic sandstones of the Imbé Formation (Dias et al. 1994, Bueno et al. 2007). The Cidreira Formation deposits prograde into the basin, merging with the Imbé Formation sediments, which were deposited in more distal portions.

### PALEONTOLOGY

Contributions derived from benthic foraminifera and ostracods of the pre-Quaternary succession are relatively abundant, providing paleoenvironmental



**Fig. 1** - Area location and sampling of the well 2-TG-96-RS in Pelotas Basin (a-b). Stratigraphic column of the interval studied, showing the position of micropaleontological and  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopes samples analyzed in the present study (c) and list of palynological samples (d) (MP-P refers to the slide collection of the LPMMT/IG/UFRGS).

interpretations (e.g., Koutsoukos 1982, Carreño et al. 1999, Ceolin et al. 2011). Simões et al. (2008) presented a taxonomy review of brachiopods recorded from some Neogene deposits of the onshore portion. Biostratigraphic data is mainly obtained through the study of planktic foraminifera and calcareous nanofossils (Koutsoukos 1982, Gomide 1989, Anjos and Carreño 2004, Coimbra et al. 2009). Most biostratigraphic information of the Neogene deposits comes from boreholes, drilled in the onshore portion of the basin.

Quaternary deposits reveal a varied fossil content, including vertebrates and microfossils, such as foraminifera, palynomorphs and diatoms (e.g., Closs 1970, Lopes et al. 2010, Macedo et al. 2010, Hermany et al. 2013). Palynological analysis has provided paleoclimate interpretations and paleoenvironmental reconstructions for Quaternary deposits, mainly focusing on the marine influence on the coastal plain of the state of Rio Grande do Sul (Bauermann et al. 2009).

Palynological studies from the pre-Quaternary section (Arai et al. 2006, Premaor et al. 2010, Silva et al. 2011, Fischer et al. 2013) represent a new stage of systematic work developed in recent years. Palynological associations of Late Cretaceous (Arai et al. 2006, Premaor et al. 2010), Paleogene (Fischer et al. 2013) and Miocene/Pleistocene (Silva et al. 2011) ages were presented. Abundant and diversified assemblages of spore-pollen taxa and dinoflagellate cysts, in addition to foraminiferal linings, scolecodonts, and algae species.

#### MATERIALS AND METHODS

The well 2-TG-96-RS was drilled by the CPRM on the onshore portion of the Pelotas Basin (29°46'12"S/50°05'02"W) (**Fig. 1a, b**). The sedimentary section related to the sampled interval (73.50 to 140.20 m of depth) consists of 66.7 m of mudstones, with intercalations of siltstones rich in pelecypods fragments (*Ostrea* sp. and *Anomalocardia* spp.) (**Fig. 1c**). Eight samples were collected from

this interval (**Fig. 1c**), from which palynological data were derived. Foraminiferal specimens were only recovered from two basal levels (134.30 m and 140.20 m).  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope data was obtained from benthic foraminifera shells recorded at 134.30 m of depth (**Fig. 1c**).

#### PALYNOLOGY

Palynological samples were prepared at the Laboratório de Palinologia "Marleni Marques-Toigo", Departamento de Paleontologia e Estratigrafia in the Instituto de Geociências at Universidade Federal do Rio Grande do Sul (LPMMT/IG/UFRGS), following the conventional method for pre-Quaternary material described by Wood et al. (1996), employing hydrochloric and hydrofluoric acids. Final residues were obtained by sieving; from which slides were mounted using the fraction between 20 and 250  $\mu\text{m}$ . Fucina pigment was added to some residues to facilitate taxonomic identification. A total of 56 slides was prepared, which are stored in the LPMMT/IG/UFRGS collection under the code "MP-P" (**Fig. 1d**). Taxonomical analyses were performed using an microscope Olympus BX-61, with phase contrast and fluorescence light (mercury).

Quantitative data and the ensuing palynofacies analysis were obtained by counting at least 400 particles from each sample which enabled the generation of graphs exhibiting variation in composition of particulate organic matter along the studied section. Quantitative results were processed with Tilia and Tiliagraph softwares (Grimm 1987, 1990). All organic particles were identified and classified in the following categories: continental palynomorphs (pteridophyte and bryophyte spores, gymnosperm pollen, angiosperm pollen, fungi, freshwater algae) and marine (dinoflagellate cysts, foraminiferal linings); phytoclasts (opaque and translucent phytoclasts, cuticles) and amorphous organic matter. The cuticles are represented separately within the translucent phytoclasts due to their abundance in certain levels.

FORAMINIFERA AND STRONTIUM RATIO ( $^{87}\text{Sr}/^{86}\text{Sr}$ )

An aliquot of 60 g of sediments per sample was prepared following the conventional micropaleontological techniques for calcareous microfossils (Thomas and Murney 1985). Foraminiferal shells from 125 and 250  $\mu\text{m}$  were hand-picked under an Olympus SZ1145 stereomicroscope. Taxonomic determinations were also supported by employing a scanning electronic microscope JEOL JSM 5800 at the Centro de Microscopia Eletrônica - UFRGS.

Well-preserved specimens of the benthic foraminifera species *Nonionella atlantica*, *Nonionoides grateloupii* and *Hanzawaia boueana* from two samples (134.30 m and 140.20 m) were separated and ultrasonically cleaned with ultrapure water (Milli-Q) to remove particles adhered to the shells. Strontium ratio ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) analyses were performed using these selected foraminifera, at the Laboratório de Geologia Isotópica (IG/UFRGS). Isotopic ratios were measured in static mode with a VG Sector 54 multi-collector mass spectrometer. An average of 120 ratios was collected with a 1-volt  $^{88}\text{Sr}$  beam. Strontium ratios were normalized to  $^{87}\text{Sr}/^{86}\text{Sr} = 0.1194$ . Measurements are considered for the NBS-987 standard  $^{87}\text{Sr}/^{86}\text{Sr} = 0.710250 \pm 0.000007$ . The standard curve used for the age assessment was derived from the database compiled by McArthur et al. (2001) and McArthur and Howarth (2004).

## RESULTS

## MICROPALAEONTOLOGICAL CONTENT

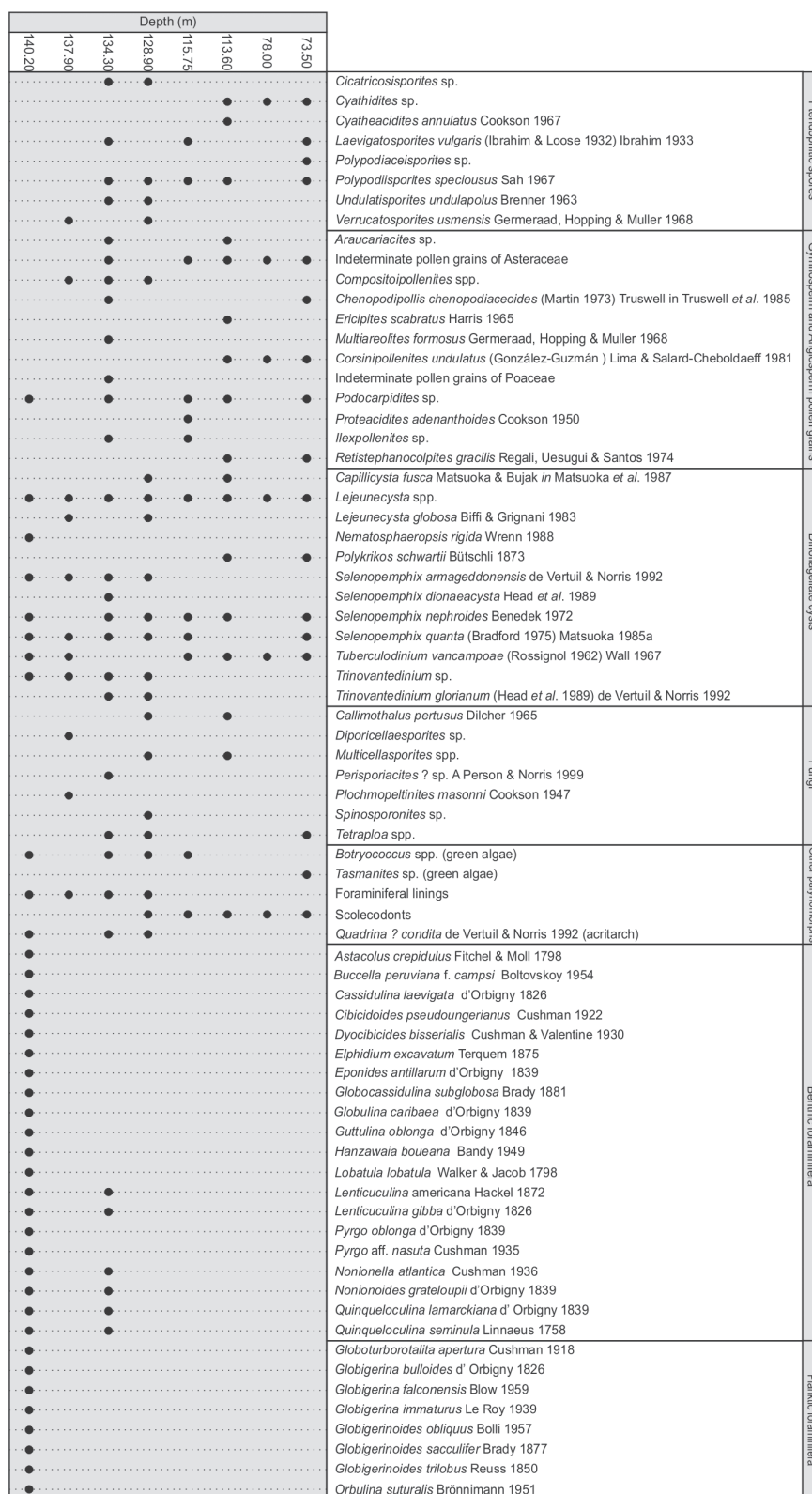
Most of the samples presented palynological associations composed mainly of dinoflagellate cysts and foraminiferal linings. Twelve species of dinoflagellate cyst belonging to seven genera were identified, as well as eight species of pteridophyte spores, twelve taxa of gymnosperm and angiosperm pollen grains, besides specimens assigned to fungi, acritarch, green algae, foraminifera linings and scolecodonts. The taxonomic list and the stratigraphical distribution of palynomorphs and foraminifera (benthic and planktic) are presented in **Table I** and **Figure 2**. Selected taxa of palynomorphs are illustrated in **Figure 3**.

The amorphous organic matter dominated the palynological assemblages, whereas phytoclasts and palynomorphs were subordinate, but phytoclasts is very well represented at all levels (**Fig. 4**). Terrestrial palynomorphs represented by spores and pollen grains were present in all levels, varying from 5% to 40% of the total assemblage. Well preserved angiosperm pollen grains comprise specimens of Chenopodiaceae, Compositae, Asteraceae and Onagraceae. Gymnosperm pollen grains reached a maximum of 40%, while dinoflagellate cysts reached up 45% of the assemblage. The latter were mainly represented by species of

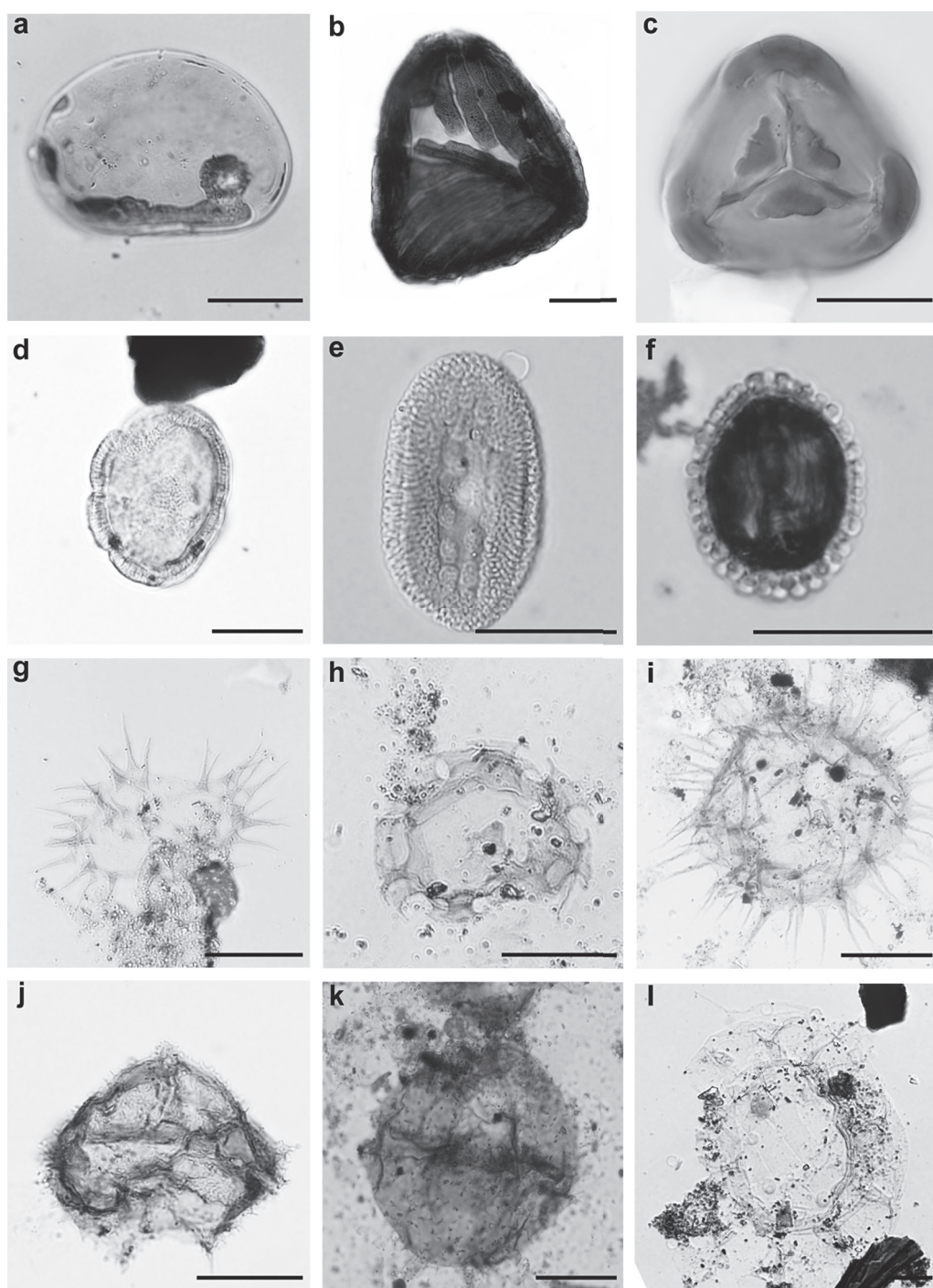
**TABLE I**  
Abundance of genera of palynomorphs  
and foraminifera in the studied samples.

Samples	Spores	Pollen grains	Dinoflagellate cysts	Benthic foraminifera	Planktic foraminifera
8	4	5	5	0	0
7	1	2	2	0	0
6	3	6	5	0	0
5	2	4	4	0	0
4	4	1	8	0	0
3	4	8	7	6	0
2	1	1	6	0	0
1	0	1	7	20	8



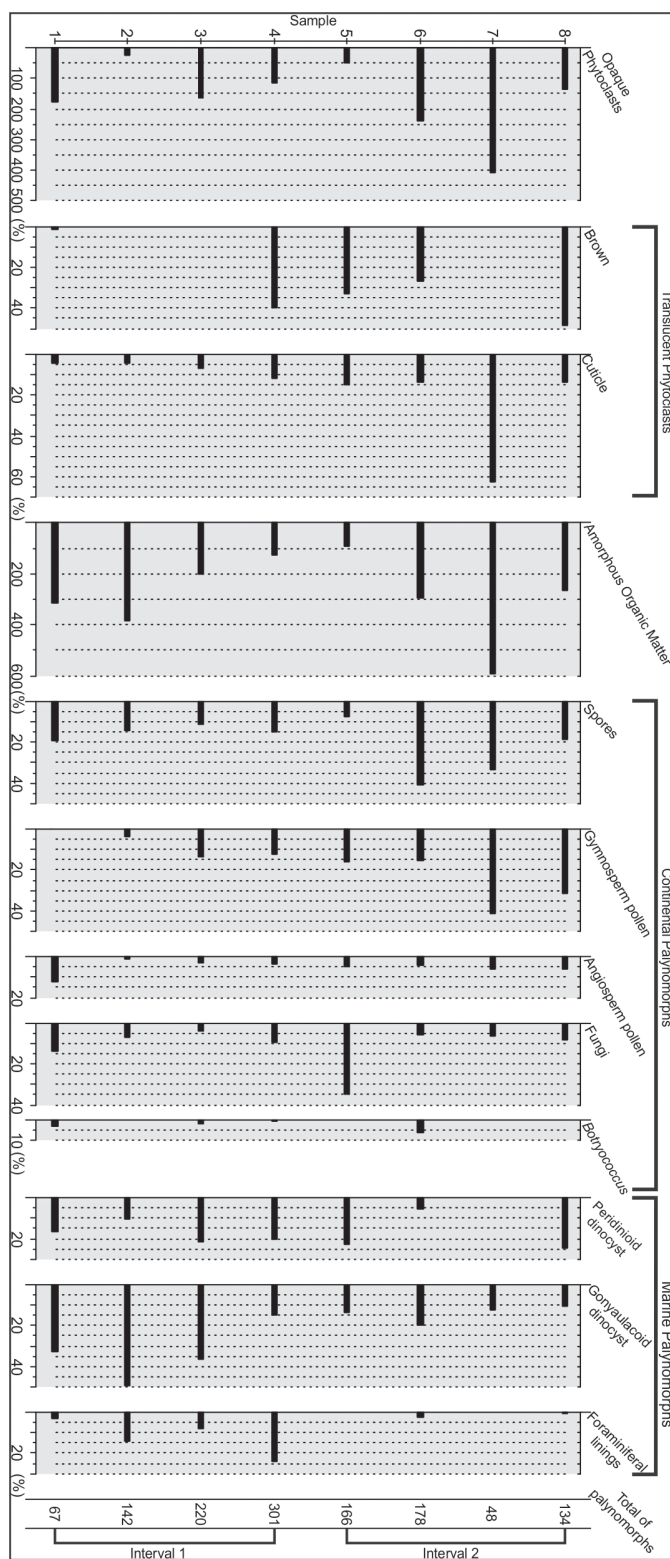


**Fig. 2** - Stratigraphic distribution of the micropaleontological content (palynomorphs and foraminifera) in well 2-TG-96-RS.



**Fig. 3** - Selected palynomorphs recorded from well 2-TG-96-RS. **(a)** *Laevigatosporites vulgaris* (slide MP-P 5425; England Finder coordinate: N40-4); **(b)** *Cicatricosisporites* sp. 2 (5454; W60-1); **(c)** *Cyatheadites annulatus* (5446; L56); **(d)** *Retistephanocolpites gracilis* (5403; T41-4); **(e)** *Multiareolites formosus* (5423; D30-1); **(f)** *Ilexpollenites* sp. (5431; M42-1); **(g)** *Quadrina ? condita* (5430; P30-3); **(h)** *Selenopemphix armageddonensis* (5452; N40); **(i)** *Selenopemphix quanta* (5617; K35-2); **(j)** *Trinovantedinium glorianum* (5423; O37-3); **(k)** *Capillicysta fusca* (5448; O57); **(l)** *Tuberculodinium vancampoe* (5414; P38). The scale bars represent 20  $\mu$ m.





**Fig. 4** - Relative frequencies (%) of particulate organic matter along the study section of the well 2-TG-96-RS and the two paleoenvironmental intervals characterized here.

*Selenopemphix*, *Tuberculodinium*, *Lejeunecysta* and *Trinovantedinium*. Unidentified spiral forms of foraminiferal linings reached up 25% of the association (**Fig. 4**).

Planktic foraminifera were recorded in only one sample, at the base of the studied section (140.20 m), where eight species were identified: *Globigerina apertura*, *Globigerina bulloides*, *Globigerina falconensis*, *Globigerinoides trilobus*, *Globigerinoides immaturus*, *Globigerinoides sacculifer*, *Globigerinoides obliquus* and *Orbulina suturalis*. Benthic foraminifera specimens were recorded in two levels (134.30 m and 140.20 m), and are represented by 20 species, belonging to 17 genera (**Fig. 2**). Specimens of foraminifera are illustrated in **Figure 5**.

Counting of benthic foraminifera specimens by families (Cassidulinidae, Cibicididae, Elphidiidae, Eponididae, Gavelinellidae, Hauerinidae, Nonionidae, Polymorphinidae and Vaginulinidae), revealed two distinct intervals. The basal sample (140.20 m) was characterized by a high proportion of specimens of two families: Cibicididae (33.70%) and Gavellinielidae (32.30%). All other families presented low number of specimens at the 134.30 m sample (**Fig. 6a**).

Most of the foraminifera shells from well 2-TG-96-RS were affected by partial dissolution. As a result, only one sample (at 134.30 m) contained well preserved specimens suitable for  $^{87}\text{Sr}/^{86}\text{Sr}$  analysis. The age assignment obtained from this sample indicates an age of 6.05 Ma, that corresponds to the Late Miocene (Messinian) (**Fig. 6b**).

## DISCUSSION

### BIOSTRATIGRAPHY

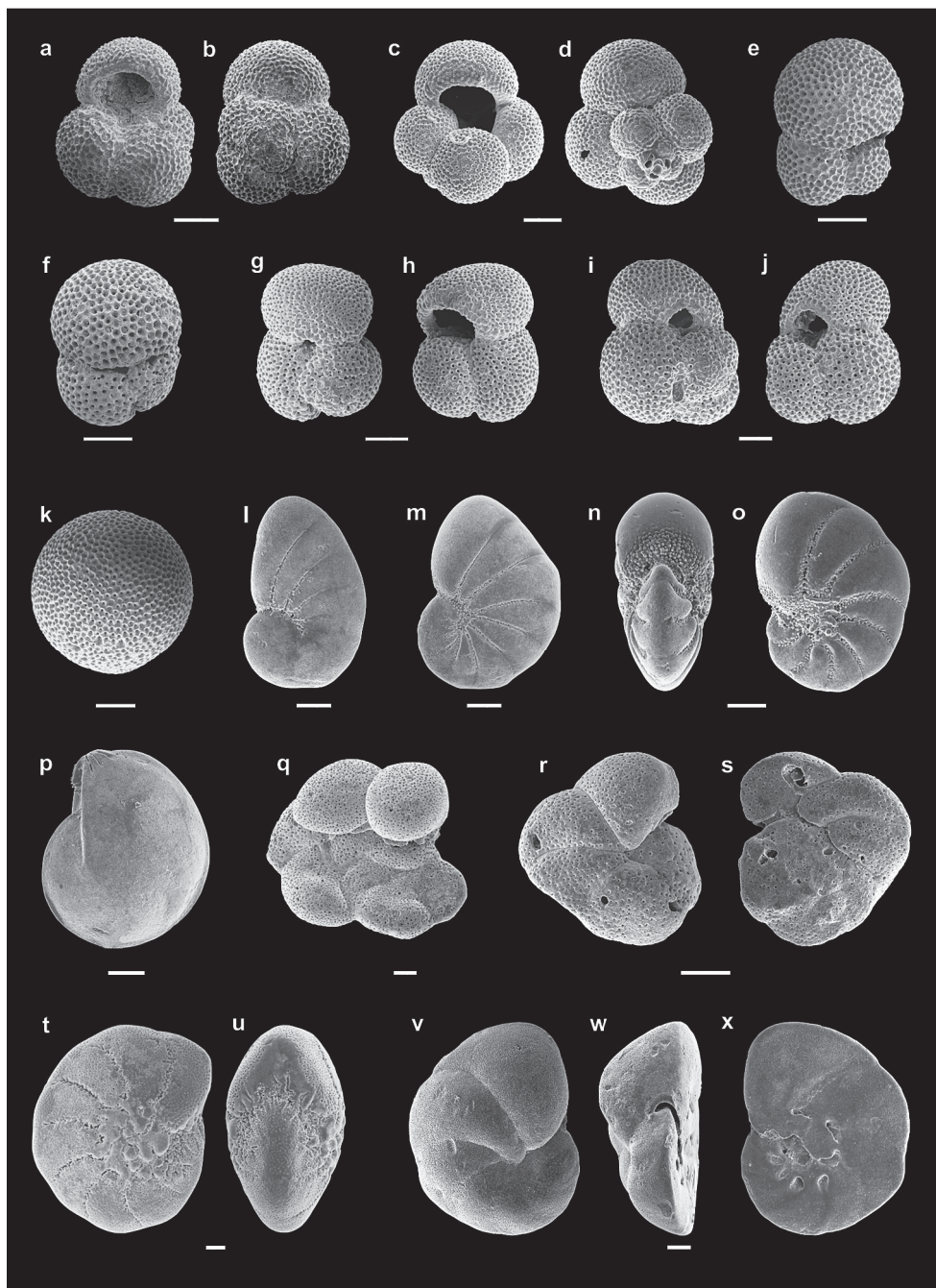
The age of the studied section was mainly based on the previously known stratigraphic ranges of palynomorphs and planktic foraminifera (**Fig. 7 and 8**). Ranges of dinoflagellate cysts were compiled from Head (1993), Williams et al. (2004), Powell and Brinkhuis (2004) and in the computer data base TAXON (R.L. Ravn, personal

communication 2003). Stratigraphical distribution of terrestrial palynomorphs was derived from Regali et al. (1974a, b), Lima and Angulo (1990), Pinto and Regali (1990) and Garcia et al. (2008) (**Fig. 7**), while those used for planktonic foraminifera were based on Kennett and Srinivasan (1983) and Bolli and Saunders (1985) (**Fig. 8**); geochronology was calibrated according to Gradstein et al. (2012).

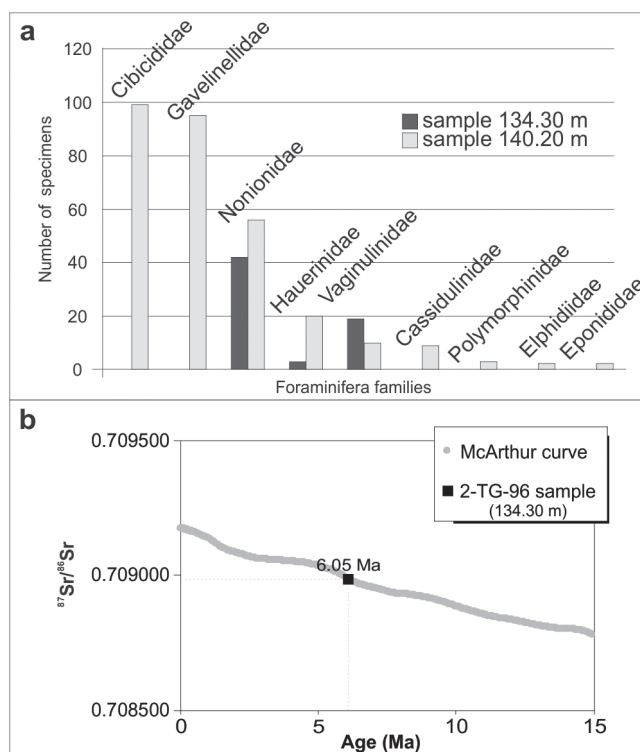
According to Williams et al. (2004), in the Northern hemisphere the first appearance of *Trinovantedinium glorianum* (**Fig. 3j**) (134.30 m and 128.90 m) occurs at the top of the Serravalian stage (Middle/Late Miocene), whereas *Selenopemphix armageddonensis* (**Fig. 3h**) (140.20 m-128.90 m) is known from Late Miocene (**Fig. 7**). *Quadrina ? condita* (**Fig. 3g**) (140.20 m, 134.30 and 128.90 m) has been recorded from Middle to Late Miocene (Kurita and Obuse 2003) and *Capillcysta fusca* (**Fig. 3k**) (128.90 and 113.60 m) has its last occurrence (LO) in the Early Pliocene (Head 1993) (**Fig. 7**).

The species of sporomorphs *Cyatheacidites annulatus*, *Multiaerolites formosus* and *Retistephanocolpites gracilis* were used in the zonal scheme established for the Meso- and Cenozoic Brazilian basins (Regali et al. 1974a, b). *M. formosus* (**Fig. 3e**) (128.90 m) presents its LO in the Late Miocene, and has been recognized in Miocene deposits throughout the Brazilian margin (Regali et al. 1974a, b) (**Fig. 7**). *C. annulatus* (**Fig. 3c**) (113.60 m) has been used as a marker in the Brazilian marginal and interior basin for the interval between the Early Miocene and the Pliocene (Regali et al. 1974a, b, Lima and Angulo 1990, Pinto and Regali 1990, Garcia et al. 2008); (**Fig. 7**). *R. gracilis* was recovered from deposits dated from the Early Miocene to the Pliocene (**Fig. 3d**) (113.60 m and 73.50 m) (Regali et al. 1974a, b, Lima and Angulo 1990, Garcia et al. 2008) (**Fig. 7**).

The palynological content of samples collected between 140.20 m and 128.90 m indicated a Late Miocene age, due to the occurrence of the dinoflagellate cysts species *T. glorianum* and



**Fig. 5** - Selected foraminifera recorded from the well 2-TG-96-RS. **(a-b)** *Globoturborotalita apertura* **(a)** umbilical view, **(b)** spiral view; **(c-d)** *Globigerina bulloides* **(c)** umbilical view, **(d)** spiral view; **(e-f)** *Globigerinoides trilobus* **(e)** umbilical view, **(f)** spiral view; **(g-h)** *Globigerinoides obliquus* **(g)** umbilical view, **(h)** spiral view; **(i-j)** *Globigerinoides sacculifer* **(i)** umbilical view, **(j)** spiral view; **(k)** *Orbulina suturalis*; **(l)** *Nonionoides grateloupi* (spiral view); **(m-o)** *Nonionella atlantica* **(m)** apertural view, **(n)** umbilical view, **(o)** spiral view; **(p)** *Lenticulina americana*; **(q)** *Dyocibicides bisserialis*; **(r-s)** *Lobatula lobatula* **(r)** umbilical view, **(s)** spiral view; **(t-u)** *Elphidium excavatum* **(t)** umbilical view, **(u)** spiral view; **(v-x)** *Hanzawaia boueana* **(v)** spiral view, **(w)** lateral view, **(x)** umbilical view. The scale bars represent 100  $\mu\text{m}$ .



**Fig. 6** - Number of specimens of benthic foraminifera per family in the samples 140.20 m and 134.30 m (a) and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio and the obtained age for the analyzed sample (b).

*S. armageddonensis* and *Q. ? condita* (acritarch). This assignment is reinforced by the occurrence of pollen grains attributed to *M. formosus* (Fig. 7). The simultaneous records of *C. annulatus* and *R. gracilis*, associated with the LO of *C. fusca* at 113.60 m, indicate that the samples between 115.75 and 73.50 m are related to the Early Pliocene (Fig. 7). Based on this evidence, the samples analyzed from the well 2-TG-96-RS are considered to be from the Late Miocene to Early Pliocene in age (Fig. 6b and 8).

Based on the zonal schemes of Kennett and Srinivasan (1983) and Bolli and Saunders (1985), planktonic foraminifera recovered from the well 2-TG-96-RS indicates an age range from the Late Miocene to Early Pliocene, taking into account the concurrent presence of *Globoturborotalita apertura* (Fig. 5a, b) (Zone N16-N21 of Blow 1969) and *Globigerinoides obliquus* (Fig. 5g,

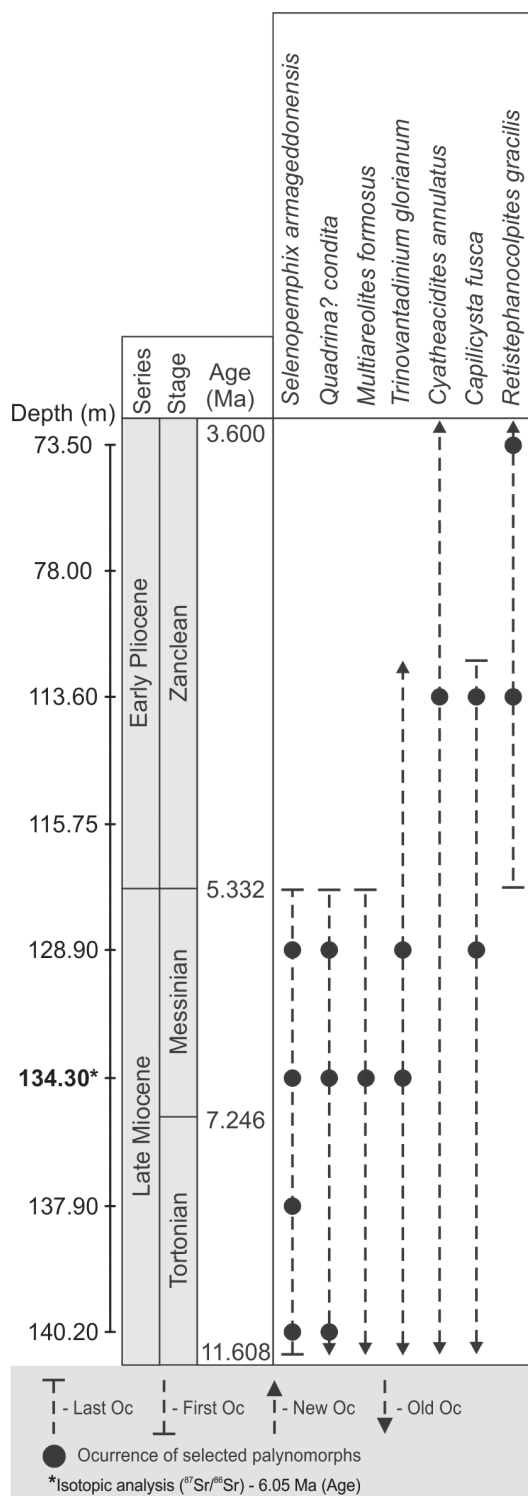
h) (Zone N8 – N19 of Blow 1969) (Fig. 8). According to Chaisson and Pearson (1997), *G. apertura* ranges from 11.19 to 1.64 Ma (Zone N14 to lower Zone N22).

#### PALEOENVIRONMENTAL INTERPRETATION

The paleoenvironmental interpretation of the studied interval is based on the integration of lithological and micropaleontological data, especially particulate organic matter (Fig. 4). The presence of foraminifera only in the lowest section indicates a shallowing of the environment. However, the continuous presence of pelecypods (Fig. 1c) and dinoflagellate cysts in the entire interval studied herein, indicates marine conditions throughout the study interval.

The section was subdivided into two intervals mainly based on the ratio between marine (dinoflagellate cysts and foraminiferal linings)





**Fig. 7** - Stratigraphic range and occurrence of certain taxa of palynomorphs along the studied samples and their correspondent as discussed in the text. (Last Oc: Last Occurrence, First Oc: First Occurrence, New Oc: Newer Occurrence, Old Oc: Older Occurrence).

and continental elements (sporomorphs), which shows inversely proportional distributions (**Fig. 4**). Counting was carried out to identify the organic matter compositional trend for each sample, changes in the relative abundance of certain particulate organic matter and palynomorph groups are linked to sea-level changes.

#### INTERVAL 1 (140.20 m–128.90 m) – LATE MIOCENE

In this interval (four samples), marine palynomorphs occur in high proportions (**Fig. 4**). Dinoflagellate cysts are dominant, up to 60% of the assemblage (at 137.90 m). The percentage of this group decreases downward but maintains a frequency close to 35% (**Fig. 4**). Foraminiferal linings present peaks of abundance at 137.90 m (15%) and 128.90 m (25%).

Spores represent 20% of the palynomorphs assemblages at 140.20 m, and about 15% at 137.90 m, 128.90 m and 134.30 m (**Fig. 4**). Gymnosperms pollen grains are absent in the basal sample, but occur in all overlying levels, varying from 5% to 20% of relative frequency (**Fig. 4**). Angiosperm pollen and fungal elements rarely occur, representing < 15% of the palynomorphs assemblage at 140.20 m. Fresh water algae (*Botryococcus*) is very rare throughout the section, presenting less than 5% of the assemblage (**Fig. 4**).

Translucent phytoclasts occur only in the sample at 128.90 m (40%), including cuticles which have frequency from 5% to 15% upward in the section (**Fig. 4**). Opaque phytoclasts and amorphous organic matter are the predominant constituents of the particulate organic matter. Opaque phytoclasts are the most abundant particulate organic matter of terrestrial origin, while cuticles, spores, pollen and fungi occur subordinately (**Fig. 4**).

The abundance of partially degraded woody tissue (opaque phytoclast, translucent phytoclast and cuticles), which dominate the particulate organic matter, indicates fresh water input. Spores, pollen (angiosperm and gymnosperm) and fungal elements occur with low relative abundance



Age		Blow (1969)	Bolli and Saunders (1985)		<i>G. bulloides</i>	<i>G. falconensis</i>	<i>Gs. immaturus</i>	<i>Gs. trilobus</i>	<i>Gs. sacculifer</i>	<i>Gs. obliquus</i>	<i>G. apertura</i>	<i>O. suturalis</i>
Pliocene	Mid.	N21	<i>Globorotalia</i>	<i>Gr. exilis</i>								
		N20	<i>miocenica</i>	<i>Gs. trilob.fistulosus</i>								
	Early	N19	<i>Globorotalia</i>	<i>Gr.mar.evolutae</i>								
		N18	<i>margaritae</i>	<i>Gr.mar.margaritae</i>								
Miocene	Late	N17	<i>Globorotalia humerosa</i>									
		N16	<i>Globorotalia acostaensis</i>									
		N15	<i>Globorotalia menardii</i>									
		N14	<i>Globorotalia mayeri</i>									
	Middle	N13	<i>Globigerinoides ruber</i>									
		N12	<i>Globorotalia fohsi robusta</i>									
		N11	<i>Globorotalia fohsi lobata</i>									
		N10	<i>Globorotalia fohsi fohsi</i>									
		N9	<i>Globorotalia fohsi peripheroronda</i>									
		N8	<i>Praerbulina glomerosa</i>									

**Fig. 8** - Stratigraphic ranges of selected taxa of planktonic foraminifera occurrence in the sample 140.20 m and their biostratigraphical significance (zones and ages according to Bolli and Saunders 1985).

and diversity. Furthermore, these elements are generally poorly preserved, limiting a satisfactory taxonomic assess. Poor preservation and the low abundance of the terrestrial palynomorphs indicate a long distance between the depositional site and the source area.

The predominance of marine palynomorphs (dinoflagellate cysts and foraminiferal linings) and the high percentage of amorphous organic matter denote a marine depositional environment for this interval. Among the dinoflagellate cysts, predominance of gonyaulacoid forms (e.g., *Nematosphaeropsis*) suggests neritic environments (Edwards and Andrieu 1992, Matsuoka 1992).

The benthic foraminifera assemblage is typical of nearshore environments (Yassini and Jones 1995, Scott et al. 2001). Most of the identified species are commonly found in recent coastal environments of the Brazilian margin

(e.g., Closs and Barberena 1962, Semensatto-Jr and Dias-Brito 2004, Vilela et al. 2004, Burone and Pires-Vanin 2006). However, the presence of deeper dwelling forms such as the Cassidulina and Globocassidulina, together with the planktonic foraminifera probably indicates middle to outer neritic environments.

#### INTERVAL 2 (115.75 m–73.50m) – EARLY PLIOCENE

This interval comprise four samples and is characterized by an increase in continental particulate organic matter. Terrestrial palynomorphs consist mainly of bisaccate pollen (Podocarpaceae), which make up about 40% of sporomorphs in most samples. Angiosperm pollen grains belong to the families Asteraceae, Chenopodiaceae and Aquifoliaceae. Terrestrial palynomorphs are more frequent in this interval than in the underlying one. Spores present percentages between 9% and 40%, angiosperm

pollen 5%, gymnosperm pollen between 15% and 40% and fungi between 15% and 35%.

Dinoflagellate cysts represent from 5% to 25% of total palynomorphs, and are mainly composed of *Lejeunecysta*, *Selenopemphix*, *Tuberculodinium* and *Polykrikos*, which characterize an inner neritic environment (Wrenn and Kokinos 1986, Stover et al. 1996). Foraminiferal linings are locally recorded (< 5% at 113.60 m) (**Fig. 4**).

All the samples in this section present high percentages of opaque phytoclasts and amorphous organic matter. Translucent phytoclasts (30% - 45%) and cuticle (15% - 60%) are very well represented (**Fig. 4**). The high frequencies of well preserved translucent phytoclasts including cuticles indicate short distance and non-turbulent transport from the continental source. The increase of continental palynomorphs is indicative of a strong fresh water input, probably in response to coastline progradation.

Reworked palynomorphs of Paleozoic and Mesozoic ages were assigned to genera *Lunatisporites* sp. (137.90 m), *Vittatina* sp. (78.00 m), *Vittatina subsaccata* Samoilovich 1963 (134.30 m), *Limitisporites rectus* Leschik 1956 (113.60 m) and *Murospora florida* (Balme) Pocock 1961 (115.75 m, 113.60 m, 73.50 m). The latter is known from Upper Jurassic to Early Cretaceous deposits (Pocock 1961 and Burger 1996). All other specimens are very common in Gondwana Basins Permian deposits. With respect to the occurrences in Brazil, the pollen grains are recorded from Permian biozones of the Paraná Basin (Souza and Marques-Toigo 2005). The occurrence of the *Lunatisporites* sp., *Vittatina* sp., *Vittatina subsaccata*, *Limitisporites rectus* suggest that the Paraná Basin Permian strata served as a source for the analyzed sediments.

The absence of foraminifera in the upper part of the section can be related to an upward shallowing in the section. On the other hand, the location of the well 2-TG-96-RS leads to the assumption that the complete dissolution of calcareous bioclasts is due to rain water infiltration. According to Morad

et al. (2000), widespread areas of the continental shelf can be exposed by regressive events and, as a result, an increase in the recharging zones can occur and provide the input of precipitation.

## CONCLUSIONS

This study presents biostratigraphic and paleo-environmental interpretations based on Miocene and Pliocene palynomorph and foraminiferal associations from well samples. Additionally, an age assignment based on strontium isotopes ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) is presented. This data constitutes an integrated approach to study the Neogene deposits in the Pelotas Basin.

The palynological associations, recovered from the onshore well 2-TG-96-RS, indicate an age range from Late Miocene to Early Pliocene. The proposed palynological interpretation is corroborated by the  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopes data, which provided an age of 6.05 Ma for the sample at 134.30 m, corresponding to the Messinian stage. Furthermore, the planktonic foraminifera recovered from the lowermost sample indicates an age range from Late Miocene to Early Pliocene, supporting the age assignment based on dinoflagellate cysts.

Based on the palynological content, the studied section was subdivided into two intervals. Comparing these intervals, the decrease in frequency of dinoflagellate cysts and the absence of foraminiferal linings in the upper interval suggest deposition in more proximal conditions, in nearshore environments with a nearby fresh water influx. The major input of continental palynomorphs and woody tissue (opaque phytoclast, translucent phytoclast) corroborates with this interpretation. The section shows a gradual upward shallowing, probably related to the depositional environment.

The results obtained represent a contribution to the knowledge of the stratigraphic and paleoenvironmental evolution of pre-Quaternary coastal plain deposits from the Pelotas Basin.

The studied section was deposited on top of Gondwana rocks, and can be considered the oldest marine transgression recorded in the area. A shallowing upward trend is demonstrated in the section characterizing a marginal marine environment that was subsequently subjected to fresh water input during the Early Pliocene.

Paleozoic and Mesozoic palynomorphs were found in the upper portion of the studied interval and are interpreted to have been reworked from nearshore outcrops Gondwana strata. These pre-Cenozoic deposits compose the paleorelief of the neighboring northern portions of the coastal plain of the Pelotas Basin in the Neogene.

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#### RESUMO

Este trabalho apresenta a integração da análise micropaleontológica (palinologia e foraminíferos) e de isótopos (razão  $^{87}\text{Sr}/^{86}\text{Sr}$ ) de um intervalo selecionado do poço 2-TG-96-RS, perfurado na porção *onshore* da Bacia de Pelotas, Rio Grande do Sul, Brasil. Um total de oito amostras da seção entre 140,20 e 73,50 m de profundidade foi selecionado para análise palinológica, revelando associações de palinómorfs abundantes e diversificados. Espécies de esporos, grãos de pólen, cistos de dinoflagelados são os palinómorfs mais comuns encontrados. Foraminíferos calcários bentônicos e planctônicos foram recuperados dos dois níveis mais inferiores da seção (140,20 e 134,30 m). Com base na amplitude estratigráfica de espécies de

cistos de dinoflagelados e esporómorfs, um intervalo de idade entre o Mioceno Superior e o Plioceno Inferior é atribuído. A idade relativa obtida a partir da razão  $^{87}\text{Sr}/^{86}\text{Sr}$  em carapaças de foraminíferos calcários indica correspondência no Mioceno Final (Messiniano), corroborando o posicionamento bioestratigráfico realizado com palinómorfs. Interpretações paleoambientais baseadas na distribuição quantitativa dos componentes orgânicos (palinómorfs, fitoclastos e matéria orgânica amorfa) ao longo da seção e na associação de foraminíferos indicam ambiente marinho raso para a seção. Dois intervalos palinológicos foram reconhecidos com base na análise de palinofácies, relacionados a condições de plataforma média a externa (140,20 a 128,90 m) e de plataforma interna (115,75 a 73,50 m).

**Palavras-chaves:** Micropaleontologia, Bioestratigrafia, Neógeno, Bacia de Pelotas.

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