CALCAREOUS NANNOFOSILS FROM CRETACEOUS/PALEOGENE BOUNDARY AND EARLIEST DANIAN OF SANTOS BASIN (SÃO PAULO PLATEAU, BRAZIL) – ODP LEG 39-SITE 356-CORES 28/29

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ABSTRACT – Qualitative and quantitative analyses of calcareous nannofossils from Cores 28 and 29, Site 356, DSDP/ODP Leg 39, found in 18 m of nannofossil- and foraminiferal-rich calcareous mudstone, in the interval uppermost Maastrichtian and the lowermost Danian provided a continuous record of the Cretaceous/Paleogene boundary. 24 species were identified in the Maastrichtian, and 35 in the lower Danian. The following biozones were recognized: UC20 Zone, *Markalius inversus* Zone, *Cruciplacolithus tenuis* Zone, and the *Chiasmolithus danicus* Zone. Acme events of *Thoracosphaera* sp. (lowermost Danian) and *Praeprinsius dimorphosus* (lower Danian) were observed.

Keywords: Calcareous nannofossils, Cretaceous/Paleogene boundary, Danian, Santos Basin.

INTRODUCTION

Qualitative and quantitative analyses of calcareous nannofossils in DSDP (Deep Sea Drilling Project)/ODP (Ocean Drilling Program Leg) 39, Site 356, Cores 28/29 was carried out aiming to check the biostratigraphic continuity in the uppermost Cretaceous and lowermost Tertiary time interval, in the Santos Basin, Brazil.

The *El Kef* section, in Tunísia is regarded as the world’s most complete K-P boundary. Smit & Romein (1985, apud Sarkis, 2002) identified a pattern in the sequence of events in a section containing the K-P boundary. This pattern is composed of five lithologic units deposited in a neritic marine environment:

- **Unit 1**, formed by Cretaceous rocks with bioturbations mainly on the top;
- **Unit 2** (extraterrestrial components unit), of about 0.5 cm, that represents a mass extinction, iridium-rich and spherules, in addition to bioturbations and a low percentage of calcium carbonate;
- **Unit 3**, represented by an argillaceous layer (boundary clay), that also contains a low percentage of calcium carbonate, bioturbations, iridium, anomalous marine microfauna and microflora represented by reworked Cretaceous species and some survivors;
- **Unit 4** is defined by the first occurrence of planktonic foraminifers and typical Paleocene nannofossils;
- **Unit 5**, a new Tertiary planktonic biota occurs. This sequence does not always occur completely (Bohor, 1990).

According to Worsley (1974), good Maastrichtian/Paleocene carbonate sections are only present on
continental shelves, and CCD in the open ocean had shallowed into the photic zone, precluding abundant deposition of carbonates at any great depth by this time. This hypothesis is not corroborated considering evidences found at the Santos Basin.

In Brazil there is a record of calcareous nannofossils from K-P boundary of rock exposures in the Pernambuco/Paraíba basin. Albertão (1993) identified a series of events in this basin, including bioturbated layers, iridium-rich layers, impact spherules, of the Unit 2 of Smith & Romein (1985). According to Koutsoukos (1996), the foraminiferal species found in this unit suggest a middle to deep neritic environment.

A record of K-P Boundary at a submerged portion of Brazilian sedimentary basins was recognized by Grassi (2000) in the Campos Basin. The extraterrestrial bolide theory has been reinforced by the presence of impact structures such as microtectites and spherules (Smit & Klaver, 1981). The impact caused the vaporization of large amounts of sulphur in the atmosphere, which blocked the sunlight for 6 to 9 months, causing the cooling, and near freezing, of superficial waters, and their acidification. The introduction of great quantities of CO₂ in the atmosphere caused an increasing greenhouse effect (O’Keefe & Ahrens, 1989). This phenomenon affected the carbon cycle on the Earth and lead to significant, but gradual, changes in the biota (McLean, 1985). In the oceans, the injection of CO₂ brought about drastic changes in the pH and temperature water due to the alteration of physical-chemical properties that interfered with the biomineralization of carbonate. Consequently, a great part of microplanktonic flora and fauna commonly producing calcium carbonate became extinct.

According to Burnett (1998), only 17 species of calcareous nannofossils survived to events succeeding the bolide impact.

Sarkis (2002) observed an inverse relation between dinocysts, studying the dinoflagellates in the K-P Boundary in the Pernambuco-Paraíba basin, and found that 27.9% of the total number of species present in the Maastrichtian became extinct at the end of that period. The mentioned author observed also an inverse relation with respect to the occurrence of organic-walled and calcareous-walled dinocysts of the thoracosphaeridean group. When events of low diversity of organic-walled dinocysts occur, there is an increase of thoracosphaerideans (calcareous nannofossils), and vice-versa.

Global sea level was lowering during the final Maastrichtian period, that changed in the beginning of the Danian and the sea level began to rise (Zachos et al., 1993). Data obtained from oxygen and carbon isotopes collected in DSDP and ODP wells show a tendency for the values of dδ18O and d13C to diminish in the earliest Danian (Keller & Lindinger, 1989).

This paper aims to identify and count the calcareous nannofossil species in the Cretaceous/Paleogene boundary stratigraphic interval of the DSDP/ODP Leg 39 well – Site 356 – cores 28 and 29 to determine their abundance and appearance, the biozones which have already been defined by other authors, the possible extinction events, and make paleoenvironmental comments about this time interval.

**MATERIAL AND METHODS**

Site 356 is positioned 28°17’22”S and 41°05’28”W on the southeastern edge of the São Paulo Plateau, Santos Basin, Brazilian continental margin, at a water depth of 3,175 meters. The plateau is triangular in plan view, and extends up to 950 km offshore from the shoreline (Figures 1 and 2).

Most of the area of the São Paulo Plateau is underlain by diapirs. An east-west basement ridge marks the southern margin of the plateau. This ridge can be followed westward for some distance in the sub-bottom and may connect on land with the southern edges of the Precambrian Ponta Grossa Arch (Kumar et al. 1977). Site 356 is in the zone between the escarpment of the São Paulo Plateau and the area of diapirs.

The total penetration was 741 meters and the oldest sediments drilled were of late Albian age. Crystalline basement was not reached. The sequence consists of calcareous, calcareous hemipelagic, pelagic siliceous-calcareous, and terrigenous sediments. The sequence has been divided into seven units. Figure 3 summarizes the lithology and stratigraphy of the sedimentary section drilled at Site 356 (Perch-Nielsen et al., 1977). The section studied corresponds to the Unit 4.

According to Perch-Nielsen et al. (1977), the Unit 4 extends from Core 17 to Core 30, is distinguished from the overlying unit 3 by a lack of siliceous material, and is composed of nannofossil and nannofossil-foraminifer chalks. Sometimes this composition gradually changes to marly nannofossils chalk and zeolitic nannofossil chalk. The terrigenous component increases toward the base of the unit. Cores 28 and 29, studied herein, contain several 10 to 40 cm-thick layers of ferruginous calcareous mudstone. Colors in this unit are very diverse, and range from greenish black, light bluish gray, pale yellowish brown to pinkish.
FIGURE 1. Location map of Site 356 compiled from Perch-Nielsen et al. (1977).


gray. Unit 4 is composed of 60% clay, 25% silt-, and 15% sand-size material, and contains 40% nannofossils and 10-15% foraminifers. Clay minerals form 10-15% of the sediment, and the authigenic carbonate, 10%. The remaining 20% includes zeolite, opaque minerals, feldspars and glauconite. The bedding in this unit is not readily apparent, except as color banding. Most burrows are parallel to the bedding, but some are at angles up to 90° with bedding. Slumped material occurs in the unit at several levels. A 1.5-meter-thick bed of dolomitic calcareous chalk occurs in the core 28.

The length cored in Site 356 for the cores 28 and 29 is about 19 meters and length recovered corresponds to 18 meters. The samples were collected at intervals of 50 cm. 25 slides of calcareous nannofossils were
prepared following the Wanderley (2004) method. The nannofossil assemblages were identified by using a petrographic microscope and augmentation of 1,200X, and individuals were counted. Their relative and absolute abundances were determined. Quantitative methods follow Styzen (1977). Biostratigraphical analysis follows Martini (1971), Perch-Nielsen (1985) and Burnett (1998). Paleoecological interpretations are based on Zachos et al. (1993) and Haq et al. (1988), Shimabukuro (1994) and Wanderley et al. (2005). The species were photographed and measured by a digital camera Zeiss-AxioCam MRC.

RESULTS

The studied cores correspond to a sedimentary sequence of about 18 meters of nannofossils and foraminiferal chalks, deposited between the uppermost Maastrichtian and the earliest Danian. There is a continuous record through these two periods (Cretaceous-Paleocene boundary) and no biostratigraphic hiatus was recognized between them. The K-P boundary occurs on Core 29, section 03, between the samples collected at 20/21 cm and 36-37 cm. This sedimentary record was accumulated at a depth of 1,000 meters, according to foraminiferal data deposited in situ (Perch-Nielsen et al., 1977), contrary to Worsley’s (1974) hypothesis, according to which good Maastrichtian/Paleocene carbonate sections are

only present on continental shelves, and CCD in the
open ocean had shallowed into the photic zone,
precluding abundant deposition of carbonates at any
great depth by this time.

Thirty three Cretaceous species and 32 Paleocene
species were identified. The Cretaceous species
identified are: *Arkhangelskiella cymbiformis*
(Campanian-Maastrichtian), *Arkhangelskiella
maastrichtiana* (Maastrichtian), *Biscutum* sp.,
*Calculites* sp., *Ceratolithoides kamptineri*
(Maastrichtian), *Ceratolithoides self:tailiai*
(Campanian-Maastrichtian), *Chiastozigus litterarius*
(Barremian-Maastrichtian), *Cretahabdus crenulatus*
(Berriasian-Maastrichtian), *Cribrosphaerella
ehrembergii* (Albian-Maastrichtian), *Eiffellithus
turriseiffelii* (Albian-Maastrichtian), *Lithraphidites
quadra tus* (Maastrichtian), *Lithraphidites
pra equadra tus* (Campanian-Maastrichtian), *Micula
decussata* (Coniacian-Maastrichtian), *Micula mur us*
(Maastrichtian), *Micula prinsii* (Maastrichtian), *Micula
swastica* (Coniacian-Maastrichtian), *Nephrolithus
frequens* (Campanian-Maastrichtian), *Praediscosphaera
spinosa* (Aptian-Maastrichtian), *Praediscosphaera
stoveri* (Campanian-Maastrichtian), *Rhagodiscus
splendens* (Aptian-Maastrichtian), *Staurolithites crux*
(Santonian-Maastrichtian), *Thoracosphaera* sp.,
*Tranolithus orionatus* (Albian-Maastrichtian),
*Watznaueria barnesae* (Bajocian-Maastrichtian),
*Zeughrabdotus sigmoides* (Campanian-Paleocene).

(Plates 1, 2).

**PLATE 1.** Cretaceous species of studied cores.
PLATE 2. Cretaceous species of studied cores.

The Paleocene species identified are: Blackites perlongus (Upper Paleocene-Middle Eocene), Hornibrookina teuriensis, Lanternithus duocavus (Danian-Selandian), Markalius inversus (Campanian-Oligocene), Neochiastozygus chiastus (Danian), Neochiastozygus perfectus (Danian), Chiasmolithus danicus (Danian), Coccolithus pelagicus (Upper Danian-Holocene), Cruciplacolithus edwardsii (Danian), Cruciplacolithus intermedius (Danian), Cruciplacolithus primus (Danian), Cruciplacolithus tenuis (Paleocene), Placozigus fibuliformis (Paleocene), Praeprinsius dimorphosus (Paleocene), Zeughrabdotus sigmoides (Cretaceous-Paleocene). (Plates 3, 4).

The following biozones were recognized: UC20 nannofossil Zone (Uppermost Maastrichtian), Markalius inversus Zone (Earliest Danian), Cruciplacolithus tenuis Zone (Early Danian) and Chiasmolithus danicus Zone (Late Danian). Table 1.

**UC20 NANNOFossil ZONE**

Author: Burnett (1998).

**Definition:** First occurrence of Lithraphidites quadratus to the last occurrence of unrewored, non-survivor Cretaceous taxa.

**Age:** Lower Upper Maastrichtian to Cretaceous/Paleogene boundary.

**UC20d TP NANNOFossil SUBZONE**

Author: Burnett (1998), approximately equivalent to subzone CC26a of Perch-Nielsen (1985).

**Definition:** First occurrence of Micula prinsii to last occurrence of unrewored, non-survivor Cretaceous taxa.

**Age:** Uppermost Maastrichtian.

**MARKALIUS INVERSUS ZONE (NP1)**


**Definition:** Last occurrence of Cretaceous coccoliths or first occurrence of acme of Thoracosphaera to first occurrence of Cruciplacolithus tenuis.

**Age:** Earliest Danian.

**Remarks:** The first occurrence of Praeprinsius dimorphosus is in this zone.

**CRUCIPLACOLITHUS TENUIS ZONE (NP2)**


**Definition:** First occurrence of Cruciplacolithus tenuis to first occurrence of Chiasmolithus danicus.

**Age:** Early Paleocene (Early Danian).
**PLATE 3.** Paleocene species of studied cores.

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**CHIASMOLITHUS DANICUS ZONE (NP3)**

Author: Martini (1970)

**Definition:** First occurrence of *Chiasmolithus danicus* to first occurrence of *Ellipsolithus macellus*.

**Age:** Early Paleocene (Late Danian).

**Remarks:** Only the base of this zone was recognized. An acme event of *Praeprinsius dimorphosus* is present in this zone. According to Varol (1998), this event corresponds to an influx (>50% of total assemblage) which, in the North Sea, occurs in the *Cruciplacolithus tenuis* Zone (NP2).

The biostratigraphic distribution of species of Site 356 is shown on Tables 2 and 3.

*A Thoracosphaera* acme event occurs at the base of *Markalius inversus* Zone. This event also occurs in the earliest Paleogene strata of Tunisia and Southwest of France where the K-P boundary is preserved.

Another acme event (~3,500 individuals/slide) of the *Praeprinsius dimorphosus* species was recognized in the lower part of the *Chiasmolithus danicus* Zone. Danian fossils were not recognized below the *Markalius inversus* Zone and lithology changes very markedly.
PLATE 4. Eocene species of studied cores.

TABLE 1. Biozonation of Site 356, cores 28 and 29.

<table>
<thead>
<tr>
<th>Core</th>
<th>Section</th>
<th>Depth (m)</th>
<th>Biozones (Martini, 1971; Burnett, 1999)</th>
<th>Chronostratigraphy</th>
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<td>UC20 TP Nannofossil Subzone</td>
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* Acme of Praepninus dimorphous.
** First occurrence of acme of Thoracosphaera.
TABLE 2. Biostratigraphical distribution of species of Site 356, cores 28 and 29.

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<th>SAMPLES</th>
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<th>Micula morus</th>
<th>Neophris rhombus quadra</th>
<th>Lithaphidites praecursor</th>
<th>Lithaphidites praecuratoris</th>
<th>Anthangiokilia maastrichtiana</th>
<th>Eoellipsoides tumefaciens</th>
<th>Pseudocycopsoma cretacea</th>
<th>Micula decussata</th>
<th>Microdiasporoides brachiatus</th>
<th>Spheronia flavus</th>
<th>C. ehrenbergi</th>
<th>T. laevius</th>
<th>C. exiguus</th>
<th>A. acutida</th>
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(1) C. danicus  (2) C. tenuis  (3) Markalia inversus  (4) UC20  (5) UC20 *IP*

DISCUSSION

Phytoplanktonic bloom is a phenomenon in which there is a sudden proliferation of species occurring in any eutrophized aquatic environment (rich in nutrients, especially phosphorus, nitrogen and potassium) as long as there is enough light to support photosynthesis. Wanderley et al. (2005) observed in the Quaternary of the Santos Basin that changes in the position of the thermocline, resulting in an increase of the photic zone, led species adapted to less lit waters to migrate to deeper, nutrient-richer waters and proliferate remarkably. Shimabukuro (1994) considers that eutrophization processes linked to sudden changes in environmental conditions, such as high pluviosity or storms, which cause the desestratification of the water column and bring nutrients to the surface, producing anomalous blooms. The areas of oceanic resurgences,
where the advection of deep, nutrient-rich waters reach the photic zone, constitute a favorable environment for the proliferation of certain species.

**ACME OF THORACOSPHAERA**

In the transitional layers above the K-P boundary on site 356 there is a bloom of calcareous dinoflagellate of the *Thoracosphaera* genera. In other regions of the world this event can also be observed in the passage from Cretaceous to Paleocene (Burnett, 1998). Evidence of anomalous blooms of *thoracosphaerideans* and *braarudosphereideans* are also found in the Danian of the Sergipe-Alagoas and Campos basins (Troelsen 1972, *apud* Shimabukuro, 1994).

According to Keller & Lindinger (1989), there has been a diminishing in the levels of δ¹³C in the oceans, in the lowest layers of the Paleocene, which suggests the occurrence of a low productive process during this interval (Figure 5). An alternative hypothesis would be that the impact of a bolide, which vaporized a large quantity of sulphur, blocked the sunlight, causing the cooling, near freezing, of superficial waters and their acidification, and altered the thickness of the photic zone, thus leading to the proliferation of species which are capable of photosynthesis in the deeper waters of the photic zone, *i.e.*, the *thoracosphaerideans* and probably the *braarudospherideans*.

The calcification of nannofossils seems to be related to photosynthetic processes (Young, 1994), and organisms which are capable of photosynthesis in the conditions mentioned above would be able to survive and proliferate.

**ACME OF PRAEPRINSIUS DIMORPHOSUS**

The *Praeprinsius dimorphosus* species seems to be an opportunistic species. Opportunistic organisms are those organisms which take advantage of certain

FIGURE 5. Isotopic data and organic carbon content at K-P Boundary based on Keller & Lindinger, 1989 (apud Ferreira, 2002).
environmental circumstances, restrictive to the majority of other taxa, to occupy a primary or secondary niche (vacant niche) in terms of trophic resources (Shimabukuro, 1994). Generally these organisms are eurithopic (show high tolerance to environmental changes), have a high capacity for multiplication, are small, and are known as r-strategists. The acme event of the section studied occurs in the *Chiasmolithus danicus* Zone (NP3). According to Varol (1998), this event corresponds to an influx (>50% of total assemblage) and, in the North Sea, it occurs in the *Cruciplacolithus tenuis* Zone (NP2). The samples where it was observed were estimated ~3,500 individuals/slide. The size of individuals is ~3,03 µ.

**CONCLUSIONS**

The calcareous nanofossils assemblages studied in Cores 28 and 29 of Site 356 allow the recognition of the following biozones: UC20 Zone (Uppermost Maastrichtian), *Markalius inversus* Zone (lowermost Danian), *Cruciplacolithus tenuis* Zone and *Chiasmolithus danicus* Zone (lower Danian).

No biostratigraphic hiatus was found in the sedimentary section studied, and the record of the Cretaceous/Paleogene (K-P boundary) passage is preserved. An acme event of the Thoracosphaera was observed in the *Markalius inversus* Zone (lowermost Danian), and the acme event of the *Praeprinsius dimorphosus* species occurs in the *Chiasmolithus danicus* Zone.

**AKNOWLEDGMENTS**

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**BIBLIOGRAPHIC REFERENCES**


