CALCAREOUS NANNOFOSSILS 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.

RESUMO – *M.D. Wanderley & R.P. de Aguiar - Nanofósseis calcários do limite Cretáceo-Paleogeno e Daniano mais antigo da Bacia de Santos (Platô de São Paulo, Brasil) – ODP Leg 39/Site 356/Testemunhos 28/29.* Foram realizadas análises qualitativas e quantitativas dos testemunhos 28 e 29 do poço DSDP/ODP-Leg 39/Site 356. Os testemunhos estudados correspondem a uma seqüência sedimentar de aproximadamente 18 m de lama calcária, rica em nanofósseis e foraminíferos, depositada entre o Maastrichtiano mais superior e o Daniano mais inferior. Há um registro contínuo através do limite Cretáceo/Paleogeno. Foram reconhecidas 24 espécies no Maastrichtiano e 35 no Daniano inferior. As seguintes biozonas foram reconhecidas: Zona UC20, Zona *Markalius inversus*, Zona *Cruciplacolithus tenuis* e Zona *Chiasmolithus danicus*. Foram observados eventos acme de *Thoracosphaera* sp. (Daniano inicial) e de *Praeprinsius dimorphosus* (Daniano inferior).
Palavras-chave: Nanofósseis calcários, limite Cretáceo/Paleogeno, Daniano, Bacia de Santos.

INTRODUCTION

Qualitative and quantitative analyses of calcareous nannofossils in DSDP (Deep Sea Drilling Project)/ODPL (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 bioturbaded 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 CO_2 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 CO_2 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 $d^{18}0$ and $d^{13}C$ 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

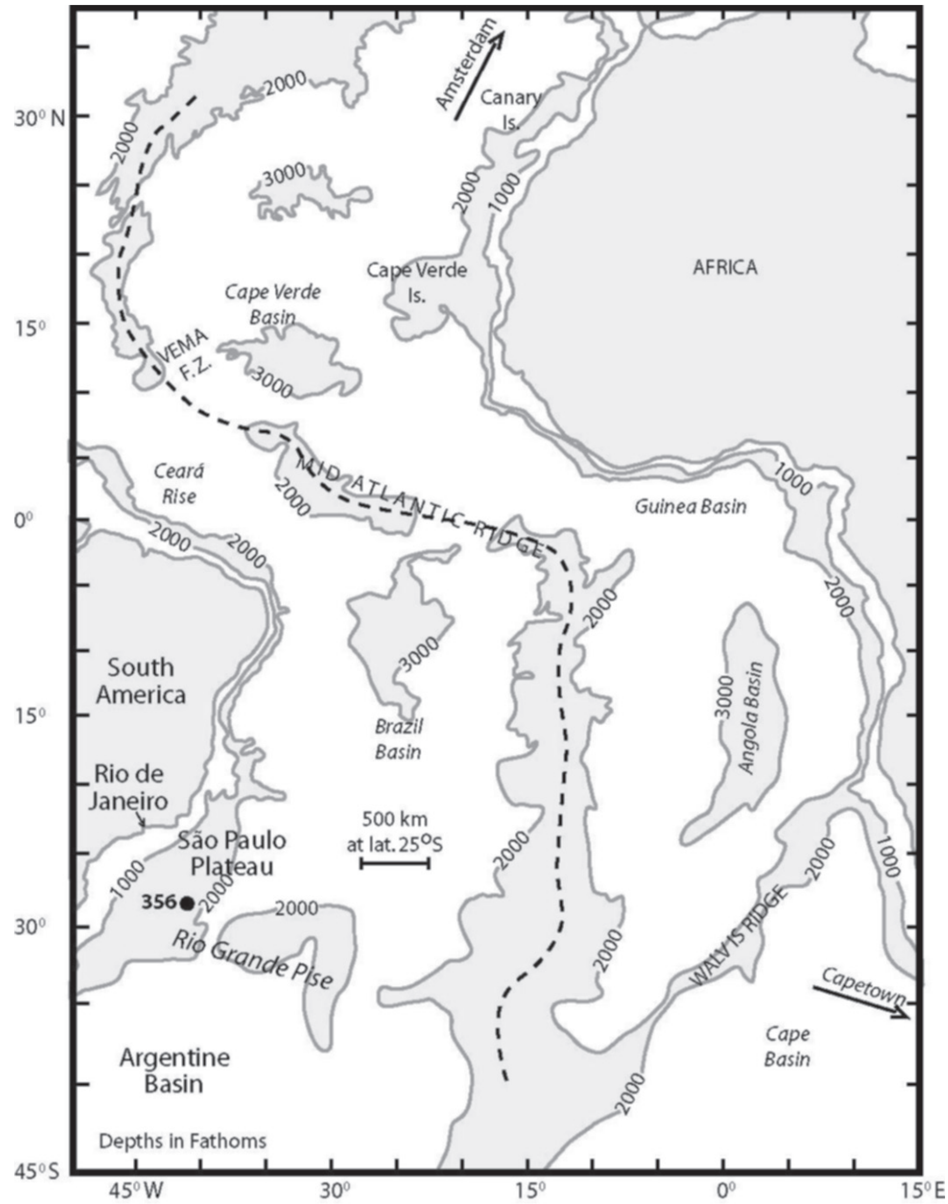

FIGURE 1. Location map of Site 356 compiled from Perch-Nielsen et al. (1977).

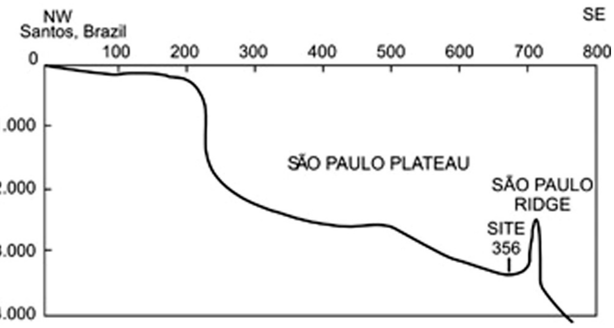

FIGURE 2. Site 356 showing São Paulo Plateau compiled from Perch-Nielsen et al. (1977).

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

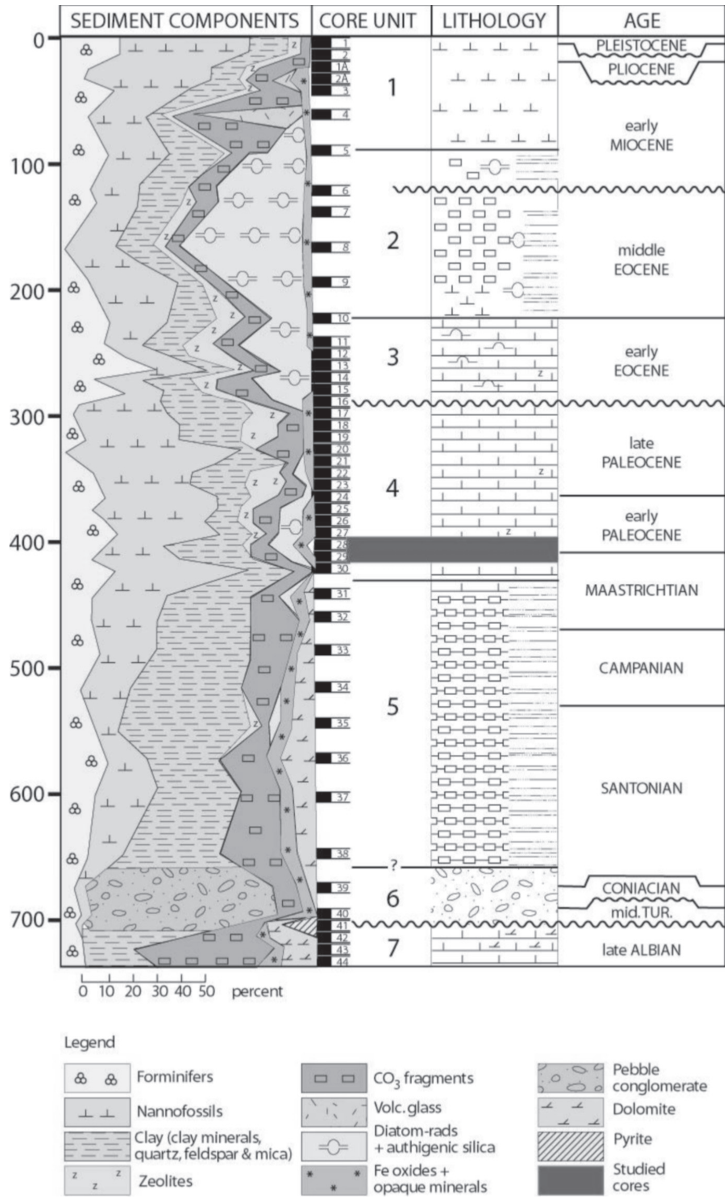

FIGURE 3. Summary of lithology and stratigraphy of Site 356 based on Perch-Nielsen et al. (1977).

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 quadratus* (Maastrichtian), *Lithraphidites praequadratus* (Campanian-Maastrichtian), *Micula decussata* (Coniacian-Maastrichtian), *Micula murus* (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).

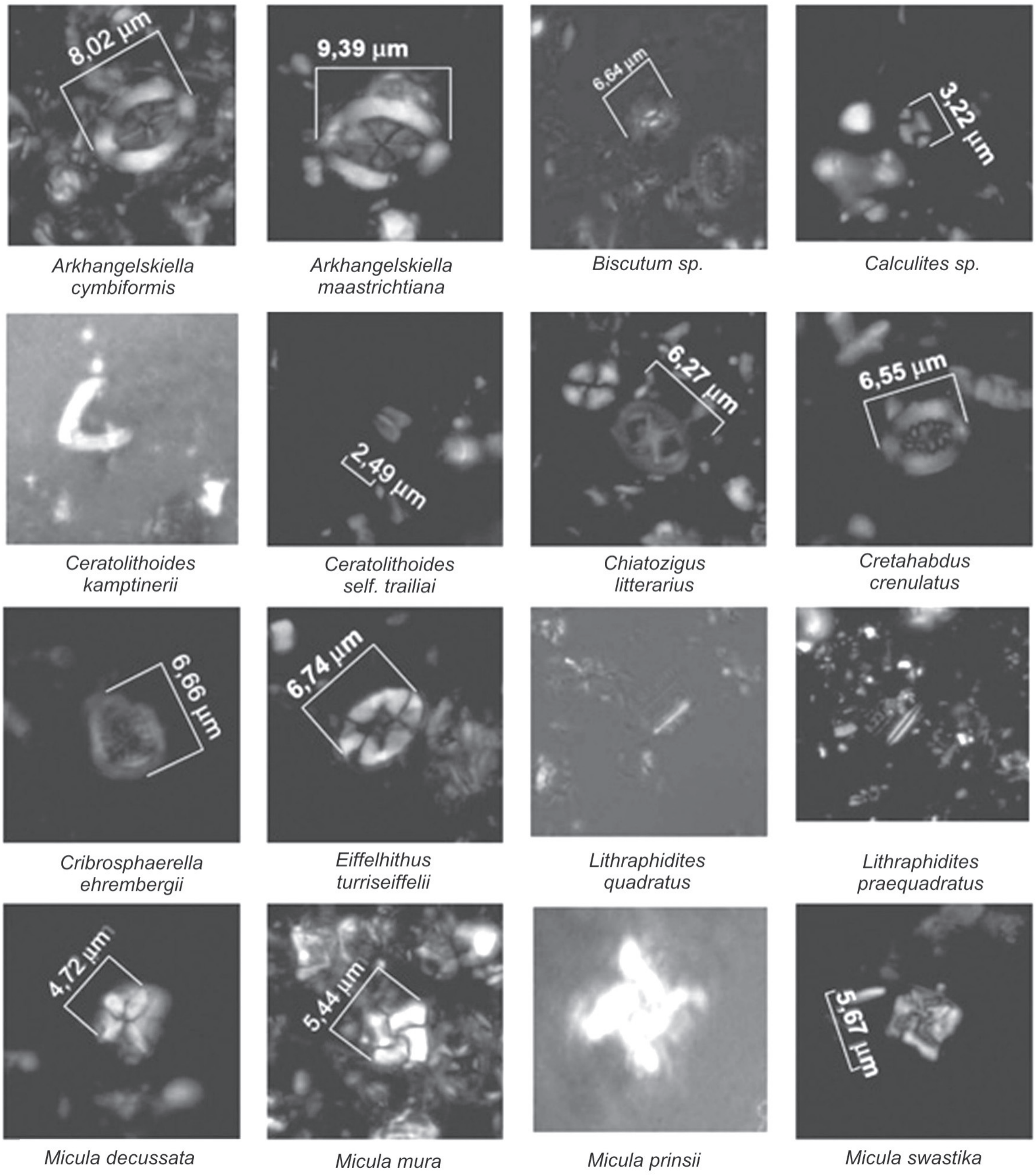

PLATE 1. Cretaceous species of studied cores.

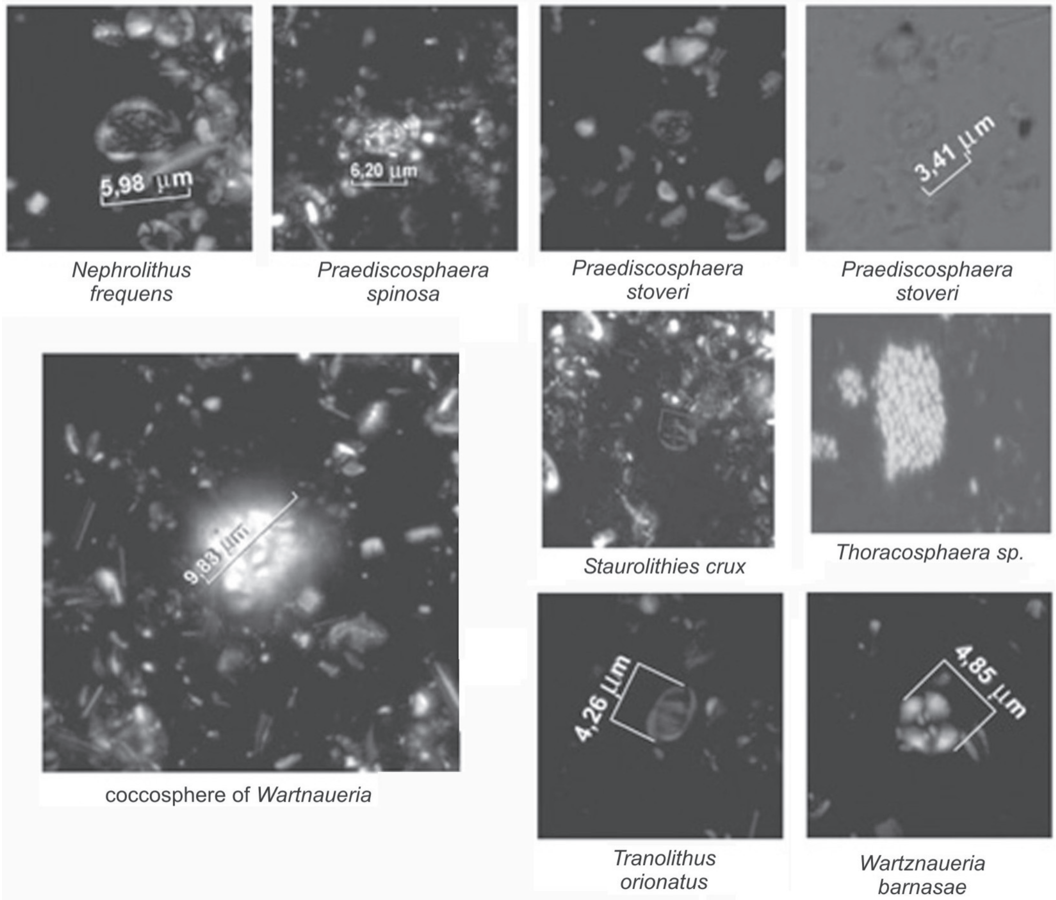

PLATE 2. Cretaceous species of studied cores.

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 ocurrence of *Lithraphidites quadratus* to the last ocurrence of unreworked, 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 ocurrence of *Micula prinsii* to last ocurrence of unreworked, non-survivor Cretaceous *taxa*.

Age: Uppermost Maastrichtian.

MARKALIUS INVERSUS ZONE (NP1)

Authors: Mohler & Hay in Hay *et al*. (1967, emend. Martini (1970).

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

Age: Earliest Danian.

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

CRUCIPLACOLITHUS TENUIS ZONE (NP2)

Authors: Mohler & Hay et al. (1967, emend. Martini (1970).

Definition: First ocurrence of *Cruciplacolithus tenuis* to tirst ocurrence of *Chiasmolithus danicus*.

Age: Early Paleocene (Early Danian).

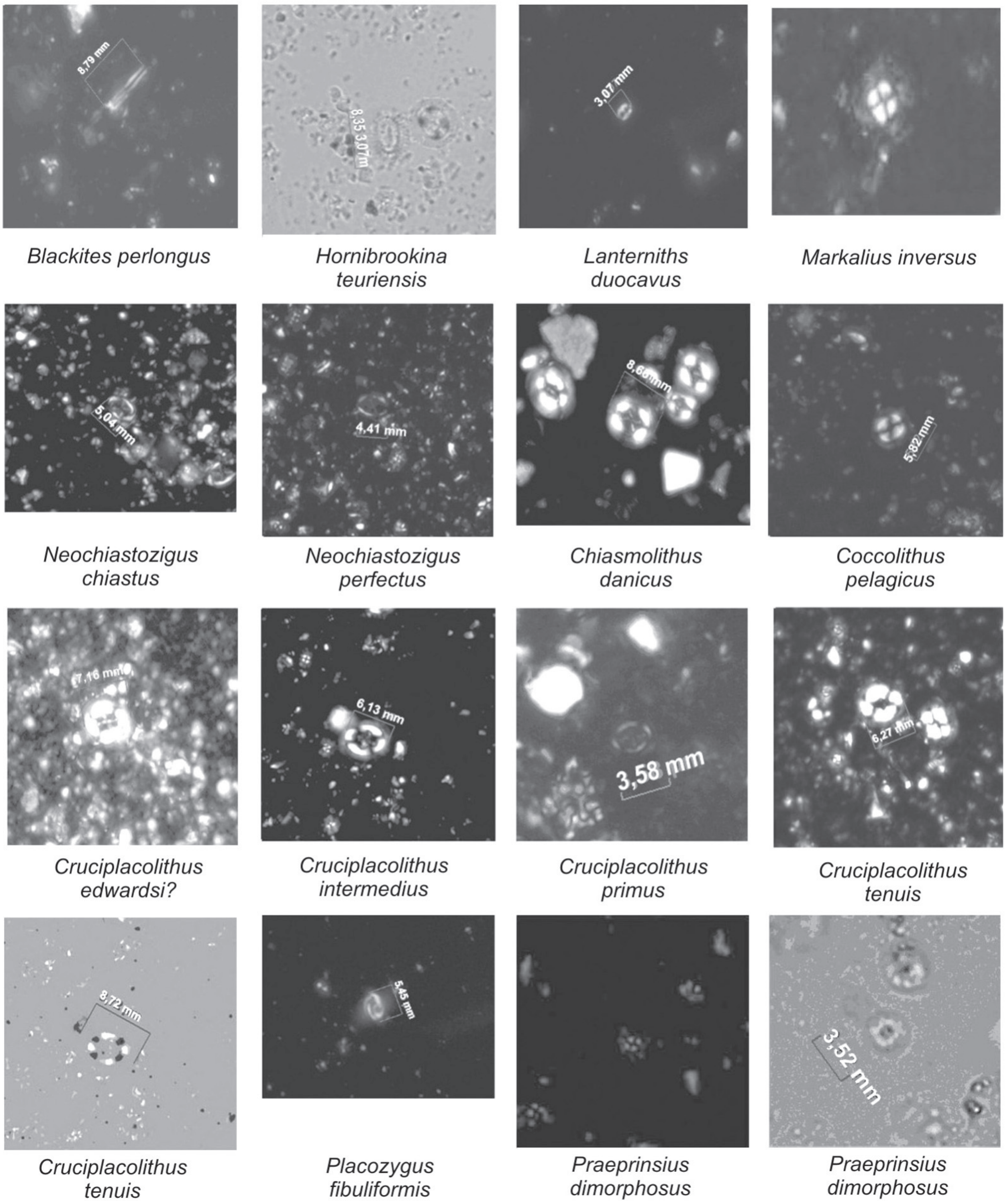

PLATE 3. Paleocene species of studied cores.

CHIASMOLITHUS DANICUS ZONE (NP3)

Author: Martini (1970)

Definition: First ocurrence of *Chiasmolithus danicus* to first ocurrence 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.

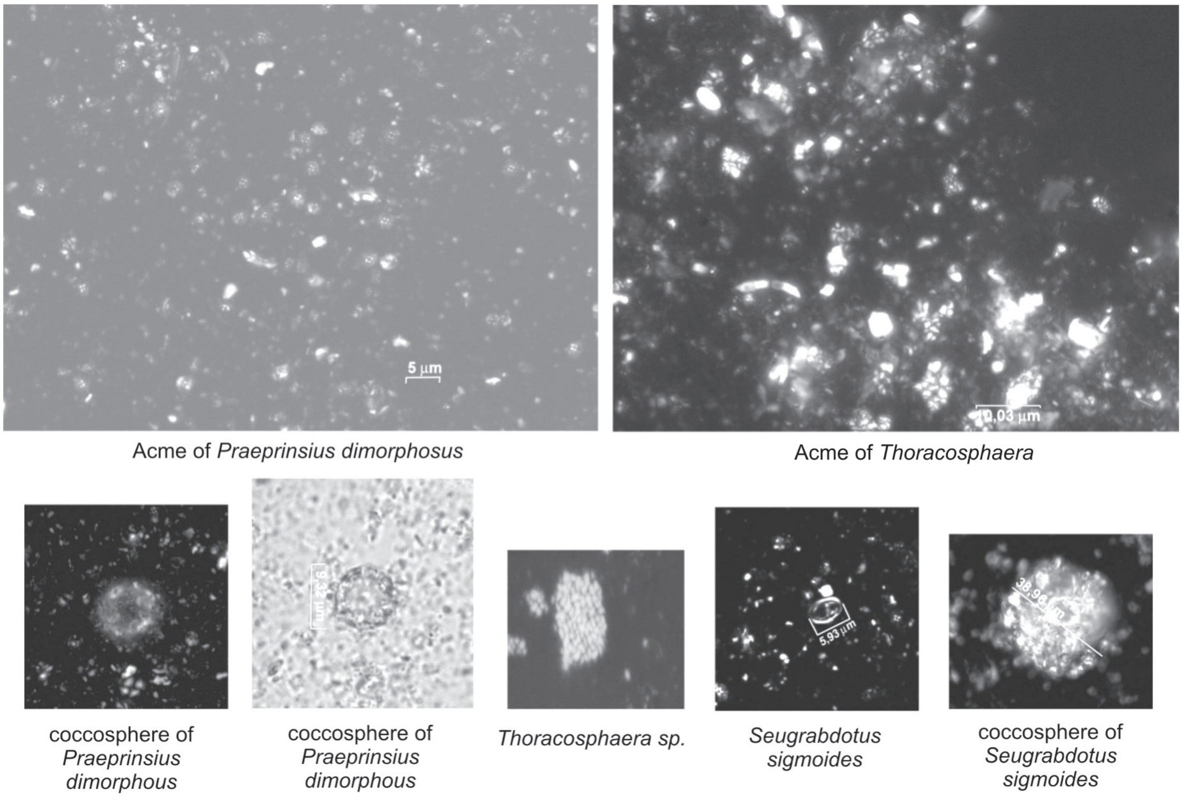

PLATE 4. Plaeocene species of studied cores.

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

Core	Section	Depth (m)	Biozones (Martini, 1971; Burnett, 1998)	Chronostratigraphy
28	01	032-033*	*Chiasmolithus danicus*	Late Danian (Early Paleocene)
28	01	065-066		
28	02	063-064		
28	03	065-066		
28	04	045-046		
28	04	083-084		
28	04	103-104		
28	04	121-123		
28	04	141-142		
28	05	048-049		
28	05	078-079		
28	05	101-102		
28	05	130-131		
28	06	016-017		
28	06	065-066		
28	06	145-146		
29	01	016-017	*Cruciplacolithus tenuis*	Early Danian (Early Paleocene)
29	01	032-033		
29	01	062-063	*Markalius tenuis*	Earliest Danian (Early Paleocene)
29	02	010-009		
29	02	063-065		
29	02	130-131		
29	03	020-021**		
29	03	037-039	UC20 Nannofossil Zone	Uppermost Maastrichtian
29	03	078-080	UC20 ^{TP} Nannofossil Subzone	

* Acme of *Praeprinsius dimorphosus*.
** First occurrence of acme of *Thoracosphaera*.

TABLE 2. Biostratigraphical distribution of species of Site 356, cores 28 and 29.

SAMPLES	*Micula prinsii*	*Micula murus*	*Nephrolithus frequens*	*Lithaphridites quadratus*	*Lithaphridites praequadratus*	*Arkhangelskiella cymbiformis*	*Arkangelskiella maastrichtiana*	*Eifellithus turriseiffelli*	*Placozigus fibuliformis*	*Watznaueria barnesae*	*Micula decussata*	*Praediscosphaera cretacea*	*Microhabdulus decoratus*	*S. flavus*	*S. zoensis*	*C. ehrembergi*	*S. crenulata*	*T. minimus*	*C. exiguum*	*A. octoradiata*	*R. splendens*	*C. kamptineri*	*Markalius inversus*	Biozones
28-01 032/033)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
28-01(065/066)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
28-02(063/064)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
28-03(065/066)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
28-04(045/046)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
28-04(083/084)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
28-04(103/104)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	(1)
28-04(121/122)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
28-04(141/142)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.
28-05(048/049)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.
28-05(078/079)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
28-05(101/102)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.
28-05(130/131)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
28-06(016/017)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.
28-06(065/066)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
28-06(145/146)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	.
29-01(016/017)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	(2)
29-01(032/033)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.
29-01(062/063)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
29-02(09/010)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	(3)
29-02(63/065)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
29-02(130/131)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.
29-03(020/021)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	(4)
29-03(037/039)	1	16	1	3	3	43	4	65	114	479	92	47	64	39	7	29	16	1	1	.	.	.	.	.
29-03(078/080)	1	16	3	10	7	59	26	65	132	230	149	84	113	34	34	78	66	25	2	1	1	1		(5)

(1) *C. danicus* (2) *C. tenuis* (3) *Markalius inversus* (4) UC20 (5) UC20 TP

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 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,

TABLE 3. Biostratigraphical distribution of species of Site 356, cores 28 and 29.

SAMPLES	*Cruciplacolithus primus*	*Placozigus sigmoides*	*Lanternithus duocavus*	*Thoracosphaera spp.*	*Amaurolithus amplificus*	*Cruciplacolithus latipons*	*Neochiastozigus modestus*	*Neochiastozigus saepes*	*Neochiastozigus perfectus*	*Praeprinsius dimorphosus*	*Prinsius tenuiculus*	*Toweius pertusus*	*Toweius selandianus*	*Zigrablithus bijugatus*	*Cruciplacolithus subpertusus*	*Cruciplacolithus intermedius*	*Cruciplacolithus subrotundus*	*Cruciplacolithus tenuis*	*Lanternithus sp.*	*Neochiastozigus chiastus*	*Neochiastozigus sp.*	*Prinsius martini*	*Rhabdosphaera sp.*	*Toweius sp.*	*Zigodiscus plectopons*	*Markalius apertus*	*Neochiastozygus junctus*	*Zygodiscus sp1*	Biozones
28-01(032/033)	.	10	.	.	.	1	.	.	7	3.972	5	.	42	.	.	34	80	4	.	3	1	.	.	10	.	.	1	.	.
28-01(065/066)	12	6	.	144	.	.	3	.	9	3.852	52	.	6	.	.	2	27	.	.	9	.	.	.	7	.	.	.	.	.
28-02(063/064)	360	50	.	144	.	1	.	.	40	542	11	42	67	.	.	264	50	21	.	2	34	.	.	290	.	.	2	.	.
28-03(065/066)	156	57	.	120	.	2	.	2	36	128	4	.	92	.	.	302	120	10	.	7	348	.	.	51	.	.	1	.	.
28-04(045/046)	248	43	.	82	.	2	3	1	60	20	80	.	144	.	.	13	20	3	.	51	43	.	.	41	.	.	1	.	.
28-04(083/084)	111	23	.	74	.	.	.	.	121	8	20	.	74	.	.	31	100	20	.	47	74	.	.	9	.	1	1	.	(1)
28-04(103/104)	252	11	.	60	.	2	.	.	61	45	11	.	80	.	.	32		5	.	21	51	.	.	100	.	.	1	.	.
28-04(121/122)	732	54	.	44	.	7	156	5	528	8	5	18	26	.	.	10	20	60	.	5		.	.	35	.	.	1		
28-04(141/142)	.	61	1	120	.	2	.	.	71	18	9	.	120	.	.	35	144	42	.	18	34	.	.	120	.	.	.	.	.
28-05(048/049)	160	132	8	81	.	5	3	6	78	4	34	.	168	.	.	40	204	120	.	37	30	.	.	.	.	.	2	.	.
28-05(078/079)	542	8	2	28	.	2	2	7	60	60	8	.	54	.	.	10	60	3	.	54	73	.	.	51	.	.	16	.	.
28-05(101/102)	372	102	20	132	.	8		2	57	10	60	.	216	.	.	100	168	57	4	10	8	1	.	5	.	3	1	.	.
28-05(130/131)	336	7	.	53	.	.	3	3	132	1	30	.	144	.	.	24	92	.	.	52	12	.	.	94	.	1	.	.	.
28-06(016/017)	576	37	5	109	.	.	1	26	130	17	36	.	132	.	.	36	180	40	.	27	12	.	.	60	.	.	6	.	.
28-06(065/066)	228	15	52	52	.	4	5	2	63	17	12	.	34	.	.	24	63	20	.	11	15	9	.	60	.	.	5	.	.
28-06(145/146)	100	13	3	132	.	10	.	.	10	13	9	.	10	.	.	14	23	.	.	6	1	.	.	26	.	.	.	.	.
29-01(016/017)	276	70	4	204	.	34	1	1	85	10	25	.	120	.	.	63	10	.	.	35	16	.	.	85	1	.	1	.	(2)
29-0(032/033)	540	40	.	132	.	18	.	6	163	?	37	.	43	.	.	120		26	.	16	17	.	.	80	3	4	2	1	.
29-01(062/063)	180	20	.	144	.	40	.	3	8	264	.	.	168	.	9	13	2	17	7	16	10	2	2	10	2	.	.	.	.
29-02(09/010)	5	.	7	50	2	4	14	3	3	216	84	6	20	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	(3)
29-02(063/065)	95	45	11	263	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
29-02(130/131)	10	10	1	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
29-03(020/021)	22	8	1	1.421	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	(4)
29-03(037/039)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
29-03(078/080)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	(5

(1) C. danicus (2) C. tenuis (3) M. inversus (4) UC20 (5) UC20 TP

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). Figure 4. Evidence of anomalous blooms of *thoracosphaerideans* and *braarudospherideans* 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 an diminishing in the levels of $\delta^{13}C$ 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. Oportunistic organisms are those organisms which take advantage of certain

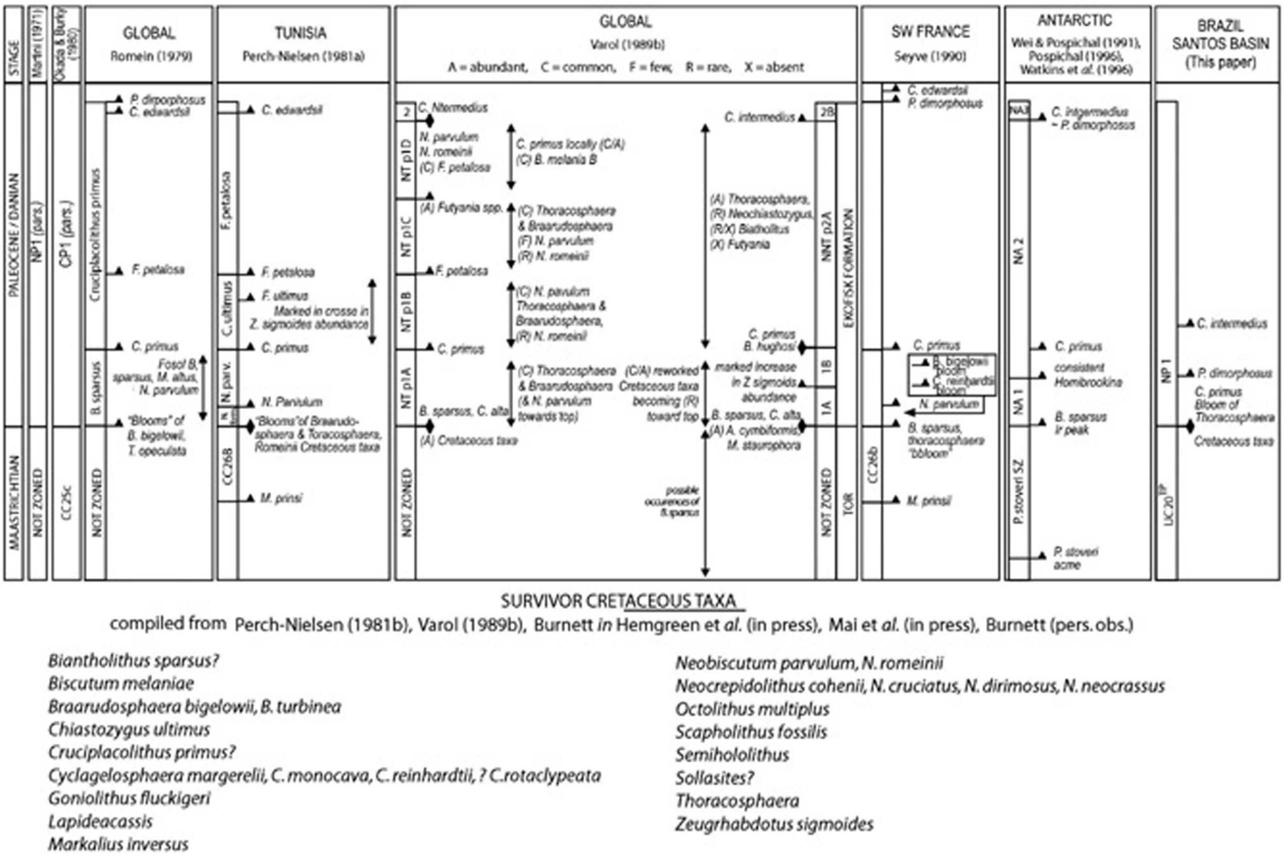

FIGURE 4. Biostratigraphical events and diverse zonal schemes based on Burnett (1998).

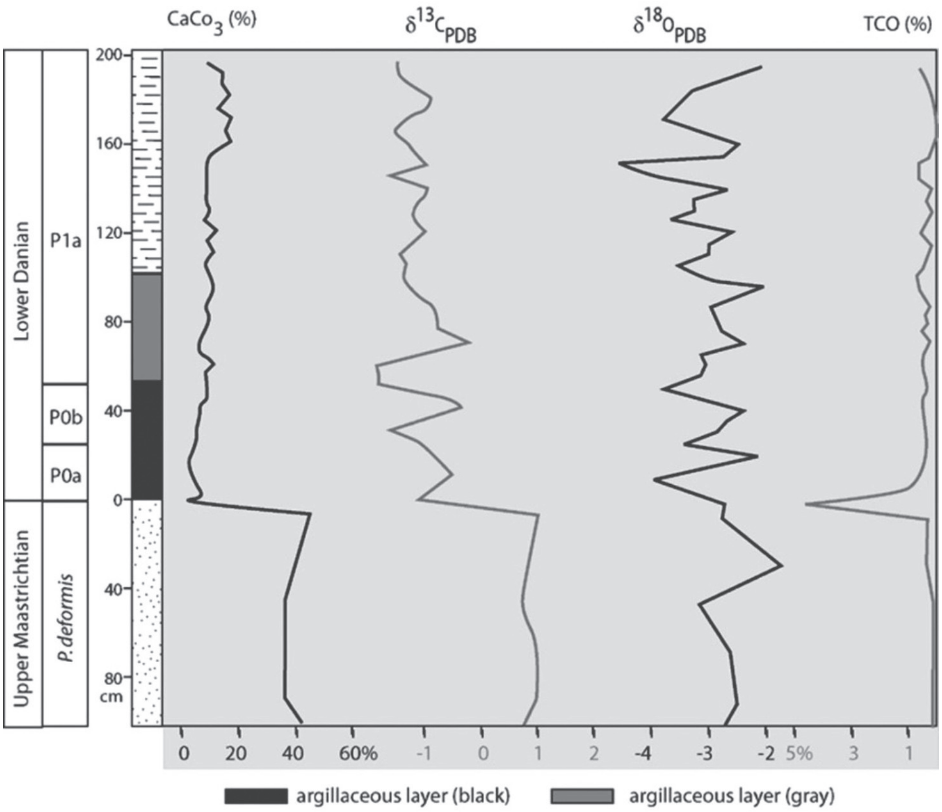

FIGURE 5. Isotopic data and organic carbon content at K-P Boundary based on Keller & Lindinger, 1989 (*apud* Ferreira, 2002).

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 nannofossils 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.

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