BRAARUDOSPHAERA BLOOMS AND ANOMALOUS ENRICHMENTS OF *NANNOCONUS* : EVIDENCE FROM THE TURONIAN SOUTH ATLANTIC, SANTOS BASIN, BRAZIL

Armando A. Scarparo Cunha & Seirin Shimabukuro, PETROBRAS-CENPES,
Cidade Universitária, Quadra 7, Ilha do Fundão, 21949-900 Rio de Janeiro, Brazil

Abstract: Evidence for *Braarudosphaera* blooms, and some abundance peaks of the genus *Nannoconus*, was found in the Lower Turonian Nannofossil Zone CC12 (Lucianorhabdus maleformis Zone) of the Santos Basin on the Brazilian Continental Margin. Calcareous nannofossils in 40 samples from Well 1-SPS-14A, core #1 (2 775-2 779m) were investigated quantitatively. Foraminifera, ammonoids, palynomorphs, and organic geochemistry-petrography provided additional information about the age and the palaeoenvironment of the sequence.

The discovery of faecal pellets composed mainly of braarudosphaerids represents the sedimentary imprint of special environmental conditions. The absence of bioturbation and benthic foraminifera is attributed to the formation of disoxic-anoxic bottom-waters which prevented the development of organic-sediment feeders in an area of high planktonic productivity. Available data suggests that an episodic influx of continental, nutrient-rich fresh-water favoured eutrophication of the upper layer of a stratified water-column, thus triggering the blooms of *Braarudosphaera*.

Introduction

Phytoplankton blooms occur when environmental conditions, including light, temperature and nutrient levels (eutrophication), are favourable for phytoplankton growth. Under such conditions, 'opportunistic organisms' are favoured since they reproduce rapidly and out-compete so-called 'equilibrium forms'. Braarudosphaerids and nannoconids could be considered to be opportunists. Their occurrence is reported from several bloom episodes through geological time. The aim of this paper is to describe a conspicuous braarudosphaerid bloom and an anomalous nannoconid peak (bloom?) in a stratigraphically short Turonian section from the Santos Basin on the Brazilian Continental Margin.

Samples and methods

Calcareous nannofloras in 40 samples from Well 1-SPS-14A, core #1 (2 775-2 779m) in the Santos Basin were investigated (Figure 1). The quantitative analyses were accomplished with a light-microscope at 1200x magnification. In order to obtain a quantitative estimate, a minimum of 300 specimens of *Watznaueria barnesae* and co-occurring species were counted. Some samples contained so few nannofossils that a minimum count of 300 specimens of *W. barnesae* was not possible. In those cases, we attempted to counted at least 300 specimens of all taxa present. However, there were few samples that contained such a poor nannofossil assemblage that <300 specimens could be counted (see the total number of specimens counted per sample in Figure 2). Foraminifers, ammonoids, palynomorphs and organic geochemistry-petrography provided additional information about the age and palaeoenvironment.

Biostratigraphy

Based on the presence of *Eiffellithus eximius* and the absence of *Marthasterites furcatus*, the studied section can be assigned to CC12 (the Lucianorhabdus maleformis Zone of Sissingh, 1977). This zone was originally assigned to the Upper Turonian-Lower Coniacian, although Burnett (1996) confined it to the Middle-Upper Turonian. Application of the integrated zonation for the Cenomanian-Turonian of Bralower (1988) and Bralower *et al.* (1995) implies that the studied samples are from the E. eximius Subzone of Lower Turonian age. This Subzone is defined on the last occurrence (LO) of *Microstaurus chiastius* (base) to the LO of *Rhagodiscus asper* (top). The first occurrence (FO) of *E. eximius* was lies in that interval.

Figure 1: Location map of Well 1-SPS-14, Santos Basin, Brazil.

According to Varol (1992) the presence of *Radiolithus planus* and *Lithastrinus moratus* in the assemblages also points to the Lower Turonian. The LO of *Braarudosphaera africana* has been used as an auxiliary Cenomanian event by Perch-Nielsen (1979, 1985). However, *B. africana* is present in the studied samples together with the younger marker-species and does not appear to have been reworked. It is also worth noting that Burnett (1996) suggested that the LO of *Stoverius achylosus* predated the FOs of *Ahmuellerella octoradiata* and *E. eximius*, whereas we found an overlap between these species in the present section (Figure 2).

Results

The core consists of homogeneous dark grey, silty, calcareous, laminated shale with mm-thick, light-coloured laminae of silty and fine arenites without evident bioturbation (Figure 3). The organic carbon content varies between 1.37% and 1.92% and the carbonate content between 29% and 35%. Fluctuations in components of the coupled laminae may explain the low values of the carbon content. The dark grey units contain more organic matter, iron oxide and micrite specks (either as pellets or detrital elements) than the light-coloured laminae. However, lithological and geochemical characteristics of the core are similar to those found across the Cenomanian-Turonian boundary event (OAE 2) by several authors (Diester-Haass, 1978; Bralower & Thierstein, 1984; Thierstein, 1989; Arthur *et al.*, 1990). In petrographic thin-section, the rock appears laminated and consists of silty to very fine-grained quartz-feldspar sands alternating with biogenic faecal pellets and some isolated foraminifera, nannoconids and coccospheres. The faecal pellets appear as isolated, lenticular (~200µm long) monospecific aggregations of *Braarudosphaera bigelowii* in various preservational states (whole and fragmented), or forming laminae of amalgamated pellets (Figure 4). Pockets of monospecific *Nannoconus* were also observed, probably also of pelletal origin.

According to Arai (1987), the Cenomanian-Turonian sedimentation rate was 3.71cm/kyr. If that rate is correct, then the entire studied section was deposited in a relatively short time (approximately 110 000 years). In that context, the abundance peaks of *Nannoconus* spp. and *Braarudosphaera* spp. appear to represent very short-
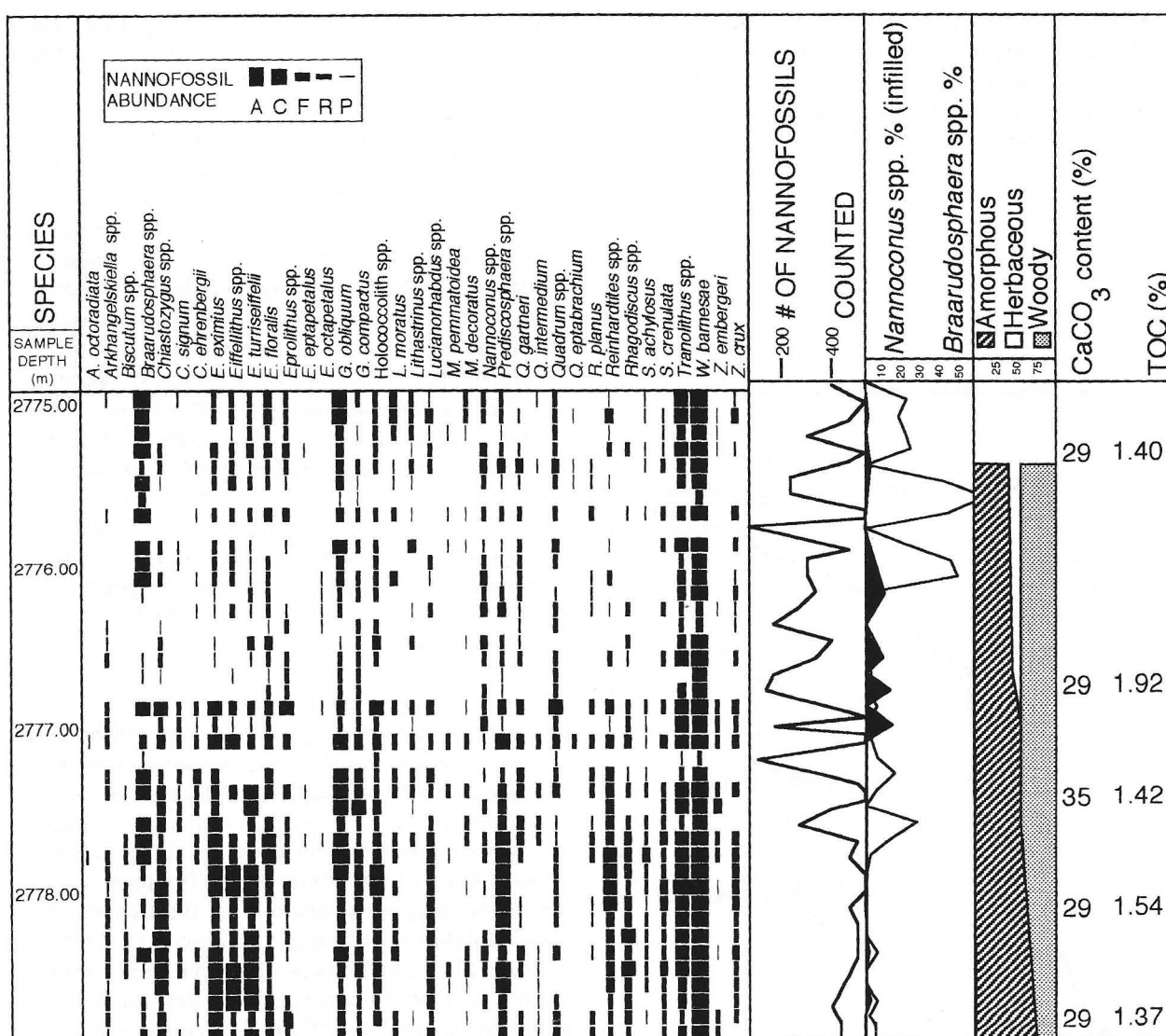

Figure 2: Stratigraphic distribution and relative abundances of calcareous nannofossils (abundance categories correspond to: P = 1-2 specimens counted; R = 3-10; F = 11-50; C = 51-100; A = >100) illustrated alongside organic geochemistry-petrographic information.

Figure 3: Core 1, depth 2775.4m. Observe alternation between dark grey, silty, calcareous shale units and mm-thick light-coloured laminae of silty and fine arenites without evident bioturbation (after Arai, 1987).

term environmental fluctuations. However, to calculate that rate, Arai (1987) assumed that the sedimentation rate was constant for 7m.y., during which 260m of the black shales were deposited. Arai (1988) argued that such black shales are not as rich as mid-Cretaceous black shales recovered at most DSDP sites, probably due to dilution by a greater sedimentation rate.

In spite of the fact that, in the studied core, the planktonic and benthic foraminifera are rare, foraminiferal analysis by Koutsoukos (1982) indicated a neritic environment for the entire section. Based on nannofossil and palynofacies analyses (Arai, 1987), two intervals are recognised in our core (Figure 2): (a) a lower part (2779-2776.9m) with high diversity, well-preserved nannofossils and a predominance of amorphous organic matter; and (b) an upper part (2776.9-2775m) with low diversity assemblages rich in *Braarudosphaera* spp. and *Nannoconus* spp., and a similar percentage abundance of woody-herbaceous debris and amorphous organic matter.

Phytoplankton blooms: temporal distribution and ecological remarks

Braarudosphaera: Modern braarudosphaerids are found in some coastal environments with low salinities and are rare in deep oceans (Gran & Braarud, 1935; Gaarder, 1954 *apud* Parker *et al.*, 1985; Hulbert & Rodman, 1963; Borsetti & Cati, 1972 *apud* Parker *et al.*, 1985). Most modern studies suggest that braarudosphaerid blooms are more closely linked to relatively eutrophic waters rather than to shallow-water environments or low-salinity conditions (Wise
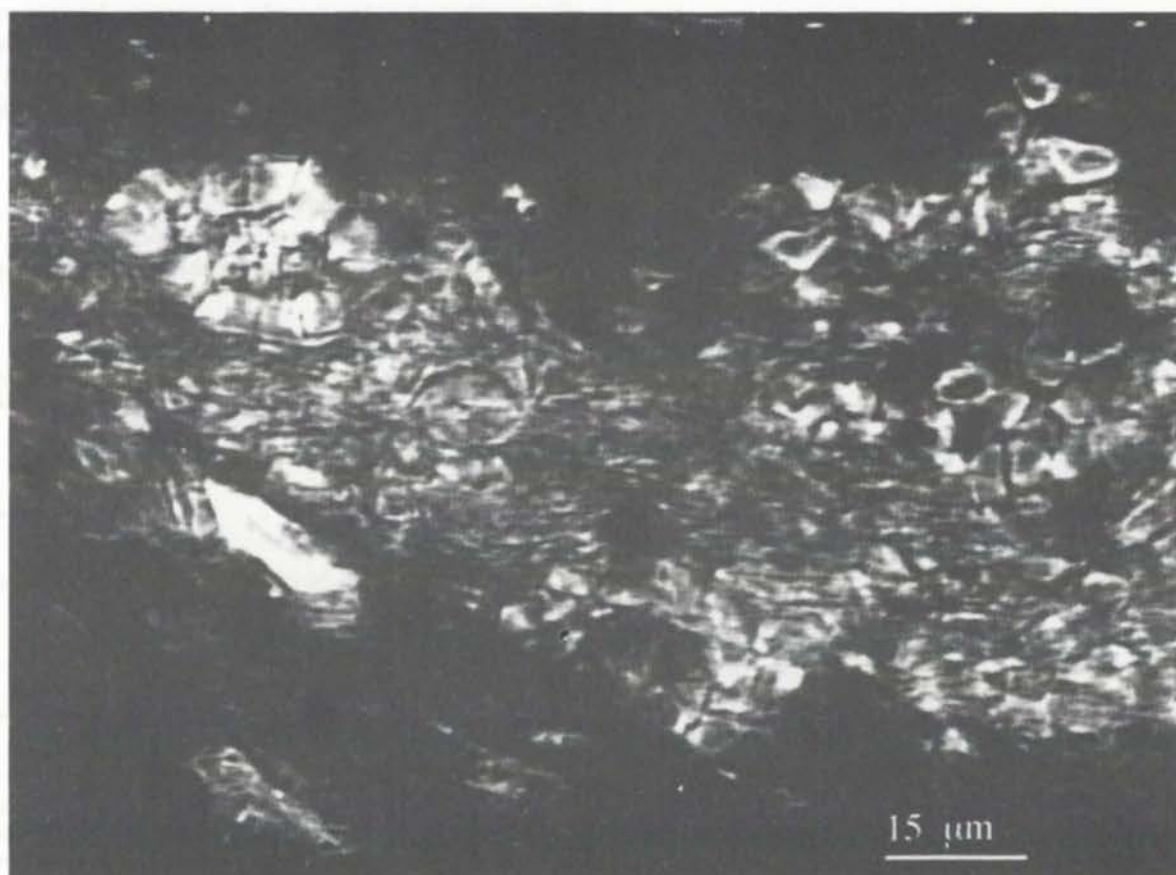

Figure 4: Petrographic aspect of the monospecific aggregation of *Braarudosphaera bigelowii* forming faecal pellets.

& Kelts, 1972; Siesser *et al.*, 1992; Shimabukuro, 1994). By analogy with modern blooms, we infer that during the Late Cretaceous, blooms of braarudosphaerids in coastal environments were triggered by the influx of nutrient-rich continental waters from rivers or estuaries, or by coastal upwelling. In both cases, this leads to a lowering of salinity coupled with eutrophication.

Geologists have recognised variations in global taxonomic diversity. Times of maximum diversity alternate with times of reduced diversity. The relationship between biotic diversity cycles and oceanographic processes are complex. However, according to Fisher & Arthur (1977), polytaxic times tend to coincide with marine transgression, while oligotaxic times coincide with marine regression. They reported that such cyclic fluctuations recur with a periodicity of 32m.y.. *Braarudosphaera* blooms are interpreted as episodes associated with oligotaxic times and they were plotted alongside a time-scale in the Hauterivian, Palaeocene and Oligocene, corresponding to the cycle of 32m.y., except that a Turonian *Braarudosphaera* bloom was not recorded (Fisher & Arthur, 1977, p.21, fig.1). Actually, *Braarudosphaera* blooms have been recorded from the Hauterivian (Bukry & Bramlette, 1969), Turonian (this paper), Danian (Perch-Nielsen, 1985) and Oligo-Miocene (Parker *et al.*, 1985; Siesser *et al.*, 1992; Shimabukuro, 1994), supporting this cyclic fluctuation model.

Nannoconus: Nannoconid bloom events have been reported mainly from Lower Cretaceous sediments (Colom, 1955; Mutterlose, 1987; Erba, 1992, 1994; van Niel, 1995). The processes controlling such phenomena remain unsolved and are more difficult to unravel than in the case of *Braarudosphaera*, since *Nannoconus* became extinct in the Late Cretaceous and thus no living representatives can be studied. Several authors have suggested that *Nannoconus* was adapted to oligotrophic, rather than eutrophic, conditions (Busson & Noël, 1991; Coccioni *et al.*, 1992; Erba, 1994). However, in some aspects the researchers contradict themselves. Busson & Noël (1991), for example, compared nannoconid blooms with the phenomenon of the 'red tides', wherein a bloom of dinoflagellates poison the marine waters. Nowadays, this phenomenon is triggered by an increase in nutrients. Indeed blooms normally require relatively high nutrient levels (eutrophication). On the other hand, published data show a positive correlation between nannoconid-rich sediments, high carbonate content, low diversity, and shallow-water environments, with some of these conditions better developed in areas with low terrigenous influx (Roth & Krumbach, 1986; Mutterlose, 1987; Busson & Noël, 1991; Erba, 1992). The peaks of *Nannoconus* spp. correspond to high relative abundance in that group, normally more than 10% of the whole assemblage, whilst the total number of coccoliths fall. This event perhaps could not be interpreted as a *Nannoconus* spp. bloom. However, the inverse correlation between *Nannoconus* spp. and other coccoliths may indicate that the environmental conditions favourable to *Nannoconus* spp. were not favourable to the other groups.

Interpretation and conclusions

The nutrient input necessary to trigger the observed *Braarudosphaera* bloom could have been caused by several processes. One of these could be the increase in nutrient supply from deeper, cold waters. According to Berger *et al.* (1989), "sporadic nutrient supply from a deep reservoir would be stressful to pelagic organisms adapted to low fertility (producing blooms of opportunist algae such as *Braarudosphaera*)". However, the palynofacies data indicate an increase in continental influence towards the top of the core, evidenced by the gradual replacement of amorphous organic matter by herbaceous-woody organic matter, with a marine origin for the amorphous organic matter and a continental origin for the herbaceous-woody organic matter. This could reflect a positive fresh-water balance, caused by large rivers carrying nutrients and herbaceous-woody organic matter from the land directly onto the continental shelf. Consequently, it seems possible that increased fresh-water runoff (fresh-water being less dense that salt-water) led to a higher trophic level favouring eutrophication of the upper layer in a stratified water-column and triggering blooms. A modern analog was proposed by Ittekkot *et al.* (1992) in order to explain the increased primary production in the Bay of Bengal-Indian Ocean induced by anthropogenic eutrophication (Figure 5).

The occurrence of faecal pellets consisting mainly of braarudosphaerids constitutes the sedimentary imprint of eutrophic environmental conditions, since it can be assumed that *Braarudosphaera* was the only (or predominant) food supply for grazers. The same reasoning suggests eutrophic conditions to be the cause for the *Nannoconus* abundance peaks, since some *Nannoconus*-pellet-rich laminae were observed to alternate with those of *Braarudosphaera*. Our study has not yet supplied information necessary for definitive conclusions or further speculations.

Acknowledgements
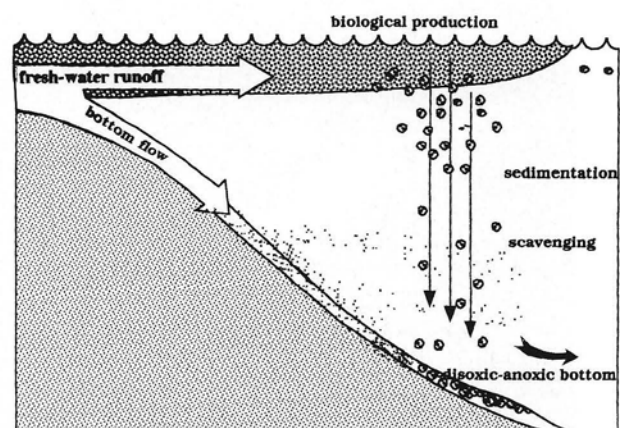
Figure 5: Modern model proposed to explain increased primary production in the Bay of Bengal-Indian Ocean by anthropogenic action. A similar model is proposed to explain an episodic influx of nutrient-rich fresh-water which resulted in eutrophication and triggered *Braarudosphaera* and *Nannoconus* blooms in the Early Turonian (modified after Ittekkot *et al.*, 1992).

References

Arai, M. 1987. Caracterização geoquímica orgânica do registro de anoxia do Cretáceo médio da Bacia de Santos, Plataforma continental do sudeste brasileiro. Unpublished Master's thesis, Universidade Fluminense, 131pp..

Arai, M. 1988. Geochemical reconnaissance of the Mid-Cretaceous anoxic event in the Santos Basin, Brazil. *Revista Brasileira de Geociências*, **18**(3): 273-282.

Arthur, M.A., Jenkyns, H.C., Brumsack, H.J. & Schlanger, S.O. 1990. Stratigraphy, geochemistry, and paleoceanography of organic carbon-rich Cretaceous sequences. *In*: R.N. Ginsburg & B. Beaudoin (eds). *Cretaceous Resources, Events and Rhythms*. Kluwer Academic Publishers: 75-119.

Berger, W.H., Smetacek, V.S. & Wefer, G. 1989. Ocean productivity and Paleoproductivity - An overview. *In*: W.H Berger, V.S. Smetacek & G. Wefer (eds). *Productivity of the ocean: present and past*. John Wiley & Sons: 1-34.

Bralower, T.J. 1988. Calcareous nannofossils biostratigraphy and assemblages of the Cenomanian-Turonian boundary interval: Implications for the origin and timing of oceanic anoxia. *Paleoceanography*, **3**: 275-316.

Bralower, T.J., Leckie, R.M., Sliter, W.V. & Thierstein, H.R. 1995. An integrated Cretaceous microfossil biostratigraphy. *In*: W.A. Berggren, D.V. Kent & M. Aubry (eds). *Geochronology, Time Scales and Global Stratigraphic Correlation. SEPM, Special Publication*, **54**: 65-79.

Bralower, T.J. & Thierstein, H. R. 1984. Low productivity and slow deep-water circulation in mid-Cretaceous oceans. *Geology*, **12**: 614-618.

Bukry, D. & Bramlette, M.N. 1969. Coccolith age determinations, Leg 1. *IRDSDP*, **1**: 369-387.

Burnett, J.A. 1996. Nannofossils and Upper Cretaceous (sub-) stage boundaries - state of the art. *Journal of Nannoplankton Research*, **18**: 23-32.

Busson, G. & Noël, D. 1991. Les nannoconidés, indicateurs environnementaux des océans et mers épicontinentales du Jurassique terminal et du Crétacé inférieur. *Oceanologica Acta*, **14**: 333-356.

Coccioni, R., Erba, E. & Premoli-Silva, I. 1992. Barremian-Aptian calcareous plankton biostratigraphy of the Gorgo Cebara section (Marche, Central Italy) and implications for plankton evolution. *Cretaceous Research*, **13**: 517-537.

Colom, G. 1955. Jurassic-Cretaceous pelagic sediments of the western Mediterranean zone and the Atlantic area. *Micropaleontology*, **1**: 109-124.

Diester-Haass, 1978. Sediments as indicators of upwelling. *In*: R. Boje & M. Tomaczar (eds). *Upwelling ecosystems*. Springer-Verlag: 261-300.

Erba, E. 1992. Calcareous nannofossil distribution in pelagic rhythmic sediments (Aptian-Albian Piobbico core, Central Italy). *Rivista Italiana Paleontologia e Stratigrafia*, **97**(3/4): 455-484.

Erba, E. 1994. Nannofossils and superplumes: the early Aptian "nannoconid" crisis. *Paleoceanography*, **9**(3): 483-501.

Fisher A.G. & Arthur, A.M. 1977. Secular variations in the pelagic realm. *SEPM, Special Publication*, **25**: 19-50.

Gran, H.H. & Braarud, T. 1935. A quantitative study of the phytoplankton in the Bay of Fundy and the Gulf of Maine (including observations on hydrography, chemistry and turbidity). *Journal of the Biological Board of Canada*, **1**: 279-467.

Hulbert, E.M. & Rodman, J. 1963. Distribution of phytoplankton with respect to salinity between the coast of southern New England and Bermuda. *Limnology and Oceanography*, **8**: 263-269.

Ittekkot, V., Haake, B., Bartsch, M., Nair, R.R. & Ramaswamy, V. 1992. Organic carbon removal in the sea: The continental connection. *In*: C.P. Summerhayes, W.L. Prell & K.C. Emeis (eds). *Upwelling Systems: Evolution since the Early Miocene. Geological Society Special Publication*, **64**: 167-176.

Koutsoukos, E. 1982. Geohistória e paleoecologia das bacias marginais de Florianópolis e Santos. *Congresso Brasileiro de Geologia, 32, Curitiba, Sociedade Brasileira de Geologia*, **5**: 2369-2382.

Mutterlose, J. 1987. Calcareous nannofossils and belemnites as warm water indicators from the NW-German middle Aptian. *Geologisches Jahrbuch*, **96**: 293-313.

Niel, B.E. van 1995. Unusual twinned specimens of *Nannoconus abundans* (calcareous nannofossils, Incertae sedis). *Journal of Micropalaeontology*, **14**: 159-164.

Parker , M.E, Clark, M. & Wise, S.W. 1985. Calcareous nannofossils of Deep Sea Drilling Project Sites 558 and 563, North Atlantic Ocean: Biostratigraphy and distribution of Oligocene braarudosphaerids. *IRDSDP*, **82**: 559-589.

Perch-Nielsen, K. 1979. Calcareous nannofossils from the Cretaceous between the North Sea and the Mediterranean. *IUGS Series A*, **6**: 223-272.

Perch-Nielsen, K. 1985. Mesozoic calcareous nannofossils. *In*: H.M. Bolli, J.B. Saunders & K. Perch-Nielsen (eds). *Plankton Stratigraphy*. Cambridge University Press: 329-426.

Roth, P.H. & Krumbach, K.R. 1986. Middle Cretaceous calcareous nannofossil biogeography and preservation in the Atlantic and Indian Oceans: implications for micropaleontology. *Marine Micropaleontology*, **10**: 235-266.

Shimabukuro, S. 1994. "Braarudosphaera chalk": investigações sobre a gênese de um marco estratigráfico. Unpublished Master's thesis, Universidade Federal do Rio Grande do Sul: 117 pp..

Siesser, W.G., Bralower, T.J. & De Carlo, E.H. 1992. Mid-Tertiary *Braarudosphaera* -rich sediment on the Exmouth Plateau. *Proceedings of the ODP, Scientific Results*, **122**: 653-663.

Sissingh, W. 1977. Biostratigraphy of Cretaceous calcareous nannoplankton. *Geologie en Mijnbouw*, **56**: 37-65.

Thierstein, H.R. 1989. Inventory of paleoproductivity records: The mid-Cretaceous enigma. *In*: W.H. Berger, V.S. Smetacek & G. Wefer (eds). *Productivity of the Ocean: Present and Past*. John Wiley & Sons: 355-375.

Varol, O. 1992. Taxonomic revision of the Polycyclolithaceae and its contribution to Cretaceous biostratigraphy. *Newsletters on Stratigraphy*, **27**: 93-127.

Wise, S.W. & Kelts, K.R. 1972. Inferred diagenetic history of a weakly silicified deep sea chalk. *Transactions of the Gulf Coast Association of Geological Societies*, **22**: 177-302.