Calcareous nannofossils from the Nkalagu Formation type locality (Middle Turonian to Coniacian, southern Nigeria): biostratigraphy and palaeo-ecologic implications

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ABSTRACT—The calcareous nannofossil assemblages of the Nkalagu Formation have been investigated at its type locality, concerning their biostratigraphic and palaeo-ecological applicability. Two calcareous nannofossil zones can be distinguished in the Nkalagu quarry sections: the *Eiffellithus eximius* zone (Middle Turonian to early Late Turonian) and the *Marthasterites furcatus* zone (Late Turonian to Coniacian). The first appearance of *Marthasterites furcatus* indicates the lower boundary of the *Marthasterites furcatus* zone. This boundary is within the Late Turonian, as shown by the first appearance of the index species long before the first appearance of Coniacian planktonic foraminifera and the co-occurrence with Late Turonian inoceramids. The dominating species *Watznaueria barnesae* points to oceanic environments at Nkalagu for the Middle Turonian to Coniacian interval. © 2001 Elsevier Science Limited. All rights reserved.

INTRODUCTION

The only paper on calcareous nannofossils from the Upper Cretaceous of Nigeria published so far is that by Perch-Nielsen and Petters (1981). They mention the occurrence of 14 species (without figures) in the Band 20 section of Nkalagu, most of which also have been found in the samples investigated here. The older Band 18 section has been sampled for the first time and inclusion of its data allows a more exact dating of the strata.

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Figure 1. Geology of the investigated area. Upper left inset shows the important tectonic elements. Upper right inset shows the geological map of the Anambra Basin and the Lower Benue Trough. Lower half shows the geological map of Nkalagu and its vicinity (geology according to Umeji, 1993).
major tectonical structure in the Lower Benue Trough. Detailed descriptions of the structural relationships in the region have been presented in previous studies by Agagu and Adighije (1983), Benkhelil (1988, 1989) and Ojoh (1990). Most of the previous authors describe the depositional environment of the entire Benue Trough as shallow marine and (in parts) anoxic (e.g. Petters, 1978, 1982). However, more recent studies on sedimentological structures and facies indicate different depositional environments, at least in the lower part of the Benue Trough. This includes a new interpretation of the limestone layers as turbidites (see below) and new faunal analyses (foraminifera, ostracods: Gebhardt, 1999, 2000). The calcareous nannofossils also emphasise the oceanic character of the sediments at Nkalagu.

The depositional framework of the investigated sediments can be described as a deep embayment, which allowed for deep water sedimentation (upper bathyal; Gebhardt, 2000). The area is a key area for biostratigraphical studies because sediments of corresponding age in the Middle Benue Trough were deposited under marginal marine (paralic) and continental conditions (Obaje, 1994; Ojo, 1997).

The investigated sediments were formed during the second of three major Cretaceous transgressions which flooded the Benue Trough (e.g. Adeleye, 1975; Petters, 1978). Because of the lack of lithological differences, the former Eze-Aku and Awgu Formations have been combined to the Nkalagu Formation by Petters and Ekweozor (1982). Nkalagu Shale, Ezillo Silt and Isinkpuma Sandstone (Fig. 1) are considered to be sub-units of the Nkalagu Formation. The outcrops in the Nkalagu Quarries have been chosen by Petters and Ekweozor (1982) to be the type locality for the Nkalagu Formation.

The 23.5 m thick Band 18 section (Figs 1 and 2) begins with several thick limestone beds at its base, intercalated by thin shale layers. The limestone beds (mainly floatstones) show typical characteristics of turbiditic sedimentation, such as graded bedding and exotic components (e.g. shallow water bivalves). They represent the proximal fan facies and are very similar to the basal limestone beds in the Band 20 section. The top 20 m are built up of shales and silt shales, interrupted only by two marly layers which have been classified as planktonic foraminifera dominated wackestones in thin sections (distal turbidites: Oti, 1990; Gebhardt, 2000).

The 26 m thick Band 20 section (Figs 1 and 3) consists of shales to silty shales, intercalated by limestones and marls. A 6 m thick stack of limestones close to the base of the section has been quarried for cement production. It is intercalated with thin shale or marl layers. Several centimetre to metre thick limestone and marl beds are interbedded with the shales towards the top of the section. Limestone and marl beds are interpreted as turbidites because they show their typical characteristics (fining-upward sequences, matrix supported exotic components, etc.), although typical Bouma cycles are not present. This follows earlier interpretations by Banerjee (1981), Oti (1990) and Amajor (1992). Thick coarse massive beds represent proximal fan facies close to feeder channels, while thin fine-grained laminated layers represent distal facies. Some thin sandy limestone layers could be interpreted as contourites, due to their sedimentological characteristics (worn out fossils, sharp upper and lower contacts, etc.) (Gebhardt, 2000).

**Paleo-ecology of coccolithophorids**

Together with dinoflagellates and diatoms, coccolithophorids form the main constituent of modern marine phytoplankton. As primary producers, they are responsible for a major part of the O production of the oceans of today. Their calcareous remains form a main constituent of recent deep sea oozes. Being photosynthetic, they live in the photic zone (to about 150 m water depth, 200 m maximum), but have their highest frequency a little below the water surface (ca 50–100 m in the tropics, 10–20 m elsewhere), i.e. always above the thermocline. Below this depth they become less frequent and may switch to heterotrophy (Reinhardt, 1972; Haq, 1978; Tappan, 1980; Houghton, 1991). Occurrence of certain species depends on temperature, causing strong frequency fluctuations. Their biogeographic distribution reflects the different climatic zones. The number of species increases with temperature, but around the poles even monospecific floras may occur (Reinhardt, 1972). Tappan (1980) discriminates seven latitudinal surface-water zones (tropical, subtropical [north and south], transitional [north and south], sub-arctic, sub-antarctic).

Most coccolithophorids are fully marine forms, some species dwell in litoral or brackish environments and only very few fresh water species are known (Reinhardt, 1972; Houghton, 1991). Tidal currents may transport coccoliths into estuaries or tidal flats as silt in suspension and, therefore, serve as a link between oceanic and continental record (Houghton, 1993).

Diversity is highest in the open ocean and decreases in marginal seas and towards the coastline. Coccolithophorids dominate the plankton communities if low nutrient influx prevails. Oceanic nannoplankton can stand much lower minimum nutrient contents (Ks-value, e.g. nitrate) than larger organisms because of their minute cells, but
Figure 2. Distribution of calcareous nannofossils in the Band 18 section, the biostratigraphic marker species and the calcareous nannofossil zones. FA: first appearance.
Calcereous nannofossils from the Nkalagu Formation type locality

Figure 3. Distribution of calcereous nannofossils in the Band 20 section.
disappear from tidally mixed waters (where sufficient nutrients for algal growth are present) before a significant growth can take place (Houghton, 1991).

Most coccoliths reach the ocean floor inside faecal pellets of their consumers, mainly copepods. The pellets serve as a shelter against dissolution during sinking through the water column. This also increases the sinking velocity significantly ('faecal pellet express').

Utilisation for ecological questions usually requires quantitative analyses, which could not have been done in this case due to the reasons explained below. Examples from the Cretaceous focus on e.g. temperature variations (Mutterlose, 1989), identification of transgressive events (Bischoff and Mutterlose, 1998) or eutrophication events (Cunha and Shimabukuro, 1996).

MATERIAL AND SAMPLE PREPARATION

Smear slides were prepared from all 74 samples of both sections according to the standard procedure explained in Perch-Nielsen (1985). A formerly planned application of a method according to Flores and Sierro (1997), with defined quantities for sedimentation and the possibility of a quantitative analysis of the floras, was not possible because nannofossils are too rare in the samples. Using 400 × magnification, 50–100 visual fields were scanned per smear slide. Classification of coccoliths was done with 1000 × magnification.

The material on the smear slides contained large portions of siliclastic (mainly mica) and/or carbonaceous detritus and other organic matter. The nannofossils are relatively rare because of this dilution effect. Only every 10th or 20th visual field showed nannofossil elements, mostly isolated coccoliths. Compared with Bralower (1988), the frequency of all species could be classified as few to rare. In the present case, the low nannofossil content is caused mainly by sedimentary effects; diagenetic reasons seem to be of secondary importance.

Many nannofossil remains could not be classified exactly. This was caused by:

i) broken or incomplete specimens;

ii) partial dissolution and recrystallisation (neomorphism); or

iii) partial or complete coverage by sedimentary particles, mainly mica.

Despite these difficulties, sufficient material has been found to carry out a biostratigraphic zonation and to infer a palaeogeographic and palaeo-ecologic interpretation.

BIOSтратigraphic Zonation

Figures 2 and 3 show the occurrence of species in Band 18 and 20 sections. The first appearance of Marthasterites furcatus indicates a zonal boundary. Therefore, two nannofossil zones can be distinguished, an older Eiffellithus eximius zone and a younger Marthasterites furcatus zone. They cover the period from the Middle(?)-Turonian to the Coniacian. Because of the species occurring at Nkalagu, zonation schemes according to Verbeek (1977) or Tappan (1980) have been chosen. Some further zonations for the interval investigated are shown in Fig. 4 for comparison. The beginning of the Marthasterites furcatus zone is between samples 17 and 18 of the Band 18 section (see Fig. 2). This interval represents part of the Late Turonian (Cythereis vitiligiosa reticulata zone, according to ostracods: Gebhardt, 1999; Marginotruncana sigali zone according to planktonic foraminifera: Gebhardt, 2000). Perch-Nielsen and Petters (1981) investigated only the Band 20 section. They allocated the entire section to the Marthasterites furcatus zone and, corresponding to the general opinion at that time, to the Coniacian. Because the base of the Marthasterites furcatus zone is not equivalent with the base of the Coniacian (see zonal definitions), the bigger (lower) part of the Band 20 section is classified here as Late Turonian (Fig. 3).

Eiffellithus eximius zone

Category: Interval zone.

Author: Manivit et al. (1977).

Definition: Interval from the first appearance of Eiffellithus eximius (Fig. 5.4, 5.5) to the first appearance of Marthasterites furcatus.

Age: Middle Turonian to late Late Turonian.

Remarks: According to Verbeek (1977), the base of this zone is within the Praeglobotruncana helvatica (planktonic foraminifera) zone; its upper boundary is within the Marginotruncana sigali (planktonic foraminifera) zone. The base of this zone is not exposed in the investigated quarries at Nkalagu. Its upper boundary at Nkalagu, exposed within the Band 18 section, is within the Marginotruncana sigali (planktonic foraminifera) zone (Gebhardt, 2000) or within the Cythereis vitiligiosa reticulata (ostracod) zone.

Further coccolith species occurring within the Eiffellithus eximius zone at Nkalagu are: Marthasterites inconspicuus (Fig. 5.1), Watznaueria barnesae (Fig. 5.6, 5.7), Tranolithus phaeolus, Gartnerago obliquum (Fig. 5.10, 5.11), Eiffellithus turrisellifelii (Fig. 5.8, 5.9), Glaucolithus diplogrammus (Fig. 5.12, 5.13), Nannoconus regularis, Stradneria crenulata and Prediscosphaera spp.
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Figure 4. Several calcareous nannofossil zones for the investigated period. *: zonal names in brackets if different from Sissingh (1977); dots: first appearance Martasterites furcatus.
**Figure 5.** Most frequent calcareous nanofossils found at Nkalagu. All are the same scale, ca X2400. (1) Marthasterites inconspicuus Deflandre, sample Band 20/15. (2) and (3) Marthasterites furcatus (Deflandre); (2) sample Band 20/19 and (3) sample Band 20/17 (Subspecies M. f. crassus). (4) and (5) Eiffellithus eximius (Stover), sample Band 20/36; (4) x-nicols. (6) and (7) Watznaueria barnesae (Black), sample Band 18/14; (6) x-nicols. (8) and (9) Eiffellithus turrisseiffeli (Deflandre), sample Band 20/17; (8) x-nicols. (10) and (11) Gartnerago obliquum (Stradner), sample Band 20/31; (10) x-nicols. (12) and (13) Glaukolithus diplogrammus (Deflandre), sample Band 20/27; (12) x-nicols. (14) and (15) ?Prediscosphaera cf. poniculata (Bukry), sample Band 18/19; (14) x-nicols.

According to Verbeek (1977), *Lucianorhabdus maleformis* and *Marthasterites inconspicuus* have their first appearance within this zone. Because *Lucianorhabdus maleformis* has not been found within this interval at Nkalagu, *Eiffellithus eximius* has been chosen as index species for the interval before the first appearance of *Marthasterites furcatus*. Therefore, the zonation of Verbeek (1977) is preferred here (compare Fig. 4).

**Marthasterites furcatus zone**  
**Category:** Interval zone.  
**Author:** Cepek and Hay (1969).

**Definition:** Interval from the first appearance of *Marthasterites furcatus* (Fig. 5.2, 5.3) to the first appearance of *Micula decussata* (= *Micula staurophora*: Perch-Nielsen, 1985).  
**Age:** Late Turonian to Coniacian.  
**Remarks:** The base of the *Marthasterites furcatus* zone correlates with the upper part of the *Marginotruncana sigill* (planktonic foraminifera) zone. It contains the entire *Dicarinella primitiva* (planktonic foraminifera) zone and the early part of the *Dicarinella concavata* (planktonic foraminifera) zone (Coniacian: Gebhardt, 2000). The upper boundary of the *Marthasterites furcatus* zone is
not exposed in the Nkalagu quarries. Consequently, species representing the next zone Micula decussata (= Micula staurophora) or Brainsonia lacunosa (see Fig. 4) were not found at Nkalagu. Perch-Nielsen (1985) discussed the definition of the upper boundary of the Marthasterites furcatus zone in detail. In contrast to the upper boundary, the definition of the base of this zone is generally accepted with the typical and easily recognisable species Marthasterites furcatus (Wise, 1988). Many authors working on upper Cretaceous calcareous nannofossils traditionally correlate the base of the Cenomanian with the first appearance of Marthasterites furcatus (e.g. Birkelund et al., 1984; Bralower et al., 1995). This concept does not correspond to the original concept of the Turonian-Coniacian boundary at its type locality close to Cognac. Marthasterites furcatus occurs together with typical Late Turonian ammonites, even before their acmes (Kauffman et al., 1996). Just as at Nkalagu, the first appearance of Marthasterites furcatus is long before the first appearance of the planktonic foraminifera Discinarella primitiva and Discinarella concavata. Marthasterites furcatus occurs also together with Late Turonian inoceramids (Gebhardt, 2000). This opinion (first appearance of Marthasterites furcatus was within the Late Turonian) is supported by Crux (1982), Wise (1988), Cech (1989) or Kauffman et al. (1996).

In addition to species already occurring in the Eiffellithus eximius zone, the following species are present in rocks from the Marthasterites furcatus zone at Nkalagu: ?Prediscosphaera cf. ponticula (Fig. 5.14, 5.15), Lithraphidites pseuodoquadratus, Ceratolithina sp., Corollithion signum, Lucianorhabdus arcuatus and Lucianorhabdus maleformis.

INFLUENCE OF DIAGENETIC EFFECTS AND DISPLACEMENT

Selective dissolution of coccolith parts or certain floral elements can have a considerable influence on the associations found in rock samples. Coccolith assemblages are more influenced by dissolution than by recrystallisation (Roth and Bowdler, 1981). Possible causes for such effects are: low sedimentation rates, sinking below carbonate compensation depth (CCD), or, indirectly, the existence of a mid-water O minimum zone (OMZ) in the ocean (which enhances CO₂ production for carbonate dissolution via sedimentation of organic-rich marine deposits and oxidation of organic C). Black laminated sediments usually contain the worst preserved calcareous nannofossils (Roth and Bowdler, 1981; Roth and Krumbach, 1986; Bralower, 1988). In the case of Nkalagu, the first two possibilities are very unlikely because a high sedimentation rate can be assumed and the CCD in the South Atlantic was around 3200 m water depth during the Turonian-Coniacian period (Sliter, 1977; Roth and Bowdler, 1981; Roth and Krumbach, 1986). Such a water depth was certainly never established at Nkalagu (ratio between planktonic and benthic foraminifera, presence of calcareous microfaunas and nannofloras).

Coccolith species, resistant to dissolution, therefore, dominate calcareous nannofossil associations if preservation is poor. Thierstein (1976), Perch-Nielsen (1985b), Roth and Bowdler (1981), Roth and Krumbach (1986) and Bralower (1988) are listing species resistant to dissolution, some authors even gave a ranking of such species. Generally, Watznaueria barnesae is assumed to be the most resistant species. Further resistant species found at Nkalagu are: Glaukolithus diaphragmus, Marthasterites furcatus, Gartnerago obliquum and Eiffellithus turisellii.

Additional dissolution and recrystallisation events can occur during diagenesis. This can lead to partial or complete destruction of the calcareous nannofossils, e.g. by circulating groundwater or carbonate-free rainwater close to the surface. Dissolution/corrosion and recrystallisation can be observed at the bases of both sections investigated and in the uppermost part of the Band 18 section.

The frequently reported displacement (e.g. Perch-Nielsen, 1985) could not be observed or proven at Nkalagu (with very few exceptions). However, this does not exclude this phenomenon from the Nkalagu samples. The most frequent species, Watznaueria barnesae, is also the most resistant species and occurs since the Jurassic. Therefore, one has to take into consideration the possibility of reworking from older sediments.

PALÆOBIOGEOGRAPHY, PALÆOECOLOGICAL INTERPRETATION AND DISCUSSION

During the ‘Middle’ Cretaceous, the latitudinal temperature gradient was considerably lower than today. There was a broad tropical belt between ca 40°N to 40°S with similar nannoplankton associations, influenced by warm Tethyan waters since the Aptian, while nearly monospecific floras were dominant in high and mid-latitudes, caused by upwelling of cold nutrient-rich waters or low salinities (Roth and Bowdler, 1981; Roth and Krumbach, 1986; Wise, 1988; Wagreich, 1992; Watkins et al., 1998). The floras found at Nkalagu are very similar to those of the Tethys, but show also many similarities to floras from areas further north (compare e.g. Crux, 1982; Wagreich, 1992). In regions far south (Falkland Plateau: Wise, 1988) completely different floral elements dominate, with only Marthasterites furcatus being in common.
The available information (e.g. from DSDP sites) is insufficient for a well-based latitudinal zonation of calcareous nannofossils, in particular for the Coniacian-Santonian interval (Wise, 1988; Wagreich, 1992). For the Mid-Cretaceous South Atlantic, Roth and Bowdler (1981) assume an anti-estuarine circulation system with low O content of the ocean water, driven by evaporation and denser water sinking to the bottom in the equatorial Atlantic area. The surface current direction was, similar to the present, counterclockwise (Fig. 6; see also Roth and Bowdler, 1981; Lloyd, 1982; Roth and Krumbach, 1986; Wise, 1988; Koutsoukos, 1992). In addition to this, Roth and Bowdler (1981), Roth and Krumbach (1986) and Wise (1988) assume an up-welling area along the western coast of Africa (i.e. off Angola; Fig. 6), based on nannofossil distribution patterns.

Although no quantitative analysis was possible because of the relatively low number of fossils, the species can be classified subjectively as (relatively) frequent, few or rare. Species occurring frequently are Watznaueria barnesae, Marthasterites inconspicuus, Marthasterites furcatus, Eiffellithus eximius, Stradneria crenulata, Prediscosphaera spp., Corlolithion signum, Lucianorhabdus arcutus and Lucianorhabdus maleformis. The frequent species are also relatively resistant against dissolution. Selective dissolution has, therefore, to be considered. However, fragile species occur together with more robust species and intensive dissolution can, therefore, be excluded or is restricted to certain intervals (see above; compare also Bischoff and Mutterlose, 1998).

The most frequent species at Nkalagu, Watznaueria barnesae, is interpreted as oceanic species (Roth and Bowdler, 1981; Perch-Nielsen, 1985; Roth and Krumbach, 1986) and has been found most frequently in deep sections (DSDP) or at settings where intermediate water meets the slope. It is rare in nutrient-rich up-welling areas. Contrary to this, Nannoconus spp., Glaucolithus diplogrammus and Lucianorhabdus spp. are interpreted as neritic. These species are, however, rare at Nkalagu. Typical neritic associations should, therefore, be rich in Nannoconus spp. and poor in Watznaueria barnesae (Roth and Bowdler, 1981; Roth and Krumbach, 1986). The situation at Nkalagu is reverse and a relative deep (oceanic) environment without excessive nutrient supply (no upwelling, no monospecific acmes) can be inferred. Also the nannofossil associations of the Deep Ivorian Basin (off Ghana, Ivory Coast) point to low nutrient contents of the surface water at that time (Watkins et al., 1998). The associations are similar to those of Nkalagu (same frequent species) but contain a higher number of species.

**CONCLUSIONS**

Two calcareous nannofossil zones can be distinguished in the Nkalagu quarry sections (type locality of Nkalagu Formation):

i) the *Eiffellithus eximius* zone (Middle Turonian to early Late Turonian); and

ii) the *Marthasterites furcatus* zone (Late Turonian to Coniacian).

The first appearance of *Marthasterites furcatus* indicates the lower boundary of the *Marthasterites furcatus* zone. This boundary is within the Late Turonian, as shown by the first appearance of the index species long before the first appearance of Coniacian planktonic foraminifera and the co-occurrence with Late Turonian inoceramids.

The dominating species *Watznaueria barnesae* points to oceanic environments at Nkalagu for the Middle Turonian to Coniacian interval.

**ACKNOWLEDGEMENTS**

The author is grateful to Nigerian Cement Co. plc. for permission to work at the quarry faces at Nkalagu,
Calcareous nannofossils from the Nkalagu Formation type locality

to a friend and colleague Dr O. J. Ojo (University of Ilorin) for his company during field work and Prof. Dr H. Keupp (Freie Universität Berlin) for his advice and useful comments. J. Feith and U. Schröder (Technische Universität Berlin) assisted with the French résumé. The author thanks Prof. Dr Altermann and an anonymous reviewer for their comments on an earlier version of the manuscript.

This paper is a contribution to IGCP Project 381, South Atlantic Mesozoic Correlations.

More detailed information on frequency and distribution of calcareous nannofossils found at Nkalagu shall be provided upon request by the author.

Editorial handling - W. Altermann

REFERENCES


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