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Turonian and Coniacian Calcareous Nannofossils of the Awgu Formation, Calabar Flank, Southeastern Nigeria

Dedicated to Herbert Stradner (* May 23, 1925) on the occasion of his 95th birthday

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3 Text-Figures, 1 Plate

Calcareous nannofossils
Turonian to Coniacian
Awgu Formation
Calabar Flank
Cross River State
Nigeria

Contents

Abstract

Cretaceous calcareous nannofossils are present in rock samples from the Awgu Formation taken for raw material prospection near Bakoko in Cross River State, southeastern Nigeria. The findings show the presence of Lower Turonian shales with *Lucianorhabdus maleformis* (UC7 Zone), Middle–Upper Turonian shales with *Marthasterites furcatus* and *Eiffellithus eximius* (UC8 Zone), and Lower–Middle Coniacian shales with ?*Micula staurophora* (UC10 Zone) and *Eiffellithus nudus*. The presence of *Gartnerago obliquum* and thoracosphaers indicates shallow sea with close contact with the open sea and *Braarudosphaera bigelowii* points to possible supply of terrestrial material. The revision of an internal report by Stradner and Čepek from 1980 showed that the stratigraphic conclusions are nearly the same.

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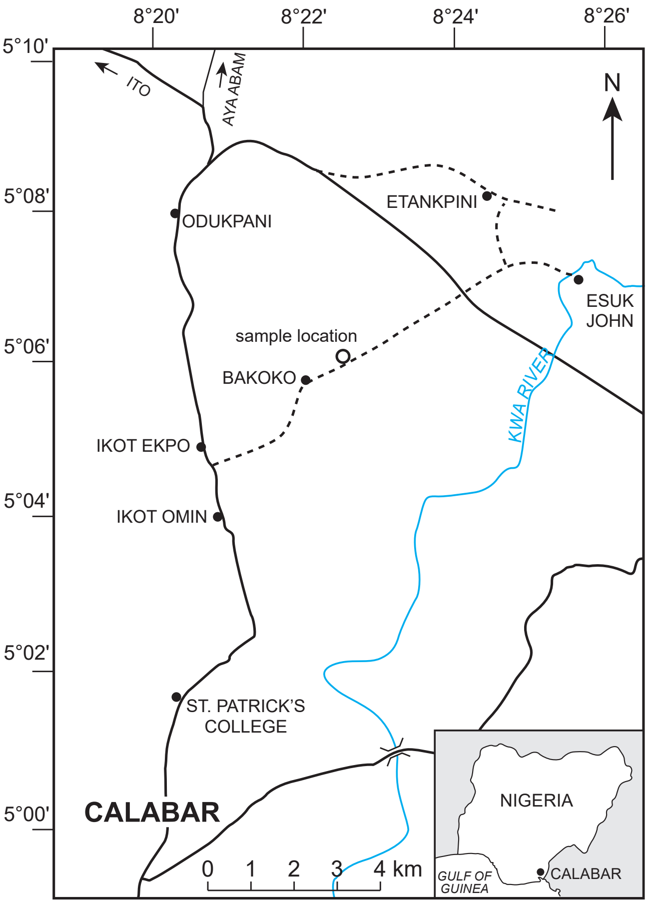
Kalkige Nannofossilien der Awgu-Formation (Turonium und Coniacium), Calabar Flank, Südostnigeria

Zusammenfassung

Es wurde kreidezeitliches kalkiges Nannoplankton aus Gesteinsproben der Awgu-Formation aus der Umgebung von Bakoko in Cross River State, südöstliches Nigeria, untersucht. Die Ergebnisse zeigen das Vorkommen von Tonsteinen des Unteren Turoniums mit *Lucianorhabdus maleformis* (UC7-Zone), des Mittleren bis Oberen Turoniums mit *Marthasterites furcatus* und *Eiffellithus eximius* (UC8-Zone), sowie des Unteren bis Mittleren Coniaciums mit ?*Micula staurophora* (UC10-Zone) und *Eiffellithus nudus* an. Das Vorkommen von *Gartnerago obliquum* und Thoracosphaeren deutet auf flaches Wasser sowie die Nähe zum offenen Meer, und das von *Braarudosphaera bigelowii* auf die mögliche Zufuhr von terrestrischem Material hin. Die Revision eines internen Berichts von Stradner und Čepek aus dem Jahr 1980 zeigt, dass die stratigrafischen Schlussfolgerungen nahezu gleich geblieben sind.

Introduction

The samples described in this paper were collected in 1976 in the course of cement raw material prospecting by Harry Lobitzer in close cooperation with the geologists from the Calabar Cement Company (Calcemco). Special focus of these extensive field investigations was put not only on limestone, but also on supplementary industrial rocks suitable for cement production, such as sand, clay, marl, shale, bauxite and lateritic soils. These commodities supply the bulk of the silica, alumina and ferric oxide for blending of the raw meal for the desired cement-clinker composition, which in practice is determined by the locally available raw materials. Claystones from the Cenomanian Eze-Aku and Turonian–Coniacian Awgu formations were geochemically and micropalaeontologically examined. The subject of this paper is the revision of the nannofossil stratigraphy, which was reported internally by Stradner & Čepek (1980).



Text-Fig. 1.
Location of Bakoko village in Cross River State, southern Nigeria. Sketch map based on Directorate of Overseas Surveys (1966).

Geological setting

On the so-called “Calabar Flank” sensu Murat (1972), which extends along the southern slopes of the Precambrian crystalline basement complex of the Oban Hills, sedimentation started in the Aptian with limnic fluvio-deltaic clastic sediments of the Awi Formation (Adeleye & Fayose, 1978). The Oban Hills acted as a source area of sediments for the Calabar Flank, which structurally is part of the foundered southeastern Nigerian continental margin, respectively constitutes the southernmost part of the Benue Trough (Benkhelil et al., 1989).

As a consequence of the opening of the South Atlantic Ocean – hand in hand with the separation of South America from Westafrica, on the Calabar Flank shallow marine carbonatic sedimentation started in the middle Albian with the establishment of the “Mfamosing Limestone carbonate platform” sensu Kennedy et al. (2019). The Mfamosing Limestone carbonate platform survived until the Albian/Cenomanian boundary, when it was abruptly terminated by the development of a hardground and omission surface. The Mfamosing Limestone (Oti & Koch, 1990; Reijers, 1998; Reijers & Petters, 1987; a.o.) in the closer surroundings of the old Mfamosing limestone quarry is overlain by well bedded grey shales, silty-sandy shales and more rarely greyish-buff calcareous sandstones of the Eze-Aku Formation and the conformable overlying Awgu Formation. The Campanian–Maastrichtian Nkporo Shales cap the Cretaceous marine sequence of the Calabar Flank. A modern overview of Late Cretaceous stratigraphy and palaeogeography of Nigeria is presented by Edegbai et al. (2018).

At the sampling area near Bakoko (Text-Fig. 1), alternating beds of predominantly fine clastic grey shales, silty-sandy and more rarely brownish or greyish-buff calcareous sandstones dip with 215/09. Some of the numerous exposures of these fine-clastic sediments probably belong to the Cenomanian Eze-Aku Formation. However, all the samples described here belong to the conformably overlying Awgu Formation (Text-Fig. 2). Only at the sample point Bakoko 4 conspicuous macrofaunistic elements could be observed, namely shell debris of the thick prismatic layer of the epibenthic pelecypod *Inoceramus* and very scarce poorly preserved ammonite casts. In some coarser grained sandstone intercalations, also pyrite is present in variable

Text-Fig. 2.
The photograph shows the approximately 6 m thick outcrop of the Awgu Formation of sample point Bakoko 4. Use airline bag as scale.

amounts and the beds have an intense bituminous odour. In the washing residues, planktic foraminifera and subordinately ostracods and fish-teeth are present.

The Awgu Shales and the underlying Eze-Aku Shales can be merged to the Nkalagu Formation (Petters & Ekweozor, 1982). However, in all samples from both the Cenomanian Eze-Aku Shales and the Odukpani Formation the characteristic foraminifer *Thomasinella punica* is omnipresent in the coarse grained washing residues. This occurrence is probably the first proof of this species for Nigeria (Kennedy et al., 2019; Kennedy & Lobitzer, 2019). The first published record of calcareous nannofossils from southern Nigeria is the paper of Perch-Nielsen & Petters (1981).

Previous study: the report of Stradner & Čepek (1980)

In 1976, Herbert Stradner processed and studied, probably without any separation method, more than 150 smear slides of clays and marls from the wider surroundings of the (old) Mfamosing Limestone Quarry. While all the preparations of the Cenomanian Eze-Aku Formation were found to be barren of calcareous nannofossils, they could be detected in three samples of the Awgu Formation, marked as Bakoko 2, Bakoko 3 and Bakoko 4. In 1980, Stradner, assisted by Pavel Čepek from the Bundesanstalt für Geowissenschaften und Rohstoffe in Hannover, Germany, studied the samples again. An internal report was prepared (Stradner & Čepek, 1980), which is now revised in the present paper.

Material and methods

Material

The scattered clay outcrops consist of well bedded clastic sediments of the Awgu Formation, which are exposed along a bush track about half an hour´s walk to the NE of Bakoko village, which is located at latitude 5°05’41”N, longitude 8°22’15”E, about 10 km ESE of Odukpani village, or about 13 km NE of Calabar, the capital of Cross River State in southeastern Nigeria (Text-Fig. 1). Field sampling points were relatively easy to localize on the topographic map (sheet 323 Uwet S.E., Directorate of Overseas Surveys, 1966). Climbing down a few meters from a terrain terrace to a heavily damaged concrete bridge, before entering a swampy plain in the rainforest, served as a topographical fixed point for localizing the outcrops.

Methods

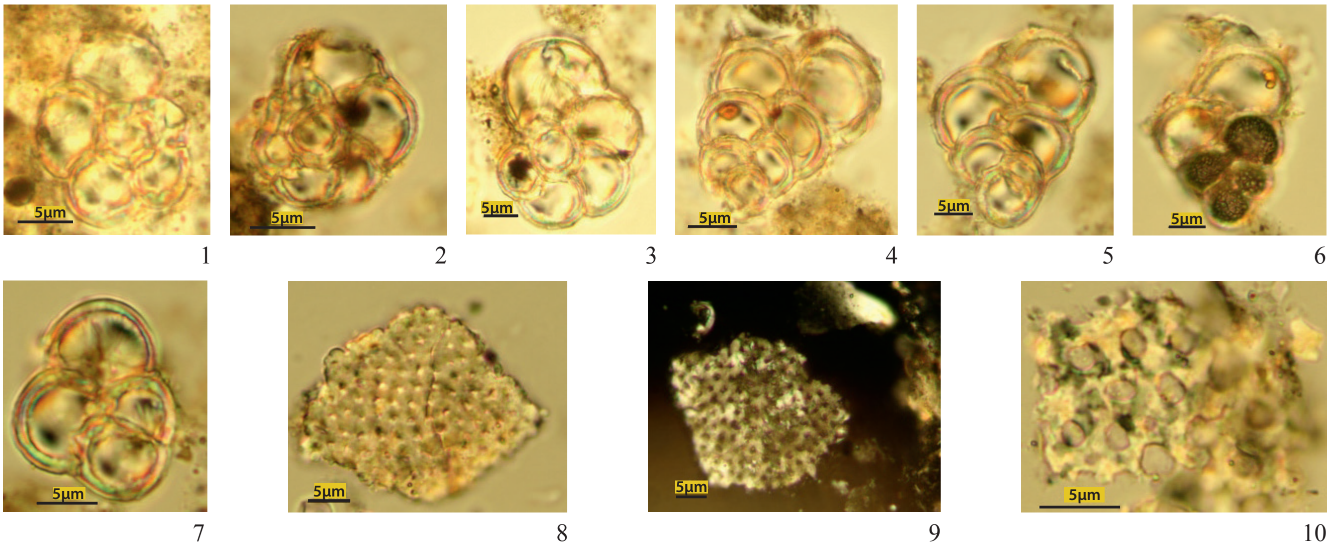
Herbert Stradner processed smear slides probably without any separation method. For this revision study, these original smear slides marked as Bakoko 2, Bakoko 3 and Bakoko 4 were observed under a Nikon Microphot-FXA transmitting light microscope with immersion objectives of ×100 magnification. Photodocumentation was made by digital camera Nikon DXM1200F using SW ACT-1. Smear slides are kept in the collections of the Geologische Bundesanstalt in Vienna under the acquisition numbers GBA 2020/003/0001, GBA 2020/003/0002 and GBA 2020/003/0003.

The species identification follows Burnett (1998) and Nannotax website (Young et al., 2018). Biostratigraphic data were interpreted with the reference to nannofossil zonations of Burnett (1998, Upper Cretaceous UC Zones). The following abbreviations were used in the text: FO = the first occurrence of taxon, LO = the last occurrence of taxon, FVM = field of view of the microscope.

Results

Sample Bakoko 2

Mostly fragmented calcareous nannofossils in abundances of 1–2 specimens in 10 FVM were found in the fine particles of predominantly inorganic material. Fragments of *Gartnerago obliquum* quantitatively prevail over *Watznaueria barnesiae*. Outer rims of other coccoliths such as genus *Prediscosphaera* and small unidentifiable nannofossils with a diameter of ± 1–2 μm were also present. In addition, presumably the juvenile stages of planktonic foraminifers (size 5 to 15 μm) were rarely present.



Text-Fig. 3.
Foraminifera and macrofossil elements found in smear slides. **1–3.** *Muricohedbergella* sp. (probably *M. delrioensis*). **4–6.** *Heterohelix* sp. **6.** with framboidal pyrite in early chambers. **7.** Foraminifera, genus not classifiable. **8–10.** Echinoderm fragments (sclerites). **10.** probably holothurian sclerite (sea cucumber).

The following species were identified: *Broinsonia enormis, Calculites ovalis, Chiastozygus litterarius, Discorhabdus ignotus, Eiffellithus perch-nielseniae, Eiffellithus* sp. (central fields strongly etched), *Gartnerago obliquum, Lucianorhabdus maleformis, Manivitella pemmatoidea* (fragments), *Microrhabdulus decoratus, Octolithus* sp., *Prediscosphaera columnata* (outer rims), *P. cretacea, Prediscosphaera* sp. (fragments of the outer rims), *Thoracosphaera* sp., *Watznaueria barnesiae, W. biporta, Zeugrhabdothus diplogrammus, Z. praesigmoides, Zeugrhabdothus* sp. (small specimens with a diameter 1–2 µm).

Sample Bakoko 3

The smear slide contains particles of mainly inorganic origin of various sizes. Calcareous nannofossils occur with 3–12 specimens in 10 FVM and are mostly fragmented. The assemblage is characterized by relative abundant *Gartnerago obliquum* (partly fragmented) and by the genera *Watznaueria* and *Eiffellithus.* Outer rims of the genera *Prediscosphaera*, *Zeugrhabdotus, Eiffellithus,* etc. are present. One questionable specimen of *Micula staurophora* was detected. High number of juvenile stages and fragments of adult tests of planktic foraminifers are present.

The following species were identified: *Ahmuellerella octoradiata, Braarudosphaera bigelowii parvula, Corollithion signum, Cretarhabdus conicus, Eiffellithus eximius, E. nudus, E. perch-nielseniae, Gartnerago obliquum, Helicolithus trabeculatus, Lucianorhabdus maleformis, Manivitella pemmatoidea* (fragment), *Marthasterites furcatus, Microrhabdulus decoratus,* ?*Micula staurophora, Placozygus fibuliformis, Prediscosphaera columnata, P. cretacea, P. spinosa, Retacapsa surirrela, Rhagodiscus angustus, Thoracosphaera* sp., *Watznaueria barnesiae, W. biporta*, *Zeugrhabdotus diplogrammus, Z. scutula.*

Sample Bakoko 4

Poorly preserved and mostly fragmented calcareous nannofossils occur in abundances with 1–3 specimens/10 FVM were found within particles of inorganic origin. The assemblage is characterized by small specimens (3–6 µm) including relative abundant and also small *Gartnerago obliquum*. Compared to sample Bakoko 3, the number of *Lucianorhabdus maleformis* is significantly lower. On the contrary, *Marthasterites furcatus* is relative abundant. Probably juvenile stages of planktic foraminifers (size 5 to 25 µm) are rarely present.

The following species were identified: *Biscutum* sp., *Braarudosphaera bigelowii bigelowii, Broinsonia enormis, B. signata, Chiastozygus litterarius, Discorhabdus ignotus, Eiffellithus eximius, E. perch-nielseniae* (fragment), *Gartnerago obliquum, Helicolithus trabeculatus, Lucianorhabdus maleformis, Marthasterites furcatus, Microrhabdulus decoratus, Octolithus multiplus, Placodiscus fibuliformis, Prediscosphaera cretacea, Retacapsa crenulata, Rhagodiscus angustus, R. splendens, Staurolithites crux, Thoracosphaera* sp., *Watznaueria barnesiae, Zeugrhabdotus diplogrammus*.

Foraminifera and macrofaunal elements

In the smear slides, also planktic foraminifera and skeletal elements of macrofossils were found (Text-Fig. 3). Planktic foraminifera include *Muricohedbergella* sp. (most likely *M. delrioensis*) and *Heterohelix* sp. Foraminiferal chambers may contain framboidal pyrite (Text-Fig. 3.6). Found macrofaunal elements are sclerites of echinoderms, some of them likely from holothurians.

Biostratigraphic results

The nannofossil record is different in each of the three Bakoko samples. The assemblages were secondarily depleted. Particularly the presence of *Eiffellithus nudus* in Bakoko 3 and the relatively abundant *Marthasterites furcatus* in Bakoko 4 had to be taken into account in the stratigraphic interpretations. Calcareous nannofossils indicate the following relative ages of the investigated deposits (from basis to top):

Bakoko 2: Lower Turonian (upper part) with *Lucianorhabdus maleformis*, UC7 Zone.

Bakoko 4: Middle–?Upper Turonian with *Marthasterites furcatus* and *Eiffellithus eximius*, UC8 Zone. The FO of *M. furcatus* in South England (lower latitudes; Burnett, 1998) correlates within the lower part of UC9a Zone, Middle–Upper Turonian. Nevertheless, the marker species of this zone was not found. The relative age is supported by *Placozygus fibuliformis* with its FO in the Upper Turonian (Young et al., 2018).

Bakoko 3: Lower–Middle Coniacian with ?*Micula staurophora* (Pl. 1, Figs. 27, 28), UC10 Zone. The Coniacian Stage is indicated not only by one problematic specimen of *M. staurophora*, but also by *Eiffellithus nudus* (Pl. 1, Figs. 11–14) with its FO in the Coniacian (Shamrock & Watkins, 2009).

Discussion

40 years since the report of Stradner & Čepek

When reading the Stradner & Čepek (1980) text, we have to take into account that samples were studied forty years ago and conclusions correspond to the knowledge at that time. Since 1980, many new nannofossil taxa have been described. The stratigraphic ranges of nannofossil markers were refined and correlated with other fossil groups. New nannofossil zones have been defined that more precisely determine the relative age of the Upper Cretaceous sediments (Sissing, 1977; Perch-Nielsen, 1985; Burnett, 1998). For the nearby Lower Benue Trough, Gebhardt (2001) suggested a zonation for the Turonian to Coniacian sediments for the Nkalagu Formation. Since 1980, nannofossil evolution lineages, such as the Polycyclolithaceae (Varol, 1992), including the lineage *Quadrum-Micula* or of the genus *Eiffellithus* (Shamrock & Watkins, 2009), have been published.

Based on their observations, Stradner & Čepek (1980) stratigraphically correlated sediments from Bakoko with the *Eiffellithus eximius* nannoplankton zone of Verbeek (1976) which ranges from the uppermost Turonian to Lower Coniacian. They took into account the finding of poorly preserved specimens of "*Tetralithus pyramidus*" sensu Roth & Bowdler (1979) and interpreted them as morphotypes of *Micula staurophora*. Therefore, they mentioned also the nannoplankton zone *Tetralithus pyramidus* of Čepek & Hay (1969) as the interval from the FO of *T. pyramidus* to the *FO of Marthasterites furcatus*. In the 1970s, the FO of *Micula staurophora* was correlated with the Upper Turonian and the FO of *M. furcatus* with the Upper Coniacian (see Stradner & Čepek 1980).

With respect to Polycyclolithaceae, only one specimen of a questionable *Micula staurophora* was found in Bakoko 3 (Pl. 1, Figs. 27, 28). Like Stradner & Čepek in 1980, after forty years there are doubts as to whether it is really *M. staurophora*. It should be noted that no marker species of zone UC9 were found, which spans the interval from the upper Middle Turonian up to the base of the Middle Coniacian.

The revision of calcareous nannofossils from the same smear slides prepared by Herbert Stradner in 1976 and presented by Stradner & Čepek in an unpublished report in 1980, showed that the stratigraphic conclusions are very similar to ours.

Palaeoenvironmental interpretations

As the results by Herbert Stradner demonstrated, all samples of the Cenomanian Eze-Aku Shales from the wider surroundings of the Mfamosing quarry and also from the Mid-Cenomanian Odukpani Formation along the Odukpani–Itu highway, were barren of calcareous nannofossils (see Kennedy et al., 2019; Kennedy & Lobitzer, 2019). Apparently, calcareous nannofossils in the sedimentary sequence of the Calabar Flank probably occurred not earlier than in the Turonian to Coniacian Awgu Shales. This is similar to the situation in the Lower Benue Trough where calcareous nannofossils were not reported before the Turonian (Gebhardt, 2001).

Palaeo-water depth estimations for the Awgu Formation changed during the last decades. In the adjacent Lower Benue Trough, estimations based on benthic foraminiferal assemblages and intercalated calcarenites and bioturbated shallow-water sandstones were in the range of 30 to 50 m (Petters, 2014; Petters & Ekweozor, 1982). However, new studies re-interpreted the sedimentary facies of the central parts (Nkalagu area) as deep-water shales and turbitite systems with upper bathyal palaeo-water depths of 200 to 400 m (Oti, 1990; Gebhardt, 2001, 2004; Gebhardt et al., 2020). Long-term sea-level changes were attributed to 405 Kyr eccentricity cycles (Gebhardt et al., 2020).

Because of similar sedimentological parameters and nearly identical microfossil assemblages with the Lower Benue Trough, also outer neritic to upper bathyal depositional environments could be assumed for the Turonian to Coniacian Awgu Formation of the Bakoko area. However, the presence of *Gartnerago obliquum* (Pl. 1, Figs. 22, 23) and thoracosphaers in the investigated samples point to a shallow sea but with close contact with the open sea. *Braarudosphaera bigelowii* (Pl. 1, Figs. 29, 30, 35, 36) may indicate supply of terrestrial material from nearby land. The restricted marine species *Watznaueria barnesiae* (Pl. 1, Fig. 19) is not dominating the nannofossil assemblages at Bakoko, a fact that supports the proximity of land at the time of deposition (see e.g., Perch-Nielsen; 1985; Roth & Bowdler, 1981; Roth & Krumbach, 1986 for ecologic preferences of calcareous nannoplankton species).The area occasionally attained anoxic levels at least in the porewater of the sediment, as presence of framboidal pyrite in some foraminiferal chambers suggests (e.g., Wilkin et al., 1997; Wignall & Newton, 1998; Text-Fig. 2.6).

Conclusions

This study of calcareous nannofossils in the same smear slides prepared by Herbert Stradner in 1976 (Stradner & Čepek, 1980) showed that the stratigraphic conclusions are nearly the same. This shows clearly the high professional erudition, skills and foresight of both experts. The study of nannofossils has received a great deal over the last forty years: dozens of new species have been described, attention has been focused on the nannofossil phylogeny and the data correlated with macro-, micro- and chronostratigraphic information. All this contributed to the definition of new nannoplankton zones, which made stratigraphic correlations more precise.

The stratigraphic and palaeoenvironmental conclusions of Stradner & Cepek (1980) and this review work are similar: Bakoko 2: Lower Turonian with *Lucianorhabdus maleformis*, UC7 Zone. Bakoko 3: Lower–Middle Coniacian with ?*Micula staurophora,* UC10 Zone. The Coniacian stage is indicated also by *Eiffellithus nudus* (sensu Shamrock & Watkins, 2009). Bakoko 4: Middle–Upper Turonian with *Marthasterites furcatus* and *Eiffellithus eximius*, UC8 Zone. The presence of *Gartnerago* *obliquum* and thoracosphaers indicates a shallow sea with close contact with the open sea and *Braarudosphaera bigelowii* draws attention to the possible supply of terrestrial material.

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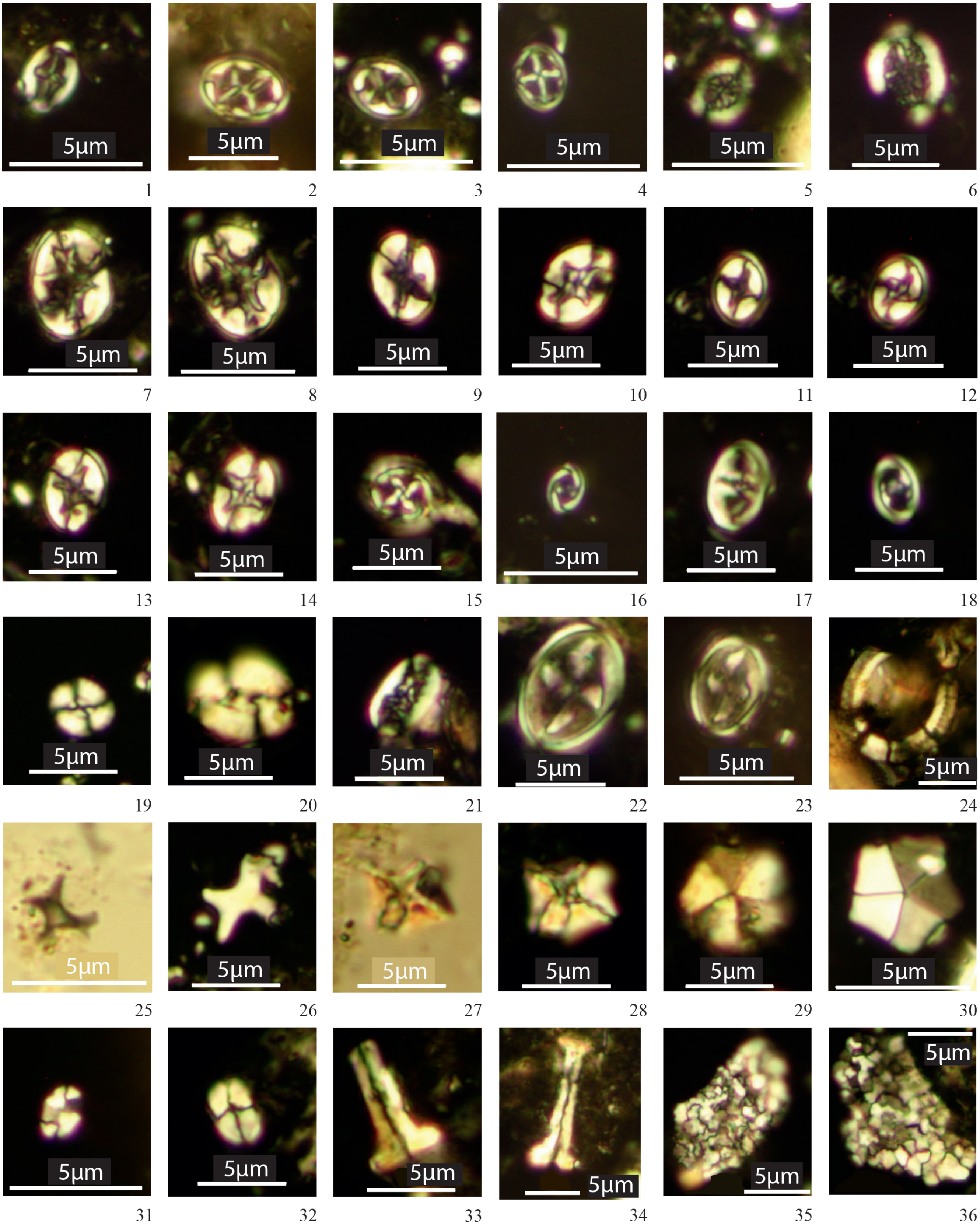
Plate 1

Calcareous nannofossils from the localities Bakoko 2, 3 and 4. Cross-polarized light, Figs. 25 and 27 in plane-polarized light.

Fig. 1: *Broinsonia signata*, Bakoko 4.
Figs. 2, 3: *Helicolithus trabeculatus*, Bakoko 3.
Fig. 4: *Staurolithites crux*, Bakoko 4.
Fig. 5: *Retacapsa* sp., Bakoko 4.
Fig. 6: *Cretarhabdus conicus*, Bakoko 3.
Figs. 7–10: *Eiffellithus eximius*. **7, 8:** specimen in 0° and 15°. **9, 10:** specimen in 0° and 30°, Bakoko 3.
Figs. 11–14: *Eiffellithus nudus*. **11, 12:** specimen in 0° and 15°. **13, 14:** specimen in 0° and 15°, Bakoko 3.
Fig. 15: *Prediscosphaera cretacea*, Bakoko 3.
Fig. 16: *Placolithus fibuliformis*, Bakoko 4.
Fig. 17: *Zeugrhabdotus diplogrammus*, Bakoko 4.
Fig. 18: *Zeugrhabdotus praesigmoides*, Bakoko 2.
Fig. 19: *Watznaueria barnesiae*, Bakoko 3.
Fig. 20: *Watznaueria biporta*, Bakoko 2.
Fig. 21: *Rhagodiscus* sp. Bakoko 2.
Figs. 22, 23: *Gartnerago obliquum*. **22:** Bakoko 2. **23:** Bakoko 3.
Fig. 24: *Manivitella pemmatoidea*, Bakoko 3.
Figs. 25, 26: *Marthasterites furcatus*, Bakoko 4.
Figs. 27, 28: ?*Micula staurophora*, Bakoko 3.
Fig. 29: *Braarudosphaera bigelowii bigelowii*, Bakoko 3.
Fig. 30: *Braarudosphaera bigelowii parvula*, Bakoko 4.
Fig. 31: *Octolithus multiplus*, Bakoko 4.
Fig. 32: *Calculites ovalis*, Bakoko 2.
Figs. 33, 34: *Lucianorhabdus maleformis*, Bakoko 3.
Figs. 35, 36: *Thoracosphaera* sp., Bakoko 3.


5µm
1 2 3 4 5 6
7 8 9 10 11 12
13 14 15 16 17 18
19 20 21 22 23 24
25 26 27 28 29 30
31 32 33 34 35 36

Appendix

Calcareous nannofossils mentioned in the text in alphabetical order of genera

Ahmuellerella octoradiata (Górka) Reinhardt

Braarudosphaera bigelowii bigelowii (Gran & Braarud) Deflandre

Braarudosphaera bigelowii parvula Stradner

Broinsonia enormis (Shumenko) Manivit

Broinsonia signata (Noël) Noël

Calculites ovalis (Stradner) Prins & Sissingh

Chiastozygus litterarius (Górka) Manivit

Corollithion signum Stradner

Cretarhabdus conicus Bramlette & Martini

Discorhabdus ignotus (Górka) Perch-Nielsen

Eiiffellithus eximius (Stover) Perch-Nielsen

Eiffellithus nudus Shamrock

Eiffellithus perch-nielseniae Shamrock

Gartnerago obliquum (Stradner) Noël

Helicolithus trabeculatus (Górka) Verbeek

Lucianorhabdus maleformis Reinhardt

Manivitella pemmatoidea (Deflandre) Thierstein

Microrhabdulus decoratus Deflandre

Micula staurophora (Gardet) Stradner

Octolithus multiplus (Perch-Nielsen) Romein

Placozygus fibuliformis (Perch-Nielsen) Romein

Prediscosphaera columnata (Stover) Perch-Nielsen

Prediscosphaera cretacea (Arkhangelsky) Gartner

Prediscosphaera spinosa (Bramlette & Martini) Gartner

Retacapsa surirrela (Deflandre & Fert) Grün

Rhagodiscus angustus (Stradner) Reinhardt

Rhagodiscus splendens (Deflandre) Verbeek

Staurolithites crux (Deflandre & Fert) Caratini

Watznaueria barnesiae (Black) Perch-Nielsen

Watznaueria biporta Bukry

Zeugrhabdothus diplogrammus (Deflandre) Burnett

Zeugrhabdotus praesigmoides Burnett

Zeugrhabdotus scutula (Bergen) Rutledge & Bown