Cretaceous foraminiferal biostratigraphy and palaeoecology of Ikono-1 Well, Calabar Flank, southeastern Nigeria

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Abstract

The Cretaceous sediments in Ikono-1 Well, Calabar Flank, consist of a sequence about 1,878 m thick of calcareous sandy shale (Uppermost Mfamosing limestone Formation) at the base, overlain by continuous alternating sequence of black to dark and light grey shales with sandstone (Nkporo Shale) and calcareous black fissile shale (Nkporo Shale) at the top. The sediments are fossiliferous and were deposited in a shallow inner neritic environment of less than 50 m depth. Two marine transgressions were recognized, the Cenomanian-Turonian and Early Senonian transgressions.

The Cenomanian is recognized by the presence of Hedbergella delrioensis, Hedbergella planispira, Rotalipora baliernaensis, Trochammina sp. and Dorothis oxyinoa, while the Turonian-Santonian stage is characterized by the abundance of Heterohelix reussi, Heterohelix ultimatumida, Praebulimina fang, Gavelinella guineana, Nonionella robusta and Whithebelum baltica. Foraminifera indicative of Late Santonian-Early Campanian were not recovered, thus a period of erosion and/or non-deposition is suggested. Diagnostic species of Campanian-Maastrichtian age (Nkporo shale) are Globotruncana gansari, Afrobolivina afr, Bulimina brevispera, and Globigerinoides multispinatus.

Introduction

Earliest biostratigraphic studies of the Calabar Flank were conducted by Reyment (1956a, 1956b, 1965) and Dressauvage (1965). Reyment (1956a) used ammonites to assign a Cenomanian age to the lower part and a Turonian age to the upper part of the Odukpani type section. The Cenomanian age assigned to the lower limestone (M famosing limestone) at Odukpani was later supported by Dressauvage (1968) and Fayose (1979) using foraminiferal evidence. Fayose (1978) already pointed out that the basal arenaceous member of the Odukpani Formation is both petrologically and structurally correlateable with M amfe Formation of Albian age. The M famosing limestone was however dated more accurately as Albian age using ammonites (Forster and Schulz, 1979) and foraminifera (Nair et al., 1981; Petters, 1982). Nair et al., (1981) found that the M famosing Limestone is devoid of foraminifera but pointed out that the underlying shale contains Late Albian to Earliest Cenomanian planktonic foraminiferal assemblage. Hence, they asserted that the underlying limestone is not younger than Late Albian. Iwobi (1989) also confirmed Albian-Cenomanian age for the M famosing limestone using the occurrence of Globigerinoides caseyi and Rotalipora baliernaensis.

Fayose and De Klasz (1976), working on the carbonate/shale sequence of the Eze-Aku Shales, exposed at the Nkalagu limestone quarry in Lower Benue Trough, found abundant species of Heterohelix and Hedbergella suborder and some ostracodes such as Brachycythere, Ovocythereida and Paracypsis which gave a Lower Turonian age. Petters (1980) also, used Hedbergella planispira; Heterohelix moremani; Guembelitria harris and Praebulimina fang assemblages found in the Nkalagu Formation to assign a Turonian age to the Eze-Aku Shales. This agrees with the Early Turonian ammonite age given by Offodile and Reyment (1976). The Awgu Shales exposed in this area was also dated and assigned Late Turonian - Early Coniacian age.

Odebode and Skarby (1980) and Odebode (1982) carried out foraminiferal studies of outcrop samples along Calabar-Itu highway and established Santonian - Campanian age for the lower part of the Nkporo Shale using the species of the suborder Rugoglobigerina, Heterohelix, Ventilabrella, Globotruncana and Gabonita. In his review, Iwobi (1989) considered this dating as inaccurate as it was based on long-ranging Heterohelicids. However, more accurate dating for the Nkporo shale was presented by Nyong and Ramanathan (1985) and K. umaran and Ramanathan (1986) using species of Heterohelix reussi, Globotruncana fornicata, G. trincanata and Rugoglobigerina sp. to assign Late Campanian age for the lower part of the Nkporo Shale, while the upper part was dated Maastrichtian based on the presence of Bolivina afr, Gabonita dongata, Gabonita lata and Praebulimina bantu. The Maastrichtian age agrees with the works of Reyment (1968) and Petters (1980) using ammonite and foraminifera assemblages respectively.

Ikono-1 well was drilled in 1959 by Shell D’Arcy (now Shell Petroleum Development Company of Nigeria) as an oil exploratory well on the Calabar Flank, located on the southeastern part of the Benue Trough (Fig. 1). Geographically, the well lies on longitude 5°7’N and latitude 7°47’E and was drilled to a maximum depth of 3,359 m (11,020 ft) at a sampling rate of 12 m (40ft). This study identifies the Cretaceous planktic and benthic foraminifera species in Ikono-1 Well in order to determine the ages of the Mesozoic rock sequences penetrated by this well and the result compared with the existing stratigraphy of the Calabar Flank. Foraminiferal fauna association will also be used to determine the depositional environments of the rock sequence.
Megatectonic framework and geology of the Calabar Flank

The term Calabar Flank was first introduced by Murat (1972) as that part of the southern Nigerian sedimentary basin, which is bordered by the Precambrian Oban Massif in the north and the Recent Niger Delta in the south (Fig. 2). The Afikpo syncline marks the northwestern limit while the Cameroon volcanic ridge bounds it in the east. The origin of the Flank is associated with the break-up of South America from Africa during the opening of the Gulf of Guinea in the Mesozoic.

Tectonically, the geologic history of southern Nigeria has been controlled by three major tectonic phases (Murat, 1972). These tectonisms, resulted in the displacement of the axis of the main basins giving rise to three successive basins in which Calabar Flank is one. The Calabar Flank is a hinge zone (Fig. 2) which consists structurally of NW-SE trending basement horsts (the Oban Massif and the Ituk high), separated by a graben-the Ikang Trough (Petters and Reijers, 1987). These basement horst and graben structures as well as eustatic sea-level changes controlled the Mid-Cretaceous sedimentation in the basin (Nyong and Ramanathan, 1985).

Sedimentary succession of southeastern Nigeria is marked by a series of marine transgressions and regressions. In the Calabar Flank, the Asu River Group begins with a medium to very coarse, often pebbly, poorly sorted, arkosic cross-stratified sandstone (Adeleye, 1975). This basal sandstone was later called the Awi Formation (Adeleye and Fayose, 1978), forming the basal sands of the Odukpani Formation of Reyment (1965). The Awi Formation unconformably overlies the weathered granites, schists, migmatites and gneisses of the Precambrian Basement Complex (Oban Massif). The Awi Formation is devoid of fauna but was assigned an Albian age based on its correlation with the Mamfe Formation in the Cameroons (Adeleye and Fayose, 1978). Overlying the Awi Formation is the carbonate sequence of the Mfamosing limestone with sandstones and shales that were deposited during the Cenomanian regression in the Calabar Flank (Nwachukwu, 1972). The lower Limestone beds of Odukpani Formation of Reyment (1965) and the Mfamosing Limestone described by Petters and Ekwette (1982) are the same (Fig. 3). The limestone is sandy and has alternating shale beds at the top (Fayose, 1978) with type sections at Abini and Mfamosing quarries.
Fig. 2. Structural elements of the Calabar Flank and adjacent areas (after Nyong and Ramanathan, 1985)

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Fig. 3. Different views on the ages of Cretaceous sediments in the Calabar Flank
Lithostratigraphy was done by inspecting and identifying lithologic and biostratigraphic analysis. The samples, retrieved from Ikono-1 well were subjected to a total of two hundred and seventy two (272) ditch cutting Materials and methods (Fig. 3).

Regarding the nomenclature of the stratigraphy of this region and there is no consensus of opinion amongst workers with regard to the Calabar Flank is filled with Cretaceous to Recent sediments. From the above discussions, in the Tertiary-Recent continental sands of the Benin Formation, which persisted in some parts of the Calabar Flank brought maestrichtian – lower Paleocene time, this led to the occurrence has been reported in the Ikang Trough, between the Oban Massif and the Ituk High (Whiteman, 1982). The Nkporo Shale consists of dark shales and sandstone and has been assigned a Campanian-Maestrichtian age by Petters and Ekweozor (1982) proposed the name Nkalagu Formation to replace the upper shaly part of Odukpani, Eze-Aku and Awgu Shales (Fig. 3). According to them, all the limestones, shales and the inter-fingerling regressive sandstones (M akurd, A gala, A masiri and A gbani Sandstones) of the Cenomanian-Early Santonian age belong to the N kalagu Formation which is bounded at the bottom by the Early Cenomanian and at the top by the Late Santonian unconformities. Petters and Ekweozor (1982) proposed the Cross River Group for the Cenomanian-Early Santonian sequence while the Pre-Albian – Albian sequences still belong to the A su River Group of Reyment (1965).

After the Santonian-Campanian deformation, marine sedimentation resumed and the Nkporo shale was deposited as the first set of clastic sediments on the Flank. Its occurrence has been reported in the Ikang Trough, between the Oban Massif and the Ituk High (Whiteman, 1982). The Nkporo Shale consists of dark shales and sandstone and has been assigned a Campanian-Maestrichtian age by Reyment (1965). Cox (1952) used mollusks and fish remains from corehole samples to assign a M aestrictian age to the Nkporo Shale, which is in line with the works of Yong and Ramanathan (1985) and K umaran and Ramanathan (1986). Nkporo Shale can therefore be said to cap the Cretaceous sequence of the Calabar Flank. Repeated periods of erosion and/or non-deposition occurred during Upper M aestrictian – Lower Paleocene time, this led to the paucity of outcrops of Nkporo Shale on the Flank. However, the Late Eocene witnessed a regressive phase which persisted in some parts of the Calabar Flank brought in the Tertiary-Recent continental sands of the Benin Formation (Reyment, 1965). From the above discussions, Calabar Flank is filled with Cretaceous to Recent sediments and there is no consensus of opinion amongst workers with regard to the nomenclature of the stratigraphy of this region (Fig. 3).

Materials and methods
A total of two hundred and seventy two (272) ditch cutting samples, retrieved from Ikono-1 well were subjected to lithologic and biostratigraphic analysis. The lithostratigraphy was done by inspecting and identifying the different rock type in each sample bag. For biostratigraphic analysis, the samples were disaggregated by boiling with anhydrous sodium carbonate and water in a sample bowl. Boiling was allowed to continue until the rock showed signs of complete disintegration. Highly indurated rock samples were crushed to smaller sizes before boiling. Disaggregated samples were wet-sieved through a clean 200 mesh (75µ) sieve under a gentle jet of water from the tap. All materials trapped on the sieve were filtered and dried overnight in an oven at 50°C. The dried samples were sieved through 20, 40 and 60 mesh sizes and were picked for foraminiferal analysis.

Results and discussion

Lithostratigraphy of Ikono-1 Well
The lithostratigraphy of the Cretaceous portion of the Ikono-1 well is shown in Fig. 4. Cretaceous sediments penetrated by this well range from 1481 m to the bottom at 3359 m. Three distinct lithologic units were recognized consisting of shale, coarse to fine grained sandstone and basal calcareous sandy shale.

Unit 1: (1,481-1,660 metres, fissile shales)
The Nkporo Shale (Campanian-Maestrichtian) which is about 179 m thick capped the Cretaceous sediments penetrated by Ikono-1 well and was initially recognized by its characteristic black fissile shale with a thin bed of limestone at the base (Kumar and Ramanathan, 1986).

Unit 2: (1,660-3,260 metres, black shales)
Underlying the Nkporo Shale is a thick continuous alternating sequence of grey to black shales with intermediate limestone beds. The shale beds grade from medium to coarse-grained sandstone and siltstone at the top. Throughout this unit, volcanic fragments were observed in all the samples examined and at certain interval (3,010-2,410 m) a thick band of igneous rock fragments predominate (Fig. 4).

Unit 3: (3,260-3,359 metres, shale with igneous rock fragments)
This unit is about 99 m thick, marking the base of Ikono-1 well. It consists of calcareous black sandy shale with minor igneous rock fragments. The contact with the basement is not seen in this unit as earlier reported by Petters and Reijers (1987).

Biostratigraphy of Ikono-1 Well
Cretaceous foraminiferal analysis of Ikono-1 well showed diverse assemblages of benthic and planktic forms with the benthics exhibiting higher diversity and abundance than the planktics. A total of 116 foraminiferal species (40 planktics, 76 benthics) were identified. Some diagnostic species are illustrated in Figs. 5a and 5b and the common
ones listed in Fig. 6. The lower part of the well contains more planktics that are generally not well preserved thus making their identification difficult. Also some individuals are very small in sizes and contain many species that are badly ferruginized at some depths. The middle and upper parts of the studied section of the well, contain more benthics, some of which have restricted stratigraphic range while the planktics are dominated by fauna of Hedbergella and Heterohelix which are generally long-ranging (Fig. 6). Biostratigraphic interpretations are solely based on the planktic and benthic foraminiferal assemblages, however, shells of mollusk, gastropod, ostracod and echinoid spines recovered at some depths were useful for paleoenvironmental interpretation.

Discussion
Biostratigraphy
The Cenomanian-Turonian boundary is drawn at a depth of 3,260 metres (Fig. 4). Foraminiferal fauna recovered from the fossiliferous calcareous sandy shale below this depth yielded a rich planktic assemblage with rare benthics. The planktic species include; Hedbergella delrioensis, Hedbergella planispira, Hedbergella sp., Dorothia oxycon. Rotalipora balernaensis and Trochammina sp. Hedbergella delrioensis and Dorothia oxycon were initially described from Cenomanian sediments in the Ituk-2 Well (Fayose, 1979). Absence of species belonging to suborder Heterohelix which are mainly restricted to Turonian age further confirms this age. Sediments of Turonian age are recognized on the basis of the occurrence of Heterohelix reussi, Heterohelix

Fig. 4. Lithostratigraphic section, foraminifera population and species diversity of Ikono-1 well. Notice that the sections with igneous rock fragments are barren of foraminifera
Fig. 5a. Foraminifera species from Ikono-1 Well. 1-3, Hedbergella detrioensis; 4-6, Hedbergella plaispira; 7-9, Hedbergella archaeocretacea; 10-12, Globotruncana gansseri; 13-15, Whiteinella altica. All magnifications x 100.
Fig. 5b. Foraminifera species from Ikono-1 Well. 1-2, Heterohelix lobulosa x 160; 3-4, Heterohelix striata x 160; 5-6, Heterohelix striata x 160; 5-6, Heterohelix reussi x 160; 7-8, Orthokarstenia clavata x 16; 9, Heterohelix ultimatumida x 320; 10, Dorothisia oxycona x 96; 11-12, Afrobolivina afra x 40; 13, Praebulimina fang x 64; 14, Nonionella robusta x 160; 15, Buliminella brevispira x 160; 16-18, Gavelinella guineana x 160
Fig. 6. Range chart of common and biostratigraphically important foraminifera species in Ikomo-1 Well
ultimatumida, Heterohelix moremani, Heterohelix striata, Heterohelix pulchra, Praeglobotruncana stephani, Globigerinelloides bentonensis, Dorothia oxycona, Eouvigerina sp. and Praebulimina fang. Similar assemblages have been reported by Fayose (1979), on the Turonian sediments in Ituk-2 well, and Petters (1980) from road-cut samples of the Eze-Aku Shales at km 24.8 on the Calabar-Itu highway. Quantitatively, planktic forms are more abundant in this interval.

The Coniacian-Santonian interval is dominated by diverse fauna of benthic foraminifera (Fig. 6). Planktic species do occur but are very scanty. Depth range for the interval is between 2,360 m and 1,660 m. Abundant specimens of Orthokarstenia clavata, Afrobolivina afra, Gavelinella guineana, Gavelinella sp., Nonionella robusta, Planulina beadnelli, Globotruncana cretacea, G. rosetta, Whiteinella baltica, Marginotruncana sp. Hedbergella archaeocretacea, Heterohelix striata and H. globulosa were recovered within this interval. Heterohelix globulosa, H. striata, Gavelinella sp., Nonionella robusta and Whiteinella baltica have been described from Late Turonian to Early Santonian A wgu outcrops in the lower Benue Trough (Petters, 1980). The Campanian-Maestrichtian is recognized between 1,660 m and 1,481 m. Above this boundary, the foraminiferal assemblages recovered are mainly Tertiary forms therefore justifying drawing the Cretaceous-Tertiary boundary at the depth of 1,481 m (Fig. 4). Stratigraphically important foraminiferal species recovered from this interval are: Afrobolivina afra, Praebulimina bantu, Buliminella brevispira, Orthokarstenia oveyi, Gavelinella brotzeri, Globigerinelloides subcarinata, Globotruncana gansseri, and Globigerinelloides multispinatus. A similar assemblage was reported by Fayose (1979) from Maestrichtian sediments in Ituk-2 well and by Nyong and Ramanathan (1985) from outcrop samples along Calabar-Itu highway.

Paleoecology of Ikono-1 Well
Studies of modern foraminiferal ecology have provided distinct criteria for the reconstruction of marine paleoenvironments (Bandy and Arnal, 1960). Foraminifera are also in many respects ideal zonal indices for ancient marine rocks. For the purpose of basin evolution of the Calabar Flank, Ikono-1 well is suitable because the sediments penetrated are fossiliferous and exhibit many diverse benthic and planktic foraminiferal fauna. Based on the biostratigraphic boundaries recognized and the lithostratigraphic studies, the Cretaceous sediments recovered are grouped into four distinct units which are correlatable with depositional environments. They are the Upper Mfamosing Limestone, Eze-Aku Shales, A wgu Shales and the Nkporo Shales (Fig. 4). In the lowest unit (Cenomanian), there is dominance of planktic over the benthic forms. This does not necessarily suggest a very deep marine environment of deposition. The presence in addition, of arenaceous benthic forms such as Trochammina sp. and Dorothia oxycona together with the planktonic species of the suborder Hedbergella suggest rather a protected, occasionally open shallow marine depositional environment (Fig. 7). The Eze-Aku Shale shows general paucity of arenaceous species and a dominance of Heterohelix and Hedbergella fauna, probably due to shallow water and restricted paleoecologic conditions.
The Awgu Shales encountered in this interval has similar depositional environment with the Eze-Aiku Shales. Diverse fauna of Nonionella and Buliminella coupled with simple chambered arenaceous forms in this shaly section tend to support a shallow open marine environment (Fig. 7). Also, abundance of echinoid spines, mollusks shells and gastropod remains present in this unit support an inner shelf (inner neritic) of less than 50 m of water depth. The Campanian-M aeriithtian Nkporo Shales forming the topmost part of the Cretaceous sediments contains diverse species of benthic foraminifera, including abundant shallow marine genera of Gavelinella, Buliminella, Globigerinelloides and Nonionella, which reveal a shallow marine depositional setup. Also, the absence of porcelaneous species indicates non-existence of continental or paralic conditions during the deposition of Nkporo Shales.

Two main cycles of marine transgressions can be delineated in this study. During the Late Cenomanian and Turonian, there was a major transgression and the rich planktic fauna at certain levels indicate continuous deposition in an open marine environment. There was shallowing at the end of the Turonian, marked by the presence of the intercalated sandstones in the Eze-Aku Shales. This was followed by a transgressive phase in the Early Senonian time resulting in the depositing of the Awgu Shales. Since the foraminiferal assemblage characteristic of Late Santonian to Early Campanian age were not recovered from the sediments, this interval is assumed a period of non-deposition and/or erosion in the Calabar Flank. The Late Campanian-M aeriithtian, characterised with abundance and high diversity of benthic over planktic foraminifera (Fig. 6) represents a period of gradual retreat of the sea.

Conclusions
The lithostratigraphy of the studied section is in conformity with the surface rock stratigraphy of the interval in the Calabar Flank. Foraminiferal assemblage from the sediments contains diagnostic forms upon which biostratigraphic boundaries were delineated (Figs. 5a and 5b). Based on the biostratigraphy, a Cenomanian-M aeriithtian age is assigned to the studied section. The sediments contain abundance of planktic and benthic forms with high species diversity. The presence of Hedbergella delrioensis, H. planispira, Rotaliplora balernaensis, Trochammina sp. and Dorothisa oxycona have been used to infer a Cenomanian age for the lowest unit in the section. The Turonian-Santonian sediments (Nkalagu Formation) were recognized based on the presence of diagnostic forms which include Heterohelix moremani, H. rausi, H. ultimatumida, H. pulchra, H. striata, H. globulosa, Praebulimina fang, Gavelinella sp., Nonionella robusta and Whiteladia baltica. Between 1,660 m and 1,481 m depth interval, abundant specimens of Afrobulinova afrara, Praebulimina bantu, Buliminella brevispira and Globigerinelloides subarunata were found, restricting the sediments within this interval to Campanian-M aeriithtian age and delineating the Cretaceous-Tertiary boundary at 1,481 m.

The combination of Dorothisa, Trochammina and Hedbergella fauna indicates a protected occasionally open shallow marine environment of deposition for the lowest unit in the study well. The Eze-Aku, Awgu and Nkporo Shales were deposited in an inner neritic environment of water depth less than 50m, based on the presence of Heterohelix, Gavelinella, Globigerinelloides, Buliminella and Nonionella microfauna.

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References


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