FORAMINIFERAL BIOFACIES AND PALEOENVINRONMENTS OF THE UPPER CRETACEOUS OF CALABAR FLANK, SOUTHEASTERN, NIGERIA.

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ABSTRACT

The foraminiferal assemblages recovered in this study belong to the Guinean Faunal Province and are similar to those of other parts of the tropical world suggesting similarity of paleoceanographic conditions. From the systematic descriptions of the foraminiferal assemblages, twenty-two genera and thirty-eight species were identified. The heterohelicids and the globigerine-shaped hedbergellicid planktonic foraminifera showed predominance in their distribution. The benthics consist of few arenaceous and perforate forms. *Marginotruncana* and *Globorotruncana* were the only keeled planktics present. The foraminifera composition and distribution within the Calabar Flank were largely influenced by varying depths of deposition, partly induced by fluctuations in eustatic sea level and local tectonics of faulted blocks. In general, there is an upward increase in the number of species and genera diversities from Albian to Maastrichtian. The overall species diversity rises steeply but irregular through these intervals. Species abundance and diversity are found to be lowest during the Cenomanian. This study shows that Turonian, Coniacian, Campanian and Maastrichtian diversities are at least 2 to 10 times higher than that of Cenomanian. The observed trend in the depositional environment is that deepening from the littoral, brackish water environment to an open marine deepening to open marine outer shelf environment in Coniacian and Late Campanian. This study further shows that during the Upper Cretaceous, the nature of oceanic environment in the Gulf of Guinea was completely different from those in the present-day. Instead of oxygen-rich marine water, as we have today, we have generally lowered oxygen contents, with anaerobism developing in certain periods. During Cenomanian-Turonian interval, the bottom waters of the Atlantic Sea in the Calabar Flank became increasingly dysaerobic, making living conditions very difficult for microfossils, due to the persistence of low seawater oxygen levels. As a result, many microfossil groups experienced mass extinction. It took some time before this fauna could regain its original diversity. The factors controlling the fluctuation and distribution of faunas seem to result from a combination of biologic, environmental, sea level changes, paleo-oceanographic conditions and tectonics

INTRODUCTION

The Calabar Flank is one the major sedimentary fill along the southern Nigerian continental margin. It was active during the Cretaceous times. It is located at the southernmost embayment of the Gulf of Guinea, immediately north of the Cameroon trend. This unique cretaceous basin is located at the easternmost embayment of the Guinea, immediately north of the Cameroon Trend. It is bounded to the east by the Oban Massif, to the south by the Equatorial Atlantic Ocean, to the west by the Niger Delta and to the north by the sub-basins of the Benue Trough- the Abakaliki Trough, the Mamfe Rift and Afikpo Syncline, in order of decreasing age. Sedimentation and stratigraphic development in the basin were controlled by the major transgressive phases. Those identified in this study occurred during Mid-Albian, Cenomanian, Turonian, Early Coniacian and Late Campanian. During the Albian time, the first marine transgression of the proto-south Atlantic began to invade the rift system from the south, forming a narrow and elongated embayment. The continental shelf underwent further subsidence and seaward tilting and became the site of a carbonate platform whose deposits were predominantly the alga stromatolitic/oncolitic packstones and mudstone. Progressive widening of the ocean ensued during Cenomanian Turonian time was accompanied by further seaward tilting of the continental shelf, in which the platform carbonates subside as a unit and were transgressed by a sequence of argillaceous sediments of the Ekenkpon Shale. The basal Cenomanian, black, pyritic, fissile, organic-rich hard shale generally regarded as typical of the Ekenkpon Shale was deposited under oxygen-deficient environments in inner to middle neritic water depths. The Early Turonian dark-gray organic-rich soft shale with associated calcareous mudstone and marl interbeds was deposited during frequent reversals between oxic and anoxic conditions.

The Coniacian shoreline was wave-dominated. As a result a storm-dominated muddy shelf is believed to have formed during this interval in the Calabar Flank. The New Netim Marl comprises of two units: the lower tide-current dominated near shore shoreface complexes around the fringing of Oban massif and the upper storm-dominated deep water muddy shelf to the south bordered by the Ikang trough.

The Nkporo Shale in the Calabar Flank was deposited during the final major transgression and regression of the late Cretaceous Epicontinental Sea in Nigeria. The Late Campanian- Maastrichtian strata of the Calabar Flank was deposited in a variety of depositional environments ranging from open marine shelf, through marginal marine and finally in a non-marine environment.

Locations of study

The study areas is a section in the central portion of Calabar basin stretching from Mfamosing, Obarekai and Agbung areas in the east through the region of Etankpini, New Netim and Odukpani in the central part, down to Okonyong. Also, the exposed rock succession along the newly constructed Odukpani-Etankpini road track provided an excellent opportunity for sample collection. This new road track cuts across most of the formations on the Calabar Flank. The study areas have an acute shape and rim the Precambrian Oban Basement complex. The exposed rocks here are mainly marine shales, marls, limestones and sandstones succession. Within these sedimentary sequences are adequate micropaleontological records from which information may be retrieved, which relates to past ages, biological, oceanographic and climatologic conditions for the whole region.

Aims of study

The main purpose of this work is to establish the foraminiferal sequence biostratigraphic of the mid-late

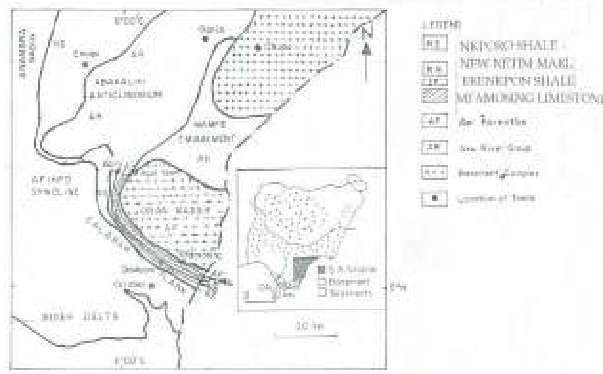

FIGURE 1: The Geologic Map of South-Eastern Nigeria.

Cretaceous succession on the Calabar Flank, within the previous age framework presented for ammonite [1,2] foraminiferal [3,4,5] and coccolith [6] biostratigraphies. This investigation was designed to elucidate in details the geological framework and the basinal characteristics especially microfaunal characteristics of Calabar Flank. This work also aims at providing a detailed illustration of the microfossils found in the basin. It will accomplish a systematic description of these microfossils in comparison with species known from other African and South America basin.

Methods of Study

Fresh samples from the area of study (Fig. 2) were obtained from road cuts, mining and quarry sites, ridges and hill crest, boreholes and occasionally from stream beds. In the field, these samples were described in detail, including their lithological variations, sedimentary structures and other sedimentary features, which were used to define their sedimentary facies. Vertical lithological columns were drawn for

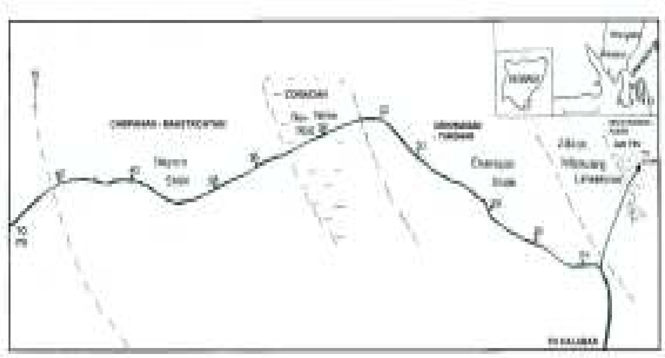

FIGURE 2: Locality map where samples were taken along Calabar –Itu Highway.

each of the sections. Samples collected were placed in labeled sample bags and taken for laboratory analysis.

Methods of sample preparation for micropaleontological studies vary, depending on the nature of the sample and the microfossil group investigated. Foraminifera and ostracoda were separated from their host rock matrix and concentrated for study using various techniques. Descriptions given by Passangno, [7] Zingular, [8] and Brasier, [9] were modified during the present study. The sodium carbonate (Na_2CO_3) method described by Brasier, (1980) was adopted with slight modifications. Samples were first crushed into fragments, about 2-3mm in size in an agate mortar, all the time avoiding grinding, as this would have destroyed the microfossils, though not necessarily so. The crushed samples were soaked in Kerosene for 6-8 hours and then wet sieved through a 200 mesh- (75 micons) sieve. Washed samples were then boiled with 1-2 teaspoonfuls of sodium carbonate (Na_2CO_3) and allowed to cool before wet sieving again. This process was repeated once or twice till most of the clay particles were washed away. The residues were washed into a funnel with a filter paper, and dried in an oven at a temperature of 110^c. The dried samples were separated into coarse, medium and fine fractions using 40 and 100 mesh sieves. The different fractions were then sprayed on a picking tray and examined separately under a wild Heerbrugg M.3 binocular microscope. The coarse fractions were invariably found to be devoid of foraminifera, but could contain ostracodes. Free-hand drawings of all the species encountered in this study were made with the help of a binocular microscope.

Mfamosing quarry site location

Very low specimen abundance and diversity characterized the foraminiferal assemblages recovered in this locality. Foraminiferal composition in the basal, anaerobic black laminated hard shale of the Ekenkpon shale exposed directly on the Mfamosing Quarry site is exclusively arenaceous, except in restricted interval where about 80-90 percent of the total foraminiferal assemblages consist of planktic foraminifera .

The benthic foraminifera are dominated by *Ammobaculities agresti* (Cushman and Applin), *A. subcretacea* (Cushman and Alexander), *A. bergguisti* (Cushman and Applin), *A. texanus* (Cushman) and *A. coprolithoforms* (Schwager). Other common arenaceous benthics are *Ammodiscoides turbinatus* (Cushman), *Trochammina exigua* (Cushman and Applin), *T. taylorana* (Cushman), and *T. wickedeni* (Loeblich). The calcareous benthics were completely absent. The planktonic foraminifera are dominated by *Globigerinelloides caseyi* (Bolli, Loeblich and Tappan), *G. algeriana* (Cushman and Ten Dam), *Hedbergella delrioensis* (carsey), *H. sigali* (Moullade), *H. portsdownensis* (William-Mitchell) and *Heterohelix striata* (Ehrenberg). It is important to note that these sediments contain numerous species of pelagic gastropods and pelecypods and that pyritization is an important means of preservation.

Mfamosing village location

The foraminifera assemblages in this locality are characterized by very low specimen abundance and diversity. Benthic foraminifera make up less than 30 percent of the foraminiferal population. These sediments contain species of arenaceous foraminifera such as Trochaminina taylorana (Cushman), T. wickedeni (Loeblich), Ammobaculities agresti (Cushman and Applin), A. subcretacea (Cushman and Alexander), Textularia subconica (Cushman) and Ammodiscoides turbinatus (Cushman). The fauna are heavily pyritized and smaller in size. The calcareous benthic are completely absent.

Odukpani junction location

The benthic foraminiferal assemblages recovered were exclusively arenaceous taxa. These faunas are heavily pyritized. The upper part of the succession yielded richer and more diverse foraminifera assemblage than the base. Samples show regular fluctuation in the number of planktic species from 2 to 8 species per sample. Species of Hedbergella, Heterohelix, Globigerinelloides and Whiteinella are common in some horizon. The benthics were dominated by arenaceous foraminifera such as Ammobaculites, Ammoastuta, Reophax and Trochammina. A few individuals of Lenticulina and Planularia represented the calcareous benthics. At the basal part of the succession, arenaceous taxa occurred almost exclusively. The calcareous benthics were rare. The fauna here are heavily pyritized and smaller in size. Samples show regular fluctuation in the number of planktic species ranging from 2 to 3 species per sample.

Ekenkpon village location

The foraminifera assemblages recovered in the sequence of shale exposed at km 29 from Calabar on the Calabar-Itu road were dominated by arenaceous foraminifera such as Trochammina taylorana (Cushman), T. wickedeni (Loeblich), Ammobaculities agresti (Cushman and Applin), A. subcretaceus (Cushman and Alexander), Ammodiscoides turbinatus (Cushman), Textularia subconia (Cushman), Ammoastuta nigeriana (Petters), Ammodiscus incertus (D'Orbigny), Reophax guineana (Petter) and Spiroplectammina semicomplanata (Carsey) Plunner. The planktonic foraminifera were present in some horizons. The common planktonic foraminifera are Hedbergella delrioensis (Carsey), H. planispira (Tappan), H sigali (Moullade), Heterohelix globulosa (Ehrenbergi), H. moremani (Cushman), H. reussi (Cushman), Hedbergella amabilis (Loeblich and Tappan) and Whiteinella archaeocretacea (Pessangno). The calcareous benthics were represented by Cassidella tegulata (Reuss), Planulina beadnelli (Said and Barakat) Lenticulina taylorensis (Plummer), Planuria tricarrinella (Reuss) Cushman and P. texana (Cushman). The arenaceous benthics were represented by Trochammina exigua (Cushman and Applin), T. taylorana (Cushman), T. wickedeni (Loeblich), Reophax minuta (Tappan), R. guineana (Petters), Ammobaculites agresti (Cushman and Applin), Spiroplectammina semicomplanata (Carsey) Plummer and Ammoastuta nigeriana (Petters).

Pamol-Etankpini road location

At about 250m from the Pamol Palm oil processing Centre on Pamol-Etankpini road, the foraminiferal assemblages were dominated by planktonic foraminifera. The following species were common Hedbergella portsdownensis (Williams-Mitchell), H. sigali (Moullade), H. sigali (Moullade) H. delrioensis (Carsey), Whitinella archaecretacea (Pessangno), W. inornata (Bolli), Clavihedbergella simplex (Morrow), C. subcretacea (Tappan), Heterohelix moremani (Cushman) H. striata (Ehrenbergi) and H. pulchra (Brotzen). The calcareous benthics foraminiferal was represented by Planulina beadnelli (Said and Barakat), Cassidella tegulata (Reuss), Lenticulina taylorensis (Plummer) and Planularia tricarinellan (Reuss) Cushman.

New Netim Village location

The foraminiferal composition for the succession at the back of the new Netim Primary School, Odukpani, shows that the assemblages were dominated by planktonic foraminiferal. The keeled planktonic foraminifera were common and abundant in all samples. The planktic assemblages were represented by Marginotruncana renzi (Gandolfi), M. sigali (Reichel), M. difformis (Gandolfi), Hedbergella delrioensis (Carsey), H. amabilis (Loeblich and Tappan), H. simplicissima (Magne and Sigali), H. brittonensis (Loeblich and Tappan), H. hoezli (Hagn and Zeil), H. crassa (Bolli), H. portsdownesis (Williams-Mitchell), Clavihedbergella simplex (Morrow), C. subdigitata (Carman), Whiteinella baltica (Douglas and Ranki), Heterohelix globulosa (Ehrenberg), H. reussi (Cushman), H. globucarina (Cushman) and Globigerinelloides prairiehillensis (Pessangno). The samples were characterized by low benthic assemblages density. The calcareous benthics were represented by Nonionella robusta (Plummer), Cibicides harperi (Sandidge) Cushman, Gavelinella sp, Planulina beadnelli (Said and Barakat), P. texana (Cushman) and Bolivina cretosa. The arenaceous benthics were represented by Reophac guineana (Petters), Ammodiscus incertus (D'Orbigny), Ammobaculities taxana (Cushman), Ammotium nwalium (Petters) and A. nkalagum (Petters).

New Netim-Calabar road Location

The foraminifera composition of the succession at km 22.8 north of Calabar on the Calabar-Ikom road, was dominated by high planktonic foraminifera density. The keeled planktics were conspicuously present. The planktic assemblages were represented by Marginotruncana sigali (Reichel), M. renzi (Gandolfi), M. difformis (Gandolfi), Hedbergella crassa (Bolli), H. Delrioensis (Carsey), H. planispira (Tappan), H. portsdownensis (Williams-Mitchell), H. hoelzi (Hagn and Zeil), H. amabilis (loeblich and Tappan), Clavihedbergella simplex (Morrow), C. subcretacea (Tappan), Whiteinella archaeocretacea (Pessangno), Heterohelix globulosa (Ehrenberg), H. moremani

9Cushman), H. pulchra (Brotzen) and H. reussi (Cushman). The calcareous benethics were represented by bolivina cretosa (Cushman), Nonionella robusta (Plummer), praebulimina exigua (Cushman and Parker), P. prolixa (Cushman and Parker), Planulina texana (Cushman) and P. beadnelli (Said and Barakat). The arenaceous foraminifera were very few and were represented by Ammobaculities agresti (Cushman and Applin) and A. subcretacea (Cushman and Alexander.

Ikot Nyong and Ikot Essien location

The foraminiferal composition of the road cut at km 34, Ikot Nyong and Ikot Essien villages was dominated by high planktonic foraminifera density. The planktonic assemblages were represented by Marginotrucana renzi (Gandolfi), M. sigali (Reichel), Hedbergella crassa (Bolli), H. amabilis (Loeblich and Tappan), H. hoelzi (Hagn and Zeil), H. planispira (Tappan), Heterohelix globulosa (Ehrenberg), H. moremani (Cushman), H. pulchra (Brotzen) and H. reussi (Cushman). The calcareous benethics were represented by praebulimina exigua (Cushman and Parjer), Bolivina cretosa (Crushman) and Planulina texana (Cushman).

Obarekai location

The foraminiferal composition of the succession at the Black Hill and Obarekai areas was dominated by high planktonic foraminifera density. The planktonic assemblages were represented by Marginotruncana renzi (Gandolfi), Heterohelix globulosa (Ehrenberg), H. moremani (Cushman), H. pulchra (Brotzen), H. hoelzi (Hagn and Zeil) and H. amabilis (Loeblich and Tappan). The few calcareous benethics present were represented by Preabulimina exigua (Cushman and Parker), Bolivina cretosa (Cushman) and Planulina texana (Cushman).

Atan Market locations

At km 35 north of Calabar along Calabar-Itu road by the banks of the river beside Atan Market, the foraminiferal assemblages were totally dominated by high planktic foraminifera density. The largest number of individuals and species of keeled taxa in the present study were recovered in the locality. The planktonic assemblages were represented by Globotruncana fornicate (Plummer), G. aegyptica (Nakkady), G. rossetta (Carsey), Rugoglobigerina rugossa (Plummer), R macrocephalla (Bronnimann), Archaeoglobigerina cretacea (D'Orbigny0 Passangno, Heterohelix glabulosa (Ehrenberg), H. navarroensis, H. moremani (Cushman), H. Pulchra (Brotzen), H. reussi (Cushman), Globigerinelloides escheri (Kauuffmann) Bolli, Pseudoguembelina costulata, Planoglobulina carseyae and Pseudotextularia elegans. The Benthic foraminifera were conspicuously absent.

Mkpara village location

At km 36.8 north of Calabar-Itu road, the upper part of the succession yielded richer and more diverse benthic foraminiferal assemblages than the base. The benthic assemblages dominate the foraminiferal that occur here are Bolivina afra (Reyment), Cibicides harperi (Sandidge) Cushman, Nonionella ausinlana (Cushman), Ga bonita elongate (de Klasz, Marie and Mayer). G. lata (de Klasz, Marie and Meijer), G. spinosa (de Klsz, Marie and Meijer), G. distorta (de Klasz, Marie and Meijer), G. levis (de Klasz, Marie and Maijer), G. nigeriensis (Odebode), G. elongate centrocastata (Odebode), Praebulimina prolix (Cushman and Parker), P. opima (de Klasz, Magne and Rerat0, P. bantu lata (de Klasz, Magne and Rerat), P. laddi (Cushman and Hedbergella), Quinqueloculina antique (Franke) Cushman, Ellipsonodosaria subnodosa (Guppy) Cushman, Orthokarstenia clavata (Chenouard, de Klasz and Meijer), Miliammaina onyeamaensis (Petters) and Haplophragmoides hausa (Petters).

Odukpani village location

At km 0.5 south of Odukpani village along Calabar-Itu highway, the foraminiferal assemblages were totally dominated by high planktonic foraminifera density. The benthic foraminifera were totally absent. The planktic assemblages were represented by Globotruncana fornicate (Plummer), G. rossetta (Carsey), Rugoglobigerina rugosa (Plummer), Archaeglobigerina cretacea (D'Orbigny), heterohelix globulosa (Ehrenberg). H. moremani (Cushman), H pulchra (Brotzen), H. reussi (Cushman) and Globigerinelloides escheri (Kauffmann) Bolli. The benthic foraminifera were conspicuously absent. At km 20 and 20.4 north of Calabar on the Calabar-Odukpani road, the foraminiferal assemblages were dominated in the upper part by benthics and in the lower part by planktonic foraminifera. The planktonic assemblages were represented by Globotruncana fornicate (Plummer), Rugoglobigerina rugosa (Plummer), Archaeoglobigerina cretacea (D'Orbiny) Passengno, Heterohelix globulosa (Ehrenberg), H.

moremani (Cushman), H pilchra (Brotzen), H. reussi (Cushman) and Globigerinelloides escheri (Kauffmann) Bolli. The benethic foraminifera were represented by Gabonita elogata (de Klasz, Marie and Meijer), G. lata (de Klasz, Marie and Meijer), Bolivina afra (Reymennt), Cibicides harperi (Sandidge) Cushman, Praebulimina prolix (Cushman and Parker), Miliammina onyeamaensis (Petters) and Gabonita levis (de Klasz, Marie and Meijer).

Results and Discussions

Planktonic foraminiferal evidence for the Cenomanian, Turonian, Coniacian and Campanian is presented as follows.

Cenomanian

In the present study, planktonic foraminiferal evidence for the Early Cenomanian is provided by the

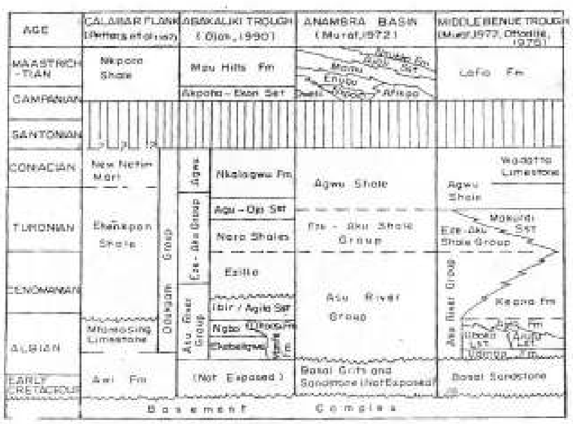

FIGURE 3: Stratigraphic Correlation of Calabar Flank, Benue Trough and Anambra Basins

association of Globigerrinelloides caseyi (Bolli, Loeblich and Tappan), G. algeriana (Cushman and Ten Dam), G. bentonensis (Morrow), Hedbergella delrioensis (Carsey), Clavihedbergella subcretacea (Tappan), Hedbergella portsdownensis (William-Mitchell), H. sigali (Mollade) and Heterohelix striata (Ehrenberge). Petters [4] define the Cenomanian using the association of Globigerinelloides caseyi (Bolli, Leoblich and Tappan) and Hedbergella sigali (Molluade). Globigerinelloides caseyi (Bolli, Loeblich and Tappan) seems to be restricted to the Cenomanian sediments in the US Gulf Coaster plain [7].

Turonian

The Early Turonian in the present study is characterized by the first appearance of Whiteinella archaeocretacea (Pessangno), W. inornata (Bolli) W. brittonensis (Loeblich and Tappan), W. baltica (Douglas and Rankin), Heterohelix reussi (Cushman), H. globucarinta (Cushman), H. moremani (Cushman) and Clavihedbergella simplex (Morrow). Heterohelix moremani (Cushman) reaches its peak abundance in the Earliest Turonian in this present investigation. Other planktonic foraminifera in this study are Hedbergella crassa (Bolli), H. hoelzi (Hagn and Zeil), H. nportsdownensis (Williams-Mitchell), H. simplicissima (Magne and Sigali), H. brittonensis (Loeblich and Tappan), Globigerinelloides bolli (Pessangno), G. ehrebergi (Barr) G. multispinata (Lacliker0 Douglas and G. prairiehillensis (Pessangno).

Whiteinella archaeocretacea was first describes in Turonian to Santonia sediments of the US Gulf Coastal plain, with its peak abundance in the Late Turonian [7] but ranged into the uppermost Cenomanian in California [10]. Robaszynski et al, [11] has used the first appearance of Whiteinella archaeocretacea to define the Cenomanian-Turonian boundary in the type Turonian region of France. The W. archaeocretacea Zone has been dated as early Turonian by Caron and Homewood [12].

Coniacian

The Early Coniacian in the present study is characterized by first appearance of the keeled planktonic foraminifera such as Marginotruncana renzi (Gandolfi), M. difformis (Gandolfi) and M. sigali (Reichel) which indicate Late Turonian to Coniacian age. Other planktonic foraminifera in this study are Heterohelix striata, H. reussi (Cushman), H. pulchra (Brotzen), Whiteinella baltica (Doulas and Rankin), Hedbergella amabilis (Loeblich and Tappan), H. crassa (Bolli), H. delrioensis (Carsey), H.portsdownensis (William-Mitchell), H. hoelzi (Hagn and Zeil), Clavihedbergella simplex (Morrow) and C. subdigitata (Carman). The presence of Marginotruncana renzi (Gandolfi), Hedbergella hoelzi (Hana and Zeil) and H. crassa (Bolli) suggested a Late Turonian to Coniacian age for these strata. The basal portion of the New Netim succession lies within the Turonian-Coniacian boundary, while the top occurs at the uppermost Early Coniacian. The diversity of heterohelicids planktonic foraminiferal species such as Heterohelix striata (Ehrenberg), in these sediments favours Senonian age. But, the association of Marginotruncana renzi (Gandolfi), M. difformis (Gandolfi) and M. sigali (Reichel) correlates theses strata with the Late Turonian- Early Coniacian Globotruncana renzi-G. sigali Range Zoce of Van Hinte [13].

Upper Campanian

Foraminiferal indicative of Late Coniacian-Early

Campanian age were not recovered in the present study. This interval is regarded as a period of non-deposition and/or erosion. An exclusive planktic foraminiferal assemblage was recorded for the upper Campanian while exclusively benthic assemblage characterizes the Maastrichtian. The upper Campanian-Maastrichtian strata stretch from Calabar as an unbroken band into the lower Benue Trough, Anambra Basin and the Benin Flank. This formation is known as Nkporo Shale [14]. The presence of Globotruncana fornicate (Plummer) and its association with an exclusively planktic assemblages composed of Globotruncana roseta (Carsey), Rugoglobigerina rugose (Plummer), Heterohelix pulchra (Brotzen), H. globulosa (Ehrenberg), H moremani (Cushman), H. planate, H. pulchra, H. reussi, H. robusta (Stenested Achaeoglobigerina cretacea D'Orbigny), Ventilabrella glabrata (Cushman) provided the evidence in favour of a Late Campanian age in the Calabar Flank.

Discussion

The distribution of foraminiferal fauna in modern environments is a useful tool in making paleoenvironmental reconstruction [15,16,17]. Douglas, [18] stated that paleoecological interpretations based on modern foraminiferal distributions rely on the assumptions that physiological adaptation of species and their depth distributions are constant through time. These assumptions are not always true, and this imposes some restrictions on the application of ecological data from modern environments to paleoecology.

The distribution of the different foraminiferal shell types is dependent on the availability of calcium carbonate ($CaCO_3$) for shell construction [19]. The calcium carbonate requirement of arenaceous taxa is low, and so such taxa dominate in hyposaline marginal marine environments and also below the Calcite Compensation Depth (CCD). Miliolids on the other hand are usually confined to shallow tropical hypersaline environmental settings. Douglas, [19] therefore, suggests that the rate of arenaceous benthics to calcareous benthics is a good index of salinity conditions. The paleoenvironments recognized in this study are as follows:

1. Tidal Marshes
2. Estuarine – lagoon
3. Normal Marine Epeiric Sea
4. Normal shelf Sea
5. Anoxic Epeiric Sea

Tidal Marshes

The Nkporo Shale was deposited during the final major transgression and regression of the epicontinental sea in the Gulf of Guinea. The lithology of the Nkporo Shale in the Calabar Flank is variable, ranging from primarily marine shale to primarily non-marine sandstone. The entire Nkporo Formation appears to be composed of sediments deposited in a non-marine nearshore through shelf environment. The Nkporo Shale displays a progradation from hypersaline marsh conditions through normal marine conditions. In the middle part of the Nkporo Shale, arenaceous taxa are dominated almost exclusively by Ammobaculites. The congregation of vertebrates (freshwater fishes, marine turtles, mosaurus and crocodiles) furnishes better evidence for the existence of tidal marshes.

Estuarine-lagoonal system

The New Netim Marl forms a belt extending along depositional strike across the entire Calabar Flank. From the shallow shoal-water and shoreface complexes to the deep water Ikang trough, the ramp measured approximately 30km wide. Distinct microfacies belts are found occupying predictable positions around the Oban Massif. To the west of the Oban Massif, the New Netim Marl outcrops reflect an estuarine-lagoonal setting. To the east of the Oban Massif, the outcrops reflect a storm-dominated muddy shelf setting. Alternating shale and marlstone compose the lower New Netim Marl and forms a lithologic succession that is transitional between the black shales below and the marly limestone above. These transitional rocks are recognized and are distinctive in the field because of their rhythmicity.

The lower New Netim Shale/Marl alternation is up to 20m thick, with the proportion of shale decreasing upward while marly limestone increases. The interbedded shales are commonly calcareous and locally contain abundant ostracods, bivalvles, gastropod echinoids and foraminifera. The benthic foraminifera assemblages recovered here are dominated exclusively by arenaceous foraminifera comprising Miliammina, Ammotium, Reophax, Ammodiscus, Haplogragmoides and Ammobaculiltes. This arenaceous assemblage represents brackish estuarine or lagoonal condition. These lower strata represent mud deposition within a shallow marine embayment during transgression.

Normal marine epeiric sea

The Albian Mfamosing Limestone was deposited in a warm, shallow agitated, normal marine environment. The ooids and packstones suggest shallow turbulent bottom conditions while the abundance of coralline algae suggests shallow depths of probably less than 10m. Corals, echinoids, ostracods and foraminifera also suggest normal marine conditions.

Normal continental marine shelf

The shape of the Calabar Flank suggests that during the Cretaceous times, it must be connected with the Benue Trough and South Atlantic Ocean during all its major transgressive phases and history. The Coniacian shoreline must have been opened to the South Atlantic Sea and must be wave-dominated. The rock successions present in the New Netim Marl outcrop belt suggest that the shelf must have extended a little farther south and become shallow towards Oban Massif. The character of the rocks through the successions indicates that these strata record a gradually deepening-upward depositional history. In its upper part, the New Netim Marl consists of 20m thick storm deposited units with planar-laminated bed bases and climbing-ripples, cross-stratified tops. A storm-dominated muddy shelf is believed to have formed during the deposition of the upper parts of the New Netim Marl, between a high-energy ooid shoals and shoreface complexes in the north and a storm-dominated muddy basin to the south that bordered the Ikang trough. The whole system or ramp sloped southward at a very low gradient and water depths ranged from intertidal in the shallow-water shoals in the north to approximately 200m at the shelf slope break some 30km away. Strong tropical storms or hurricanes probably were generated over warm seas which occasionally swept across the shelf in a northerly direction. As these storms attacked shallow-water ooids shoals that had formed along depositional strike, wind-forced flows eroded carbonate sediments from the lower shoreface and redeposit it in the shelf. A variety of bedding sequences have been documented at various outcrops, and most of the sequences are believed to represent individual depositional events related to tropical storms or hurricanes that impinged the Calabar Flank shelf.

Rhythmically bedded marlstones/limestones are interpreted to be shelf-storm deposits because of their stratigraphic positions, bedding sequences and fauna. The foraminifera assemblages recovered here were quite abundant, diverse and almost entirely composed of planktic species Heterohelix, Hedbergella, Whiteinella and short-ranging keeled planktonic foraminifera such as Marginotruncana, dominate the planktonic assemblages.

Anoxic epeiric sea

The recognition that Ekenkpon Shale was deposited under a dyserobic condition was first mentioned in passing by Murat,[20] but, was documented in detail for the Cenomanian-Santonian interval by Petters,[3] and Petters and Ekweozor, [23] . These authors evaluated the source rock potentials of these sediments and attempted an explanation for the cause of paleo-anoxia in the Benue Trough. An anoxic aquatic environment is a mass of water so depleted in oxygen that virtually all aerobic biologic activity has ceased [23]. Anoxic water is that containing less than 0.5millimeters of oxygen per liter of water, depending on water, temperature and salinity. The most common cause of anoxia is the incapacity of the oxygen supply in water to meet the biochemical oxygen demand. Anoxic conditions occur where the natural demand for oxygen in water exceeds the supply. Oxygen demand relates to surface biologic productivity, whereas oxygen supply largely depends on water circulation, which is governed by global climatic patterns and the Coriolis force. Lack of vertically mixing and oxygen renewal in deep waters is, perhaps, the most important factor controlling the location of anoxic layers. Thus, biochemical processes are responsible for the position. Biochemical oxygen demand is indeed the triggering mechanism of anoxicity in general, but deep circulation patterns govern the distribution and position of these regional anomalies. Arthur and Schalanger,[24] and Jenkyns,[25] have reported major episodes of anoxia on a global scale. The major Cretaceous intervals of global anoxia recognized by Jenkyns were as follows:

1. Late Barremian-Aptian-Albian
2. Late Cenomanian to Early Turonian and
3. Late Turonian to Coniacian .

Conclusion

The foraminifera assemblages show that the faunas recovered were characterized by few species and were dominated by the long ranging taxa. The foraminiferal distribution charts for the different outcrop shows that the faunas were characterized by few species. Hedbergellids and heterohelids in the Ekenkpon Shale and New Netim Marl dominated the planktic. The heterohelix, rugoglobigerinds and globotruncanids dominate the Nkporo Shale. In the basal part of the Ekenkpon Shale, arenaceous taxa occurred almost exclusively. The calcareous benthics are very rare. The fauna here are heavily pyritized and are smaller in size. Samples show regular fluctuations in the number of planktic species ranging from 2 to 3 species per sample. The upper part of the Ekenkpon shale yielded a richer and more diverse foraminiferal assemblage than the base. Samples show regular fluctuation in number of planktic species ranging from 2 to 8 species per sample. The benthics were dominated by arenaceous foraminifera such as Ammobaculites, Ammoastuta and Trochammina. A few individuals of Lenticulina, Planularia and Dentalina represented the calcareous benthics. The planktic foraminiferal assemblages were dominant comprising about 50-80 per cent of the foraminiferal assemblage. Species of Hedbergella, Heterohelix, Globigerinelloides and Whiteinella are common in some horizon. The middle and upper parts of the new Netim Marl are characterized by low density of benthic foraminiferal assemblages. Genera such as Planulina, Praebulimina and Nonioella are common. The keeled planktics were dominant. They are represented by the genera Marginotruncana. The lower part of the Nkporo Shale yielded a rich foraminiferal assemblages composed mainly of planktics. The largest number of individuals and species of keeled taxa in the present study occurred in this formation. Heterohelicids, rugoglobigerinids and globotruncanids dominated the planktics. Benthic foraminifera were totally excluded from this assemblage. The middle part of the Nkporo shale yielded entirely benthic assemblages dominated by the West Africa endemic species of Afrobolivina, Gabonita, Praebulimina, Nonionella and Gavelinella. Arenaceous benthics were also common.

In summary, there is a general trend on increasing species and general diversity from Albian at the base to Maastrichtian at the top. The overall species diversity rises steeply but irregularly from Mid-Albian to Early Maastrichtian interval. Species abundance and diversity are found to be lowest during the Cenomanian. This study shows that Turonian, Coniacian, Campanian and Maastrichtian diversities are higher than that of Cenomanian. The factors controlling the fluctuation and distribution of faunas seem to be a combination of biological, environmental, sea level changes, paleo-oceanographic conditions and tectonics.

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