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Full Length Research Paper

Foraminiferal analysis and palaeoenvironmental interpretation of borehole ET (BH-ET) in the Calabar Flank, South-eastern Nigeria

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Foraminiferal biostratigraphy and palaeoenvironmental interpretation was carried out on core samples (5 samples between intervals 5-55 m) recovered from borehole ET (BH-ET) located in Etankpini area of the Calabar Flank, south eastern Nigeria. Lithologic description of the borehole samples were carried out and the borehole was sampled at 5 m interval. The samples were later composited at 10 m interval and a total of six samples were subjected to standard micropaleontological preparation procedures. Results from the lithologic analysis show that the basal section of the well (55-60 m) was made up of granite gneiss; overlain by light grey, calcarenite, bioclastic, pisolitic and stylolitic limestones (30-55). Dark grey fissile shales directly overlie the limestone (5-30 m). The foraminiferal recovery was generally low and characterized by planktonic species (*Guembelitria harrisi, Hedbergella crassa, Hedbergella delrioensis, Hedbergella simplicissima, Hedbergellid* spp., *Heterohelix globulosa, Heterohelix planata, Heterohelix reussi, Hedbergella planispira and Hedbergella sigali*). The absence of benthonic forms may be an indication of anaerobic bottom conditions. An age of Cenomanian-Early Turonian was assigned to the studied well based on diagnostic foraminiferal species assemblages. The recovered foraminiferal assemblage points to deposition within the Inner Neritic to Middle Neritic depositional setting for the studied well.

Key words: Neritic, Calabar Flank, biostratigraphy, planktonic, anaerobic.

INTRODUCTION

The Calabar Flank is one of the coastal sedimentary basins in Nigeria located at the north-east of the Gulf of Guinea. It is separated from other coastal basins (Douala basin) to the southeast by the Cameroon Volcanic Line (CVL). The basin is bounded to the north by the Oban Massif, to the south by the Calabar hinge line and the Niger Delta basin, to the west it is delimited by the Ikpe Platform (Figure 1) (Nyong and Ramanathan, 1985).

Five stratigraphic units constitute the Cretaceous sediments of the Calabar Flank viz: The Awi Formation,

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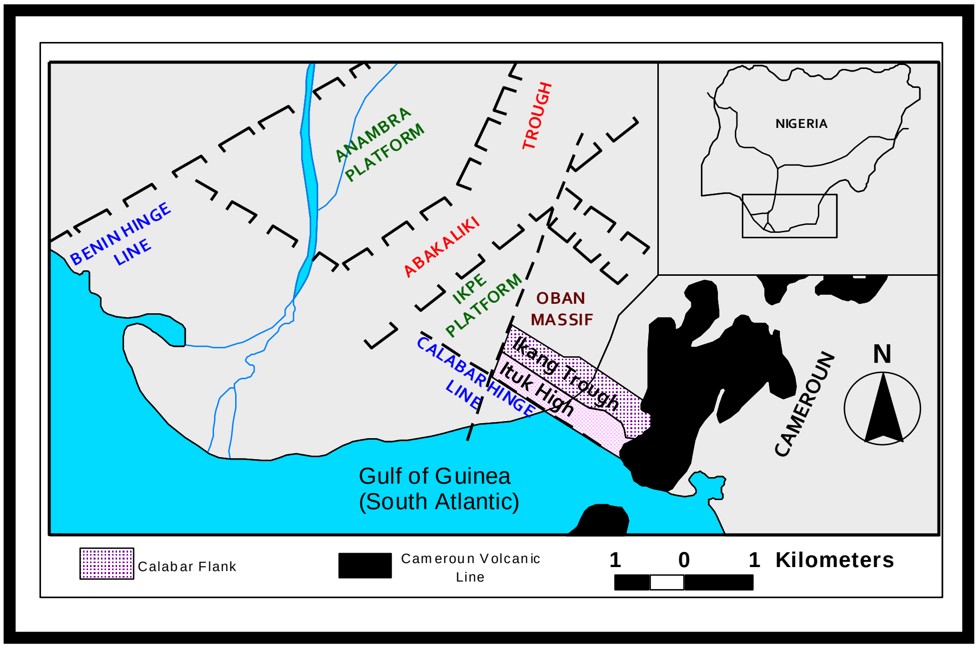

Figure 1. Map showing the structural elements of the Calabar Flank and adjacent areas (Redrawn from Nyong and Ramanathan, 1985).

Mfamosing Limestone, Ekenkpon Formation, New Netim Marl and Nkporo Shale, with limestones and shales being deposited during marine incursion in the Middle Albian age. This limestone (Mfamosing Limestone) overlies the Awi Formation which constitutes the basal sediments in the basin but in some other places, the Mfamosing Limestone lies directly on the basement as observed in this study well (borehole ET). This research work utilizes the information derived from core samples to highlight the foraminiferal distribution and palaeoenvironment of borehole ET (BH-ET) drilled recently in Etankpini area of the Calabar Flank.

Geologic setting

The Calabar Flank is that part of southern Nigeria sedimentary basins characterized by crustal block faulting trending in the NW-SE direction. The sedimentary basin was controlled by vertical movements of faulted blocks notably the Ituk High and the Ikang Trough and by associated transgressions and regressions (Murat, 1972; Nyong, 1995).

This sedimentary basin contains up to 4000 m of Albian to Maastrichtian marine deposits in outcrop section (Ehinola et al., 2008) sitting on continental (fluvio-deltaic) Awi Formation. Essien et al. (2005) pointed out the uniqueness of the basin such that within a stretch of about 8 km from the basement complex down-dip, the whole sections can be studied. The stratigraphic successions in the Calabar Flank consist of mostly Cretaceous deposits (Figure 2) however, at some locations near Calabar, these sediments are capped by the deposits of the Benin Formation of the Tertiary (Paleogene – Neogene) and younger Niger Delta. The basin is structurally controlled by horsts and graben structures as a result of crustal block faulting (Murat, 1972). The basal Neocomian-Aptian syn-rift fluvial sandstone, the Awi Formation (Adeleye and Fayose, 1978) marks the onset of sedimentation in the basin (Boboye and Okon, 2014).

The Albian and Late Cretaceous marine post-rift Odukpani Group (Petters et al., 2010) which consists of the mid-Albian Mfamosing Limestone (Akpan, 1992), the Late Albian-Turonian Ekenkpon Formation and the Coniacian New Netim Marl which were deposited during a relative rise in sea level directly overlie the Awi Formation. This group (Odukpani Group) is overlain unconformably by the Late Campanian-Maastrichtian Nkporo Shale (Edet and Nyong, 1993). The Tertiary (Paleogene – Neogene) and younger regressive sands and gravel beds of the Benin Formation overlie these Cretaceous successions.

Several research works so far have been carried out on sediments of the Calabar Flank for diverse reasons. Pioneer works include those of Reyment (1955, 1956, 1959, 1965), Dessauvagie (1965, 1968, 1974) and Murat (1972) among others. Akpan (1996) used the faunal

AGE	LITHOLOGY		DESCRIPTION
Recent Eocene -	Benin Formation		Loose sands, pebbly and arkosic
Maastrichtian L. Campanian -	Nkporo Shale		Dark grey, very fissile carbonaceous shale with gypsum bands and some calcareous nodules
Santonian	Santonian Deformation		Santonian deformational episode characterized by period of folding of pre-existing rocks and erosion and/or non deposition.
Coniacian	ODUKPANI GROUP	New Netim Marl	Dark grey massive marls intercalating with flaggy, calcareous grey shale with thalassinoides structures
Turonian		Ekenkpon Shale	Grey fissile shale with thin bands of calcareous nodules, limestone and mudstone units. Abundant shell fragments, keeled ammonite, juvenile
Cenomanian		Un-named Shale	Dark gray shale, highly fissile and separated by the upper shale unit by a regressive mudstone
Mid - Albian		Mfamosing Limestone	White to light grey limestone, stromatolitic at the base, with abundant fossils (gastropods, corals, shell fragments)
Neocomian - Aptian	Awi Formation		Reddish brown, coarse to medium grained arkosic sandstone. Pebbly at the base and exhibit fining upward succession in cycles, graded bedding.
Precambrian	Precambrian Basement Complex		Southeastern Basement Complex – Oban Massif composed predominantly of granite gneisses, granites and granodiorites.

Figure 2. Stratigraphic chart of the Calabar Flank (Modified after Petters et al., 2010).

evidence of the bivalvia *Protocardia* spp. to identify areas with exaerobic bottom conditions and this was in agreement with an earlier work by Petters (1978) in the area. Reijers and Petters (1997), studied sequence stratigraphy and characterized the microfacies including stromatolites to enable the recognition of a late phase in the formation of a high stand systems tract and of a flooded surface followed by a low stand system tract in the Mfamosing limestone.

Bassey (1991) and Njoh (2008) worked on the Cretaceous biostratigraphy of the Calabar Flank and adjourning areas. Ukpong et al. (2008), carried out foraminiferal biostratigraphic analysis of the upper part of the Type section of the Ekenkpon Formation which revealed dominant occurrence of the planktonic over the benthonic forams. The nature of the benthonic forams indicated fluctuating oxygen concentration which characterizes shallow oxic and anoxic marine settings worldwide during this geologic period. Njoh et al. (2009) characterized the early Paleogene foraminiferal assemblages within the Calabar Flank and suggested that sedimentation extended into the Paleogene. There is however, some controversies about Paleogene marine influence in the Calabar Flank. The petroleum generation potentials of the Calabar Flank deposits have also been studied (Essien et al., 2005, Ehinola et al., 2008, Ekpo et al., 2013; Boboye and Okon, 2014). Their studies show that the basin has promises for gaseous hydrocarbon deposits.

METHODOLOGY

The samples used for this study were recovered from borehole ET within the Calabar Flank (Figure 3). The borehole has a total depth of 60 m and was sampled initially at 5 m interval. Lithologic description was carried out on the borehole and three principal lithologies (granite gneiss, limestone and shale) were identified. The first 5 m was ignored due to overburden and the last 5 m was crystalline basement rock. The samples were later on composited at 10 m interval making a total of six (6) samples prepared for micropaleontological analysis. Standard procedures (Armstrong and Braisier, 2005) were strictly adhered to during preparation of the samples in the laboratory.

Samples were washed to be mud free and then dried. A small quantity (about 20 – 30 g) of each composited sample was treated with one teaspoonful of anhydrous sodium carbonate for thorough disaggregation. Enough water was added to cover the sample and they were allowed to stand over-night. The soaked samples were washed using a 63 µ mesh sieve. Drying of samples at a minimum temperature of 20°C was later carried out followed by sieve analysis to separate the samples into coarse, medium and fine fractions. Fine brushes were used for the picking of foraminifera and finally, foraminifera samples were placed in a 30-60- squared cardboard faunal slides and covered with water soluble glue. The slides were examined using the wild Heerburg binocular microscope for the identification of species, abundance counts and diversity. This information were plotted on a foraminifera distribution

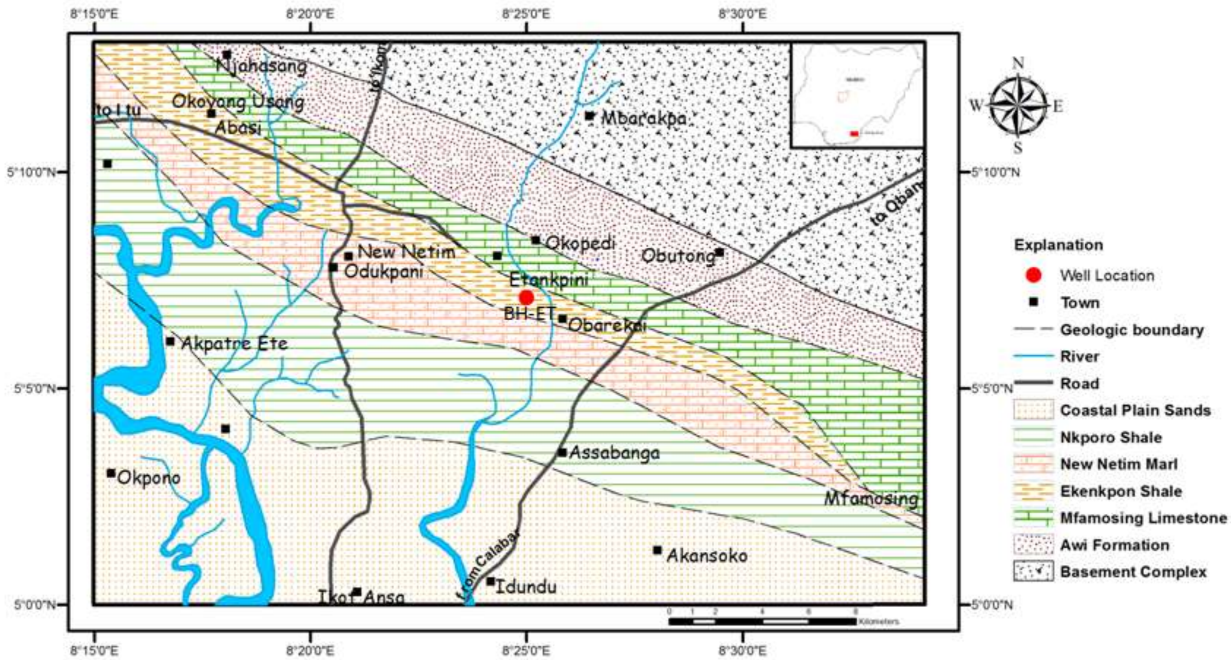

Figure 3. Geologic map of Calabar Flank showing the well location.

chart. The age determination of the well was carefully based on the use of last appearance datum and first appearance datum of age diagnostic foraminiferal species for borehole ET. Biofacies analysis (based on association of organisms that represent a particular depositional environment) was also carried out. This analysis was carried out in the micropaleontology laboratory of the South Sea Petroleum Consultants, Nigeria.

RESULTS AND DISCUSSION

Lithostratigraphy

Borehole ET penetrated lithologic units consisting of lateritic overburden (topsoil), shales, limestone and terminated on the granite gneiss. Figure 4 gives a clear description of the various lithologic units encountered downhole. The first interval (0-10 m) was made up of lateritic topsoil. This was followed by another interval (10-30 m) consisting of dark-grey, highly fissile and fossiliferous shale of the Ekenkpon Formation. Next to this is an interval (30-55 m) consisting of light-grey, calcarenitic, bioclastic, pisolitic and stylolitic limestone of the Mfamosing Limestone. The lower part of the Mfamosing Limestone unconformably overlies the crystalline basement rock from a depth of 55 m.

Foraminiferal biostratigraphy

The six composited samples obtained from the (interval 0-55 m) yielded planktic foraminifera. Some of the intervals were however barren while some yielded undiagnostic forams. Generally, foraminiferal abundance could be described as rare with low species diversity (Figure 5). The limestone yielded no foraminifera most probably due to its high state of induration. Some age diagnostic foraminiferal assemblage recovered from the studied samples include *Hedbergella* species *(Hedbergella crassa, Hedbergella delrioensis, Hedbergella simplicissima, Hedbergella* spp., *Hedbergella planispira), Heterohelix* species (*Heterohelix globulosa, Heterohelix moremani, Heterohelix planate, Heterohelix reussi), Archeoglobigerina* spp. and *Guembelitria harrisi* (Appendix, Plates 1 and 2).

This foraminiferal assemblage is indicative of Cenomanian to Early Turonian age. *Guembelitria harrisi* is restricted to the Turonian age in the Eze-Aku Formation in the Benue Trough (Petters, 1980). It occurs in the Cenomanian of the U.S Gulf Coast (Pessagno, 1967) but ranges into the Turonian in New Jersey (Petters, 1977). *Heterohelix reussi* has its first appearance datum (FAD) in the Turonian age in the Benue Trough (Petters, 1980) while *Heterohelix moremani, Heterohelix globulosa, Hedbergella planispira* and *Hedbergella delrioensis* were recorded in Cenomanian –Turonian age in the Eze-Aku Formation of the Benue Trough (Petters,1980). Bassey (1991) also used these species to indicate Cenomanian-Turonian in the subsurface of the Calabar Flank while Ukpong et al. (2008) used a similar assemblage to indicate

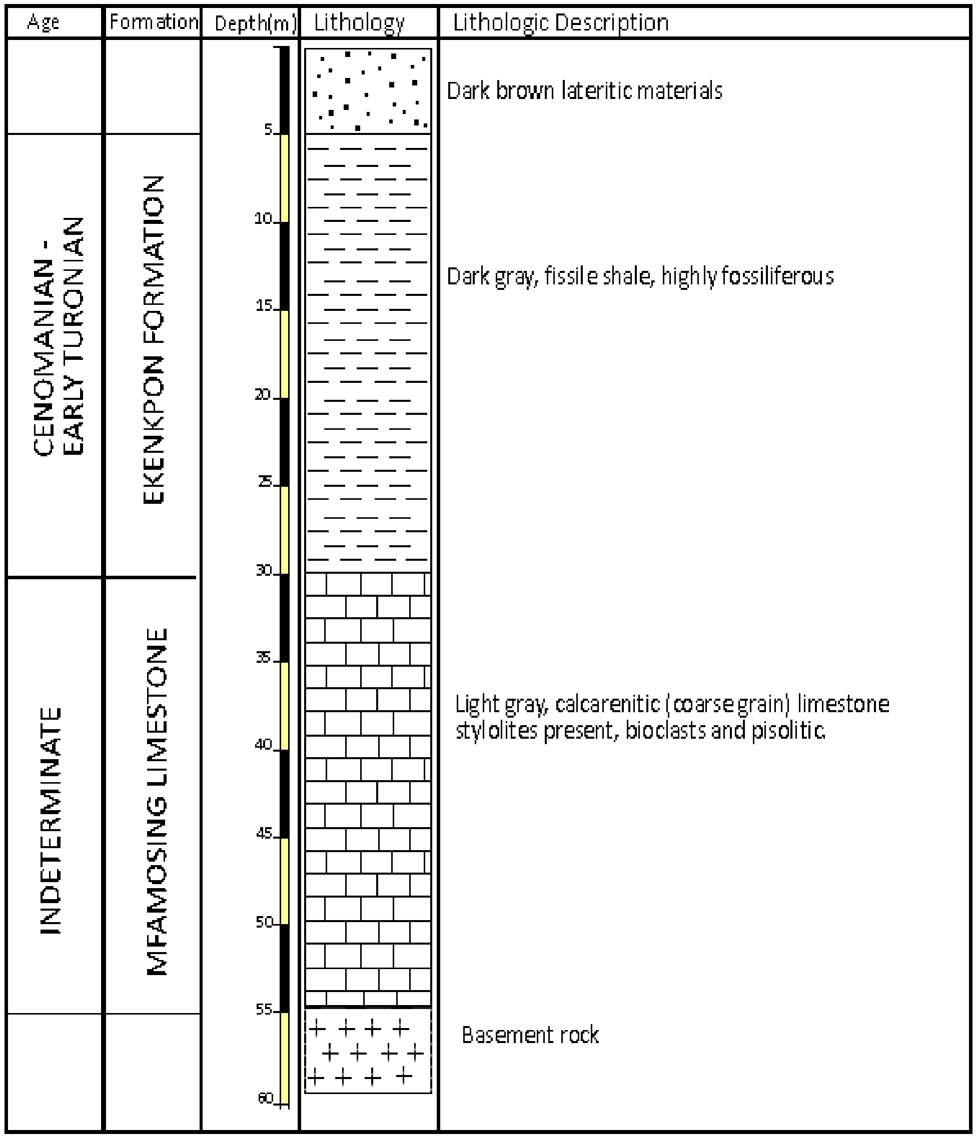

Figure 4. Lithostratigraphy of borehole ET.

Cenomanian-Turonian age in the upper part of the Type-section of the Ekenkpon Formation in the Calabar Flank.

The middle part of the studied borehole (depth below 30 m) is barren of foraminifera and a precise age could not be assigned to the Mfamosing Limestone that underlies the Ekenkpon Formation (Figure 5). Although, Akpan (1992) used the occurrence of an itieriid gastropod *Peruviella dolium* (Roemer) to assign a middle Albian age to the Mfamosing Limestone, Essien and Ufot (2010) assigned Albian-Early Cenomanian age to the Mfamosing Limestone on the basis of pollen and spores recovered among which are *Classopollis jardinel, Lycopodium sporites,* etc.

Palaeoenvironmental Interpretation

The palaeoenvironmental interpretation based on foraminifera distribution in borehole ET (BH-ET) indicates that the Cenomanian-Early Turonian sediments were deposited in an Inner neritic – Middle neritic marine environment (Figure 5). Generally, forams are affected by ecological conditions of their environment and they react to various environmental settings (Petters, 1980; Akpan, 1985; Nyong and Ramanathan, 1985). Thus, it could be deduced that the bottom oxygen concentration was too low during certain periods for benthonic organisms to thrive, so the planktonic forms survived during these

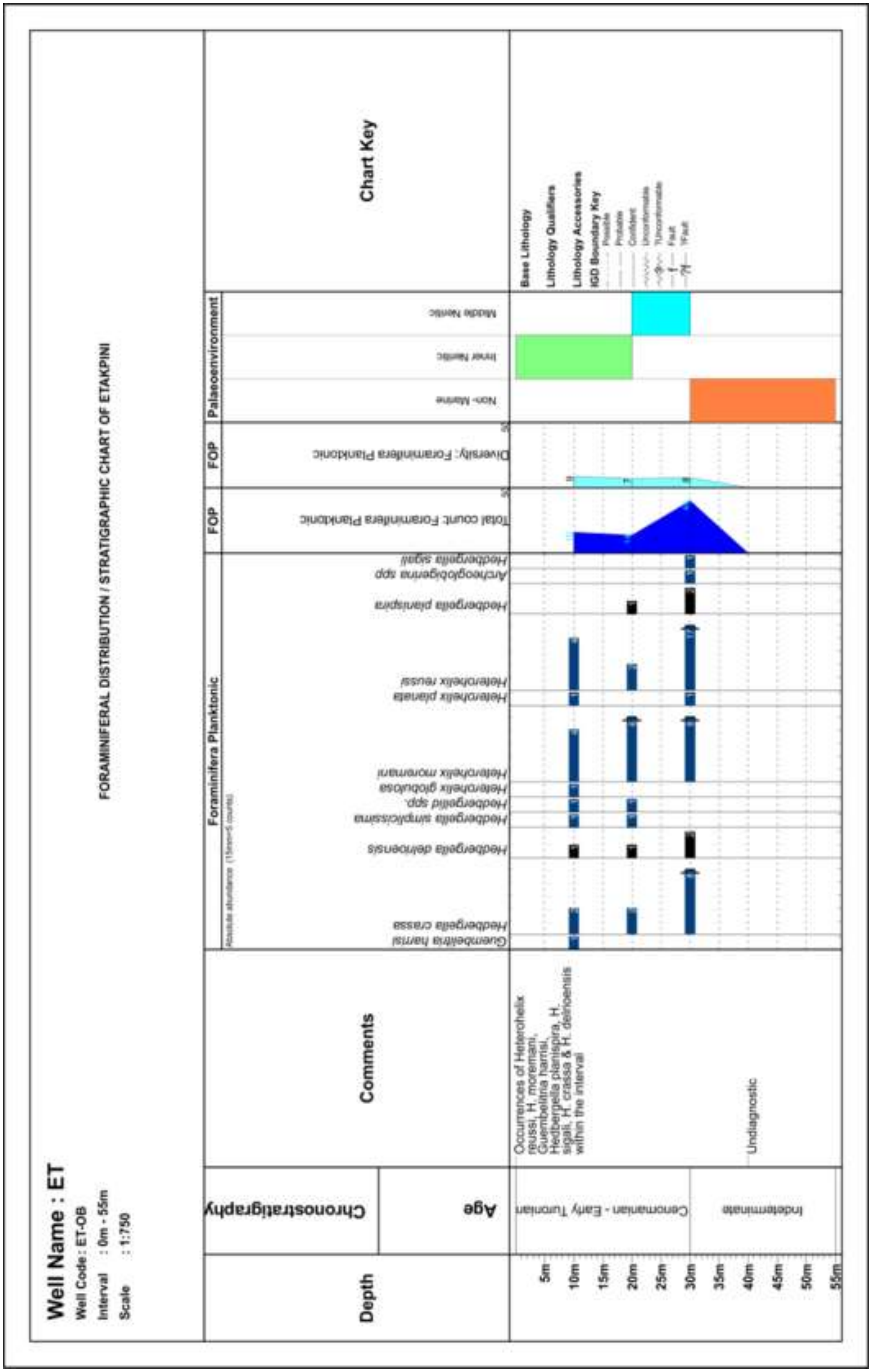

Figure 5. Foraminiferal distribution/stratigraphic chart of borehole ET (BH-ET).

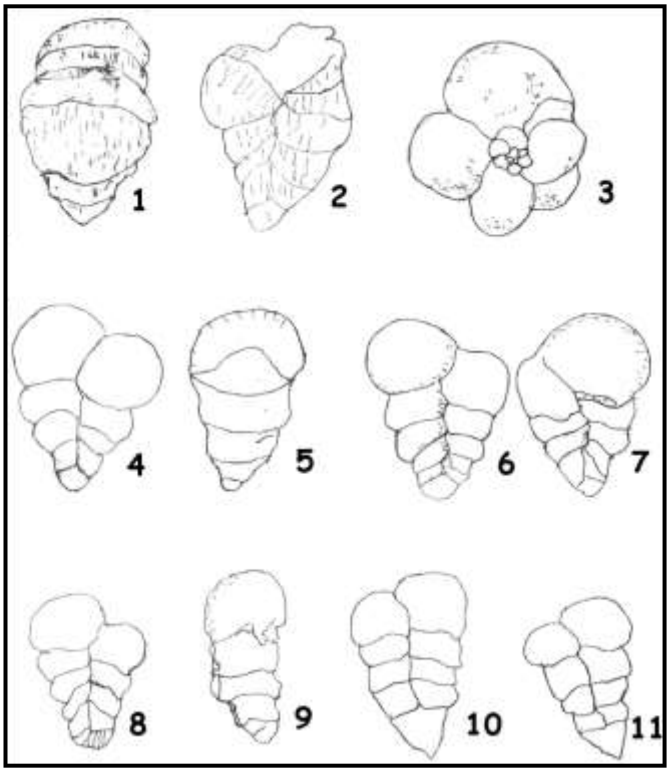

Plate 1. 1, 2, 3: *Heterohelix planate*; 4, 5, 6, 7: *Heterohelix reussi;* 8, 9, 10, 11: *Heterohelix globulosa.*

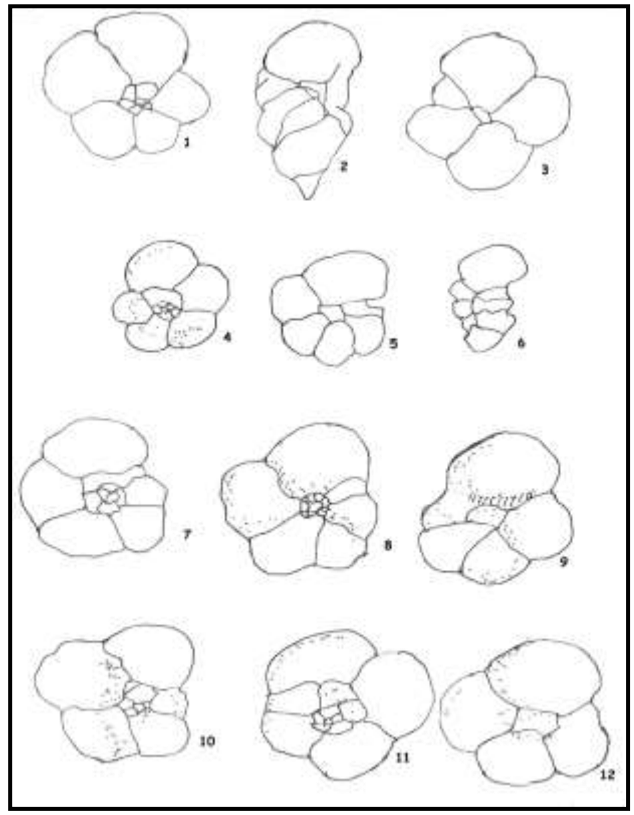

Plate 2. 1, 2, 3: *Hedbergella delrioensis;* 4, 5, 6: *Hedbergella planispira;* 7, 8, 9: *Hedbergella crassa;* 10: *Hedbergella simplicissima;* 11, 12: *Hedbergella sigali.*

periods, with depths not shallower than they could inhabit. The dominant occurrences of planktonic foraminiferal species lend credence to the inferred paleoenvironment.

Conclusion

Planktonic foraminiferal distribution of borehole ET (BH-ET) samples reveals the age of the study well as Cenomanian-Early Turonian while the lithology supports the penetration of two formations (the Mfamosing Limestone and the Ekenkpon Shale) in the sedimentary basin. This stratigraphic relationship indicates that the first marine transgression in the Etankpini area of the Calabar Flank started with the Mfamosing Limestone which unconformably overlies the basement in borehole ET.

Micro faunal and lithologic study indicates Inner-middle neritic environments of deposition for the studied borehole. The result from these data further indicates a sea level rise at 20-30 m interval which conforms to the high micro-faunal abundance and diversity associated with the onset of deep marine transgression which resulted in the deposition of the Ekenkpon Formation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Appendix

SYSTEMATIC PALEONTOLOGY

It deals with the similarities and differences as well as the relationship of fossils. Systematic palaeontology involves classification and nomenclature (naming). Classification is the arrangement of fossils and modern plants and animals into natural groupings to reflect hierarchy relationship and evolutionary trend. Nomenclature is the allocation of names to the groups or units produced by such classification.
Kingdom: Protista
Phylum: Protozoa
Class: Sarcodina
Order: Foraminiferida
Suborder: Miliolina
Family: Globotruncanidae
Subfamily: Hedbergellinae
Genus: Hedbergella

Species: *Hedbergella planispira*
Description: Test free, small, low trochospiral, compressed, spiral side flat to slightly depressed, axial peripheral rounded, equatorial peripheral lobate; chambers 5 to 7, usually 6 in last whorl, globular, increasing regularly in size, compressed on spiral side; wall calcareous, finely perforate, surface finely hispid to nearly smooth; umbilicus wide and deep; aperture, a low interio-marginal, extraumbilical- umbilical arch, with a narrow bordering lip which may expand as a subtriangular flap near the umbilicus.
Dimension: Maximum diameter: 0.11-0.29 mm; Maximum thickness: 0.07-0.18 mm

Species: *Hedbergella delrioensis*
Description: Test free, low trochospiral coil of about 3 whorls, almost biconvex, early whorl flush or slightly depressed below last whorl on spiral side, umbilical side deeply umbilicate, equatorial periphery, strongly lobate, axial periphery rounded; chambers 4 to 6 but usually 5 in last whorl, much inflated, nearly spherical increasing rapidly in size; sutures distinct, strongly depressed, straight to slightly curve, all calcareous, perforate, surface faintly spinose to smooth, umbilicus narrow and deep; aperture, an interiomarginal, extraumbilical-umbilical arch, partially borded by a lip which flares slightly at its umbilical end.

Species: *Hedbergella crassa*
Description: Test free, small, trochospiral, spiral side flat, umbilical side inflated, peripheral lobate, peripheral margin rounded, chambers 5 to 6 in whorl, globular to subglobular, compressed on spiral side, increasing rapidly in size, last one or two chambers distinctively inflated on umbilical side ; sutures distinct, depressed, radial to slightly tangential on spiral side, radial on umbilical side; wall calcareous perforate, surface finely pitted to smooth, umbilicus very narrow and deep, aperture, an interiomarginal, extraumbilical – umbilical arch, with a narrow bordering lip.
Dimension: Maximum diameter 0.21- 0.44 mm; Maximum thickness 0.11-0.18 mm

Family: Heterohelicidae
Subfamily: Heterohelicinae
Genus: Heterohelix

Species: *Heterohelix moremani*
Description: test elongate, 3 times as long as broad, gradually tapering throughout, only slightly enlarging in the later portion, biserial, periphery strongly lobate numerous chambers, globular to subglobular increasing slightly in size; sutures distinct and depressed throughout; wall calcareous, smooth, finely perforate; aperture, a high arched opening at the inner margin of the last formed chambers, with slight lip.
Dimension: Maximum length (0.35-0.45 mm); Maximum width (0.15-0.18 mm)

Species*: Heterohelix reussi*
Description: Test small, about one and half times as long as broad, rapidly tapering, greatest width formed at last pair of chambers, biserial in adult and early chamber may be planispiral, periphery of early part usually entire but later distinctly lobate, chambers globular to subglobular, inflated, increasing rapidly in size, often the last one or two pairs are very large and highly inflated; sutures distinct, depressed, wall calcareous, finely perforate, surface smooth to finely costale; aperture a low to moderate arch on inner margin of last chamber.
Dimension: Maximum length (0.40-0.50 mm); Maximum width (0.28-0.30 mm); Maximum thickness (0.22-0.25 mm)

Species: *Heterohelix planata*
Description: Biserial test, small, compressed about one and half times as long as broad, rapidly tapering with greatest width at last pair of chambers, periphery slightly keeled in the early portion and deeply lobate in the later portion; chambers broader than high throughout, somewhat compressed; sutures distinctly depressed and somewhat curved; wall smooth, finely perforated, the

perforations tending to be longitudinal lines, aperture a high, arch with distinct, lateral flanges running out into the proceeding chamber.
Dimension: Maximum length (0.21-0.35 mm); Maximum width (0.16-0.24 mm); Maximum thickness (0.12-0.15 mm)

Species*: Heterohelix globulosa*
Description: Test tapers rapidly, small, biserial in adults, greatest width towards apertural end, initial end subacute, two times as long as broad, periphery lobate throughout, last chambers distinctly larger; chambers globular and inflated throughout, 5 to 6 pairs increasing moderately in size; sutures, distinct, depressed, straight; wall calcareous, finely perforate, surface smooth to finely striate; aperture broad, low arch with slight lip at inner margin of last chamber.
Dimension: Maximum length (0.12-0.39 mm); Maximum width (0.11-021 mm)

Family: Heterohelicidae
Subfamily: Gueubelitrinae
Genus: Guembelitria

Species: *Guembelitria harrisi*
Description: test small, triserial and tapers rapidly with largest diameters at the last formed chambers; chambers are globular to near spherical, they increase rapidly in size; sutures are depressed, the wall is smooth, finely perforated; aperture at the inner margin of the last formed chambers, small and semicircular.
Dimension: Maximum length (0.23-0.27 mm); Maximum width (0.17-0.20 mm)