



Microfacies and Biostratigraphy of the Limestone-Shale Sequences of Gboko Formation, Middle Benue Trough, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author ODO designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors ODO, OAO and AE managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The drive to ascertain the paleodepositional environments of the inland sedimentary basins of Nigeria, necessitates a detailed biostratigraphy studies of limestone-shale sequences of Gboko Formation; Middle Benue Trough, Nigeria.

A total of 26 representative samples were collected and properly packaged from different locations in Tse-kucha, Ukogh and Alonso-biam. Petrographic study, which is a routine carbonate mineralogical observation, textural description, and modal analysis were carried out on the rock slabs and standard thin section of eighteen (18) Limestone samples, under a petrographic microscope. Biostratigraphic study, which is the study of rock strata using the fossils assemblages contained within them, was carried out on twenty-six (26) samples.

The lithological assemblages show sedimentary sequences of shale and limestone, that represents

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transgressive-regressive cycle with many short lived environments. Petrographic studies which entails routine carbonate mineralogical observation, textural description and modal analysis under petrographic microscope, shows that the limestone as a whole have both mud-supported and grain supported textures with micrite forming over 75% of the bulk. The microfacies recognized include mudstone, bioclastic packstone, intrapelsparite packstone-grainstone, bioclastic grainstone, bioclastic wackestone-packstone, oncologic grainstone-packstone, intrabiomicrite wackestone-packstone, stomatolitic boundstone and bioclastic wackestone microfacies. Foraminifera, algae, ostracods, gastropods, pelecypods and skeletal grains, constitute the major bioclasts, while pellets; oncoids and lithoclasts are the major non-bioclastic components of the microfacies. The systematic biostratigraphic analysis, which entails the identification, classification and description of the microfossils using the binocular microscope, yielded few stratigraphically significant planktonic and benthonic species of foraminifera. Some of the foraminifera species recovered from the sediments include *Ammobaculites coprolithiformis*, *Reophax guineana* and *Gvellingella species*. Ostracods, few echinoids remains and gastropods are the other microfuna recorded. The Integration of interpretations from the lithologic and biostatigraphic data suggests that the sedimentary sequence was deposited in a shallow marine, shelf lagoonal environment.

Keywords: Gboko; benue; petrographic; biostratigraphic; paleoenvironment; limestone.

1. INTRODUCTION

The mid-Cretaceous sediments of the Benue Trough are rich in foraminiferal and ostracods assemblages, which are relevant for paleoenvironmental and paleoecological studies. The presence of foraminifera, abundance of lime mud, oncolite pellets and carbonaceous organic matter as well as glauconite and limited benthic faunal diversity and virtual absence of planktonic micro-organisms suggest quite, shallow water peritidal, lagoonal depositional environment in the Albian Gboko limestone [1,2,3,4,5].

The understanding of depositional environment of an area is quite important in appreciating the geology of the area. This helps to put together the geologic history of a region. The climates of the past, life forms of the past and geography of the past can be reconstructed by reconstructing paleodepositional environments. A depositional history of an area enhances the ability to locate energy deposits in the form of coal or oil, each of which originates in a certain type of depositional environment.

A good understanding of the petrological characteristics of an area, which entails routine carbonate mineralogical observation, textural description and modal analysis, would help to establish the lithofacies. The understanding of the paleontological characteristics which entails the study of rock strata using fossils, would help to establish the biofacies. In this work, petrological characteristics of the rocks exposed

well in a quarry in Tse-kucha, were used to establish lithostratigraphic units and their corresponding lithofacies.

The studied area falls within the Albian Asu River Group [ASRG] sediments of the Middle Benue Trough [MBT] (Fig. 1). To date, little appears to have been published on the Middle Benue Trough have, Unlike the Lower Benue Trough [LBT] where many researchers have worked. Petters [6] worked on the paleontology of Albian sediments exposed at Yandev. Nair and Ramanathan [7] studied the sedimentology, stratigraphy and paleogeographic significance of the Albian limestone at Yandev. Adekeye and Akande [8] studied the depositional environment of carbonates of the ASRG around Yandev. Adekeye [9] further carried out a quantitative analysis and paleoecological interpretation of foraminiferal fauna. This research will combined the lithologic and biostatigraphic data to determine the paleoenvironment of the Limestone-Shale Sequences.

1.1 Research Objectives

The main objectives of this research work are

- a) To determine the allochem and biofraction modal compositions of the Limestones in Gboko Formation.
- b) To examine foraminifera from the Formation and interpret the paleodepositional environment.

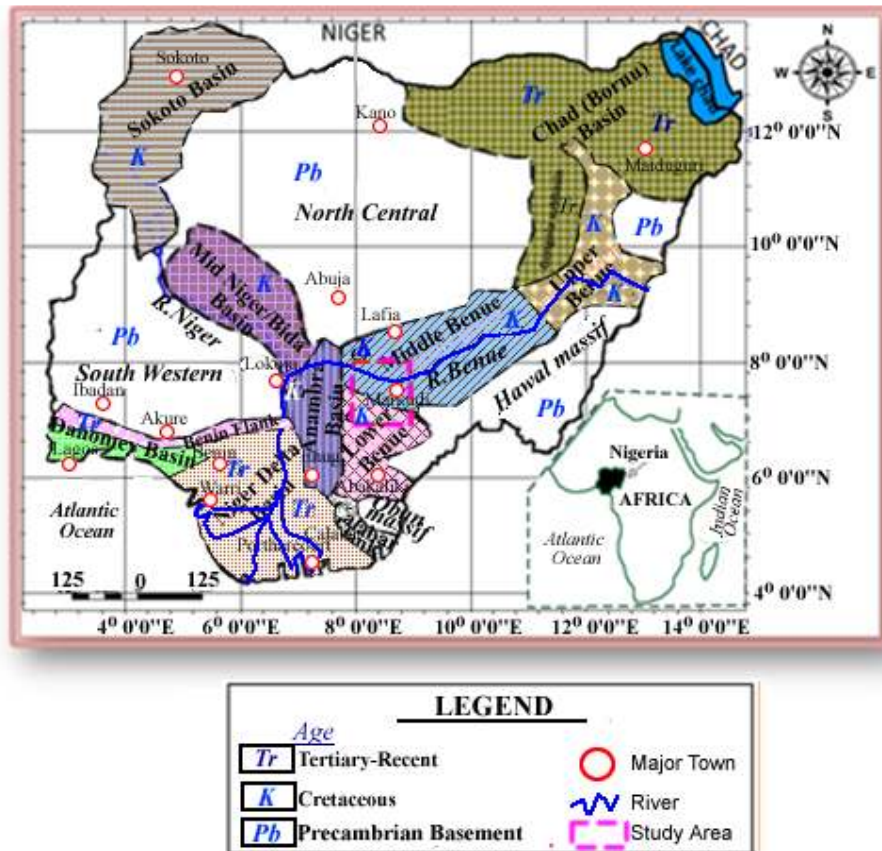


Fig. 1. Map of Nigeria sedimentary basin showing the study area

1.2 The Study Area

1.2.1 Location and accessibility

The study area is located within Latitudes $7^{\circ}00'00''N$ and $8^{\circ}00'00''N$ and Longitudes $8^{\circ}00'00''E$ and $9^{\circ}30'00''E$ (Fig. 2). It lies completely within Benue State, Nigeria and it is accessible by major roads, several minor roads and foot paths. Some portions of the area were practically inaccessible, being largely under the swamp-forming influence of the Benue River.

Geomorphologically, the study area is lying within a depression (largely the Benue river valley) and High plains (i.e. parts of Benue lowlands lying above the river plain but below the 300 m contour line [10].

1.2.2 Drainage, climate and vegetation

The drainage density of the study area is high and the texture is considered fine. The drainage setting belongs largely to river Benue, and

subordinately the river Cross, system. The Benue River which is the major river draining the area is a typical alluvial river.

Gboko Formation largely lies within the tropic region of the Middle Belt Climatic Region of Nigeria and falls within the geographical region that experience two main seasons, rainy and dry seasons. The climatic factors support the rainforest vegetation. The trees in this area are generally isolated and located far apart except along stream channels where they are more luxuriant and form gallery forests which are composed of relatively large trees.

1.2.3 Geologic setting of the study area

The Benue Trough is a basin in Nigeria to which other basins are genetically related. It developed as the failed arm of the R-R-R triple junction, during the episodes of marine transgressions and regressions in the Cretaceous and early Tertiary. It is located in early Cretaceous times at the site of the present day Niger Delta [11].

The Cretaceous sediments of the Benue Trough are geographically divided into Lower, Middle and Upper Benue Trough (Fig. 1) [12,13,14]. They consist of sedimentary sequences of shale and limestone (Fig. 2). The stratigraphic succession of the Middle Benue basin comprises of the Albian Asu River Group (Table 1). The Albian Arufu, Uomba, Gboko Formations are generally referred to as the Asu River Group [15]. These sediments are interpreted as sediments of the first marine transgressions into the Benue valley. This Group is succeeded by the late Albian - early Cenomanian Awe Formation; a regressive phase which succeeded the first marine transgressive phase. Overlying this Formation is the Keana Formation, the lateral equivalent of Makurdi Formation. This was deposited in fluvial environments during the Cenomanian regression in the Middle Benue region. The late Cenomanian - early Turonian Eze-Aku Formation overlies the Keana

Formation. It marks the beginning of the second depositional cycle (marine strata). Overlying this Formation in the upper section is the late Turonian-Early Santonian Agwu sediments. This represents the last shallow marine deposits of the second depositional cycle. This was followed by Mid-Santonian period of folding throughout the Benue Trough. The post-folding Campano-Maastrichtian Lafia Formation unconformably overlies Agwu Formation. It ended the sedimentation in the Middle Benue Trough. This Formation represents sediments of the third depositional cycle in the middle Benue region. The sediments were deposited in a continental (fluvial) environment.

The purpose of this paper is to document the distribution of the foraminifers and ostracods in the outcrop sections of the limestone-shale sequences and their significance in regard to the depositional environment.

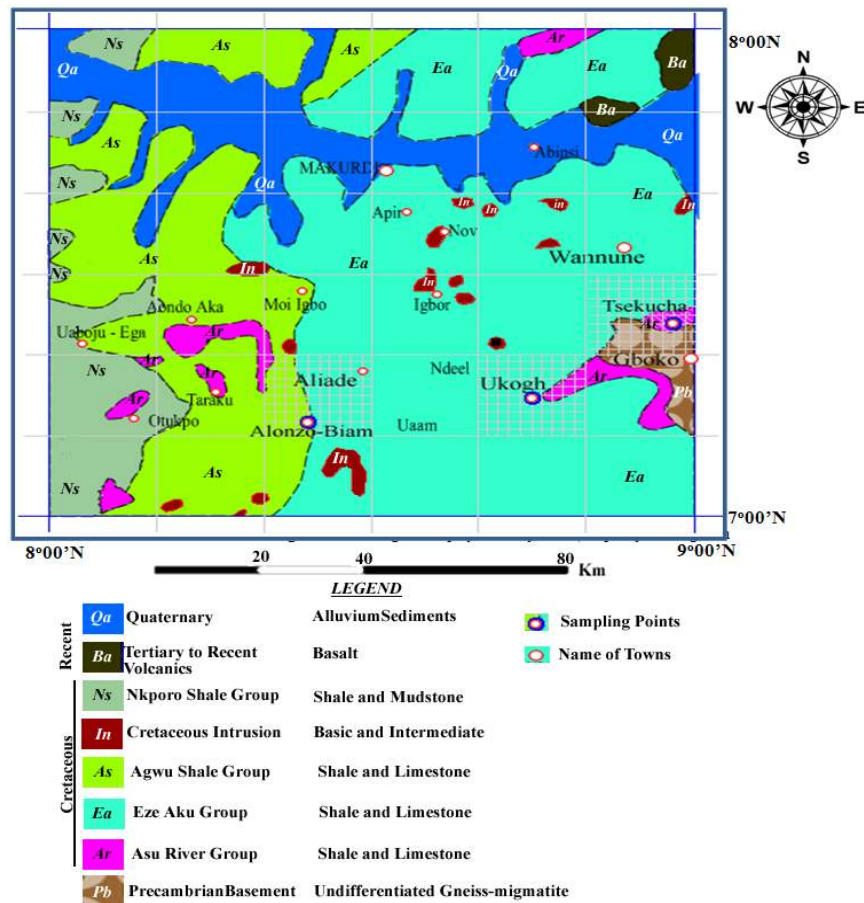


Fig. 2. Geological map of middle Benue trough showing the stratigraphic successions and sampling points (adapted from Nigeria Geological Survey Agency [16])

Table 1. Cretaceous paleoenvironments and lithostratigraphy of the Middle Benue trough

Million year	Age	Sea movement	Lithostratigraphy	Paleoenvironment
54.9	Eocene		Volcanics	Volcanics
	Paleocene			
65	Maastrichtian	Regression (deposit of 3 rd depositional cycle)	Lafia Formation	Continental to marginal marine (deltaic to estuarine)
73	Campanian			
83	Santonian	Transgressive (Last deposit of 2 nd depositional cycle)	Agwu Formation	Complete marine inundation in both southern and central parts, paralic in the north
		Transgressive (Beginning of 2 nd depositional cycle)		
87.5	Coniacian	Regressive (Beginning of 2 nd depositional cycle)	Eze Aku Fm	Both marine and transitional regimes
88.5	Late Turonian		Makurdi Formation	Fluctuation from marginal marine occasional full marine to fluvial
	93	Early turonian	Keana Formation	Continental Fluvial
100		Late Cenomanian	Awe Formation	Marginal Marine Lagoonal/evaporitic to Fully Marine
119	Early Cenomanian			
	Late Albian	Asu River Group Arufu Limestone, Uomba, Gboko Formation, Pre-Bima sandstone	Marine-Continental (Alluvial fan-Fluvial)	
	Early Albian			1 st Marine Transgression
	Aptian Barremian Hauterivian			Sea shore about mid way up Middle Benue Trough
Precambrian - Cambrian		Basement Complex		

===== = **Unconformity**

2. MATERIALS AND METHODS

This study involved measurements, documentation of sedimentologic features and

collection of representative samples. Fresh samples of shale and limestone were selected for further studies.

2.1 Sampling Process and Method

This involved reconnaissance survey, which was followed by a detailed geological mapping in October. Global Positioning System (GPS) was employed in locating accurately the geographical position of exposures and these locations were plotted immediately on the base map. This method entails proper observation, identification and systematic description of the rocks, and eventual collection of representative rock samples from exposures, river channels, road cuts. The lithologies of the sampling locations were drawn and also the rocks features such as colour, thickness, texture, structures were noted down on the field note. The samplings were carried out at different locations in the following places; Benue Cement Company Quarry in Tsekucha, Ukhogh, and Alonso-Biam. The samples collected were labeled appropriately and brought for further studies in the laboratory.

2.2 Biostratigraphic Studies

Biostratigraphy is the study of rock strata using fossils. A total of 26 samples were processed for microfossils (especially foraminifera). The systematic paleontology is based on the published reports of species, which were already described in literature in the works of Petters [6,17] and Reyment [18].

About 25g of the pre-treatment samples were placed in the sample plate with corresponding labels attached and were securely placed on the hot plate. The hot plate was put on and regulated to a temperature of about 80°C for 2-3 hours and allowed to cool. The dried samples were then weighed. Microfossils especially foraminifera and Ostracods were washed out of the samples in the laboratory using routine washing technique with hydrogen peroxide (H₂O₂) and deionised water. After drying, each sample was sieved into coarse, medium and fine fractions before picking. Each of these fractions was scattered gently and evenly in a picking tray. The identification, classification and description of the microfossils were carried out using the binocular microscope (EFMA, No 772822). Microfauna found were picked onto a labeled slide with the aid of moistened picking brush. This analysis was carried out in the laboratory of Global Energy, Lagos.

2.3 Petrographic Studies

Routine carbonate mineralogical observation, textural description and modal analysis were

carried out on the rock slabs and standard thin section of 18 Limestone samples. The samples were broken into smaller chunks using hammer, before they were taken to the petrological laboratory for thin sectioning.

In the laboratory, a cutting machine was used to cut the rocks samples into a small flat polished surface chips. The mounting slides were also grinded to produce a flat polished surface, using a mechanized grinding machine. This was to prevent the slide from breaking when mounting the chip on it. The polished chips surface was mounted on the prepared glass slide (76 mm x 25 mm x 1.2 mm) using superglue. It was then left to dry up. The mounted chips were then grinded to a thickness of 30 microns.

The thin sections of the limestone were studied under a petrographic microscope. The constituent minerals were observed. The microfacies determinations were carried out using a petrographic microscope (Olympus CX31-P) with transmitted light. Folk [19], Wilson [20] check list, and Dunham [21] charts were used for the carbonate rock classification. The analysis was carried out in the Geological department, University of Ibadan, laboratory.

3. RESULTS AND DISCUSSION

3.1 Lithostratigraphic Description and Depositional Environments

Three outcrop sections within the Gboko Formation were studied. The section exposed on the quarry face is about 80 m thick (Fig. 3). This was divided into two sections, a lower section consisting of limestone with millimeter-thick shale partings and an upper section consisting of meter thick shale and limestone beds. The beds show alternation of shale and limestone (Fig. 3). The alternation of the shale and limestone units suggest relatively unstable carbonate shelf platform in which at intervals, clastics were supplied from adjacent highlands at low sedimentation rate [22]. The shale/limestone couplets are remarkably laterally persistent. The shale beds are thinly laminated, dark grey, carbonaceous and generally devoid of micro fauna. The limestone beds are light gray and thin to very thickly bedded (<10 cm to 100cm) (Fig.5).

In the lower half of the exposed section, shale occurs as paper-thin laminae to thin beds rhythmically alternating with the limestone beds. In the upper half, the limestone layers show a

narrow thickness range, the shale range in thickness from less than one millimeter to over a meter. The shale thus exhibits a thickening upward trend which is not as clearly evident for the limestone. In the lower half of the quarry face, the very sharp boundary between the paper-thin shale and limestone beds is attributable to diagenetic overprinting. In the process, carbonate was dissolved and moved from the initially more clayey layers to the purer carbonate layers where calcite cement was precipitated. Thus the layers initially richer were further enriched. The initially more clayey members then collapsed into shale seams, or into stylolites.

The sediments are fossiliferous, and contain numerous ammonites (Fig. 4), bivalves, few gastropods, and pelecypods fossil. Pyritized worm burrows are common (Fig. 4). Laminated shale with phosphatic nodules scattered all around. The presence of quartz indicates

nearness to the shoreline while the pyrite suggests marine and/or reducing depositional environment. The rhythmic carbonate-shale alternation, i.e. a more or less regular alternation of chemical and clastic depositional conditions, may be due to quiet water sedimentation (resulting in mud/clay snerling) regularly alternating with slight deepening to clearer water conditions, promoting micrite precipitation. Such rhythmic alternation of shales and carbonate layers has also been attributed to diagenetic unmixing whereby secondary carbonate migration accentuated primary inhomogeneities [23,24]. However the sharpness of the lithological boundaries, presence of carbonate-filled burrows in some of the shale beds and the perfect horizontality of the strata suggest origin by primary sedimentation. A shallow marine shelf to lagoonal environment was established, based on the earliest marine transgression into the Benue Trough in the Aptian to Albian [7,8].

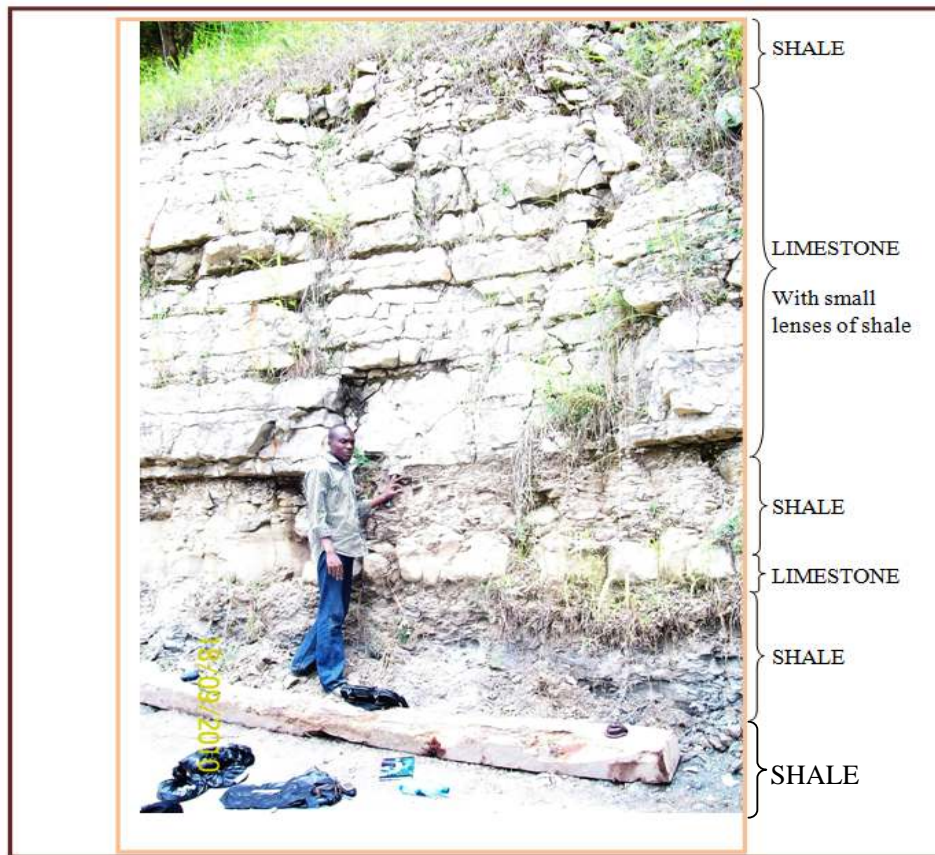


Fig. 3. A photograph of shale beds rhythmically alternating with the limestone beds at Benue cement quarry, Tse-kucha; Benue State. (Scale: Geologist=1.77m tall)



A. A limestone showing pyritization collected



B. A completely pyritized planolites burrow in a limestone collected



C. A complete remains of an ornated Ammonite in limestone collected from Tse-kucha



D. A recrystallised calcite in limestone collected from Tse-kucha



E. A bivalve shell collected from Tse-kucha limestone

Fig. 4. Features collected from limestone-shale sequence of Gboko formation

In Ukogh village (near Akpergher), the limestone are exposed on the farmland and along stream channels. They are grayish in colour with microcrystalline texture. Tiny or juvenile bivalve impressions were observed. The topsoil is

dominantly lateritic and clayey in places. Most of the grasses and plants are flourishing very well due to soil conditioning capacity of the limestone. In Alonso-Biam (off Aliade), the limestone also occurred as large boulders exposed along

stream channel. They are grayish in colour. The topsoil is lateritic and brownish-black in colour (lateritic shale).

The lithostratigraphic section of Gboko Formation logged at Benue Cement Company Quarry, Tse-kucha is presented in Fig. 5. The carbonates were described and grouped using Folks [19] classification table (based on composition) and Dunham [21] classification table as modified by

Embry and Klovan [25] (based on depositional texture). Texturally, the limestones ranges from grainstones to mudstones and the allochems include gastropod, coralline algae, pelecypods, foraminifera, brachiopods, echinoid fragments and other skeletal debris. Such an assemblage points to a shallow marine environment [26]. The presence of oncolitic grainstones points to a moderately high-energy areas in very shallow waters [8].

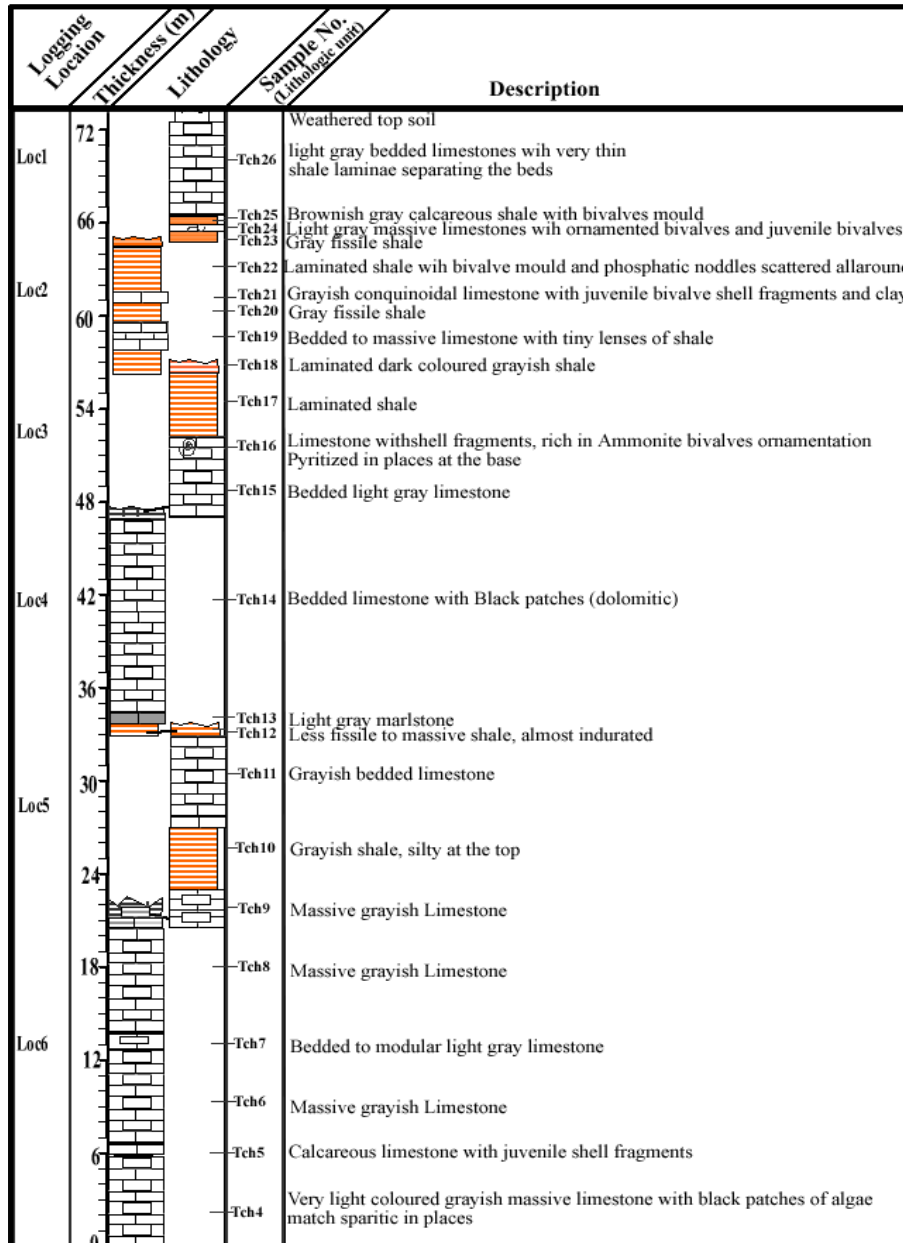


Fig. 5a. The lithostratigraphic section of Gboko formation logged at Benue cement company quarry, Tse-kucha

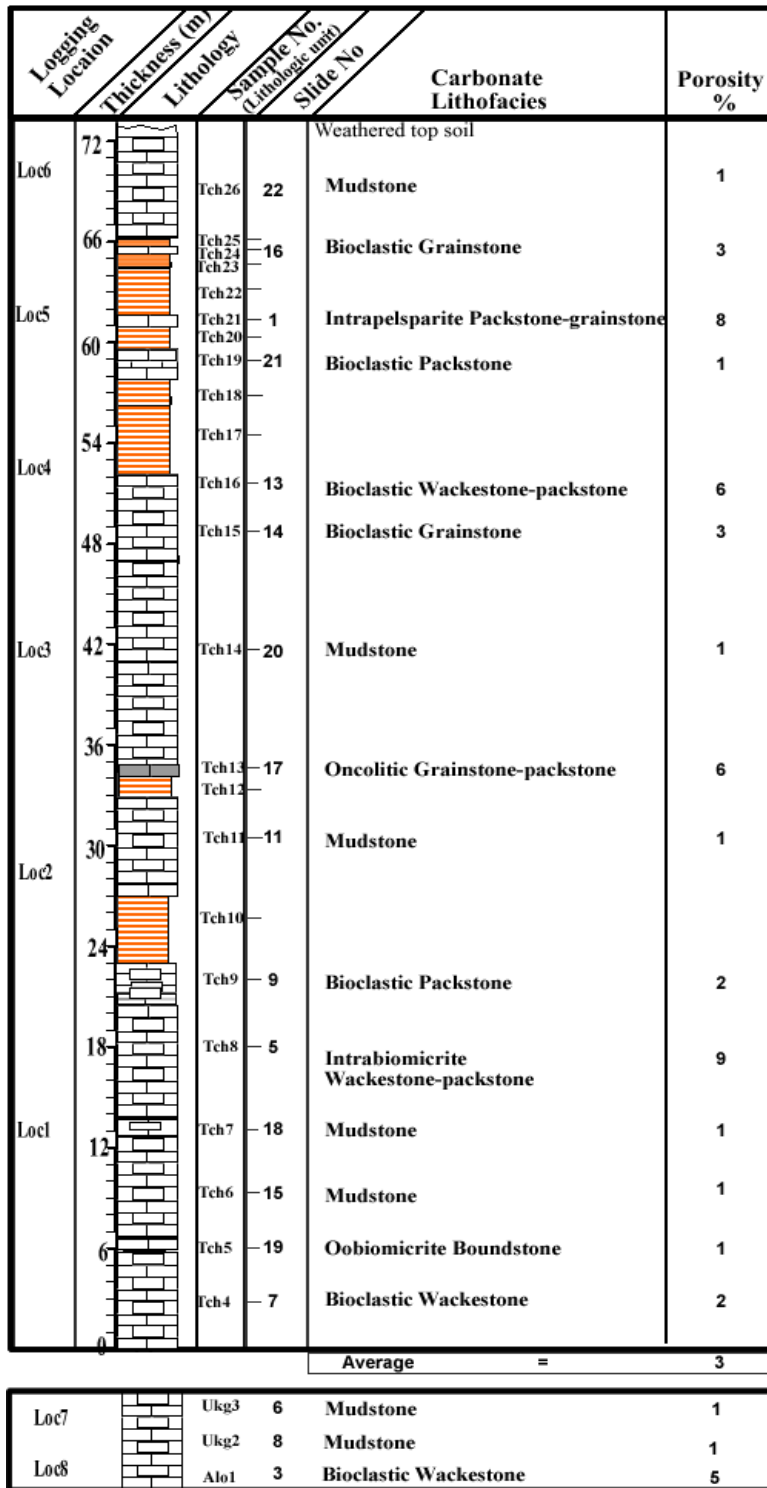


Fig. 5b. The carbonate lithofacies and visual porosity for associated limestones.

The prevalence of micrite which is uniformly created by worms, are common evidence of a recrystallised to drusy cement and burrows shallow intertidal environment characterized by

low energy [20]. The abundance of lime mud in the groundmass combined with a shallow marine fauna, gastropods and coated grains indicating mild protection and occasional tidal energy; suggest that these facies formed in a protected shallow marine inner shelf setting [27]. The bioclastic packstone-wackestones which show high diversity and abundance of micro and macrofauna were probably formed in the shallow open marine environment with moderate circulation and agitation [22,28]. The bioclastic wackestones are characteristics of shoreward deposit of subtidal restricted lagoon and shoals. The bioclastic grains are those derived from carbonate secreting organisms living in the subsurface area. The bioclastic packstone and intrapelsparite packstone-grainstone microfacies with some coated and abraded broken fragments of bioclasts resemble deposits in an area textural inversion, where dominant particles from the high energy environment have moved down local slopes to low energy setting [8,20]. The bioclastic grainstone are common in intertidal zone of shallow marine water.

3.2 Paleocology and Distribution of the Foraminiferal Fauna

The summary of the foraminiferal biostratigraphic studies is presented in Table 2. The studied sediments yielded few foraminifera species. Fossils were only recorded at particular intervals while others were completely barren of fossils. Some of the foraminifera species recovered (Fig. 6) from the sediments were used based on their abundance occurrence, well preserved state in marine and brackish water, their stratigraphic relationship with the environment they live in, and similarity between biofacies of tertiary and recent.

Ammobaculites: - This genus covers almost all ecological niches in modern seas [29]. They are infaunal deposit feeders. The organism lives in muddy sediments of brackish to normal marine salinity in marsh to upper bathyal environments [30,31]. *Ammobaculites* are tolerant to low oxygen level. *A. corproolithiformis* *Ammobaculites* sp. and *Ammobaculites benuensis* were found in the studied section.

Ammotium: - This is an infaunal deposit feeder, restricted to shallow brackish water of tidal marshes, brackish lagoons and estuaries and enclosed brackish shelf seas [31]. *Ammotium nwalium*, *Ammotium* sp. and *Ammotium nkalagum* were found in the studied section.

Gavelinella: - This epifaunal genus may be allocated to dysoxic environments. It is an active deposit feeder that tolerates low oxygen level. The only species found in the sections of the Gboko Formation that was studied is *Gavelinella* sp.

Anomalina: - These species are infaunal deposit feeders. They are decretive mud dwellers living in marine shelf seas [31]. This genus tolerates low oxygen levels. The only species found in the studied sections of the Gboko Formation is *Anomalina plummerae*.

Miliammia: - The species occurs in a very wide range of environments from brackish water to hypersaline marshes down to upper bathyal [30]. This is an infaunal deposit feeder dwelling in muddy and silty sediments [31]. The only species found in the studied sections of the Gboko Formation is *Miliammia pindigensis*.

Reophax: - This genus is commonly found in mud and sands of lagoons, shelves and bathyal regions [29]. It may occur in brackish lagoon and estuaries [32] and mostly in infaunal deposit feeder. The only species found in the studied sections of the Gboko Formation was *Reophax guineana*.

Fursenkoina: - This genus is infaunal deposit feeder thriving in muddy sediments under marine conditions, in lagoons, shelf seas and upper bathyal realm [30]. The only species found in the sections of the Gboko formation that was studied is *Fursenkoina dibollensis*.

Lenticulina: - Ramanathan and Kumaran [33] described these species from the Lower Cretaceous subsurface sediments in Calabar flank, Nigeria. Schiebnerova [34] also described and illustrated it to be from Aptian to Albian interval of the Indian Ocean. Only a solitary specimen was recovered i.e. *Lenticulina taylorensis*.

Heterohelix: - This genus is a shallow water fauna (0-50 m); epipelagic. It is Planktic species that shows a wide variation in trochoidity. It ranges from Upper Albian to Maastrichtian. The species found in the section of the Gboko Formation that was studied are *Heterohelix moremani*: - It has been used to date rocks of Cenomanian age in the Gulf Coast of United State and Brazil. *Heterohelix reussi* recorded it first appearances in early Turonian. Biostratigraphic record from Texas, Arkansas,

Mississippi, Bohemia, Mexico and Egypt shows that *Heterohelix reussi* ranges from Turonian to Maastrichtian [35].

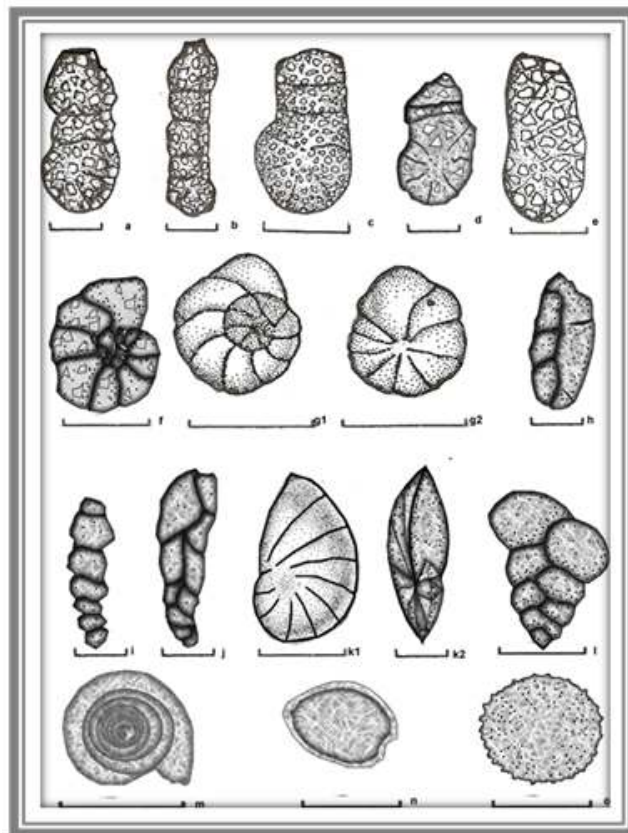
Hedbergella: - This genus is a shallow water fauna (0-50 m); epipelagic. It is of late Aptian to early Albian in age. Rugosity is a preserved artifact of hedbergellids of this age, although Leckie [36] has argued against widespread poor preservation as the principal cause for the marked decline in planktonic foraminiferal diversity during latest Aptian-early Albian time. The only species found in the studied sections of the Gboko Formation is *Hedbergella* sp.

Ostracods: - Ostracods is found from the Cambrian to recent. They have been particularly useful for the biozonation of marine strata on a local or regional scale, and they are invaluable indicators of paleo-environments because of their widespread occurrence, small size, easily-

preserve generally-molted calcified bivalve carapaces, and the valves are a commonly found microfossil.

Gastropod: - are found worldwide, in marine, freshwater, and terrestrial environments. They are numerous with low species diversity. Most gastropods are benthic, some are crawlers. The fossil history of this class goes all the way back to the Late Cambrian.

Echinoid remains: - Echinoderms are found at every ocean depth, from the intertidal zone to the abyssal zone. They are wholly marine organisms (echinoids, sea urchins, crinoids), they occupy reefs and associated environments, whereas crinoids are in deeper waters and not significant as carbonate producers. The echinoderms are important geologically, as their ossified skeletons are major contributors to many limestone formations, and can provide valuable clues as to the geological environment.



- (a.) (b.) *Ammobaculites coprolithiformis*.
- (c.) *Ammobaculites* sp.
- (d.) *Ammobaculites benuensis*.
- (e.) *Ammotium* sp.
- (f.) *Gavelinella* sp.
- (g1.) (g2.) *Anomalia plummerae*
- (h.) *Miliammina pindigensis*.
- (i.) *Reophax guineana*
- (j.) *Fursenkoina dibollensis*
- (k.) *Lenticulina taylorensis*.
- (l.) *Heterohelix reussi*.
- (m.) Gastropod.
- (n.) Ostracods.
- (o.) Echinoid.

Fig. 6. Foraminifera species and other microfauna from Gboko formation. (Bar length indicates 0.2 mm).

Table 2. The foraminifera discovered in percent genera

SAMPLE	Benthonic								Planktonic		Other Microfauna		
	Arenaceous (Agglutinated)							calc	Heterohelix	Hedbergella	Ostracods	Gastropod	Echinoids remains
	48%							1%					
	<i>Ammobaculites</i>	<i>Ammolium</i>	<i>Gavelinella</i>	<i>Anomalina</i>	<i>Miliammina</i>	<i>Reophax</i>	<i>Fursenkoina</i>	<i>Lenticulina</i>					
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Tch26	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch25	13	0	0	0	0	6	0	6	6	6	25	38	0
Tch24	0	0	0	0	0	0	0	0	0	0	100	0	0
Tch23	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch22	0	43	0	29	14	14	0	0	0	0	0	0	0
Tch21	0	0	0	0	0	0	0	0	0	0	82	4	14
Tch20	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch19	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch18	50	0	0	0	0	0	33	0	0	17	0	0	0
Tch17	5	7	85	0	0	0	0	0	2	0	0	0	0
Tch16	0	0	0	0	0	0	0	0	0	0	36	64	0
Tch15	0	0	0	0	0	0	0	0	0	0	100	0	0
Tch14	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch13	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch12	0	0	100	0	0	0	0	0	0	0	0	0	0
Tch11	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch10	43	14	14	0	0	0	0	0	0	0	14	14	0
Tch9	0	0	0	0	0	0	0	0	0	0	100	0	0
Tch8	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch7	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch6	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch5	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch4	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch3	-	-	-	-	-	-	-	-	-	-	-	-	-
Tch2	0	0	0	0	0	0	0	0	0	0	100	0	0
Tch1	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Percent	8	5	29	2	1	2	2	1	2	2	32	13	3

3.3 Paleoenvironment Interpretation of the Limestone-Shale Sequences of Gboko Formation

The paleoenvironment and probable age of the samples is summarized and presented in Table 3. The criteria considered when assigning environment include Species diversity, Planktic foraminiferal count, Foraminiferal population and Planktonic Benthonic ratio.

The recovered foraminifera include both the planktonic and benthonic forms (Table 2). In term

of abundance, the foraminiferal recovered could be described as rare to moderate with low species diversity. High dominance and low diversity is characteristic of nearshore-shallow water marine environments. The benthonic forms were dominant and dwarfed, while the planktonic forms were relatively scanty. The benthonic is predominantly composed of agglutinated taxa (48%) with very few calcareous taxa (1%) and planktonic taxa (3%). Ostracod, echinoid remains, scaphopod and gastropod are the other microfauna (48%) recorded (Table 2). The assemblages differ from normal marine which

consist predominantly of calcareous species. Funas consisting dominantly of agglutinated forms are attributed to brackish environments or to stagnant conditions [37]. The relative abundance of the Foraminiferal suborders was also considered because of low diversity of species. This was by a triangular plot of Textulariina, Milioliina, and Rotaliina abundance which show the fields marine environments as reported by Murray [31]. From the triangular plot (Fig. 7) it is evident that the sediments were deposited on hyposaline lagoons.

Benthic foraminifera are generally mostly affected by ecological conditions of their environment and they thus react appropriately to various environmental settings [6]. Reliable paleoecological interpretations of past environment with regard to paleobathymetry, paleosalinity, or paleo-oxygenation can be made with the aid of benthonic foraminifers, at least as far back as the Cretaceous [31,38]. This method was used based on successes recorded by previous workers. The average percentages of the benthic foraminiferal assemblages in the studied beds are made of two categories: the calcareous species have average population density of 1% while the arenaceous benthics have average population density of 48%. *Ammobaculites* (8%) and *Gavelinella* (29%) are the most frequent genera at tse-kucha, while additional occurrences of *Ammotium* (5%), *Reophax* (2%) are indicative for brackish

conditions at tse-kucha (Table 2). The planktics recovered are *Heterohelix* (2%) and *Hedbergella* (2%) which indicates a shallow-water regime, probably between 0 to 50 m depth. The Heterohelicids are age diagnostic according to Gebhardt [30]. *Heterolix moremani* (Cushman) ranges from Albian to Turonian while *Heterohelix reussi* (Cushman) ranges from Turonian to Campanian. Non-foraminiferal fossils referred as accessories were identified and classified as ostracods, gastropod species and echinoid remains etc. The gastropods are benthic forms which clearly reveal near shore confined shallow marine environment. The distributions of the accessories are given as 32%, 13%, and 3% respectively. The calculated average percentage of planktic foraminiferal assemblages in the studied beds is 3%, benthonic is 50% while that of the accessories is 48% (Table 2).

The predominant factor that controls the distribution of foraminifers and other marine microfossils is salinity [39]. The occurrence of a predominantly agglutinated foraminiferal assemblage in the studied strata suggests the existence of a low salinity environment of deposition for the sediments. In low salinity condition, shallow marine foraminiferal assemblages are characterised by a low population with benthonic species dominating. This is because of the intolerant nature of the planktonic species to wide salinity ranges, especially to low salinity [40].

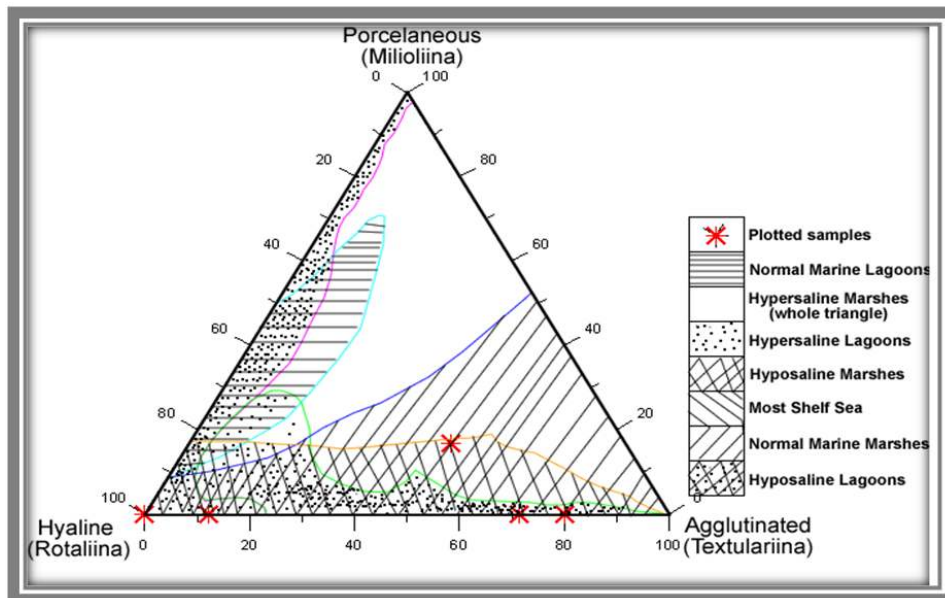


Fig. 7. Triangular diagram showing depositional environment adapted from Murray [41])

Table 3. The paleoenvironment and probable age of the limestone-shale bed

SAMPLE	PALEOENVIRONMENT OF DEPOSITION	PROBABLE AGE	COMMENT
Tch 26			
Tch 25	Marginal/Shallow marine	Upper Cretaceous	Foraminifera common
Tch 24	Fluvial/Marginal Marine	Non Diagnostic	No Foram, Ostracod present
Tch 23	Continental	Non Diagnostic	Barren of Foraminifera and other microfossils
Tch 22	Marginal/Shallow marine	Upper Cretaceous	Rare foraminifera
Tch 21	Shallow Marine	Non Diagnostic	no Foram, Microfauna represented by echinoid remains, Ostracods and gastropod
Tch 20	Continental	Non Diagnostic	Barren of Foraminifera and other microfossils
Tch 19			
Tch 18	Marginal/Shallow marine	Upper Cretaceous	Rare foraminifera
Tch 17	Shallow Marine	Upper Cretaceous	fairly abundant foraminifera
Tch 16	Fluvial/Marginal Marine	Non Diagnostic	Microfauna represented by gastropod and ostracod
Tch 15	Fluvial/Marginal Marine	Non Diagnostic	Ostracod only
Tch 14	Continental	Non Diagnostic	Barren of Foraminifera and other microfossils
Tch 13	Continental	Non Diagnostic	Barren of Foraminifera and other microfossils
Tch 12	Shallow Marine	Non Diagnostic	Rare foraminifera
Tch 11	Continental	Non Diagnostic	Barren of Foraminifera and other microfossils
Tch 10	Shallow Marine	Non Diagnostic	Few foraminifera
Tch 9	Continental	Non Diagnostic	Barren of Foraminifera and other microfossils
Tch 8	Continental	Non Diagnostic	Barren of Foraminifera and other microfauna
Tch 7	Continental	Non Diagnostic	Barren of Foraminifera and other microfossils
Tch 6	Continental	Non Diagnostic	Barren of Foraminifera and other microfossils
Tch 5	Continental	Non Diagnostic	Barren of Foraminifera and other microfossils
Tch 4	Continental	Non Diagnostic	Barren of Foraminifera and other microfossils
UKG 3	Continental	Non Diagnostic	Barren of Foraminifera and other microfauna
UKG 2	Fluvial/Marginal Marine	Non Diagnostic	Ostracod only
ALO 1	Continental	Non Diagnostic	Barren of Foraminifera and other microfauna

The planktonic forms were relatively scanty, which suggests that the environment was unfavourable for their survival. Bernhard [42] categorizes oxygen levels as anoxic (<0.1 ml/1O₂), dysoxic (0.1-0.5 ml/1O₂) and oxic (>0.5 ml/1O₂). Anoxic bottom conditions are characterized by the absence of calcareous benthonic foraminifera but the presence of

planktonic foraminifera [43,44,45]. Agglutinated benthonic foraminifera, however can survive under dysoxic to anoxic conditions [44,46]. Low-oxygen content may also create difficulties in calcium carbonate secretion [42], [47] and therefore leaves agglutinated foraminifera as the only survivors under strong oxygen deficiencies. The dominance of

agglutinated foraminifers and abundance of infaunal forms with some planktonic species indicate oxygen depletion and are therefore interpreted to represent a dysoxic to suboxic environments for the study area.

The small number of planktonic foraminifers (3%), relative to the benthonic foraminifers (49%) in the limestone-shale sequences of Gboko formation indicates deposition under shallow water marine condition. A low percentage of planktonic foraminifers, a relatively low diversity of species and a dominance of benthonic over planktonic forms are reasons to infer a shallow water environment for the Gboko formation.

4. CONCLUSION

This Gboko Formation lithounits comprises study has attempted to analyze the biostratigraphy of Limestone and Shale sequences in Gboko Formation; Middle Benue Trough, Nigeria. Shale and limestone were the major lithologies of the Formation that were critically assessed.

The limestone beds are light to dark grey, thin to massive, wavy laminated, and stylolitized. The shale beds are generally dark-grey, laminated and fossiliferous. Ammonites, pelecypods and molluscs are abundant. Carbonaceous detritus, glauconite and detrital pyrite occur in various forms both in the limestone and shale beds. However the sharpness of the lithological boundaries, presence of carbonate-filled burrows in some of the shale beds and the perfect horizontality of the strata suggest origin by primary sedimentation.

The presence of Heterolids (Heterolix moremani and Heterolix reussi) which are age diagnostic confirmed that all the samples are Cretaceous in age and that they were derived from a mixture of terrestrial and marine biota deposited under anoxic/dyoxic condition. The studied sediments are generally low in fauna population and diversity. A good number of the samples are barren of foraminifera and other microfauna. Some of the foraminifera species recovered from the sediments include *Ammobaculites coprolithiformis*, *Ammotium* sp, *Gvelinella* sp, *Anomalina*, *Miammia*, *Reophax guineana*, *Fursenkoina dibollensis*, *Lenticulina taylorensis*, *Heterohelix* and *Hedbergella* species. Ostracods, echinoid remains, scaphopods, and gastropods are the other microfauna recorded. The dominant arenaceous benthic foraminifers and the smooth ostracods

suggest a mainly shallow marginal marine brackish water environment with an increase in water depth represented by horizons with planktonic foraminifers.

The presence of abundant lime mud supported carbonate rock types, glauconites, oncolites, corals, few monotonous species of bioclasts, limited benthic foraminifera and ostracods (population and diversity) and almost complete absence of planktonic foraminifera suggest a shallow marine shelf lagoonal depositional environment. Sea level fluctuation, probably due to intermittent subsidence was responsible for the alteration of shale and limestone in the formation.

The Integration of interpretation from the lithologic and biostratigraphic data suggests that the sedimentary sequence was deposited in a shallow marine, shelf lagoonal environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Logging Location	Thickness (m)	Lithology	Sample No. (Lithologic unit)	Description	PALEOENVIRONMENT OF DEPOSITION
Loc1	72		Tch26	Weathered top soil	
				light gray bedded limestones with very thin shale laminae separating the beds	
Loc2	66		Tch25	Brownish gray calcareous shale with bivalves mould	Marginal/Shallow marine
			Tch24	Light gray massive limestones with ornamented bivalves and juvenile bivalves	Fluvial/Marginal Marine
			Tch23	Gray fissile shale	Continental
			Tch22	Laminated shale with bivalve mould and phosphatic nodules scattered allaround	Marginal/Shallow marine
			Tch21	Grayish conquinoidal limestone with juvenile bivalve shell fragments and clay	Shallow Marine
			Tch20	Gray fissile shale	Continental
			Tch19	Bedded to massive limestone with tiny lenses of shale	
			Tch18	Laminated dark coloured grayish shale	Marginal/Shallow marine
			Tch17	Laminated shale	Shallow Marine
	Loc3	54		Tch16	Limestone withshell fragments, rich in Ammonite bivalves ornamentation Pyritized in places at the base
			Tch15	Bedded light gray limestone	Fluvial/Marginal Marine
48					
Loc4	42		Tch14	Bedded limestone with Black patches (dolomitic)	Continental
			Tch13	Light gray marlstone	Continental
			Tch12	Less fissile to massive shale, almost indurated	Shallow Marine
	36		Tch11	Grayish bedded limestone	Continental
Loc5	30		Tch10	Grayish shale, silty at the top	Shallow Marine
			Tch9	Massive grayish Limestone	Continental
	24		Tch8	Massive grayish Limestone	Continental
	18		Tch7	Bedded to modular light gray limestone	Continental
Loc6	12		Tch6	Massive grayish Limestone	Continental
			Tch5	Calcareous limestone with juvenile shell fragments	Continental
	6		Tch4	Very light coloured grayish massive limestone with black patches of algae match sparitic in places	Continental
	0				

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