Facies Evaluations and Paleoenvironmental Reconstruction of the Turonian Nkalagu Formation, South Eastern Nigeria

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ABSTRACT

The Turonian Nkalagu Formation exposed at NIGERCEM (Nigerian Cement Company) within the Lower Benue Trough was studied in this work in order to determine and establish the lithostratigraphic successions and reconstruct the paleoenvironment of the deposition. Two major litho-facies were delineated. The first is matrix-supported bioclastic shell lag wackestone facies which account for about 70% of the carbonates. The second is a massive fossil-poor micritic limestone. However, using the fossil contents, five distinct micro-biofacies were recognized namely: massive lithoclastic floatstone, bioclastic wakestone, siliceous fossil-poor limestone, bioclastic (bivalve debris) wackestone and bioclastic packstone. The litho-clast consists of probably shallow water transported materials while still in various degrees of lithification from shelf into deeper basin. Many of the lithoclasts are sub-angular whereas others have rounded shape. Textural gradient was upward fining and algae were completely absent which is typical of shallow calcareous marine sediments of the photic zone. The trends of the textural characteristics fall in pattern correlatable with the different facies outlined in the study. Thus, the evidence from this study has put Nkalagu Formation as a deposition in shallow marine environment but later displaced into relatively deeper water, probably that of the off-shelf zone, by some sedimentary flow mechanisms.

Key words: Turonian, paleoenvironmental reconstruction, lithoclasts, bioclasts, facies, Nkalagu Formation

INTRODUCTION AND GEOLOGICAL BACKGROUND

The Turonian Nkalagu Formation characterized the Mid-Cretaceous cyclic succession of shale and limestone and it is the major shale/carbonate stratigraphic unit of the Mid – Late Cenomanian to Turonian within the Lower Benue Trough of Nigeria (Simpson, 1955; Reyment, 1965; Peters and Ekweozor, 1982). The type section of the Nkalagu Formation is located at the Nkalagu limestone quarry of Nigeria, where it is well exposed in two quarry faces (Fig.1) Each outcrop is about 30m thick and comprises alternating successions of shale and limestone of varying thickness. The beds at Nkalagu area have NE – SW strike and dip averagely $6^0 – 8^0$ to the NW. A total of twenty-five limestone beds have been identified and serially numbered by Amajor (1992), (Fig. 2).

Figure 1: (A) Nkalagu limestone quarry

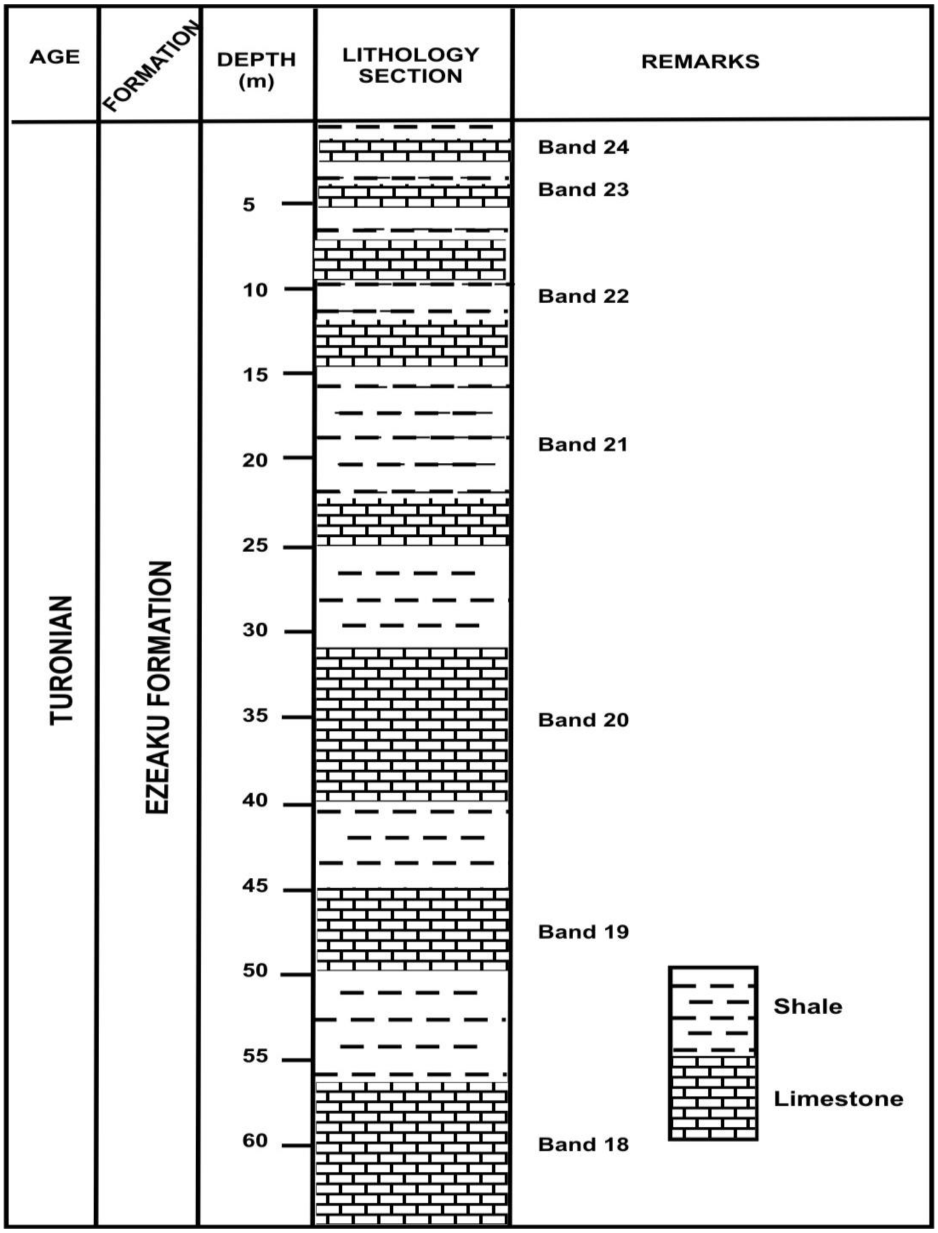


Figure 2: Typical vertical lithologic section at NIGERCEM quarry face at Nkalagu (Modified Amajor, 1992)

Many workers; Reyment (1965), Murat (1972), Fayose and de Klasz (1976), Peters (1978a, b and 1980) and Peters and Ekweozor (1982) have worked on the age, biostratigraphy and environment of deposition of the formation. They all agreed on a Lower Turonian age and shallow marine depositional environment except Peters and Ekweozor (1982) and Banerjee (1981) who proposed an Upper Turonian to Lower Coniancian age and high density turbidity current in deeper water environment, respectively.

In this study, the detailed analysis of the limestone with emphasis on the micro and lithofacies of the formation was determined to provide new evidences for paleoenvironmental reconstruction and to determine and establish the lithostratigraphic succession as well as the different microfacies types.

The study area is a quarry site of Nigerian Cement Company (NIGERCEM, PLC) located in Nkalagu (SE Nigeria). It lies between the latitudes 6^0 10'N and 6^0 40'N and longitudes 7^0 35'E and 7^0 50'E covering a vast area in term of its landmass. Accessibility is enhanced through a network of roads from adjourning towns as shown in (Fig. 3). The drainage pattern is dendritic with interconnections of streams and rivers. Vegetation is more of grassland with scanty trees and farmlands.

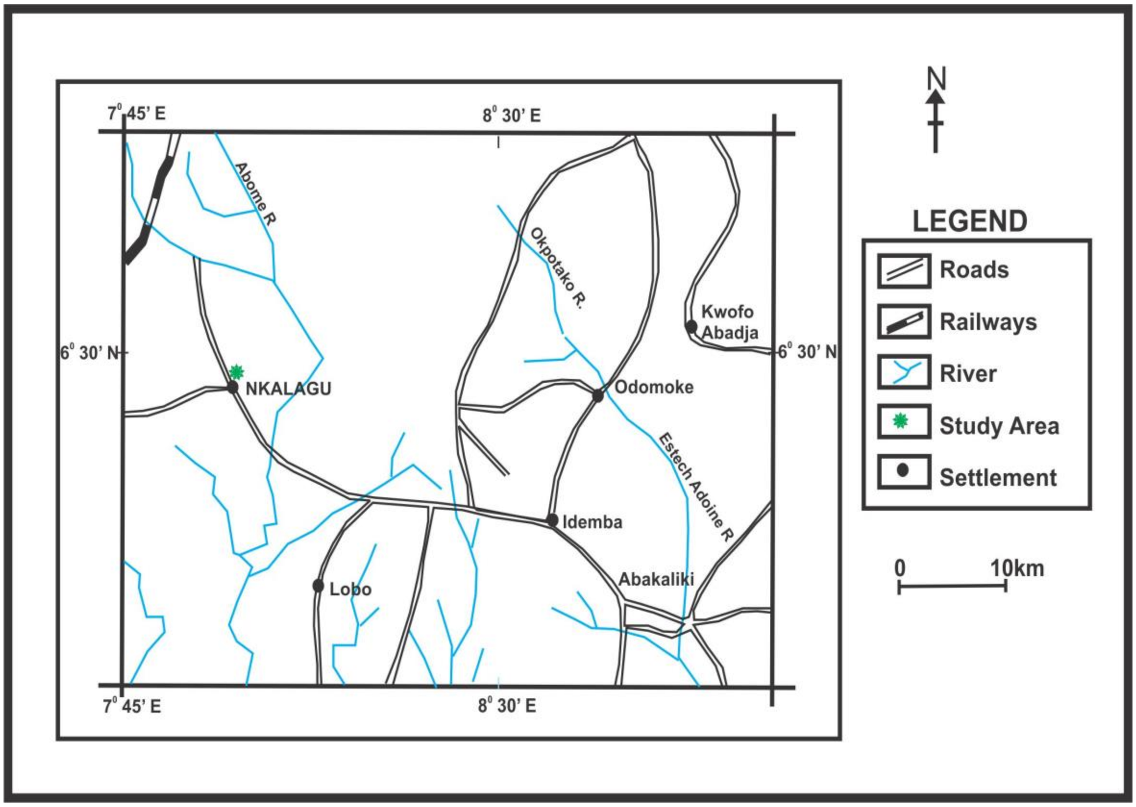


Figure 3: Location Map of the Study Area

The geology of the area consists of a cyclic sequence of fossiliferous upward fining shales and limestones beds. The limestone beds thicken southwardly and grade laterally into shales. Towards the Abakaliki – Okigwe Anticlinorium axis to the east and north east they became more sandy and finally grade into sandstone (Umeji, 1984). The limestone of Nkalagu belongs to Eze-Aku shale group (Fig. 4). This is a major shale/carbonate stratigraphic succession of the Middle – Late Cenomanian to Turonian age (Simpson, 1955; Amajor, 1992).

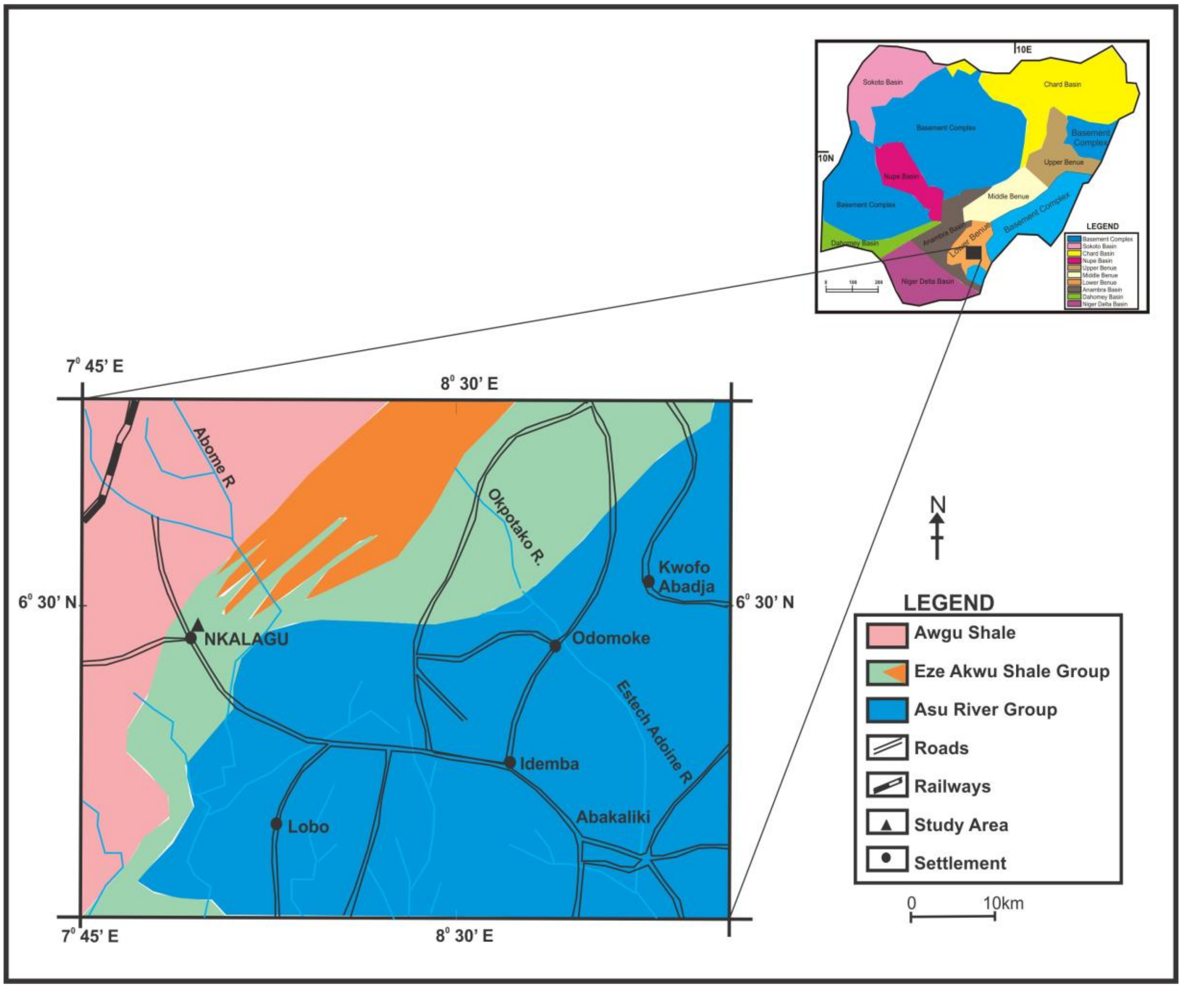


Figure 4: Geological map of Nkalagu and its environ with geological map of Nigeria (modified After Amajor, 1992)

SAMPLING AND METHODOLOGY

The field sampling was preceded by a reconnaissance survey where identification and measurement of different lithologies in the quarry were done to enable a systematic sampling of different horizons in the vertical section. Lithologic description was also carried out at the same time based on such characteristics as colour, texture, bedding and prominent sedimentary structures.

A total of fifteen (15) limestone samples were collected at different stratigraphic succession along the profile. Excavations were made to enhance collection of fresh samples from the bottom to the top of the sequence at intervals (Fig. 5). On the average, each quarry section is about 30m thick and approximately 2.5 km wide. Generally, the quarry faces reveal a laterally continuous cyclic succession of shale and limestone beds within the Turonian – Coniacian interval (Peters, 1978a). The shale and limestone beds vary from 1.2 to 5.7 m and 0.8 to 6.1 m respectively.

The sample chips were smoothened, carefully mounted on glass strips by means of Canada balsam before grounding down to the required thickness of 0.3mm with carborundum to produce the slides prior to petrographic study. The prepared slides were examined under the flat stage of a petrological and binocular microscope. The petrographic study enabled the identification of various fossil contents as photomicrograph of each slide were taken under crossed nicols and compared with carbonate photomicrograph catalogue to ascertain their compositional features.

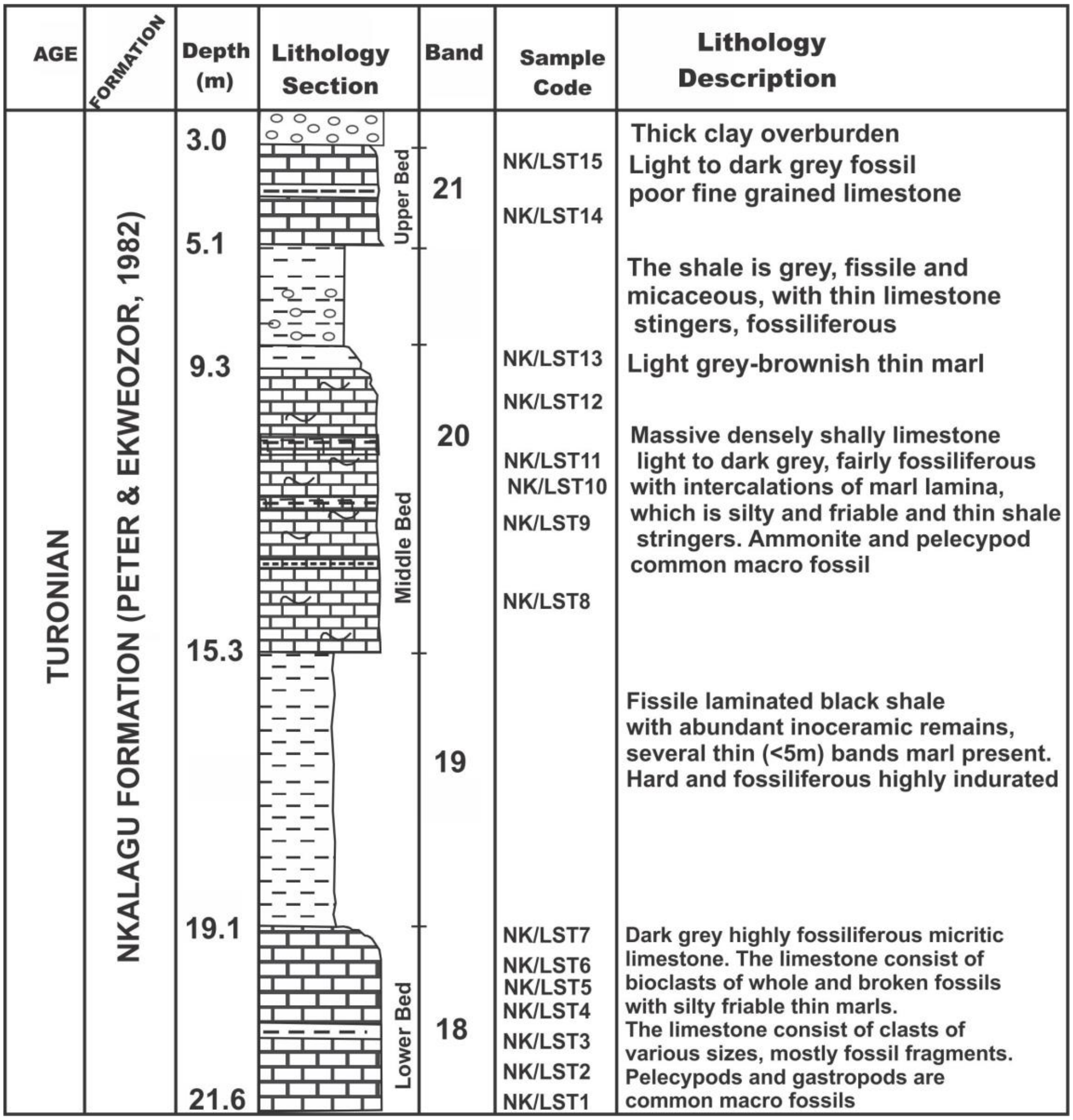


Figure 5: A Composite Lithologic section from Quarry Face B and C at NIGERCEM Quarry Nkalagu

RESULTS AND DISCUSSION

Lithostratigraphy

A total of 15 limestone samples were taken from Band/Bed 18, 20 and 21 limestones which correspond to the low, middle and upper limestone bed in the litho- section of the quarry as indicated in (Fig. 5) and analyzed. The lower limestone and shale beds form the basal part in the litho-section. They are generally light grey coloured, massive, fossiliferous, fine grained and largely composed of diverse bioclasts, including fragment of ostracods (Amajor, 1992), ammonites, pelecypods and whole fossils. The middle bed (band 20) in (Fig. 5), consist of four sub-units separated by thin dark grey silty marl horizons. The bed has bioclastic limestone with angular clasts containing fragment and whole skeletons of ammonites, pelecypods and gastropods, poorly sorted and characterized by a sharp erosive base (Banerjee, 1981). Some shale stringers are observable here.

On the basis of variation in lithology, texture and sedimentary structures as observed in the field, the entire stratigraphic column can be grouped into two inter-gradational component classes using the approach of Dunham (1962):

1. Matrix-supported bioclastic shell lag facies, and
2. Massive micritic fossil-poor limestone

1. The matrix-supported bioclastic shell lag facies is characterized by skeletal remains and molds. Gastropod, pelecypods and ostracods are very common with ammonite trace fossils (Plate 1). Angular limestone clasts and shale intraclasts (Fig. 5) are of secondary importance. The longest clast varies from 2 – 10 cm. Generally, some clasts are unabraided and very poorly sorted with the entire shells mostly convex upwards. The abundance of angular shale and limestone intraclasts suggest that the current was able to scour, scoop and redeposit fragments of underlying lithologies while the nature of macrofossils (entire), clasts (angular) and mixed fauna indicates little or no significant transportation history of the detritus. This is supported by the occurrence of similar microfossils in the micritic matrix and interbedded shales (Peters, 1978a, b) suggesting autochthonous or para-autochthonous origin for these sediments. Also, the unabraided and unsorted nature of the fossils and clasts, and normal grading suggest rapid deposition from suspension probably from a waning flow.

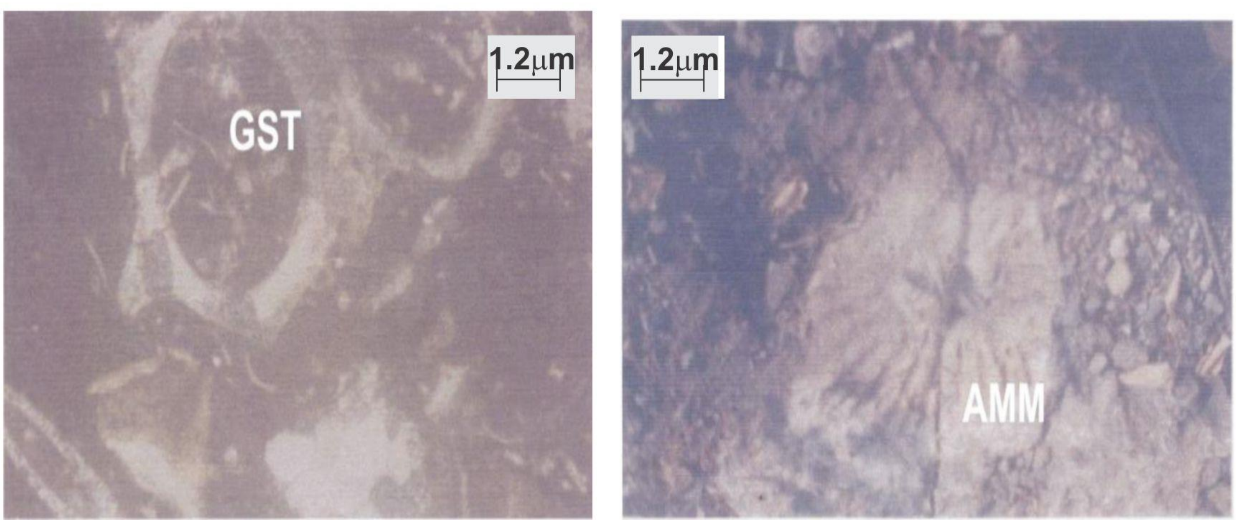
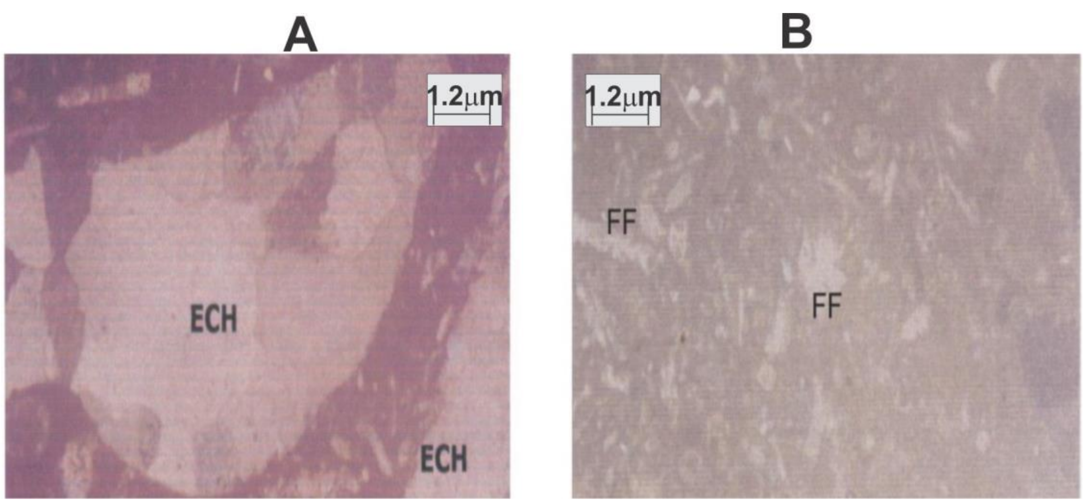


Plate 1: Samples of macro and trace fossils in the study area

2. The massive micritic fossil-poor limestone facies is light to dark grey, structureless limestone mud. However, a few whole fossils and limestone clasts of random orientation were observed in some places. This facies is generally better sorted than the other. The lithologic and textural characteristics show that deposition occurred under relatively lower flow velocity. The massive character of fairly homogeneous composition and fine texture of this sub-facies are suggestive of rapid deposition indicative of much fall-out from suspension and thus of an initially high concentration of suspended sediments in the same flow that deposited the underlying basal shell lag facies. The occurrences of randomly oriented entire fossils in this unit probably suggest entrapment by rapid fall-out from suspension or caused by rapid transformation and deposition in the flow. The similarity in micro faunal content with the adjacent shales confirms an autochthonous origin for most of the sediments.

Facies evaluation and petrography.

The results of petrographic analysis of the Nkalagu limestone revealed three main constituents: allochem (grain), carbonate matrix (micrite) and sparry calcite (cement). The allochem, which form the structural framework of the limestone, consists essentially of bioclasts, lithoclasts and intraclasts with few voids, quartz and iron mineral. Different schemes have been used to characterize limestone formation globally (Al –Jaboury and McCann, 2008; Jassim and Buday, 2006). Here, the bioclast and lithoclast components are used together. The most dominant fossils (bioclast) in these samples are brachiopods, molluscs (bivalves and gastropods), echinoderms (echinoids and crinoids) and bryozoans. Some of these fossils occur as whole skeleton (bivalve, echinoids and brachiopods) (Plate 2a) or as fragments (molluscs and echinoids) (Plate 2b).



ECH – Echinoid FF – Fossil Fragment

Plate 2: Samples of whole and fragment Fossils

Nkalagu limestone could therefore be grouped into the following facies based on the lithologic and fauna compositions:

1. **Massive lithoclastic floatstone facies:** Made up of lithoclasts and bioclasts commonly within the basal limestone beds (NK / LST 1 – 7; Fig. 4). The clast

components include brachiopods, bryozoans, echinoids and intraclasts in varying proportions (Plate 3a). The following classification can be observed within this lithoclastic floatstone facies - lithoclastic molluscan (brachiopod floatstone), with the clasts floating on a micritic matrix (Plate 3b) and lithoclastic brachiopod containing massive bryozoans floatstone (Plate 3c)

2. **Bioclastic (brachiopods – echinoids) wackestone facies:** This comprises skeletal grains of brachiopods and echinoids with few voids and angular grains. The clasts are embedded within the micritic matrix. The facies occurs at the basal to middle unit of the litho-section (NK/LST 8-11 – Middle Bed, Fig.4). The grains are poorly sorted and some of them have changed from decomposed bioclasts to structureless microcrystalline rounded grains; (Plate 4).
3. **Siliceous fossil - poor lime mudstone facies:** The fossil content here is extremely low with abundant fine grained lime mud and well sorted silt-size quartz and feldspar fragments and some iron minerals. The quartz and feldspar, which account for about 25% of the rock, are set within a lime mud matrix. It also contains a fragment of echinoids as seen in Plate 5.

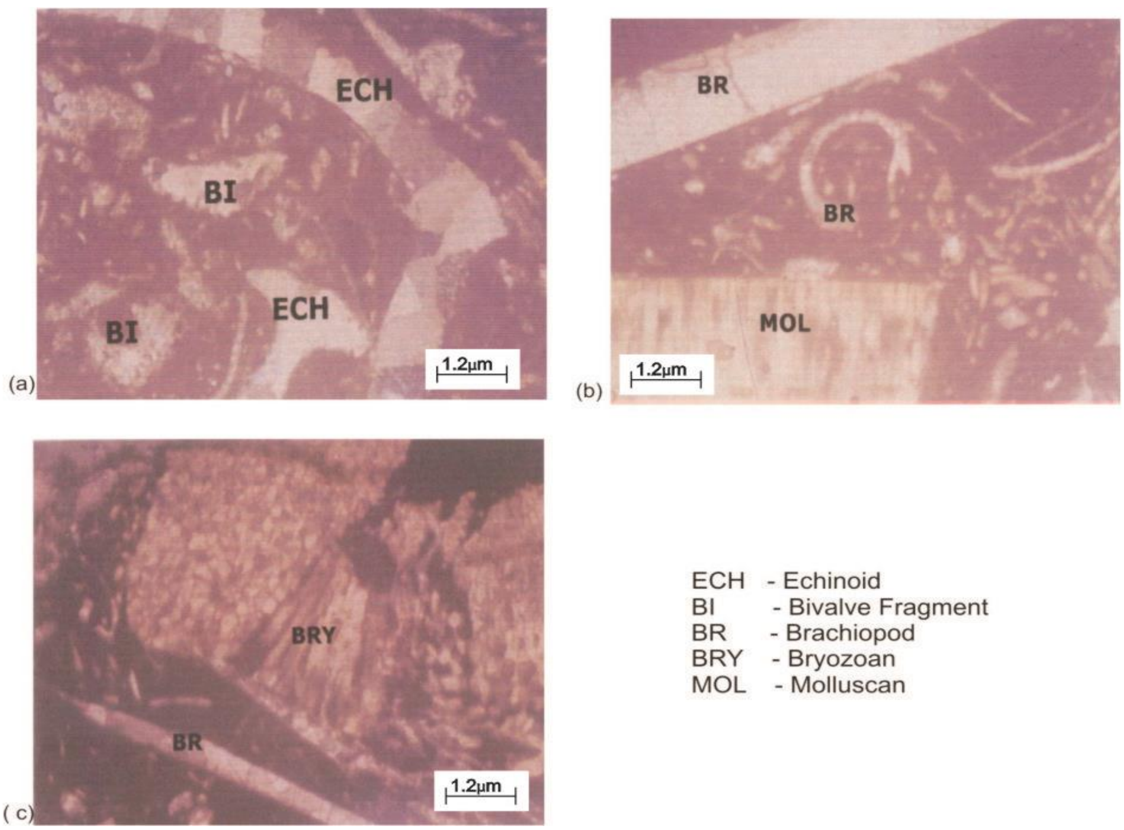


Plate 3: Massive lithoclastic floatstone at NIGERCEM Quarry, Nkalagu

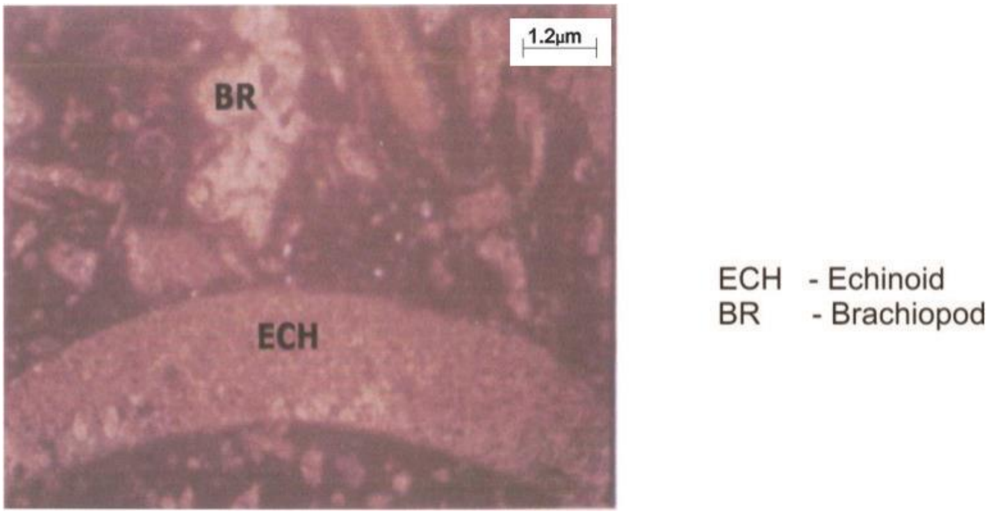


Plate 4: Bioclastic wackestone at NIGERCEM Quarry, Nkalagu

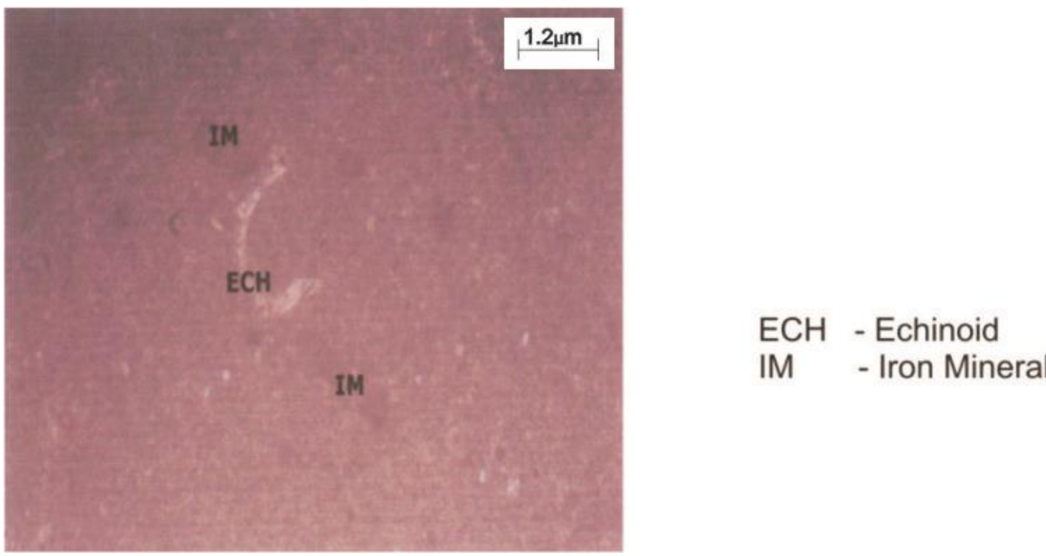
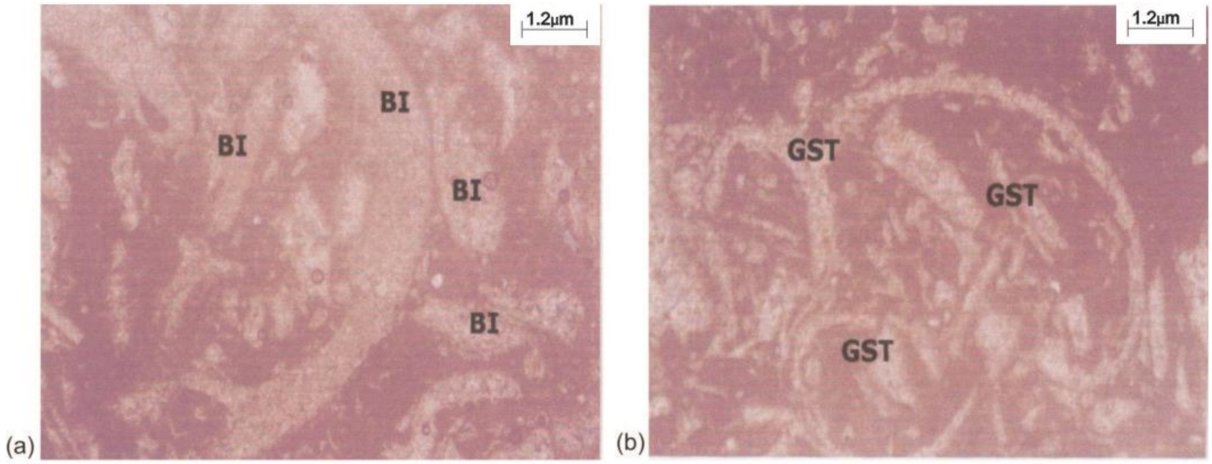


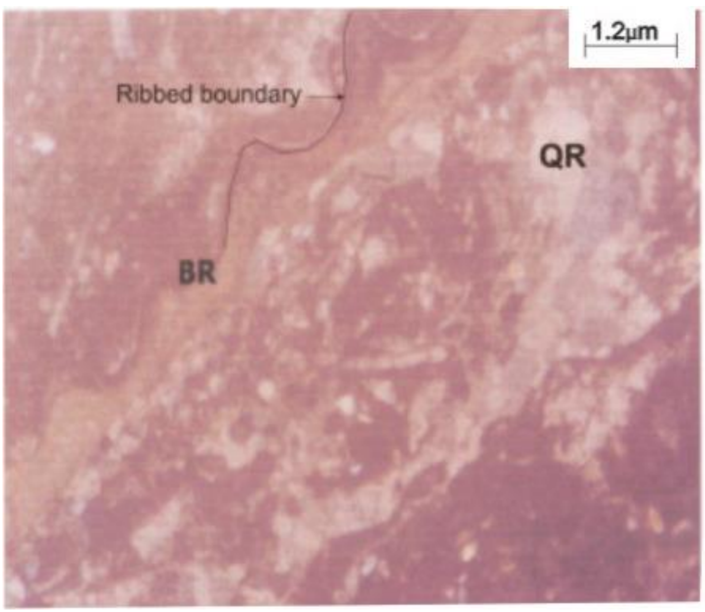
Plate 5: Siliceous fossil-poor lime mudstone at NIGERCEM Quarry, Nkalagu

4. **Bioclastic wackestone facies**: It consists essentially of bivalve debris set within the lime mud matrix fragments (Plate 6a) and it differs from the former bioclastic facies in the sense that it contains mainly bivalves with neomorphosed gastropods (Plate 6b).
5. **Bioclastic packestone facies**: This microfacies was observed through the whole section, especially in litho units overlain by shale. It is marked by high percentage of bioclasts (brachiopods, echinoids), embedded in micrite, and few lithoclasts are also recognized. Plate 7 shows ribbed brachiopod in bioclastic limestone with detrital quartz grain. The rock is grain-supported and contains substantial amount of lime mud. Sparry calcite cements are also observed in the internal pores of some of the bioclast grains. (Plate 7).



BI - Bivalve GST - Gastropod

Plate 6: Bioclastic wackestone at NIGERCEM Quarry, Nkalagu



BR - Brachiopod
Qg - Quartz grain

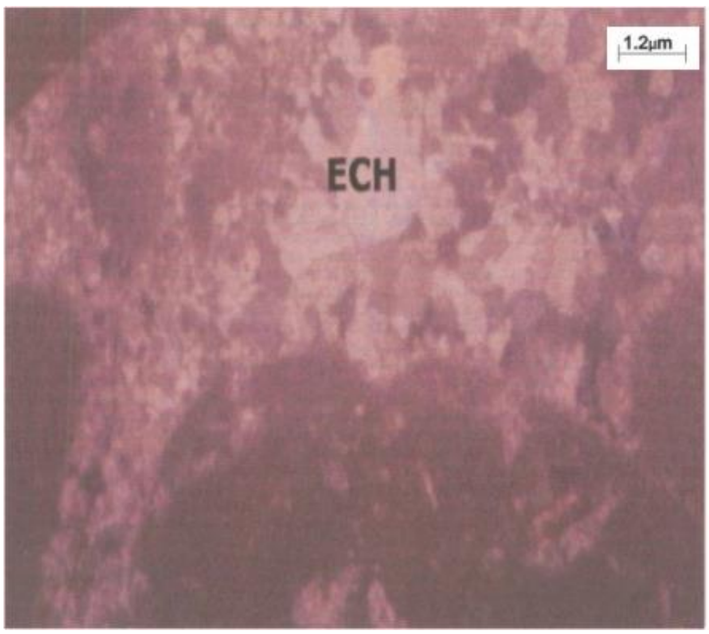
Plate 7: Bioclastic packestone at NIGERCEM Quarry, Nkalagu

Diagenesis

In addition, the petrographic studies revealed the effect of syndepositional marine diagenesis superimposed by meteoritic water in most of the carbonate microfacies. Systematic analysis of the textures and structures preserved in the samples revealed that the limestone deposits were affected by several diagenetic changes involving cementation, micritization, compaction / pressure dissolution and growth of several stages of cement.

Cementation by micrite is about the first diagenetic stage here. At shallow depth after the deposition of carbonate materials, diagenesis commenced. The deposited materials are cemented first by micritic cements. It was observed in some cases that the primary micrite has been re-

crystallized to microspar calcite cement (Plate 8). Bioclastic components including corals, algae, shell of gastropods and pelecypods are preserved as a result of micritized rinds.
Dissolution and internal micritization of the rind cement follow partial and complete dissolution of the carbonate materials as evident in some samples (Plate 6a and b). This occurs as a result of underground percolation of water (vadose alteration). The dissolution process led to the collapse structures and brecciation leading to secondary porosity development. The calcite cement in the internal rims of the bioclasts developed after the dissolution of the internal micritic rinds. This is followed by compaction. Microscopic studies reveal that both the carbonate bioclastic and non-bioclastic grains were moderately packed (Plate 2b). The compaction process led to the concentration and lithification of the carbonate beds, which resulted in the formation of massive carbonate beds in some places within the area.
The last stage is the formation of sparry calcite cements. It involves the growth of several proportions of cements. Both the first and the second generations of calcite cement were seen in the bioclasts (Plate 5a). The sparry calcite cement is common along the boundaries of the open space generated during the previous stages. The last diagenetic event had led to the reduced porosity and permeability in the carbonate rock under study (Plate 8).

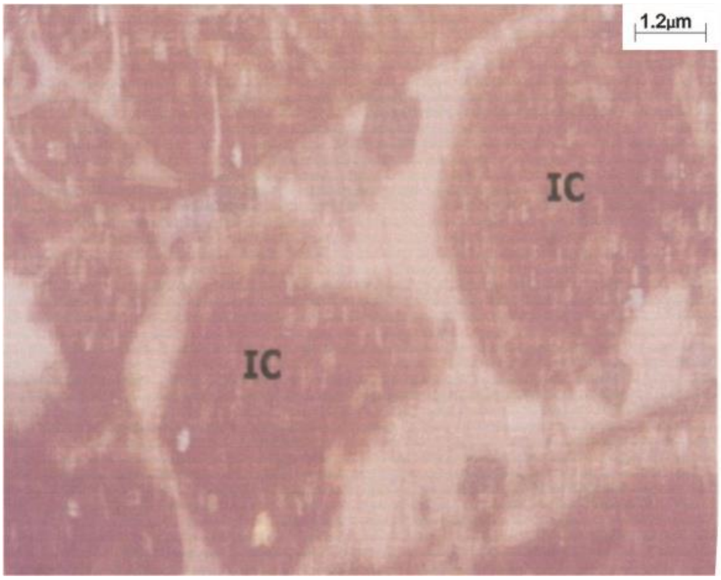


ECH - Echinoid

Plate 8: Re-crystallized echinoid

In general, diagenetic features indicated in the rocks are divisible into generations, namely, those that are associated with and limited only to the internal organization of the lithoclastic components and those that transcend these encompass the whole rock. Many of the lithoclastic components are angular whereas others acquire a high degree of roundness (Plate 9). Isopachous rim cements (Plate 8) are common, an indication of early submarine cementation, which originally consisted of mg-calcite now stabilized to calcite. Within the lithoclasts, most of the components are shells which now consist of blocky sparite having previously lost than original texture and mineralogy through dissolution and re-precipitation, indicating that the source rocks were at some stage exposed to sub-aerial meteoric diagenesis.

The siliceous fossil-poor mudstone facies shows diagenetic features characterized by cementation by micrite, meteoric phreatic spar in fossil chambers and other voids and neomorphism of the lime mud into micro spar. In the wackestone facies, the matrix lime underwent early submarine lithification that cemented the fossil in an originally mud-supported fabric.



IC - Intraclast

Plate 9: Lithoclasts - showing high degree of roundness

CONCLUSION

The litho- and bio- facies studies of the Turonian Nkalagu Formation as exposed at NIGERCEM of the Lower Benue Trough were carried out in order to determine the depositional environment. Based on this study, two major lithofacies were delineated. The first consists of matrix supported bioclastic shell lag wackestone facies which account for about 70% of the carbonates. The second is a massive fossil-poor micritic limestone.

On the basis of fossil contents, five distinctive micro-biofacies were recognized which are: massive lithoclastic floatstone, bioclastic (brachiopod – echinoid) wackestone, siliceous fossil-poor limestone, bioclastic (bivalve debris) wackestone and bioclastic packstone.

The massive lithoclastic floatstone facies in which lithoclasts of various sizes (both mega and microscopic) float has mud supported fabric. The lithoclast consists of shell carbonate deposits, bryozoans, echinoids characteristic of shallow water material transported while still in various degrees of lithification from shelf into deeper basin. Many of the lithoclasts are sub-angular, others are rounded. Generally, there are no algae. Therefore, this study indicates that the Nkalagu Formation deposited in a shallow marine environment but later displaced into relatively deeper water probably that of the off shelf zone, by some sedimentary flow mechanics. The upward fining textural gradient typical of these beds suggests deposition by a warning flow such as characterized storm and turbidity currents. By far, the most important observation on which this conclusion is based is the absence of algae which are notoriously ubiquitous in shallow calcareous marine sediments of the photic zone. It can then be concluded that in as much as these biota indicate clear water environment, the implication is that water depths (even prior to displacement of the shallow marine shelf derived wackestone) must have exceed 100m. Accordingly, the breccias of the basal limestone units were derived from the outer continental shelf to continental slope in various states of lithification.

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