Microfacies analysis, geochemistry and depositional environment of Turonian Nkalagu Limestone, Southeastern Nigeria

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Abstract
The integration of petrographic, microfacies and geochemical data were used to interpret the depositional settings of the Turonian Nkalagu Limestone within Lower Benue. Three different microfacies were delineated within the limestone beds, these are: bioclastic mudstone-wackestone facies, bioclastic wackestone facies and Siliceous lime mud facies. The Bioclastic mudstone-wackestone and the Bioclastic wackestone facies are generally matrix-supported, fossil-rich with whole fossils of brachiopods, gastropods and disaggregated fossils such as shell fragments. They possess abundant carbonate of about 61.1%, the lithoclasts are generally angular to sub-angular showing poor-sorting. They are composed of very fine-grained aggregates of micritic matrix/carbonate mud with dispersed and random orientation of bioclasts which suggests deposition in warm, shallow sub-tidal environment. The Siliceous Lime Mud Facies are generally low in fossil content with presence of pellets dispersed in lime mud and lithoclasts of quartz and feldspar which indicates varying periods of siliciclastic influx. Dispersion of pellets in lime mud hints deposition in protected shallow-marine platforms in low to medium energy conditions. The pattern of diffraction for limestone sample shows decrease in calcite concentration from Bioclastic wackestone, Bioclastic mudstone-wackestone and Siliceous lime mud respectively. Calcite constitutes about 61.1%, with 12% quartz and 19% albite in Bioclastic wackestone. Muscovite occurs in tiny amounts as well as kaolinite (2.0%) and gypsum (1.9%). The Siliceous lime mud is silica rich with 22.6% quartz, 13.9% albite and 7.8% k-feldspar. Calcite only occurs in 52.7% with illite and pyrite of 2.0% and 1.0% respectively. The trace elements show higher concentrations in the Siliceous lime mud faces than bioclastic wackestone and bioclastic-mudstone wackestone facies. The trace element thus shows diagnostic pattern of distribution that differentiate deepening water depth of the depositional setting. The integration of microfacies, X-ray diffraction and trace element concentration therefore pointed towards a shallow marine depositional setting.

Keywords: Microfacies, Nkalagu Formation, Wackestone, Bioclast, Depositional Setting.

1. Introduction
The depositional settings of the Turonian Nkalagu limestone have been a subject of discourse and disagreements from various authors. Among these authors, Banerjee (1981) suggested deposition in high-density turbidity current in deeper water environment, however, works of Reynet (1965), Murat (1972), Fayose and de Klasz (1976), Petters (1978a, 1978b and 1980), Petters and Ekweozor (1982) and Ikhan, Folorunso, Nton, Oluwalaanu and Oyebolu (2012) implied deposition in shallow marine environment. Ehinola, Ejeh, and Chinyyere (2010) suggested a shallow marine (shelf) depositional environment with fluctuations in low to medium energy condition based on microfacies analysis and field relationship study. In this study we combine petrographic and geochemical data to determine the paleo-depositional setting of the limestone sequences of the Nkalagu Formation, Southern Benue Trough. The study area extends from the quarry site of Nigerian Cement Company (NIGERCEM) to Ezillo Village in the South-eastern part of Nigeria (Figure 1a and 1b). It lies between the latitudes 6° 10’N and 6° 40’N and longitudes 7° 35’E and 7° 50’E covering a vast area in term of its landmass. Accessibility is improved through a network of roads, such as Obolo-Nkalagu Road and Enugu-Abakaliki Expressway improved the accessibility to the exposures. Drainage in Ebonyi state is largely controlled by Cross River and its tributaries. The drainage pattern is dendritic with interconnections.
of streams and rivers. Vegetation is dominantly grassland with sparse tree.

Figure 1a. Geological map of parts of Anambra Basin and Lower Benue Trough, including the study area (Onuba et al., 2013)

Figure 1b: Access map of the study area
1.1. Geologic setting: The Southern Benue Trough

Benkhelil (1989) described the NE-SW trending sedimentary basin as a linear, intracratonic sedimentary basin that formed during the early Cretaceous closely related to the opening of the Atlantic Ocean. The Albian marks the first stage of the basin’s evolution, which gave rise to formation of isolated basins with continental sedimentation and development of a great delta in the Northern Benue Trough. The first marine transgression from the rifting of the Gulf of Guinea took place in the Lower division of the Basin reaching the Central Benue Trough. During the Turonian, the extensive marine transgression caused interaction between the Atlantic and Tethys waters via the Sahara, Niger Basins and the Benue Trough. Transcurrent folding through an axial fault system was the major driving force of tectonic evolution of the Basin, this faulting led to the development of local tensional and compressional regimes and result in the horsts and graben along the bends of the faults under stress.

The sediment infill of the Benue Trough involves three stages of tectonism (Murat 1970). The initial tectonic activity leads to the development of Anambra platform and Abakaliki sub-basin during the Early Santonian. The second tectonic event is a compressional episode that lead to the folding of earlier Cretaceous sediments in the Lower Benue Trough. This compressional deformation trend along NE-SW and give rise to the chains of anticlines within the region. (Benkhelil, 1986).

The focus of deposition shift to these depressional platforms from Campanian to the Paleocene time. The beginning of the folding episode was accompanied by magmatic intrusion into the host rock evident by intrusive igneous rock within Abakiliki shale around Afikpo and Abakaliki areas with lead-zinc mineralization.

Sedimentation in the Southern Benue Trough (figure 2) began with the Neocomian to Albian Asu River Group sediments, although some pyroclastics of Aptian – Early Albian age have been reported (Uzuakpunwa, 1974; Ojoh, 1992). The Asu River Group is believed to be the deposits of first marine incursion into the Benue Trough. The oldest group of the South Benue Trough consists predominantly of shales with interbedded sandstones, siltstones and limestone (Reyment, 1965; Murat, 1972; Nwachukwu, 1972; Tijani et al., 1997), including intrusive and extrusive material of the Abakaliki formation in the Abakaliki area and the limestone deposit of the Mfamosing in the Calabar Flank (Petters, 1982). Akande, Ojo, Adekeye, Egenhoff, Obaje and Erdtmann (2011) also described the Asu River Group as consisting of volcano-clastics, marine shales, arkosic sandstones, siltstones and limestone which overlie the older crystalline basement rocks. They opined that the sediments were mainly derived from the extensive weathering of the crystalline rocks which were intruded by basaltic rocks of alkaline nature preceding the initial rapid marine transgression of the mid-Albian times.

The Asu River group was then overlain by the black shales, limestones, siltstones of Cenomanian - Turonian Nkalagu Formation and the interdigitating regressive sandstones of the Amaseri and Agbani Formations. The mid-Santonian deformation and magmatism in the Benue Trough led to the subsequent downwarping of the Anambra platform to form the extensive Anambra Basin. This means that the Anambra Basin constitutes a major part of the post-depositional sedimentation in the Lower Benue Trough.
Figure 2: General stratigraphy of Benue Trough (Reyment, 1965; Murat, 1972)
2. Methodology

2.1 Field methodology

This study involved measurements, documentation of sedimentary structures and collection of samples. Fresh limestone samples were collected for studies and analysis. Samples were collected from three exposures of the Nkalagu Limestone at different locations in close proximity to NIGERCEM and a nearby settlement called Ezillo. The method involves detailed observation, identification and systematic description of the rocks, this is followed by collection of rock samples. Collection of fresh samples was carried out with the use of a rock hammer and were adequately preserved in polythene sample bags. Generally, the quarry outcrops reveal a laterally continuous cyclic succession of shale and limestone beds within the Turonian – Coniacian interval (Peters, 1978a).

2.2 Laboratory methodology

X-ray diffraction analysis, trace element analysis and petrographic thin section study were done on three rock samples. Thin sections were prepared in the laboratory in order to carry out a detailed study and characterize the rock sample with the use of a polarizing petrographic microscope or electron microscope. A thin slice of the rock was cut out from the main sample with a diamond saw and is then ground until it is optically flat. After this, it is placed on a glass slide (also called an epoxy dish) and then using an abrasive, is smoothen until the sample is about 30 micrometers in thickness. Minerals usually possess, their own optical properties under the microscope and unique or distinguishing features which makes them stand out and easier to be identified.

3. Results and Discussion

3.1. Outcrop description

3.1.1. Outcrop 1 – Abandoned NigerCem cement factory, Nkalagu. This outcrop consists of massive to low lying 6.50 m thick section of limestone and mudstone (figure 3). The low-lying, gentle sloping outcrop is fine grained in texture. The limestone is highly fossiliferous, and rich in fossils such as ammonites, bivalves and brachiopods (Spirifer).

Figure 3: Low lying outcrop at location 1

3.1.2. Outcrop 2: 2km along Obolo-Nkalgu road (off Enugu-Abakaliki Road) This outcrop consists of low lying 1.50 m thick section of highly fossiliferous limestone and mudstone (figure 4). The
low-lying, gentle sloping outcrop is fine grained in texture. The limestone is highly fossiliferous, and rich in fossils such as ammonites, bivalves and brachiopods (Spirifer).
3.2. Microfacies and Petrographic analysis

Three lithofacies were identified in the Nkalagu limestone described in Nkalagu and Nbolo area. These are (1) Bioclastic wackestone facies (2) Bioclastic mudstone-wackestone facies, (3) Siliceous lime mud facies. The lithofacies are discussed in details as follows:

3.2.1 Bioclastic Wackestone Facies

The lithofacies is entirely bioclastic limestone. The bioclast includes whole skeletons of ammonites, bivalves, and brachiopods. The fossil assemblage viewed under the microscope corresponds to the wide range of fossils seen on the field. There is increased presence of molluscs such as gastropods (figure 6) as well as dispersed shell fragments of varying sizes and orientation (figure 6). Clasts and bioclasts are dispersed in very fine-grained carbonate mud matrix which indicates that it is mud-supported. There are also traces of hematite (figure 7).

**Interpretation**

The bioclasts and clasts assume a random and dispersed orientation without touching each other which is characteristic of Sparse Fossiliferous Biomicite/Bioclastic Wackestone because the grains is more than 10%, dominant mud-support and the bioclasts are not in contact with one another.

Presence of very fine-grained aggregates of carbonate mud which suggest deposition in warm waters with availability of light and little siliciclastic input, along with its highly fossiliferous content including gastropods, brachiopods and fragment of shells suggest deposition in low-latitude, sub-tidal environment. The presence of iron oxide signifies varying periods of exposure of limestone to the atmosphere due to intermittent receding of water level.

Figure 6: Photomicrograph of outcrop 1 showing Gastropod (GS) and fossil fragments (FF) dispersed in micrite matrix (ppl)
3.2.2 Bioclastic Mudstone-Wackestone Facies
This lithofacies consists of bioclast with mixs of mudstone. The allochems generally consists of bioclasts and quartz grains. The matrix and cement material are limemud and iron oxides (figure 8 and 9). The dominant fossils clasts (the bioclasts) observed in the slides from the samples are brachiopods and shell fragments. The quartz grains are angular and fine-grained clasts of with traces of pyrite dispersed within the carbonate mud. Some of the allochems are fragmented and sometimes filled with quasi-opaque material (possibly lime mud). The carbonate forms very fine aggregate that constitutes a large percentage of the thin section. Also, this very-fine grained nature of the carbonates and the dispersed-nature of the grains and bioclasts suggests that the carbonate represents the original mud material of the sedimentary rock. This lithofacies is seen in both location 1 and 2.

Interpretation
The fine-grained texture of the limestone with mud matrix and the abundance of carbonate secreting macro-fossils signifies that the limestone was deposited in low energy environment in shallow, warm water conditions. The presence of randomly-oriented bioclasts and mineral grains dispersed throughout the section making no contact with one another in very-fine grained crystalline lime mud matrix classifies the limestone as Sparse Biomicrite/Bioclastic Mudstone-Wackestone. The abundance of calcite (61.1%) and fine-grained aggregates of carbonate mud denotes deposition in calm, shallow seas with low siliciclastic input. The grains of quartz are angular and generally poorly-sorted. Highly fossiliferous content including brachiopods and fragment of shells suggest deposition in low-latitude, sub-tidal environment.

The presence of iron oxide signifies periods of exposure of limestone to the atmosphere due to intermittent receding of water level.
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Figure 8: Photomicrograph of outcrop 2 showing bioclasts and petrographic characteristics. Brachiopod (bc), quartz grains (qz), traces of iron oxide (Fe) and discontinuous cracks (white arrows) (ppl)

Figure 9: Photomicrograph of outcrop 2 showing presence of fossil fragments floating in matrix (FF) (ppl)

3.2.3 Siliceous Lime Mud Facies
This lithofacies consists of predominantly silty size to muddy limestone. The lithofacies is very fine grained with no visible bioturbation. This lithofacies was observed only in location three. In thin section, pellet allochems are dispersed throughout the matrix (figure 10). Quartz and felspathic mineral were observed to be floating in the mud matrix (figure 10 and 11). Presence of pellets scattered in micrite matrix suggests Sparse Pelmicrite.
3.3. X-Ray Diffraction and Trace element Geochemistry

The pattern of XRD and concentration of trace elements for the microfacies are presented in figures 12, 13 and table 1 below. The pattern of diffraction for limestone sample shows decrease in calcite concentration from outcrop 1 to 3. At location 1 Calcite constitutes about 61.1%, with 12% quartz and 19% albite. Muscovite occurs in tiny amounts as well as kaolinite (2.0%) and gypsum (1.9%). The limestone at location 3 is silica rich with 22.6% quartz and 13.9% albite with 7.8% k-feldspar. Calcite only occurs in 52.7% with illite and pyrite of 2.0% and 1.0% respectively (figure 12 and 13).

The trace elements show higher concentrations in the Siliceous lime mud facies than bioclastic wackestone and bioclastic-mudstone wackestone facies (table 1). The trace element thus shows diagnostic pattern of distribution that differentiate deepening water depth of the depositional setting. Both the XRD and trace element concentration therefore pointed towards a shallow marine depositional setting.
Figure 12: X-ray diffractogram for Location 1

Figure 13: X-ray diffractogram for Location 3
Table 1: Trace element concentration of Nkalagu limestone

<table>
<thead>
<tr>
<th>Sample location</th>
<th>FE (ppm)</th>
<th>Mn (ppm)</th>
<th>Sr (ppm)</th>
<th>Zn (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outcrop 1</td>
<td>1729</td>
<td>436</td>
<td>571</td>
<td>9.2</td>
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<tr>
<td>Outcrop 2</td>
<td>2143</td>
<td>876</td>
<td>634</td>
<td>11</td>
</tr>
<tr>
<td>Outcrop 3</td>
<td>2673</td>
<td>1384</td>
<td>979</td>
<td>14</td>
</tr>
</tbody>
</table>

3.4. Discussion

Based on the field study, the Nkalagu Limestone shows various facies associations with generally very fine-grained micritic matrix and dispersed orientation of allochems which mostly indicate deposition in shallow sub-tidal platforms where there is low energy and availability of sunlight with high rates of carbonate production, bioturbation and micrite-rich sediments. Sub-tidal platforms collectively describe sub-aqueous but shallow-marine sedimentary environment. Petters (1978a, 1978b and 1980) has also worked on sedimentary environment of the Nkalagu limestone and suggested that the limestone was deposited in shallow marine environment. Ehinola et al. (2010) similarly stated that the limestone was deposited in a shallow marine shelf environment, however deposited during periods of fluctuations from low to medium energy. Agumanu (2009) concluded that the Nkalagu limestone facies zones correspond to shelf lagoon environment with open circulation.

On the contrary, Banerjee (1981) and Gebhardt (1999, 2000) concluded that the limestone was deposited in high-density turbidity currents of deeper water environments. The reason for interpreting the limestone layers as turbidites as suggested by Gebhardt (1999, 2000) was due to pronounced occurrence of calcareous nannofossil content of the Nkalagu sediments. This was also supported by the depositional framework (deep embayment) which allows turbiditic sedimentation i.e. sedimentation in deep waters. Part of the reason for interpreting the limestone as turbidites is due to the fact that they show fining-upward sequence and are mostly matrix-supported. Ikhane et al., (2012) agreed with both broad conclusions and suggested deposition of limestone in shallow marine environment with further displacement into relatively deeper water, probably that of the off-shelf zone, by some sedimentary flow mechanisms.

In Location 1, the presence of randomly-oriented bioclasts and mineral grains dispersed throughout the section making no contact with each other in very-fine grained crystalline micrite matrix classifies the limestone as Sparse Biomicrite, according to classification scheme of Folk (1959, 1962) and Bioclastic Mudstone-Wackestone Facies, according to the classification by Dunham (1962). The abundance of calcite (61.1%) and fine-grained aggregates of carbonate mud denotes deposition in calm, shallow waters with low siliciclastic input. The grains of quartz are angular and generally poorly-sorted. Highly fossiliferous content including brachiopods and fragment of shells suggest deposition in low-latitude, sub-tidal shelf environment. Agumanu (2009) also noticed the Mudstone-Wackestone Facies as part of the microfacies association of the Nkalagu Formation.

In Location 2, the allochems assume a random and dispersed orientation without touching each other which is characteristic of Sparse Fossiliferous Biomicite/Bioclastic Wackestone due to the presence of more than 10% angular grains of quartz and other impurities which are generally poorly-sorted, dominant mud-support and no contact between the bioclasts. Presence of very fine-grained aggregates of carbonate mud which suggest deposition in warm waters with availability of light and little siliciclastic input, along with its highly fossiliferous content including aggregates of...
gastropods, brachiopods and fragment of shells suggest deposition in low-latitude, sub-tidal environment. Ehinola et al. (2010) similarly identified the Bioclastic-Wackestone Facies and stated that its fossil assemblage consists of poorly sorted fossil fragments along with whole gastropods, pelecypods, algae and foraminifera. According to their studies, they suggested a shallow marine (shelf) depositional environment with fluctuations in low to medium energy condition.

At location 3, the presence of dispersed pellets in lime mud matrix suggests sparse pelmicrite. High amounts of silica impurities suggest high siliciclastic input indicating several periods of influx of clastics into the shoreline. No fossil content was found. This matches with the field observations at Location 3, Ezillo in which there was absence of visible fossils. These characteristics suggest siliceous fossil-poor limestone. Occurrence of pellets suggest protected shallow-marine platforms with low energy and minimal subsea cementation. This suggest a shallow marine (shelf) depositional environment with fluctuations in low to medium energy condition. Ikhane et al., (2012) described the fossil content as extremely low with dominant lime mud matrix and well-sorted siliciclastic grains. They characterise it as generally better sorted than the Bioclastic Mudstone and Wackestone facies.

Conclusion
The Nkalagu Limestone is a massive Limestone Formation of the Lower Benue Trough that is composed of very-fine grained to fine-grained textures. Although this indicates deposition in low-energy environments, fine-grained textures are however deposited in higher energy conditions than very fine-grained aggregates. The Formation shows an association of microfacies which includes: Bioclastic Mudstone-Wackestone Facies, Bioclastic Wackestone Facies and Siliceous Lime Mud Facies. The Bioclastic Mudstone-Wackestone Facies and the Bioclastic Wackestone Facies are generally matrix-supported, fossil-rich and possess abundant carbonate of about 61.1%. The lithoclasts are generally angular to sub-angular showing poor-sorting. They are composed of very fine-grained aggregates of micritic matrix/carbonate mud with dispersed and randomly oriented bioclasts which suggests deposition in shallow, sub-tidal environment. The Siliceous Lime Mud Facies are generally low in fossil content with high siliciclastic input of quartz (42.6%) and feldspar (17.8%) indicating varying periods of siliciclastic influx into the shoreline. Dispersion of pellets in lime mud hints deposition in protected shallow-marine platforms in low energy conditions.

References


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