Ruhuna Journal of Science
Vol 14 (1): 1-13, June 2023
eISSN: 2536-8400
http://doi.org/10.4038/rjs.v14i1.130

Faculty of Science
University of Ruhuna

Paleoenvironment and diagenetic aspects of the limestone (Gboko Formation) around Igumale, Central Benue Trough, Nigeria: Evidence from petrography

I. A. A. Etobro, O. I. Ejeh and O. Odedede*

Department of Geology, Delta State University, Abraka, Nigeria

*Correspondence: odedede@delsu.edu.ng; ORCID: https://orcid.org/0000-0002-6022-1345

Received: 19th March 2022, Accepted: 31th October 2023, Published: 30th June 2024

Abstract Limestone core samples from Igumale-1 and Igumale-2 wells, Central Benue Trough, Nigeria were petrographically studied in detail to determine their paleo-depositional environment and diagenetic history. Petrographic examination of the limestone shows that the limestone comprised monocrystalline quartz, ferroan calcite (3-15 %), peloids (3-20 %), ooids (7-10 %), micrite (33-48 %) and sparites (10-50 %). Fossil fragments consist of foraminifera and gastropods (17-57%), and suggest subtidal to shallow marine environment. Four sedimentary facies (oobiosparite, biosparite, biopelmicrite, and biomicrite) were recorded and characterised by moldic and vuggy porosity. This study has provided a petrographic synopsis of the limestone for further consideration and may impact both the exploration and development of the limestone deposit.

Keywords Benue Trough; Diagenesis of limestone; Gboko Formation; marine environment; moldic and vuggy porosity.

1 Introduction

Earliest geological studies of the Central Benue Trough were reported by numerous workers in the literature (Olade 1975, Benkhelil 1989, Akande *et al.* 1988, Zaborski *et al*. 1997, Guiraud 1990, Odedede 2011, Odedede and Adaikpoh 2011, Petters 1980). Despite these numerous previous works and explorations of limestone in the Benue Trough, diagenetic aspects of the limestone have not been given adequate priority or not reported in the literature. Benkhelil (1989) described the structural geology of the Benue Trough. Bolarinwa and Idakwo (2013) reported major oxides and trace elemental concentrations of the limestone around Yandev and inferred a shallow marine environment of deposition and reservoir potential. Akori *et al.* (2023) recently investigated the hydrocarbon potential of the Gboko Formation. They reported that it could generate only gas. The limestone under investigation (Figure 1) lies within the Gboko Formation. Okosun (1999) stated that Gboko Formation consists of limestone, shale, mudstone, fine-grained sandstone, and siltstone. It unconformably overlies the Basement Complex. Ramanathan and Nair (1984) dated the formation of Late Aptian-

Middle Albian on the basis of foraminiferal assemblages, while Wright (1985) assigned Albian age. The Gboko Formation is considered the lateral equivalent of the Abakaliki Formation in the Southern Benue Trough (Okosun 1999).

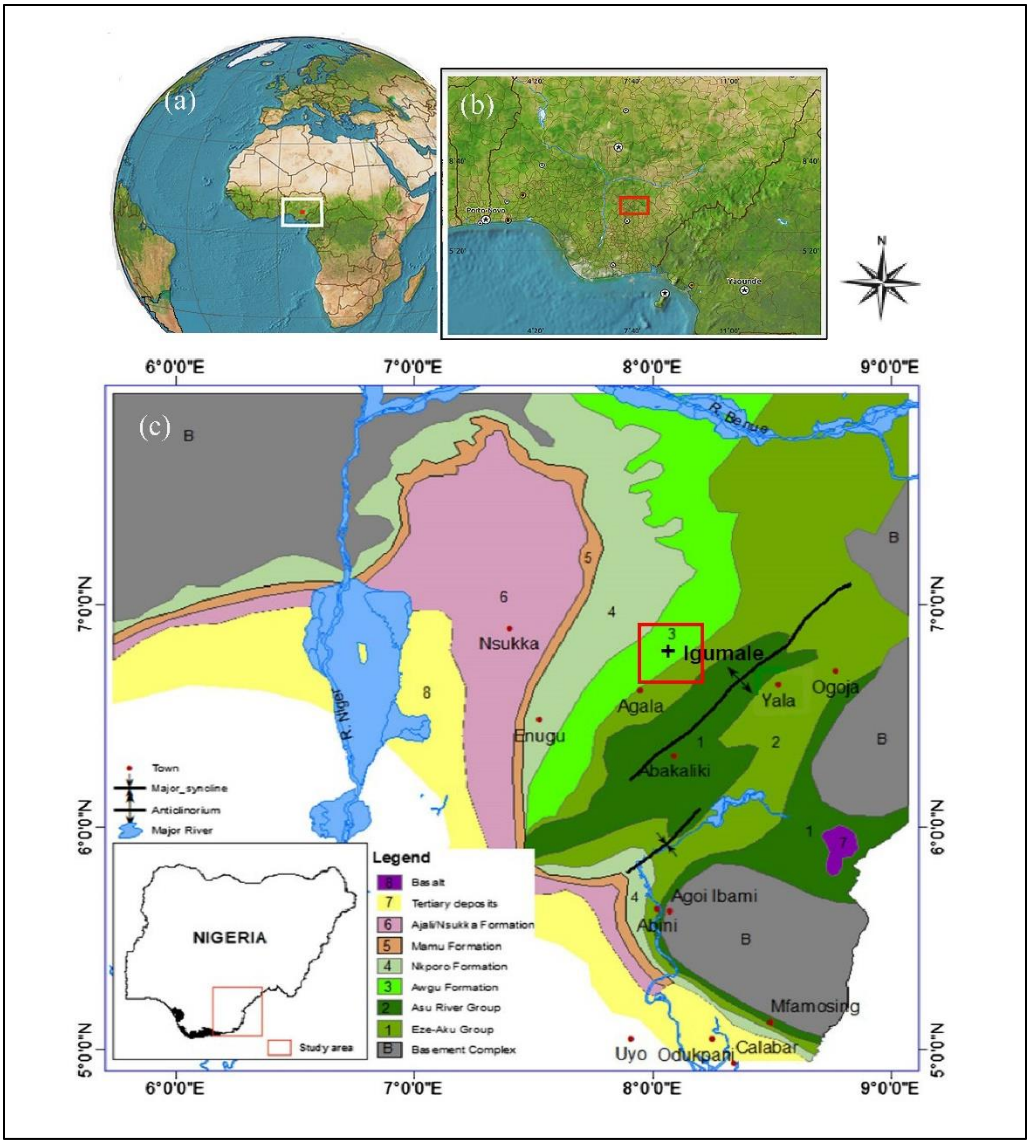

Fig. 1. Location and geologic maps of the study area.
(a) Hemispherical map of Africa indicating the location of Nigeria, (b) Satellite location map of Nigeria showing the study area (from www.Maphill.com), (c) Geological map of the study area (Igumale) (modified after Aniekan and Okereke, 2022).

However, limestone is a critical raw material to Nigeria's manufacturing and allied industries (Adekoya 2021) and serves as a hydrocarbon potential source and reservoir rocks in many basins of the World (Chilingar *et al*. 1972). The greatest of the world's oil and gas resources are produced from carbonate reservoirs (Montaron 2008). For example, the Tupi Field, Northeast in the Santos Basin, Brazil, housed 30,000 barrels of oil daily from an appraisal well (Burrows and Thethi 2010). This success from carbonate reservoirs implies that active exploration of carbonate rocks will lead to the next boom and exploitation far surpassing clastic reservoirs (Fitch 2010). However, due to the prospects and enormous potential of carbonate rocks, there is a need to thoroughly investigate the vast deposits of limestone occurring extensively in most parts of the Central Benue Trough to understand their paleo-depositional environment and diagenetic events through geologic time.

2 Geological Setting

Many workers have accounted for the evolution of the Benue Trough. The failed rift basin has been regarded as a product of aulacogen, developed due to the separation of African and South American plates in the Early Cretaceous (Olade 1975; Burke *et al*. 1972). The Benue Trough is divided into Southern, Central, and Northern ensembles, previously referred to as Lower, Middle, and Upper Benue Trough respectively (Nwajide 2022). Stratigraphically, the Central Benue Trough consists of the Asu River Group, the oldest marine sediments in the Central Benue Trough (Okosun 1999) and made up of the Albian Arufu, Uomba and Gboko Formations (Offodile 1976). Overlying the Asu River Group is the Awe Formation. The Keana Formation resulted from the Cenomanian regression, which deposited fluvio-deltaic sediments (Offodile 1976; Offodile and Reyment 1977). Other sedimentary sequences of depositions in the basin included the Eze-Aku, the Awgu, and the overlying Lafia Formations; these are characterised by ferruginised sandstones, flaggy mudstones, clays, and claystones (Okosun 1999).

3 Materials and Methods

Forty (40) core samples were obtained from two quarries (Igumale-1 and Igumale-2) sections of the limestone deposits around Igumale, Central Benue Trough (Figure 2, 3). The samples were macroscopically described in detail, and twenty (20) thin sections were prepared at the Department of Geology Laboratory, University of Ibadan, Nigeria. Thereafter, slides, mineral identification, allochems and quantitative modal analysis were examined on the thin sections using a polarising microscope. Classification of the limestone was feasible with the aid of Folk (1962) and the monographs of Adams *et al*. (1988) and Tucker (2003). Sections of interest were photographed (Fig. 5) to aid further identification, analysis of principal allochems and other detrital minerals.

3.1 Geology of the Limestone around Igumale

The studied sections penetrated three lithofacies units: limestone, shale, and clays. The limestone unit is the main object of this current study. The limestone is alternating with the shale in both wells (Igumale -1 and -2). The limestone varies from fine- to medium-grained and light to dark grey. It consists of some Gastropod and Foraminifera shells. Oolitic grains rarely occur at both wells except in Igumale-1 (Figure 2).

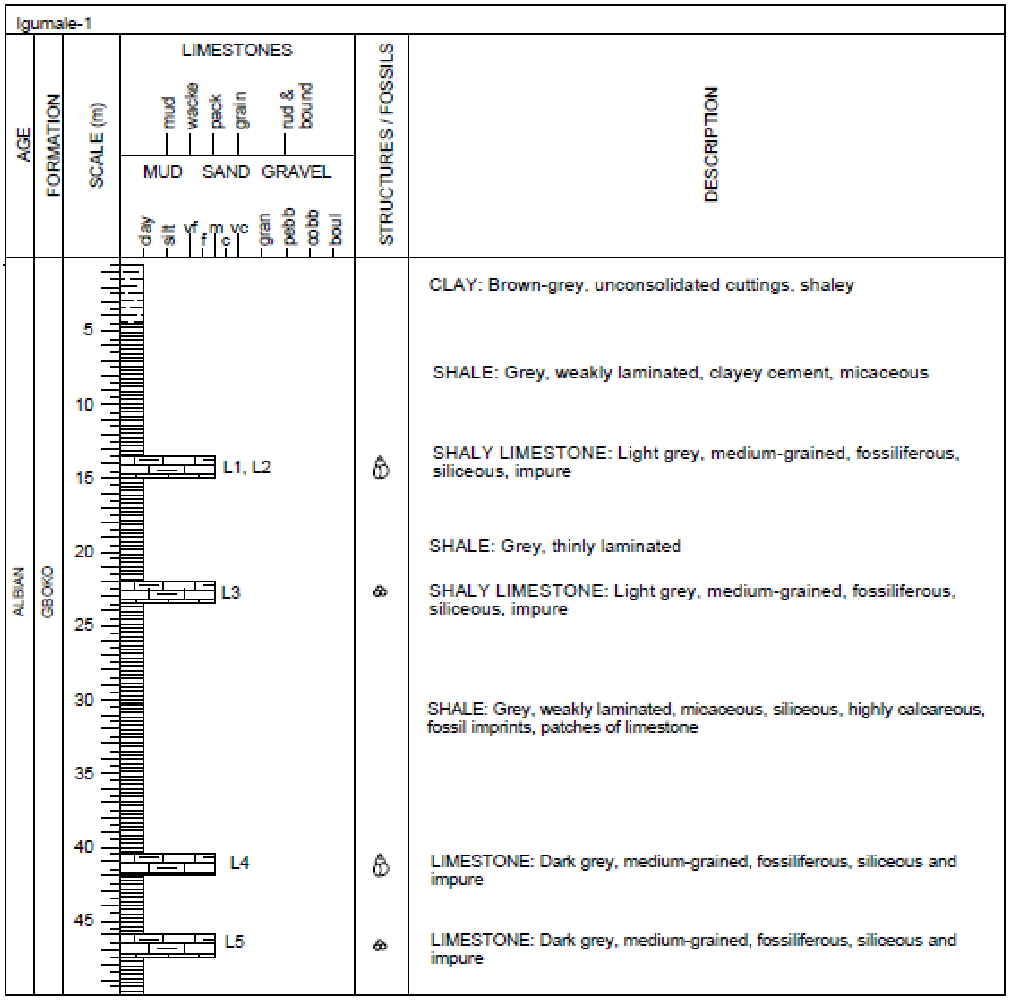

Fig. 2. Lithostratigraphy of the Gboko Formation around Igumale -1 well.

The limestone comprises micaceous, calcitic, and occasionally siliceous grains. Calcitic cement (possibly sparite) binds the grains. The limestone is generally weakly laminated. Of the 50 m thick successions of rocks penetrated by Igumale -1, only a total thickness of 8 m limestone was encountered, representing four layers, with each layer 2 m thick alternating the shale (Figure 2). Igumale-2 penetrated 35 m consisting of 8.8 m of limestone (Figure 3). The 8.8 m of the limestone accounts for three layers of varying thicknesses that generally thin upwards. The thinning upward of the limestone layers in Igumale-2 (Figure 3) suggests upward shoaling of the marine environment. The shale consists of brown, light to dark grey, micaceous, and siliceous grains. It is fissile, however, weakly laminated. A total of 38 m thick of shale was penetrated by Igumale-1 well (Figure 2), while a total thickness of 26.2 m was encountered in Igumale-2 (Figure 3). The clay was only observed in Igumale-1 well where it occurs as the topmost unit, thus the youngest unit in the studied sections. It has a colour variation of brown to grey. Its thickness is 4 m (Figure 2). The three lithofacies units are generally correlative as the studied sections at both wells show thickening of the limestone units away from Igumale-1 towards Igumale-2 (Figure 4).

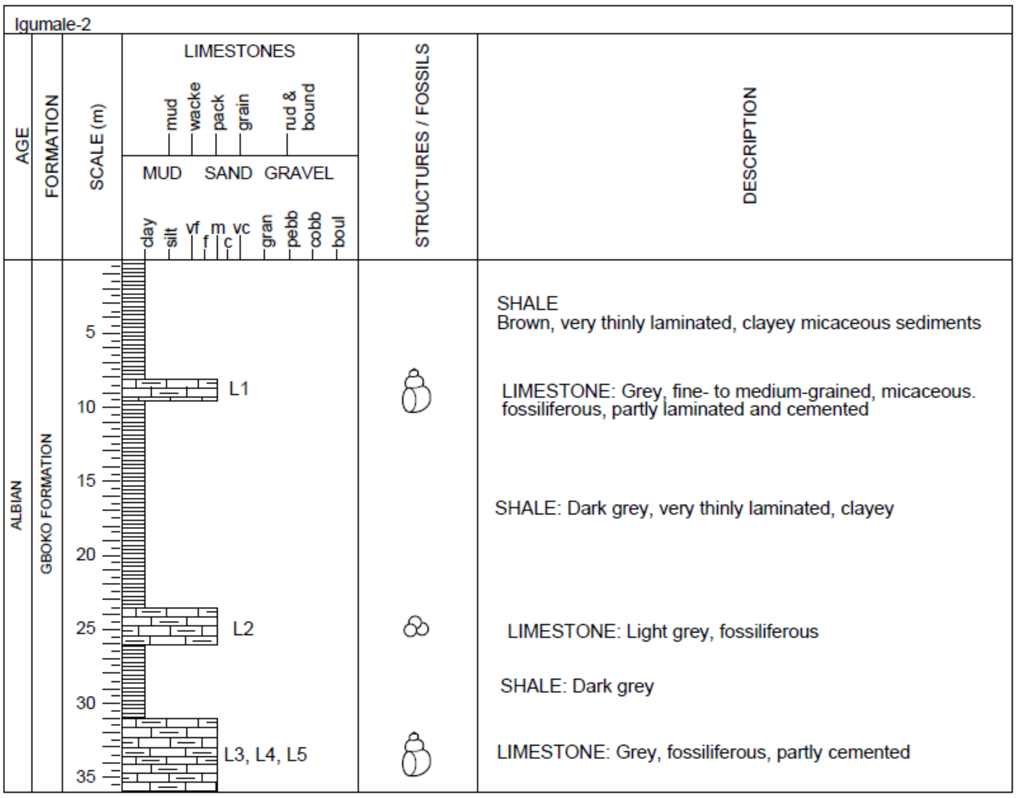

Fig. 3. Lithostratigraphy of the Gboko Formation around Igumale -2 well.

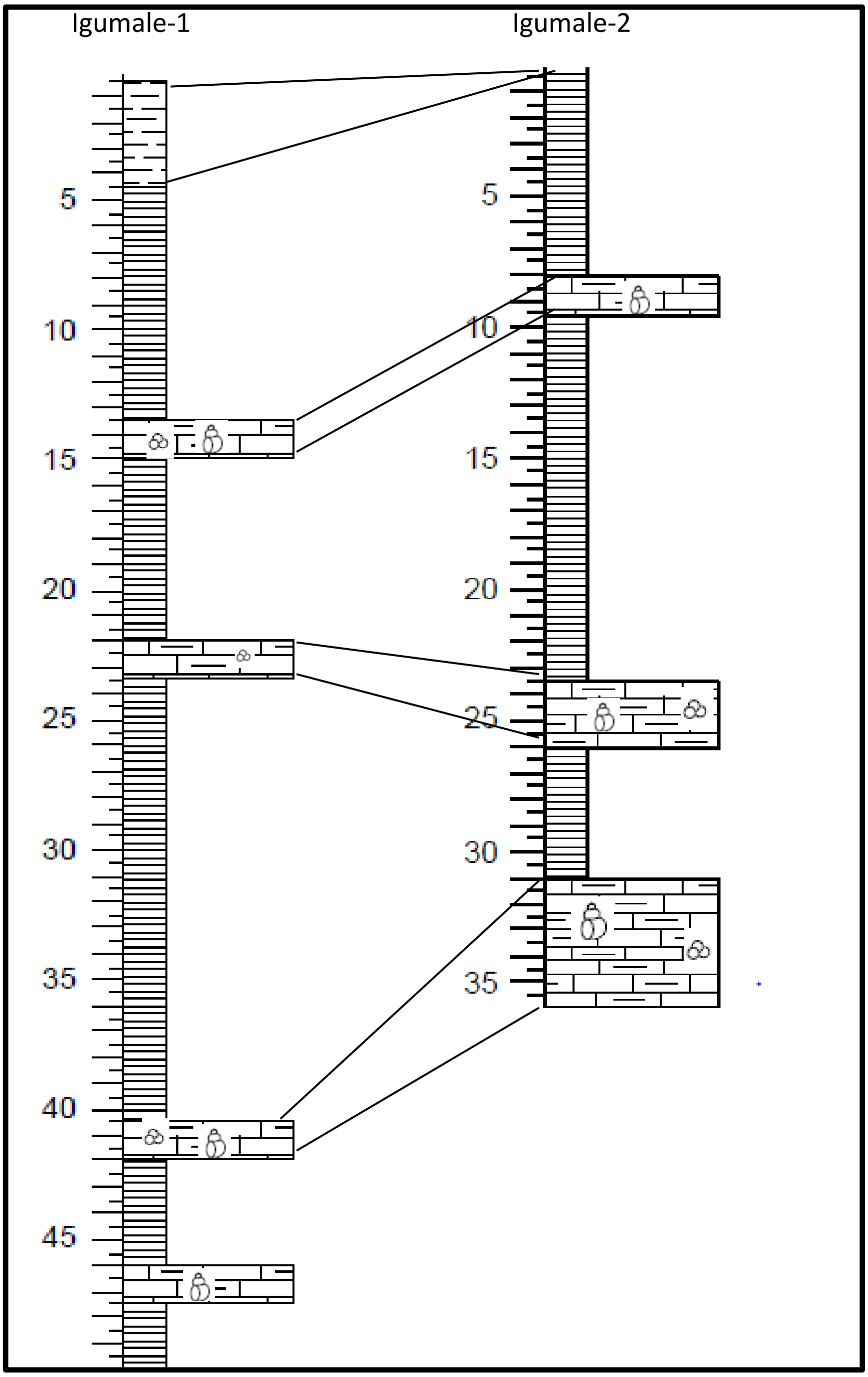

Fig. 4. Lithostratigraphic correlation of the studied sections
(note the thickening of the limestone units from Igumale-1 well towards Igumale-2 well)

4 Results and Interpretations

4.1 Petrography

Textural characteristics, quantification of allochems and classification of the limestone were based on Folk (1962) and Tucker (2003). Various compositions of the limestone were grouped into terrigenous, allochemical and non–skeletal components. Detrital quartz displays high relief, sub-angular to very angular and sutured. The percentage value of the detrital quartz ranges from 3 to 15 % (Table 1; Figure 5), suggesting a nearby basement metamorphic source of derivation (Adams *et al*. 1988). The non-skeletal allochems of the limestone include ooids and peloids, while sparite and micrite are the cement and matrix, respectively (Table 1).

Table 1: Allochemical composition of limestone around Igumale, Central Benue Trough

S/#	Depth (m)	+TC (%)	Ooids (%)	Sparite (%)	Peloids (%)	Micrite (%)	Fossil (%)	*Limestone type
				Igumale-1 Samples				
L1	13.5	15	7	43	-	-	35	Biosparite
L2	14.0	05	-	-	03	35	57	Biopelmicrite
L3	22.5	12		03	-	48	37	Biomicrite
L4	41.5	03	20	50	10	-	17	Oobiosparite
L5	47.0	05		10	05	33	47	Biomicrite
				Igumale-2 Samples				
L1	8.50	15	7	43	-	-	15	Biosparite
L2	23.0	07	3	-	13	45	27	Biopelmicrite
L3	32.5	17	-	03	-	48	32	Biomicrite
L4	34.0	03	27	50	10	-	10	Biosparite
L5	34.5	35	-	15	5	33	12	Biomicrite

+TC= Terrigenous Constituents; *After Folk 1959; 1962

The skeletal materials consist of fossil fragments (comprising mainly foraminifera and gastropod shells). The ooids are rounded and range from 7 to 10 % in the samples studied (Figure 5). The peloids are near elliptical shape and vary from 3 to 20 % (Table 1; Figure 5), while the micrites range from 33 to 48 %. Sparite appears as pores filling cement and poorly defined grained boundaries ranging from 10 to 50 % (Table 1; Figure 5). Fossil fragments and traces of various carbonate-secreting organisms of multiple dimensions were observed, ranging from 17 to 57 %. (Table 1; Figure 5). Following Folk's (1959, 1962) classification scheme, the limestones around Igumale were classified as oobiosparite, biosparite, biopelmicrite, and biomicrite (Table 1; Figure 5a - d).

4.2 Diagenetic features of the Gboko limestone

Several diagenetic processes that occur within the different samples from the limestone formation include grain compaction, micritisation, sparry calcite cementation and dissolution.

Compaction: Compaction is the mechanical process triggered by the increasing overburden of sediments during burial and increasing temperature and pressure conditions (Adams *et al*. 1984). According to Flugel (2010), the compaction process decreases the bulk volume of a single grain or packing of grains. In the studied samples, the preservation of early diagenetic sedimentary structures and the presence of allochems (Figure 5) suggest an insignificant role in the compaction effect during early diagenesis. Compaction features observed in Igumale-1 (Figure 2) is marked by loosely packed grains and well-preserved allochems suggesting an early eogenetic environment.

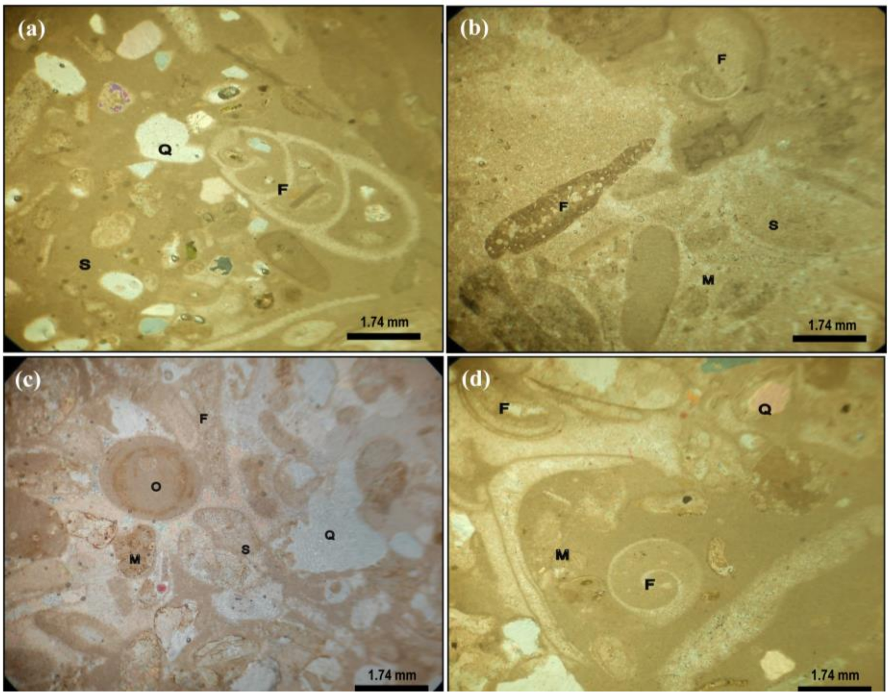

Fig 5. Photomicrographs of representative limestone facies units observed at Igumale well-1 and -2. (a). Biosparite consisting of corroded monocrystalline quartz grain and ferroan calcite in Igumale limestone. (b). Biospelmicrite comprising abundant Foraminifera sp. (c). Oobiosparite containing some corroded microcrystalline quartz grains was observed in Igumale-1 well. (d) Biomicrite, consisting of abundant preserved fossil fragments. Note: Q = Detrital quartz; F = Fossil fragments (G = Gastropods, F = Foraminifera); S = Sparite; M = Micrite; and O = Ooids.

Micritisation: Bioclastic grains are altered on the sea floor or just below by bacteria, fungi and endolithic algae in quieter-water areas leading to the formation of micritic envelopes around bioclast (Adams *et al*. 1984). Some of the analysed samples exhibit micritisation and micritic coating of grains (Figure 5), suggesting a shallow marine environment of deposition.

Dissolution and Cementation: Some of the studied samples exhibit dissolution evidenced by corroded medium quartz-grained (Figure 5) and occur in moderate burial and alkaline environments. Cementation is evidenced by the microcrystalline sparry calcite that precipitated from the solution and filled void space (Figure 5a - c).

4.3 Reservoir Potentials and exploration implications

Choquette and Pray (1970) outlined the classification of pore types and porosity applicable to carbonate rocks in thin sections (Figure 6), this approach was employed in pore assessment, and description of the analysed limestone (Figure 5).

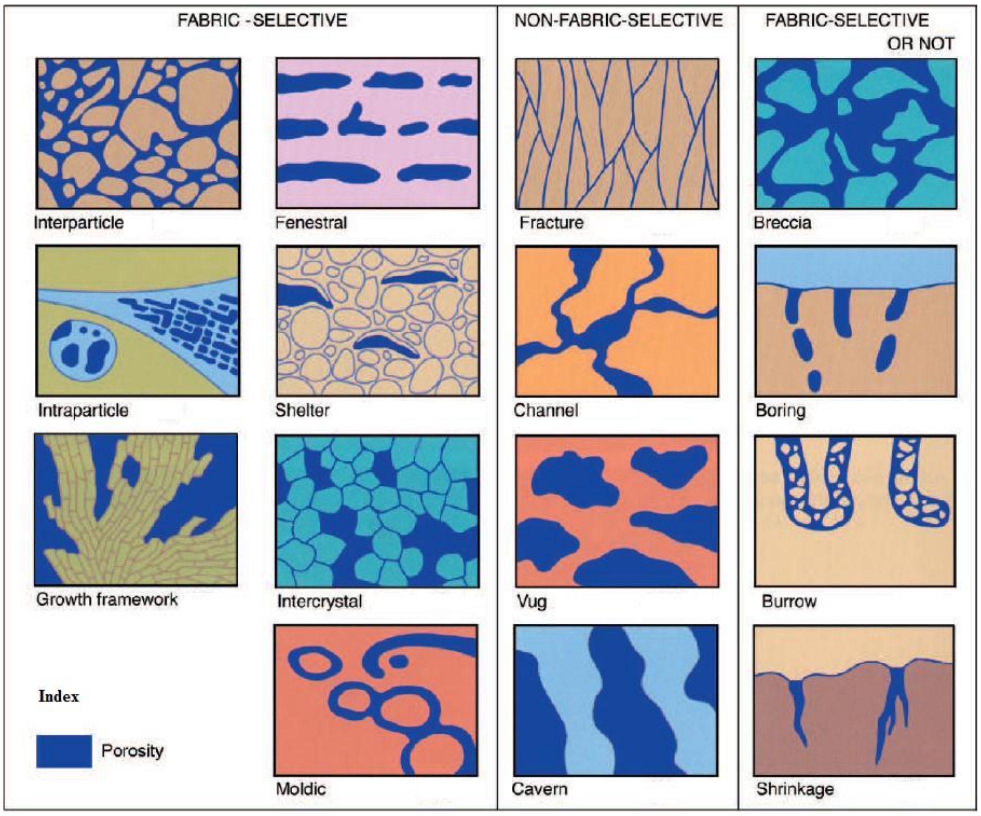

Fig. 6. Pore types and porosity classification of Limestones.
(Source: Choquette and Pray 1970)

Based on the observed pore attributes of the limestone, vuggy and moldic porosity were recognised (Figure 5). Other reservoir characteristics include low porosity and permeability due to the infilling of sparry calcite cement and micritic matrix associated with the Igumale limestone. Such infilling will thus decrease the reservoir quality of the Igumale limestone. Secondary porosity was created due to the dissolution of skeletal grains observed in some analysed samples (Figure 5). Dissolution of skeletal grains is often thought to enhance the porosity and permeability of the sedimentary rock, thereby increasing its reservoir quality. However, the extent of skeletal dissolution in the analysed limestone samples is minimal compared to the infilling of pore spaces. It can be adduced that the petrophysical attribute of the Igumale limestones (ranked class 3 of Lucia (2004), therefore, have poor reservoir performance.

4.4 Paleo-depositional environment

Allochems compositions and stratigraphy were integrated to deduce the depositional environment of the limestone. The occurrence of peloids, ooids, terrigenous constituents, and medium-grained quartz surrounded by carbonate cement (Figure 5) indicates a tidal flat environment. Furthermore, the presence of gastropod shells (Figure 5), peloids (Table 1) and micritisation as the main diagenetic process indicate environments with limited water circulation (Shakeri 2013). The moldic and vuggy porosity arising from the investigated limestone was formed from the diagenetic dissolution of the fossil fragments, enhancing the reservoir quality. Cementation (sparry ferroan calcite) of various scales present in the limestone may reduce its porosity and affect reservoir quality.

5 Discussion

Lithological units around Igumale comprise five (5) facies, namely, micaceous shale, dark grey limestone, shaly limestone, shale, and clay facies which exhibited a fining-upward sequence. The fining-upward sequence and micritic large allochems revealed deposition in a low-energy environment, suggestive of the lagoonal environment (Shakeri 2013). Skeletal constituents comprising diagenetically altered gastropods and foraminifera show that the limestones were probably a product of reduced sea level where a high proportion of pelagic deposits increase (Grammer *et al*. 1993, 2004) and suggest quiet-water conditions. Deik *et al.* (2019) also asserted that peloids of subtropical to cool-water carbonate settings are formed as a result of faecal pellet. The ooids were poorly sorted, relatively low in abundance (7-20 %) in the studied area and suggested allochthonous (Folk 1962) in origin and transported by wave or current action (Folk 1962). Reyment (1965) attributed the deposition of this formation to a product of the first transgressive phase of the Late Albian. Parallel lamination, the presence of developed ooids and preserved skeletal grains suggest deposition in moderately agitated waters. The preservation of abundant skeletal grains and the formation of ooids may be due to suitable water salinity and temperature (Lees 1975). The monocrystalline quartz grains and some patches of ferroan calcite observed in some of the samples indicate siliciclastic input during deposition and freshwater diagenesis (Ali *et al.* 2020). Petrographically, the limestones are classified as oobiosparite, biopelmicrite and biomicrite, respectively. The diagenetic fabric of the limestone includes dissolution and micritisation. However, the litho-stratigraphical succession of the measured core sections can be correlated to a modern marine setting. This study envisaged that probably during high sea, a lot of abundant pelagic materials were probably exported onto the Basement Complex rocks by currents flowing out of the Tethys Sea during the Late Aptian–Middle Albian times with deposition of the limestone in a subtidal-shallow marine setting.

6 Conclusions

The limestones around Igumale-1 and Igumale-2 wells, Central Benue Trough, were studied to determine the compositions, paleo-depositional environment and diagenetic history. The limestones are light to dark grey, fine to medium-grained and fossiliferous. Petrographic examination of the limestones shows that they comprise quartz and ferroan calcite (3-15 %), non-skeletal components such as peloids (3-20 %), ooids (7-10 %), micrite (33-48 %), sparites (10-50 %) and fossil fragments consisting of foraminifera and gastropods (17-57 %). Consideration of the non–skeletal and the skeletal allochems classified the limestone as oobiosparite, biopelmicrite, and oobiosparite. The paleo-depositional environment ranges from sub-tidal to shallow marine environments. Moldic and vuggy porosity were encountered, and the diagenetic events included micritisation, dissolution, and cementation. This study has provided a petrographic synopsis of the limestone for further consideration and may impact both the exploration and development of the limestone.

References

Adams AE, Mackenzie WS, Guilford, C. 1988. *Atlas of sedimentary rock under the microscope*. William Clowes Ltd, London, 102 pp.

Adekoya JA. 2021. Metallic and Industrial Minerals of Nigeria. College Press, Ibadan Nigeria. 425pp.

Akande SO, Horn EE, Reutel C. 1988. Mineralogy, fluid inclusion and genesis of the Arufu, and Akwana Pb-Zn-Fe mineralization, Middle Benue Trough, Nigeria. *Journal of African Earth Science* 7:167 – 180.

Akori FD, Mode AW, Akpofure E. 2023. An Evaluation of the Hydrocarbon Potentials of the Gboko Formation, Middle Benue Trough, Nigeria. *Global Journal of Geological Sciences* 21: 31-41.

Ali F, Hanif M, Zhang S, Latif K, Ahmad S, Jan IU, Khan H. 2020. Ooid fabric in the Jurassic of the Indus Basin, Pakistan: control on the original mineralogy. *Current Science* 119(5): 831 -840.

Aniekan E, Okereke C. 2022. Investigation of hydrogeological conditions of a fractured shale aquifer in Yala Area (SE Nigeria) characterized by saline groundwater. *Applied Water Science* 12: 194, 1-25

Benkhelil J. 1989. The origin and evolution of the Cretaceous Benue Trough. *Journal of African Earth Sciences* 8: 251-282.

Bolarinwa AT, Idakwo SO. 2013. Evaluation of Albian Limestone Exposed at Dangote Cement Quarry, Tse-kucha Near Yandev, North Central Nigeria: A Geochemical Approach. *International Journal of Science and Technology* 2(12): 847-856.

Burke KC. Dessauvagie TFJ. Whiteman AJ. 1972. Geological History of the Benue Valley and adjacent areas. In: Dessauvagie, T.F.J. and Whiteman AJ (eds.). *African Geology*, Ibadan University Press, Ibadan, pp 187-205.

Burrows N, Thethi J. 2010. Press release: BG Group confirms high productivity from well test on Tupi North- East in the Santos Basin, Brazil, http://www.bg.group.com/ Media Centre/Press/Pages/24th Mar. 2010.

Deik H, Reuning L, Petrick B, Takayanagi H. 2019. Hardened faecal pellets as a significant component in deep water, subtropical marine environments. *Depositional Record* 5: 348-361. https://doi.org/10.1002/dep2.64

Chilingar GV, Mannon RW, Rieke HH. 1972. *Oil and gas production from carbonate rocks*. Elsevier, New York, 408pp.

Choquette PW, Pray LC. 1970. Geologic nomenclature and classification of porosity in sedimentary carbonate. *American Association of Petroleum Geologists Bulletin* 54 (2): 207-250.

Fitch PJR. 2010. *Heterogeneity in the petrophysical properties of carbonate reservoirs.* Published Thesis: Doctor of Philosophy, Department of Geology, University of Leicester, 1-265pp.

Flugel E. 2010. *Microfacies of Carbonate rocks*, Springer- Verlag, New York, USA, 1006 pp.

Folk RL. 1959. Practical petrographic classification of limestones. *American Association Petroleum Geologists Bulletin* 43: 1-38.

Folk RL. 1962. Spectral subdivision of limestone types. In: WE. Ham(ed.), Classification of carbonate rocks, *American Association of Petroleum Geologists Memoir* 1: 62 -84.

Grammer GM, Ginsbury RN, Harris PM. 1993. Timing of deposition, diagenesis and failure of steep carbonate slopes in response to a high amplitude, high-frequency fluctuation in sea level, Tongue of the ocean, Bahamas. In: RG. Loucks and JF. Sarg (Eds). Applications, *American Association of Petroleum Geologists Memoir* 57: 107-131.

Grammer GM, Harris PM, Eberli GP. 2004. Integration of outcrop and modern Analogs in Reservoir modeling: Overview with Examples from the Bahamas. *In*: GM. Grammer, Harris PM, Eberli GP. (eds). An Integration of outcrop and modern Analogs in Reservoir modeling. *American Association of Petroleum Geologists memoir* 80:1-22.

Guiraud M. 1990. Tectono- sedimentary framework of the Early Cretaceous continental Bima Formation (Upper Benue Trough, NE Nigeria). *Journal of African Earth Sciences* 10, 341 – 353.

Lees A. 1975. Possible influences of salinity and temperature on modern shelf carbonate sedimentation. *Marine Geology* 19, 159 – 198.

Lucia F. 2004. Origin and Petrophysics of dolostone pore space. In: Rizzi G, Darke, Braithwaite C.J.R. (eds.). The geometry and paragenesis of dolomite hydrocarbon reservoirs. *Geological Society of London, special publications* 235: 7-63.

Montaron B. 2008. *Carbonate Evolution. Oil and Gas Middle East*, Online article, https://www.oilandgasmiddleeast.com/products-services/article-4852-carbonate-evolution, Accessed on February 3, 2022.

Nwajide CS. 2022. *Geology of Nigeria's Sedimentary Basins*. 2nd Edition, Albishara Educational Publications, Enugu, Nigeria. 693pp.

Odedede O. 2011. Sedimentology and Paleoenvironment of the Gombe Sandstone and Lower Kerri-Kerri Formation around Biri Fulani, Upper Benue Trough, Nigeria. *Journal of Mining and Geology* 47(1), 1 -17.

Odedede O. Adaikpoh EO. 2011. Sequence stratigraphy of the Gombe Sandstone and Lower Kerri –Kerri Formation exposed around Fika-Potiskum, Upper Benue Trough, Nigeria: Consideration for hydrocarbon reservoirs. *Indian Journal of Science and Technology* 4 (5): 492-498.

Offodile ME. 1976. The Geology of the Middle Benue Nigeria. *Cretaceous Research, Paleontological Institute: University of Uppsala. Special publication.* 4:1-166.

Offodile ME. Reyment RA. 1977. Stratigraphy of the Keana-Awe area of the Middle Benue Region of Nigeria. *Bulletin Geological Institutions University Uppsala*, 7:37-66.

Okosun E. 1999. stratigraphy of Gboko Formation, Middle Benue Trough, Nigeria. *Journal of Environmental Science* 3(2): 169 – 172.

Olade MA. 1975. Evolution of the Nigeria Benue Trough (Aulacogen): A tectonic Model. *Geological Magazine* 112: 575 -583.

Petters SW. 1980. Biostratigraphy of Upper Cretaceous foraminifera of the Benue Trough, Nigeria. *Journal of Foraminifera Research* 10 (3):191-204.

Ramamathan RM, Nair KM. 1984. Lower Cretaceous Foraminifera from Gboko limestone, Eastern Nigeria. *Journal of Mining Geology* 21(1-2): 41-48.

Reyment, RA.1965. Aspects of Geology of Nigeria. Ibadan University Press, 145pp.

Shakeri AR. 2013. Microfacies, Depositional Environment and Diagenetic Processes of the Mauddud Member, in a Field in the Persian Gulf. *Journal of Geology and Geosciences* 2: 122. 1-10. doi: 10.4172/2329-6755.1000122.

Tucker ME. 2003. *Sedimentary rocks in the field*. John Wiley and Sons Ltd. 30pp.

Wright JB. 1985. *Geology and mineral resources of West African*. George Allen and Unwin, London, 187 pp.

Zaborski P, Ugodolunwa F, Idornigie A, Nnabo P, Ibe K. 1997. Stratigraphy and structure of the Cretaceous Gongola Basin, Northeastern Nigeria. *Bulletin de Centredes Recherches Exploration Production Elf Aquitaine* 21, 153 -186.