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CARBONATE MICROFACIES, DIAGENESIS AND RESERVOIR POTENTIAL ANALYSIS OF THE GONGILA LIMESTONE, GONGOLA BASIN, NORTHEAST NIGERIA

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ABSTRACT

The limestone facies of the Gongila Formation constitute an important sedimentary unit in the Gongola Basin. Because these limestones are intercalated with potential source rocks in the basin and well exposed at Ashaka Cement quarry, systematic logging and sampling of the limestones were carried out and samples selected for petrographic, geochemical and petrophysical examinations to describe their microfacies distribution, diagenetic history and petroleum reservoir quality implications. Limestone and shale are the main lithofacies. Microfacies assemblage of the limestone includes peloidal wackestone, bioclastic wackestone, bioclastic wackestone - packstone and bioclastic packstone. These microfacies reflect shelf lagoon to shallow open waters. Diagenetic imprints show stages of micritization, cementation, compaction, dissolution, and neomorphism. Geochemical data (XRF) indicates the Ca/Mg ratio of (average of 65.81) and high amount of Ba (mean value of 226 ppm) suggest little or no dolomitization. The porosity estimation of the Ashaka limestone can be classified as poor to fair. Porosity types include; interparticle, moldic, vugs and fractures. The petrophysical analysis of five samples indicated porosity values which range from 3 to 10 % and permeability values from 24 to 189 mD. Based on the results, the porosity and permeability can be classified as low and therefore the petroleum reservoir potential of the limestone is of low quality.

Keywords: Ashaka, dolomitization, limestone, micrite, vugs, wackestone

INTRODUCTION

The investigated sediments, the Upper Cenomanian to Turonian Gongila Formation limestone is located at Ashaka Cement Quarry, Ashaka Village, Gongola Basin. The area constitutes part of Gombe sheet 36NE of the Geological Survey of Nigeria (GSN) and lies between Latitudes $10^{0}52^{1}$ to $10^{0}55^{1}$N and Longitudes$11^{0}30^{1}$ to $11^{0}32^{1}$E (Fig. 1). It is located about 80 km NNE of Gombe and from Gombe town-northwards along Gombe-Ashaka-Potiskum road.

Previous investigations on the geology of the Upper Benue Trough includes; Carter *et al.* (1963) which outlined the structural and stratigraphy framework of the Upper Benue trough. Petters (1977, 1982) investigated the foraminiferal biostratigraphy of the Upper Benue sediments. Adegoke *et al.* (1978) dated the Kerri-Kerri Formation based on the microfaunal contents. Also Lawal (1982) and Lawal & Moulade (1986) on the basis of pollens and dinoflagelates dated the Fika Member (Yolde Formation) in the Gombe-Kumo as Turonian to Maastrichtian. Gebhardt (1997) carried out carbon and oxygen isotope measurements across the Cenomanian–Turonian boundary in the Upper Benue Trough (Ashaka) and concluded that the palæotemperature coincides with the previously published data from other equatorial areas of the world. He also suggested that the globally observed negative shift of the carbon isotope values at the Turonian boundary was developed in the nearshore and brackish settings at Ashaka. Ojo and Akande (2001) investigated the paleoenvironmental and paleoclimatic characteristics of the Cenomanian to Coniancian sediments of the Upper Benue Trough and concluded that a relatively stable Gongola basin secured a low siliciclastic input and allows carbonate deposition for certain intervals. Ojo (2004) classified the limestone's

microfacies of the Pindiga Formation based on the textural parameters and suggest relatively low energy open marine to quiet water lagoonal environments for this Formation.

Other previous work on the study area focused on the lithofacies and petrography of the limestone facies (Popoff *et. al.*, 1986; Iwuagwu, 1987; Oti, 1990; Rebelle, 1990). To date, however, no detail published report on the quantitative assessment of the porosity and permeability evaluation of the limestone in the area. Therefore, this work is aimed at reservoir evaluation of the limestone. New geochemical data provided would also permit better understanding of the diagenetic processes and environments. The current interest of the Federal Government of Nigeria to encourage and promote exploration for hydrocarbon in the hinterland sedimentary basins makes this aspect of the study to be relevant at this point in time.

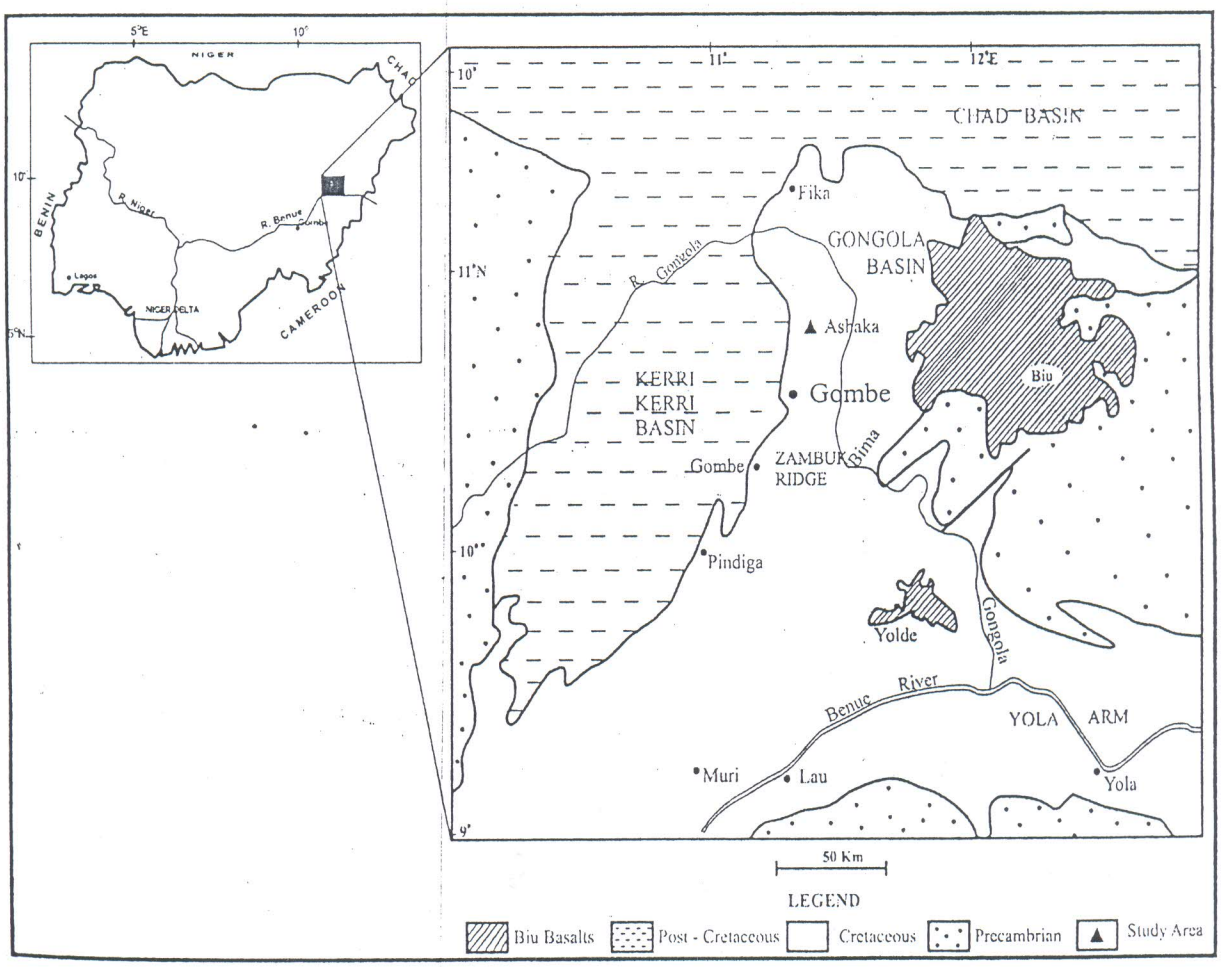


Fig. 1: The location map of Ashaka quarry with inset (Nigeria) (modified from Gebhardt, 1997).

EVOLUTION, STRATIGRAPHY AND GEOLOGICAL SETTINGS

Olade (1975) classified the Benue Trough as an aulacogen based on the concept of the rift origin. Wright (1981) presented the spreading ridge hypothesis and applied the Y-shaped triple junction rift model (R-R-R) to the break-up of African and South American plates in which two arms of the triple rift model

continue to spread while the spreading in the third arm was aborted. According to this model, the three radial rift systems that met at an RRR triple junction in the Gulf of Guinea became active during the early Cretaceous. The south Atlantic, the Gulf of Guinea and the Benue Trough represent rift arms of this triple junction. Sedimentary successions in the Benue Trough were deposited during three cycles (Albian – Cenomanian, Turonian – Conancian and Campanian – Maastrichtian) which where interrupted by unconformities (Cratchley and Jones, 1965; Petters, 1977).

In the Gongila Basin, an arm of the Upper Benue Trough, the continental deposits of Bima Sandstones occupied the rifted basin from the Jurassic period till the Aptian/Albian age and this was followed by marine sediments infilling enhanced by thermal sag phase development of the basin (Guiraud, 1990). The Aptian-Albian Bima Sandstone which overlies the Precambrian-Lower Paleozoic basement complex predominantly migmatitic-gneisses occur commonly on the flanks of the Gongola and Yola Basins (Fig. 2). The Bima Sandstone is overlain by the Cenomanian to Turonian Yolde Formation which is succeeded by the marine Turonian-Coniacian Pindiga Formation (a stratigraphic equivalent of Gongila Formation) in the Gongola Basin. The marine Pindiga and Gongila formations in the Gongola Basin consist of sequences of shales and limestones. These successions are overlain by the Campanian - Maastrichtian Gombe Sandstone in the Gongola Basin and the Lamja Sandstone (lateral equivalents) in the Yola Basin. The Tertiary Kerri-Kerri Formation capped the succession west of Gombe in the Gongola Basin. The Yola Basin is the E-W trending portion of the Upper Benue Trough and it comprises of the continental Bima Sandstone overlain by the paralic Yolde Formation. The older sequence is succeeded by the marine Turonian – Coniacian Dukul, Jessu, Sekuliye, Numanha shale and Lamja Sandstone formations and they are equivalents to the Gongila and Pindiga formations in the Gongola Basin.

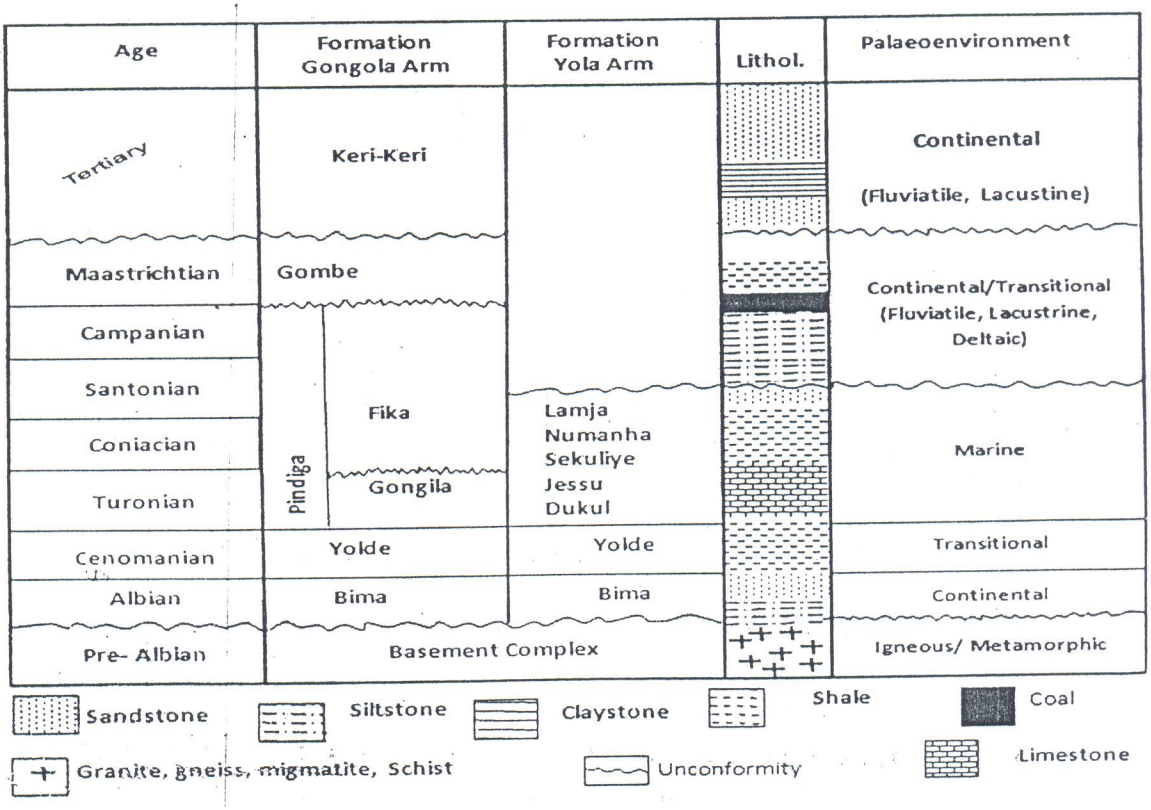


Fig. 2: Stratigraphic succession of the Upper Benue Trough (Modified after Ojo, 1999)

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MATERIALS AND METHODS

Representative limestone samples were collected from the eastern, central and western part of the quarry. The thicknesses of the beds were logged and the lithostratigraphic columns constructed (Fig. 3). Thin section of the carefully selected limestone samples were prepared for petrographic examinations at the Geology Department Workshop of the University of Ilorin. Fifteen of the samples were analyzed for major and trace elements determination using XRF and ICPMS method at Acme Laboratory, Canada. Porosity and Permeability test were carried out in Fugro Geosciences Laboratory, Warri, using standard procedures outlined in Active Standard Test Method (ASTM C127) (Eraser, 1935).

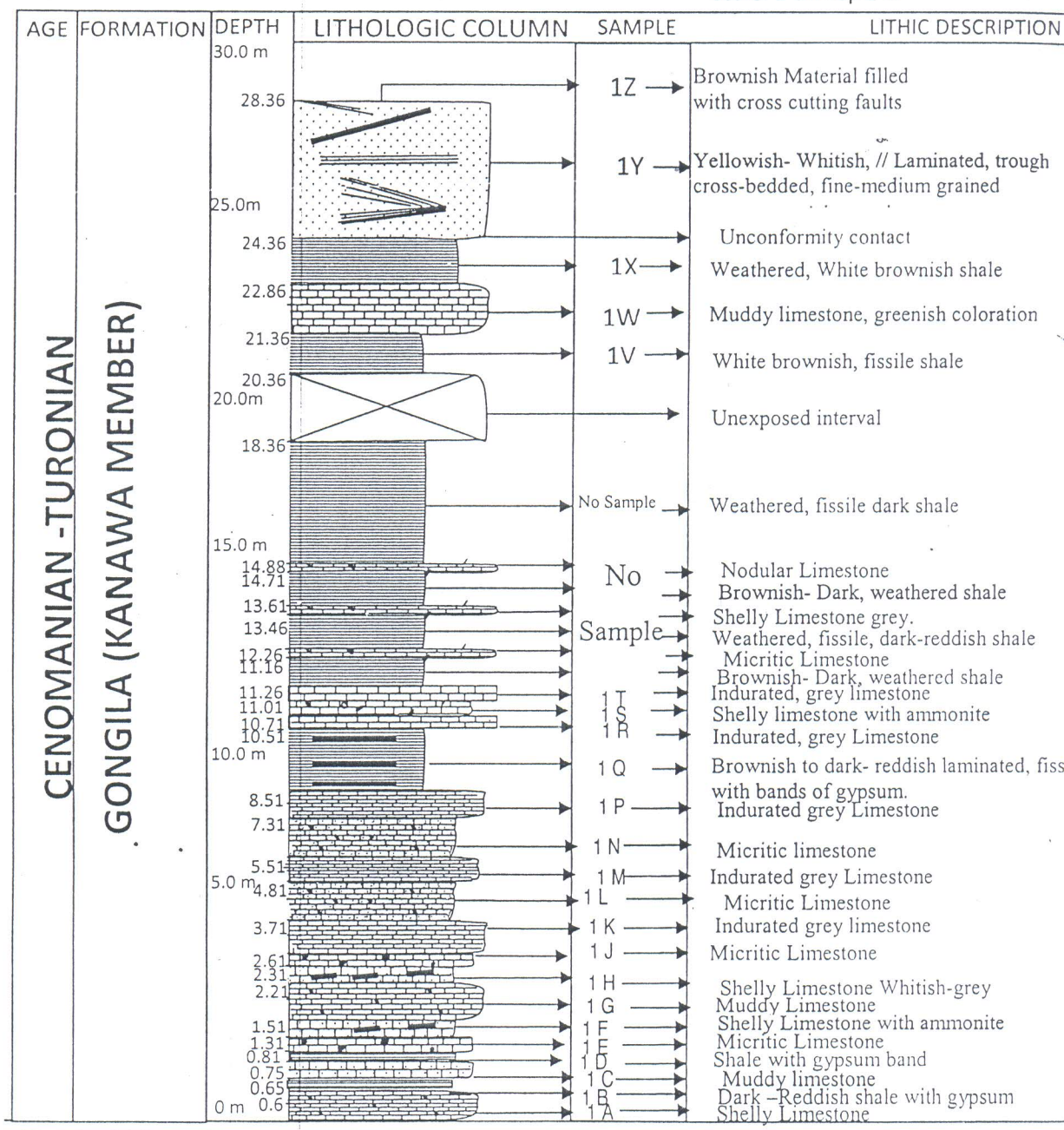


Fig. 3: Lithologic section of Gongila Formation at Ashaka Cement Quarry (ASQ1). Eleva bottom=290.3 m, Long. =N10^{0}56^{1}100^{11}, Lat. =E11^{0}27^{1}278^{11}, Elevation at the top=303.6 m.

RESULTS AND DISCUSSIONS

Description of Lithostratigraphic section

The Lithologic sections consists of three different lithofacies; limestone, shale and minor sands The thickest section is about 28.36 meters and this represents the central part of the quarry. The basal p represented by alternating limestone-shale beds. The limestone is rich in macrofossils, containing br shells of gastropod, pelecypod, echinoids, brachiopods, bivalves, ammonite as well as the broken she some unidentified faunas. The limestone is shelly, micritic, indurated and in places stylotized. The sli brown to grey shale is rich in gypsum. The gypsum occurs as thin layers in the shale in order few cm t Limestone beds have average thickness of 2.5 m, while the shale is about 0.5 m.

In the middle part of the section, the shales are thicker than limestone. Average shale thickness i m while the limestone bed has an average thickness of 1.0 m. There is gradual increase in the ammonite

content and shells of other fauna up-section and the shale here also contain phosphatic nodules. This interval probably corresponds to the *Paravascoceras cauvini* to *Pseudotissotia nigeriensis* zones, an important zone of the Kanawa Member, (Zaborski *et al.*, 1997). At the top of the section is a thick, white-yellowish, parallel laminated, cross stratified, fine-medium grain sandstone that grades into reddish-brown, coarse sandstone. This sandstone is affected by normal faults and the faults planes observed to be filled with reddish brown materials.

The shale-limestone sequence can be interpreted as deposits of marine environments. The thick limestone beds suggest conducive platform (warm and clean water) for carbonate sedimentation. The lateral equivalent (Pindiga Formation) at the Pindiga village was interpreted as inner shelf marine deposit (Ojo, 2004). Wilson and Jordan, (1983) suggested that shelves are suitable environment for the formation of rhythmically bedded shales and limestones. The abundance and diversity of the marine biota in the shales and limestones support the sustained marine processes (Akande and Mucke, 1993; Oti, 1990).

Microfacies and Depositional environment

The following carbonate microfacies; bioclastic wackestone, peloidal wackestone, bioclastic wackestone-packstone and bioclastic packstone (Flugel, 1982) were recognized from the petrographic study.

Bioclastic wackestone

The bioclastic wackestone microfacies is generally poorly sorted and mud supported (Fig. 4a). It consists of gastropods, bivalve shells, pelecypod, echinoids, brachiopods, ammonite as well as the broken shells of some unidentified faunas. This microfacies is composed of both transported and indigenous fossils in a pellet matrix cemented with sparry calcite. The grains are poorly sorted and show poor grain-to-grain contacts. The main cements are micrite matrix which exhibits both pelleted textures.

This microfacies which show high diversity and abundance of macrofauna were probably formed in the open marine with oxygenated water. The features resemble microfacies belt 7 and 8 of Wilson (1975) characterized by high mud content relative to grains.

Peloidal wackestone

Peloidal wackestone microfacies obtained in the study area composed dominantly of peloids and some sand sized quartz grains. Few gastropods present are commonly preserved as moulds only and most of these are plugged within micrite and calcite cement. Most of these peloids appear squashed while some are agglutinated. There is no evidence of transition from rotten bioclasts to structureless microcrystalline rounded grains. The fabric is mud supported (Fig. 4b). The bioclasts present are commonly larger than the average pellet and this leads to a bimodal size distribution when present. The dominant cement is sparry calcite.

This microfacies show features indicative of low energy shallow marine. The high amount of mud relative to grains suggests probably a restricted marine. Low bioclasts may be an indication of poor aeration (Reijers and Petters, 1987; Ojo, 1999).

Biolastic wackestone-packstone

The biolastic wackestone-packstone microfacies contain essentially of gastropods and pelecypods Few of the bioclasts are filled with micrites some of which have undergone recrystallization and it is wel sorted. Well preserved internal shell structures are scarce as most internal shell structures have been deeply micritized (Fig. 4c). The nucleus material of coated grains is made up of quartz, peloids, skeletal fragments and coated grains. The coating is linked to the presence of encrustering organisms. Lithoclasts consist o quartz, calcite, and carbonate particles. They are platy to enlogate in shape. Most lithoclasts are smaller tha the associated peloids. The poor sorting and the mud supported texture suggest that this microfacies is simila to microfacies belt 7 and 8 of Wilson (1975). The microfacies lack ooids and oncoids.

Bioclastic Packstone

The bioclastic packstone is characterized by the presence of abundant gastropod fragments. The biota consists of a variety of organisms (bivalve shells, echinoid) dominated by gastropods. The fabric is poorly sorted, grain supported and with mud infiltration between grains (Fig. 4d).

The microfacies were probably deposited in the marginal part of the open marine. Constant reworking by waves would have probably winnowed the mud and therefore enhancing the grain support fabric. The poor sorting is however a kind of textural inversion.

Diagenetic history

The diagenetic process that has affected the Ashaka limestone includes; compaction, micritization, cementation, dissolution and neomorphism. The first stage of diagenetic process evident in the microfacies is compaction (Fig. 4a). A major compaction phase occur leading to the fragmentation of bivalves and sutured contacts between the skeletal grains in the bioclastic packstone-wackestone and bioclastic wackestone microfacies. This occurs early in the diagenetic history due to overburden and probably due to prevalent mud-supported fabric in the carbonates (Ojo and Akande, 2000; Ojo, 2004).

Carbonate cementation (micritization), apparently the second stage of diagenesis, binds loose grains and fills pores with one or more carbonate crystal growth forms (Fig. 4b) in the phreatic zones (Barthust, 1974). In packstone type, leaching of the skeletal grains were significantly larger than the surrounding matrix. The dissolution and subsequent leaching created secondary pores in form of moulds and vugs (Akande and Mucke, 1993). Other diagenetic imprints favourable for porosity enhancement are neomorphism which involved the mineralogical recrystallization of micrite into sparry calcite (Fig. 4c). Early diagenetic micritization of the bioclasts is observed in the peloidal wackestone and bioclastic wackestone microfacies (Fig. 4d). Bioclastic packstone microfacies are also micritized. The rinds of the bioclasts are commonly micritized. Grains originally composed of high-magnesian calcite such as composite grains, coated grains and micritized grains are either moldic or microporous.

Minor structural effects include stylolitization and fracturing. The stylolite is formed by the combination of pressure and dissolution. A few may remain open, or become opened during later dissolution, in which case they may provide access for fluid migration (Fig. 4e). Fracturing can give rise to physical cracks, such as fractures, joints, e.t.c. They originate from folding, faulting, or any other crustal movements that might have occurred in the deposits. Most fractures are partially open and they are shown more in the upper part of sections. Fractures may contribute to secondary porosity in the limestones.

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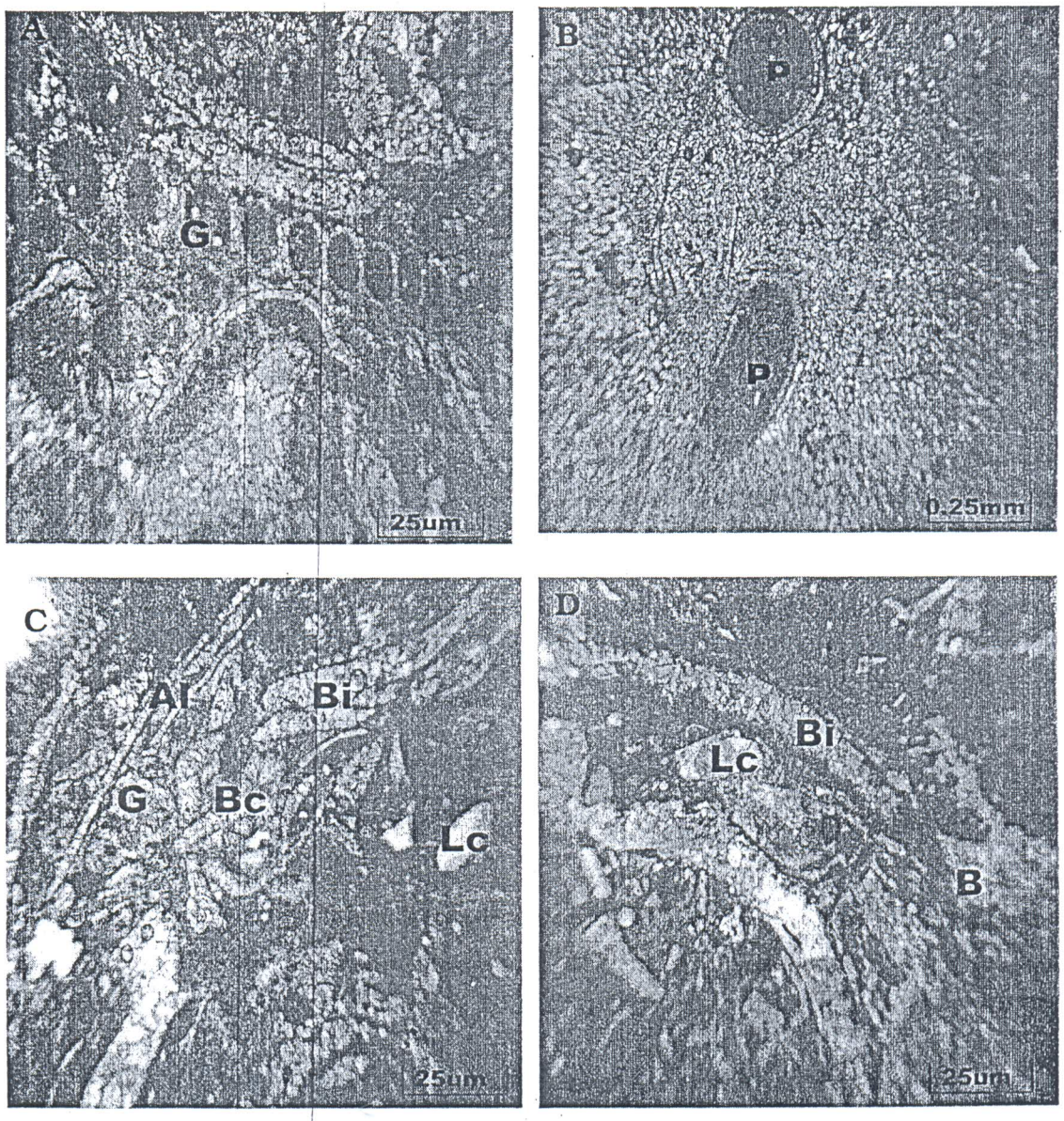


Fig. 4: Photomicrograph showing (a) bioclastic wackestone; (b) peloidal wackestone; (c) bioclastic packstone and (d) bioclastic wackestone-packstone. Note the algae (Al), gastropod (G); bivalve (Bi); bioclasts (Bc), lithoclast (Lc), Peloids (P).

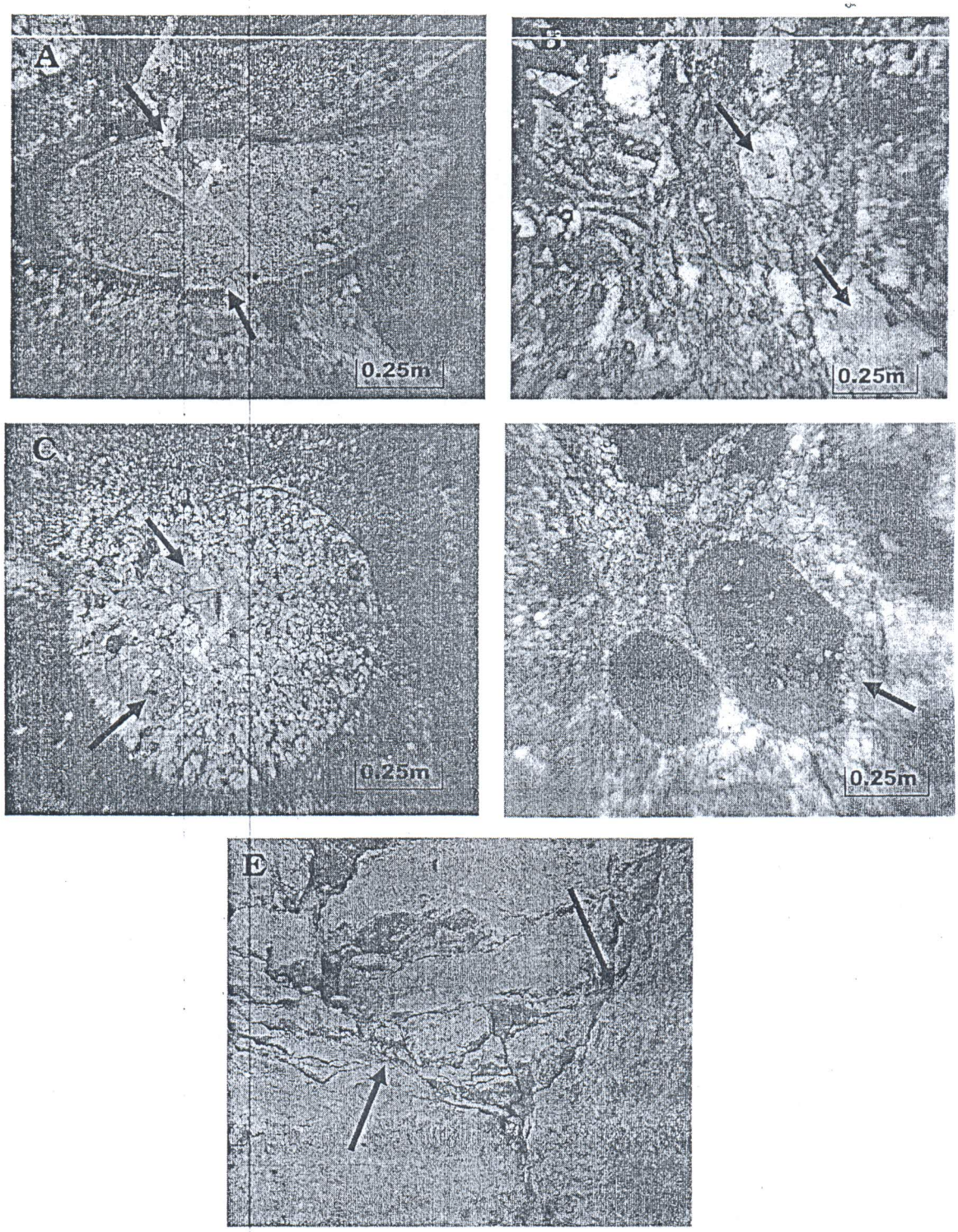


Fig. 5: Photomicrograph showing the diagenetic processes; (A) bivalve fragmentation due to compacti (bioclastic wackestone); (B) Cementation in bioclastic wackestone-packstone; (C) neomorphism bioclastic wackestone microfacies; and (D) mictitization in peloidal-wackestone. Also, the Pos depositional effects on (E) Field Photograph showing Fracture in the eastern part of the Quarry.

Geochemical Data and Interpretation

Major and Trace Elements bulk geochemical analyses results are presented in Tables 1 and 2. Calcium Oxide (CaO) contents vary from 35.96 to 54.19 % (averaging 43.064 %). While the Magnesium Oxide (MgO) also ranges from 0.39 to 0.92 % (averaging 0.702 %). The geochemical results show that calcium oxide is the dominant constituent of the limestone which is due to the fact that the limestones are primarily calcite (Pettijohn, 1975). The high CaO contents also indicate a high degree of purity of the limestone and this suggests a marine environment origin because there is always a progressive increase in calcium oxide content towards the nearshore marine environment (Cloud, 1962).

The mean value of MgO is generally low and shows little or no dolomitization process occurring in the area. This is supported by the mean value of Ba (226 ppm) which is greater than 60 ppm obtained as the limit between dolomitic and non-dolomitic limestones by Rao (2008). Furthermore, the insoluble residue (Ca/Mg ratio) is high indicating the absence of dolomitization process in the area (Chilingar, 1956; Chilingar *et al.*, 1967). In all analyzed samples, the amount of insoluble residue increases from the bottom of the studied section to the top (Table. 1). MgO and insoluble residue contents are both related to the solution porosity, because secondary solution increases the relative MgO content of limestone due to the selective leaching of calcite, in addition to increasing the insoluble residue content.

The ratios of Mn/Ti and Sr/Ba in the studied samples are greater than 1 indicating marine environment (Chunrui *et al.*, 2007). Therefore, the marine environment indicated by other evidences and also suggested by previous studies is confirmed.

Table 1: CaO/MgO and the average values of Limestone Samples

Sample No	Microfacies	CaO (%)	MgO (%)	CaO/MgO
ASQ1C	Bioclastic Packstone	43.0	0.78	55.13
ASQ1F	Bioclastic Wackestone	43.93	0.7	62.76
ASQ1H	Bioclastic Wackestone	37.64	0.66	57.03
ASQ1J	Bioclastic Packestone	38.96	0.64	60.88
ASQ1M	Peloidal Wackestone	54.19	0.39	138.98
ASQ1N	Bioclastic Wackestone-Packstone	41.53	0.6	69.233
ASQ1P	Bioclastic Packstone	49.25	0.72	68.40
ASQ1S	Bioclastic Packstone	36.58	0.77	47.51
ASQ1T	Bioclastic Packstone	49.6	0.84	59.05
ASQ1W	Bioclastic Packstone	35.96	0.92	39.09
Mean		43.0	0.70	65.81

Table 2: Trace elements of Gongila Limestone and Shale samples and their average values

Sample No	Mn	Ti	Mn/Ti	Sr	Ba	Sr/Ba
ASQ1B	0.02	0.50	0.04	157.5	319.0	0.49
ASQ1C	0.08	<0.10	<0.80	410.8	168.0	2.45
ASQ1D	0.03	0.50	0.06	98.8	359.0	0.28
ASQ1F	0.06	0.20	0.30	562.2	85.0	6.60
ASQ1H	0.11	0.20	0.55	305.4	182.0	1.68
ASQ1J	0.09	0.10	0.90	693.7	204.0	3.40
ASQ1M	0.36	0.10	3.60	242.4	26.0	9.32
ASQ1N	0.10	<0.10	<1.00	387.7	96.0	4.04
ASQ1P	0.21	<0.10	<2.10	344.8	101.0	3.41
ASQ1Q	0.02	<0.10	<0.20	258.0	181.0	1.43
ASQ1S	0.13	<0.10	<1.30	348.8	117.0	2.98
ASQ1T	0.18	<0.10	<1.80	362.3	42.0	8.63
ASQ1V	0.04	0.10	0.40	909.7	305.0	2.98
ASQ1W	0.17	0.60	0.28	343.5	108.0	3.18
ASQ1X	0.01	<0.10	<0.10	222.9	1097.0	0.20
Mean	0.11	0.29	0.77	376.57	226.0	3.40

Petrophysical Characteristics and Reservoir Potential

The primary consideration in the assessment of the reservoir potential is reservoir porosity and permeability. Porosity indicates storage capacity available for fluids; permeability indicates the ability to transmit fluids; and pore-size distribution indicates the capability to retain fluids selectively. Porosity is influenced by the depositional fabric of the reservoir sediment and the post depositional diagenetic changes that have taken place (Selley, 1985). The distribution of reservoir quality of Gongila Formation limestone resulted from the combined effects of depositional architecture and diagenetic evolution.

The types of porosities in the limestones are basically interparticle, mouldic and vugs. Fractures and stylolites observed may also present secondary porosity (Archie, 1952; Choquette and Pray, 1970; Longman, 1980). The interparticle porosity appeared to have been diminished by compaction and micritization in the microfacies. However, in few places, neomorphism enhanced the development of interparticle porosity.

The results of the quantitative assessment of the porosity and permeability shows that the limestone of the area belong to poor to fair porosity class with the values ranges of 3-10 % while its permeability values range from 24 to 189 mD (Table 3). Sample ASQ1M (Peloidal wackestone microfacies) has the highest porosity but lowest permeability. The high porosity may be due to the moderate sorting and solution porosity in the microfacies while the micrite and the presence of sparry calcite and poor fractures may cause the low permeability. The value of the rate of its absorption which is directly related to the rate of the permeability is very small (0.86 %), and this may also be attributed to a microporous pore system that is relatively tight due to cementation or compaction. Generally, the poor porosity and permeability may be due to lack of dolomitization process. Also, most low energy mud supported limestone microfacies are inherently poor in porosity and permeability (Lucia, 1995).

Table 3: Petrophysical Properties of Ashaka Limestone

Sample No	Microfacies	Absorption (%)	Specific gravity	Porosity (n) (%)	Permeability (k) (md)
ASQ1M	Peloidal Wackestone	0.86	2.990	10	0.024
ASQ1K	Bioclastic Wackestone	2.48	2.643	4	0.101
ASQ1F	Bioclastic Wackestone	4.72	2.661	3	0.189
ASQ1J	Bioclastic Wackestone-Packstone	2.43	2.752	5	0.095
ASQ1S	Bioclastic Wackestone	1.85	2.580	3	0.072

CONCLUSIONS

Field measurements of the Gongila exposures reveal limestone-shale interbeds and they were probably deposited in shelf. The limestone in the study area is classified into four microfacies; bioclastic wackestone, peloidal wackestone, bioclastic wackestone-packstone and bioclastic packstone. The microfacies were probably formed in low energy open marine with oxygenated water.

Cao is relatively high indicating calcite as the principal mineral. Low MgO contents suggest lack of dolomitization process in the limestones. Geochemical parameters like Mn/Ti and Sr/Ba support full marine origin for the limestones.

Diagenetic imprints suggest early compaction followed by micritization, dissolutionand neomorphism. Porosity and permeability is fair to poor, which may be due to little or no dolomitization and the mud supported fabric of the microfacies.

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