Petrophysical and Geochemical Studies of the Gongila Formation at Ashaka, Gongola Basin, Nigeria

S.A. Adepoju and O.J. Ojo

ABSTRACT

The Gongila Formation consists of interbedded limestones and shales which are well exposed at the Ashaka Cement quarry, Gongola Basin, northeastern Nigeria. Samples of the limestones and shales were collected and selected for petrographic, geochemical and petrophysical analyses to examine the microfacies, diagenetic history and the petroleum reservoir quality of the limestone. The study also focuses on the provenance of the shales.

The limestone microfacies vary from peloidal wackestone, bioclastic wackestone, bioclastic wackestone–packstone to bioclastic packstone and were deposited in lagoon to open marine environment. Diagenetic imprints suggest micritization, compaction, dissolution and neomorphism which have influenced the porosity. Chemical analysis reveals major elements; CaO (43.06%), SiO_2 (11.97%), Al_2O_3 (4.36%) and MgO (0.70%). The high CaO/MgO (65.81) ratio suggests little or no dolomitization. The porosity types include the intraparticle, interparticle, mouldic, vugs and fractures. Porosity values of the limestone ranges from of 3 to 10% and permeability values ranges from 0.024 to 0.189 mD. These indicate that porosity and permeability are low and therefore reservoir potential is of low quality.

The geochemical parameters like ratios of Al_2O_3/TiO_2, La/Co, Th/Co, La/Th and Y/Ho of shales were compared with those of sediments derived from felsic and basic rocks Upper Continental Crust (UCC) and Post-Archean average Australian Sedimentary rocks (PAAS) which reveal felsic source rocks. Mean ratios of V/(V+Ni), U/Th, Ni/Co and Cu/Zn suggest prevalence of dysoxic and anoxic conditions.

INTRODUCTION

The clamour for exploration in some of the hinterland sedimentary basins in Nigeria by the Federal Government of Nigeria has been on the increase in recent time. This study becomes essential because the Upper Benue basins may have possibilities of shallow prospects, just like in the very shallow Paleocene Amal Formation in which significant volume of oil has been discovered in the Muglad Basin of Sudan (Schull, 1988; Mohamed et al., 1999). The study area is located in Ashaka Chem quarry, Ashaka part of Gombe sheet 36NE of the Geological Survey of Nigeria (GSN) (Fig 1).

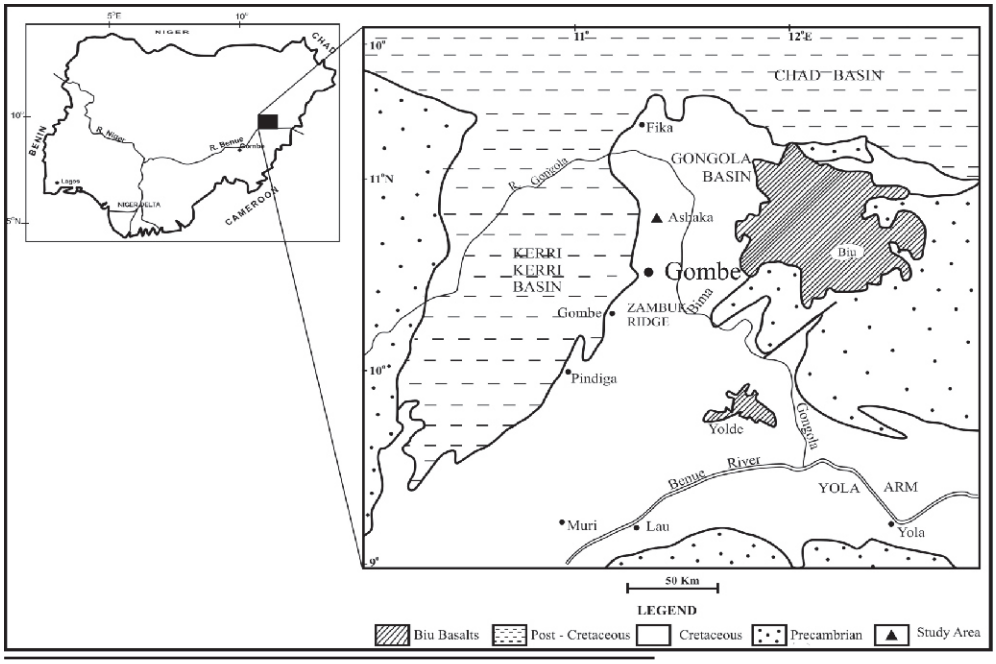


Fig. 1: Map of study area showing location of the investigated section at Ashaka (modified after Gebhardt, 1997)

© Copyright 2013. Nigerian Association of Petroleum Explorationists.
All rights reserved.

Department of Geology and Mineral Sciences, University of Ilorin, Ilorin.

Various geological investigations have been carried out in the Upper Benue Trough. Carter et al. (1963) outlined the structural and stratigraphy framework of the Upper Benue trough. Adegoke *et al.* (1978) dated the Kerri-Kerri Formation based on the microfaunal contents. Iwuagwu (1990) in his lithofacies analysis and depositional environmental study of the lower limestone-shale member of the Gongila Formation exposed at Ashaka concluded that the mud-dominated microfacies are products of subtidal open shelf marine. Rebelle (1990) and Oti (1990) have also use some ecological and sedimentological data and submitted independently that the Gongila Formation is believed to have been deposited in shallow water carbonate platform environment. Gebhardt (1997) suggested that the boundary of Cenomanian/Turonian is exposed in Ashaka quarry. Gibson (1989) and Obaje *et al.* (2000) used plantonic and benthonic data to suggest shallow anoxic water types for the Gongila Shales. Obaje et al. (2004) submitted that the shales of Gongila Formation at Ashaka could be a potential source rock for both oil and gas in the downdip of the basin, where it may have attained localized maturity. Ojo and Akande (2001) worked on the paleoenviromental and paleoclimatic characteristics of the Cenomanian to Coniacian sediments of the Upper Benue Trough and concluded that a relatively stable Gongola basin secured a low siliciclastic input and allowed carbonate deposition for certain intervals.

From the foregoing, most published works on the limestone series in this region concentrated on the petrographic, microfacies and environmental studies (e.g. Popoff *et al.*). To date, geochemical data is scarce and no quantitative porosity and permeability assessment of the limestone in this area has been attempted. This study examines the diagenetic processes based on the geochemical characteristics and the effects on the reservoir properties of the limestones. The provenance and the oxygenation conditions of the sediments are also investigated.

STRATIGRAPHY AND GEOLOGIC SETTINGS

The evolution of the Benue Trough was linked with the opening of the Atlantic which began with the separation of South America from Africa in the Carboniferous through the process of Sea floor spreading consequent to continental updoming and rifting (Wright, 1968). The Benue Trough trends SSW-NNE for about 800 km and is about 150 km wide and it contains up to 6000 m of Cretaceous – Tertiary sedimentary rocks that has been folded, faulted and uplifted. Reviews of the geology of the Upper Benue Trough have been presented by Petters (1977), Benkhelil (1989), Dike (1993) and Zaborski *et al.,* (1997). The Gongola Basin together with the Yola Basin makes up the Upper Benue Trough.

The Stratigraphy of the Upper Benue Trough is shown in Fig 2

MATERIALS AND METHODS

Samples of limestone and shale were collected from the eastern, central and western parts, of the quarry. Graphic Lithologic logs representing the field occurrences of the rocks were constructed. The selected samples were then subjected to various standard analyses which includes; petrogaphic study (thin section), polish slab, inorganic geochemical studies (XRF and ICP-MS) and porosity and permeability study by specific gravity, absorption and coarse aggregate methods.

RESULTS AND DISCUSSIONS

Lithologic Description

The thickest section at the Ashaka cement quarry is about 28.36 m and its graphic log is shown Figure 3. This section is located at the central part of the quarry and is divided into three parts; lower part (0-8.51 m), middle part (8.51-24.36 m) and upper part (24.36-28.36 m). The lower part consists mainly of limestone with a few thin shale beds interbedded within the limestone. It is also represented by limestone-shale interbeds of about 1.0 m thick. The sequence changes to shale-limestone interbeds at the middle part of the section. This part is characterized by thicker shale beds than limestone, unlike the lower part. At the top of the section is a sandstone bed. The sandstone is faulted and the fault plane is observed to be filled with reddish brown materials.

Microfacies and Depositional environment

The thin-section examinations of the selected limestones under petrological microscope revealed four microfacies which includes; bioclastic wackestone, peloidal wackestone, bioclastic wackestone-packstone and bioclastic packstone using Durham, (1962) and Flugel, (1982) classifications, According to Ojo et al., 2012, the depositional environments Based on fossil content indicate a shallow marine environment (low energy open marine with oxygenated water).

Diagenesis and Porosity

The main diagenetic processes observed through petrographic studies include; micritization, cementation, compaction, dissolution and neomorphism. The compaction commenced immediately after deposition and increased in intensity as overburden increased. It has reduced the porosity in the micritic portions of bioclastic wackestones-packstones and bioclastic packstones as some bivalve fragments are compacted and result in porosity reduction (Fig 4a). Carbonate cement often binds the loose grains and also fills pore with carbonate crystal growth and so concentrated in sheltered microenvironments such as the chambers of gastropod and in sponge bores resulting to cementation. In the bioclastic wackestone, it is noted that the skeletal grains are bored around the margins and holes are later filled with cements casing radial obliteration of the

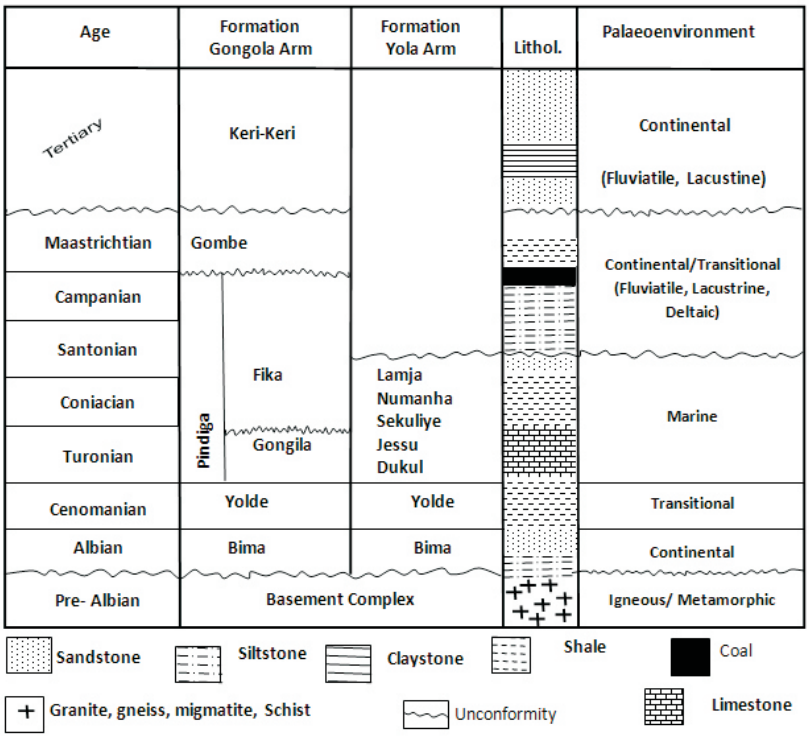


Fig. 2: Stratigraphic succession in the Upper Benue Trough (Modified after Obaje et al., 1999)

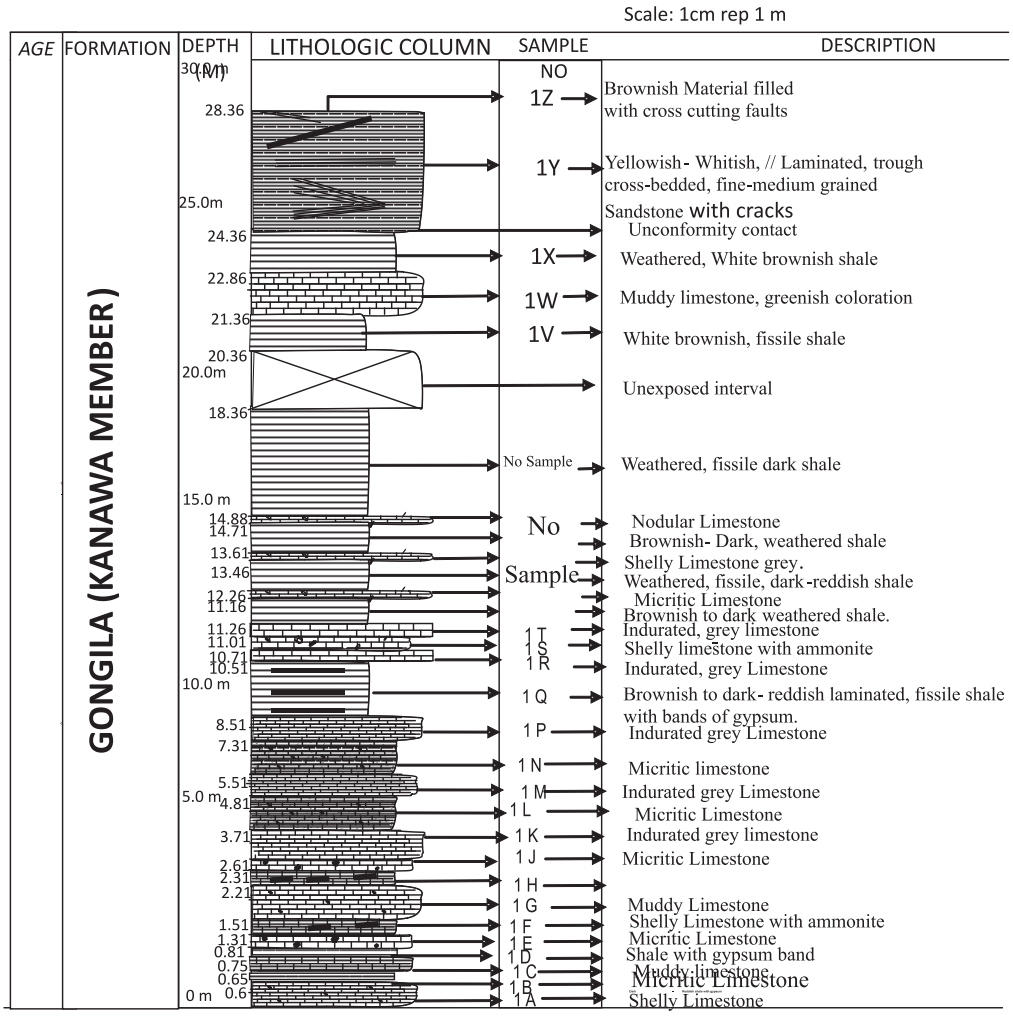


Fig. 3: Lithologic section of Gongila Formation at the central area of Ashaka Cement Quarry (ASQ1). Elevation at bottom=290.3 m, Long. =N10^{0}56′100″, Lat. =E11^{0}27′278″, Elevation at the top=303.6 m, Bearing=110^0

original structures, leading to reduction in porosity (Fig 4b).

Dissolution and neomorphisim have both accounted for porosity increments. In bioclastic packstone microfacies, the grains that were significantly larger than the surrounding matrix are typically leached. The original aragonitic grains of gastropods, pelecypods and probably ooids dissolved to form moldic pores that are easily compatible. Porosity is high in lithofacies where dissolution left empty vugs (Fig 4c). Microporosity is also common in the limestone facies where micritic spars are precipitated. Neomorphic recrystallization in the bioclastic-packstone microfacies increases the porosity (Figure 4d). Minor structural processes including stylolitization and fracturing have also enhanced the porosity.

Diagenetic environments inferred for the Gongila Formation is meteoric (eogenetic). This zone is marked by the presence of pore fluids that has a high potential for the generation of secondary porosity by dissolution. Porosity modification by dissolution and cementation is quickly accomplished. Boring algae and fungi that are bound together by micrite cements as calcite (aragonite or magnesian calcite) are believed to increase the initial intraparticle porosity of sediment during and shortly after deposition. The relationships and association of compaction and cements fill after the rupture of bivalve (Fig 4a) also characterize meteoric zone. Under most normal conditions of calcite cement precipitation in meteoric environment, the sediment or rock pore is totally saturated with water and cement is precipitated equally around the periphery of the pore and produces equant calcite cement (Fig 4d).

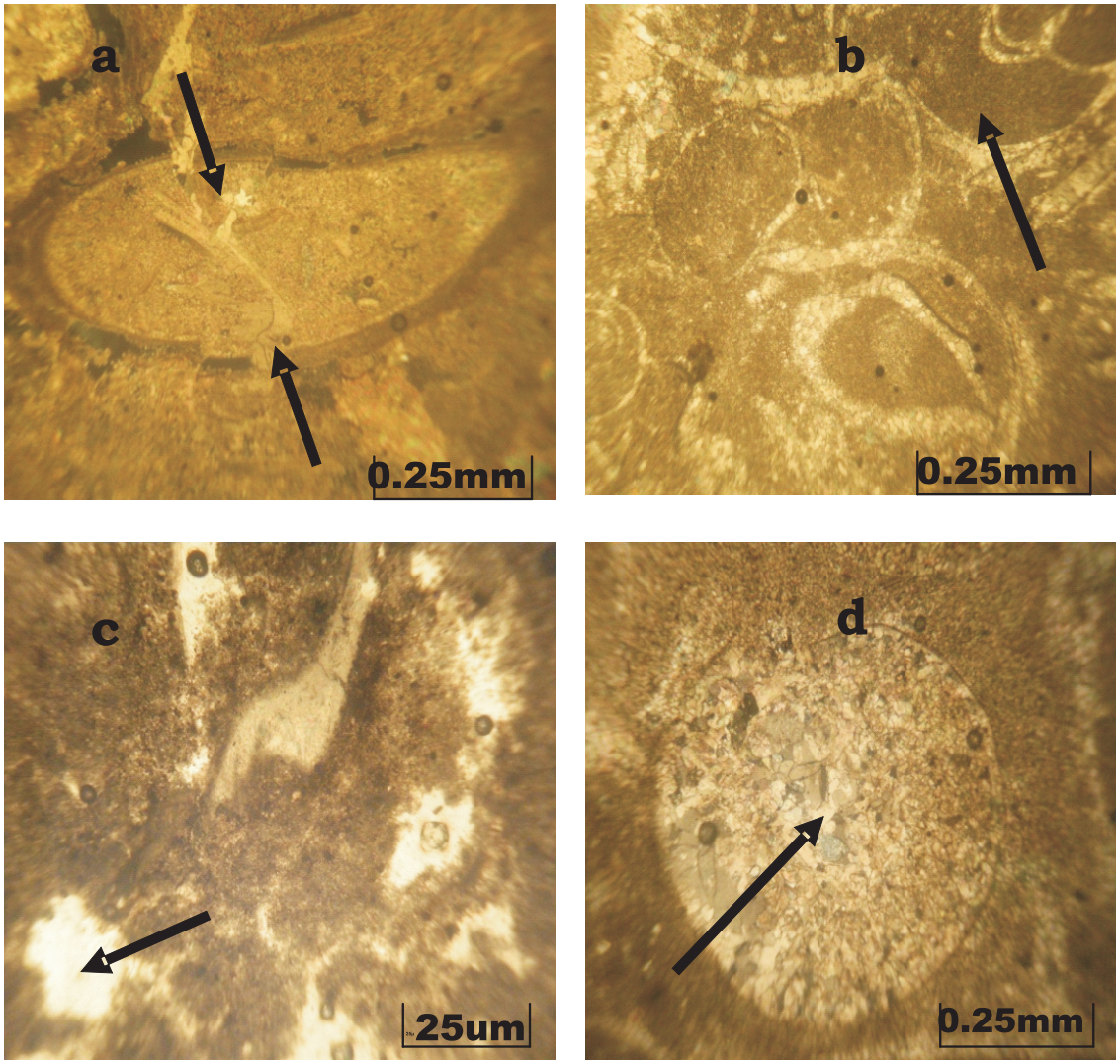


Fig. 4: Photomicrograph showing (A) compaction of bioclastic wackestone resulting to broken of bivalve and (B) cementation in bioclastic wackestone samples resulting in cement fillings; (C) dissolution in bioclastic wackestone and (D) neomorphism on coral tube in bioclastic packstone microfacies

Reservoir characteristics of the Gongila Limestone

The type of porosity examined from the petrographic study of the Gongila limestone is mostly intraparticle, interparticle (Figs. 5a and 5b). Others include moldic and vugs, arising from diagenetic modifications. The moldic and vuggy porosities owe their pores existence to dissolution of large grains (e. g. gastropods) (Fig. 5c). The total porosity seems to be little affected by meteoric diagenesis in a local meteoric lens while secondary porosity is generated and cement is precipitated into inter-particular pore spaces. The micritic matrix of some bioclastic wackestones has led to reduction in porosity by pore infilling of the pores by cements, while the development and appearance of stylolites and fractures produced by the combination of compaction and dissolution may enhance the flow capacity of reservoirs.
The porosity and permeability values of the microfacies (qualititative) are presented in Table 1. The result shows that the limestones have fair to poor porosity with values range of 3-10 % , while permeability ranges from 0.024 to 0.189 mD. The rate of absorption is very low (0.86 %), and this probably signify a microporous pore system that is relatively tight due to cementation or compaction; or a low-permeability secondary moldic pore system for the Gongila Limestone. The primary pore system was represented by meso interparticle pores in bioclastic wackestone types and by macro in the post-sedimentation processes. This has appreciably altered the primary textures and thus affect the reservoir rock properties of the limestone in the area.
Sample ASQ1M, has the highest porosity of 10 % but lowest permeability. This is probably due to the fact that this sample contains more shelly materials that allows the porosity increase through the diagenetic processes (porosity enhancement type). It may also be due to high depositional porosity and relatively rigid bryozoans present within the constituents.
The living chambers, structural tests and skeletal grains of various organisms such as gastropods, brachiopods and ammonites often provide significant and common presence of interparticle and intraparticle porosity that occupy a significant percentage of the bulk volume (Fig. 5d).

Table 1: Porosity and permeability values of Gongila limestone

Sample No	Mirofacies	Absorption (%)	Specific gravity	Porosity (n) (%)	Permeability (k) (m/s^2)	Permeability (k) (mD)
ASQ1M	Peloidal wackestone	0.86	2.990	10	$2.32X10^{-11}$	0.024
ASQ1K	Bioclastic wackestone	2.48	2.643	4	$9.96.X10^{-11}$	0.101
ASQ1F	Bioclastic wackestone	4.72	2.661	3	$1.86X10^{-10}$	0.189
ASQ1J	Bioclastic wackestone-packstone	2.43	2.752	5	$9.39X10^{-11}$	0.095
ASQ1S	Bioclastic wackestone	1.85	2.580	3	$7.14X10^{-11}$	0.072

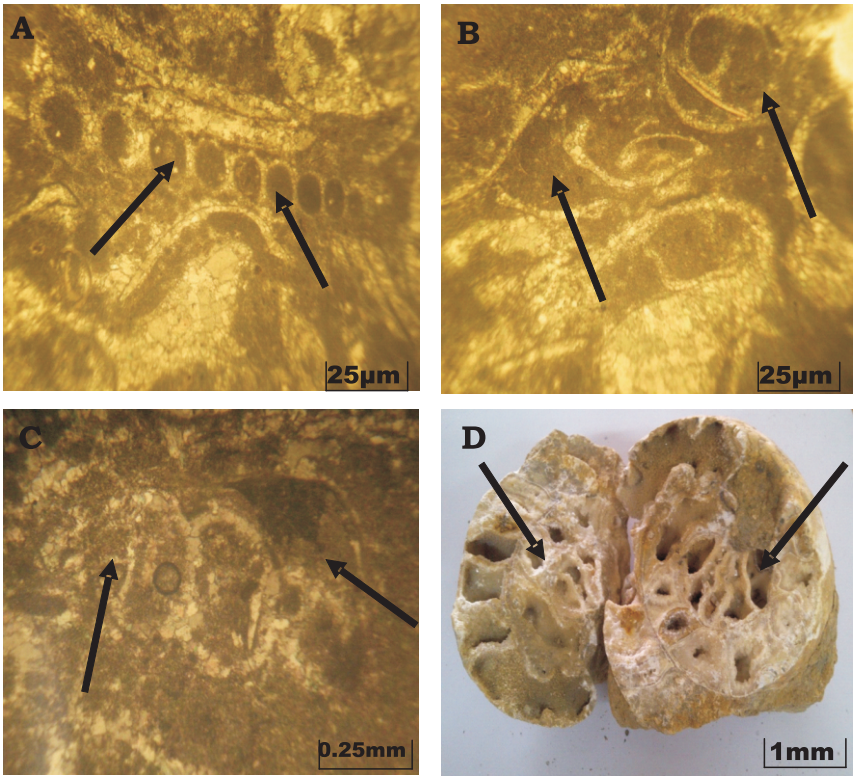


Fig. 5: Photomicrograph of Intraparticle porosity (A), Interparticle porosity (B), Mouldic porosity in gastropod formed through dissolution of test (C) and Vuggy porosity formed through the solutional enhancement of ammonite shell (D)

Provenance and Paleo-redox condition

The result of chemical analysis shows that CaO ranges from 1.66 - 8.01 % (mean-4.42 %) and this indicates presence of calcareous components in the shales. SiO_2 values ranges from 44.10 - 62.40 % (mean-50.24 %). Also, Al_2O_3 range between 16.7 and 18.01 % (average-17.38 %). K_2O and MgO values range between 1.30 and 3.64 % (mean-2.36 %) and 0.49 - 1.22 % (mean-0.81 %) respectively (Table 2). The interbedded shale samples are richer in oxides of carbonates minerals (CaO and MgO) than those of silicate minerals (Na_2O and K_2O) and confirms that the shales are calcareous. Ba has concentration ranging between 181.0 - 1097.0 ppm (mean-452.2 ppm) while Sr ranges from 98.8 - 909.7 ppm (mean-329.3 ppm). The higher mean ratio of Ba, with lower mean value of Sr and Sr/Ba ratio (1.08), suggest shallow water sediments. Also, the mean concentration of Pb and Zn are low with 4.92 ppm and 15.9 ppm respectively (Table 3). It is noted that, there is an increase in the values of the CaO with the corresponding decrease in Sr concentration across the section; this may suggest that Sr and CaO are substituting for each other which may be due to some diagenetic processes. This is common to the basal limestone facies, differentiating them from the overlying unit.

Table 2: Major oxides composition (%) and ratios of some elements in the Gongila shales

Sample No	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	Al_2O_3/TiO_2
ASQ1B	51.5	16.78	5.20	5.09	0.49	0.06	2.32	0.02	0.69	24.32
ASQ1D	44.1	16.89	5.17	8.01	0.58	0.08	2.45	0.03	0.77	21.94
ASQ1Q	45.2	17.28	7.28	5.20	1.22	0.03	1.30	0.02	0.94	18.38
ASQ1V	48.0	17.94	10.12	1.66	1.20	0.03	2.08	0.04	0.93	19.29
ASQ1X	62.4	18.01	1.96	2.13	0.58	0.12	3.64	0.01	0.75	24.01
Mean	50.24	17.38	5.95	4.42	0.81	0.06	2.36	0.02	0.82	21.58

Table 3: Trace and rare earth element composition (ppm) of Gongila shales

Sample No	ASQ1B	ASQ1D	ASQ1Q	ASQ1V	ASQ1X
V	75	75	106	109	48
Ni	19.4	25.7	11.0	9.7	5.5
Co	9.2	11.5	8.1	2.7	9.8
U	3.9	4.0	2.1	2.1	4.2
Th	18.7	22.4	17.0	16.8	21.2
Y	17.2	23.9	13.3	13.3	34.6
Ho	0.61	0.84	0.52	0.50	1.16
La	51.3	56.3	45.7	73.1	70.0
Sr	157.5	98.8	258.0	909.7	222.9
Ba	319.0	359.0	181.0	305.0	1097.0
Cu	30.4	35.1	20.8	19.3	8.8
Zn	51.0	50.0	24.0	19.0	19.0
V+Ni	94.4	100.7	117.0	118.7	53.5
V/V+Ni	0.79	0.74	0.91	0.92	0.90
U/Th	0.21	0.18	0.12	0.13	0.20
Ni/Co	2.11	2.23	1.36	3.59	0.56
Cu/Zn	0.60	0.70	0.87	1.02	0.46
Sr/Ba	0.49	0.28	1.43	2.98	0.20
Y/Ho	28.2	28.2	25.6	26.6	29.8
La/Co	5.58	4.90	5.64	27.07	7.14
Th/Co	2.03	1.95	2.10	6.22	2.16

The ratios of Al_2O_3/TiO_2 of most clastic and terrigenous rocks are useful for inferring the source rock compositions. Al_2O_3/TiO_2 ratio ranges from 3 to 8 signify mafic igneous rocks, 8 to 21 for intermediate rocks while 21 to 70 shows felsic igneous rocks (Hayashi et al., 1997). In the analyzed shale samples, Al_2O_3/TiO_2 ratio varies between 18.38 and 24.32 (mean-21.58) which essentially fits into the felsic igneous origin.

The REE patterns of europium anomaly in sedimentary rocks also provide important clues regarding source rock characteristics (Taylor and McLennan, 1985). Higher LREE/HREE ratios and negative Europium (Eu) anomalies are generally associated with felsic rocks, whereas the mafic rocks exhibit low LREE/HREE ratios and none or small Eu anomalies (Cullers, 1995). The result shows slightly high mean LREE/HREE ratios (16.82) and negative Europium (Eu) anomalies, suggesting that the shales were mainly derived from intermediate to felsic granitic source rocks (Table 4). Mean Rare Earth Elements concentration (REE) of the shales are as follows; Y (20.5 ppm), La (59.3 ppm), Th (19.2 ppm), Ho (0.70 ppm), Co (8.30 ppm) (Table 4).

La/Co and Th/Co ratios is another source rock tool that shows significant variations of felsic and mafic rocks and are most useful in deducing the provenance composition (Cullers et al., 1995). Calculated mean ratios of La/Co (10.07) and Th/Co (2.89) suggest that these shales may be from intermediate granitic source rocks (Table 5). Thus, the results suggest that associated shafes of the Gongila Formation most probably were sourced from intermediate to felsic origin. There is slight LREE enrichment, which also suggests that the shales were mainly derived from intermediate to felsic source rocks.

The proportionality of vanadium to nickel, mainly expressed as V/(V+Ni), has been commonly used to deduce Eh, pH and sulphide activities in the depositional environment (Tribovillard et al., 1994). Gongila limestones show relatively similar (V/(V+Ni) ratios (0.82) when compared with shales (0.85) (see Table 3). V/(V+Ni) ratios of the limestones are higher than those of normal marine systems (V/(V+Ni) ratio (≤ 0.5) as calculated by Lewan (1984). The shales also generally show V/(V+Ni) ratios higher than 0.5, which strongly suggests that they were deposited under dysoxic/anoxic conditions. The V/(V+Ni) ratios are also greater than 0.8, and indicate the presence of significant dissolved H_2S in highly reducing bottom waters of a marine environment (Tribovillard et al., 1994). The V/(V+Ni) ratios in shales (0.85) are higher than 0.8, which indicates moderate frequency in the redox state of the depositional environment of the shale of Gongila Formation.

Table 4: Rare earth element (REE) concentrations of the Gongila Shales compared with Post Archean Shale Sediments (Taylor and McLennan (1985), Chondrite (Wakita *et al.,* 1971 and Taylor and McLennan, 1981), Upper Continental Crust (Taylor and McLennan, 1985) and NASC (Gromet et al, 1984).

REE	Atomic No.	Gongila Shales	PAAS[1]	Chondrite[2]	UCC[3]	NASC[4]
Y	39	20.5	-	2.1	22	NR
La	57	59.3	16.0	0.354	30	31.1
Ce	58	127.8	345.0	0.934	64	67.03
Pr	59	13.7	-	0.129	7.1	9.1
Nd	60	47.7	128	0.676	26	30.4
Sm	62	7.5	16.2	0.213	4.5	5.98
Eu	63	1.3	1.31	0.080	0.88	1.25
Gd	64	5.3	6.12	0.283	3.8	5.5
Tb	65	0.8	-	0.053	0.64	0.85
Dy	66	4.0	3.05	0.341	3.5	5.54
Ho	67	0.7	-	0.082	0.8	1.27
Er	68	2.0	1.25	0.225	2.3	3.275
Tm	69	0.3	-	0.034	0.33	0.54
Yb	70	1.9	1.00	0.234	2.2	3.11
Lu	71	0.3	-	0.036	0.32	0.456
ΣREE[5]		293.1	517.93	5.8	168.4	165.4
LREE/HREE[6]		16.82	44.4	1.9	9.5	7.1
[1] (Eu/Eu*)		0.21	N.D	N.D; [2]	0.65	0.67

[1]Post Archean Shale Sediments values reported by Taylor and McLennan (1985); [2]Chondrite concentrations are the average of values reported by Wakita et al., (1971) and Taylor and McLennan (1981); [3]Upper crust values reported by Taylor and McLennan (1981), [4]North American shale composite, reported by Gromet *et al.,* (1984); [5]Sum of all REEs + Y; [6]Ratio of the sum of the concentrations of the light REEs (La through Eu) divided by the sum of the heavy REEs (Gd through Lu); ND, Not determined and NR, Not Recorded.

Table 5: Range of elemental ratio of the Gongila Shales compared to the similar elemental ratio derived from felsic rocks, mafic rocks and Upper Continental Crust, (Taylor and McLennan, 1985).

Elemental Ratio	Range of the Gongila Shales sediments	Range of sediments from felsic source	Range of sediments from mafic source	Upper Continental Crust
La/ Co	4.90-27.07	1.80-13.8	0.14-0.38	1.76
Th/Co	1.95-6.22	0.04-3.25	0.04-1.40	0.63

Low contents of U are generally found in sediments deposited in oxygenated conditions in marine environment (Madhavaraju and Ramasamy, 1999), whereas high value are found in sediments from the oxygen minimum zone (Nath *et al.,* 1997). Gongila limestone and shales show moderate to high content of U (0.5 - 3.0 ppm; mean-1.58 and 2.1 - 4.0 ppm, mean=3.26 ppm respectively). The observed moderate to high content of U in both limestones and shales are mainly due to enrichment of U in the source rocks, which contributed more U to these shales.

The ratio of uranium to thorium (U/Th) is used as a redox indicator with U/Th ratio being higher in organic rich mudstones (Jones and Manning, 1994). U/Th ratios below 1.25, suggest oxic conditions of deposition, whereas values above 1.25 indicate suboxic and anoxic conditions (Nath et al., 1997). Limestones and shales of Gongila Formation show low U/Th ratios (0.15–0.45, mean=0.27 and 0.12–0.21, mean=0.17 respectively), which indicate that these shales were deposited in an anoxic environment.

Ni/Co ratio is also a tool for redox indicator; ratio below 5 indicates oxic environments while above 5 suggest suboxic and anoxic environments (Jones and Manning, 1994). The limestones and shales show low Ni/Co ratio (0.13–1.87, mean=0.95 and 0.56–3.59, mean1.97 respectively), which suggest that these sediments were deposited in a well oxygenated environment. In addition, according to Hallberg (1976) high Cu/Zn ratios indicate reducing depositional conditions while low Cu/Zn ratios suggest oxidizing conditions. Thus, the low Cu/Zn ratios of (0.30–1.54 ppm, mean-0.55) and (0.46–1.02, mean-0.73) respectively indicate that they were deposited under anoxic conditions.

SUMMARY AND CONCLUSIONS

The microfacies (bioclastic-wackestone, peloidal-wackestone, bioclastic wackestone-packstone and bioclastic-packstone) also characterizes shallow-water shelf and slope deposit. Diagenetic imprints indicating stages of micritization, compaction, dissolution and neomorphism chracterised the microfacies. Non dolomitic, meteoric diagenetic environment prevailed.

The porosity types include interparticle, intraparticle, moldic and vuggy and fracture. Petrophysical evaluation of the limestone facies indicates low porosity and permeability and therefore petroleum reservoir potential is of low quality in the study area.

The Gongila Formation shales were derived from intermediate to felsic igneous origin and deposited in dysoxic and anoxic condition.

REFERENCE CITED

Adegoke, O. S., R. E. Jan Du Chene, A. E. Agumanu and P. O. Ajayi, 1978, Palynology and age of the Kerri Kerri Formation, Nigeria: Rev. Esp. micro. Paleont., v. 10, p. 267-283.

Akande, S. O., Ojo, O. J., Erdtmann, B. D. and Hetenyi, M., 1998, Paleoenvironments, source rock potential and thermal maturity of the Upper Benue rift basins, Nigeria: implications for hydrocarbon exploration. Organic Geochemistry, 29, 531-542.

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

Carter, J. D., W. Barber, E. A. Tait, and G. P. Jones, 1963, The Geology of part of Adamawa, Bauchi and Borno Provinces in the North Eastern Nigeria: Bulletin Geological Survey of Nigeria, v. 30, no. 1, 108p.

Cullers, R. L., 2000, The geochemistry of shales, siltstones and sandstones of Pennsylvanian-Permian age, Colorado, U.S.A.: implications for provenance and metamorphic studies: Lithos, v. 51, p. 305-327.

Cullers, R., D. R. Lowe, R. L. Cox, 1995, The influence of sediment recycling and basement composition on evolution of mudrock chemistry in the southwestern United States: Geochim. Cosmochim. Acta., v. 59, no.14, p. 2919-2940.

Dike, E. F. C, 1993, Stratigraphy and structure of the Kerri Kerri Basin, North-eastern Nigeria: Bulletin of Geological Survey of Nigeria, v. 20, no. 1, p. 70-86.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture, In: Harm, W.E (Eds): classification of carbonate rocks. AAPG Memoir 1, p. 108-121.

Flugel, E., 1982, Microfacies analysis of limestones: Springer-Verley Berlin Heidelberg New York, 633p.

Gebhardt, H., 1997, Cenomanian to Turonian foraminifera from Ashaka (NE Nigeria); quantitative analysis and palaeoenvironmental interpretation: Cretaceous Research, v. 18, p. 17-36.

Gibson, T. G., 1989, Planktonic Benthic foraminiferal ratios, modern patterns and Tertiary applicability: Marine Micropalaentology, v. 15, p. 28-52.

Gromet, L. P., Dymek, R.F., Haskin, L. A., and Korotev, R. L., 1984, The "North American shale composite"—Its compilation, major and trace element characteristics: Geochimica et Cosmochimica Acta, v. 48, p. 2469–2482.

Hallberg, R. O., 1976, A geochemical method for investigation of palaeoredox conditions in sediments: Ambio, Special Report, v. 4, p. 139-147.

Hayashi, K., H. Fujisawa, H. Holland, H. Ohmoto, 1997, Geochemistry of -1.9 Ga sedimentary rocks from northeastern Labrador, Canada: Geochim. Cosmochimica Acta, v. 61, no. 19, p. 4115-4137.

Iwuagwu, C. J., 1990, Lithofacies analysis and depositional environment of the Lower Limestone-Shale member of the Gongila Formation, Ashaka, Bauchi-State, Nigeria: Giornale di Geologia, Bologna, v. 49, p. 93-101.

Jones, B., D. C. Manning, 1994, Comparison of geochemical indices used for the interpretation of paleo-redox conditions in Ancient mudstones: Chemical Geology, v. 111, no. 1-4, p. 111-129.

Lewan, M. D., 1984, Factors controlling the proportionality of vanadium to nickel in crude oils: Geochim. Cosmochimica Acta, v. 48, p. 2231-2238.

Madhavaraju, J., Ramasamy, S., 1999a, Rare earth elements in limestones of Kallankurichchi Formation of Ariyalur Group, Tiruchirapalli Cretaceous, Tamil Nadu: Journal of Geological Society of India, v. 54, p. 291-301.

Mohamed, A. Y., Pearson, M. J., Ashcroft, W. A., Illiffe, J. E. and Whiteman, A. J., 1999, Modeling petroleum generation in the Southern Muglad rift basin, Sudan. AAPG Bull., v. 83, p. 1943-1964.

Nath, B.N., M. Bau, B. Ramlingeswara-Rao, Ch. M. Rao, 1997, Trace and rare earth elemental variation in Arabian Sea sediments through: a transect across the oxygen minimum zone: Geochim. Cosmochim. Acta, v. 61, p. 2375-2388.

Obaje, N. G., O. K. Ulu, S. A. Maigari, and M. B. Abubakar, 2000, Sequence Stratigraphic and Paleovenvironmental Interpretations of Heterohelicids from the Pindiga Formation Northeastern Benue Trough, Nigeria: Journal of Mining and Geology, v. 36, p. 191–152.

Obaje, N. G., Wehner, H., Scheeder, G., Abubakar, M. B. and Jauro, A., 2004, Hydrocarbon prospectivity of Nigeria's inland basins: From the viewpoint of organic geochemistry and organic petrology: AAPG Bull., v. 88, no. 3, p. 325- 353.

Ojo, O. J, Adepoju, S. A. and Akande, S. O., 2012, Carbonate microfacies, diagenesis and reservoir potential analysis of the Gongila limestone, Gongola Basin, Nigeria. Pure and Applied sciences. Accepted for Publication (Published by Faculty of Science, University of Ilorin)

Ojo, O. J., and S. O. Akande, 2001, Depositional environments and diagenessis of the carbonate facies of Dukul and Jessu Formations in the Yola Basin, N.E. Nigeria; Implications for Reservoir potential: Nigerian Association of Petroleum Explorationist Bulletin, v. 15, p. 47-59.

Oti, M. N., 1990, Lower Turonian carbonates on the Zambuk Ridge, southeastern Chad Basin, The Ashaka Limestone. In: Ofoegbu, C. E. (ed), The Benue Trough, Structure and Evolution, p. 287- 319.

Petters, S. W., 1977, Mid Cretaceous paleoenvironments and biostratigraphy of the benue Trough, Nigeria: Geological Society of American Bulletin, 89, 419-442.

Poppof, M., 1986, The Upper Cretaceous Gongila and Pindiga Formations, Northern Nigeria Subdivision, Age, Stratigraphic Correlation and Paleogeographic Implications: Echope Geol. Helv. Besel, v. 79, p. 263-343.

Rebelle, M. 1990, The marine trangression in the Benue Trough (N-E Nigeria): a palaeogeographic interpretation of the Gongila Formation: Journal of African Earth Sciences, v. 10, p. 643-655.

Schull, T. J., 1988, Rift basins of interior Sudan: Petroleum exploration and discovery. AAPG Bull., v. 72, p. 1128-1142.

Taylor, S. R. and S. M., McLennan, 1985, The Continental Crust: Its Composition and Evolution. Blackwell, Oxford, 312 p.

Taylor, S. R. and S. M. McLennan, 1981, The composition and evolution of the continental crust: Rare earth element evidence from sedimentary rocks: Philosophical Transactions of the Royal Society of London, Series A, Mathematical and Physical Sciences, v. 301, p. 381–399.

Tribovillard, N. P., A. Desprairies, E. Lallier-Verges, , P. Bertrand, N. Moureau, A. Ramdani, L. Ramanampisoa, 1994, Geochemical study of organic-matter rich cycles from the Kimmeridge Clay Formation of Yorkshire (UK); productivity versus anoxia: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 108, p. 165-181.

Wright, J. B, 1968, South Atlantic continental drift and Benue Trough: Tectonophysics, v. 6, no 4, p. 301–310.

Zarboski, P.M, Ugodulunwa, F., Idornigie, A., Nnabo, P. and Ibe, K., 1997, Stratigraphy and Structure of the Cretaceous Gongola Basin, northeastern Nigeria: Bull. Centre Rech. Elf Exploration Production, 21, 153-178.