Assessment of the Reservoir Qualities of the Cretaceous Yolde Sandstone around Dadin Kowa and Briyal. Gongola Sub-Basin. Northern Benue Trough. North East Nigeria

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Abstract
Sedimentology, petrography and petrophysical studies were applied to the Cretaceous Yolde Formation sediments around Dadin kowa and Briyal, to evaluate its reservoir quality. The Yolde Formation round Dadin kowa is about 4.5m (Jangargari), 3m (Wuro gari) and Briyal 15m. The Sandstones are structurally characterized by planar, tabular and trough cross-beds, , and hummocky cross-stratifications Grainulometric analysis shows that the sandstones are moderately sorted to moderately well sorted (0.60- 0.71)∂I, the grains sizes are very fine to medium (3.4-1.73)MZ Leptokurtic to very leptokurtic (0.9-1.9)KG and are coarse to strongly fine skewed (-0.04-0.15)SKI. Petrographic analysis shows that the sandstone samples are texturally matured. The Quartz grains are both monocrystalline and polycrystalline in nature while thesub-rounded to rounded nature of the grains suggests that the sediments were transported from a long distance. The framework components of the sandstonesbased on the QFR plot shows that the sandstones are Quartzarenite, Sublitharenite to Litharenite and Subarkorse to Arkosic in nature. Grainulometric analysis showsThe petrophysical evaluation indicated porosity values ranging from 5% (moderate) to 29 %(high), and permeability values between 83.27(low) to 507.1(high). These values when compared to the reservoir rocks of proven petroleum basins of the North Sea and Niger Delta. Therefore, the Yolde Sandstones of the study area can have great potential to serve as good reservoir rock in the Gongola Basin.

INTRODUCTION

The successful discovery of petroleum in commercial quantities in Chad basin, Niger republic (termit – agades basin) and Sudan (Muglad Basin) had generated a lot of momentum in Nigeria in which frontier exploration activities was conducted by the NNPC in the inland basin. The aftermath of such activities was the discovery of commercial quantity of hydrocarbon (oil and gas) with an estimated reserve of 1 billion barrel of crude oil and 500 billion cubic feet of gas deposit in Kolmani River II, in Alkaleri local government of Bauchi state as announced by the NNPC in 2019.

The well was drilled to about 13701 feet (4110m) in which from the geology Yolde Formation was the reservoir rock and limited studies were made on the reservoir quality of Yolde Formation.

Reservoir rocks are primarily sedimentary rocks that result from the recycling of rock debris due to the weathering of pre-existing rocks, such as sandstone, limestone, dolomite, and shale. The reservoir rocks' interconnected pore spaces enable petroleum to migrate and accumulate in a trap. This interconnectivity is described as permeability, which measures the hydrocarbon flow's ease in the reservoir. A good reservoir system comprises the reservoir, trap, and impervious stratum, usually called cap rock or seal, such as shale, overlying the reservoir. The ability of the reservoir rock to host and produce hydrocarbons largely depends on the degree of reservoir connectivity and the porosity/permeability characteristics of the reservoir unit during sediment deposition and subsequent burial. This work attempt to evaluate the reservoir quality of the Yolde Formation, hoping that it will add to the existing literature and making pathway for further research. Figure 1 is the map of the study area.

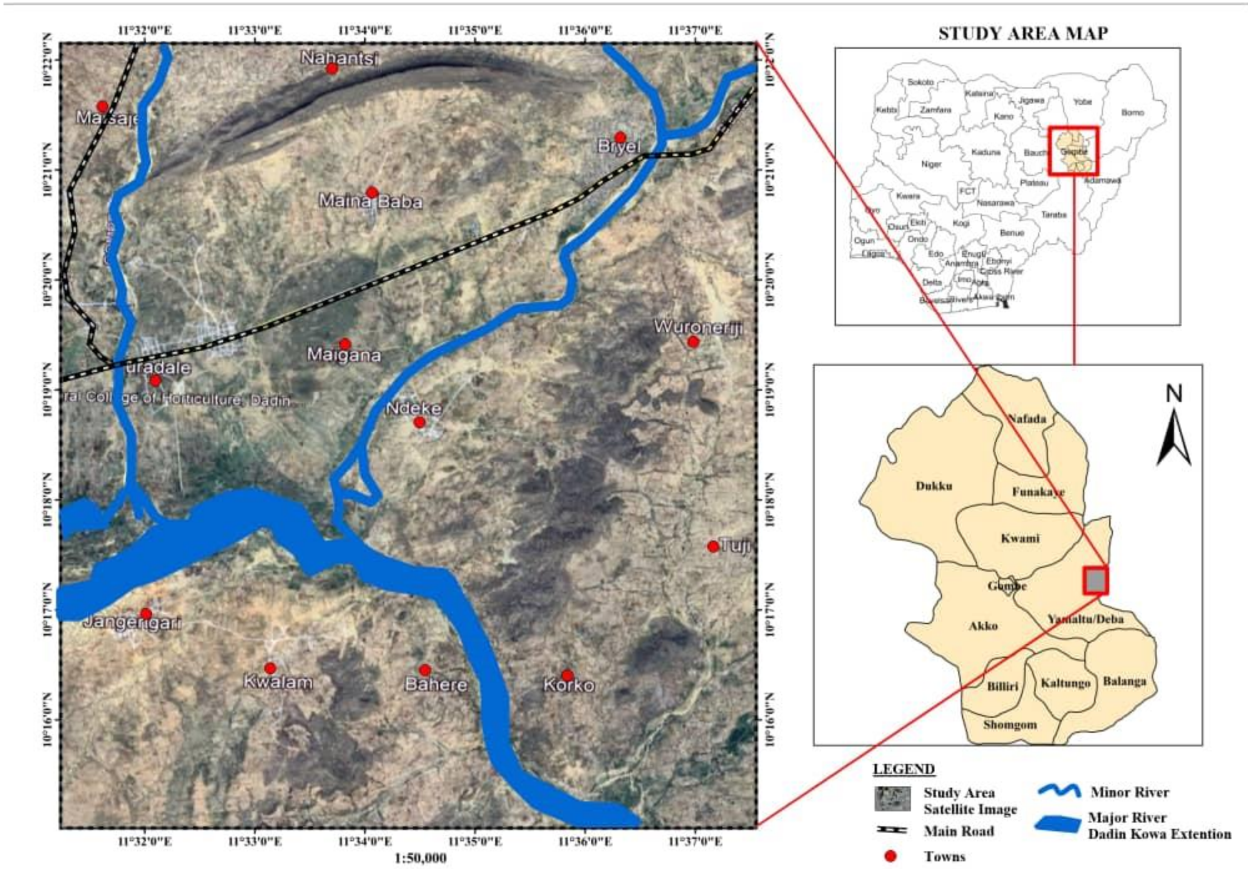

Figure 1: Map of the study area

The Benue Trough of Nigeria (**Figure 2**) is an intra- continental basin in Central West Africa that extends NE to SW. It is over 1000 km in length and exceeds 150 km in width. Its southern outcrop limit is the northern boundary of the Niger Delta Basin, while the northern out cropping limit is the southern boundary of the Chad Basin separated from the Benue Trough by an anticlinal structure termed the "Dumbulwa-Bage High". The Benue Trough is filled with up to 6000 metre of Cretaceous sediments associated with some volcanic. It is part of a mega-rift system termed the West and Central Africa Rift System (WCARS). The WCARS includes the Termit Basin of Niger and western Chad, the Bongor, Doba and Doseo Basins of southern Chad, the Salamat Basin of Central African Republic and the Muglad Basin of Sudan. The Benue Trough is geographically subdivided into southern, central and northern parts (**Figure 2**). The origin and tectonic history of the Benue Trough and indeed the entire WCARS is associated with the separation of Africa and South America (break-up of Gondwanaland) during the early Cretaceous time. This break-up was followed by the drifting apart of these continents, the opening of the South Atlantic and the growth of the Mid- Atlantic ridge.

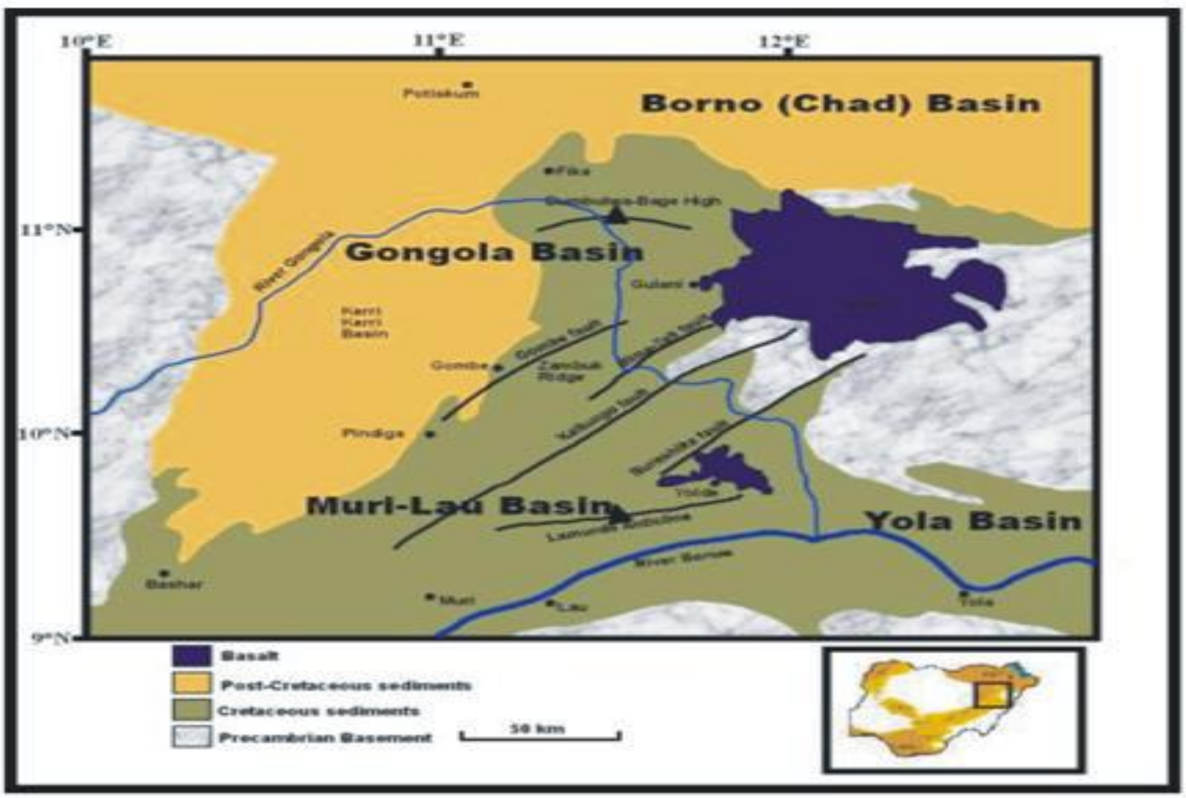

Figure 2: Geological Map of Upper Benue Trough (modified from Zaborski *et al* 1997)

3. GEOLOGIC SETTING AND STRATIGRAPHY

The Northern Benue Trough bifurcates into two arms namely; the Gongola Arm and the Yola arm. Some authors (Akande et al., 1998) consider the main (central) arm, Lau Gombe, a sub- basin too, thus amounting to three sub-basins.

Common to the two arms is the Albian Bima Sandstone unconformably overlying the Precambrian Basement. The Bima Formation was deposited under continental conditions namely; fluvial, deltaic and lacustrine conditions. It is made up of coarse to intermediate grained sandstones intercalated with carbonaceous clays, shales, and mudstones. Carter *et al. (*1963) subdivided the Bima Sandstone into Lower, Middle and Upper Bima Members. The Middle Bima is said to be predominantly shaley with some limestone intercalations and was speculated to have been deposited under a more aqueous anoxic condition (lacustrine, brief marine). Closely related match to this description are the dark, carbonaceous shales within the Bima Sandstone in the section along the river channel to the south of the bridge, 200m just prior to the village of Bambam. Identical shales also occur within massively outcropping units of the Bima Sandstone on the Lamurde anticline (2km away to the town of Lafiya, via the Gombe -Numan road). Favourable exposures of the Bima Sandstone (excluding the so-called Middle Bima) can be found at Biliri, Filiya and Shani (Obaje, 2009).

The Yolde Formation conformably overlies the Bima Sandstone. It is Cenomanian in age and marks the onset of marine transgression into this portion of the Benue Trough. It was deposited under a transitional/coastal/marginal marine environment and comprises sandstones, limestone, shales, clays and claystones. Type localities of the Yolde Formation are situated along the Valley of Pantami River in Gombe town and in the village of Yolde, 50km before the town of Numan.

On the Gongola Arm, the laterally equivalent Gongola and Pindiga formations and probably younger Fika Shale conformably overlie the Yolde Formation (Obaje, 2009). These formations indicate full marine transgression into the Northern Benue during the Turonian – Santonian times. Lithological compositions of these formations include dark/black carbonaceous shales and limestones, intercalated with pale colored limestones, shales and minor sandstones. The Gongola Formation's typical locality is at the Quarry of the Ashaka Cement Company at Ashaka, while that of Pindiga Formation is at Pindiga village.The Fika Shale is lithologically composed of bluish-greenish carbonaceous shales which are sometimes pale gypsiferous and highly fissile with periodic limestones in places. It is marine and is typically located at Nafada village along the Gombe – Ashaka road (Obaje, 2009). (Fig 3).

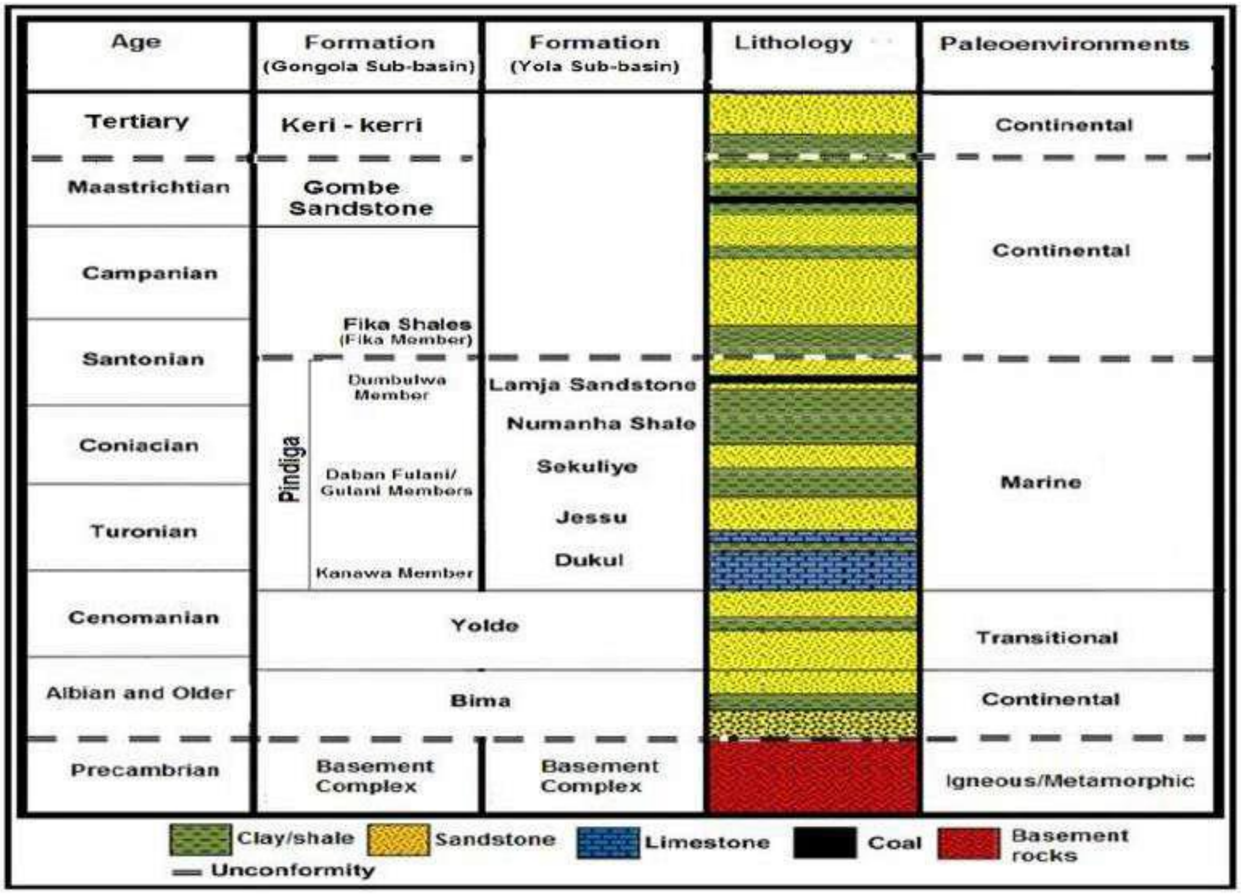

Figure 3: Stratigraphic successions in the Northern Benue Trough (after Lar et al., 2018)

On the Yola Arm, the Turonian – Santonian equivalents of the Gongola and Pindiga Formations are; the Dukul, Jessu and Sekuliye Formations: The Numanha Shale, and the Lamja Sandstone. The Turonian - Santonian deposits in the Yola Arm are lithologically and Palacoenvironmentally identical to those of the Gongola Arm, save for the Lamja Sandstone which is predominantly marine sandstone (Obaje, 2009).

The deposition of Dukul, Jessu and Sekuliye Formations under shallow marine neritic shelfal environments was proven by various arenaceous and planktonic foraminifera assemblages recovered from samples obtained from them. The village of Dukul is the type locality of the Dukul Formation. There are also good exposures of Dukul Formation at Bambam and Lakun on the Gombe Yola road. All the other formations (Jessu,Sekuliye, Numanha and Lamja) have their type localities in the villages named after them (Obaje,2009)
.The Santonian period which was marked with folding and deformation in the entire Benue Trough yielded post-folding sediments including the continental Gombe Sandstone of Maastrichtian age and the Keri-Keri Formation of Tertiary age. The Gombe Sandstone is lithologically identical to

the Bima Sandstone, thus proving the recurrence of the continental Albian palaeoenvironmental condition (Obaje, 2009).

The Gombe Sandstone Formation, however contains coal, lignite, and coaly shale intercalations which in places are very thick. The type locality of the Gombe Sandstone can be found along the bank of Pantami River in Gombe town. It is also well exposed in many parts of Gombe town and Birin Fulani village (Obaje, 2009).

The Keri-Keri Formation is lithologically composed of predominant claystones, with whitish grey sandstones and siltstones. Type Sectional exposures can be found in Gombe Aba, Dukku (not Dukul) and Alkaleri (Obaje, 2009).

3. METHODOLOGY

3.1 Petrographic Analysis

Rock samples were prepared into thin sections and observed under plane polarized and cross polarized light using a polarizing microscope. Equipment and material used are petrographic Microscope, electrical hot plate, Canada balsam, glass slide, carborundum powder, araldite and diamond cutter. The rock slides were analyzed under the petrographic microscope to determine the texture, framework minerals (quartz, feldspar and other rock fragments) and other accessory minerals based on their optical properties

3.2 Granulometric Analysis

This method is aimed at investigation individual grains of sedimentary rocks based on their size which is interpreted for various sedimentological parameters. Instrument used are, pestle, mortar, brush, electronics weighting machines and mesh size, using the following procedures. Samples collected were disaggregated by the use of pestle and mortal in a gentle manner to avoid breaking the original grain. A 200g representative sample was weighed by the weighing machine .Each of the samples was then placed in a set of mesh sieves, mounted on a mechanical sieve shaker and allowed to shake for 10 minutes as described by Krumbein and Pettijoin (1983), Folk and Ward (1957). Samples retained on each mesh sieve were then measured using digital weighing machine and kept in a protected cellophane bag to avoid losing the grain particles .The results were tabulated for further analysis.

The statistical parameters used as proposed by (folk, 1957) are: Graphic Mean (Mz), Graphic Kurtosis (KG), Inclusive Graphic Skewness (SK1) and Inclusive Graphic Standard Deviation ($\partial 1$)
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3.3 Porosity Test

The samples were oven dried at 105oc for about 4 hours then dried weight was taken for each of the samples. The samples were then immersed in water for 24 hours. The saturated samples were then weighed to give the saturated weight. The porosity was then computed from the test for all the samples using the formula:

Porosity (n) = VT/Vv
VT = Volume of void ratio
Vv = Total volume of rock

3.4 Permeability Test

A Falling head permeability test was employed to determine the permeability of the eleven samples collected which involve a flow of water through a relatively short sample connected to a standpipe which provide the water head and also allows measuring the volume of water passing through the sample. The diameter of the standpipe depends on the permeability of the tested rock.

Before starting the measurement, the following instructions were taken in to consideration

a. The sample was saturated and the standpipes were filled with de-aired water to a given level.
b. The test started by allowing the water to flow through the sample until the water in the standpipe reaches a given lower limit
c. The time required for the water in the standpipe to drop from the upper to the lower level was recorded
d. The standpipe was refilled and the test is repeated for couple of times.
e. The recorded time was the same for each test within an allowable variation of about 10% otherwise the test is failed
f. The permeability of the sample was calculated on the basis of the test result using the this formula

$$K = \frac{2.303al}{A(t2-t1)} \log 10 \frac{h1}{h2}$$

Where,
a= the cross section of the standpipe (cm^2)
L= length of the specimen (cm)
A = Area of the specimen (cm^2)
t= Time required for the water to be discharged (sec)
h_1 = Upper water level (cm)
h_2 = Lower water level (cm)
D= Diameter of sample

TABLE 1: POROSITY AND PERMEABILITY RANGES

POROSITY (%)		PERMEABILITY (MD)
Low	<5	<100
Moderate	5-10	101-150
Good	11-15	>150
High	16-30	
Very high	>30	

Evaluating methods of oil and gas reservoirs (China), 2011

4.0 RESULTS AND DISCUSSION.

4.1 LITHOSTRATIGRAPHY

Three different sections were logged and studied in the study area which is presented as follows:

4.1.1 Briyal Section. It is a composite section which has a total thickness of about 15M from the base upward, it consists of a very thick fine grained slightly yellowish to greenish sandstone which is overlain by a thin bed of mudstone followed by fine grained sandstone that is highly indurated and then overlain by a thin bed of mudstone. The bed passes upward in to a fine grained slightly reddish planner cross bedded sandstone which is overlain by fine grained planner cross bedded sandstone; it is then overlain by fine grained sandstone with hummocky structure intercalated with thin bed of mudstone. It is then overlain by a loose mudstone at the base followed by thick indurated, dark to brownish massive sandstone followed by thin bed of mudstone overlain by a thick bed of 90cm of fine grained planner bedded sandstone. It is then overlain by the intercalation of thin bed of mud stone followed by fine grained sandstone and thick bed of sandstone with thin layer of mudstone at the top

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Plate 1: Fine grained sandstone slightly reddish Plate 2: Hummocky cross bedded sandstone

Plate 3 : Sandstone with mudstone intercalation

Plate 4 : A thin bed of mudstone

Plate 5: Planner cross bedded sandstone

Plate 6: massive sandstone reddish brown

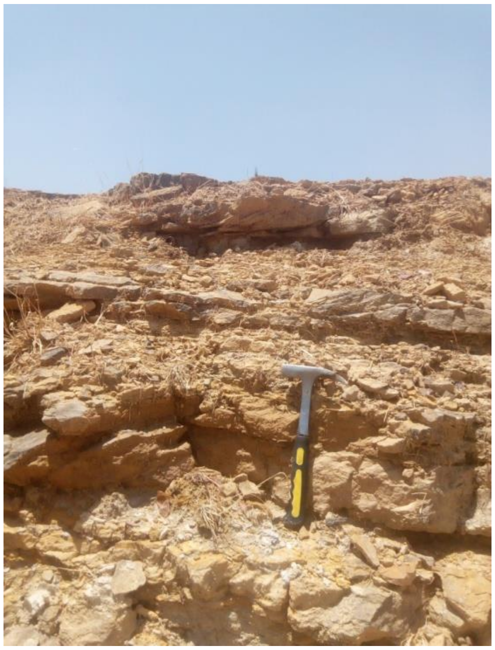


Plate 7: Planner cross bedded sandstone Mudstone intercalation

Plate 8: massive sandstone reddish brown

Plate 9: Thin bed of mudstone indurated sandstone massive laminated sandstone

Plate 10: Mudstone overlain by

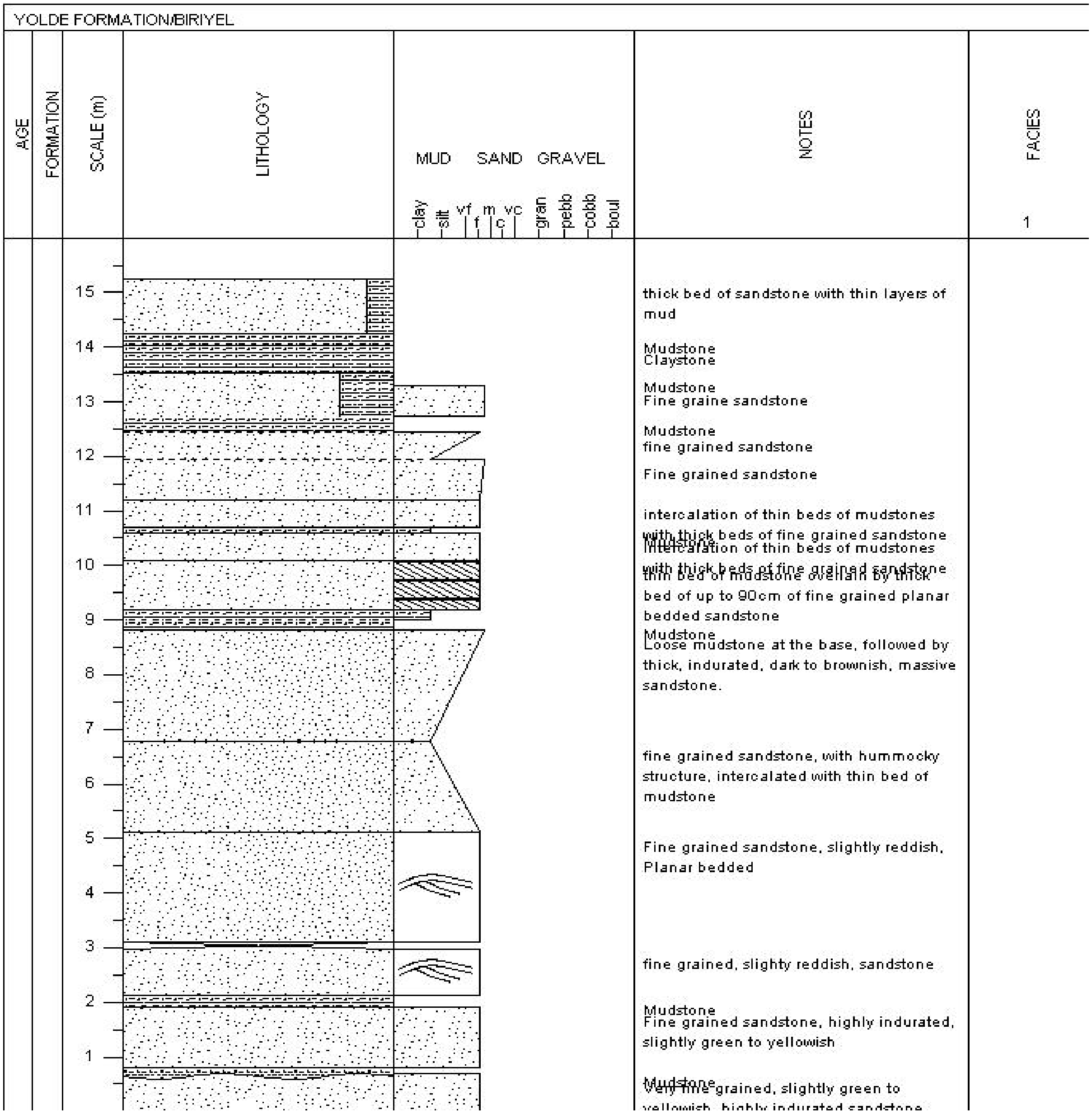
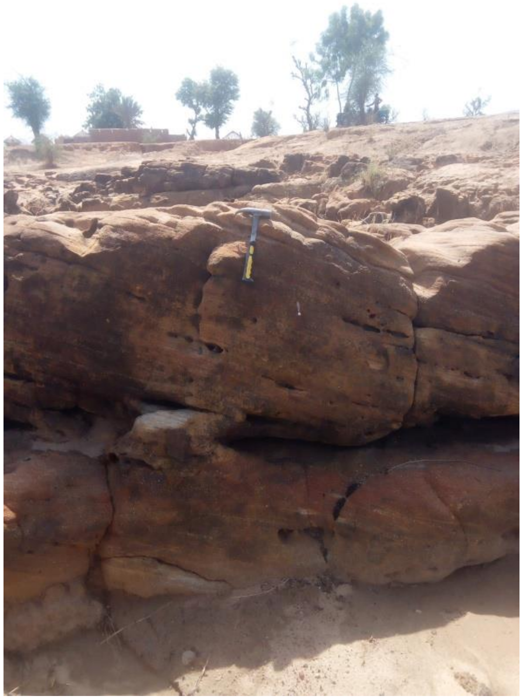


Fig 4: composites log section at Briyal town Bayo local government

4.1.2 Jangargari Section. The section has a total thickness of about 4.5M. Its consists of fine to medium grained horizontally bedded red dish sandstone at the bottom overlain by a fine grained slightly brownish massive sandstone then followed by fine grained slightly reddish massive sandstone overlain a mudstone which is then finally overlain by a fine grained massive sandstone.



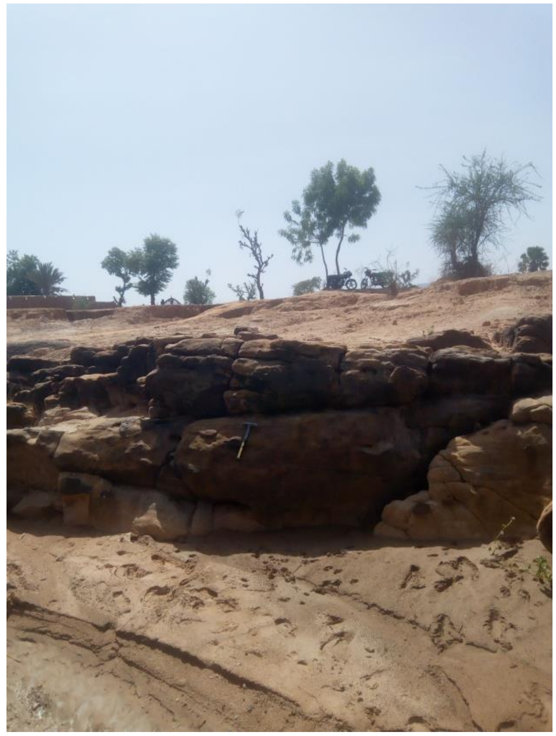


Plate 11: horizontally bedded sandstone reddish brownish massive

Plate 12: Sandstone slightly

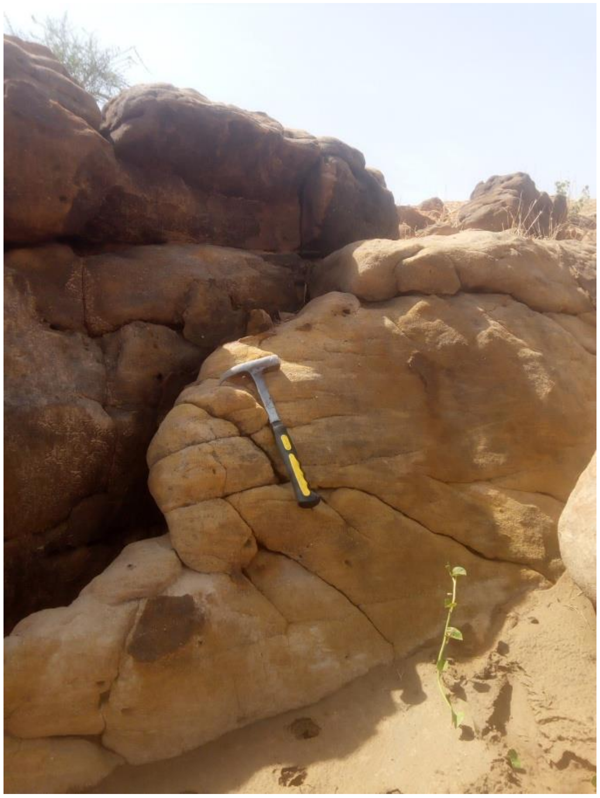


Plate 13: fine grain sandstone slightly reddish massive grain sandstone massive

Plate 14: mudstone overlain by fine

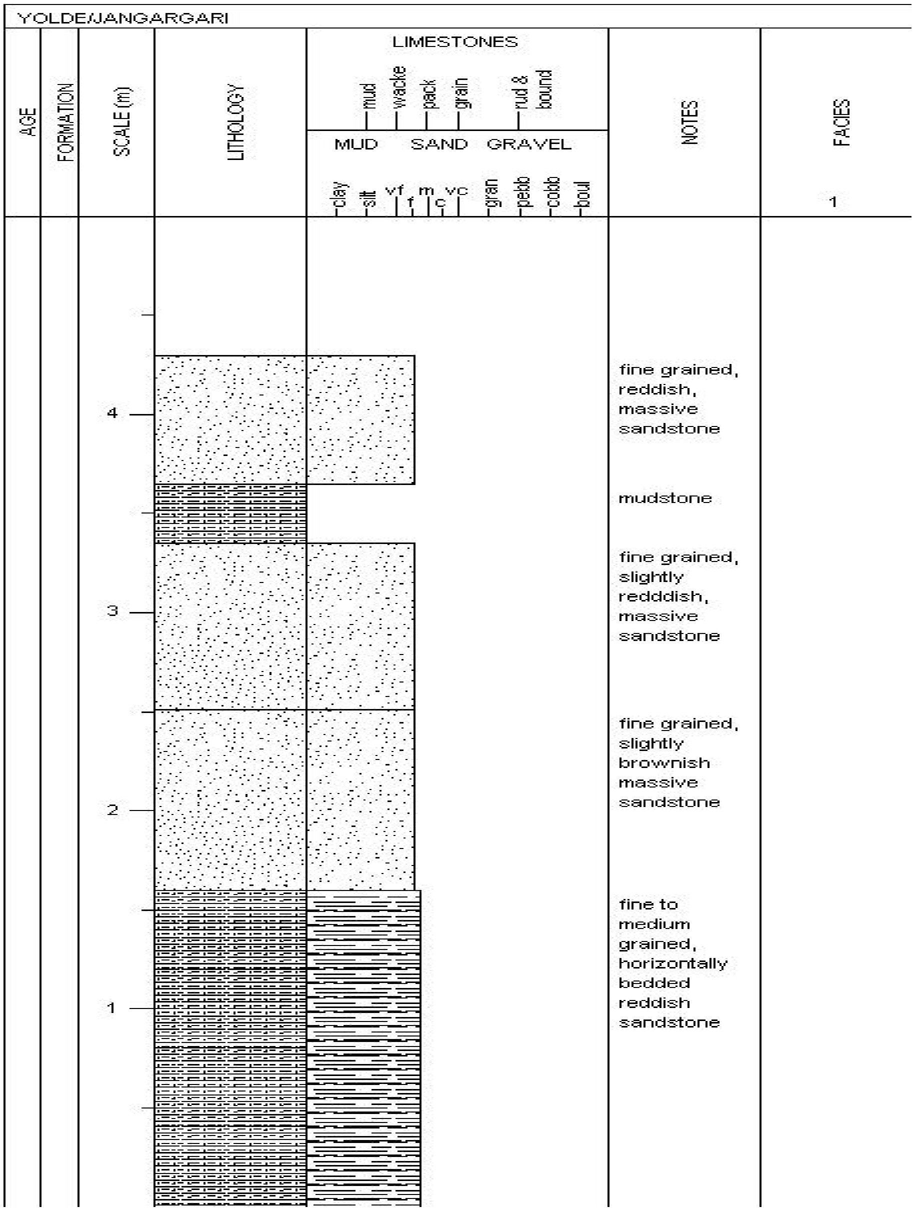


Fig 5: Lithologic section at Jangargari village

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4.1.3 Wuro Gari Section.

The section has a total thickness of about 3M. Its consist of fine grained slightly brownish trough cross bedded sandstone overlain by mud stone which is finally overlain by a fine grained trough cross bedded sandstone.

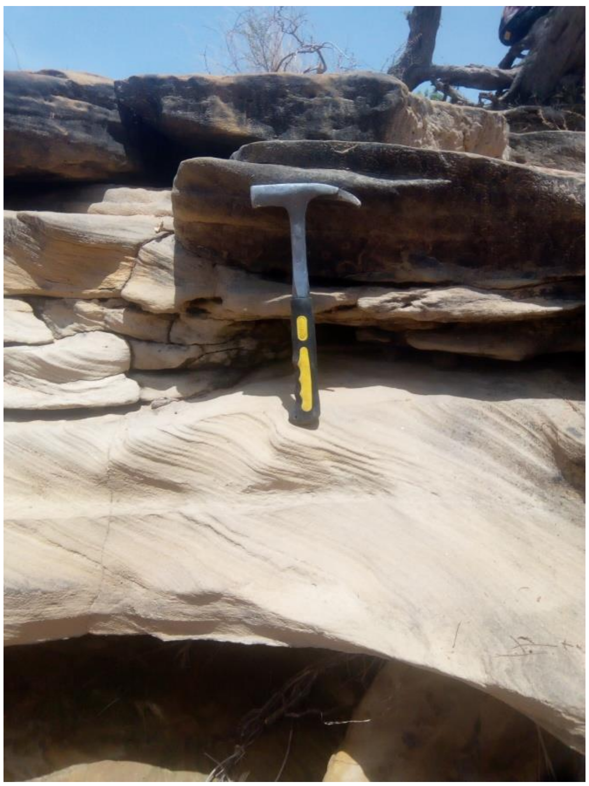


Plate 15: Trough crossbedded sandstone Plate 16: Planner Cross Bedded Sandstone

Plate 17: Mudstone Overlain By Fine Grain Sandstone

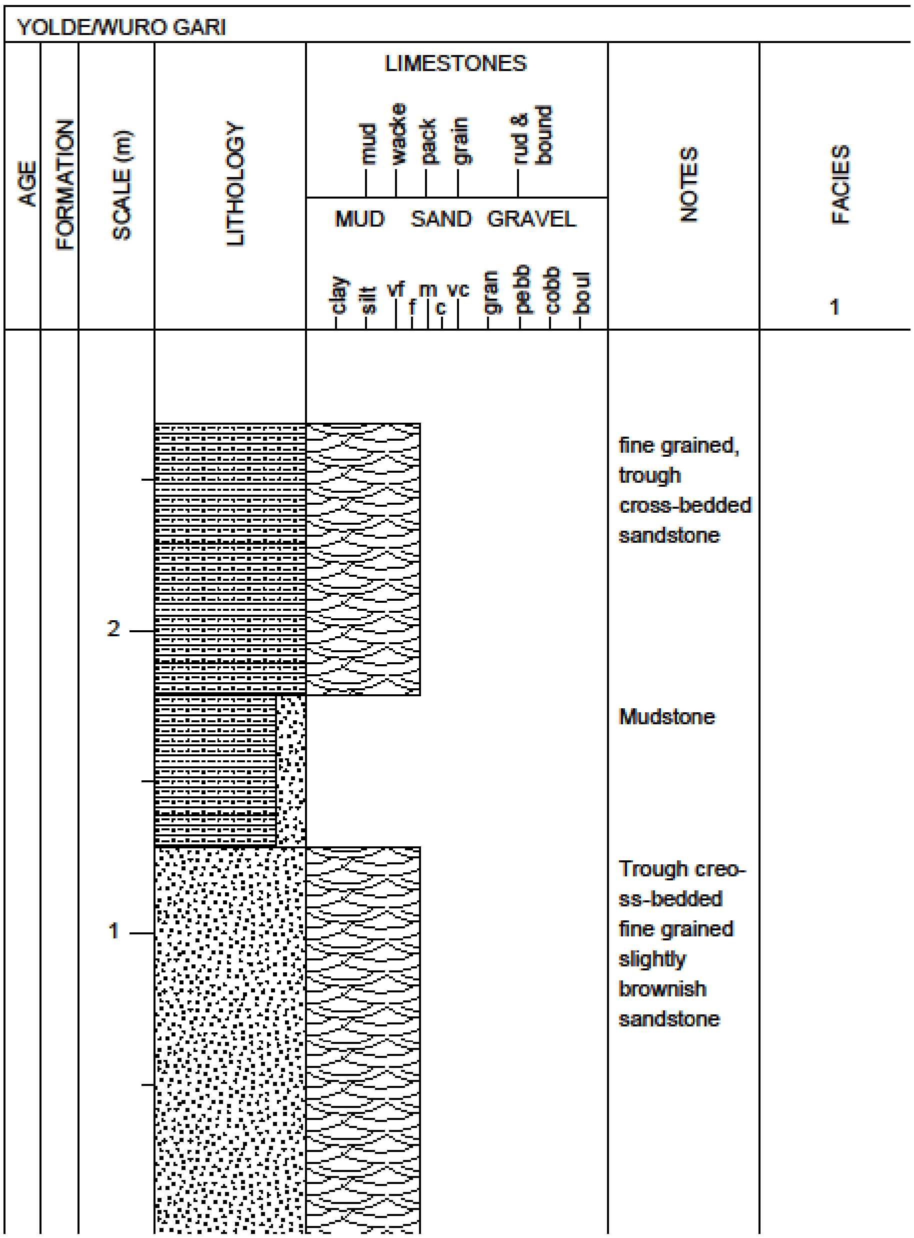


Fig 6: Lithologic section at Wuru gari village

4.2 GRANULOMETRIC ANALYSIS

Eleventh (11) sandstone samples were subjected for sieve analysis. The individual weight percent of the material retained on each sieve was determined for each sample. The results were used in plotting the histogram and cumulative frequency curves. The summary of the sieve analysis result are shown in table 2:

Table 2: Summary Of Result For Granulometric Analysis Obtained From Cumulative Frequency Curves.

SAMPLE NO	MEAN (Mz) Φ	STANDARD Φ DEVIATION	KURTOSIS Φ	SKEWNESS Φ
B1	2.76 Fine grained	0.60 Moderately well sorted	2.04 Very leptokurtic	-0.80 Very coarse skewed
B2	2.97 Fine grained	0.60 Moderately well sorted	3.37 Extremely leptokurtic	-0.711 Very coarse skewed
B3	2.76 Fine grained	0.56 Moderately well sorted	3.66 Extremely leptokurtic	-0.04 Coarse skewed
B4	3.4 Very Fine grained	0.63 Moderately well sorted	2.12 very Leptokurtic	1.70 Very fine skewed
B5	3.13 Very Fine grained	0.64 Moderately well sorted	2.10 Very Leptokurtic	1.67 Very fine skewed
B6	2.53 Fine grained	0.64 Moderately well sorted	2.13 Very leptokurtic	0.15 Fine skewed
B7	2.56 Fine grained	0.71 Moderately sorted	0.98 Mesokurtic	-0.07 Coarse skewed
H1	2.96 Fine grained	0.67 Moderately well sorted	2.08 Very Leptokurtic	-0.175 Coarse skewed
J1	1.40 Medium grained	0.79 Moderately sorted	1.79 Very Leptokurtic	0.15 Strongly fine skewed
J2	1.63 Medium grained	0.93 Moderately sorted	1.46 Leptokurtic	0.005 Fine skewed

J3	1.73 Medium grained	0.77 Moderately sorted	1.26 Leptokurtic	0.1 Coarse skewed

The graphic mean size for the various sample (table 2) ranges from 1.40Φ -3.4Φ (medium to very fine grained sands.) and the fluctuation of the values may reflect change in the strength of deposition.

The values of standard deviation table 2 tend to show that the sample range from moderately well sorted (0.56Φ) to moderately sorted (0.93Φ) with an average of 0.68 which implies that the whole formation is moderately well sorted.

The sample analysed have skweness value ranging from -0.035Φ to 1.67Φ which shows that the sediment are very coarse to very fine skewed. However sample (B1, B2, B3, B4, B7, H1,) have negative skewness indicating that clay and silt have been removed from the sediment. While sample (B5, B6, J1, J2, J3,) have a positive skewness indicating that clay and silt have not been removed by current. The values for kurtosis table 2 for the various samples range from 1.26 Φ to 10.9 Φ that is leptokurtic to extremely leptokurtic.

4.3 PRTROGRAPHIC ANALYSIS.

Six sandstone samples were thin sectioned and the slides were petrographically studied under the microscope. The microscopic study was done under both plane polarised light (PPL) and Cross polarised light (XPL) in order to reveal the mineral content and texture of the rock samples respectively.

Sample B1: It is texturally matured and is Quazarenite in nature .It has polycrystalline structure with quartz overgrowth that could lead to porosity lost. The grain shapes are rounded to sub rounded with low sphericity. It is moderately sorted based on grains packing.

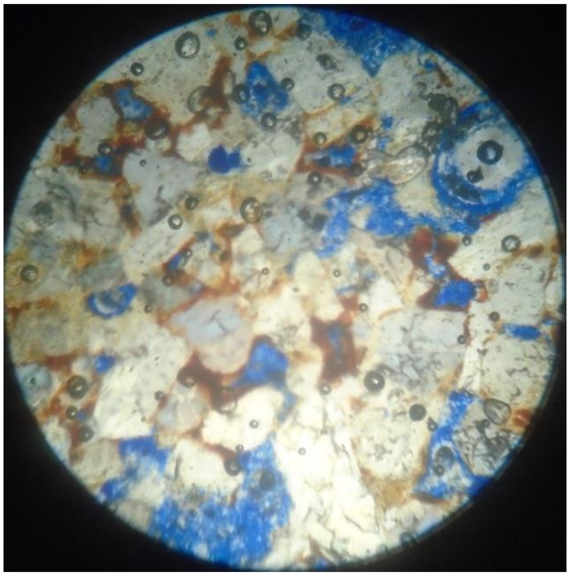
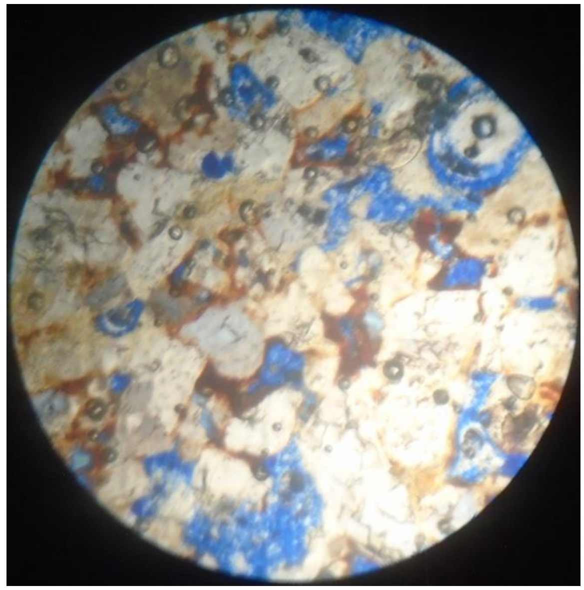



Plate 18: Sample B1 under PPL Sample B1 under XPL

Sample B4: It is texturally matured and sublitharenite in nature with a monocrystalline structure. The grain shapes are rounded to subrounded with high sphericity. It is moderately sorted based on the grain packing.

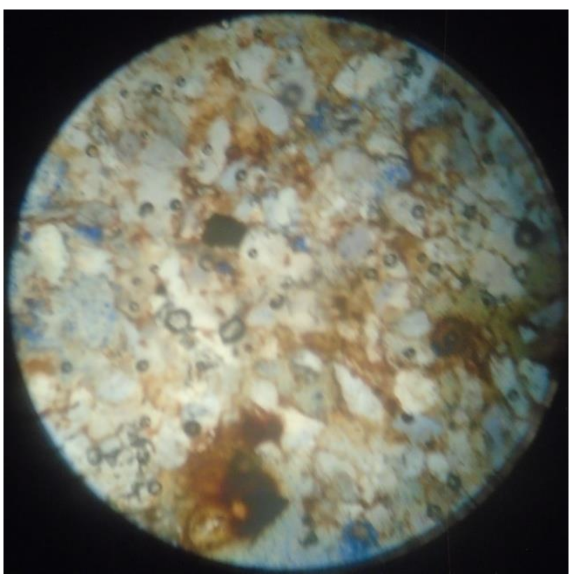
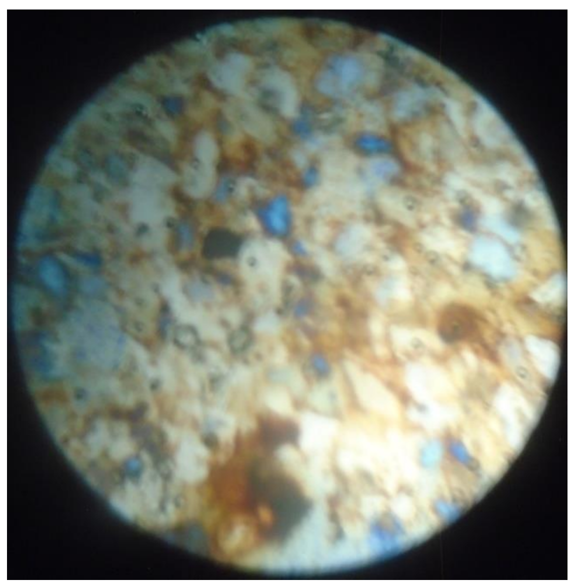



Plate 19: Sample B4 under PPL Sample B4 under XPL

Sample B7: It is texturally matured and is subarkose in nature with a polycrystalline structure. The grain shapes are sub rounded to rounded having a high sphericity. It is moderately well sorted based on the grains packing.

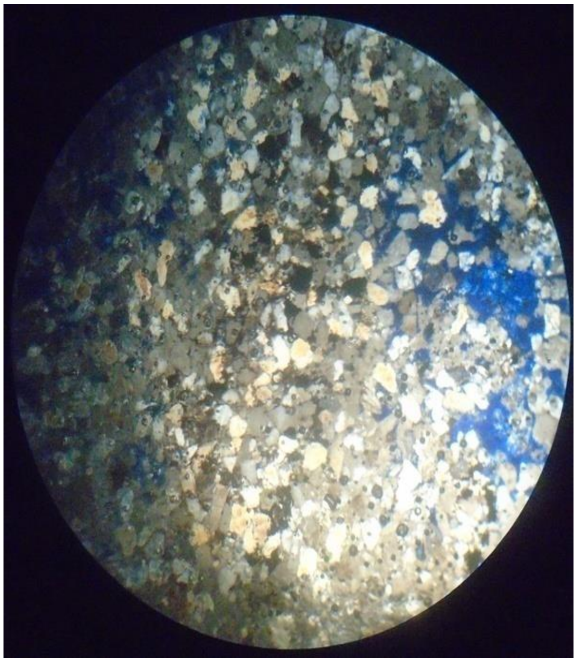
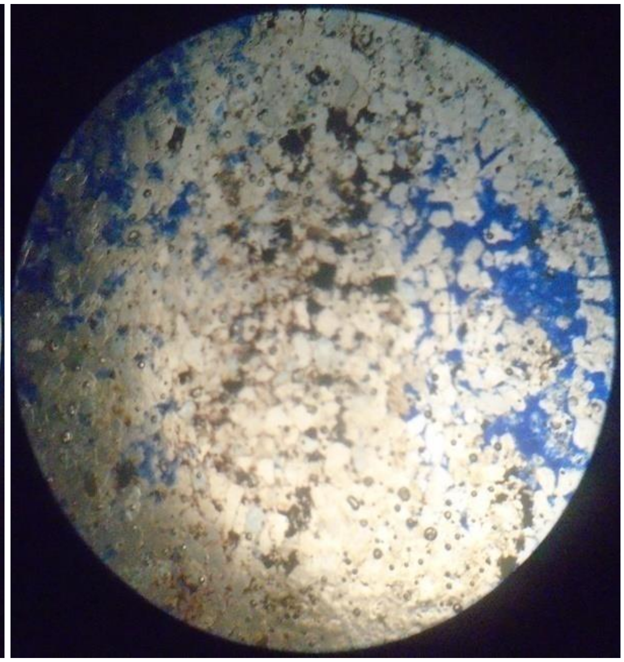
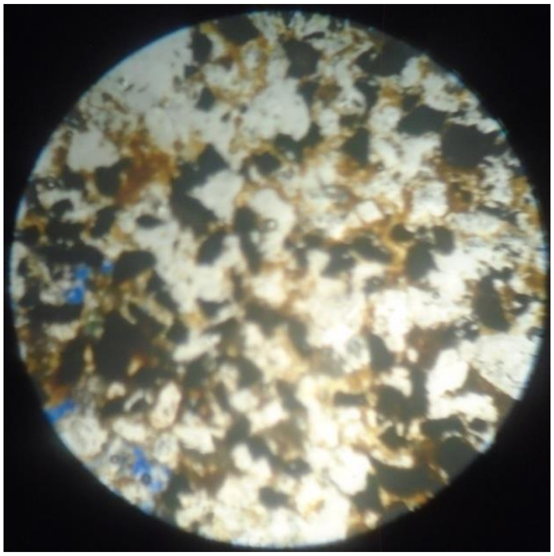



Plate 20: Sample B7 under PPL. Sample B7 under XPL.

Sample H1: It is texturally matured and is subarkose in nature. The grain shapes are rounded to subrounded with high sphericity. It is moderately sorted base on the grains packing.



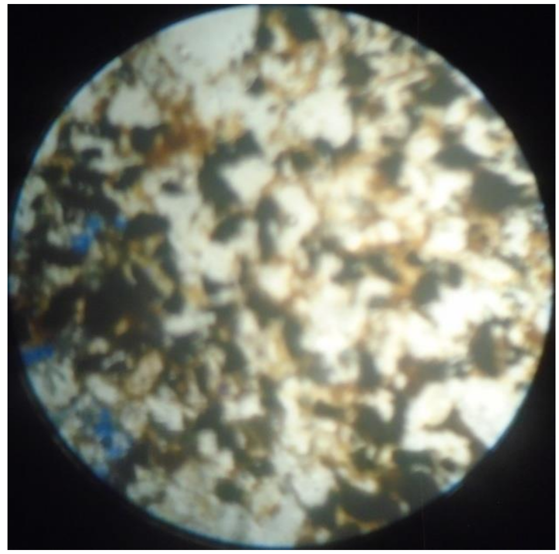
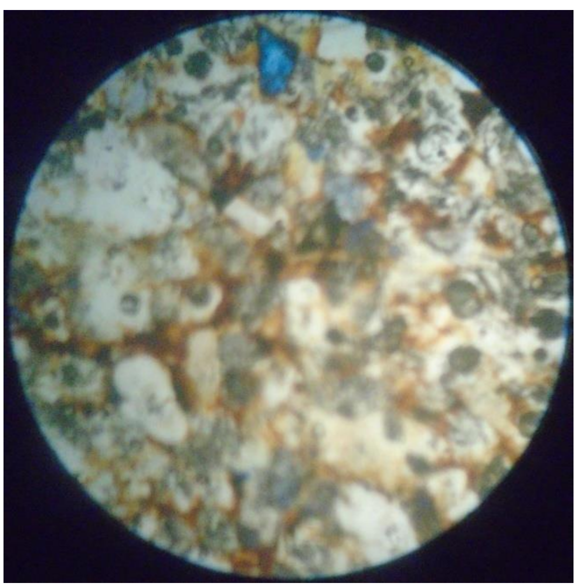


Plate 21: Sample H1 under PPL Sample H1 under XPL

Sample J1. It is texturally matured and is Sub arkose in nature. It has a polycrystalline structure. The grain shapes are rounded to sub angular with high sphericity. It is moderately well sorted based on the grain packing.



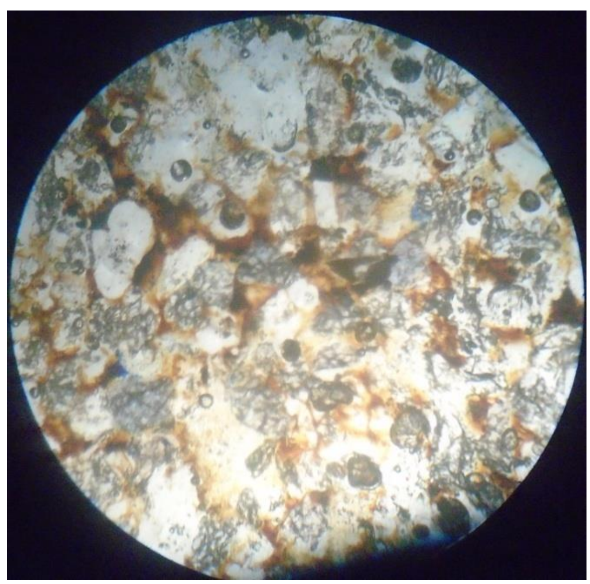
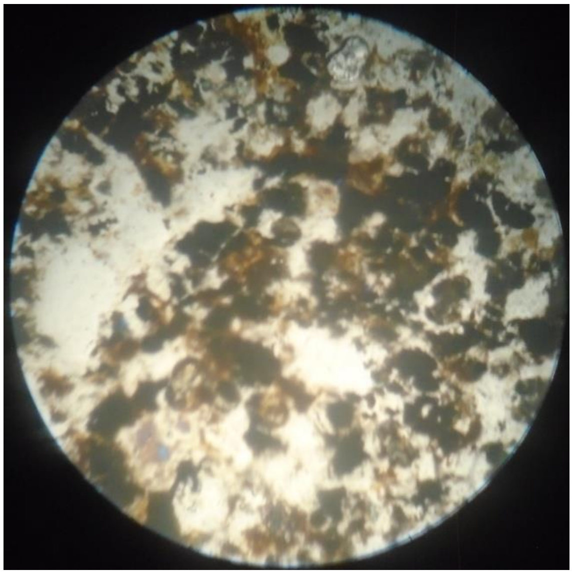


Plate 22: Sample J1 under PPL Sample J1 under XPL

Sample J2. It is texturally matured and is subarkose in nature. It has a monocystalline structure with sutured grains. The grain shapes are rounded to subrounded with high sphericity. It is moderately sorted based on the grain packing.



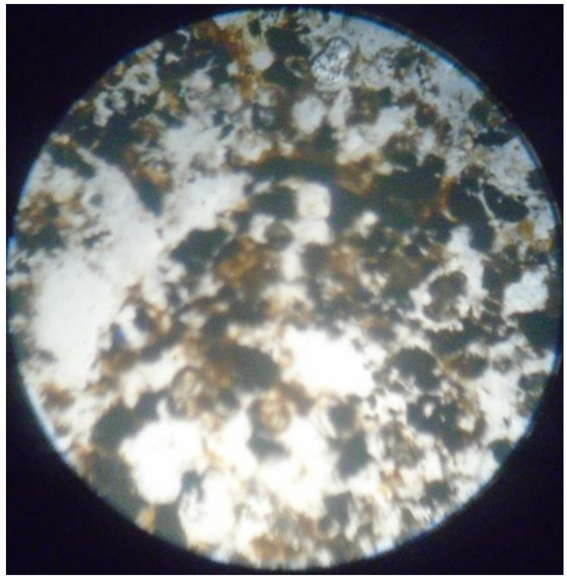


Plate 23: Sample J2 under PPL   Sample J2 under XPL

Table 3: Petrographic Analysis Results

Sample No.	Mineral Composition			Texture		
	Quartz (Q)	Feldspar (F)	Rock Fragment (RF)	Sorting	Roundness	Sphericity
BI	85	12	3	Moderately Well Sorted	well rounded	high
B4	75	20	5	Moderately Sorted	subrounded	low
B7	72	24	4	moderately well sorted	subrounded	high
HI	80	16	4	moderately sorted	well rounded	high
JI						

J2	68	25	7	moderately sorted	sub rounded	high
	77	20	3	moderately well sorted	well rounded	high

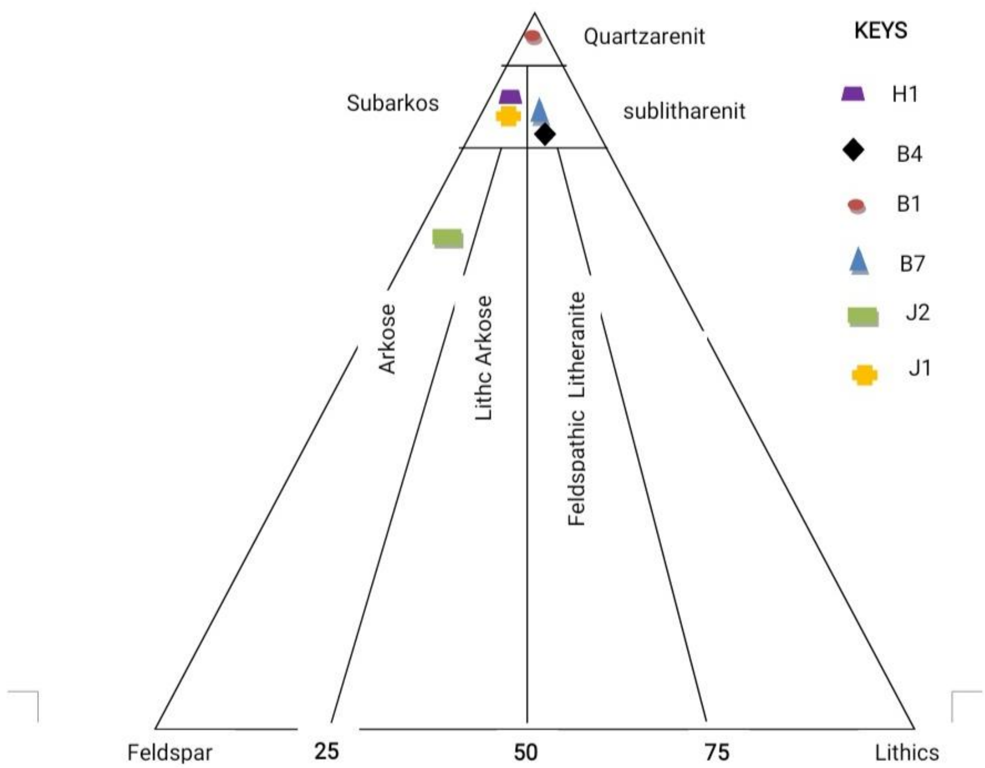


Figure 7: QFR plot showing framework composition of sandstone of the studied area

4.4 Petrophysical Analysis.

4.4.1 Permeameter analysis: Eleven (11) **Core** samples of the Yolde Sandstones were subjected to falling head permeameter analysis in order to determine its permeability. Samples (BI, B2, B3, B4, B5, B6, B7, B8, H1, JI, and J3) showed a high permeability result while sample J2 have a low permeability result. The permeability results of the studied rocks ranged from 83.27 – 507 Md as shown the table 4. These values when compared to the reservoir rock of a major petroleum field of prolific hydrocarbon province of North Sea (25%) and Niger delta (agbada formation) (15%), the studied rocks could serve as a potential Petroleum reservoir.

4.4.2 Porosity Evaluation: The porosity evaluated of the studied rocks ranged from high to moderate (table 4). Samples (B3, B5, B6, H1, and J3) have a high porosity value and sample (J, J2, and B4) have a good porosity values while samples (B1, B2, and B7,) have a moderate porosity values. The porosity values of the studied rocks range between 5% – 29%, with an average of 15.1% indicating a good porosity.

Table 4: Summary of Petrophysical Analysis

SAMPLE No.	Hydraulic Conductivity(k) cm/sec	Permeability Md	Porosity %
B1	1.6×10^{-4}	165.71 high	6 moderate
B2	1.6×10^{-4}	165.71 high	8 moderate
B3	4.9×10^{-4}	507.49 high	24 high
B4	3.2×10^{-4}	331.43 high	14 good
B5	2.2×10^{-4}	227.86 high	21 high
B6	1.9×10^{-4}	196.79 high	16 high
B7	3.4×10^{-4}	352.14 high	5 moderate
H1	2.7×10^{-4}	279.64 high	29 high
JI	1.3×10^{-4}	134.64 high	14 good
J2	8.04×10^{-5}	83.27 low	13 good
J3	2.3×10^{-4}	238.21 high	16 high

5. 0 CONCLUSION AND RECOMMENDATION..

5.1 CONCLUSION

The lithology of the study area was found to contain basically fine grained planner cross bedded sandstone, hummocy cross bedded sandstone, medium grained sandstone.

The results from granulometric analysis indicated that the samples are medium to fine grains which are moderately well sorted.

The Sandstones consist mainly of quartz, feldspars and mica as framework elements with clay matrix as cement. The framework composition of these sandstones is varied and is presented in table 8. The textures of these sandstones tend to show poorly to moderate sorting. The grain shape ranges from well rounded to sub rounded with subrounded dominating and spherecity varies from low to high.

Quartz comprises of about 75% of the framework. Feldspars generally range from 4-15% and potassium feldspar predominates.

A plot of QFR diagram (figure 8) indicates that the sandstone range from Qurtzarenite to subarkose and their textural maturity ranges from sub mature to mature.

Results from permeability analysis of the studied sample showed a high permeability value where as sample J2 showed a low permeability value. And the porosity values showed high to moderate porosity and when compared with the porosity and permeability values of the prolific reservoir of the Agbada formation of the Niger delta ,Yolde formation can serve as a potential petroleum reservoir rock,

5.2 RECOMMENDATION

I recommend that more work should be done on the reservoir potential of Yolde formation in various places in order to obtain more data to add to the existing literature

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