IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 8, Issue 5 Ser. II (Sep. – Oct. 2020), PP 39-49
www.iosrjournals.org

Petrography and Paleodepositional Environment of the Campanian-Maastrichtian Patti Formation exposed at AHOKO North Central Nigeria

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Abstract:
Background*: The BidaBasin is the least studied of Nigeria's inland frontier basins but is believed to have oil and gas resources. No exploration wells have been drilled in the basin. However, it has recently become a subject of intense debate because of the renewed commitment by the state oil company, NNPC to commence exploration in the Basin in a bid to raise the country reserves by 40 billion barrels by 2023. This has made it imperative to increase research efforts to characterize the basin in terms of its petroleum system elements and understand the environment of deposition of its sediments.*
Materials and Methods*: The research involves outcrop studies of sedimentary road cut sections and quarry sections of the Patti Formation, grain size analysis, petrographic analysis, foraminifera analysis and Total organic carbon (TOC). The field work exercise involved detailed section measurement, description of lithologic unit and sample collection. The equipment and the materials used for the successful mapping of the area include the Global Positioning System (GPS), clinometers compass, sample bag, masking tape, hammer and chisel, topographic map, measuring tape, hand lens, digital camera and field note.*
Results*: The result of the grain size analysis reveals that the samples are fine grained (average values of 2.777, 2.165, 2.475), poorly sorted samples (average values of 1.661, 1.534, 1.887) and texturally mature. They are mainly platykurtic siltstones. The nature of the histogram is an indication of slow water current. Deduction from thin section petrographic analysis of the ironstone samples suggested the presence of goethite, siderite, quartz and some clay minerals. Diagenetic processes identified are compaction and cementation. Goethite is the predominating mineral of the ironstones. Structures observed in the section were massive bedding, laminations, fractures, concretions and bioturbations. Thin section petrography of the ironstone facies reveals that weathering and changes in the oxidation to reduction condition of the inter particle fluid between the pores of the ironstones during diagenesis lead to the ferruginisation of the precursor sandstones and clays in an oxidizing environment. Foraminifera results for the shale samples yielded generally low percentage of benthic foraminifera while the species observed include Bolivina spp., Bulimina spp., Miliammina spp. and Textularia spp. These benthic species dwells in an environment ranging from brackish to normal marine environment with oxic to dysoxic conditions. Total Organic Carbon (TOC) analysis of twelve shale samples was carried out which range from 1.08 wt. % to 4.07 wt. % revealed that the shale samples have a good potential for hydrocarbon.*
Conclusion:*The Patti Formation consists of four lithofacies which are shale, siltstone, claystone and ironstone.The siltstone samples are fine grained, poorly sorted and majorly platykurtic which suggests that they were deposited in a low energy quiet water environment probably the fluvial environment. Deduction from the petrographic studies showed that the ironstones of the Patti Formation is composed of minerals such as siderite, goethite, quartz and clay matrix with the clay matrix serving as cementing minerals.Total Organic Carbon analysis of the shale samples revealed an average value of 2.51 wt. % which shows that the shales are good source rocks for hydrocarbon generation upon maturity.With the occurrence of species such as, Bolivina species, Bulimina species, Miliammina species and the Textularia species the shale samples are of shallow marine sources of anoxic conditions.*
Key Word*:Fluvial; Foraminifera; Total Organic Carbon; Patti formation; Grain size analysis.*

Date of Submission: 10-11-2020 Date of Acceptance: 25-11-2020

I. Introduction

The Bida Basin is one of the seven sedimentary basins in Nigeria and it is located in the central part of the country. It is a NW-SE trending intracratonic structure extending from Kontagora in Niger State in the North to the area slightly beyond Lokoja in the South and covering a distance of about 420km. Gravity studies in the

Bida Basin put the maximum thickness of the sedimentary successions at about 3.5 km (Ojo, 1984) in the central axis. A recent spectral analysis of the residual total magnetic field in different sections of the basin showed that the average depth to basement is about 3.4 km, with sedimentary thicknesses of up to 4.7 km in the central and southern parts of the basin (Udensi and Osazuwa, 2004). In general, sediment thickness decreases smoothly from the center to the flanks of the basin. It is delimited in the NE and SW by the basement complex and merges with the Anambra and Sokoto Basins to the SE and NW respectively (Figure 1). The basin is filled mainly with Campanian- Maastrichtian sediments of shallow marine to fluvial origin. This Basin consists of Upper Cretaceous clastic sequence of sandstones, shales, siltstones, claystone and ironstones.

According to oil and gas journal, the Basin is the least studied of Nigeria's inland frontier basins but is believed to have oil and gas resources. No exploration wells have been drilled in the basin. However, it has recently become a subject of intense debate because of the renewed commitment by the state oil company, NNPC to commence exploration in the Basin in a bid to raise the country reserves by 40 billion barrels by 2023 (ibekachikwu.com). This has made it imperative to increase research efforts to characterize the basin in terms of its petroleum system elements and understand the environment of deposition of its sediments.

Grain-size characteristics are widely used by geologists to reveal depositional process, hydrodynamic condition and depositional environment (Boggs, 2009). In addition, grain size parameters also provide valuable clues to the sediment provenance, transportation mechanism and depositional conditions (Blott, 2001). Several other researchers have worked on the sedimentology and hydrocarbon potential of this basin. Olusola et. al (2018) revealed a TOC of 0.79-12.9 wt.% for the Patti Formation implying a moderate to high concentration of organic matter, hydrocarbon source potential range from 0.19-0.70 mgHC/g rock except for a certain interval with high yield (30.23 mgHC/g rock) in the Patti shales and concluded that the Maastrichtian source rocks were sourced terrestrially under a prevailing oxic condition and dominated by Type III organic matter but with possibility of type II organic matter in the Agbaja area. Ojo and Akande (2003) and Ojo and Akande (2009) reported on facies relationship and depositional environments of the Upper Cretaceous Lokoja Formation as well as the sedimentology and depositional environment of the Patti Formation within the Bida basin respectively using field relationship, textural and paleocurrent characteristics.

This research involves outcrop studies, sedimentology, petrographic studies on thin section, grain size analysis, TOC studies on shale samples with the aim of reconstructing the paleo-depositional environment of the Patti Formation of the southern Bida Basin. This study would provide additional insight and information for exploration geoscientist and researchers working on the Basin.

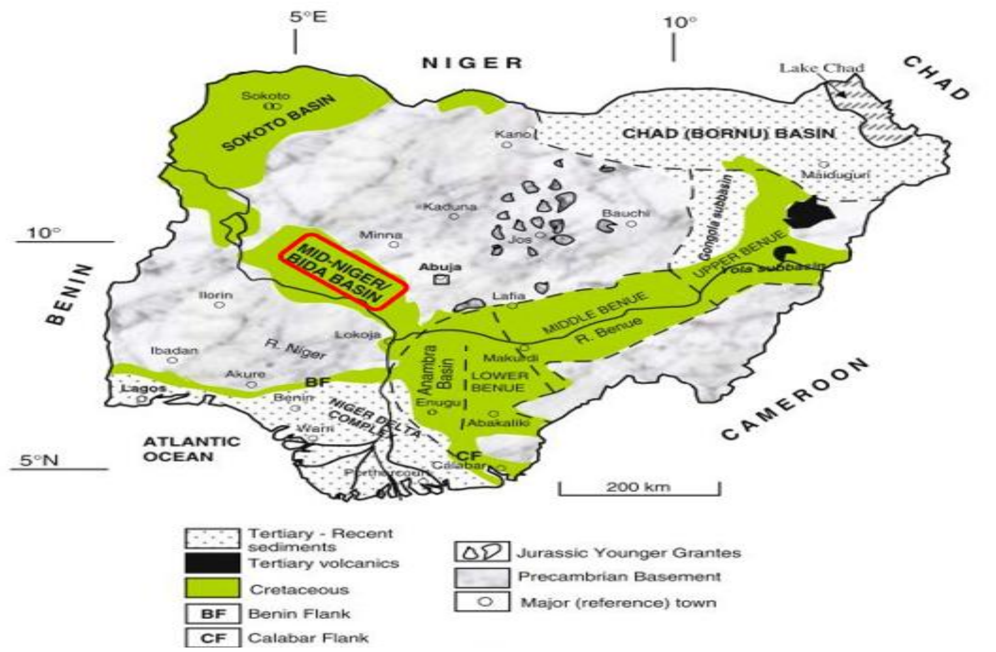


Figure 1: Geological map of Nigeria showing the Location of the study area (After Obaje, 2010)

II. Material and Methods

This study was carried out in the geoscience laboratory at the University of Ilorin. A total oftwelve ironstone samples were selected for thin section analysis and Foraminifera studies was conducted on twelve shale samples. A separate set of 12 samples were selected for Total organic carbon (TOC) studies.

Study Location: The study areas are located at Ahoko 49km from Lokoja where the deepest part of the Patti Formation is exposed along Lokoja-Abuja expressway. The studied outcrops are road cut sections with coordinates of longitude N 006005'27.9", latitude E 008018'6.1" with an elevation of 88m and the Ahoko Quarry with longitude N 006051'26.7", latitude E 008078'15.0" and an elevation of 94m respectively (Figure 2).

Procedure methodology

The research involves outcrop studies of sedimentary road cut sections and quarry sections of the Patti Formation, grain size analysis, petrographic analysis, foraminifera analysis and Total organic carbon (TOC). The field work exercise involved detailed section measurement, description of lithologic unit and sample collection. The lithologic units at each location were described based on physical attributes such as color, grain-size, bedding and sedimentary structures. Photographs were taken for detailed lithofacies study and proper documentation. All sections were logged from the base to the top. The equipment and the materials used for the successful mapping of the area include the Global Positioning System (GPS), clinometers compass, sample bag, masking tape, hammer and chisel, topographic map, measuring tape, hand lens, digital camera and field note. Representative samples like the ironstone, siltstone, claystone and shales were sampled and labeled accordingly.

Grain size analysis was carried out using weighting balance, mechanical sieve shaker, set of sieves, cleaning brush and a plain sheet of paper. Twelve sieves of different mesh sizes aided by mechanical sieve shaker was used to sieve the sample into different sizes and the retained weight from each mesh size received on the plain paper was weighed using the weighing balance.

Twelve ironstone samples were selected for thin section analysis. Petrographic analysis was carried out on thin section using a polarizing microscope to determine the optical properties of the samples. The materials used in the preparation of thin section includes canadabasalm, carborundum of 400, 600 and 800 grits, araldite while the equipment used were the logitech rock cutting machine, smooth glass, hot plate and the glass slide. The samples were firstly cut with the rock cutting machine into 3mm-4mm thickness, surfaced with the Caborundum, mounted on the glass slides with the aid of araldite, pressed together to remove air bubbles using forecept and placed on the hot plate after which the sample chip is then ground down on the other side with successively finer grades of Caborundum powder. When a suitable thickness of about 0.03mm is obtained, a cover slip is cemented on it with the use of the Canada basalm. After this, photomicrograph studies were carried out on the thin section samples under a polarizing microscope to determine the optical properties.

Foraminifera studies was conducted on twelve shale samples. Mortar and pestle were used to pulverize the sample into roughly 1mm-2mm fragments and air dried to remove the moisture content. The crushed samples were weighted and each poured into the plastics, 10% hydrogen peroxide and water were added in the ratio 1 to 3 respectively using the measuring cylinder for measurements and they were left to stand while they boil and release effervescence due to their richness in organic matter or clay. The mixture was then left for 24 hours for proper disintegration of the foraminifera from the shale grains. It was then washed with a sieve of size 0.063mm under running water until the liquid coming through the sieve is clean. The residue left in the sieve is then dried and kept in a sample container. The dried residue was viewed under a binocular microscope so as to pick and identify the different foraminifera present.

After this, total organic carbon (TOC) content determination was carried out on twelve samples using Walkey - Black Oxidation method (1995) to determine their percentage organic carbon. The samples were pulverized and sieved with 0.5mm mesh sieve size. 2.0g of the pulverized samples was weighed and poured into 250ml conical flask and 10ml of 1N $K_2Cr_2O_7$ solution was added to it. 20ml of concentrated H_2SO_4 was rapidly added and it was shaken together to allow proper mixing of the reagents with the sample. The suspension was placed on white asbestos and left to stand for about 30 minutes, intermittently stirred for complete oxidation after which 100ml of distilled water was added. About 3-4 drops of 0 – phenolthroline ferrous complex indicator was added. The above solution was then titrated with 0.5N ferrous sulphate solution to blush dark end point.

III. Result

3.1 Field studies report

Two section were investigated. Ahoko quarry section is having coordinate systems of longitude 6051'26.7" E, latitude 8078'15" N with an elevation of 94m while the Ahoko road cut section has co-ordinate systems of longitude 6051'27.9" E, latitude 8018'6.1" N with an elevation of 88m.

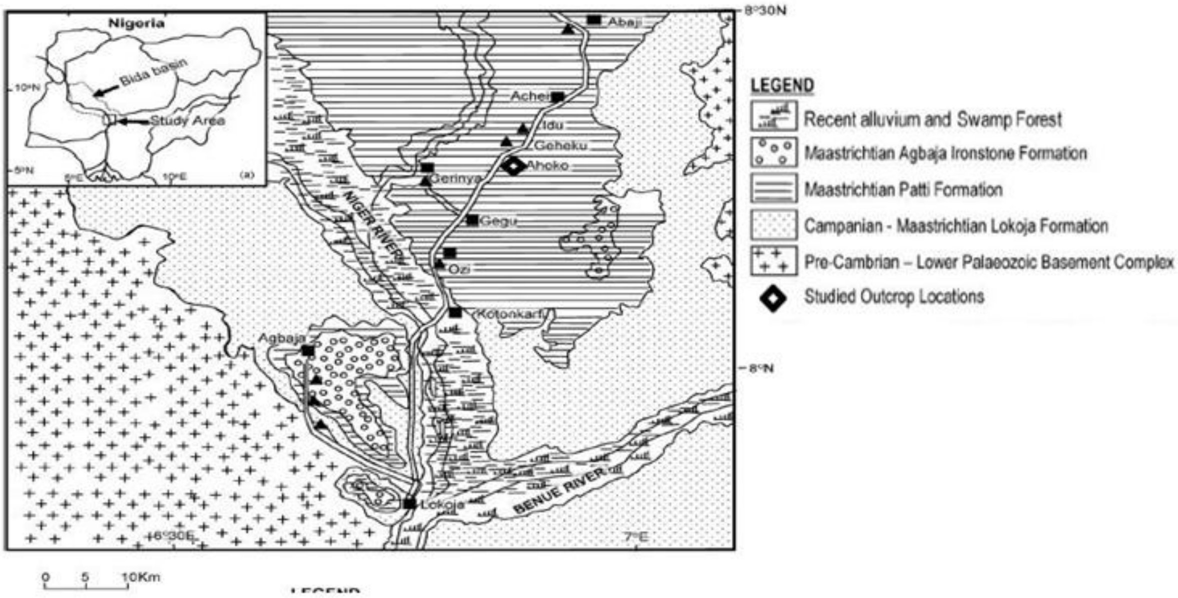


Fig. 2: Map of Nigeria showing NW/SE trending Bida Basinafter Agyingi (1991)

3.1.1 Ahoko Quarry Section

It is 20.1m thick and has four rock facies which includes claystone, shale, siltstone and ironstone (fig. 3 &4). The stratas consist of 0.5m thickbasal exposed nodular carbonaceous shale, 0.2m thinly bedded ironstone, 0.1m carbonaceous shale, 0.4m bed of ironstone overlain by 1.0m massive bedded carbonaceous shale. Occurring over this is 0.2m ferruginised laminated siltstone, 0.5m dark greyish fractured shale,0.3mpisolitic ironstone, 0.3m massive ferruginised siltstone. On top of this is 0.9m cross cutting fractured shale filled with ferruginised clayey silt, 0.3m thick laminated ironstone, 0.1m thick brownish fractured claystone, 0.7m ferruginied siltstone, 0.2 m laminated to massive ironstone with poorly developed pisoids, and 0.7m thick siltstone bed. Massive 0.15m thick claystone overlies this then 0.45mlaminated to massive ironstone, 1.55m massive bed of claystone, 0.3m concretionary ironstone, 0.7m claystone, 0.2m thick laminated to massive ironstone overlain by1m fractured claystone and another bed of 0.2m laminated to massive ironstone. A massive 3m bed of claystoneoverlies this then pisolitic ironstone, silty claystone and another bed of pisolitic ironstone. Capping this is lateritic overburden.

3.1.2 Ahoko road section

Four rock facies which includes claystone, shale, siltstone and ironstone were identified in this location (Fig. 3&4). The basal exposed rock is laminated to massive ironstone of 0.25m thickness overlain by nodular shale having fractured traces filled with pyritic patches (Fig. 5) of 1m thickness which is then directly overlain by a bed of pisolitic ironstone of 0.4m thickness. Next to this is a bed of greyish nodular fractured shale of 1.5m which is overlain by thinly laminated to massive ironstone of 0.35m. Occurring over this is nodular shale having cross cutting fractures filled with pyritic patches of 0.5m thickness which is then overlain by pisolitic ironstone of 0.23m thickness. Over this is the presence of bioturbated ferruginised silty shale of 1.65m thickness which is overlain by concretionary ironstone of 0.3m thickness. Followed by this is ferruginised siltstone of 1.95m in thickness then the occurrence of 0.7m thick greyish shale upon which there is presence of a covered interval due to terracing which was done at the time the Lokoja-Abuja road was in process in order to prevent slope failure with an approximate thickness of 0.5m. Overlain by this is a bed of silty shale of thickness 0.3m followed by a bed of shale with fractures filled with clayey-siltsone with a thickness of 0.2 m and then another covered interval. Laminated to massive ferruginised siltstone overlies this with a thickness of 0.35m overlies this and then a bed of massive claystone with thickness of 1.7m (Fig. 6). Capping this is lateritic overburden.

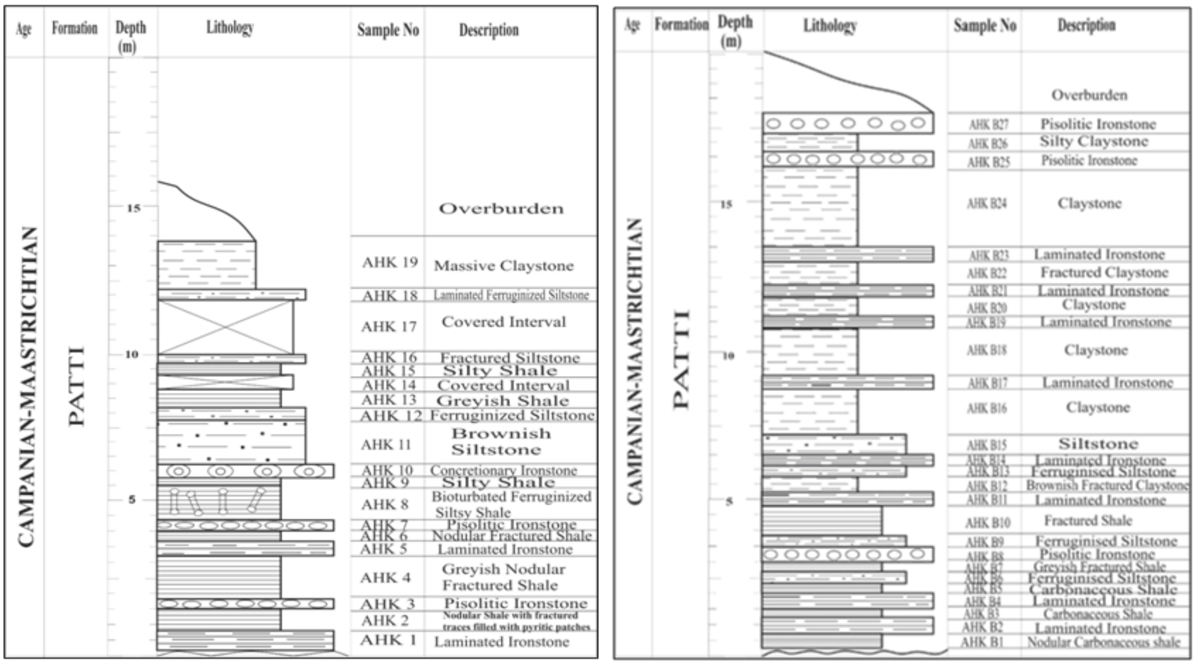


Fig. 3: (L-R) Lithologic section of Ahoko Road-cut Section and Ahoko Quarry Section.

Fig. 4: Outcrop section of the Patti formation exposed at Ahoko showing different lithologies.

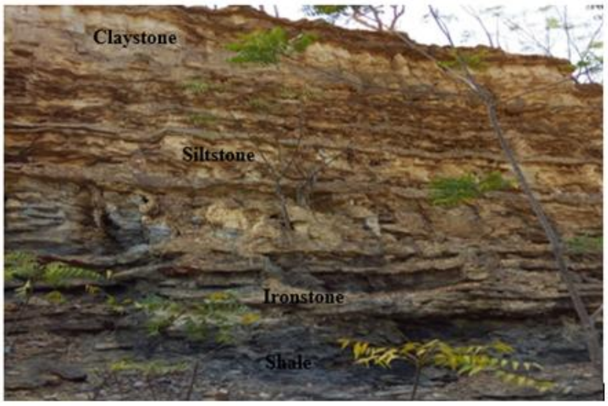


Fig. 5: (L-R) Nodular fractured shale with fractures filled with pyritic patches and presence of bioturbations.
Fig. 6: (L-R) lithofacies and massively bedded claystone at the Ahoko quarry section.

3.2 Statistical Parameters-Graphic methods

3.2.1 Graphic Mean Size (M_Z):

This depicts the average particle size or the central tendency of particles (fig. 7 – 10). Mean is calculated based on three significant percentiles on the cumulative percentage axis, the values considered are Φ16, Φ50, and Φ84 values, average of these gives the graphic mean (Folk and Ward, 1957). The values in our samples range from 2.1655 to 2.777Φ, averaging 2.472Φ (Table 1) and shows that the samples mostly 70% of the particles belong to fine grained size.

3.2.2Inclusive Graphic Standard Deviation (σ_I): This measures the sorting or uniformity of the grains indicating energy conditions that prevailed during transport and deposition. It is one of the most important parameters because it gives the effectiveness of the depositional medium in separating grains of different classes (Tucker, 1990). Sorting reflect the persistence and stability of energy condition during the depositional process meaning it is related to the ability of the transporting agent to segregate its load according to their sizes. It ranges from 1.34 – 1.887 with an average of 1.694. This is an indication of poor sorting of the sediment. The plots of mean vs sorting and skewness vs sorting indicates fluvial environment with strong variation in current velocity (fig 11).

3.2.3 Inclusive Graphic Skewness (S_{kI}): This measures the degree of asymmetry in the frequency curves in terms of predominance of fine- or coarse-grained fractions. The value of skewness in our samples ranges from -0.537Φ to -0.119Φ, with an average of -0.418 Φ (Table 1), ranging from coarsely to very coarsely skewed. A plot of skewness vs Kurtosis indicates sediments are from beach and fluvial environment (fig. 12).

3.2.4 Graphic Kurtosis (K_G):

This is the measure of peakedness of the distribution curves and it is therefore related to both sorting and degree of abnormality of the distribution. The peakedness value ranges from 0.688 to 1.177, with an average of 0.895 (Table 1). The majority of grains are platykurtic, followed by leptokurtic grains (Table 2). This shows that at major instances, tails and the central portion are equally sorted. There is only one sample which is leptokurtic which has a better-sorted central portion than the tails.

Table 1: Summary of the Grain size Analysis Results from Location Sections.

S/N	Sample No	Mean $(\bar{x})$	Sorting (σ)	Skewness (SK)	Kurtosis (K)
1	AHK B6	2.165	1.534	-0.119	0.820
2	AHK 11	2.777	1.661	-0.598	1.177
3	AHK B16	2.475	1.887	-0.537	0.688

Table 2: The Interpretation of the Grain size Statistical data from Location Sections.

S/N	Sample No	Mean $(\bar{x})$	Sorting (σ)	Skewness (SK)	Kurtosis (K)
1	AHK B6	Fine Sand	Poorly Sorted	Coarsely Skewed	Platykurtic
2	AHK 11	Fine Sand	Poorly Sorted	Very Coarse Skewed	Leptokurtic
3	AHK B16	Fine Sand	Poorly Sorted	Very Coarse Skewed	Platykurtic

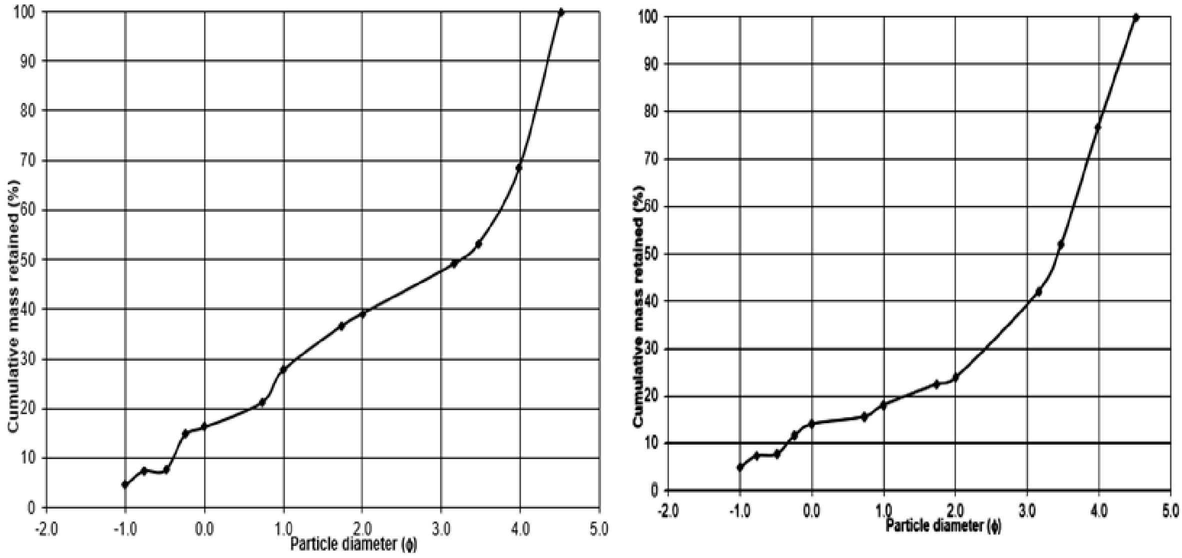
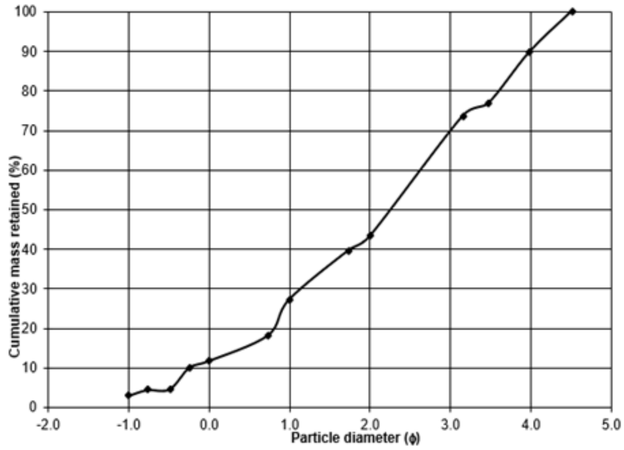
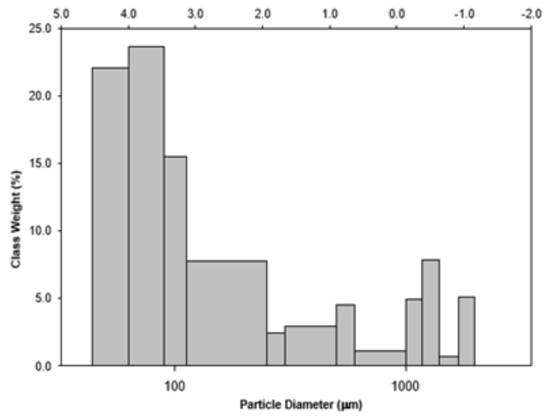


Figure 7:(L-R) Cumulative Frequency curve for Sample AHK 11 and AHK B16**.**





AHK 11 and AHK B16.

Fig. 8:Cumulative Frequency curve for Sample AHK B6Fig. 9: Histogram Plots for Sample AHK B16.

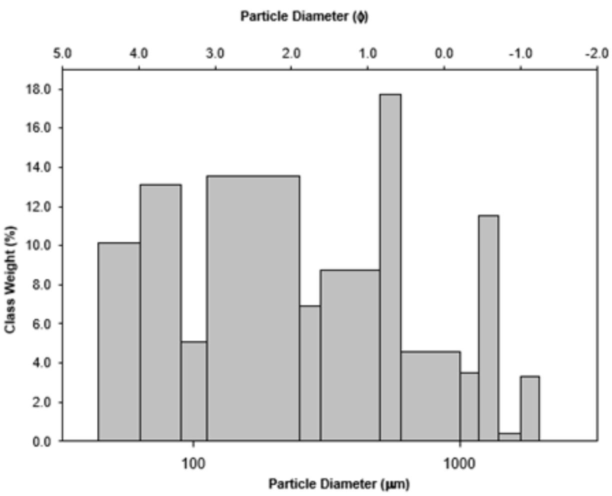


Fig.10: Histogram Plots for Sample AHK B6

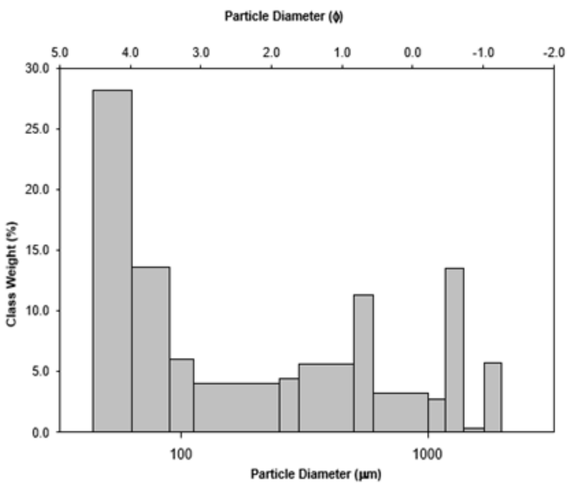


Fig. 10: Histogram Plots for Sample AHK 11.

Fig. 11: (L-R) Graph of Skewness against Sorting; Graph of Mean against Sorting (after Ojo, 2012).

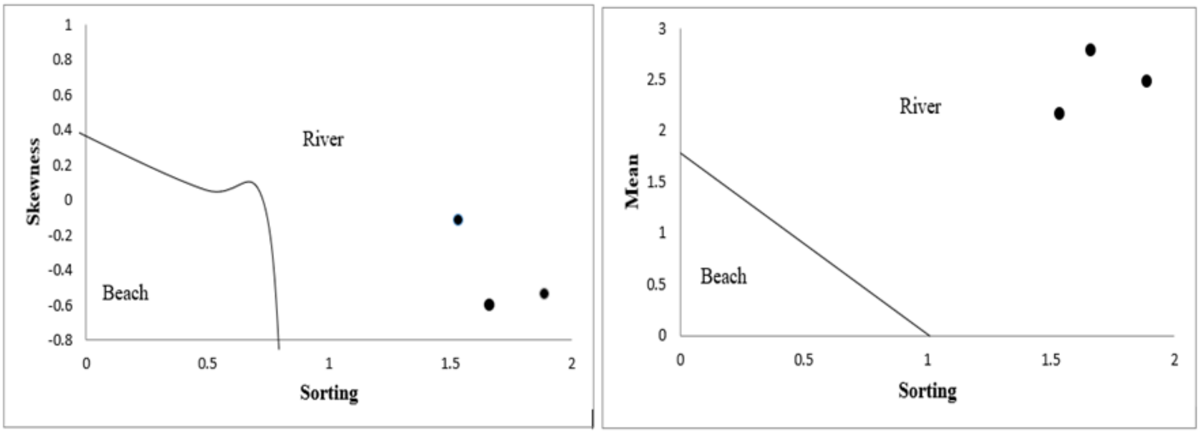


Fig. 12: Graph of Skewness against Kurtosis (after Ojo, 2012).

3.3 Petrography

Petrographic studies of twelve ironstone samples were carried out through thin section studies. These ironstones analyzed are AHK 1, AHK 3, AHK 5, AHK 17, AHK B4, AHK B8, AHK B10, AHK B14, AHK B17, AHK B20, AHK B22, AHK B24. Generally, the samples analyzed showed the abundant occurrence of siderite, goethite, quartz and clay minerals which binds these minerals together. The quartz minerals are angular to sub-round in shape. The matrix as seen in the mineralogical composition is mostly made up of clay which is believed to be sourced from degradation of another mineral (e.g., feldspar). The interparticle fluid between the pores of the ironstones during diagenesis lead to the ferruginisation of the precursor sandstones and clays in an oxidizing environment. The photomicrograph of the ironstone samples viewed under plane polarized light and cross polarized light are shown in Fig. 13 and 14 below.

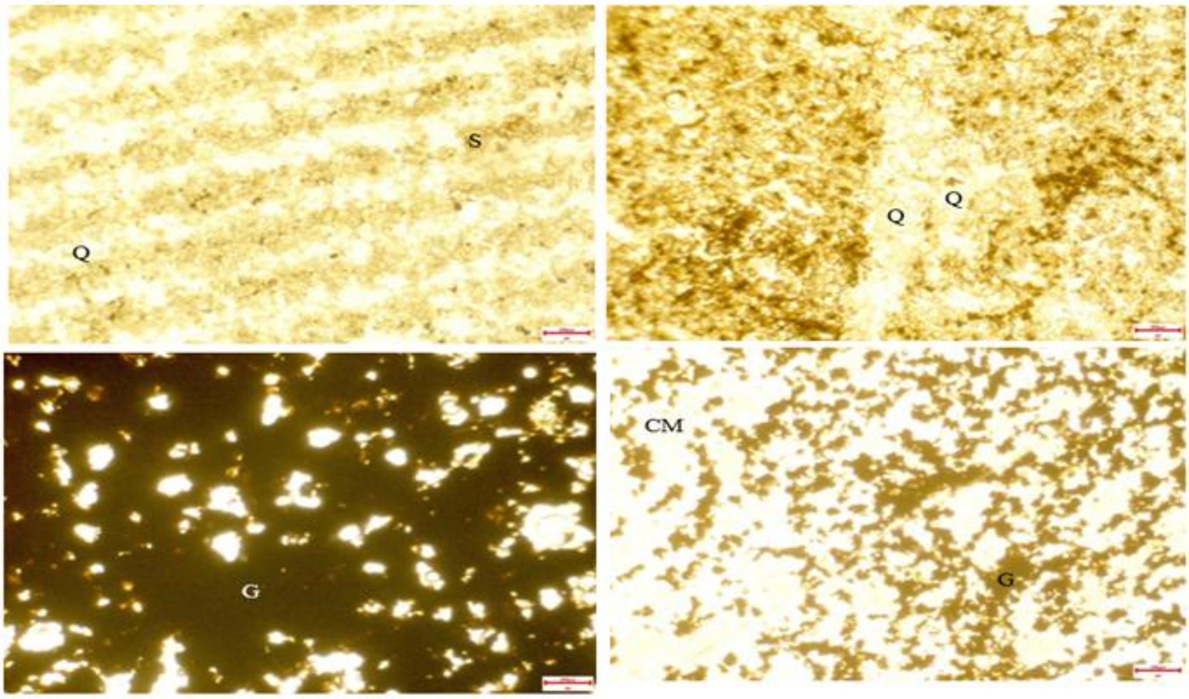


Fig. 13: Plane Polarized Light photomicrograph of Samples AHK 3, AHK 5, AHK B8, AHK B14.Q = Quartz, S = Siderite, CM = Clay Matrix and G = Goethite.

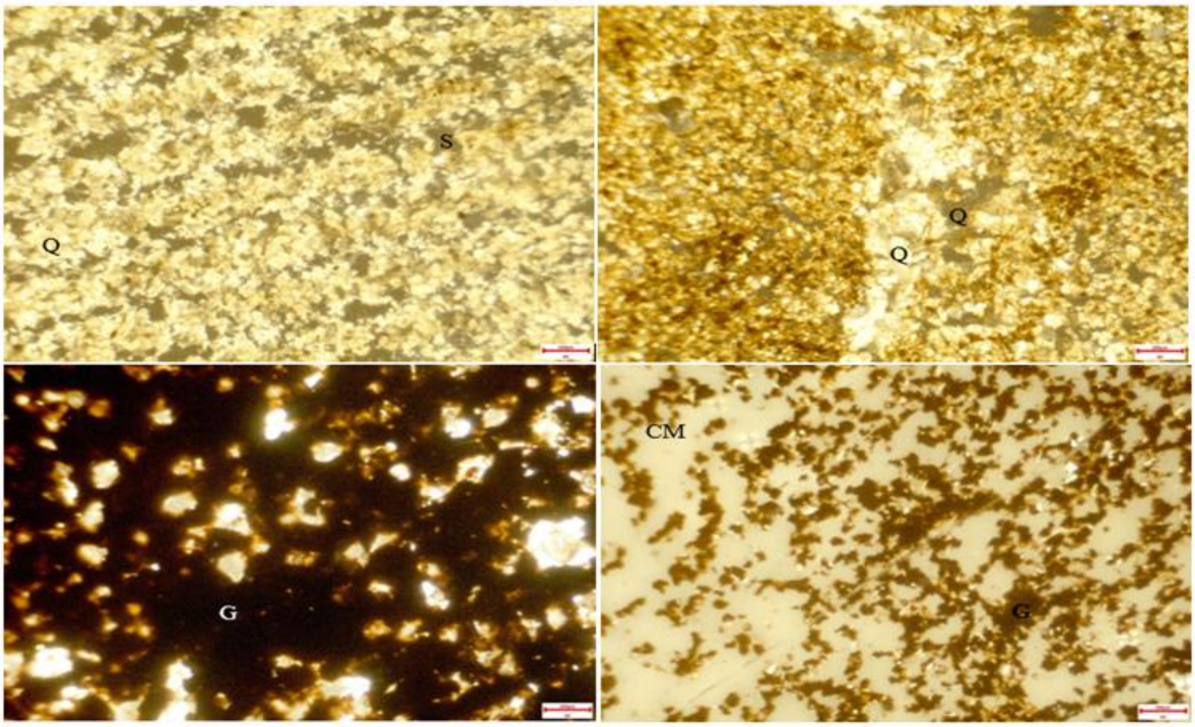


Fig. 14: Cross Polarized Light photomicrograph of Samples AHK 3, AHK 5, AHK B8, AHK B14. Q = Quartz, S = Siderite, CM = Clay Matrix and G = Goethite**.**

3.4 Foraminifera studies

Qualitative and quantitative analyses of the benthic foraminifera fauna from the Bida Basin allow detailed paleo-ecological interpretation for the investigated section and the interpretation of their depositional environments. The occurrence of foraminifera in the samples under study is generally low probably because the environment is harsh and unconducive for their adaptation, the organic nutrient is probably insufficient to support their large population and the shales generally consist of substantial percentage of silt which may also contribute to low organic nutrient. The occurrence of the benthic foraminifera species found (which are the Bolivina spp., Bulimina spp., Miliammina spp. and Textularia spp.) dominated cold, warm and temperate water depth for different parts of the section under prevalent oxic conditions with intermittent dysoxic ($0.1ml/LO_2$ to $0.5ml/LO_2$) to anoxic conditions ($< 0.1ml/LO_2$). The species found also dominated the inner neritic (7m-40m) to upper bathyal environments (~200m). Most of the species are normal marine ($32\text{-}37^{o}/_{oo}$) organisms except the Miliammina spp. which indicates unrestricted genus (salinity is slightly $< 32^{o}/_{oo}$ which is situated between marine and brackish faunas and hypersalinity is improbable). Within the investigated section, faunas at the base indicate normal-marine salinity, followed by slightly reduced salinity while in the upper part of the section, normal-marine conditions are indicated by the fauna present. The occurrence, distribution and paleo-ecological significance of the different species of the benthic foraminifera present in the shale samples are shown in Tables 3 and 4 below (KoutSoukos et al., 1990; Murray, 1991).

Table 3: Distribution of the benthic foraminifera species assemblages observed in the Ahoko section.

SAMPLE NO / SPECIES	AHK B1	AHK B3	AHK B9	AHK B15
Bolivina spp.	1			1
Bulimina spp.		1		1
Miliammina spp.		1		
Textularia spp.			1	1

Table 4: Paleoecological factors of the foraminifera species present in the Ahoko area.

Species	Water salinity (°/₀₀)	Temperature (of the bottom water)	Water depth (m)	Mode of life	Oxygen concentration (ml/L)	Environment
Bolivina spp.	32-37	Cold-Warm	100	Infauna-Epifauna	< 0.1	Inner neritic to Outer neritic
Bulimina spp.	32-37	Temperate	150	Infauna	< 0.1	Inner neritic to Outer neritic
Miliammina spp.	32- 35	Warm	250	Infauna	< 0.1	Upper bathyal
Textularia spp.	32-37	Cold-Warm	100	Epifauna	< 0.1	Inner neritc to Upper Bathyal

4.5 Total Organic Carbon (TOC)

Total Organic Carbon analysis was carried out on twelve shale samples which were collected from the Ahoko area in which five shale samples from the road cut section and seven samples from the quarry section were analyzed. Interpretation was done using standards from Javier, 1991 (Table 5). From the results, the TOC values depict that the shale samples are good to very good source rocks for hydrocarbon generation(Table 6) which ranges from 1.08wt. % to 4.07wt. %. This is due to the richness of the shale samples in organic matter which evolved in anoxic conditions at the time of deposition.

Table 5: Classic interpretations of TOC content (Jarvie, 1991).

Generation Potential	TOC in Shales (wt. %)	TOC in Carbonates (wt. %)
Poor	0.0-0.5	0.0-0.2
Fair	0.5-1.0	0.2-0.5
Good	1.0-2.0	0.5-1.0
Very Good	2.0-5.0	1.0-2.0
Excellent	>5.0	>2.0

Table 6: TOC result for the shale samples and their petroleum generation qualities.

S/N	SAMPLE NO	LOCATION	FORMATION	LITOLOGY	TOC (wt. %)	GENERATION POTENTIAL
1	AHK 2	Ahoko	Patti	Shale	4.07	Very Good
2	AHK 4	Ahoko	Patti	Shale	3.49	Very Good
3	AHK 6	Ahoko	Patti	Shale	3.97	Very Good
4	AHK 8	Ahoko	Patti	Shale	1.08	Good
5	AHK 13	Ahoko	Patti	Shale	1.84	Good
6	AHK B1	Ahoko	Patti	Shale	1.48	Good
7	AHK B3	Ahoko	Patti	Shale	1.98	Good
8	AHK B5	Ahoko	Patti	Shale	2.45	Very Good
9	AHK B7	Ahoko	Patti	Shale	1.88	Good
10	AHK B9	Ahoko	Patti	Shale	2.49	Very Good
11	AHK B11	Ahoko	Patti	Shale	2.27	Very Good
12	AHK B15	Ahoko	Patti	Shale	3.17	Very Good

IV. Conclusion

The Patti Formation within the study area consists of four lithofacies which are shale, siltstone, claystone and ironstone facies. The structures observed in the section were massive bedding, laminations, fractures, concretions and bioturbations.

Deduction from the grain size analysis and parameters indicates that siltstone samples are fine grained, poorly sorted and majorly platykurtic which suggests that they were deposited in a low energy quiet water environment probably the fluvial environment. With the occurrence of species such as, Bolivina specie, Bulimina specie, Miliammina specie and the Textularia specie the shale samples are of shallow marine sources of anoxic conditions

Deduction from the petrographic studies showed that the ironstones of the Patti Formation is composed of minerals such as siderite, goethite, quartz and clay matrix with the clay matrix serving as cementing minerals.

Results of the Total Organic Carbon analysis of the shale samples deduced an average value of 2.51 wt. % reveals that the shales are good source rocks for hydrocarbon generation. The shales are said to generate and expel hydrocarbon upon maturity

The siltstones and shales in the Ahoko section are interpreted to have been deposited in a low-energy setting, probably in a restricted body of water. The lithologies of the sections generally are fining upward sequence and it is generally believed that fluvial sequences become finer upward.

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