Communication in Physical Sciences, 2023, 9(3):288-309

Petrological, palynological analysis and Geochemistry of Maastrichtian Patti Shale in some parts of the southern Bida Basin, Nigeria: Implications for provenances and hydrocarbon studies

Godwin Okumagbe Aigbadon[1], Azuka Ocheli[2], Tope Shade Alege[1], Esther Onozasi David[1]
Received: 01 April 2023/Accepted 08 July 2023/Published 10 July 2023

Abstract*: The Patti Formations' shale and mudstones are the principal petroleum source rock of the Lokoja sub-Basin. Though only a few works on Patti Shales in the Ahoko outcrops have been published, no significant work has been done in the Agbaja-Ibaru region of the basin. Arising from the need to analyze the provenances and hydrocarbon potentials of the shales of the Patti Formation in the basin, this study used petrological, palynological, and geochemical analyses. This study will employ palynological, petrological (Scan Electron Microscope, SEM and X-ray diffractogram, XRD, X-ray fluorescence spectroscopy, XRF), and geochemical techniques to assess the sources of the basin's rock potential and depositional environment. Field observations results revealed the lithology of the Patti Formation to comprise siltstone, claystone, mudstones, and dark shales. According to the XRF results, the primary elemental oxides are SiO_2, Al_2O_3, and Fe_2O_3. The X-ray diffraction (XRD) results for all shale samples examined revealed that the principal mineral components are quartz (32-49%), kaolinite (26-38%), and illite (0.2-5.26%). The shale is classified as quartzose shale because it has a high amount of quartz. The diagnostic palynoflora association showed the occurrence of* Cingulatisporites ornatus, *Tricolporopollenites* sp., *Monocolpites marginatus, Cyathidites minor, Distaverrusporites simplex, Longapertites sp., Rugulatisporites apparatus (Campanian), Tubistephanocolpites cylindricus, Longapertites microfoveolatus, Echitriporites trianguliformis, Cyathidites minor* and Gleicheniidites sp., *indicating Maastrichtian age and predominantly Continental (Terrestrial) environment of deposition. Total organic carbon (TOC) levels range from 0.46 to 2.56%, with a mean of 1.15%. The genetic potential (GP) ranges from 0.162 to 1.235Mg/g, with a mean of 0.619Mg/g, indicating a moderate to relatively good source of the gas-rich rock. The hydrogen index (HI) varies from 7.8 to 173.9 mgHC/gTOC, with a mean of 67.29 mgHC/gTOC indicating Type III organic matter. The plots of producible hydrocarbon (S_2) against TOC and HI against maximum temperature (T_{max}) confirm the presence of type III (gas-prone) and type IV (inert) organic matter. As a result, the shale is slightly mature and successful at producing oil and gas.*

Keywords: Geochemical analyses, gaseous hydrocarbon, organic matter, microfossil, production index

Godwin Okumagbe Aigbadon
Department of Geology, Federal University Lokoja, Kogi State, Nigeria
Email: godwin.aigbadon@fulokoja.edu.ng
Orcid id: 0000-0001-6901-3123

Azuka Ocheli
Department of Geology, University of Delta, Agbor, Delta State, Nigeria.
Email: azuka.Ocheli@unidel.edu.ng
Orcid id: 0000-0003-3389-1236

Tope Shade Alege
Department of Geology, Federal University Lokoja, Kogi State, Nigeria
Email: tope.alege@fulokoja.edu.ng
Orcid id: 0000-0002-7927-3065

Esther Onozasi David
Department of Geology, Federal University Lokoja, Kogi State, Nigeria
Email: davidonozasiesther@gmail.com

1.0 Introduction

The least relatively explored in terms of Nigeria's petroleum prospectivity is the Cretaceous Bida Basin (Aigbadon *et al.*, 2022 a, 2023 b). However, a good number of works has been conducted and reported concerning the features of the basin's formation mainly from Ahoko outcropping sections and they are discussed as follows:

Obaje *et al*. (2004) and Aigbadon *et al*. (2022 a) carried out a total organic carbon (TOC) and geochemical studies on the shales of the Lokoja Sub basin. Their results they obtained suggested the existence of s a comparatively high levels of (TOC) and liptinite. The biomarker data suggest further that the hydrocarbon formation in the basin is its early stages and still sub mature and may not be expelled or migrate large quantities of hydrocarbon in the basin (Obaje et *al.*, 2004). Akande *et al.* (2005) also investigated the maceral components of the Patti Shale using incident light microscopy and geochemical analyses. They concluded that, at the current depth of outcrop occurrences, the shale source rock has a slightly fair potential for the formation of gaseous hydrocarbons and of type III/IV kerogen. The Patti Formation shale units' potential as a petroleum source was assessed by Ehinola *et al.* (2005) and they concluded that the geochemistry of the formation consits of TOC = 0.24 to 2.60 weight percent (avg. 1.5 weight percent), genetic potential (GP) values ranging from 0.78 to 2.15 mg/g, and hydrogen index (HI) values ranging from 2-100 mg/gTOC at Tmax of 410-428 ^{0}C, respectively. They also discovered that the Patti Formation Shale strata in the Bida Basin only produced gaseous hydrocarbon and contained low-grade, thermally immature organic compounds at shallow depths. Studies carried out by Ojo *et al.* (2020) to investigate the shale components of the basin using palynological and geochemical indices led to the conclusion that, based on marker bed palynomorphs the shale of the Patti Formation is Maastrichtian in age. Also, the palynological evidences obtained indicated that mangroves and a humid environment. The high total organic carbon values (0.77-8.95 wt%) recorded in the shales in the basin confirmed that the source beds most likely include a sizable amount of organic materials.

The Patti Shale outcropping at the Agbaja Ahata-Ibaru section of the Lokoja sub-Basin has rarely been mentioned /referenced, except the published work, reported by Aigbadon *et al.* (2023 c). To the best of our knowledge, much work has not been extensively reported on the Agbaja-Ahatu-Ibaru section of the basin. Little or no one has looked into the geochemistry and provenances of the shale of the basic associated with the Patti Formation . Therefore the current investigation is employing various methods to investigated this missing information concerning the basin. One of the goals of this research is to undertake a precise reconstruction of depositional history in order to achieve a realistic forecast of the source rocks. Understanding the stratigraphy, geochemistry, and depositional circumstances of the sedimentary succession is essential to the search for hydrocarbons. This study will use these criteria to evaluate the provenance, thermal maturity, paleodepositional environment, and hydrocarbon potential of the Patti Formation's shale unit in the basin. Consequently, the study was guided by the following objectives;

(i) To carry out extensive geological field mapping, petrological (XRD, XRF, and vitrinite reflectance), palynological, TOC, and rock-eval analyses on samples from selected outcrops. (ii) To evaluate the Patti Shale on Agbaja-Ahata-Ibaru outcrops, which has not received detailed investigation, and to re-evaluate the Patti Shale in Ahoko outcrop sections in the basin using the methods mentioned earlier.

1.1 Locations and Geologic Settings of the Basin

The study sections are between latitudes N070 52′ 13 ″ and N080° 23′ 23″ and between longitudes E060° 40′ 24.7″ and E060° 30′ 14″ (Fig.1).

The Bida Basin's geologic context and genesis are debatable and have been the topic of discussion over the years (Kogbe, 1983; Ojo *et al.*, 2020; Aigbadon *et al.*, 2022 c and 2023 b). It is positioned between the West African Craton and the Precambrian Northern Nigeria Massif (Braide, 1992). According to Zaborski, 1998, the basin has an axial length of about 350 km and a breadth of 75 to 150 km. Gravity investigations indicate that the sedimentary successions have a maximum thickness of about 3.5 km on the central axis (Udensi and Osazuwa, 2004). (Kogbe *et al.*, 1983; Likkason, 1993 and Adeleye, 1973) put forward three distinct tectonic models based on the genesis of the Bida trough. The models are Rift, Simple Sag, and Strike-Slip. They are Rift, Simple Sag and Strike-Slip models. The following are the geologic successions in the Bida Basin, from oldest to youngest:

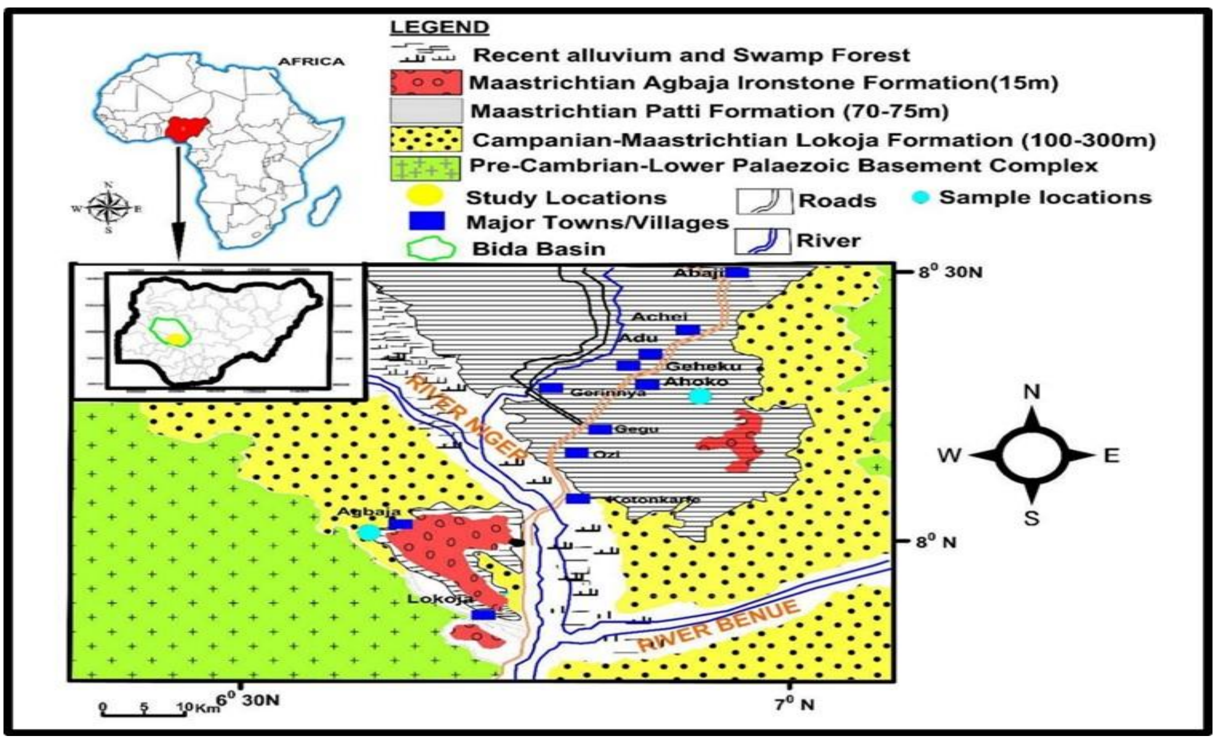

Fig.1: Geological map showing study locations (Agyingi, 1993 and Aigbadon *et al.*, 2023 b)

1.2 Lokoja Formation

In the Lokoja region, the Campanian-Maastrichtian Lokoja Formation comprises conglomerates, sandstones with various grit sizes, siltstone, and claystone with similar ages of the Bida Sandstone in the northern section of the basin. The sizes of granules are often scattered in clay matrix in the units and the conglomerate are both matrix and grainsupported. The formation of sandstone is juvenile in terms of texture and mineralogy because they are frequently weakly sorted and composed of feldspar (Adeleye, 1974).

1.3 The Patti Formation

The Maastrichtian Patti Formation is composed of sandstones, siltstones, claystone, mudstones, and shales. It has similar characteristics and age to the Enagi Formation in the north section of the trough and they are within the central part of the basin. The central regions of the basin are dominated by argillaceous units (Akande *et al.*, 2005; Aigbadon *et al.*, 2022 b).

1.4 The Agbaja Ironstone

The Maastrichtian Agbaja and Batati Ironstones operate as a shield in the basin, with the former located in the southern axis and the latter in the northern region (Braide, 1992; Aigbadon et al., 2002 b).

2.0 Materials and Methodology

Laboratory analysis and geological (field) examination were used in this study. A thorough field research was conducted to determine the different sorts of rocks and their formations. Systematic logging was done on these outcrops to produce the vertical profiles. The dark shale samples were collected from outcrops based on the depth of interest. They were placed and wrapped with paper before being covered with polythene and labelled immediately before finally placing them in the sample bags. The same approach was adopted throughout the study.

2.1 Laboratory Analysis

2.1.1 XRD Analysis

Ten (10) samples were analysed, six samples from Ahoko and four samples from Agbaja-Ibaru outcrop sections, respectively. The studied shale was ground into fine-grained (in powdery form). The prepared samples were passed through an X-ray diffraction (XRD) machine (model PW 3710) to determine the mineralogical makeup, as discussed in (Abuhagaza *et al.*, 2021)

2.1.2 XRF Analysis

Five shale samples were used for this analysis. Three samples from the Ahoko area and two samples from the Agbaja-Ibaru outcrops, respectively, were used for this analysis. Each representative shale rock sample was put into a sample cup and crushed by a disc milling machine (Genius IF Xenemetrix) to a powdery form. These prepared fine powdery samples of 3 mm thickness were passed through Xenemetrix XRF machine (model Genius IF) under 30mA, 35-40Kv in the tray at an X-ray position for 6-8 minutes to determine the oxide or elemental composition of the rock.

2.2 Palynological Analysis

All sample preparation procedures were adaptations of standard techniques employed under strict adherence to standard safety requirements (Aigbadon *et al.*, 2022; Ojo *et al.*, 2020). Wash samples underwater in a beaker and remove oily mud samples with detergent or chloroform in SOXHILET. 36% hydrochloric acid (HCI) was added to remove carbonate material and the set-up was allowed to stand for 25 minutes before decantation.. The resulting product of the sample was soaked for 24 hours in HF to remove any silicate materials through dissolution, sedimentation and decantation. To separate organic material from the samples, a few drops of zinc bromide solution, were added, stirred and centrifuged at 2000 RPM for 10 minutes. The resulting system was diluted with PVA (Polyvinyl alcohol) and distilled water to the required concentration and mounted on a microscope slide which had the following dimension: glass slides – 76mmx 26mm with coverslips – 32 x 22mm. The cover slip was turned and permanently sealed. The palynological slides were labelled after cleaning with acetone. All palynomorph species observed in the slide of each sample were recorded on separate palynological specimen logging sheets. Published international species names and scientific palynological nomenclature/charts were used after (Schranks, 1992, 1994; Fensome and

Williams, 2004; Lawal and Moullade, 1986), respectively. A light microscope photograph was prepared and included in the result and discussion section.

2.3 TOC and Rock-Eval Pyrolysis

Ten (10) investigated samples were put through TOC (Total Organic Carbon (%)) screening utilizing a LECO C230 analyser to ascertain the hydrocarbon potential of the study area. By using Rock-Eval pyrolysis analysis, the amount of residual carbon (IV) oxide formation gas (S_3), the amount of absorbed free hydrocarbons (S_1), hydrocarbons created from kerogen (S_2), and the maximum temperature of kerogen breakdown (T_{max}) were all calculated. Using the formula below, additional metrics, including the production index (PI), hydrogen index (HI), oxygen index, and genetic potential (GP), were calculated from the Rock-Eval pyrolysis data:

$$\text{Hydrogen Index (HI)} = \frac{S_2(mg|g)}{\%TOC} x100 \quad (1)$$

$$\text{Oxygen Index (OI)} = \frac{S_3(mg|g)}{\%TOC} x100 \quad (2)$$

$$\text{Production Index (PI)} = \frac{S_1}{S_1+S_2} \quad (3)$$

$$\text{Genetic Potential (GP)} = S_1 + S_2 \quad (4)$$

Equations 1, 2, 3 and 4 were applied (after Aigbadon *et al.*, 2022 a; Ocheli *et al.*, 2023). Equations 1-4 were applied to estimate the HI, OI, PI and GP of Patti Shale in Ahoko and Agbaja-Ahata -Ibaru outcrop sections.

3.0 Results and Discussion

3.1 Result

3.1.1 Lithological description

Four outcrop sections are studied within the Patti Formation (Figs. 2-5). Figs. 2 and 3 describe the lithologic units of the outcrop sections 1 and 2 at Ahoko, while Figs. 4 and 5 describe the lithologic units of the outcrop sections 3 and 4 at the Agbaji-Ahata-Ibaru axis.

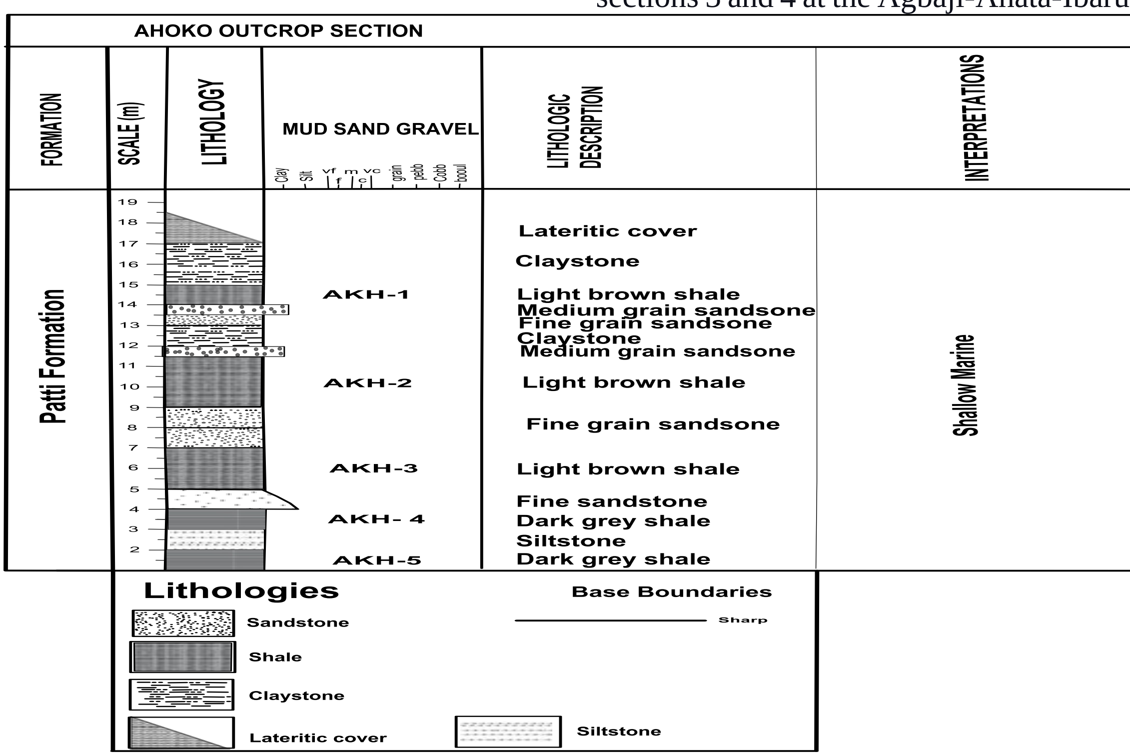

Fig. 2: Litho-section for Ahoko Outcrop

Based on the interpretations of the lithologic descriptions, the dark grey shales with intercalations of concretional ironstones in between with few siltstones, a shallow marine environment has been delineated for the Patti Formation in the Ahoko outcrop. In contrast, a swamp to the shallow marine depositional environment has been delineated for the Patti Formation in the Agbaji-Ibaru axis. Lithologic units are made up of laminated dark-grey to brownish shale, including coals seam, claystone and siltstone (Figs. 4 and 5).

The dark-grey shales are more visible at the base of the outcrop (Figs. 2 and 3 a), with the dominance of claystone facies in the outcrop (Fig 3a-b). The lithology at the Agbaja-Ahata-Ibaru axes comprises shales, mudstone, and claystone which are capped by Agbaja Ironstone at the top (Figs. 4 and 5).

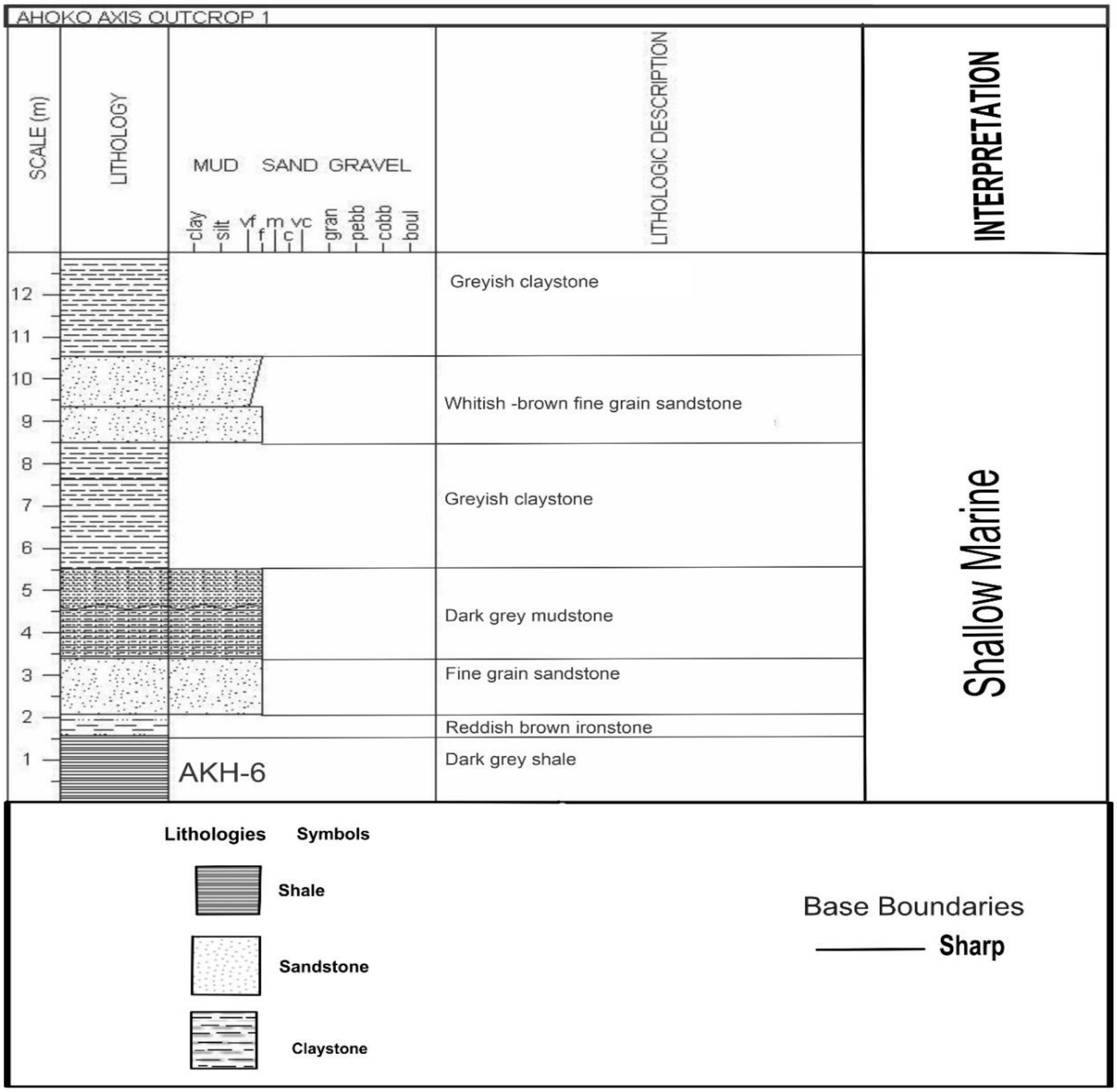

Fig. 3 a: Lithologic section for Ahoko outcrop 2

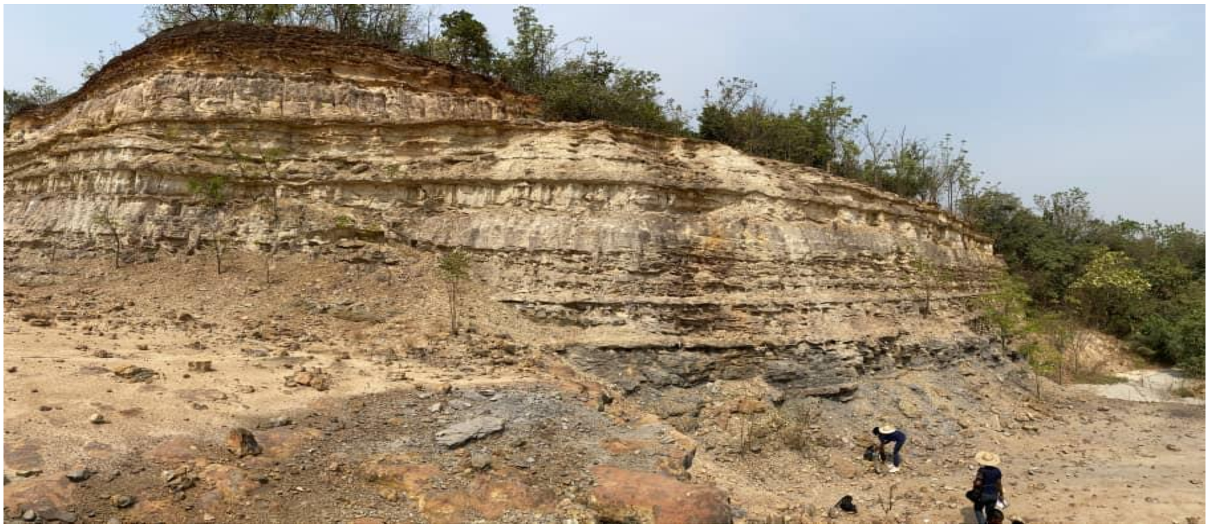

Fig. 3 b: Photography of exposed dark shale at the base of the outcrop (N 08° 18 ′ 13.4 ″ E 06° 29 ′ 0.5 ″; elevation 79.4 m).
****The dark-grey shales are more visible at the base of the outcrop (Fig.3 a and b) with the dominance of claystone facies in the outcrop.**

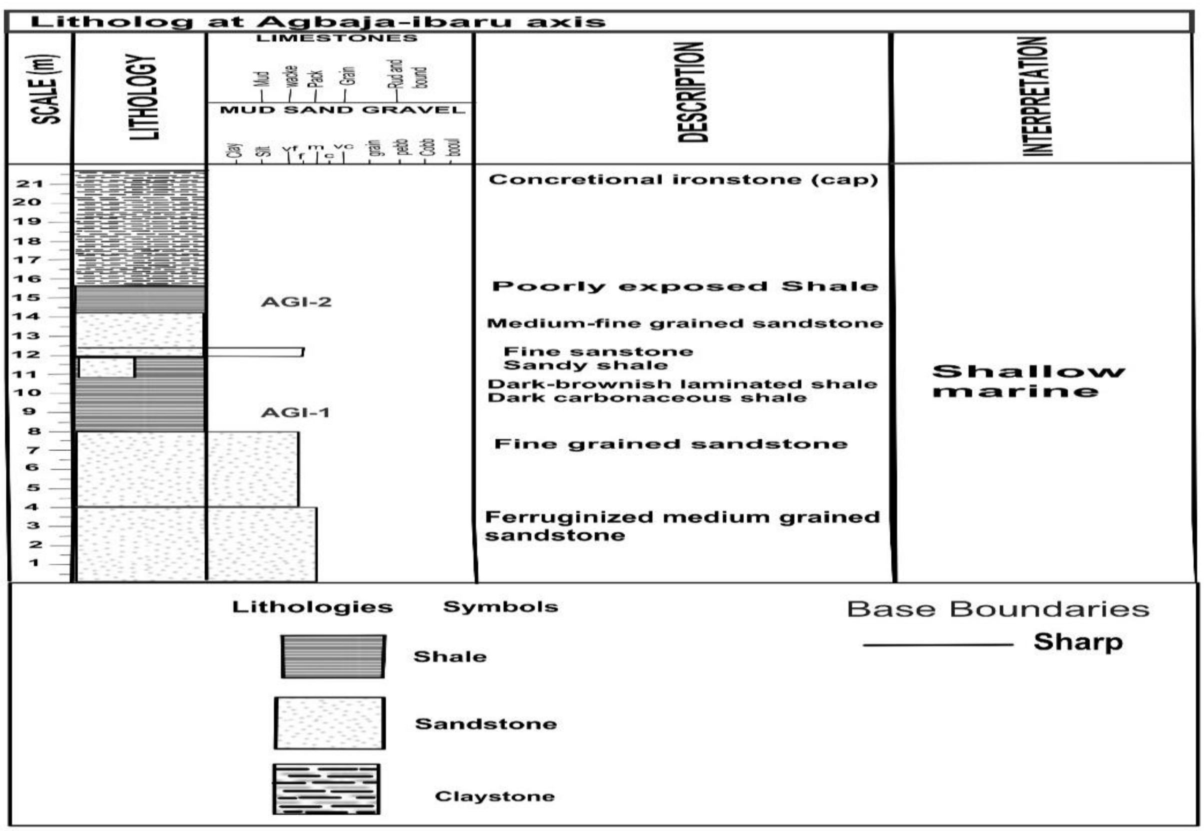

Fig. 4: Litholog and interpretation of exposure of Patti Shale, Agbaja-Ibaru axis at the Agbaja Plateau. (N 07^0 58′ 13.1″ and E 06^0 40′ 28.1″; Aigbadon *et al.*, 2023 b)

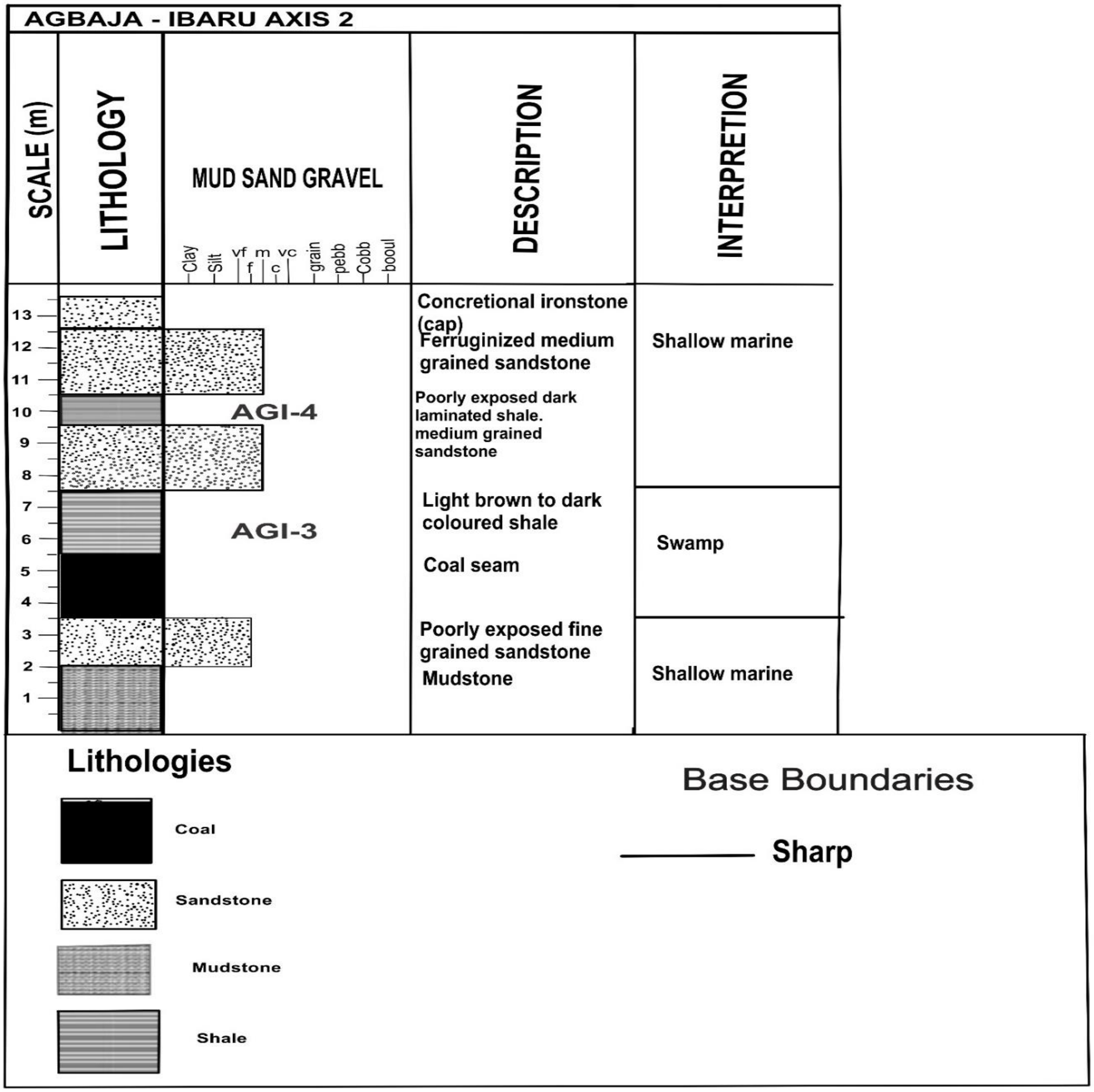

Fig. 5 : Litholog and interpretation of exposure of Patti Shale, Agbaja-Ibaru axis- 2 at the Agbaja Plateau. (N 7^0 52′ 13.4″ and E 06^0 40′ 24.7″; Aigbadon *et al.*, 2023 b)

The lithology at the Abaja-Ibaru axes comprises of shales, mudstone, and claystone which are capped by Agbaja Ironstone at the top (Figs. 4 and 5).

3.1.2. Palynomorphs recovered from outcrops section of the basin

The results show that the palynomorphs recovered from the Patti Formation in Ahoko outcrops depict a higher count in *Cyathidites* sp. and *Milfordia* sp, respectively (Table 1). The biostratigraphy revealed that the occurrence of *Longapertites microfoveolatus, Monocolpites marginatus, Echitriporites trianguliformis, Distaverrusporites simplex, Cyathidites minor,* and *Gleicheniidites* sp. diagnostic microfloral in the Ahoko outcrop suggest Maastrichtian age for the Patti Shale (Fig. 6).

Table 1: Palynonomorphs recovered from Patti shales in Ahoko outcrop sections

Sample	Palynomorphs	Type	Counts.
1-6 (AKH-1 -6)	Cyathidites sp.	S	32
	Laevigatosporites sp.	S	12
	Foveotriletes margaritae	S	15
	Cingulatisporites ornatus	S	17
	Tricolporopollenites sp.	P	3
	Longapertites microfoveolatus	P	8
	Cyathidites minor	S	24
	Monocolpites marginatus	P	18
	Echitriporites trianguliformis	P	16
	Distaverrusporites simplex	S	10
	Longapertites sp.	P	8
	Monoporites annulatus	P	18
	Cyathidites australis	S	5
	Retibrevitricolporites triangulates	P	9
	Milfordia sp.	P	20
	Inaperturopollenites sp.	P	8
	Proxapertites cursus	P	8
	Gleicheniidites sp.	S	8

Table 2: Palynomorphs recovered from Patti Shale in the Agbaja-Ahata-Ibaru outcrop section.

Samples	Palynomorphs	Type	Counts.
7-10 (AGI 1- 4)	*Cingulatisporites ornatus*	S	17
	Monocolpites sp.	P	8
	Longapertites sp.	P	4
	Cyathidites minor	S	23
	Foveotriletes margaritae	S	12
	Retitricolporites sp.	P	1
	Distaverrusporites simplex	S	10
	Psilatricolporites crassus	P	12
	Echitriporites trianguliformis	P	8
	Rugulatisporites caperatus	S	02
	Verrutricolporites irregularis	P	10
	Diatom frustules	DF	6
	Tubistephanocolpites cylindricus	P	10
	Laevigatosporites sp.	S	12
	Monoporites annulatus	P	12
	Inaperturopollenites sp.	P	8
	Monocolpites marginatus	P	10

The palynological result further revealed that the occurrence of *Psilatricolporites crassus* and *Verrutricolporites irregularis* suggest Palaeocene age for the beds in the Agbaja-Ibaru axis. The biostratigraphy of the palynoflora association of *Psilatricolporites crassus, Verrutricolporites irregularis Cyathidites minor, Distaverrusporites simplex, Longapertites* sp., *Echitriporites trianguliformis, Cingulatisporites ornatus, Rugulatisporites caperatus* (Campanian), *Tubistephanocolpites cylindricus* suggest (?) Campanian - Paleocene age for the Patti Shales in the Agbaja-Ibaru outcrop sections (Table 2; Fig. 6).

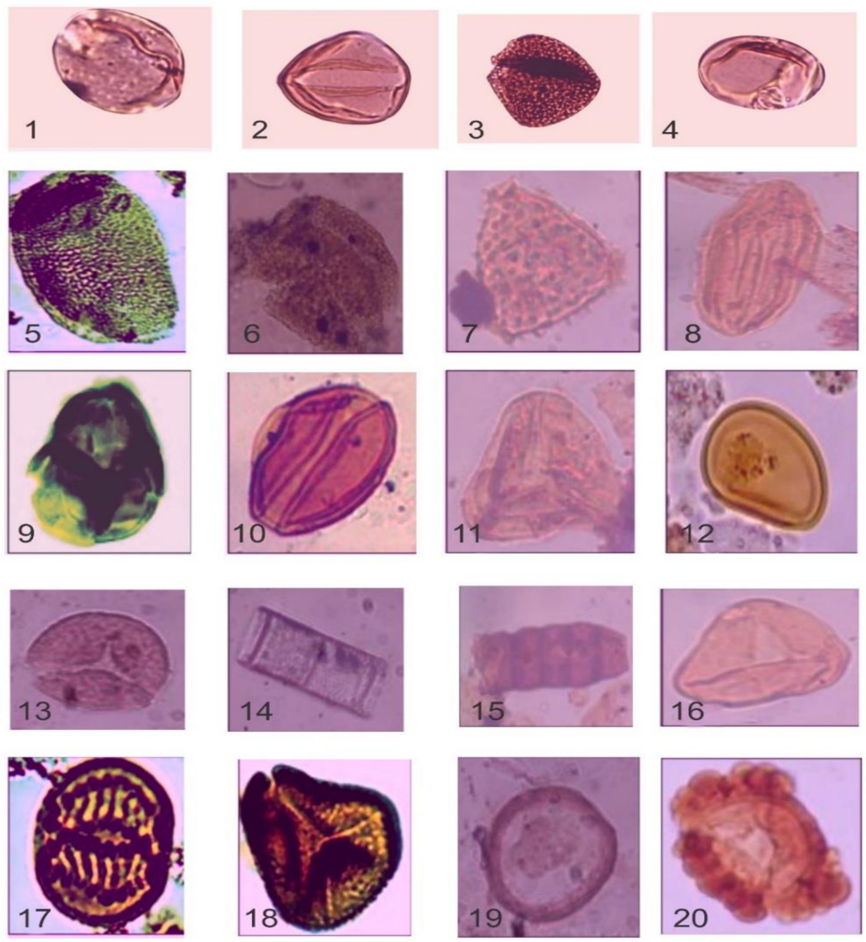

Fig. 6: Showing palynomorphs (1 - 20) recovered from the outcrops in the studied area (Aigbadon *et al.*, 2023 b)

1. Arecipites sp × 400, 2 – 3. Acritarchs of Polipodiaceosporites retigularis × 400, 4. Rotverrusporite granularis × 400, 5. *Longapertites marginatus* × 400, 6. *Longapertites sp.* × 400, 7. *Echitriporites trianguliformis* × 400, 8. *Tricolporopollenites* sp. × 400, 9. *Monocolpites marginatus*× 400 10. *Gleicheniidites* sp. × 400, 11. *Laevigatosporites* sp. × 400, 12 -13. *Rugulatisporites caperatus* × 400, 14. *Diatom frustules* × 400, 15. *Fungal spores* × 400, *16.* C*yathidites minor* × 400, 17. *Tubistephanocolpites cylindricus* × 400, 18. *Foveolatus margaritae* × 400, 19. *Cingulatisporites ornatus* × 400, 20. *Distaverrusporites simplex* × 400.

Table 3: XRD mineralogical results of the Patti Shale in studied locations in southern Bida Basin, Nigeria

S/N	1	2	3	4	5	6	7	8	9	10
FM	**Patti Fm**	**Patti Fm**	**Patti Fm**	**Patti Fm**	**Patti Fm**	**Patti Fm**	**Patti Fm**	**Patti Fm**		
Sample No	**AKH 1**	**AKH 2**	**AKH 3**	**AKH 4**	**AKH 5**	**AKH-6**	**AGI 1**	**AGI 2**	**AGI 3**	**AG 14**
Quartz%	32.0	30.0	32.0	39.0	38.0	40.9	34.0	39.0	36.0	35.0
Kaolinite%	26.0	28.0	27.0	28.0	20.0	29.7	15.0	10.0	23.0	28.0
Illite%	6.5	5.9	4.6	3.0	7.0	5.3	4.7	9.0	2.0	1.0
Osmulite%	2.0	5.0	4.8	6.4	7.2	0.2	2.4	5.0	2.0	4.0
Orthoclase%	4.0	3.0	3.2	4.0	0.8	12.7	8.0	6.0	11.0	3.0
Haematite%	14.0	12.0	8.5	9.5	32.0	1.3	12.0	6.7	9.0	12.0
Chlrorite%		5.0	4.7	3.2	6.4	1.0	6.0	5.0	2.0	5,9
Garnet%	9.9	7.1	14.6	5.9	5.2	3.4	11.5	9.3	12.0	10.1
Muscovite%	6.2	4.0	0.6	1.0	7.0	6.5	6.4	10.0	3.0	1.0

AKH 1 - 5 samples (Patti Shale from Ahoko outcrop 1 and 2); AGI 1 - 4 samples (Patti Shale from outcrops at Agbaja plateau; FM- Formation.

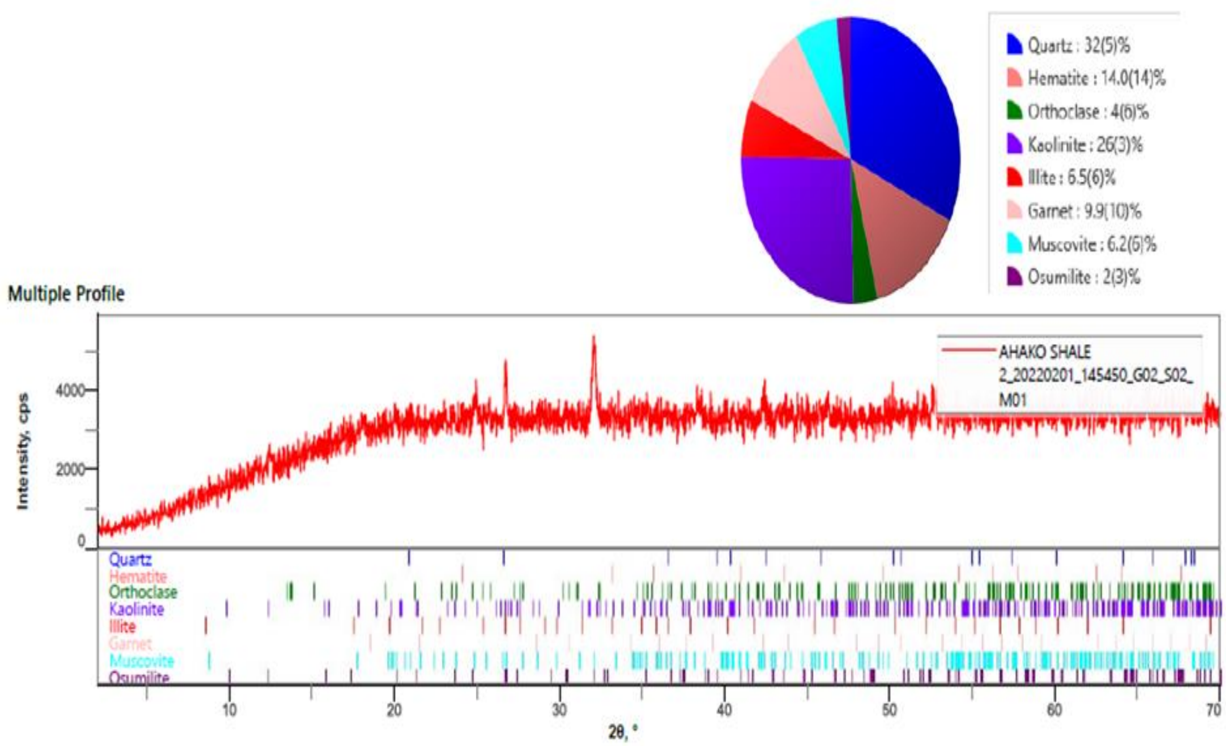

Fig.7: Mineralogical composition of Patti Shale in Ahoko outcrop

The XRD values revealed that quartz range from 32-39% with clay mineral fraction of kaolinite (20 -28%) and illite (3 -7 %) in the shales in the Ahoko outcrop units; AKH 1 - 6 (Table 3). The presence of haematite (3.2 – 14%) revealed the presence of iron material in the shale of the Patti Formation at the Ahoko Outcrop area.

The mineralogical composition of the shale in the Patti Formation in Ahoko outcrop shows that the shale consists of the following minerals; quartz 32%, kaolinite 26%, hematite 14%, garnet 9.9%, illite 6.5%, muscovite 6.5%, orthoclase 4%, and osumilite 2%. The dominant minerals present in Patti Shale in the Ahoko outcrop section are quartz and kaolinite (Fig.7; Table 3).

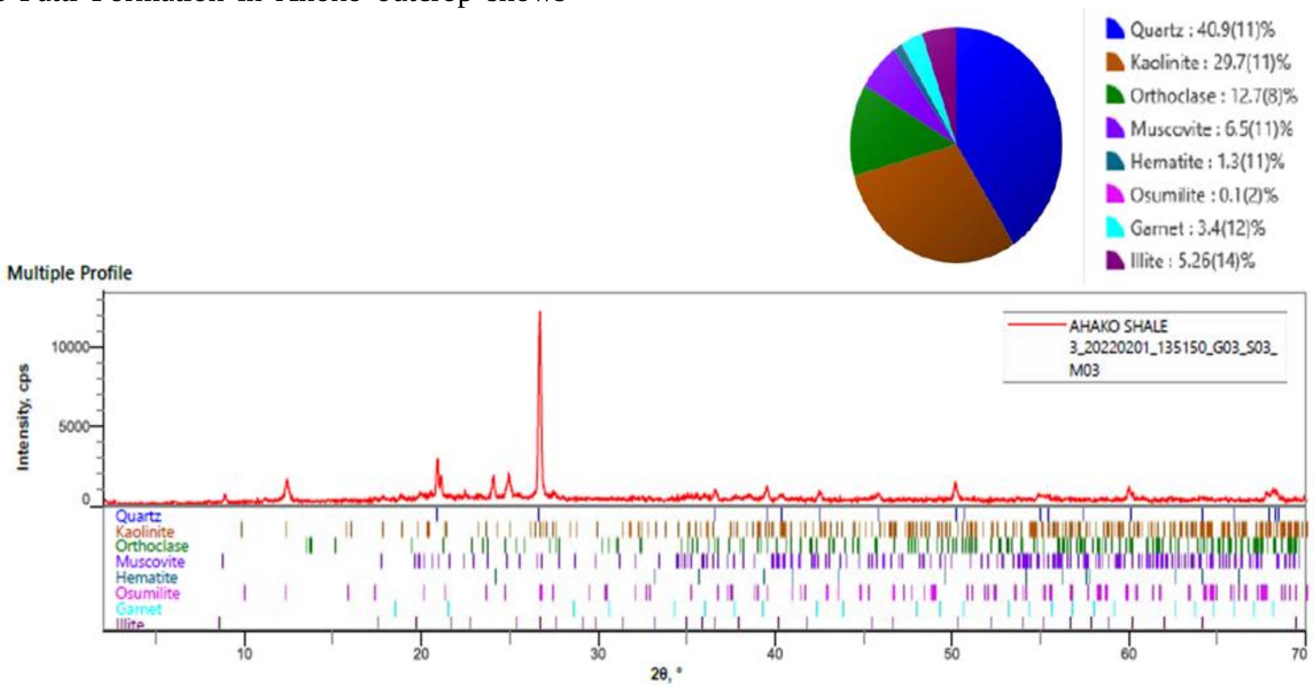

Fig.8: Mineralogical composition of Patti Shale in Agbaja-Ibaru outcrop

From table 3, the shale of Patti Formation at Agbaja-Ibaru (AGI 1-3) contains 34.- 40.95% of quartz, kaolinite of 10- 29.7%, illite 1-9%; haematite of 1.3-12%. The predominant minerals are quartz and kaolinite which are similar to the Ahoko outcrop section in the basin. The presence of haematite in the study area indicates that the shale is interbedded iron within the Patti Formation in the basin (Table 3; Fig.8).

3.1.3 XRF Result

The result of the (XRF) reveals the presence of the following major and minor elements in terms of their oxides in weight percent. They are SiO_2 (54.35-62.10Mg/cm^2), Al_2O_3 (10.64-24.44 Mg/cm^2), Fe_2O_3(2.28-3.48 Mg/cm^2), MgO (0.01-0.13 Mg/cm^2), CaO (0.02-0.07 Mg/cm^2), K_2O (0.14-2.40 Mg/cm^2), CuO (0.03 -0.05 Mg/cm^2), SO_3(2-2.67 Mg/cm^2), ZnO (0.02-0.04 Mg/cm^2) and the trace element is ZrO_2(0.02-0.33 Mg/cm^2) in the Patti Shales in the Ahoko outcrops (AKH 1,2 and 5). The Patti Shale in Agbaja-Ibaru areas (AGI 1 and 4) display SiO_2 (24-28.63Mg/cm^2), Al_2O_3 (06 - 10.83 Mg/cm^2), Fe_2O_3(3.-4.6 Mg/cm^2), MgO (0.01-0.11 Mg/cm^2), CaO (0.06-0.57 Mg/cm^2), K_2O (0.38-0.54 Mg/cm^2), CuO (0.08-0.09 Mg/cm^2), SO_3(0.12-0.16 Mg/cm^2), ZnO (0.03-0.05 Mg/cm^2) and trace element ZnO_2 (0.01-0.03Mg/cm^2). The percentage elemental oxide composition is relatively higher in the Patti

Shale in the Ahoko outcrop than Agbaja Ibaru outcrop section in the basin, except in the values CaO and CuO that are higher in the Agbaja-Ahata -Ibaru outcrop section than in the Ahoko areas. (Table 4 a and 4 b).

Table 4 a: XRF elemental result for Patti Shale in Ahoko (AKH 1, 2 and 5) and Agbaja Ibaru (AGI 1 and 4) outcrops sections.

Elements	AKH 1(Patti Fm) (Mg/cm^2)	AKH 2(Patti Fm) (Mg/cm^2)	AKH 5(Patti Fm) (Mg/cm^2)	AGI 1 (Patti Fm) (Mg/cm^2)	AG1 4(Patti Fm) (Mg/cm^2)
Al	12.33	5.33	13.44	12.20	12.08
Si	29.03	27.45	24.75	13.44	08.12
P	0.00	0.03	0.08	1.34	0.01
S	0.54	0.00	0.05	0.06	0.01
ClO_2^-	0.53	0.43	0.34	0.48	0.32
K	2.03	0.42	1.04	0.31	0.25
Ca	0.053	0.02	0.03	4.11	0.66
Ti	2.06	0.63	0.27	2.63	0.63
Fe	2.44	1.40	0.70	2.08	1.60
Zn	0.006	0.01	0.22	0.022	0.021

****AKH 1, 2, 5 samples (Patti Shales in Ahoko outcrop section), AGI 1, 5 samples (Patti Shale in Agbaja-Ahata-Ibaru outcrop sections).**

Table 4 b: XRF result showing concentrations of oxides in (Mg/cm^2) of Patti Shales at all outcrop locations.

Oxides	AKH 1 (Patti Fm) Mg/cm^2)	AKH 2 (Patti Fm) (Mg/cm^2)	AKH 5(Patti Fm) (Mg/cm^2)	AGI 1 (Patti Fm) (Mg/cm^2)	AGI 4 (Patti Fm) (Mg/cm^2)
SiO_2	62.10	59.92	54.35	28.63	**24.00**
Fe_2O_3	3. 42	3.48.	2.28	4.60	**3.00**
CuO	0.05	0.03	0.05	0.84	0.09
SO_3	2.67	2.000	2.11	0.160	0.120
CaO	0.07	0.02	0.02	5.76	0.06
MgO	0.01	0.01	0.13	0.01	0.11
K_2O	2.40	1.60	0. 14	0.38	0.54
Al_2O	24.44	10.62	20.28	10.83	06.00
ZnO	0.04	0.02	0.02	0.03	0.05
ZrO_2	0.33	0.20	0.02	0.03	0.01
ClO_2^-	0.53	0.43	0.34	0.48	0.30

AKH 1, 2, 5 samples (Patti Shales in Ahoko outcrop section), AGI 1, 5 samples (Patti Shale in Agbaja-Ahata-Ibaru outcrop sections)

3.1.4 Hydrocarbon Potential Result

The result for the sample obtained from the hydrocarbon potential indices is presented in Table 5, and the several plots derived for further interpretation are shown in Figs. 9-12.

Table 5: TOC, Rock-Eval Pyrolysis data of the shale in the Study Area

Sample	Formation	TOC (%)	S1 (Mg/g)	S2 (Mg/g)	S3 (Mg/g)	Tmax (°C)	GP (Mg/g)	HI (mgHc/g rock)	OI(mgHC/g rock)	PI	Rating
AKH 1	Patti Fm	0.80	0.042	0.18	0.34	435	0.222	22.5	42.50	0.189	IM/M
AKH 2	Patti Fm	0.82	0.035	0.13	0.60	437	0.165	15.8	73.17	0.212	IM/M
AKH 3	Patti Fm	1.90	0.045	0.15	1.20	420	0.195	7.8	63.16	0.230	IM/M
AKH 4	Patti Fm	2.00	0.035	1.20	1.30	420	1.235	60.0	65.00	0.028	IM
AKH 5	Patti Fm	2.56	0.040	0.82	1.36	422	0.860	173.9	53.10	0.046	IM
AGI 6	Patti Fm	0.46	0.025	0.80	0.13	422	0.825	30.2	28.26	0.030	IM
AGI 1	Patti Fm	0.54	0.032	0.13	0.08	432	0.162	24.0	14.81	0.197	IM/M
AGI 2	Patti Fm	0.50	0.036	0.71	0.13	435	0.746	142.0	26.00	0.048	IM
AGI 3	Patti Fm	0.90	0.060	0.91	0.18	428	0.910	101.1	20.00	0.018	IM
AGI 4	Patti Fm	0.98	0.054	0.92	0.19	427	0.974	93.8	19.39	0.055	IM
	Minimum	0.46	0.025	0.13	0.13	420	0.162	7.8	14.81	0.018	
	Maximum	2.56	0.060	1.20	1.36	437	1.235	173.9	73.17	0.230	
	Average	1.15	0.040	0.59	0.54	427.8	0.619	67.29	40.53	0.105	

where IM = immature and M = marginal, AKH1 to 6 shales indicates Patti Shale in Ahoko outcrop units, AGI 1 to 4 indicates Patti Shale in Agbaja - Ahata - Ibaru Outcrop units.

TOC result revealed that the shales of Patti Formation fall between 0.046-2.30% in the Ahoko (AKH 1-6) outcrop while 0.018-0.197% in the Agbaja-Ibaru outcrop (AGI 1-4). The S_1, S_2, and S_3 are the determinant factors for the production index, the S_1 value range from 0.002-0.06, the S_2 range from 0.13-1.20, S_3 range from 0.13-1.36 and T_{max} values ranges from 420-435^{O}C. The generating potential (GP) is higher in Patti Formation in the Ahoko area; AKH 1-6 (0.165-1.235mg/g) than Agbaja-Ahata -Ibaru outcrops; AGI 1-4 (0.825-0.974mg/g). The production Index ranges from 0.04-0.230 in the Ahoko outcrop is slightly greater than PI (0.018 -0.197) in the Agbaja- Ahata-Ibaru. HI (7.8-173.9 mgHc/grock), OI (42.50-73.17mgHc/grock) in the Ahoko outcrop is relatively greater than HI (24.0-101mgHc/grock.), OI (19.39-28.26 mgHc/grock) in Patti Shales at the Agbaja-Ibaru outcrop section in the basin (Table 5).

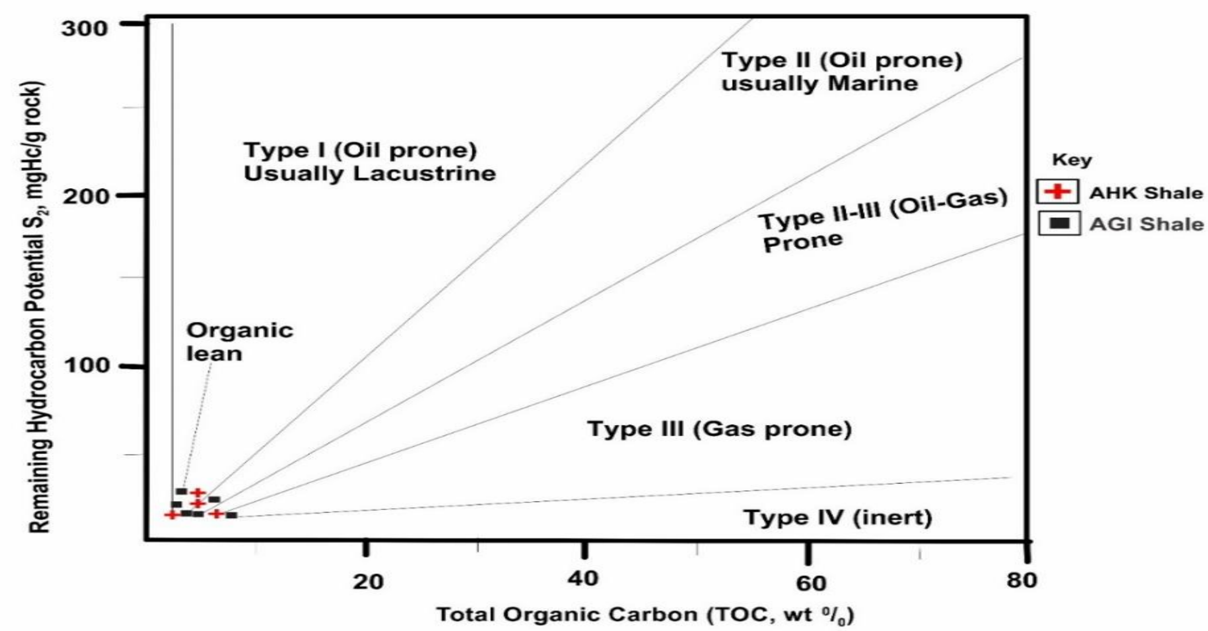

Fig. 9: Plot of Hydrocarbon produced from Kerogen (S_2) against total organic carbon (TOC). The plot of S_2 against TOC indicated that the organic matter deposited is from lacustrine-marine sources and the kerogen of the type is from oil-gas prone kerogen (Fig.9).

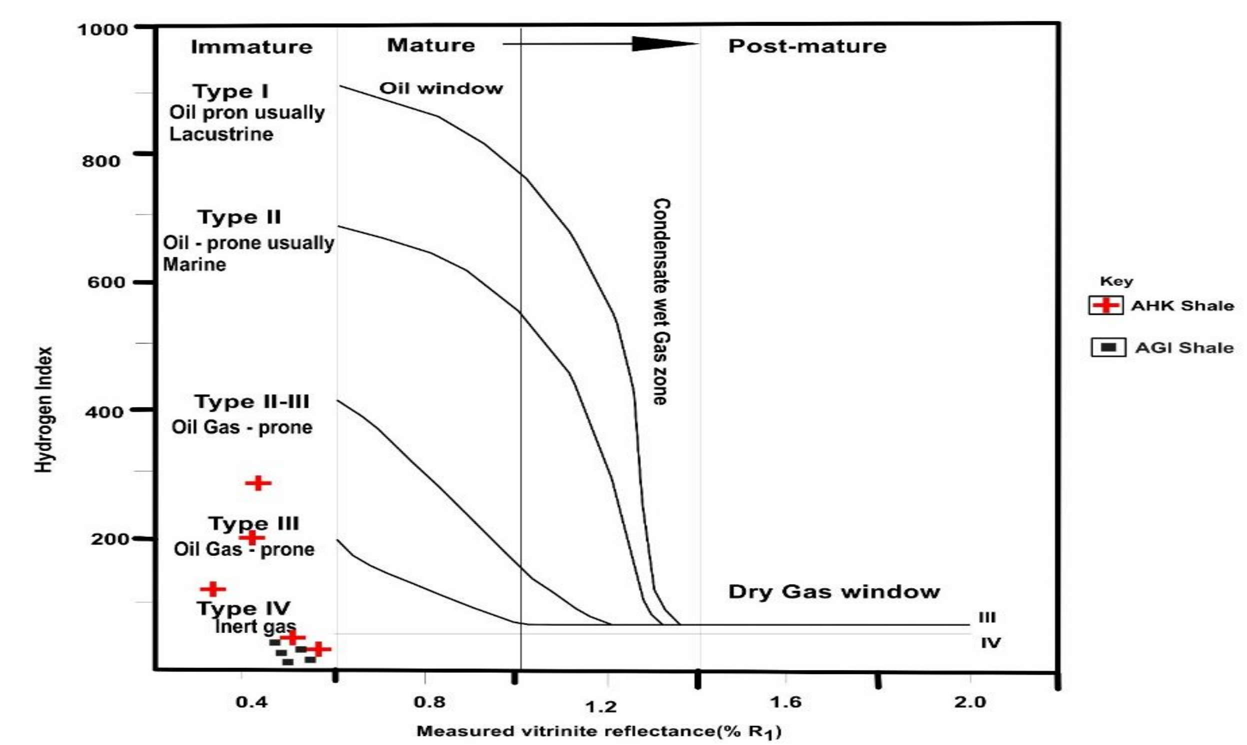

Fig. 10: Plot of (HI) against vitrinite R_1 of the shale samples in the basin. Most of the samples are immature and are of type III-IV kerogen (gas prone) mainly of vascular-sourced organic matter.

The plot of HI against R_1 shows that the Patti Shale falls between kerogen Type 11-1V (Fig.10) in all the outcrops. This also revealed that the hydrogen index value is relatively higher in the Ahoko area (AKH 1-6) from the plot (Fig.10) compare to the ones at the Agbaja-Ibaru-Ahata axis (AGI 1-4).

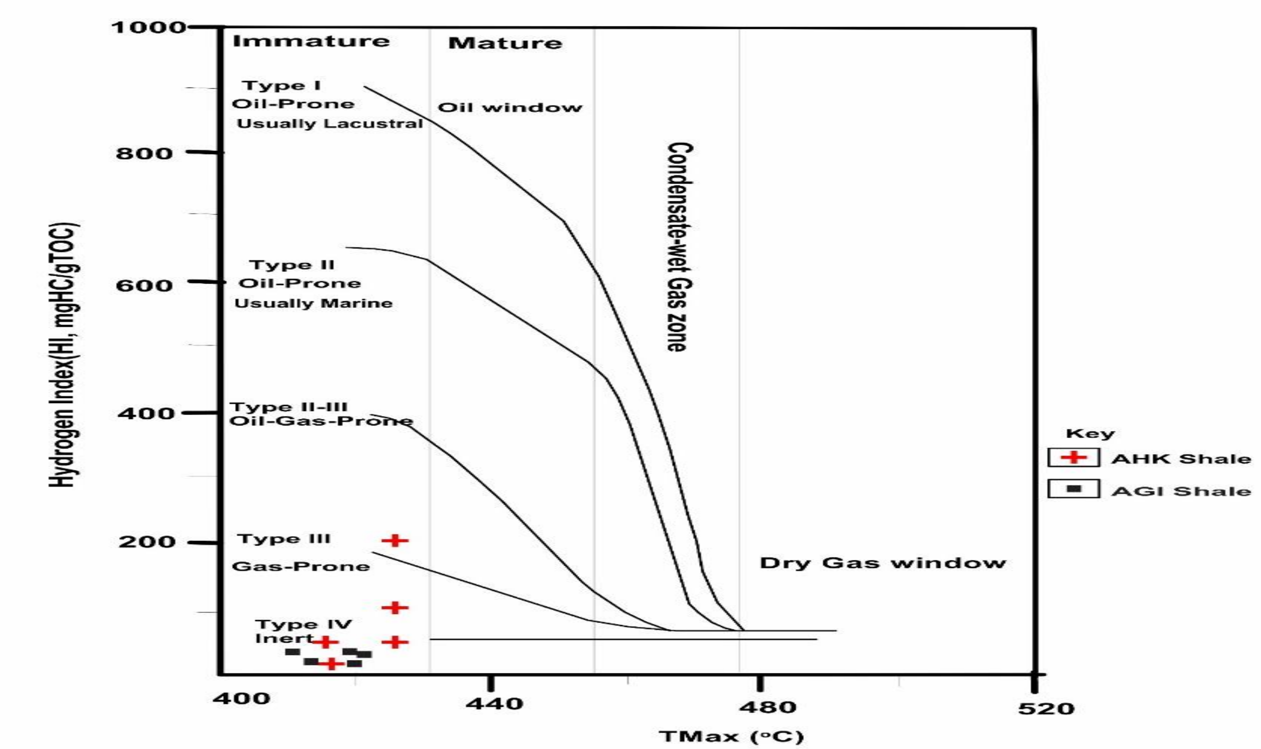

Fig. 11: Plot of hydrogen index (HI) against T_{max}

The plot of HI against T_{max} shows that the kerogen in the shale falls between Type III-IV and is majorly gas prone, with some at the oil window in all the locations (Fig.11). This also correlates with the results of the plots of the plot of HI against $R_{1,}$ indicating type II-IV kerogen.

The plot of PI against Tmax reveals a relatively low-moderate-level conversion in the Patti Shales at both Agbaja-Ahata -Ibaru and Ahoko outcrop sections respectively.

3.2 Discussion

The result from the litho-logs for the exposures of the Patti Formation reveals that the formation at each outcrop consists of sandstones, claystone, mudstone, siltstones, and shale. The shales and mudstones are dark-greyish. Shales are classified as quartzose, feldspathic, or micaceous shale, depending on the predominance of the mineral's quartz, feldspar, or mica, respectively. The X-ray diffraction (XRD) result for the samples analysed shows that the Patti Formation shale is classified as quartzose shale since all the shales contain a high percentage of quartz. Okeke and Okugbue (2011) state that clay minerals such as illite, kaolinite, and chlorite occur in non-marine (continental) environments. Therefore, the presence of kaolinite and illite in all the shales suggests that the shale is rich in clay minerals and derived from continental sources. The presence of haematite (Fe_2O_3) confirmed that presence of concretional iron interbedded within the shale of the Patti Formation. This agrees with the published works of (Obaje *et al.*, 2011; Akande *et al.*, 2005; and Aigbadon *et al.*, 2022 b, c).

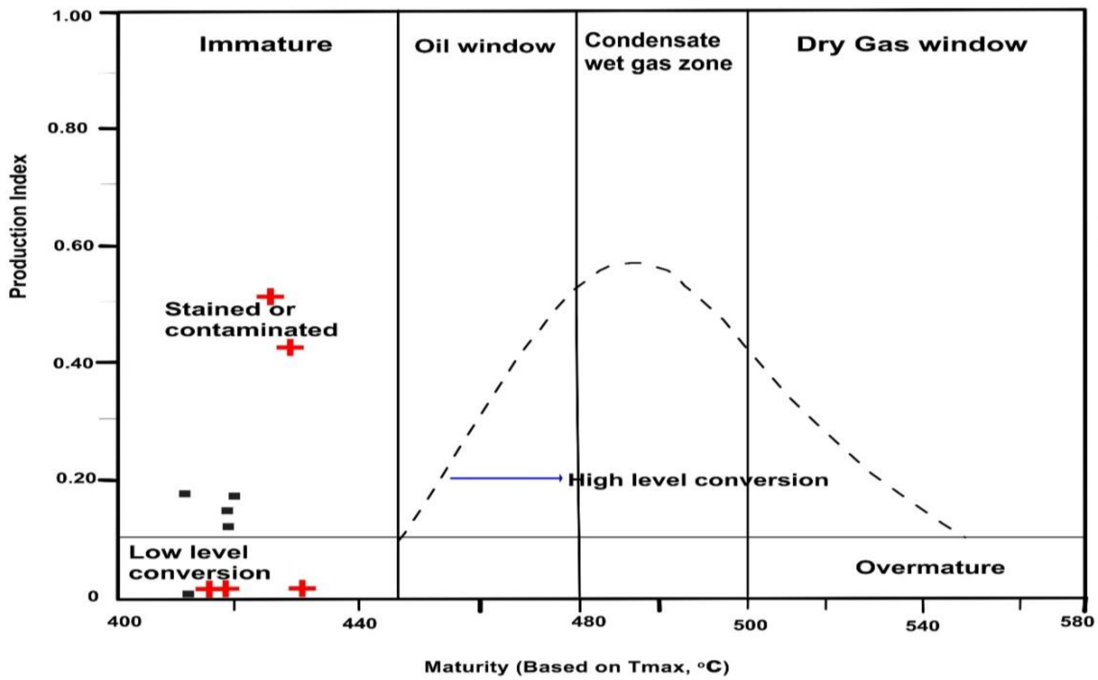

Fig. 12: Plot of production index (PI) against Tmax

In establishing the age and the paleoenvironment of deposition of the Patti Formation shales, the occurrence of significant stratigraphic species (marker species) and diagnostic palynoflora association such as *Psilatricolporites crassus, Verrutricolporites irregularis, Cyathidites minor,* Monocolpites *marginatus,* suggest (?) Campanian - Palaeocene age for the Patti Shales in the Agbaja-Ibaru outcrop sections deposited in a continental (terrestrial) environment. These correspond with the study by Lawal and Moullade,1986 (Fig. 6). The *Psilatricolporites crassus* and *Verrutricolporites irregularis,* which are Palaeocene marker beds in the Agbaja-Ibaru axis indicate a Palaeocene age and this correlate published works of (Ola-Buraimo and Adulganiyu, 2017 and Onuigbo *et al.*, 2016).

The abundance of Cyathidites minor, Distaverrusporites simplex, Longapertites sp., Echitriporites *trianguliformis, Cingulatisporites ornatus*, *Rugulatisporites caperatus* (Campanian), Tubistephanocolpites cylindricus, microfoveolatus, Monocolpites marginatus and Gleicheniidites sp. in Ahoko outcrop sections (Fig. 6) indicate Maastrichtian age and a predominantly terrestrial paleo environment of deposition with possible open forest vegetation for Patti-Shale in Ahoko outcrop section. This supports the works of (Obaje *et al.*, 2004; Akande *et al.*, 2005; Obaje *et al.*, 2011; Ojo *et al.*, 2020).

The TOC values of 0.46-2.56% with an average value of 1.15% were recorded in both the Ahoko and Agbaja Plateau outcrop sections. As Killops and Killops (1993) and Hunt (1996 a, b) state, the minimum TOC value defining a good source rock is 0.5 % for shale. The TOC values range from 1.5% to 2 %, indicating a good source rock for the Patti Formation. The shale's genetic potential (GP) value ranges between 0.162-1.235Mg/g, with an average value of 0.619Mg/g in both outcropping units at Ahoko and Agbaja-Ibaru. This value indicates a fair source rock as the potential genetic values greater than 2 mg/g is required for a potential source rock (Hunt, 1996a, b; Peters *et al.*, 2005). The hydrogen index (HI) value ranges for the shale samples from 7.8-173.9mgHC/gTOC with an average value of 67.29 mgHC/gTOC. HI less than 200 mgHC/gTOC indicates Type III organic matter (Hunt, 1996 a, b). This implies that the shale samples in the Patti Formation are dominantly kerogen Type III. The plot of S_2 against TOC (Fig. 9) and the plot of HI against OI (Fig.10) suggest Type II (oil-gas-prone) and type IV (inert), and this means the shale is immature-marginally matured and capable of mainly producing gas with little oil. The plot of HI against T_{max} (Fig.11) also indicates Type III (gas-prone) and type IV (inert) organic matter, with some of the shale samples that fall on the oil window. The production index (PI) results range from 0.018-0.230 with an average value of 0.105. This shows that almost all the shale of Patti Formation falls between low to moderate PI field (Fig. 12). The production index (> 0.1) in the shales at both outcrops also supports that the production index is high. Hydrocarbon can be expelled from the shale at favourable temperatures.

4.0 Conclusion

The southern Bida Basin's four exposed outcrops of the Patti Formations were investigated, and samples were taken for palynology, TOC and Rock-Eval, X-ray fluorescence (XRF) and X-ray diffraction (XRF) investigations. The Patti Formation is distinguished by claystone, mudstone, siltstone, and shale, according to the lithology. The Patti Shale contains minerals with varying percentages compositions of quartz, kaolinite, muscovite, orthoclase, garnet, osmulite, haematite and illite according to the results of XRF and XRD investigations. The four outcrops include a significant concentration of quartz which qualifies the shales as quartzose shale. The predominance of clay minerals like kaolinite and illite in the examined outcrops of the Patti Formation, which indicate a continental-shallow marine environment of deposition, suggests that clay minerals are likely from the underlying and overlying mudstone and claystone units.

Quantitatively, land-derived species include *Cyathidites minor*, *Longapertites* sp., *Distaverrusporites simplex*, *Tricolporopollenites* sp., *Cingulatisporites ornatus*, and *Echitriporites trianguliformis* dominate the palynoflora assemblage. The formation is considered Maastrichtian in age based on the characteristic palynomorphs found in the investigated outcrops. However, the presence of Rugulatisporites caperatus in continental settings suggests (?) Campanian.

In addition, the presences of *Psilatricolporites crassus* and *Verrutricolporites irregularis* further suggest a Palaeocene age in predominantly terrestrial (continental) to open forest vegetation. The shale is a good source rock, according to the TOC value. Additionally, the genetic potential (GP) cut-off displays a relatively fair source rock. The hydrogen index (HI) value indicated type II (oil-gas prone) and type IV (inert) based on the plots of S_2 versus TOC, HI against OI, and Tmax, respectively. The shale can produce largely gas and just a small amount of oil because it is immature to marginally develop. Almost all of the samples exhibit a low-moderate production index (PI) (less than 0.1-0.2), which indicates a low-moderate level conversion, according to the production index (PI) data.

Recommendation

The Patti Shale in the basin needs to have a more in-depth geologic examination of the source rock potential using scanning electron microscope (SEM) and isotope geochemistry methods.

5.0 References

Abimbola, A. F. (1997). Petrographic and paragenetic studies of the Agbaja Ironstone Formation, Nupe Basin, Nigeria. *Journal of African Earth Sciences* 25, pp. 169-181.

Abuhagazaa, A. A., Kassab, M. A., Wanas, H. A. & Teama, M. A. (2021). Reservoir quality and rock type zonation for the Sidri and Feiran members of the Belayim Formation, in Belayim Land Oil Field, Gulf of Suez, *Egypt. J Afri. Earth Sci*, 181, 104242, https://doi.org/10.1016/j.jafrearsci.2021.104242

Adeleye, D. R. (1973). Origin of ironstones: an example from the Mid-Niger Basin, Nigeria. *J Sediment Petrol* 43, pp. 709–727.

Adeleye, D. R. (1974). Sedimentology of the fluvial Bida sandstones (Cretaceous) Nigeria, *Sedimentary Geology*, 12, pp. 1-24.

Adeleye, D. R. (1989). *The Geology of the Middle Niger Basin*, In Kogbe, C. A., (Ed.), Geology of Nigeria, 2nd edition, Rock View (Nigeria) Limited Jos, Nigeria, 335-339.

Adeniyi, J. O. (1985). Ground total magnetic intensity in parts of the Nupe Basin and the adjacent basement complex, Niger State, Nigeria. *Nigerian J. Appl. Sci*. 3: 67–78.

Agyingi, C. M. (1993). Palynological evidence for a late Cretaceous age for Patti Formation, Eastern Bida Basin., *Nigeria. J Afr Earth Sci*, 17:513–523.

Aigbadon, G. O., Odoma, N. A., Obasi, I. A., Christopher, S. D., Nanfa, C. A., Baba Aminu, M. & Akakuru, O. C. (2022 a). Hydrocarbon prospectivity of the southern Bida and northern Anambra Basin, Nigeria using palynological and geochemical studies. *J Geosystems & Geoenvirons* 1,4, https://doi.org/10.1016/j.geogeo.2022.100103.

Aigbadon, G.O, Ocheli, A, Akakuru, C.O., Akudo, E. O., Christopher, S.D., Esharive, O., & Francis J A (2022b). Paleoenvironments and hydrocarbon reservoir potentials from the selected sedimentary basins in Nigeria using sedimentary facies and textural analyses. *J Sed Environs.* Doi:10.1007/s43217-022-00101-x.

Aigbadon, G. O., Christopher, S. D., Akudo, E.O. & Akakuru, O.C (2022 c). Sedimentary facies and textural characteristics of Cretaceous sandstones in the southern Bida Basin, Nigeria: Implication for reservoir potential and depositional environment *Energy Geoscience* 3, pp. 323-341. https://doi.org/10.1016/j.engeos.2022.05.002

Aigbadon, G. O., Akakuru, O. C., Chinyem, F. I., Akudo, E. O., Musa, K. O., Obasi, A. I., Overare, B., Ocheli, A., Sanni, Z. J., Ahmed II, J. B., Onyekuru, S. O. & Muawiya, B. (2023 a). Facies analysis and Sedimentology of the Campanian-Maastrichtian sediments, southern Bida Basin, Nigeria. *Carbonates and Evaporite*, 38, 27. https://doi.org/10.1007/s13146-023-00848-y.

Aigbadon, G. O., Igwe, E. O., Ocheli, A., Overare, B., Akakaru, O. C., Akudo, E. O., Obasi, A. I., Ahmed, J. B. & Baba Aminu, M. (2023 b). Sedimentary facies, paleoenvironments, paleogeography of the Upper Cretaceous succession in the southern Bida Basin, Nigeria. *Arabian Journal of Geosciences* 16, 349, https://doi.org/10.1007/s12517-023-11390-5

Akande, S. O., Ojo, O. J., Erdtmann, B. D. & Hetenyi, M. (2005). Paleoenvironments, organic petrology and Rock-Eval studies on source rock facies of the Lower Maastrichtian Patti Formation, southern Bida Basin *Nigeria. J. Afri. Earth Sci.* 41, pp. 394-406.

Akande, S. O., Ojo, O. J. Adekeye, O. A. & Ladipo, K. O. (2006). *A Geological Field Guide to the Southern Bida Basin. Nigerian Association of Petroleum Explorationists* (NAPE), 24th Annual Conference and Exhibition, Abuja, 21 pp.

Benkhelil, J. (1989). The origin and Evolution of the Cretaceous Benue Trough, Nigeria, *Journal of African Earth Sciences*, 8 pp. 251-282.

Braide, S. P. (1992). Syntectonic fluvial sedimentation in the central Bida Basin. *J Min Geol* 28:55–64.

Braide, S. P. (1990). Petroleum Geology of the Southern Bida Basin, Nigeria. *AAPG Am. Assoc. Pet. Geol.) Bull, 74*(5), 717pp.

Braide, S. P. (1992a). Geological development, origin, and energy mineral resources potential of the Lokoja Formation in the southern Bida Basin. *Journal of Mining and Geology*, 28, pp. 33-44.

Braide, S.P. (1992b). Syntectonic fluvial sedimentation in the central Bida Basin. Journal Mining and Geology. (**28**): 55–64.

Burke, K. (1976). The Chad Basin: an active intra-continental basin. *Tectonophysics*, 36, pp. 197–206.

Ehinola, O. A., Sonibare, O. O., Falana, A. M. & Javie, D. (2005). Organic geochemistry and biomarker evaluation of shale units of the Patti Formation, Bida Basin, *Nigeria. NAPE Bull*, 19, 1, pp. 78–88.

Fensome, R.A., Williams, G.L. (2004) The Lentin and Williams *Index of Fossil Dinoflagellates.* 2004 Edition: 909 pp.

Grant, N. K. (1978). Structural distinction between a metasedimentary cover and an underlying basement in the 600 my old Pan-African domain of North western Nigeria. *Geol Soc Am Bull*, 89, pp. 50–58.

Hunt, J. H (1996b). *Petroleum geochemistry and geology*, 2nd edn. W.H. Freeman and Company, New York.

Hunt, J. H. (1996a). *Petroleum geochemistry and geology,* 2nd edn. Freeman, New York, p 743.

Killops, S. D. & Killops, V. J. (1993). An introduction to organic geochemistry. Longman Group Ltd, UK

Kogbe, C. A. (1989). *Geology of Nigeria*. 2nd Edition, Rock View (Nigeria) Limited Jos, Nigeria. 538p.

Kogbe, C. A., Ajakaiye, D. E. & Matheis, G. (1983). Confirmation of Rift structure along the mid-Niger valley, Nigeria. *J Afr Earth Sci* 1, pp. 127–131.

Ladipo, K. O., Akande, S. O. & Mucke, A. (1994). Genesis of ironstones from the mid-Niger sedimentary basin: evidence from sedimentological, ore microscopic and geochemical studies. *J Min Geol*, 30, pp. 161–168.

Lawal, O. & Moullade, M. (1986). Palynological Biostratigraphy of Cretaceous Sediments in the Upper Benue Basin, N.E. Nigeria. Rev. de micropaleontologie, 29, 11, pp. 61-83.

Likasson, O. K. (1993). Application of Trend Surface Analysis to Gravity data over the Middle Niger Basin, Nigeria. *Journal of Mining and Geology*, 29, 2, pp. 11-19.

Nton, M. E. & Adamolekun, O. J. (2016). Sedimentological and Geochemical Characteristics of Outcrop Sediments of Southern Bida Basin, Central Nigeria: Implications for Provenance, Paleoenvironment and Tectonic History, *Ife Journal of Science*, 18, 2, pp. 345-369.

Nwajide, C. S. & Reijers, T, J. A. (1996). *Sequence architecture in outcrops: examples from the Anambra Basin Nigeria, Nigerian Association of Petroleum Explorationists (NAPE) Bulletin*. 11: 23-33.

Obaje, N. G. (2009). *Geology and Mineral Resources of Nigeria*, Springer, Heidelberg, 221p.

Obaje, N. G., Musa, M. K., Odoma, A. N. & Hamza, H. (2011). The Bida Basin in North-Central Nigeria: Sedimentology and Petroleum geology, *Journal of Petroleum and Gas Exploration Research*. 1, pp. 001-013.

Obaje, N. G., Wehner, H., Scheeder, G., Abubakar M. B., Jauro A. (2004). Hydrocarbon prospectivity of Nigeria's inland basins: from the viewpoint of organic geochemistry and organic petrology. *AAPG Bull* 87:325–353.

Ocheli, A., Aigbadon, G. O. & Abanjo, N. (2023). Subsurface Lithologies and Rock Eval Pyrolysis Analysis of Amansiodo-1 and Akukwa-1 Well sections, Nkporo Formation, Southeastern Part of the Anambra Basin, Nigeria: Implication for petroleum source rock potentials. *Communication in Physical Sciences*, 9 (2): 8082.

Ojo, O. J., Jimoh, A. Y., Umelo, J. C. &Akande, S.O. (2020). Organic geochemical and palynological studies of the Maastrichtian source rock intervals in Bida Basin, Nigeria: implications for hydrocarbon prospectivity. *J Petrol Explor Product Technol*, 10, pp. 3191–3206 https://doi.org/10.1007/s13202-020-00989-z

Ojo, S. B. & Ajakaiye, D. E. (1989). Preliminary interpretation of gravity measurements in the Mid-Niger Basin area, Nigeria. In: Kogbe, C.A. (Ed.), Geology of Nigeria. 2nd edition, Elizabethan Publishers, Lagos, pp. 347358.

Ojo, S. B., (1984). Middle Niger Basin Revisited, Magnetic constraints on Gravity Interpretations. *Nigerian Mining and Geosciences Society* Conference, Nsukka, Nigeria, Abstract. pp. 52-53.

Okeke, O. C. & Okogbue, C. O. (2011). Shales: A Review of their Classifications, Properties and Importance to the Petroleum Industry. *Global Journal of Geological Sciences* 9 (1): 55-73.

Okoro, A. U. (2007). Lithofacies and depositional environments of the bida sandstones, Bida Basin Nigeria. *Journal of Applied and Natural Sciences (JANS)*, 1, pp. 64-70.

Ola-Buraimo, A.O. and Abdulganiyu, Y. (2017). Palynology and stratigraphy of the Upper Miocene Chad Formation, Bornu Basin, northeastern, Nigeria. *Journal of Paleogeography*, 6, 2, pp. 108-116.

Peters, K E., Walters, C. C. & Moldowan, J. M. (2005). *The biomarker guide*, 2nd edn. Cambridge University Press, Cambridge.

Petters, S. W. (1978). Middle Cretaceous paleoenvironments and biostratigraphy of the Benue Trough, Nigeria. *Geol. Soc. Amer. Bull*., 89, pp. 151–154.

Petters, S. W. (1986). *Foraminiferal biofacies in the Nigerian rift and continental margin deltas*. In Oti, M. N. and Postma, G. (Editor), Geology of Deltas. A. A. Balkema, Rotterdam. 219-235.

Pettijohn, F. J. (1957). *Sedimentary rocks*. Harper Bros, New York, N.Y., 2nd edn, 718.

Rahaman, M. A. O., Fadiya, S. L., Adekola, S. A., Coker, S. J., Bale, R. B., Olawoki, O. A., Omada, I. J., Obaje, N. G., Akinsanpe, O. T., Ojog, G. A. & Akande, W. G. (2019). A revised stratigraphy of the Bida Basin, Nigeria. *J Afr Earth Sci*, 151, pp. 67–81.

Schrank, E. (1992). Non marine Cretaceous correlations in Egypt and northern Sudan: palynological and palaeobotanical evidence, *Cretaceous Research* 13, pp. 351-368.

Schrank, E. (1994). Non marine Cretaceous Palynology of northern Kordofa, Sudan, with notes on fossil Salviniales (water ferns), *Geologische Rundschau*, 83, pp. 773-786.

Udensi, E. E. & Osazuwa, I.B. (2004). Spectral determination of depths to magnetic rocks under the Nupe Basin, Nigeria. *NAPE Bull* 17:22–27.

Whiteman, A. (1982). *Nigeria: Its petroleum geology, resources and potential*. 1 & 2 Graham and Trotman, London. 349.

Zaborski, P. M., (1998). A Review of the Cretaceous System in Nigeria, *African Geosciences*. 5, pp. 385-483.

Acknowledgements

Special thanks to Dr Ikenna Arisi Obasi and Dr Ernest Akudo for their contributions in proof reading the manuscript. We sincerely appreciate the Editor-in-Chief and the anonymous reviewers for their criticism and review of the manuscript.

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data Public

Competing interest

The authors declared no conflict of interest.

.**Funding**

The authors declare no external source of funding

Authors' contributions

Godwin Okumagbe Aigbadon led the team for field mapping exercise, involved in data collection, analysis, research design, interpretation, writing of the final draft of the manuscript as well as proofreading.

Azuka Ocheli was actively involved in the field mapping, sample collection, analysis, interpretation and proofreading of the final draft of the manuscript.

Tope Shade Alege partook in the field mapping, sample collection, analysis, data interpretation and proofreading of the manuscript.

Esther Onozasi David was involved in fielding mapping, sample collections, analysis and data interpretations, as well as proofreading of the manuscript**.**