https://dx.doi.org/10.4314/dujopas.v10i3b.17
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 10 No. 3b September 2024*

Cretaceous Patti Shales of Southern Mid-Niger Basin as an insight to Provenance, Paleoenvironment, and Paleoclimate: A Comprehensive Study

Aigbadon, G.O.,[1*] and Igbinigie, N.S. [1]
[1]Department of Geology,
University of Benin, Benin City,
Edo State,
Nigeria.

Email: godwin.aigbadon@uniben.edu

Abstract
This study focuses on the geochemical, mineralogical, and palynological analyses of Cretaceous Shales of the Patti Formation within the Ahoko section of the southern Mid-Niger Basin, Nigeria. The aim of this research is to understand the provenance, paleoenvironment, and paleoclimate of the Mid-Niger Basin, Nigeria. The samples were analyzed using X-ray fluorescence (XRF), X-ray diffraction (XRD), and palynomorph analysis techniques. The results of the geochemical study (XRF) showed that the sediments were mature and recycled because of the high quantities of SiO_2 (28.759% - 62.107%), Fe_2O_3 (3.493% - 46.079%), Al_2O_3 (9.832% - 24.422%), and K_2O (1.378% - 2.449%), respectively. The results of a mineralogical investigation showed that garnet, muscovite, orthoclase, illite, and osumilite were the least common minerals, with quartz being the most common mineral (33% - 51%) and followed by kaolinite (28% - 47%). Based on geochemical data, the provenance indicates that the sediments originated from felsic igneous provenance. Palynomorph revealed diverse assemblages of terrestrial paleoenvironments from the Campanian to Paleocene ages, including open forest vegetation. Cingulatisporites ornatus, Monocolpites sp., Longapertites sp., Cyathidites minor, Foveotriletes margaritae, Distaverrusporites simplex, Psilatricolporites crassus, Echitriporites trianguliformis, Rugulatisporites caperatus, Verrutricolporites irregularis, Diatom frustules, Tubistephanocolpites cylindricus, Laevigatosporites sp., Monoporites annulatus, Inaperturopollenites sp., and Tricolporopollenites sp. are among the palynomorphs identified in the samples. Additionally, arid to semi-arid climatic conditions at the source area are indicated by the $SiO_2/(Al_2O_3 + K_2O + Na_2O)$ ratios, which have an impact on sediment maturity. The integration of the lithological, geochemical and palynological data has provided insight into the provenance, depositional setting, and paleoclimate of the Cretaceous Patti Shale in the southern Mid-Niger Basin.

Keywords: Mid-Niger Basin, geochemical data, palynological data, provenance and paleoclimate condition.

INTRODUCTION
Shale represents the typical crustal composition of the provenance more accurately than any other detrital sedimentary rock, and it is the most prevalent kind of lithified sediment in sedimentary basins worldwide (Pettijohn, 1975; McCulloch and Wasserburg, 1978). While some authors (Bhatia, 1983; Roser and Korsch, 1986) have highlighted the value of major element geochemistry of sedimentary rocks in differentiating the tectonic setting. Armstrong-Altrin and Verma (2005) have cautioned against the indiscriminate use of discrimination diagrams for provenance studies utilizing major element geochemistry. Due to their relatively

Author for Correspondence

low mobility during sedimentary processes and short residence times in seawater, some trace elements, such as the rare-earth elements (REE: La, Ce, Nd, Gd, Yb), Y, Th, Zr, Hf, Nb, Se, Cr, and Sc, especially in combination with TiO_2, are best suited for provenance and tectonic setting determination studies (McLennan *et al.*, 1993). It is anticipated that these elements will be more helpful in differentiating between tectonic environments and source rock compositions than the major elements because they are most likely transported quantitatively into clastic sediments during weathering and transportation, reflecting the signature of the parent materials (Condie, 1993; McLennan, 1989; Armstrong-Altrin *et al.*, 2004). According to a prior study, variations in parent materials may have an impact on sedimentary rocks of any age, which are mainly derived from Precambrian terranes (Armstrong-Altrin *et al.*, 2004). Additionally, according to Karadag (2014), discrete tectonic settings are distinguished by their physiochemical markers of sedimentary processes and unique provenance traits. The relative contribution of felsic and basic sources in shales from various tectonic environments has been inferred using the relative distribution of immobile elements that differ in concentration in felsic and basic rocks, such as La and Th (enriched in felsic rocks) and Sc, Cr, and Co (enriched in basic rocks relative to felsic rocks) (Wronkiewicz and Condie, 1990).

In the Mid-Niger Basin only a few works have talked about the provenance and paleo environment which led to this research study in order to bridge the gap, contributing to a better understanding of the region's geological history. Aigbadon *et al.* (2023) carried out a study on shale samples within the Patti Formation in order to determine its provenance and hydrocarbon potential. Their results revealed the shale is classified as quartzose shale and it is made up of type III kerogen, slightly mature and successful for gas production. Adebayo *et al.* (2015) also studied shale samples in order to determine their geochemical properties and paleo environment of deposition. Their results suggested the rocks were of felsic origin and bottom water oxic condition during deposition and further revealed the depositional environment to be of fluvio-deltaic source and a distal oxic environment of deposition. This study therefore aimed at identifying and reviewing the Cretaceous shale sequence, provenance, paleoenvironment and paleoclimate, using XRF, XRD and palynomorph analyses.

GEOLOGIC SETTING

The Mid-Niger Basin is a linear, intracratonic sedimentary basin that is located in central Nigeria. It travels in a NW-SE trajectory that is nearly perpendicular to the Benue Trough. It is divided from the underlying continental layer of the Sokoto Basin to the west by a narrow outcrop of crystalline basement rocks, and it is bounded to the east by the Anambra Basin (Obaje, 2009). The Mid-Niger Basin's separation into the northern and southern sub-basins was probably brought about by basin-wide facies modifications (Jones, 1958; Braide, 1992). Several published research (Kogbe *et al.* 1983; Ojo and Ajakaiye, 1989) corroborate the rift formation theory for the Mid-Niger Basin. They offered compelling evidence, supported by geophysical data and land satellite images, for the rift genesis's connection to the moving apart of the plates dividing Africa and South America. Using Landsat images, Kogbe *et al.* (1983) discovered major faults on both sides of the Niger Valley, and geophysical research confirmed their findings. Ojo and Ajakaiye (1989) described the Mid-Niger Basin as a localized subsidence region and suggested the existence of a central positive anomaly that is deeply seated and encircled by negative anomalies, a characteristic of rift structure. Unlike the lower Benue Trough, the sedimentary infill of the basin is primarily level and shows no evidence of folding. Braide (1992) also developed a plate tectonic-based model that proposed a wrench fault tectonics for the evolution and, consequently, a pull-apart genesis for the Mid-Niger Basin.

The upper Cretaceous Mid-Niger Basin's stratigraphic framework has been the subject of numerous publications, including works by Adeleye and Dessauvagie (1972) and Adeleye (1989). The Mid-Niger Basin's Northern and Southern (Lokoja) Sub-Basins are separable. The NW-SE trending band of Upper Cretaceous sedimentary rocks, which Adeleye (1974) calls the Nupe Group, is part of the stratigraphic sequence of the Mid-Niger Basin. It was formed by subsidence during the Cretaceous opening of the South Atlantic Ocean. Ojo and Akande (2003) stated that the oldest unit in the southern Mid-Niger Basin is the Campanian Lokoja Formation. With minimal claystone, its main constituents are sandstones from alluvial to fluvial channels.

It is the stratigraphic equivalent of the Mid-Niger Formation in the northern Mid-Niger Basin (Figs. 1 and 2). It is succeeded by the Maastrichtian Patti Formation. The Patti Formation was deposited in a wide range of environments, such as shorefaces, tidal marshes, tidal channels, and coastal swamps. The formation is composed of two main parts: sandstone and shale-clay materials. The sandstone member is made up of the shoreface and tidal facies association, which are made up of well-sorted, fine to medium-grained sandstone and minor coarse to very coarse- grained sandstone. The shale-clay component is composed of the swamp to marsh facies (shale, lignite, ironstone, siltstone, and claystone) (Ojo and Akande, 2009). In the northern Mid-Niger Basin, the Enagi Formation is the lateral equivalent of the Patti Formation. The Agbaja Formation, the lateral counterpart of the Batati Ironstone in the north, tops the entire series. Late Maastrichtian is most likely its age (Adeleye, 1989). The geologic successions in the northern and southern parts of the basin are correlated, with the correlation extending into the Anambra Basin to the southeast, based principally on lithological and depositional features. These lateral equivalents show continuous depositional stages that stretch from south to northwest during the Upper Cretaceous, controlled by fluctuations in sea level.

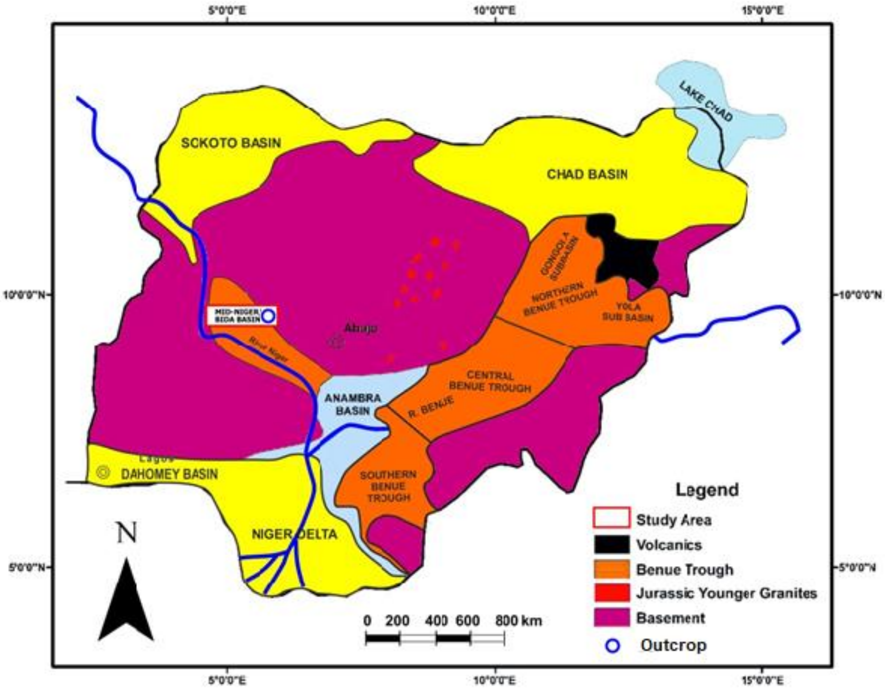

Fig 1: Geologic map of Nigeria showing the location of the Bida/Mid-Niger Basin (Modified after Obaje, 2009; Aigbadon et al., 2024 a, b).

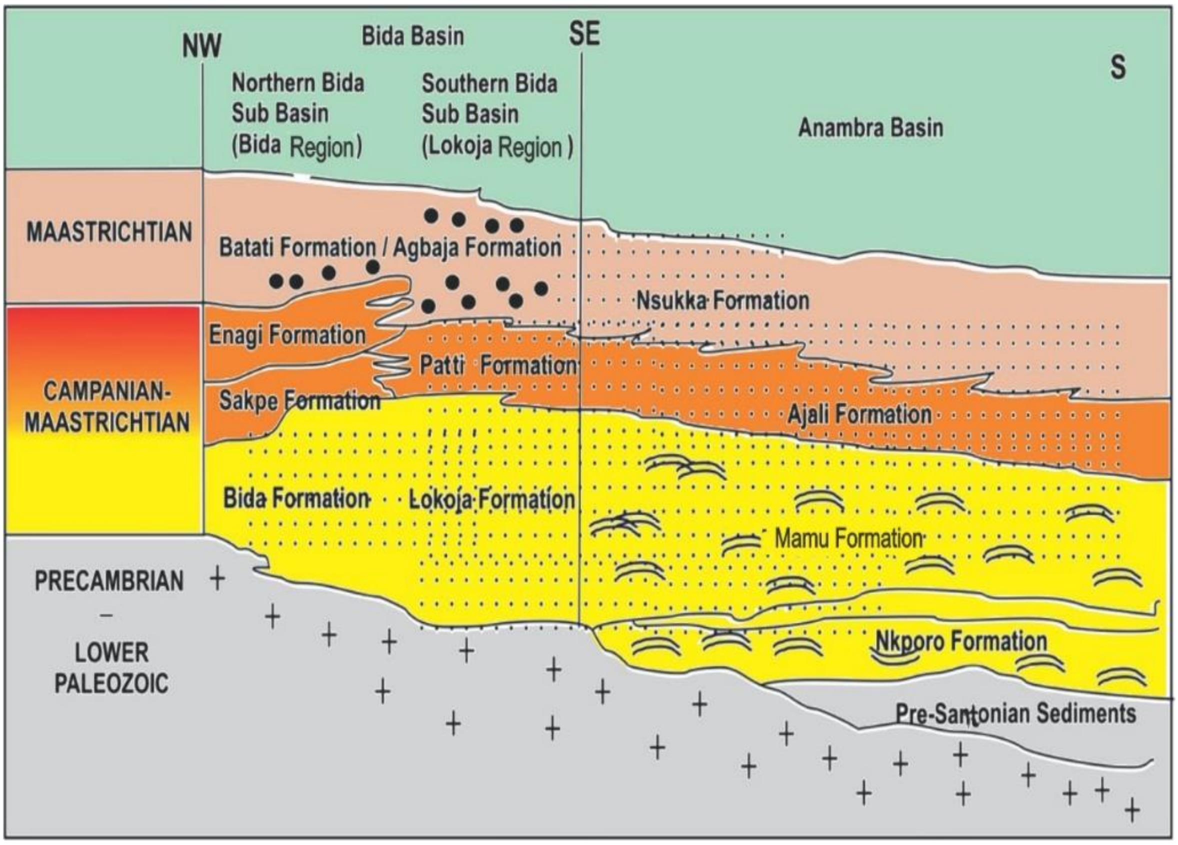

Fig. 2: Stratigraphic structure of the southern and northern Bida/Mid-Niger Basin (Akande *et al.*, 2005; Aigbadon *et al.*, 2022).

MATERIALS AND METHODS

The study area, Ahoko, is situated within Lokoja in Kogi State, located in the north-central region of Nigeria, with coordinates ranging between latitudes N07052'16.8'' to N07052'30.8'' and longitudes E06045'34.9'' to E06045'35.8''. The investigation focused on outcrops along Ahoko, employing both laboratory analyses and field studies.

A comprehensive field survey was conducted to identify various rock types and their corresponding formations. A geological map was produced with rock boundaries (Fig. 3). Vertical profiles were meticulously logged from these outcrops. Six samples of mud rock (dark shale and mudstone) were collected from distinct outcrop locations within the study area (Figs. 4 and 5). Prior to packaging in sample bags, each sample was carefully positioned, wrapped in paper, encased in polythene, and promptly labeled.

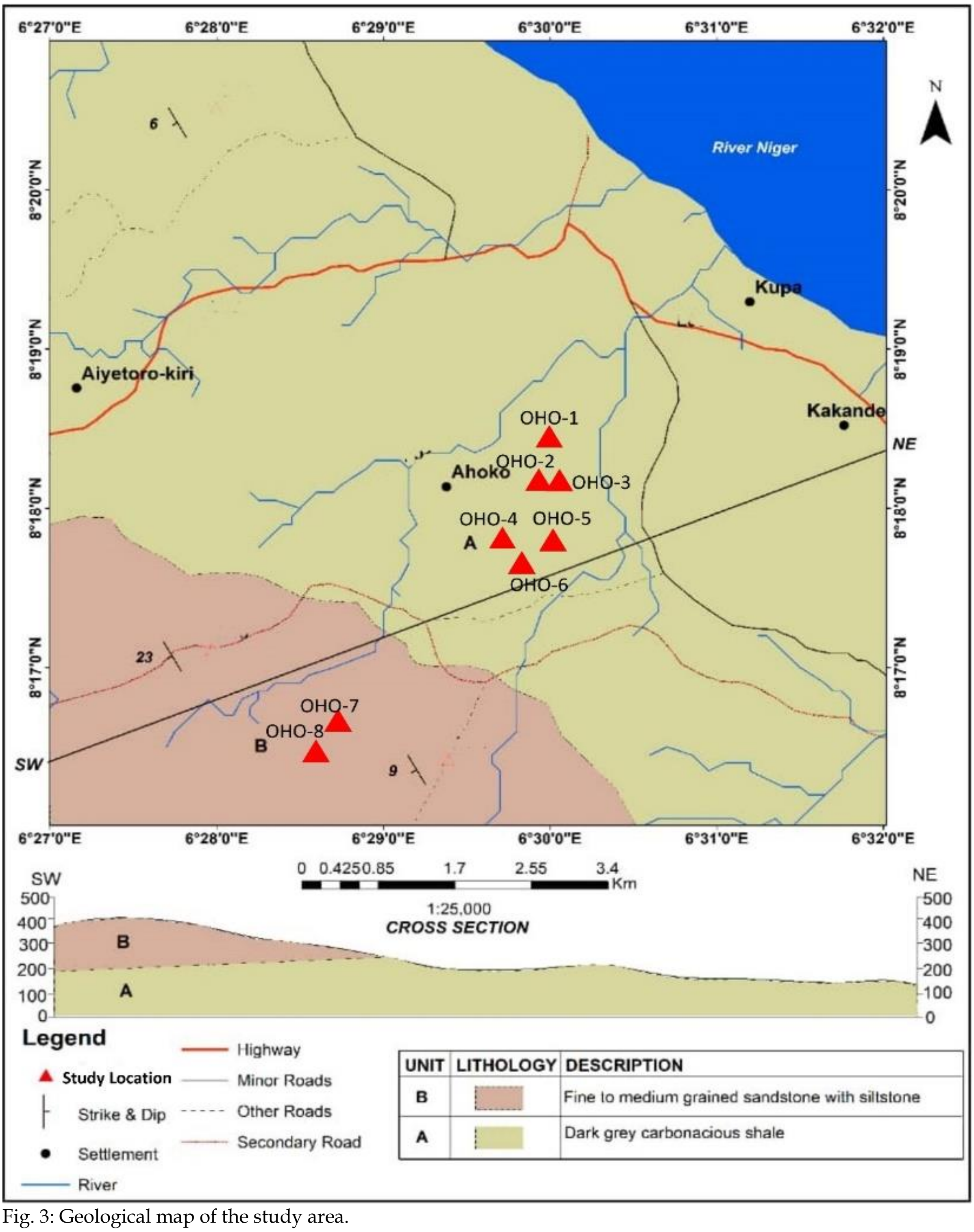

Fig. 3: Geological map of the study area.

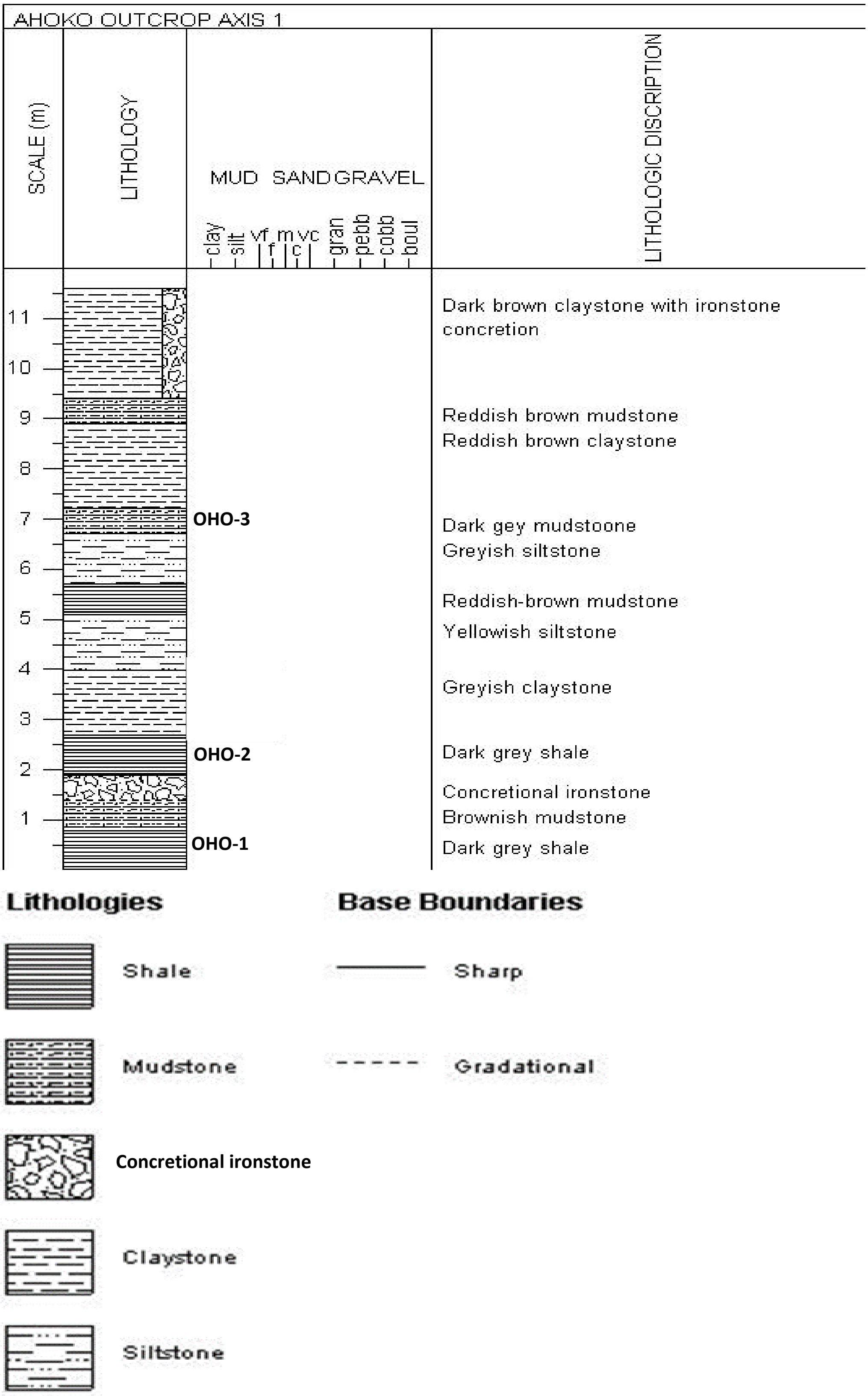

Fig.4: Lithologic section for Ahoko-outcrop 1

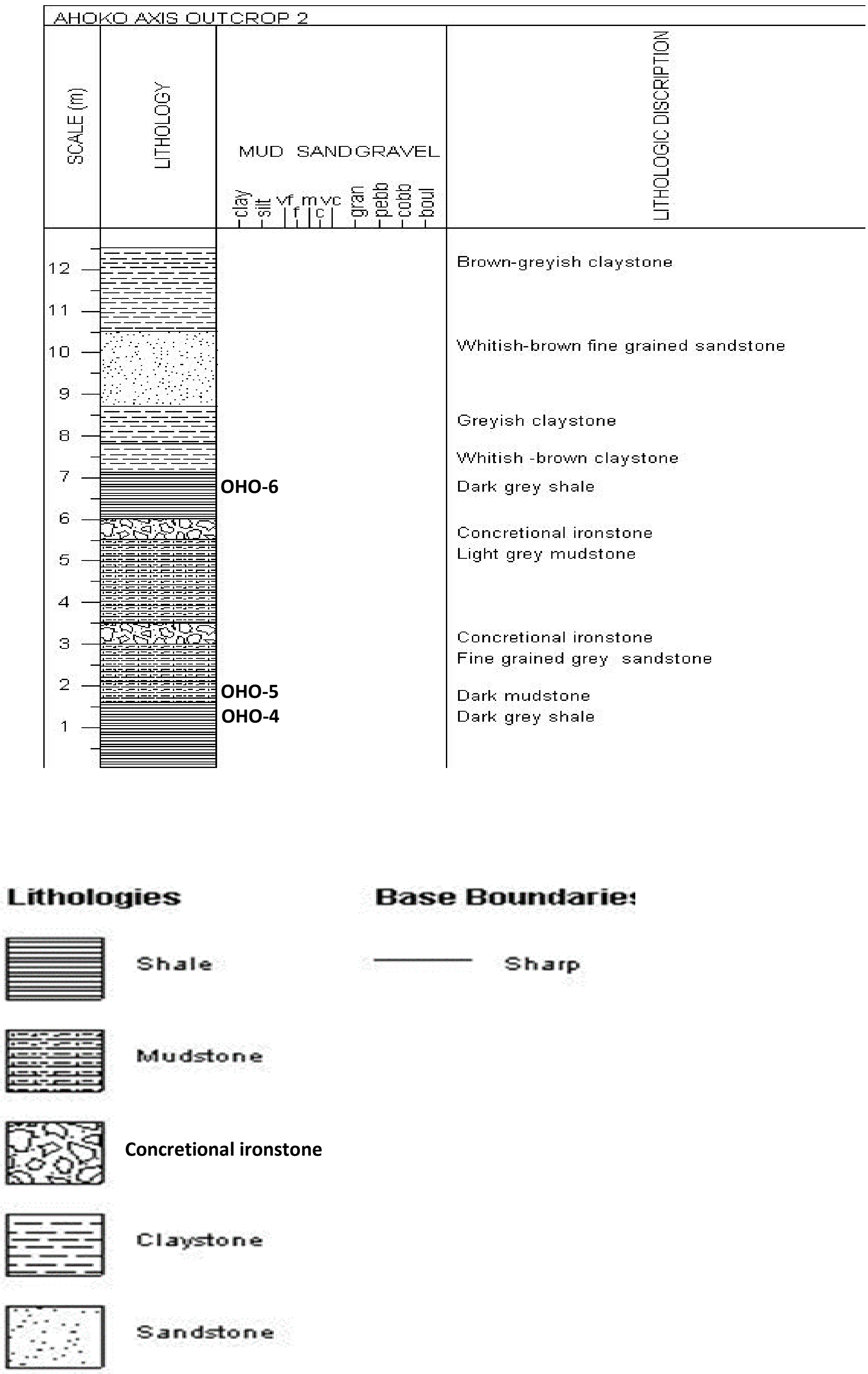

Fig. 5: Lithologic section of Ahoko outcrop 2.

The samples underwent geochemical investigations, such as X-ray diffraction (XRD) and X-ray fluorescence (XRF). To identify the main elemental oxides, pressed powder pellets were made from the samples. Next, the Xenemetrix Genius IF X-ray fluorescence spectrometer was used to analyze these pellets. A Rigaku Mineflex 600 X-ray Diffractometer was also used to examine the mineralogical composition. Using this method, samples were exposed to X-ray radiation, and the diffraction patterns that were produced were then recorded.

Along with doing the palynomorph analysis, the following procedures were carried out precisely according to safety guidelines, utilizing modified standard methodologies (Aigbadon *et al.*, 2022; Ojo *et al.*, 2020). The samples were first cleaned under water in a beaker, and any remaining oily mud was then cleaned out in a SOXHILET device using detergent or chloroform. After removing carbonate materials, 36% hydrochloric acid (HCl) was added, and the setup was let to stand for 25 minutes before being decanted. After immersing the resultant sample in hydrofluoric acid (HF) for 24 hours to dissolve any silicate components, it was subjected to sedimentation and decantation procedures. A few drops of zinc bromide solution were added, mixed, and then centrifuged for ten minutes at 2000 RPM in order to separate the organic ingredients. Before being put on a microscope slide, the resulting system was diluted with distilled water and polyvinyl alcohol (PVA) to reach the necessary concentration. The glass base of the slide was 76 mm by 26 mm, while the coverslip, which was later sealed permanently, measured 32 mm by 22 mm. The palynological slides were cleaned with acetone, labeled, and every palynomorph species that was observed was recorded on a different logging sheet. Scientific palynological nomenclature/charts and international species names were taken from pertinent sources (Schranks, 1992, 1994; Fensome and Williams, 2004; Lawal and Moullade, 1986). In addition, the results and discussion section had an image taken with a light microscope.

RESULTS AND DISCUSSION

Geochemical results

The results of the XRF analysis for the samples are given in table 1 below.

Table 1: Oxide and Elemental Composition of the Samples

Oxides Composition %	OHO-1 Shale (wt %)	OHO-2 Shale 2 (wt %)	OHO3 Mudstone (wt %)	OHO-4 Shale 4 (wt %)	OHO-5 Mudstone (wt %)	OHO-6 Shale (wt %)
SiO_2	62.107	28.759	56.825	52.213	60.625	33.759
V_2O_5	0.159	0.088	0.102	0.098	0.120	0.091
Cr_2O_3	0.045	0.024	0.065	0.039	0.039	0.043
MnO	0.047	1.603	0.581	0.028	0.041	1.908
Fe_2O_3	3.493	46.079	12.455	15.434	7.638	43.054
Co_3O_4	0.018	0.184	0.184	0.286	0.034	0.167
NiO	0.003	0.000	0.013	0.006	0.001	0.000
CuO	0.034	0.038	0.025	0.076	0.065	0.028
Na_2O_3	0.023	0.204	0.045	0.088	0.078	0.297
MoO_3	0.003	0.000	0.001	0.016	0.005	0.000
WO_3	0.000	0.055	0.023	0.001	0.000	0.067
P_2O_5	0.000	3.073	0.078	0.007	0.003	2.881
SO_3	2.672	1.278	1.980	3.731	2.413	1.677
CaO	0.075	5.763	4.651	1.359	0.114	2.332
MgO	0.000	0.000	0.000	0.000	0.002	0.000

K_2O	2.449	1.378	3.576	2.547	2.673	1.469
BaO	0.109	0.014	0.211	0.135	0.058	0.021
Al_2O_3	24.422	9.832	16.560	20.112	23.415	10.421
Ta_2O_5	0.022	0.030	0.045	0.089	0.067	0.035
TiO_2	3.436	1.052	1.811	1.112	1.900	1.158
ZnO	0.008	0.028	0.014	0.842	0.016	0.068
Ag_2O	0.008	0.000	0.002	0.012	0.013	0.000
Cl	0.532	0.484	0.385	0.378	0.396	0.645
ZrO_2	0.335	0.034	0.368	0.391	0.315	0.072
SnO_2	0.000	0.000	0.000	0.000	0.000	0.000

The primary oxide concentration of the Patti Cretaceous shale samples is displayed in Table 1. The results show that, with a range of 62.107 - 28.759%, SiO_2 has the highest incidence in the majority of the six samples. The second-highest occurrence, Fe_2O_3, ranges in weight from 46.079 - 3.493%. Al_20_3 (24.422 - 9.8325%), K_2O (2.449 - 1.469%), TiO_2 (3.436 -1.112%), CaO (5.763 - 0.075%), and SO_3 (2.672 - 1.278%) are among the other prominent oxides that are present.

Table 2: Shows the XRD Mineralogical Composition of the Samples.

Sample	Formation	Qtz %	Ka %	Illite %	Osm. %	Ortho . %	Haem .%	Cl %	Gn%	Mus .%
AHO- 1	Patti Fm	51.0	38.A0	0.2	0.6	3.0	0.3	-	1.5	5.8
AHO 2	Patti Fm	33.0	28.0	5.5	3.0	4.0	3.0	3.0	3.9	16.2
AHO 3	Patti Fm	41.0	30.7	5.0	0.12	11.70	3.30	2.40	-	4.50
AHO 4	Patti Fm	48.0	42.0	1.0	1.0	4.0	1.2	0.5	0.5	2.8
AHO 5	Patti Fm	49.0	41.0	1.5	0.5	2.5	1.0	0.5	1.0	3.0
AHO 6	Patti Fm	43.0	47.0	0.9	0.1	4.2	0.8	0.7	1.0	2.2

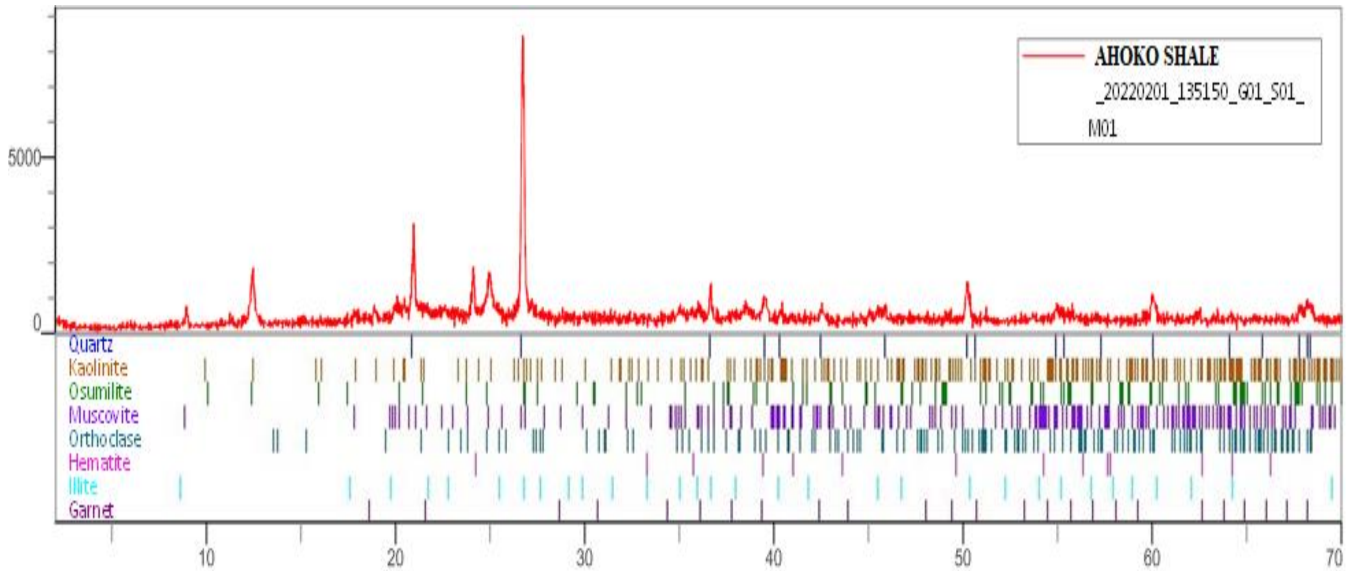

Fig. 6: XRD diffractogram showing the mineral occurrence of the sample (OHO-1)

Sample	Palynomorphs	Type	Counts.
1 - 6	*Cingulatisporites ornatus*	S	7
	Monocolpites sp.	P	5
	Longapertites sp.	P	8
	Cyathidites minor	S	13
	Foveotriletes margaritae	S	2
	Longapertites marginatus	P	1
	Distaverrusporites simplex	S	1
	Psilatricolporites crassus	P	2
	Echitriporites trianguliformis	P	3
	Rugulatisporites caperatus	S	1
	Verrutricolporites irregularis	P	1
	Diatom frustules	DF	6
	Tubistephanocolpites cylindricus	P	1
	Laevigatosporites sp.	S	3
	Monoporites annulatus	P	1
	Inaperturopollenites sp.	P	2
	Monocolpites marginatus	P	5
	Tricolporopollenites sp.	p	6
	Gleichenidites sp.	p	1

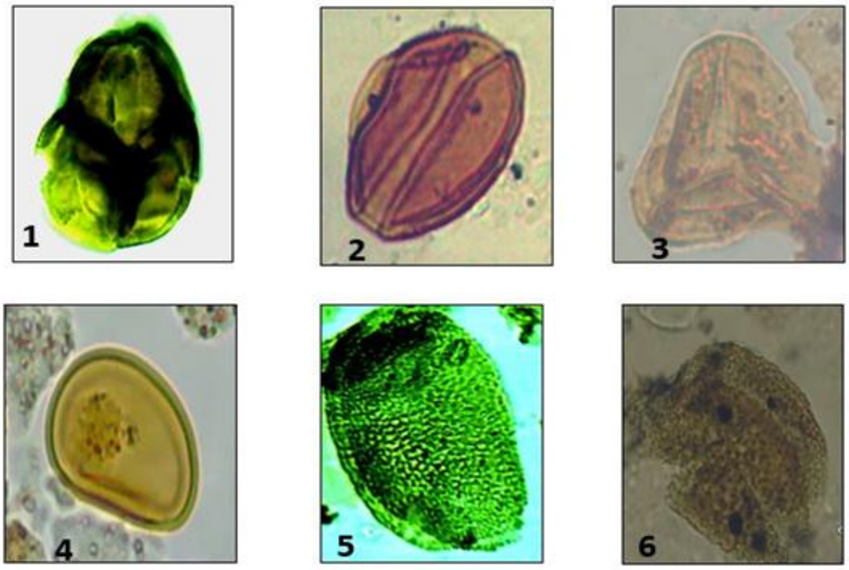

Fig 7: (1) *Tricolporopollenites sp.* (2) *Monocolpites marginatus* (3) *Gleichenidites sp.* (4) *Laevigatosporites sp.* (5) *Longapertites marginatus* (6) *Longapertites sp.*

According to the palynomorph results (Fig. 7), *Longapertites* sp., and *Cyathidites minor* had greater counts, respectively. The presence of *Cyathidites minor, Distaverrusporites simplex, Longapertites* sp., *Echitriporites trianguliformis, Cingulatisporites ornatus, Rugulatisporites caperatus, Tubistephanocolpites cylindricus, Tricolporopollenites* sp., *Monocolpites marginatus, Gleichenidite*s sp., *Laevigatosporites* sp., and *Longapertites* sp. in the samples that were collected indicates an age ranging from Campanian to Paleocene, and suggests that the environment was primarily terrestrial with possibly open forest vegetation.

Provenance Studies

The Patti Cretaceous Shale series samples' primary oxide concentration, as well as a few ratios and weathering indices, are displayed in Table 1. The results show that the samples are low in CaO and TiO_2 and enriched in SiO_2, indicating that they are highly recycled and mature (Bhatia, 1983). Deposition may have occurred under extremely oxic bottom water conditions, as evidenced by lower Mo/Al and V/Al in the samples that were analyzed from both profiles. Whereas samples A and B exhibit no discernible enrichment in the Ni/Al ratio of the examined shales, there is a distinct enrichment in the Co/Al ratio. A higher oxygen regime during deposition is suggested by lower Ni/Al and Co/Al ratios in the samples (Dickinson, 1985). Lower Sr/Al and Ba/Al ratios also point to well-oxygenated bottom water conditions. The Zn/Al ratio in studied shales shows evidence of enrichment (Cullers, 1995). The studied Cretaceous shales exhibit different degrees of trace element enrichment.

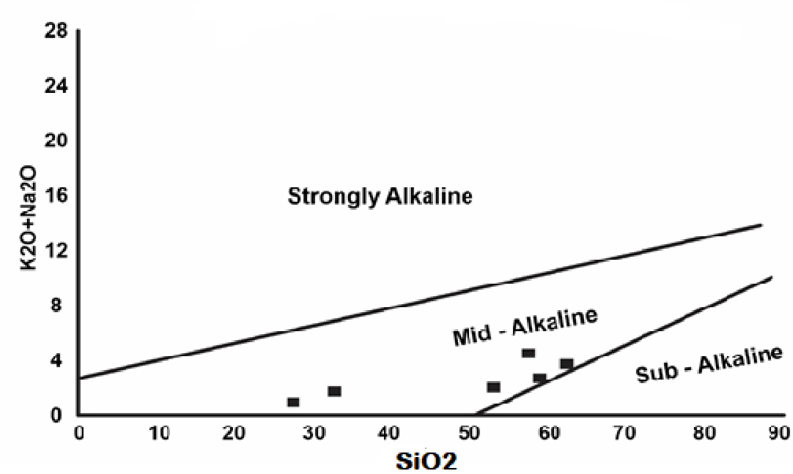

Fig. 8: Binary plot of K_2O+Na_2O VS SiO_2.

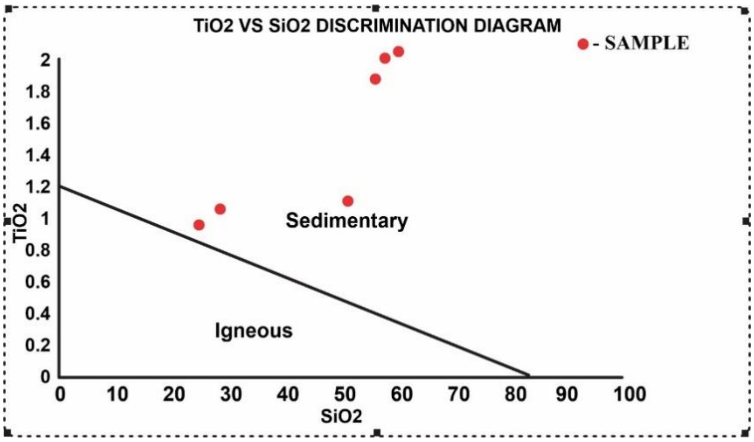

Fig. 9: TiO_2 Versus SiO_2 Discrimination Diagram.

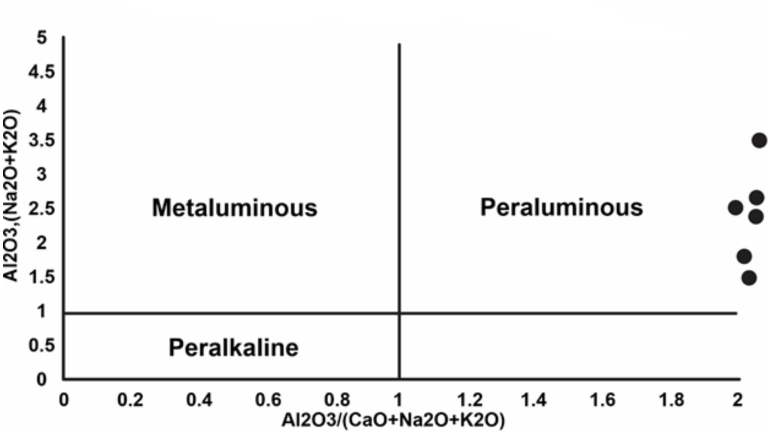

Fig. 10: Al_2O_3/(Na_2O+K_2O) Versus Al_2O_3/(Cao+Na_2O+K_2O) Molecular plot.

For provenance investigations, geochemical data (Figs. 8-10) are helpful (Taylor and Mclennan, 1985; Condie *et al.*, Cullers, 1995; Armstrong Altrin *et al.*, 2004). According to Mclennan *et al*. (1993), significant components reveal details about the makeup of the parent rock as well as the results of sedimentary processes including weathering and sorting. By elucidating the characteristics of the parent rocks, these offer distinct patterns of sedimentary history (Dickinson, 1985, 1988). From 51% to 33%, quartz was the most common mineral in all of the samples according to the XRD results of the mineralogical study, which are shown in Table 2 (Oumar *et al.*, 2022). The second most common mineral, after quartz, is kaolinite, which ranges in concentration from 47% to 28%. According to these results, the origin was most likely found in areas with abundant granitic or sandy sedimentary bedrock (Oumar *et al.*, 2022). Minor minerals including garnet, muscovite, orthoclase, osumilite, and clay-rich sedimentary rocks are also present, suggesting a variety of geological sources, possibly including felsic igneous rocks, metamorphic terrains, and sedimentary rocks rich in clay. Different levels of weathering or sedimentary environments in the source regions are indicated by the observed range in mineral concentrations among samples, which suggests variances in geological settings. Four primary provenances were identified by Roser and Korsch (1988): felsic igneous provenance, intermediate igneous provenance, mafic igneous provenance, and quartzose sediment. The examined samples show that the sediments were recycled from felsic igneous sources. Al_2O_3/TiO_2 ratios of most clastic rocks grow from 3 to 8 for mafic igneous rocks, from 8 to 21 for intermediate rocks, and from 21 to 70 for felsic igneous rocks (Hayashi *et al.*, 1997). This means that these ratios can be used to deduce the composition of the parent rock.

The intermediate rocks are most likely the source rocks of the shale samples, according to the Al_2O_3/TiO_2 ratio.

Paleo environmental reconstruction based on the recovered palynomorphs assemblages

The palynological assemblages typically reflect changes in the environment (Ojo and Akande, 2009). This is the rationale for this study's use of the relative abundances and compositions of various palynomorph groupings to understand the paleoenvironment. Based on the palynomorph characteristics of the examined dark shale and mudstone samples, paleoenvironmental inferences have been deduced (Ojo and Akande, 2009). This includes *Tricolporopollenites, Monocolpites marginatus.* Some marker species that are constrained by their environment were also taken into consideration when it came to miospores. These species included *Retitricolporites* sp., *Psilatricolporites crassus, Monocolpites* sp., and *Monocolpites marginatus.* While many of these palynomorphs morphologically resemble modern species, conclusions about their ecological needs can be drawn (Gemeraad *et al.*, 1968). For instance, *Monoporites annulatus* (savannah) lacustrine is a species representative of coastal plain habitats. The ages of the samples are interpreted to range from Campanian to Paleocene based on the diagnostic palynomorphs found in the samples: *Cingulatisporites ornatus, Rugulatisporites caperatus, Tubistephanocolpites cylindricus, Tricolporopollenites* sp., *Monocolpites marginatus, Rugulatisporites caperatus, Distaverrusporites simplex, Longapertites* sp., *Echitriporites trianguliformis, Cingulatisporites ornatus, Rugulatisporites caperatus, and Tubistephanocolpites cylindricus.* With open forest vegetation, the paleoenvironment is primarily terrestrial (continental).

Paleoclimate

Indicators of the palaeoclimatic conditions at the source area are the $SiO_2/(Al_2O_3 + K_2O + Na_2O)$ ratios. Every sample under investigation originated in the arid/semi-arid climatic zone. The research area's arid/semi-arid climate made rock disintegration dominate during weathering processes, impeding chemical maturity. Sediment maturity can be determined by analyzing the SiO_2/Al_2O_3 ratios of clastic rocks, which are subject to weathering and sediment recycling. According to Roser and Korsch (1986) and Roser *et al.* (1996), quartz outlives feldspars, mafic minerals, and lithics as sediment maturity increases.

CONCLUSION

The findings of this investigation give significant insight into the environmental factors and geological processes that shaped the Cretaceous Shale samples from the Patti Formation in the Mid-Niger Basin. The geochemical analysis provided crucial details regarding the shale samples' composition. The high levels of SiO_2, Fe_2O_3, Al_2O_3, and K_2O indicate that the sediments are mature and recycled. These components show the makeup of the parent rocks as well as the results of weathering and sorting, two processes that occur during sedimentation. SiO_2 predominance points to a silica-rich source material that may have originated in felsic igneous rocks. The presumed provenance is further supported by the presence of other significant oxides such as Fe_2O_3 and Al_2O_3, and the presence of K_2O indicates potential input from minerals rich in potassium.

By identifying quartz as the predominant material and kaolinite as the secondary mineral, mineralogical analysis supplemented the geochemical data. A variety of geological sources, possibly including clay-rich sedimentary rocks, metamorphic terrains, and felsic igneous rocks, are suggested by the occurrence of minor minerals such as garnet, muscovite, orthoclase, osumilite, and illite. Different levels of weathering or sedimentary conditions in the source locations are implied by the variances in mineral concentrations among the samples.

The paleoenvironment and age of the shale samples were further elucidated by paleomorphomorph analysis. The varied collection of palynomorph, which includes *Cyathidites minor, Monocolpites* sp., *Longapertites* sp., and *Cingulatisporites ornatus*, among others, points to a terrestrial paleoenvironment with open forest vegetation. This view is further supported by the presence of a particular palynomorph, which also provides important details about the environmental conditions surrounding the shale sample deposition. Furthermore, the age range from the Campanian to Paleocene deduced from the palynomorph advances our knowledge of the local geological chronology. $SiO_2/ (Al_2O_3 + K_2O + Na_2O)$ ratios also suggest arid to semi-arid climatic conditions at the source area, which influences sediment maturity. This data sheds light on the weathering processes that shaped the shale samples' composition and aids in reconstructing the paleoclimate of the area. The study's findings have generally contributed to our knowledge of the provenance, paleoclimate, and depositional environment of the Cretaceous Shale from the Patti Formation in the Mid-Niger Basin. Hence expanding our investigation to include more analytical methods and larger sample sizes will increase a detailed understanding of the complex geological processes operating in the Mid-Niger Basin, Nigeria.

Acknowledgements
The authors acknowledged the Head of the sedimentological laboratory unit, Federal University Lokoja for using their laboratory equipment and assistance in the course of this research.

Conflict of interest
All authors declared there is no conflict of interest of any kind.

REFERENCES

Adebayo, O. F., Akinyemi, S. A., Madukwe, H. Y., Aturamu, A. O., & Ojo, A. O. (2015). Paleoenvironmental studies of Ahoko Shale, south eastern Bida basin, Nigeria: insight from palynomorph assemblage and trace metal proxies. *International Journal of Scientific and Research Publications*, 5 (10), 1-16.

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

Adeleye, D. R., & Dessauvagie, T.F.J. (1972). Stratigraphy of the Niger Embayment, near Bida, Nigeria. In: Dessauvagie TFJ, Whiteman AJ (eds) African geology. University of Ibadan Press, Ibadan, pp. 181–185.

Aigbadon, G. O., Odoma, N. A., Obasi, I. A., Christopher, S. D., Nanfa, C. A., Baba Aminu, M., & Akakuru, O. C. (2022). Hydrocarbon prospectivity of the southern Bida and northern Anambra Basin, Nigeria using palynological and geochemical studies. *Geosystems & Geoenvironment*, 1(1),100103. https://doi.org/10.1016/j.geogeo.2022.100103.

Aigbadon, G. O., Ocheli, A., Alege, T. S., & David, E. O. (2023). Petrological, palynological analysis and Geochemistry of Maastrichtian Patti Shale in some parts of the southern Bida Basin, Nigeria: Implications for provenances and hydrocarbon studies. *Communication in Physical Sciences*, 9 (3), 288-309.

Aigbadon, G.O., Igbinigie, N.S., Obasi, A.I., Akudo, E.O., Christopher, S.D., Ocheli, A., Igwe, D.O., Francis, A.J., Joseph, G.E., & Akor, D.J. (2024 a). Mineralogy, microfacies analysis of carbonate rocks in parts of the central Benue Trough, Nigeria. *Ife journal Science*, 26 (1):101-118. https://dx.doi.org/10.4314/ijs.v26i1.78

Aigbadon, G.O., Ocheli, A., Ozulu, G. U., Akor, J.D., & Owolabi, SK. (2024 b). Sedimentary: Carbonate microfacies and mineralogy of the southern Benue Trough and eastern Dahomey basin, Nigeria. *Unconventional Resources*, 4, 100082. https://doi.org/10.1016/j.uncres.2024.100082

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. *Journal of African Earth Sciences*, 41, 394-406.

Armstrong-Altrin, J. S., Lee, Y. I., Verma, S. P., & Ramasamy, S. (2004). Geochemistry of sandstones from the Upper Miocene Kudankulam Formation, southern India:

implications for provenance, weathering, and tectonic setting. *Journal of sedimentary Research*, 74(2), 285-297.

Armstrong-Altrin, J.S., & Verma, S.P. (2005). Critical Evaluation of Six Tectonic Setting Discrimination Diagrams Using Geochemical Data of Neogene Sediments from Known Tectonic Setting. *Sedimentary Geology*, 177, 115-129. http://dx.doi.org/10.1016/j.sedgeo.2005.02.004

Bhatia, M.R. (1983). Plate Tectonics and Geochemical Composition of Sandstone. *The Journal of Geology*, 91, 611-627.http://dx.doi.org/10.1086/628815

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

Condie, K.C. (1993). Chemical Composition and Evolution of the Upper Continental Crust; Contrasting Results from Surface Samples and Shales. *Chemical Geology*, 104, 1-37. https://doi.org/10.1016/0009-2541(93)90140-E

Cullers, R.L. (1995). The Controls on the Major and Trace Element Evolution of Shales, Siltstones and Sandstones of the Ordovician to Tertiary Age in the Wet Mountain Region, Colorado, U.S.A. *Chemical Geology*, 123, 107-131.
https://doi.org/10.1016/0009-2541(95)00050-V

Dickinson, W.R. (1985). Interpreting Provenance Relations from Detrital Modes of Sandstones. In: Zuffa, G.C., Ed., Provenance of Arenites, D. Reidel Publishing Company, Dordrecht, The Netherlands, 333-362. https://doi.org/10.1007/978-94-017-2809-6_15

Dickinson, W. R. (1988). Provenance and Sediment Dispersal in Relation to Paleotectonics and Paleogeography of Sedimentary Basins, In: K. L. Kleinspehn and C. Poala, Eds., New Perspective in Basin Analysis, Springer, New York, 1988, pp. 3-25.

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

Germeraad, J.H., Hopping, C.A., & Muller, J. (1968). Palynology of Tertiary Sediments from Tropical Areas. *Review of Palaeobotany & Palynology*, 6, 189-348.

Hayashi, K., Fujisawa. H., Holland, H.D., & Ohmoto, H. (1997). Geochemistry of 1.9 Ga sedimentary Rocks from Northeastern Labrador, Canada. *Geochimica et Cosmochimica Acta*, 61, 4115-4137. http://dx.doi.org/10.1016/S0016-7037(97)00214-7.

Jones, H.A. (1958). The Oolitic Ironstones of Agbaja Plateau, Kabba Province. Record of the Geological Survey of Nigeria, 20-43.

Karadag, M. M. (2014). Geochemistry, provenance and tectonic setting of the Late Cambrian-Early Ordovician Seydisehir Formation in the Caltepe and Fele areas, SE Turkey. *Chemie der Erde*, 74 (2), 205-224.

Kogbe, C.A., Ajakaiye, D.E., & Matheis, G. (1983). Confirmation of Rift structure along the mid-Niger valley, Nigeria. *Journal of African Earth Sciences*, 1,127-131.

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

McCulloch, M. T., & Wasserburg, G. J. (1978). Sm-Nd and Rb-Sr chronology of continental crust formation. *Science* (New York, N.Y.), 200(4345), 1003–1011.
https://doi.org/10.1126/science.200.4345.1003

McLennan, S.M. (1989). Rare Earth Elements in Sedimentary Rocks: Influence of Provenance and Sedimentary Process. *Review of Mineralogy*, 21, 169-200.

McLennan, S.M., Hemming, S., McDaniel, D.K., & Hanson, G.N. (1993). Geochemical Approaches to Sedimentation, Provenance and Tectonics. In: Johnsson, M.J. and Basu, A., Eds., Processes Controlling the Composition of Clastic Sediments: Geological Society of America, Special Papers, 285, 21-40.
http://dx.doi.org/10.1130/SPE284-p21

Obaje, N. G. (2009). Geology and mineral resources of Nigeria. Berlin Springer, 120, p. 221
Ojo, S.B., & Ajakaiye, D.E. (1989). Preliminary interpretation of gravity measurements in the mid-Niger Basin area, Nigeria. In: Kogbe CA (ed) Geology of Nigeria, 2nd edn. Elizabethan Publishers, Lagos, pp 347-358.
Ojo, O.J., & Akande, S.O. (2003). Facies relationships and depositional environments of the upper Cretaceous Lokoja Formation in the Bida Basin, Nigeria. *Journal of Mining & Geology* 39, 39-48.
Ojo, O.J., & Akande, S.O. (2009). Sedimentology and depositional environments of the Maastrichtian Patti Formation, southeastern Bida Basin, Nigeria. *Cretaceous Research*, 30, 1415-1425.
Oumar, K.O., François, G.N.N., Bertrand, M.M., Nathanael, T., Constantin, B.E., Simon, M.J., & Jacques, E. (2022). Mineralogical, Geochemical Characterization and Physicochemical Properties of Kaolinitic Clays of the Eastern Part of the Douala Sub-Basin, Cameroon, Central Africa. *Applied Sciences*.12 (18), 9143. https://doi.org/10.3390/app12189143.
Pettijohn, F.J. (1975). Sedimentary Rocks. 2nd Edition, Harper and Row Publishers, New York, 628 p.
Roser, B.P., & Korsch, R.J. (1986). Determination of Tectonic Setting of Sandstone-Mudstone Suites Using SiO2 Content and K2O/Na2O Ratio. *The Journal of Geology*, 94, 635-650. http://dx.doi.org/10.1086/629071.
Roser, B.P., & Korsch, R.J. (1988). Provenance Signature of Sandstone-Mudstone Suites Determined Using Discriminant Function Analysis of Major Element Data. *Chemical Geology*, 67, 119-139. http://dx.doi.org/10.1016/0009-2541(88)90010-1.
Roser, B. P., Cooper, R. A., Nathan, S., & Tulloch, A. J. (1996). Reconnaissance sandstone geochemistry, provenance, and tectonic setting of the lower Paleozoic terranes of the West Coast and Nelson, New Zealand. *New Zealand Journal of Geology & Geophysics*, *39* (1), 1-16.
Wronkiewicz, D.J., & Condie, K.C. (1990). Geochemistry and Mineralogy of Sediments from the Ventersdorp and Transvaal Supergroups, South Africa: Cratonic Evolution during the Early Proterozoic. *Geochimica et Cosmochimica Acta*, 54, 343-354.