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Research Paper

Reconstructing The Paleoenvironmental And Paleoclimate Variabilities Of The River Niger Basin In Nigeria: Insights From Palynological And Geochemical Proxies.

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ABSTRACT: *This study reconstructs the paleoenvironmental and paleoclimate variabilities of the Paleogene-Quaternary River Niger Basin in Nigeria, West Africa, using integrated geochemical (XRF) and palynological proxies, with samples collected from three locations along a downstream gradient: JB (proximal to the Agbaja ironstone formation), AL (midstream), and JL (farthest downstream). Geochemical analysis reveals distinct trends influenced by the proximity to the Agbaja ironstone. JB sediment exhibits high Fe_2O_3 (20.538 wt.%) and MnO (0.425 wt.%) concentrations, reflecting localised ferruginous inputs and tropical weathering associated with the ironstone. Downstream, AL and JL show increasing SiO_2 content (63.546 wt.% in JB to 87.215 wt.% in JL), indicating progressive sediment dilution, greater contributions from quartz-rich sources, and prolonged transport. The palynological analysis identifies diverse microfossils, including Laevigatosporites sp., Retitricolporites irregularis, Diatom frustules, and Botryococcus braunii, providing insights into vegetation dynamics and hydrological fluctuations. Rainforest indicators, such as Sapotaceae and Proxapertites cursus, signify wetter interglacial periods, while grassland taxa like Monoporites annulatus and charred gramineae cuticles denote arid phases. Algal taxa (Pediastrum sp., Diatom frustules) reflect freshwater conditions, whereas mangrove-associated species (Acrostichum aureum, Echiperiporites sp.) highlight episodes of brackish influence during sea-level rises. This bi-proxy approach reveals alternating humid and arid phases influenced by Quaternary climate oscillations. These changes have affected vegetation cover, sediment transport, and depositional settings. The findings enhance our understanding of the paleoenvironmental evolution of West Africa, providing valuable context for regional climate models and sedimentary processes. This study makes a significant contribution to the findings on Quaternary climate variability and its impact on the ecological and geological history of the River Niger basin in Nigeria, West Africa.*

KEYWORDS*: River Niger; Paleoenvironment; Paleoclimate: Goechemistry; Agbaja Formation: Palynology*

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I. INTRODUCTION

The River Niger Basin (Figure 1), a significant hydrological and ecological system in West Africa, has played a pivotal role in shaping the region's environmental and climatic history. Understanding the paleoenvironmental and paleoclimate variabilities of this basin, particularly during the Quaternary, is crucial for reconstructing the interplay of climatic forces, vegetation dynamics, and sedimentary processes that have influenced its evolution (Salzmann et al., 2011). This study utilises palynological and geochemical proxies to elucidate these changes, providing a multidimensional approach to environmental reconstruction.

The Quaternary period, characterised by alternating glacial and interglacial phases, has significantly impacted tropical regions, including West Africa. Fluctuations in temperature, precipitation, and monsoonal dynamics influenced sediment transport, vegetation distribution, and depositional environments within the Niger Basin (Gasse, 2000). Palynology, the study of fossilised pollen and spores, offers insights into past vegetation and climate changes, serving as a direct indicator of paleoecological conditions (Hooghiemstra et al., 2006). Meanwhile, geochemical analyses, particularly elemental and mineralogical compositions, reveal sediment provenance, weathering intensity, and depositional settings (Armstrong-Altrin et al., 2004; Morley, 2018).

In the context of the River Niger Basin, previous studies have documented evidence of significant climatic oscillations. Wet phases, marked by increased vegetation cover and enhanced river discharge, alternated with arid periods characterised by reduced monsoonal activity and aeolian processes (Akande et al., 2005; Alege et al., 2022;). These variations left distinct imprints on the basin's sedimentary record, which can be deciphered through a combination of palynological and geochemical proxies. For example, elevated iron and manganese oxides may indicate periods of tropical weathering, while shifts in pollen assemblages reflect changes in regional vegetation driven by climatic conditions (Salzmann et al., 2011; Alege et al., 2013; Ayuba et al., 2024; William et al., 2024).

Despite the wealth of information on global Quaternary climate patterns, there remains a gap in localised studies focusing on the River Niger Basin in Nigeria, West Africa. This research seeks to bridge this gap by integrating palynological data with geochemical analysis (XRF) to provide a comprehensive reconstruction of the paleoenvironmental and paleoclimate variabilities. The findings aim to enhance our understanding of how regional climatic and ecological systems responded to global climate drivers, with implications for current and future environmental management in the basin.

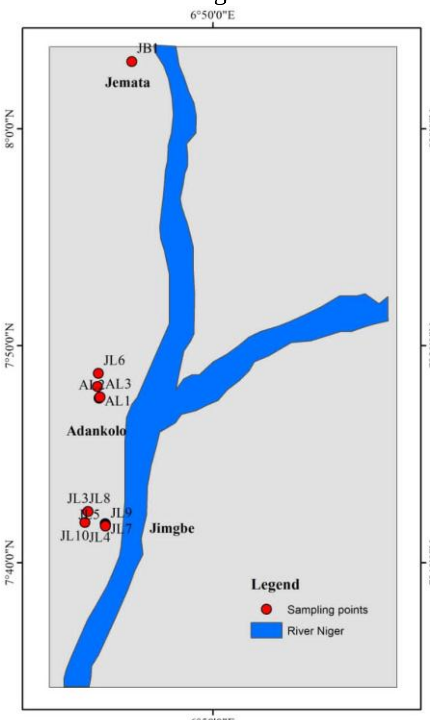


Figure 1. Location map of study area showing sample points

II. GEOLOGICAL SETTING

The southern Bida Basin, also known as the Middle Niger Basin, is an intracratonic sedimentary basin located in central Nigeria, extending from Kontagora in the north to Lokoja in the south. The basin is part of a NW-SE trending trough formed during the Late Cretaceous as a result of the tectonic reactivation of the Pan-African basement complex (Obaje, 2009; Ojo, 2012). It is flanked by the Anambra Basin to the southeast and the Dahomey Basin to the southwest, with the Niger River acting as a major geological and geomorphological feature cutting through the basin.

The southern Bida Basin is characterised by a sequence of predominantly clastic sediments comprising sandstones, siltstones, and claystones. The lithostratigraphy includes the Lokoja Formation at the base, consisting of coarse-grained sandstones and conglomerates deposited in fluvial to deltaic environments, and the overlying Patti Formation, dominated by finer-grained sandstones, shales, and coal seams indicative of lacustrine to deltaic settings (Kogbe et al., 1983; Agyingi, 1991). The Agbaja ironstone formation, a prominent feature in the southern part of the basin, consists of ferruginous oolitic and pisolitic sediments that formed in shallow marine or lacustrine settings under oxidising conditions.

The development of the basin was influenced by extensional tectonics associated with the opening of the South Atlantic during the Cretaceous period. Faulting and subsidence facilitated sedimentation, while post-depositional uplift and erosion shaped the current landscape (Ojo, 2012).

The southern Bida Basin includes key locations such as Jameta, Adankolo, and Jimgbe (this study location), which lie along the River Niger in the Lokoja area (Fig. 1). The river plays a significant role in sediment deposition, with its floodplains hosting alluvial sediments derived from upstream and surrounding geological formations. Proximity to the Agbaja ironstone formation significantly impacts the geochemistry of sediments in this area, particularly in locations closer to the formation, like Jameta.

The southern Bida Basin is notable for its mineral resources, including ironstone deposits (e.g., Agbaja), laterites, and potential hydrocarbon reservoirs. The ferruginous deposits in the Agbaja formation have been a subject of economic interest for iron ore exploitation (Adekoya et al., 2003).

III. METHODS OF STUDY

A total of 25 sediment core samples were collected from three strategically selected locations along the River Niger Basin in Nigeria: Jameta (JB), Adankolo (AL), and Jimgbe (JL), all in Kogi State (Figure 1). These locations were chosen to represent a downstream gradient away from the Agbaja ironstone formation, with JB being proximal, AL midstream, and JL farthest downstream. At each location, core samples were extracted at approximately 1 mm intervals using a specialised coring device to ensure high-resolution sampling of the sedimentary profile. The sediments were carefully packaged in sample bags and subsequently labelled to allow for proper identification.

The geochemical composition of the core samples was determined using X-ray Fluorescence (XRF) spectroscopy. This analysis provided quantitative data on major oxides (e.g., SiO_2 , Fe_2O_3 , MnO) and trace elements, enabling insights into sediment provenance, weathering intensity, and depositional processes (Alege et al., 2013; Alege et al., 2019; Aigbadon et al., 2023). The geochemical results were interpreted with respect to the influence of proximity to the Agbaja ironstone formation and downstream sedimentary trends.

The palynological examination involved processing sediment samples for fossil pollen, spores, algal remains, and other microfossils (Alege & Alege, 2013; Alege et al., 2020; Aigbadon et al., 2024). Samples were treated with standard acetolysis methods to isolate palynomorphs, which were subsequently identified and quantified under a microscope. The geochemical and palynological data were integrated to reconstruct paleoenvironmental and paleoclimatic variabilities.

IV. RESULTS

4.1. Microflora characterisation.

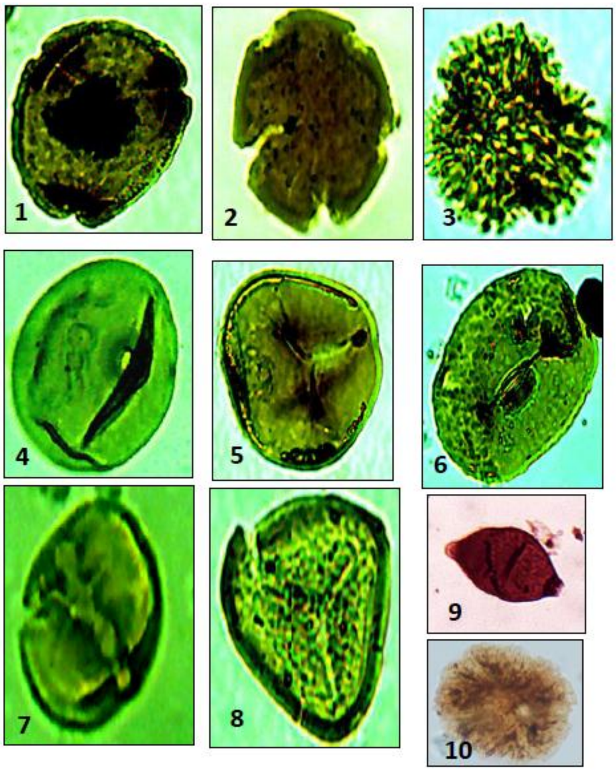
The outcrop samples are generally poorly fossiliferous and dominated by land-derived palynomorph species such as *Polypodiaceoisporites* sp., *Retitricolporites irregularis*, *Psilatricolporitescrassus*, *Laevigatosporites* sp., *Acrostichum aureum* and *Monoporites annulatus*. Common occurrences of fungal spores, diatom frustules and freshwater algae *Botryococcus braunii* were also identified (Table 1 and Figure 2).

Table 1: Palynological data and interpretation of the outcrop samples

Sample	Palynomorphs	Counts	Type
JB1-3	Acrostichum aureum (smooth trilete spore)	1	S
	Laevigatosporites sp.		
	Pachydermites diederixi	3	S
	Aletesporites sp.	1	P
	Sapotaceae	1	P
	Psilatricolporites crassus	5	P
	Retitricolporites irregularis	1	P
	Charred graminae cuticle	1	P
	Monocolpites sp.	1	CGC
	Fungal spores	3	P
	Botryococcus braunii	2	S
		1	FWA
AL1-3 Middle	Monoporites annulatus	2	P
	Trilete spore	2	S
	Laevigatosporites sp.	4	S
	Diatom frustules	3	DF
	Retitricolporites irregularis	1	P
	Botryococcus braunii	3	FWA
	Canthiumidites sp	1	P
	Psilatricolporites sp.	2	P
	Fungal spores	1	S
	CGC	1	CGC
J.L1-10	Polypodiaceoisporites sp.	9	S
	Monoporites annulatus	15	P
	Fungal spores	9	S
	Acrostichum aureum /Trilete spore.	4	S
	Verrucatosporites sp.		
	Laevigatosporites sp	12	S
	Arecipites sp.	13	S
	Diatom frustules	10	P

	Retitricolporites sp	8	DF
	Pediastrum sp.	2	P
	Psilatricolporites crassus	3	FWA
	Botryococcus braunii	4	P
	Tricolporites sp.	5	FWA
	Canthiumidites sp	1	P
	Charred graminae cuticle	4	P
	Echiperiporites sp.	2	CGC
	Sapotaceae	2	P
	Pachydermites diederixi	6	P
	Proxapertites cursus	3	P
	Aletesporites sp.	2	P
		1	S

P=Pollen; S=Spores; FWA=Fresh Water Algae; DF=Diatom frustules; CGC=Charred Graminae Cuticle



(1). *Psilatricolporites crassus* (2). *Pachydermites diederixi* (3). *Retitricolporites irregularis* (4). *Monoporites annulatus*(5). *Acrostichum aureum* (6). *Verrucatosporites sp.* (7). *Sapotaceae* (8). *Polypodiiaceoisporites sp.* (9). *Fungal spores.* (10). *Botryococcus braunii* **(Mag. X400**)

Figure 2. Photomicrographs of palynomorphs recovered in the study area

4.2. Geochemistry

Table 2. The oxide composition of the samples

Elemental Composition %	AL2 (wt.%)	JBL1 TOP (wt.%)	JL 1B (wt.%)	JL2 BOTTOM (wt.%)	JL2 MIDDLE (wt.%)	JL3 BOTTOM (wt.%)	JL5 BOTTOM (wt.%)	JL9 BOTTOM (wt.%)
O	46.842	44.511	49.576	51.445	45.232	50.331	50.154	48.304
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Al	7.798	7.659	5.747	2.990	9.195	4.387	4.814	8.289
Si	29.704	23.899	35.996	40.768	25.474	38.694	37.546	31.942
P	0.072	0.000	0.000	0.000	0.044	0.000	0.244	0.086
S	0.000	0.784	0.222	0.695	0.000	0.311	0.379	0.181
K	4.059	3.849	3.131	2.044	3.859	3.638	3.053	3.387
Ca	1.382	2.064	1.163	0.588	1.178	0.754	1.091	1.056
Ti	1.279	1.685	1.071	0.288	1.441	0.367	0.406	0.892
V	0.078	0.080	0.028	0.011	0.090	0.034	0.000	0.057
Cr	0.056	0.029	0.042	0.036	0.081	0.029	0.100	0.024
Mn	0.187	0.329	0.077	0.020	0.290	0.025	0.102	0.158
Fe	8.041	14.365	2.781	0.879	12.639	1.073	1.695	5.288
Co	0.036	0.048	0.014	0.006	0.061	0.000	0.010	0.017
Ni	0.001	0.001	0.005	0.005	0.004	0.001	0.004	0.003
Cu	0.048	0.070	0.044	0.044	0.053	0.034	0.068	0.031

Zn	0.021	0.044	0.005	0.002	0.026	0.017	0.009	0.008
Sr	0.052	0.087	0.025	0.017	-	0.037	0.034	0.028
Zr	0.220	0.362	0.031	0.009	0.198	0.017	0.021	0.083
Nb	0.017	0.030	0.006	0.006	0.014	0.005	0.006	0.006
Mo	0.007	0.008	0.003	0.003	0.006	0.004	0.003	0.001
Ag	0.037	0.047	0.011	0.008	0.034	0.023	0.017	0.020
Sn	0.000	0.000	0.000	0.000	0.000	0.104	0.000	0.000
Ba	0.027	0.000	0.000	0.109	0.072	0.045	0.178	0.121
Ta	0.033	0.049	0.022	0.021	0.009	0.039	0.053	0.017
W	0.000	0.001	0.000	0.003	0.001	0.030	0.012	0.000

Table 3. The elemental composition of the samples

Oxides Composition %	**AL2 (wt.%)**	**JBL1 TOP (wt.%)**	**JL 1B (wt.%)**	**JL2 BOTTOM (wt.%)**	**JL2 MIDDLE (wt.%)**	**JL3 BOTTOM (wt.%)**	**JL5 BOTTOM (wt.%)**	**JL9 BOTTOM (wt.%)**
SiO_2	63.546	51.126	77.007	87.215	54.497	82.777	80.322	68.334
V_2O_5	0.140	0.144	0.050	0.019	0.161	0.061	0.000	0.103
Cr_2O_3	0.082	0.042	0.062	0.053	0.118	0.043	0.146	0.036
MnO	0.242	0.425	0.099	0.026	0.374	0.033	0.132	0.204
Fe_2O_3	11.497	20.538	3.976	1.257	18.071	1.534	2.424	7.561
CoO	0.046	0.061	0.018	0.008	0.077	0.000	0.013	0.021
NiO	0.002	0.001	0.006	0.006	0.005	0.001	0.004	0.003
CuO	0.061	0.087	0.055	0.056	0.066	0.043	0.086	0.039
Nb_2O_3	0.024	0.043	0.008	0.008	0.020	0.007	0.009	0.008
MoO_3	0.011	0.012	0.004	0.005	0.009	0.007	0.005	0.002
WO_3	0.000	0.001	0.000	0.004	0.001	0.037	0.015	0.000
P_2O_5	0.166	0.000	0.000	0.000	0.101	0.000	0.559	0.197
SO_3	0.000	1.958	0.555	1.736	0.000	0.775	0.947	0.452
CaO	1.933	2.888	1.627	0.822	1.648	1.055	1.526	1.477
MgO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K_2O	4.890	4.636	3.771	2.463	4.649	4.382	3.678	4.080
BaO	0.030	0.000	0.000	0.121	0.081	0.050	0.199	0.135
AL_2O_3	14.733	14.471	10.859	5.650	17.373	8.288	9.095	15.662
Ta_2O_5	0.041	0.060	0.027	0.026	0.011	0.048	0.065	0.021
TiO_2	2.133	2.811	1.787	0.480	2.404	0.613	0.677	1.488
ZnO	0.026	0.055	0.006	0.003	0.033	0.022	0.011	0.010
Ag_2O	0.040	0.050	0.012	0.009	0.036	0.025	0.018	0.022
ZrO_2	0.298	0.489	0.042	0.013	0.267	0.024	0.028	0.112
SnO_2	0.000	0.000	0.000	0.000	0.000	0.133	0.000	0.000
SrO	0.061	0.103	0.030	0.020	-	0.043	0.041	0.033

V. DISCUSSION

5.1. Age determination

The low records and lack of diagnostic palynomorphs made it difficult to interpret the age of deposition of the outcrop samples. However, the occurrence of Pleistocene to Early Tertiary species such as *Arecipites* sp (Raphia type), *Monoporites annulatus* (Poaceae type), *Retitricolporites irregularis*, *Polypodiaceoisporites* sp. (*Pteris* sp.), *Verrucatosporites* sp. (*Stenochleana palustris*) and *Laevigatosporites* sp suggest an Early Quaternary (Pleistocene) – Early Tertiary (Paleocene) age of deposition (Alege et al. 2020; Aigbadon et al., 2023).

5.2. Provenance

The provenance of sedimentary samples can be interpreted by examining the concentrations of primary oxides, as they reveal insights into the source rock characteristics, weathering processes, and tectonic settings. The XRF data for the River Niger sediments suggest mixed sources and variable weathering intensities for the samples.

The High SiO_2 content, especially in JL (Tables 1 and 2), indicates a significant contribution from quartz-rich sources, such as mature sandstones or granitic terrains, suggesting intense weathering or prolonged transport (Blatt and Murray, 1980). The lower SiO_2 in AL and JB points to a mix of quartz and less resistant minerals like feldspar and clays. Studies in similar tropical regions, such as the southern Bida Basin, attribute high silica content to mature sediment input under arid conditions or reworking of older sediments (Armstrong-Altrin et al., 2004; Alege et al., 2020; Ayuba et al., 2024).

Sediments JB, with the highest Fe_2O_3 and MnO, reflects proximity to ferruginous formations like the Agbaja ironstone in Lokoja. These oxides are linked to mafic or ultramafic source rocks and lateritic weathering under humid conditions. Samples AL and JL show reduced Fe_2O_3 and MnO levels, reflecting dilution as sediment transport increases downstream. Akande et al., (2005) discuss similar trends in ferruginous sediment inputs from local ironstone formations in the Bida Basin.

The relatively high Al_2O_3 concentrations in AL and JB suggest a contribution from aluminosilicate minerals such as feldspar and clays, indicating active chemical weathering of felsic to intermediate igneous or sedimentary rocks. The lower Al_2O_3 in JL indicates quartz enrichment and lesser feldspar or clay input. Al_2O_3 enrichment correlates with high weathering indices, common in tropical regions (Salzmann et al., 2011; Aighadon et al., 2023). The elevated TiO_2 in JB suggests enrichment from heavy minerals, such as ilmenite or rutile, associated with high-energy environments near source areas, and in this case, the Agbaja ironstone Formation. Lower TiO_2 in JL (1.787 wt.%) indicates dilution by lighter, quartz-rich materials downstream (Alege et al., 2015; Oumar et al., 2022).The highest concentration of CaO in JB compared to the diminished concentration in location AL and JL downstream may indicate contributions from carbonate rocks or shells in the sediment source area, which may be potentially linked to proximity to freshwater carbonates or evaporate in tropical river systems (Gasse, 2000; Ayuba et al., 2024).

The primary oxides in the study locations, Jimeta (JB), Adankolo (AL) and Jimgbe (JL), reflect a mixed provenance, with samples from JB strongly influenced by local ferruginous sources from the Agbaja ironstone due to its proximity to it. On the other hand, sediments from AL and JL represent progressively more distal inputs, with contributions from quartz-rich, mature sediments indicative of upstream felsic sources. These interpretations align with regional studies that document sediment sourcing from diverse lithologies within the Niger Basin and surrounding terrains (Udoh et al., 2020).

5.3. Agbaja Ironstone factor

The XRF results (Table 2) suggest that the proximity of JB to the Agbaja ironstone formation likely contributes to its elevated Fe_2O_3 and MnO concentrations compared to samples farther downdip. Agbaja, a known ironstone deposit in Lokoja, contains sedimentary ironstones rich in hematite and goethite, which contribute to ferruginous enrichment in nearby sediments due to weathering and transport processes (Aigbadon et al., 2023). Sediment AL, being farther downdip, shows reduced Fe_2O_3 and MnO content, reflecting dilution by other sediment sources. JL, the farthest downdip, exhibits the lowest Fe_2O_3, indicating minimal contribution from the ironstone and dominance of siliceous input (Agyingi, 1991; Akande et al., 2005).

Sample AL, located farther downdip, displays lower Fe_2O_3 and MnO (0.242 wt.%) concentrations, indicating a reduced influence from Agbaja-derived material. Instead, this sample reflects mixed contributions from upstream sediments and other non-ferruginous formations within the Bida Basin. Sample JL, situated farthest downdip, exhibits the lowest Fe_2O_3 (3.976 wt.%) and MnO (0.099 wt.%), indicative of significant dilution and deposition dominated by siliceous materials, as evidenced by its highest SiO_2 content (77.007 wt.%).

These patterns align with findings from previous studies, which highlight the downstream reduction of ferruginous influence due to sediment dispersal and chemical weathering processes. Armstrong-Altrin et al. (2004) emphasise that iron-rich sediments near source areas typically display elevated iron oxides, which decrease with distance as silica and other stable minerals dominate farther downstream.

Thus, the geochemical trends of these sediments underscore the spatial variability in sediment provenance and weathering influenced by proximity to the Agbaja formation and downstream sediment transport processes (Agunleti and Salau, 2015; Aigbadon et al., 2023). These observations contribute to understanding sediment dispersal and the paleoenvironmental conditions in the southern Bida Basin.

5.4. Paleoclimate

The results revealed an overall high SiO_2 content in sediments from the JL location situated farthest downstream, which indicates a paleoenvironment dominated by physical weathering processes typical of arid or semi-arid conditions. The reduction in SiO_2 in AL and JB upstream suggests increased chemical weathering associated with humid tropical environments where quartz is less dominant and clay minerals are more prevalent (Morley, 2018; Gasse, 2000).The elevated Fe_2O_3 and MnO concentrations in JB reflect intense lateritic weathering under humid tropical conditions, favouring the accumulation of ferruginous material due to prolonged wet periods near the Agbaja ironstone formation, 1998; Agunleti & Salau, 2015).

Similarly, the high Al_2O_3 content in AL and JB points to a paleoenvironment with significant chemical weathering, likely associated with stable and warm climatic conditions. Studies indicate that high Al_2O_3 reflects the abundance of clay minerals formed during intense tropical weathering (Salzmann et al., 2011).

The high concentration of titanium oxide (TiO_2) in JB reflects a high-energy depositional environment near the source area, where heavy minerals like ilmenite and rutile accumulate. The lower TiO_2 content in JL suggests a more distal, lower-energy depositional setting, consistent with long-distance transport and sediment reworking (Armstrong-Altrin et al., 2004; Bolarinwa et al., 2013).

The relatively higher calcium oxide (CaO) content in JB and sulfates (SO_3) in both AL and JB suggests intermittent arid conditions conducive to carbonate and sulfate precipitation. This suggests a fluctuating paleoenvironment where wet conditions alternated with semi-arid phases, resulting in evaporitic mineral deposits (Gasse, 2000; Aigbadon et al., 2023).

Variability in trace elements like ZrO_2 and K_2O indicates differences in sediment maturity and depositional energy. The elevated ZrO_2 in JB suggests zircon enrichment during periods of higher energy transport, while lower K_2O in samples JL reflect feldspar depletion under arid conditions (Dill, 1998).

The downstream trends in the XRF data, particularly the dilution of Fe_2O_3 and MnO in sediments derived from AL and JL, reflect changes in sediment sources and depositional environments. Sediment JL, farthest downstream, records a sedimentary regime dominated by quartz, likely reflecting distal fluvial deposition during a stable arid or semi-arid climatic phase. In contrast, Sediment JB reflects proximity to ferruginous sources from the Agbaja ironstone, indicative of a tropical humid paleoenvironment with localised ferruginous input (Akande et al., 2005; Alege et al., 2021; Agunleti & Salau, 2015). This study suggests that wet phases promoted chemical weathering and lateritic development, while drier periods supported physical weathering and quartz enrichment. These findings align with broader paleoclimatic studies in West Africa, which document alternating humid and arid phases during the Quaternary Gasse, 2000; Salzmann et al., 2011).

5.5. Palynological paleoenvironmental Implications

The presence of spores, pollen, algae, and fungal remains found within the Quaternary sediments of River Niger found at Jameta, Adankolo, and Jimgbe locations has helped in its paleoenvironmental and paleoclimate reconstructions. The occurrences of *Retitricolporites irregularis*, *Psilatricolporites crassus,* and *Sapotaceae* pollensare indications of lowland tropical rainforests, suggesting periods of warm, humid climates that supported dense forest ecosystems (Hooghiemstra et al., 2006; Salzmann et al., 2011). The dominance of rainforest taxa highlights interglacial periods when rainfall was abundant.

The presence of diatom frustules, *Botryococcus braunii*, and *Pediastrum* sp., in the downstream sediments of AL and JL are indications of freshwater settings. Diatoms are especially indicative of stable aquatic settings, while *Pediastrum* thrives in nutrient-rich freshwater environments under humid climates (Gasse, 2000; Salzmann et al., 2011). In contrast, sediments from JB show no presence of these palynomorphs, suggesting the dominance of marine transgression and regression in the deposition of the Southern Bida Basin (Alege et al., 2023a; Aigbadon et al., 2023) and an increasing incursion of freshwater downdip from the downstream away from the basin. Also, the presence of *Acrostichum aureu*s, a mangrove fern, in the study locations signifies brackish or nearshore environments in tropical regions. Its presence reflects periods of elevated sea levels or the expansion of mangrove ecosystems due to increased precipitation and runoff (Hooghiemstra et al., 2006; Morley, 2018).

The occurrences of Proxapertites cursus and Verrucatosporites sp. indicate angiosperm-dominated forests. *Proxapertites cursus* is commonly linked to tropical forests, while *Verrucatosporites* sp. represents ferns that thrive under high humidity, corroborating evidence for rainforest expansion during wetter phases (Ayuba et al., 2024).

The presence of *Echiperiporites* sp. and *Canthiumidite*s sp. suggests proximity to brackish or coastal environments. Echiperiporites sp. is often associated with mangrove vegetation, while Canthiumidites sp. reflects coastal or estuarine conditions under fluctuating sea levels (Morley, 2018). This supports Alege et al.'s findings (2022; 2023) and Aigbadon et al. (2023) that the sediments of the southern Bida Basin are of estuarine environments.

The presence of pollen types palynomorphs, *Monoporites annulatus,* and *Psilatricolpites sp* in all study locations are characteristic of grasses and shrubs found in savannahs or open woodlands. Their presence indicates arid or semi-arid phases, during which forest cover retreats, giving way to grassland-dominated ecosystems (Salzmann et al., 2011; Hooghiemstra et al., 2006).

These palynomorph assemblages found at the different study locations of the River Niger sediments in West Africa suggest a dynamic paleoenvironment influenced by alternating wet and dry phases during the Quaternary. Wet phases supported tropical rainforest expansion, as evidenced by *Sapotaceae* and *Retitricolporites irregularis*, while dry phases promoted grasslands and open woodlands, indicated by *Monoporites annulatus* and charred plant remains. Periods of high water levels fostered diatom and algal blooms, while mangrove taxa reflect brackish environments during episodes of higher sea levels.

VI. CONCLUSIONS

The geochemical analysis (XRF) reveals distinct variations in oxide concentrations along the downstream gradient from JB (near Agbaja ironstone) to AL and JL. The elevated Fe_2O_3 and MnO contents in JB sediments confirm the influence of the Agbaja ironstone, suggesting localised ferruginous inputs under tropical weathering conditions. Downstream locations (AL and JL) exhibit higher SiO_2 content, indicative of quartz-rich sources and prolonged sediment transport.

Palynological data indicate diverse depositional environments, ranging from humid mangrove and freshwater conditions near JB, reflected by *Acrostichum aureum* and *Echiperiporites sp*., to tropical forest and open savannah ecosystems downstream, evidenced by *Sapotaceae*, *Monoporitesannulatus*, and charred grass cuticles. These variations reflect dynamic vegetation changes driven by climate and hydrological shifts during the Quaternary.

The sedimentary and palynological evidence highlight alternating humid and arid phases. Wet phases are marked by rainforest indicators such as *Retitricolporites irregularis* and algal taxa (*Pediastrum sp*., Diatom frustules). In contrast, arid phases are characterised by savannah and grassland pollen (*Monoporites annulatus*) and charred plant remains.

The downstream gradient significantly impacts sediment composition and paleoenvironmental conditions. Proximity to the Agbaja ironstone formation dominates the geochemical profile of JB. At the same time, dilution effects and contributions from quartz-rich sources become more pronounced in AL and JL, reflecting longer transport distances and sediment mixing.

By combining geochemical and palynological proxies, the study reconstructs a significant history of the River Niger Basin during the Quaternary. The results reveal the interplay between local geological inputs, climate-driven vegetation changes, and sediment transport dynamics, contributing to the understanding of the provenance and paleoclimatic evolution of the River Niger.

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