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Sedimentary Facies and Palynological Studies of Ajali Sandstones Formation Outcropping in Idah, Northern Anambra Basin, Nigeria

***[1]ALEGE, TS; [2]TELLA, TO; [1]AIGBADON, GO; [3]OMADA, JI**

*[*1]Department of Geology, Federal University Lokoja, Kogi State, Nigeria*
[2]Institute of Geosciences, University of Potsdam, Karl-Liebknecht-Str, D-14476 Potsdam
[3]Department of Environmental Science, National Open University of Nigeria

**Corresponding Author Email: topeemma12@gmail.com*
Co-Author Email: tella@uni-potsdam.de; godwin.aigbadon@fulokoja.edu.ng; jiomada@yahoo.com

ABSTRACT: The paleo-depositional environment of the Maastrichtian Ajali Sandstone Formation of the Anambra Basin has remained controversial as numerous studies have inferred differing origins of the sedimentary unit. This study presents analytical evidence on the depositional environment of the Formation based on its lithofacies and palynological characteristics by evaluating its depositional mechanisms, paleoclimate, and depositional environment. Microfacies and palynological studies were carried out on sediment samples from outcrop sections along the western flank of River Niger. Nine lithofacies and two facies' associations were identified with characteristics such as fining and coarsening upward sequences, which indicate subtidal channel and sandflat deposition in a shallow marine environment. Palynological studies reveal the occurrence of significant land-derived palynomorphs such as *Tricolporopollenites sp., Cyathidites sp., Distaverrusporites simples, Cingulatisporites ornatus, Psilatricolporites Crassus, Longapertites sp*. with freshwater algae *Botryococcus braunii* of Maastrichtian age. These results confirm that the sediments of the Ajali Sandstone are of a marginal marine system fed by continental facies. These facies have been reworked by tidal processes characteristic of an inner neritic environment deposited during regressive episodes.

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Clastic sedimentation is characterised by the interaction between physical, chemical, and biological processes of weathering, erosion, transportation and deposition that result in the Formation of sediments, sedimentary facies and sedimentary environments (Chernicoff and Whitney, 2007; Nichols, 2009). As these processes are often preserved in the sedimentary record, the use of facies character (Walker, 2006; Tucker, 2003) and palynomorphs assemblages (McGowran, 2005) are essential in the diagnosis of environments of deposition and paleoclimate of clastic sediments. The siliciclastic Maastritchtian Ajali Sandstone Formation, the focus of this study, is an important lithostratigraphic unit of the Anambra Basin, SE Nigeria, because of its excellent aquifer and reservoir characteristics.

This sedimentary unit has been studied by various authors, using its textural characteristics and petrographic peculiarities to deduce its provenance and depositional environment. By analysing the textural, mineralogical, and geochemical properties of the Formation, Tijani et al., (2010) deduced its source and weathering circumstances. Ilevbare and Omodolor (2020) used textural traits and pebble morphometry to study the sediments of the Ajali Formation on the western side and assess its depositional environment. Many authors have analysed the paleocurrent patterns, grain size analysis, and stratigraphic sequences of the Formation (Hoque and Ezepue, 1977; Ladipo, 1988; Adamu et al., 2018; Tijani et al., 2010) to determine the provenance and depositional environment of Ajali Sandstones. The depositional environment of the Ajali formation has, however, remained a subject of controversies, with different authors assigning it a spectrum of environments ranging from continental (Grove, 1951), fluvio-deltaic (Agagu, 1985; Awalla and Ezeh, 2004; Hoque and Ezepue, 1977), fluvial (Reyment, 1965; Tijani et al., 2010), subtidal and channels systems (Onuigbo et al., 2016; Ladipo, 1985) and marginal to shallow marine (Amajor, 1984; Nwajide, 2022).

This study aims to synchronise the sedimentary facies and palynological parameters to ascertain further the paleo-depositional environment of the Ajali Sandstones of Idah in the Northern Anambra Basin. Hence, the objective of this study are to generate new analytical data on the sedimentary facies of the Maastrichtian Ajali Sandstones of Anambra Basin outcropping at Idah and evaluate the diagnostic palynomorphs in the study area to establish the palynologic age and paleoclimate of the sediments.

**Corresponding Author Email: topeemma12@gmail.com*

MATERIALS AND METHODS

The study area is located in Idah on the western flank of the River Niger within the Ajali Formation of Anambra Basin. It is located between longitude $07^0$07'32" N to $07^0$07'33.9" N and latitude $06^0$44'17.0" E to $06^0$44'18.5" E. (Fig. 1). This area is accessible by undulating footpaths on the Ajegwu-Idah road and Ocheche River channels on an elevation of 30m with the river trending 20^0 NE that provides good and fresh exposures. The exposures can be found along some sections of the footpath. The streams exhibit a linear drainage pattern.

The Anambra Basin is one of the seven sedimentary domains in Nigeria and covers an area of about 40,000 km^2 (Murat, 1972). It is located at the southwestern end of the Trough and is genetically related in origin and development to the Benue Trough. The Precambrian basement complex rocks of western Nigeria form the basin's western boundary. The Abakaliki Anticlinorium forms its eastern boundary (Figure 1). Marine and paralic shales of the Nkporo Formations, overlain by the coal measures of the Mamu Formation, marked the beginning of sedimentation in the Anambra Basin. The Mamu Formation's lateral equivalents are the overlying fluviodeltaic sandstones of the Ajali and Owelli Formations (Idakwo et al., 2013). The Mamu Formation sediments were accumulated by the basin's gradual subsidence, which was started by a regression during the Maastrichtian and overlain by the Nkporo Shale and Ajali Sandstone (Reyment, 1965). The thick, friable, poorly sorted sandstones of the Ajali Formation (false-bedded sandstone) are typically white and occasionally iron-stained. The Nsukka Formation conformably overlies the Ajali Sandstone and occupies a large area of land to the west of the Udi Plateau (Reyment, 1965).

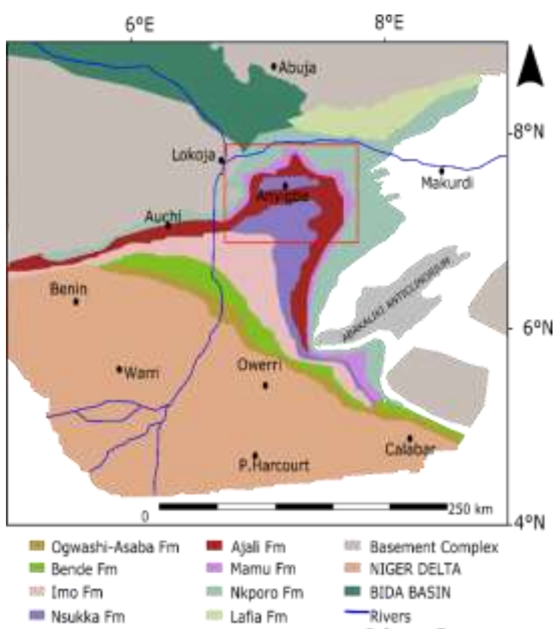

Fig 1. Geological map of the Anambra Basin (modified after Odoma et al., 2015). The red box highlights the study area.

According to Anakwuba et al., (2018) and Obi and Okogbue (2004), sediment deposition in the basin commenced in the Campanian–Maastrichtian with a brief marine transgression followed by regression.

Sample Collection and Evaluation: Unconsolidated sandstone samples were collected from seven sections of the study area at different locations (Figure 1) through detailed lithologic logging of various outcrop sections from base to top. Identifying the lithofacies, textural characteristics, and sedimentary structures of the lithologic units and the samples designated as OR1, OR2, OR3, OR4, OR5, OR6 and OR7 was done on the field. The samples were further processed and analysed for their palynomorph contents. The result was used to deduce the age and possible paleoenvironment of sediment deposition. A standard palynological processing method for the extraction of palynomorphs was applied. The procedure involves disaggregating the samples into smaller pieces, weighing 25 g of each sample, and macerating the sediments using different inorganic reagents, such as diluted hydrochloric acid (HCl), hydrofluoric acid (HF), and Nitric acid (HNO_3). These reagents remove carbonate and silicate minerals and help concentrate the palynomorphs. The acidic solution was subsequently neutralised with Potassium hydroxide (KOH) and distilled water. The palynomorph-rich residue was later mounted on labelled glass slides using a loctite mounting medium for microscopic examination. The samples' ages were determined using marker species and palynoflora association recovered from the samples. These were compared to the published works of Lawal and Moullade (1986).

RESULTS AND DISCUSSION

Field Characteristics: Seven (7) locations (OR1, OR2, OR3, OR4, OR5, OR6 and OR7) were mapped in the Ajali Formation exposed in the Idah area (Plate 1a, b, c, d, e, f and g). Each section is a well-exposed sandstone with thicknesses ranging from 1m to 10 m (Fig. 2a, b, c and d). Cross beddings and bioturbations characterise the observed sections.

Plate 1 (A): Photo-image of representative outcrop OR1

Plate 1(A) is a photo-image of representative outcrop OR1 showing coarse to pebbly sandstone with intense bioturbation and parallel laminations; B: photoPhoto-imageR2 showing coarse to pebbly sandstone with planar cross beds and fair bioturbations; C: photo-image of OR3 showing grey colour medium to coarse-grained sandstone with planar cross beds and fair bioturbations; D: photo-image of OR4 showing fairly bioturbated coarse-grained sandstone with planar cross beds and reactivation surface.

Plate 1B is a photo-image of representative outcrop OR5 showing a finning upward coarse to medium grained, trough cross-bedded sandstone with a high angle of inclination; F: photo-image of OR6 showing milky whitish fine to medium grain, fairly bioturbated cross-bedded sandstone with reactivation surface.; G: photo-image of OR4 showing fairly bioturbated coarse-grained sandstone with herringbone and trough cross-beds.

Plate 1 B: Photo-image of representative outcrop OR5

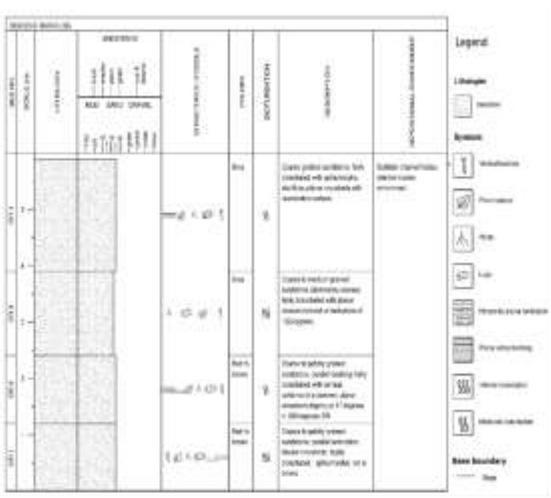

Fig 2: (a) Litholog and interpretation of sections OR1, OR2, OR3 and OR4.

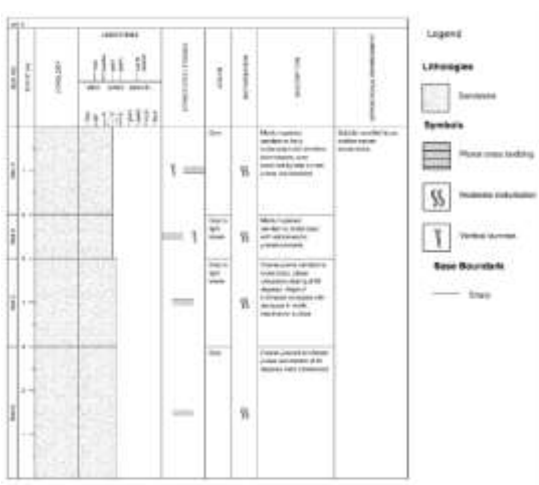

Fig 2b. Litholog and interpretation of section OR5.

Sedimentary Facies: The following sedimentary facies in the study area were inferred based on field observation of the textures and sedimentary structures.

Pebbly coarse-grained sandstone facies (A): This facies consists of poorly sorted pebbly coarse-grained sandstone that forms erosive contact with the upper bed. They occur in repeated cycles, pass upward into coarse-grained sandstone, and are overlain by coarse-grained to medium-grained cross-bedded sandstone (Plate 1 a, b). This facies occur at the bases of sections OR1 and OR2 (Fig. 2a). Bioturbations are more evident in OR1 than in OR2.

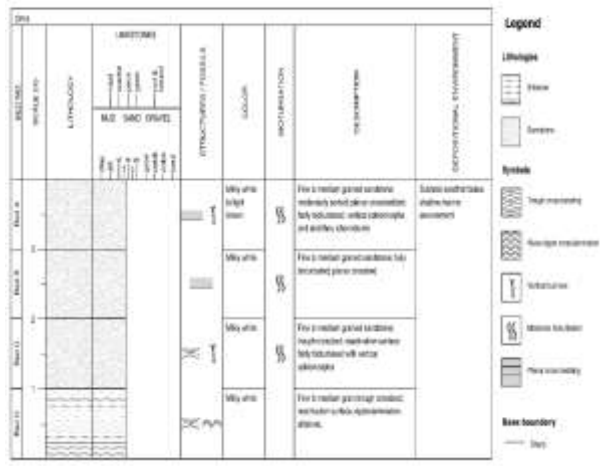

Fig 2c. Litholog and interpretation of section OR6.

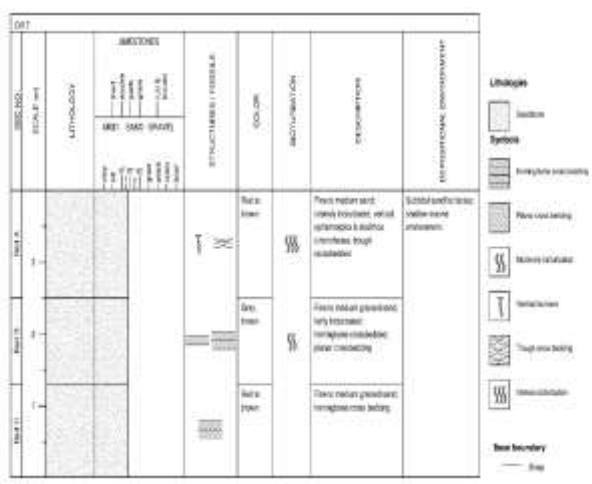

Fig 2d. Litholog and interpretation of section OR7.

Coarse-grained sandstone subfacies (B): This lithofacies occurs in sections OR1, OR2, OR3, OR4 and OR5 (Plate 1 a, b, c, d ande). It is characterised by various colours ranging from milky to grey to reddish brown and bed thickness that ranges from 1.2m to 9m, which sometimes contains elements of plant materials (Fig. 2a and b). The coarse-grained sand suggests a high-energy depositional setting (Adamu et al., 2020; Alege et al., 2020).

Medium-grained sandstone subfacies (C): This lithofacies occurs in sections OR3, OR5, OR6, and OR7 studied in the area (Plate 1c, e, f and g). They are made up of colours ranging from milky white to light brown specks and sometimes a uniform light brown. Bed thickness ranges from 2m to 5.2m with sandstone cast of tree-trunk (Fig. 2a, b, c, d) commonly seen towards the upper part of the sections. The medium-grained sand suggests moderately high energy of deposition. The poor sorting frequency indicated less sediment reworking during transport and deposition by the fluvial process (Friedman, 1967; Alege et al., 2020). The presence of sandstone cast of tree-trunk suggests fluvial deposits.

Fine to medium-grained sandstone (D): The lithofacies is fine to medium-grained, moderately sorted sandstone displaying a fining upward signature. The two sections, OR6 and OR7 (Plates 1 f and g), display planar cross beddings and trough cross beddings with an average thickness of 4m (Fig. 2c, d). These lithofacies indicate fluctuation in tidal current velocities (Kreisa et al., 1986; Nwajide, 2022). *The bioturbated sandstone subfacies (E)*: All sections are fair to intensely bioturbated (Plate 1). They comprise vertical ophiomorpha burrows with clear imprints of trace fossils from the skolithos ichnofacies (Fig. 2a, b, c, d). The identified forms of trace fossils include Skolithos ichnofacies which suggest intertidal flats and marginal marine settings (Adamu et al., 2020; Alege et al., 2020; Pemberton et al., 1992).

Herringbone cross-bedded sandstone subfacies (F): This lithofacies was obvious in the bioturbated fine to medium-grained sandstone of OR7 section with grey to reddish brown colour (Plate 1g). The outcrop has a bed thickness of 2.2 m and dipping with westerly azimuths lying in the range of 80 to 116^0 (Fig. 2d).

*Planar cross-bedded sandstone subfacies (G)***:** This lithofacies is characterised by red to brown to milky white medium to coarse-grained sandstone with parallel lamination that is conspicuously visible in all the sections of the study area. Dip angles characterise the tabular cross-beds in OR4 and OR5 up to 40^0 and a cross-bed set of an average thickness of about 2cm (Plate 1d, e). The trending sets of OR2 and OR3 were inclined to the west at an angle of 132^0, with the foreset increasing upward with a decreased width (Plate 1b, c). The nature of the cross-bed sets suggests a subtidal origin (Alege et al., 2020).

Planar cross-bedded with reactivation surface sandstone facies (H): The facies is present in OR4, OR5 and OR6 (Plate 1d, e, f), displaying bedding units that show sigmoidal features. They occur as erosional surfaces cutting across the cross-bed sets.

Trough cross-bedded sandstone facies (I): The lithofacies is fine to medium-grained, moderately sorted sandstone with trough cross-beddings showing a finning upward signature (Plate 1f, g). They are about 1m thick at the measured sections OR6 and OR7 (Fig. 2c, d).

Facies Association: Based on the facies description, two (2) facies associations have been recognised from the sedimentary structures present in the study area.

Subtidal channel facies association (FA1): This facies association (FA1) shows a finning upward succession comprising the pebbly coarse-grained sandstone (A), Coarse-grained sandstone subfacies (B) with an erosional base, bioturbated sandstone subfacies (E), Planar cross-bedded sandstone subfacies (G) and Planar cross-bedded sandstone with reactivation surface sandstone facies (H) (Fig.2a) is interpreted as the subtidal channel facies association within the shallow marine environment (Amajor, 1984; Friedman, 1967; Siddiqui et al., 2017; Adamu et al, 2020; Alege et al, 2020).

The subtidal sandflat facies association (FA2): The subtidal sandflat facies (F1) is characterised by a coarsening upward signature OR5, OR6, and OR7 (Fig. 2b, c, d) consisting of fine to medium-grained (D), moderately sorted sandstone with the trough, planar and herringbone cross-beddings and reactivation surfaces. The combination of these lithofacies is interpreted as the shallow marine environment dominated by the subtidal sandflat facies association (Amajor, 1984; Okoro et al., 2020; Nwajide, 2022).

Table 1: Distribution of the recovered palynomorphs in the OR study area.

Sample	Palynomorphs	Type	Counts	Remarks
OR-1	*Psilatricolporites* sp.	P	1	The occurrence of *Tricolporopollenites* sp. probably indicates Maastrichtian – Paleocene age Brackish- Normal marine salinity Marginal marine
	Polypodiaceoisporites sp.	S	2	
	Botryococcus braunii	FWA	2	
	Tricolporopollenites sp.	P	1	
	Psilatricolporites crassus	P	1	
OR-2	*Botryococcus braunii*	FWA	1	The palynoflora suggests the age with the OR-1 sample. Campanian-Maastrichtian age
	Polypodiaceoisporites sp.	S	1	
	Cingulatisporites ornatus	S	1	
	Monocolpites sp.	P	2	
OR-3	*Retitricolporites* sp.	P	1	The occurrence of *Proxapertites cursus* and *Tricolporopollenites* sp. suggest (?) Maastrichtian – Paleocene age
	Proxapertites cursus	P	1	
	Tricolporopollenites sp.	P	2	
	Fungal spores	S	3	
OR-4	*Laevigatosporites* sp.	P	1	Sample age with OR-3.
	Cyathidites sp.	S	1	
	Botryococcus braunii	FWA	2	
	Diatom frustules	DF	2	
OR-5	*Tricolporopollenites* sp.	P	2	The palynoflora suggests the age with the OR-1 sample.
	Inaperturopollenites sp.	P	1	
	Proteacidites sp.	P	1	
	Diatom frustules	DF	2	
	Fungal spores	S	3	
OR-6	*Distaverrusporites simplex*	S	1	*Polypodiaceoisporites* sp and *Botryococcus braunii* suggest the brackish to freshwater environment of deposition. The palynoflora assemblage suggests Maastrichtian – Paleocene age
	Monocolpites sp.	P	1	
	Fungal spores	S	2	
	Botryococcus braunii	FWA	3	
	Tricolporopollenites sp.	P	1	
	Polypodiaceoisporites sp	S	1	
OR-7	*Cyathidites minor*	S	1	Occurrence of *Cyathidites minor, Cingulatisporites ornatus* and *Inaperturopollenites* sp suggest Maastrichtian age.
	Cingulatisporites ornatus	S	1	
	Tricolporopollenites sp.	P	3	
	(?) Longapertites sp.	P	1	
	Inaperturopollenites sp.	P	1	

Palynology: Table 1 and Plate 3 below show the occurrence and distribution of palynomorph counts in samples OR1, OR2, OR3, OR4, OR5, OR6 and 0R7.

The samples are poorly fossiliferous with few land-derived pollen and spore species such as *Tricolporopollenites* sp., *Psilatricolporites* sp., *Distaverrusporites simplex*, *Cyathidites* sp. and *Cingulatisporites ornatus*. Fungal spores, Diatom frustules and freshwater algae *Botryococcus braunii* were also identified.
The samples' age was determined using marker species and palynoflora association recovered from the samples (Table 1: Plate 3). These were compared to the published works of Lawal and Moullade (1986). The details of the results of the analyses are presented.

Poor records of palynomorphs characterise OR1. However, there is the occurrence of *Psilatricolporites* sp., *Polypodiaceoisporites* sp., *Botryococcus braunii*, *Tricolporopollenites* sp., and *Psilatricolporites crassus.* *Polypodiaceoisporites* sp and *Tricolporopollenites* sp. indicate a Maastrichtian – Paleocene age. *Botryococcus braunii* suggests freshwater to the brackish marginal marine environment of deposition.

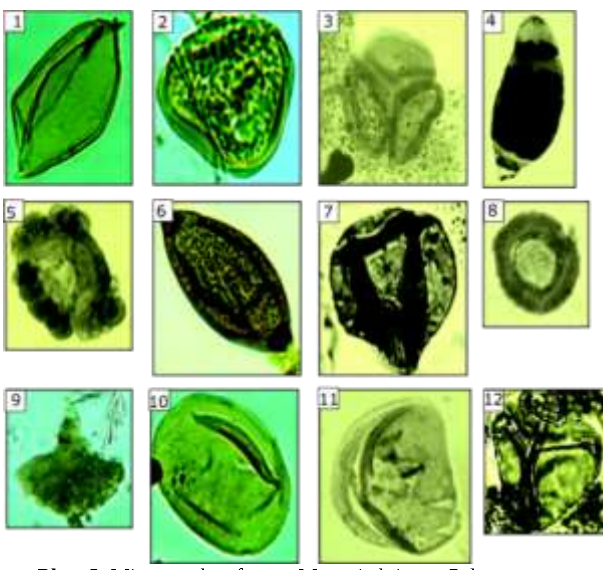

Plate 3. Micrographs of some Maastritchtian to Palaeocene palynomorphs from the study area, magnification (X 40)
1. *Monocolpites sp. 2. Polypodiaceoisporites sp 3. Tricolporopollenites sp* 4. Fungal spore; 5. *Distaverrusporites simplex 6. Fungal spore* 7. *Inaperturopollenites sp. 8. Fungal spore; 9. Botryococcus braunii 10. Laevigatosporites 11. Longapertites sp* 12. *Cyanthidites minor*

Palynological distributions: OR2 section is characterised **by** *Botryococcus braunii*, *Polypodiaceoisporites* sp., *Cingulatisporites ornatus*, and *Monocolpites* sp. The presence of these palynofloras suggests a Late Maastrichtian age.OR3 section is characterised by *Retitricolporites* sp., *Proxapertites cursus*, *Tricolporopollenites sp*. and *Fungal spores.* The occurrence of *Proxapertites cursus* and *Tricolporopollenites* sp. suggest (?) Maastrichtian – Paleocene age.OR4 section is characterised by palynomorphs such as *Laevigatosporites* sp., *Cyathidites* sp., *Botryococcus braunii* and *Diatom frustules*. *Cyathidites* sp suggests pteridophytes sporomorphs, while *Diatom frustules* suggest a brackish (saline) environment of deposition. The following palynomorphs characterise OR5: *Tricolporopollenites* sp, *Proteacidites* sp. *Inaperturopollenites* sp.*diatom, fustules* and *Fungal spores.* The palynoflora suggests a Campanian to Maastrichtian age. Diatom frustule indicates a saline marine environment that suggests a shallow marine environment. OR6 consists of *Distaverrusporites simplex, Monocolpites sp*., *Fungal spores, Botryococcus braunii, Tricolporopollenites sp.,* and *Polypodiaceoisporites sp,* which characterise this section. *Polypodiaceoisporites* sp and *Botryococcus braunii* suggest the brackish to freshwater environment of deposition belonging to the Maastrichtian – Paleocene age. Furthermore, Distaverrusporites simplex and Monocolpites also strongly suggest a Late Campanian to Maastrichtian age. The section OR7 is characterised by *Cyathidites minor, Cingulatisporites ornatus, Tricolporopollenites* sp., *Longapertites* sp., *Tricolporopollenites* sp., *Inaperturopollenites* sp. and Fungal spores. The occurrence of *Cyathidites minor, Cingulatisporites ornatus* and *Inaperturopollenites* sp suggests Maastrichtian age.

Paleodepositional Environment: Lithofacies and Granulometry: Nine lithofacies have been identified and described in Ajali Formation of Idah based on their lithology and sedimentary structures and are namely: pebbly coarse-grained sandstone facies (A), Coarse-grained sandstone subfacies (B), Medium-grained sandstone subfacies (C), Fine to medium-grained sandstone (D), The bioturbated sandstone subfacies (E), Herringbone cross-bedded sandstone subfacies (F), Planar cross-bedded sandstone subfacies (G), Planar cross-bedded with reactivation surface sandstone facies (H) and Trough cross-bedded sandstone facies (I). The presence of pebbly sandstone (A) coarse-grained (B) and medium-grained (C) sandstone subfacies (Plate 1 a- e; Fig. 2a and b) is an indication of a high energy depositional setting in a tidally influenced environment (Adamu et al., 2020). The predominance of poor sorting reflects less sediment reworking during transport and indicates rapid deposition by the fluvial process (Friedman, 1967). These features suggest deposition in the upper flow regime. The presence of sandstone cast of tree-trunk suggests fluvial deposits. Medium-grained sandstone may have been formed because of partial fluidisation and similar to high-density turbidity flows in the distal shelf (Aird, 2019; Nichols, 2009; Ramos et al., 2006) such as the Lower Eocene, Zumaya, northern Spain (Shanmugam, 2006). The bioturbated sandstone subfacies (E) identified as Skolithos ichnofacies suggest intertidal flats and marginal marine settings (Adamu et al., 2020; Pemberton et al., 1992). Furthermore, the presence of the herringbone crossbedding (Plate 1g; Fig. 2d) suggests depositions by current reversals causing dunes and sand waves to change their direction of migration. This bi-directional cross-stratification indicates beds formed during the slack water stages of tidal cycles and is associated with moderate to high energy environments indicative of tidal deposits (Alege et al., 2020; Friedman, 1967). The presence of cross-bed sets suggests a tidal depositional setting. Planar cross-stratification (G) represents low-energy wave deposition by strong traction currents diagnostic of tidal processes in a fluvial or shallow marine setting (Boggs, 2006; Walker and James, 1992). Trough crossbedding indicates a strong tidal current in migrating sinuous large-scale ripples in the ebb and tide-dominated setting (Button and Vos, 1971). Reactivation surfaces (Plates 1d, eand f)) indicate fluvial action resulting in a copious supply of medium to coarse-grained sandstone during short-term strongly asymmetric tidal flow (Boggs, 2006; Houthuys and Gullentops, 1988; Reading, 1996; Tucker, 1996). The subtidal channel facies association is characterised by a fining upward, poorly sorted, intensely bioturbated pebbly coarse to coarse-grained sandstone with planar cross-beds. The poorly sorted sandstones bounded by sharp erosional bases suggest deposition in a high-energy environment by tidal/wave action (Friedman, 1967; Siddiqui et al., 2017). The prevalence of planar bedded sandstones further indicates a tidal sand flat deposit in the upper flow regime (Flemming, 2012; Raaf et al., 1977; Schindler et al., 2015), while the cross-bed dips also support high energy deposition in a subaqueous environment. The intense bioturbation within this facies association gives credence to a shallow marine sands environment where the currents responsible for the transportation and deposition of the sand also carry nutrients for benthic organisms living in the sandy substrate (Nichols, 2009). Also, the identified vertical burrows belonging to Ophiomorpha in the Skolithos ichnofacies suggest the tidally influenced marginal marine environment within the foreshore or upper shoreface settings (Pemberton et al., 1992) (Miall, 2000; Nwajide, 2022). The presence of the planar bedding sedimentary structure is interpreted to represent low energy wave deposition which is diagnostic of tidal processes sand deposit in shallow marine settings (Walker and James, 1992). Similarly, the westerly dipping of the azimuth indicates hydraulic pressure during water escape, and the nature of the cross-bed sets also suggests a subtidal origin (Nwajide, 2022).

The subtidal sandflat environment is characterised by a coarsening upward profile of fine to medium-grained moderately sorted bioturbated cross-bedded sandstone. The identified vertical Ophiomorpha burrows in the Skolithos ichnofacies suggest colonisation by suspension feeders in a tidally influenced high-energy intertidal shallow marine environment within the foreshore or upper shoreface settings (Pemberton et al., 1992) (Nwajide and Hoque, 1979; Nwajide,2022). Herringbone cross-bedding suggests tidal currents and reworking activities, resulting in bipolar cross-bedding (Onuigbo et al., 2016; Siddiqui et al., 2017; Nwajide, 2022). The nature of the herringbone sets indicates a subtidal origin. Trough crossbedding indicates a strong tidal current in the migration of sinuous large-scale ripples in the ebb and tide-dominated setting (Button and Vos, 1971). The planar cross-bedded sandstone with reactivation surface facies (H) is characteristic of short-term strongly asymmetric tidal flow resulting in a significant supply of medium to coarse-grained sandstone. The occurrence of cross-bedded sedimentary structures as present in the study area suggests subtidal sand flat typical of the shallow marine environment (Amajor, 1984; Houthuys and Gullentops, 1988; Mbulk et al., 1985; Nwajide, 1980; Okoro et al., 2020) (Nwajide and Hoque, 1979; Miall, 2000).

Paleoenvironment (palynology): The depositional environment was interpreted based on the ecological affinities of the spores, pollens, and differences in the terrestrial and marine similarities in the assemblages (Kneller, 2009; Ogbahon, 2019) (Table 1; Plate 3). The occurrence of *Inaperturopollenites sp* and *Cyathidites* sp. suggest paleoecological affinities of pteridophytes dominated by angiosperms, which means vegetation in a warm and humid climate, which further confirms the type of climate responsible for the non-feldspar bearing provenance of the study area and the Formation of the Maastrichtian coal in the northern Anambra basin (Aigbadon et al., 2022; van der Hammen, 1954). The *diatom frustules* of saline water diatom skeleton, *Polypodiaceoisporites* sp., and *Laevigatosporites* sp. indicate the Maastrichtian age and are tied to the neritic shallow marine environment. These diatom species have also been used to interpret the shallow marine environments of the siliceous deposits in the Gafsa basin, Tunisia (Henchiri, 2007). The occurrence of land-derived palynomorphs such as *Tricolporopollenites* sp., *Cyathidites* sp., *Distaverrusporites simples, Cingulatisporites ornatus, Psilatricolporites crassus, Longapertites* sp. with freshwater species of *Retitricolporites* sp, *Psilatricolporites crassus* and *Botryococcus braunii* in the samples suggest a shallow marine deposition system with a high influx of continental (terrestrial) facies that are reworked by wave and tidal processes to upper deltaic plain (Nwajide, 2022). The palynomorph assemblages are comparable to those Ogala (2010) described in the Maastrichtian coal measures of the Anambra basin. They can be compared to those of Lawal and Moullade (1986) and Obaje et al. (2000) in the Pindiga Formation of the Upper Benue Trough. Furthermore, the presence of *Proxapertites cursus* and *Psilatricolporites,* which were found in association with marine elements, indicates brackish water within the nearshore to the inner neritic environment (Frederiksen, 1985; Ogbahon, 2019). Moreover, the record of *Botryococcus braunii* in some of the samples may also suggest a low-level salinity environment of deposition, as the form is known for its good adaptation to saline environments. The mixture of marine species dominated by diverse terrestrial palynomorphs and freshwater algae suggests a brackish freshwater environment of deposition within a marginal to shallow marine setting. Similarly, *Laevigatosporites sp* and *Proxapertites cursus* imply a humid tropical climate, as emphasised in the works of Muller (1968) and Ogala (2010). The depositional environment suggested for the study area is shallow marine with a minimal fluvial influence.

Age determination: The age of the samples was determined by using environmentally significant marker species and the palynoflora association recovered from the samples. These were compared to the published works of Lawal and Moullade (1986). All the observed palynomorph assemblages (Plate 3) in the samples were dated Early to Late Maastrichtian age due to the presence of the following vital taxa (Table 1): *Tricolporopollenites sp., Psilatricolporites sp., Distaverrusporites simplex, Cyathidites sp.* and *Cingulatisporites ornatus, Cyathidites minor, Longapertites sp., Cingulatisporites ornatus, Proxapertites cursus, Tricolporopollenites sp.* and *Inaperturopollenites sp* (Hoeken-Klinkenberg, 1964; Ikhane et al., 2011; Ladipo et al., 2001, 1992; Ogala et al., 2010; Ola-Buraimo and Adeleye, 2010; Ola-Buraimo and Akaegbobi, 2013). The appearance of *Distaverrusporites simplex* and *Monocolpites* also strongly suggests the Late Campanian to Maastrichtian age which conforms to the report of Hoeken-Klinkenberg (1964) and Lawal and Moullade (1986) in the Upper Cretaceous sediments of the (Benue Trough and Ola-Buraimo et al., 2014) in the Dahomey Basin. The occurrence of *Inaperturopollenites sp* and *Cyathidites* sp. dominated by angiosperms further suggests the Mid-Cretaceous to Mid-Cenozoic age when these flowering plants developed a more complex root system (Lidgard and Crane, 1990; Nichols, 2009). The abundance of pollen flora suggests the dominance of a brackish water environment of deposition (Adekola et al., 2014). The mixture of the brackish and freshwater palynomorphs gives credence to a marine regression represented by progradational sandstone facies corresponding to the Upper Maastrichtian age (Nwajide, 2020). This study's findings support a brief regressive phase during the Maastrtchtian period (Akpofure and Akana, 2019; Onyekuru, 2009).

Conclusion: Paleodepositional environmental studies of the Ajali Sandstone Formation outcropping in Idah of the Northern Anambra basin, Nigeria, have been carried out. Nine lithofacies and two facies associations suggesting the marginal to shallow marine environment have been indicated. The palynomorphs recovered were tied to the brief regressive phase during the Maastrichtian age. The mixture of marine species dominated by terrestrial palynomorphs and freshwater algae suggests a brackish to freshwater environment of deposition controlled by a humid tropical climate.

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