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*RESEARCH ARTICLE*

# SEDIMENTARY ARCHITECTURAL ELEMENTS AND SANDY BRAIDED FLUVIAL SUCCESSIONS IN AJALI SANDSTONE RIDGES, WESTERN AFIKPO BASIN, UTURU, NIGERIA

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## ABSTRACT

Lithofacies, bounding surfaces and sedimentary architectural elements exposed in two ridges at Uturu being quarried for construction sands were analysed to determine the paleoenvironment of deposition and the factors that control the deposition of sand units. Mainly outcropped is Ajali Formation overlying locally exposed Mamu Formation in Western Afikpo basin. Lithofacies identified include: Trough cross bedded medium- to coarse-grained (*St*), Planar cross bedded fine- to coarse-grained sandstone (*Sp*), Small scale planar cross bedded sandstone (*SSp*), Lenticular mudstone (*Fm*), Heterolithic sandstone/mudstone (*Fsm*), Horizontal stratified sandstone (*Sh*), Cross ripple laminated sandstone (*Sr*), Reddish muddy sand (*Fl*), Siltstone (*SSm*) and Shale (Fsh). The associations of lithofacies and bounding surfaces gave four fluvial and one marine architectural element. The fluvial elements which mainly characterized the Ajali Formation include: Channel-fill (CH), Macroforms Accretion (MA). Flood-Plain Fines (FF) and Channel Abandonment Fines (CAF). Offshore-shoreface fines (OSF) element defined marine Mamu Formation. The profiles of the ridges show dominance of MA followed by CH while FF is limited in occurrence and in some zones pinch-out to lenticular inter-bar mudstone. The MA is characterized by planar cross beddings, reactivation surfaces, internal grading, steep dipping ferruginized accretion surfaces and abrupt flat top which indicate mid-channel bars deposition in typical sandy braided fluvial depositional system. Generally, there is vertical aggradation/amalgamation of channel deposits and dominance of sheet alluvial architecture. Low rate of channel avulsion, moderate rate of lateral migration and aggradation, variable discharge rate and high rate of sediment supply and subsidence were considered as factors that controlled the deposition and preservations of sand units. This study provided an understanding of mesoscopic heterogeneities and compartmentalization style inherent in hydrocarbon bearing sandy braided reservoirs which can be used as analog model for its development.

## KEYWORDS

Afikpo basin, Ajali sandstone, lithofacies, architectural element, bounding surfaces

## 1. INTRODUCTION

The terrain of Uturu in Nigeria is characterized by thickly vegetated ridges and depressions, with elevations above mean sea level that ranged from 127 to 320m. The ridges are mainly the outcrop of late Cretaceous Ajali sandstone with underlying local exposures of parts of Mamu Formation, in Afikpo basin (Reyment, 1965; Akande et al., 2011). Quarrying of some of the ridges for civil construction sands has exposed hitherto hidden sedimentary facies, bounding surfaces and internal architectural elements. The Ajali Formation whose facies and internal architecture are now well exposed at Uturu sands quarrying sites has been studied by many authors at different locations. It was named Ajali sandstone and described as false bedded sandstone by (Reyment, 1965; Simpson, 1954).

Some researchers through petrographic analysis of samples classified it as quartz arenite and sub-feldspathic arenite respectively (Hogue and Ezepue, 1977; Uzoegbu and Ikwuagwu, 2016). Amajor also classified it as quartz arenite with multicycle origin based on the analysis of paleocurrent and petrographic data (Amajor, 1987). A group researcher described it as shallow marine (littoral) deposit based on some sedimentological characteristics (Adekoya et al., 2011). Other researchers, using bivariate plots of computed univariate granulometric parameters differentiated Ajali sandstone at Igbere, Afikpo basin as river or fluvial deposit, but could not categorically determined the type of river-whether straight, meandering, anastomosing or braiding. The limitations could be the inadequate exposure of the outcrop. Therefore, the aim of this paper is to document the lithofacies types, bounding surfaces and architectural elements that unequivocally defined the paleoenvironments of deposition and factors that control the deposition and preservations of sand units in the outcropped Formations by the reason of their exposure at the Uturu sands quarry sites.

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## 2. STUDY AREA LOCATION AND GEOLOGICAL SETTING

The study area is located within the western end of the Afikpo basin, Southern or Lower Benue Trough of Nigeria (Figure 1). Benue Trough belongs to the Cretaceous to early Tertiary Western and Central African Rift System and it is about 800km long from Gulf of Guinea to Chad basin in Northeast to Southwest direction (Fitton, 1980; Ofoegbu, 1990). It is the failed breakup arm of R-R-R (rift-rift-rift) triple junction of the Gulf of Guinea ($R_1$), the South Atlantic ($R_2$), and the Abakaliki-Benue ($R_3$) arms during the late Jurassic – Early Cretaceous breakup of the western Gondwanaland land (Burke et al., 1972; Whiteman, 1982; Guiraud, 1983; Benkhelil et al., 1998). R1 and R2 successfully opened up to form the Atlantic Ocean that today separates the African and south American continental plates, whereas the $R_3$ failed and formed the Benue Trough.

The Benue Trough is divided into three structural and sedimentation domains: Lower, Middle and Upper Troughs (Benkhelil, et al.1998). These structural and sedimentation domains are also respectively called Southern, Central and Northern Benue Troughs by some authors. Between Aptian and Turonian, the Southern or Lower Benue Trough had episodes and cycles of sediment depositional processes which include fluvial, marine and fluvio-marine that resulted in the deposition and preservation of The Asu River group (Aptian – Albian) and Eze-Aku / Agwu / Keana Formations (Late Cenomanian – Turonian) (Amajor, 1987; Akande et al., 2011). But in the Santonian, collisional tectonism associated with regional folding and traces of magmatism occurred along the Benue Trough resulting in the uplift of sediment filled lower Benue Trough to form the Abakaliki anticline. The then western Anambra and Eastern Ikpe platforms to the then Lower Benue Trough now down-warped to formed the Anambra and Afikpo basins respectively (Figure 1).

Consequently, from Campanian, the focus of sediment deposition was now in the two basins. The last cycle of sediment depositional processes in the lower Benue Trough now resulted in the deposition and preservation of Campano-Maastrichtian sediments called proto-Niger deltaic sequences comprising the marine Enugu/Nkporo Formation, deltaic Mamu Formation, Fluvial or fluviomarine Ajali and Nsukka Formations. It is the Mamu and Ajali Formations that are outcropped at Uturu. According to a study, the Ajali Formation is mainly characterized by white coloured sandstone, while the overlying underlying Nsukka and Mamu Formations respectively is comprised of sandstone, mudstones, shale and some coal seams (Amajor, 1987; Reyment, 1965). That is why Mamu and Nsukka Formations are considered as coal measures in Afikpo and Anambra basins. Ajali sandstone is an extensive siliclastic unit in the Southern Anambra and Afikpo basins with maximum thickness of 450m in Anambra basin, but thins to about 200m over the axis of anticlinorium at Uturu – Okigwe (Reyment, 1965; Amajor, 1987). Regionally, Ajali Formation comprises thick successions of sandstones with minor shale interbeds (Amajor, 1987).

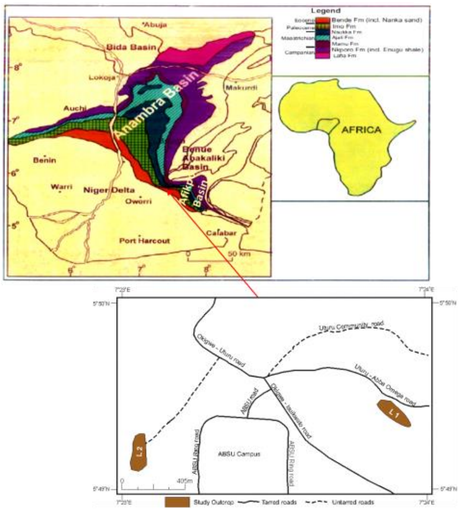

**Figure 1:** Geological map showing Anambra and Afikpo basins of southern Benue Trough and the extension of Campanian-Maastrichtian deposits across the two basins (Uzoegbu and Ikwuagwu, 2016). The insert shows the study outcrops locations and the access roads.

## 3. MATERIALS AND METHODS

Among the scattered Ajali sandstone ridges at Uturu, two being quarried for construction sands were identified at locations L1 and L2 with GPS coordinates of 5° 49.629'N/7° 24.276'E and 5° 49.4281'N/7° 23.239'E respectively (Figure 1). Quarry operation began in L1 around 2013, but quite recent in L2 as at the time of this study. Therefore, L1 was more opened for study than L2. The two ridges are oriented almost parallel to each other and about 1.96km apart. The outcrops were photographed from distant from left and right sides. The photographs were merged where necessary into photomosaic for architectural analysis. Close-up photographs were taken of distinct lithofacies; structural and depositional features. The outcrops had a very high vertical quarry faces such that close-up studies and samples collection were done up to 4m from the ground level in order not to compromise safety as the formation disturbed by quarry operations can easily collapse due to low lithological induration or consolidation. Compass-clinometer was used to determine the dip and directions of paleocurrent indicators. Bed thicknesses were measured with a measuring tape.

Paleo-fluvial sedimentation was identified and analyzed using methods and codes for fluvial depositional systems analysis but with slight modification (Tedesco et al., 2010; Allen, 1983; Miall, 1981;1985;1996). First letter of the codes, S and F represents sand and fines (silt and shale or mudstone), while the second and third letters represent the dominant characteristics of the lithofacies. The methods involved identification of lithofacies and sedimentary architectural elements bounded by surfaces. Channel hierarchies of which consist of First, second and third order channels was adopted (Bristow and Best, 1993). Lithofacies characteristics/associations and fluvial architectural elements identified in the two studied ridges were compared with that of documented fluvial facies models to know which one that best interpreted the paleodepostional fluvial environment and processes (Walker, 1976; Cant and walker, 1976; 1978; Miall, 1978; Ethridge, 1982). The methods of spatial distribution of the channel-body types (geometries) determinations were adopted to interpret the profiles of the two ridges (Hirst, 1991; Owen et al., 2019). Paleo-marine sedimentation was identified base on lithofacies and ichnofacies characteristics. Lithofacies were also coded using the same method for fluvial lithofacies. Marine sedimentary architecture was defined by the successions of lithofacies trend- aggradation, progradation or retrogradation (van Wagoner et al., 1990).

## 4. RESULTS AND INTERPRETATIONS

### 4.1 Lithofacies Descriptions and Interpretations

### *4.1.1 Trough cross bedded medium-to coarse-grained sandstone (St)*

It is characterised by concave upward beddings contacts, very coarse to rarely pebbly moderately sorted fining upward grains, brownish colouration and underlying lag laden scour or erosion surface (Figure 2). The scour surface extends across the ridge. The trough bedding structures are better defined upward and no trace of bioturbation. Mean foresets angle of inclination at the two ridges is $20^0$, while mean azimuth or paleocurrent direction ranged from $130^0$ at ridge L1 to $135^o$ at ridge L2, both to south-eastern directions. It occurs at the base of a general grains fining upward sequence. *Interpretation:* Trough cross bedding indicates deposition by migrating curved crested 3D dunes across the channel floor (Ashley, 1990). The coarse grains suggest high flow velocity and sediment discharge. The lack of bioturbation or fauna suggest high sediment discharge and river deposited sediment. The better definition of structures up the unit and the grains fining upward indicate waning flow velocity. The brownish colouration indicates continental deposition. Erosion surface is common with braiding river (Ethridge, 1982). Similarity in paleocurrent data in two studied ridges suggests deposition by rivers that flows in the same direction.

**Figure 2:** Shows trough cross bedded sandstone with basal erosive contact and underlying massive siltstone. The pen is 14.5cm long.

### *4.1.2 Planar cross bedded fine- to coarse-grained sandstone (Sp)*

It is mainly characterised by large scale planar foresets, fine to coarse friable grains and reactivation surfaces (Figure 3). Bed set thickness is greater than 60cm, while internal bed thickness is greater than 4cm. It is characterized by internal grading, with clast accumulations at inclined parallel layers especially in ridge L2 (Figure 4). The basal contact is flat, while the top is a mud lined truncated surface. Foresets angles of inclinations that decreased upward ranged from 19 to $25^0$, while their azimuth ranged from 268 to $280^0$ (west direction) in the two studied ridges. It means paleocurrent direction of *Sp* facies is oblique or almost perpendicular to the paleocurrent direction of the underlying trough cross bedded facies (*St*). No traces of bioturbation.

*Interpretation:* Internal planar-tabular cross bedding is typical of growth of transverse or linguoid bars (Collison, 1970; Smith 1974). They are formed from migration of unit bar lee avalanche faces or simply foreset deposition at the margins of transverse bars (Smith, 1972; Collison, 1996; Herbert, 2020). The lack of bioturbation indicates high sediment discharge. The reactivation surfaces indicate exposure of bar to erosion and rounding of slip face crest during low flow stage; variable discharge rate, episodic unit bar growth or increment and aggradational vertical deposition mechanism in a fluvial braiding system (Cant and Walker 1976; Collison 1996). Upward decrease in foresets angles of inclination indicate increase in flow regime (Smith,1972). Large scale cross beds and internal grading with accumulation of clast at inclined parallel layers on the bar faces suggest stronger flow at the bottom of channel. Alternating coarse and fine grains laminations is typical of transvers bar (Smith, 1972). The paleocurrent direction oblique or almost perpendicular to that of the underlying facies further substantiated its deposition as that of a unit bar in transverse or diagonal direction to the general south eastern current direction of the channel.

**Figure 3:** Shows large scale planar cross bedded sandstone in laterally accreted sand bars or sheet sandstone with steep dipping ferruginized accretion surfaces, and mud lined flat or erosional truncating top and basal boundary in L1. The man in figure points to one of the reactivation surfaces. The length from the top of the man's head to the waistline is 0.81m.

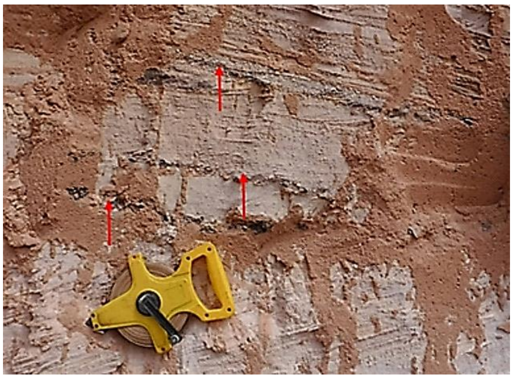

**Figure 4:** Red arrows points to the accumulation of clast at inclined parallel layers on the downstream bar faces that resulted in grains fining upward in large scale cross beds at the bottom of ridge L2.

### *4.1.3 Small scale planar cross bedded sandstone (SSp)*

The sand deposits are sheet-like in geometry and characterized by small scale planar cross beddings (less than 4cm thickness), well sorted medium to coarse sand grains, dark brown to reddish colour and set thickness that ranged from 25 to 60cm. No fauna or trace of bioturbation. The foresets have mean angle of inclination of $20^0$ and mean azimuth of $138^0$ (south east), similar to that of trough cross bedded sandstone (*St*). The angle of inclination of forests however decrease rapidly upward such that foresets become slightly asymptotic towards the top (Figure 5). It is not intensely indurated. It has variable thicknesses and multiply inter-beds with mudstone with which it has scour basal and sharp top boundaries. It occurs high in the stratigraphic sequence.

*Interpretation:* Small scale planar-tabular cross bedded sands represent migration of sand waves, and small straight-crested dunes (Walker, 1976). It is common in shallow sand-bed braided rivers (Bristow, 1993). It could also indicate small linguoid bars in shallow avulsive braided river system. The sheet-like geometry and scour surface suggest wide, low-sinuosity channel. The medium to coarse grains and moderate sorting indicate moderate discharge and strong transporting current though of shallow channel. The rapid upward decrease in foresets angles of inclination indicates rapid decrease in current velocity and subsequent slack of water current resulting in the deposition of overlying mudstone facies. Brownish or reddish colouration indicates deposition and preservation in an oxidizing shallow channel and vadose zones respectively. Its occurrence up the sequence suggest deposit of small tabular bar active in shallow channel that is largely filled or dune migration over bar top (Walker, 1976).

**Figure 5:** The red rectangle indicates small scale planar cross bedded sandstone with foresets angles of inclination decraseing upward and become slightly asymptotic towards the top. The height of the man in the Figure is 1.7m

### *4.1.1 Lenticular Mudstone (Fm)*

These are mud beds that are lenticular and characterized by thickness of 5 to 10cm and brownish grey to reddish colour (Figure 6). It inter-beds with small scale planar-tabular cross bedded coarse-grained sandstone with sharp top and scoured basal boundaries. *Interpretation:* The lenticular mudstone indicates suspension fallout during quiet channel and low discharge or flood stage. Brownish grey or reddish colouration indicates deposition in an oxidizing condition and preservation in a vadose zone. Therefore, its inter-beds with *SSp* indicates deposition during intermittent rising flow or flood stage during falling stage or sudden turning of channel into a slough in braiding river system (Walker, 1976; Cant and Walker, 1978). The mudstone is kaolinite clay which represents the last stage of silicates weathering in warm wet eogenetic environment (Worden and Burley, 2003).

**Figure 6:** Shallow channel deposits with interbedded lenticular mudstone. The compass clinometer is 10cm long.

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### 4.1.5 Heterolithic sandstone /mudstone (Fsm)

Heterolithic or centimetre-scale interbedded fines of light grey/light brown coloured sandstone and dark grey coloured mudstone. Sedimentary structures include thinly laminations to thin beddings of very fine sand with thickness ranging from less than 0.3cm to 10cm and thin lenticular mud layers, discontinuous mud drapes and films, small scale convolute laminations and traces of carbonaceous or coaly layers. (Figure 7). It is mostly characterized by organic rich zones. It overlain and underlain planar-tabular cross bedded facies (Sp) with sharp contacts but in some zone thins or pinch-out to a thin lenticular dark grey mudstone separating simple foreset bars as inter-bar mudstone (Miall, 1981).

*Interpretation:* The thin laminations indicate varied times of suspension settling. Coaly layers indicate carbonized plant debris. Therefore, the organic rich zones and carbonaceous or coaly layers suggest flood stage deposition in a vegetated overbank plain as rivers overtops its banks. Small scale convolute laminations indicate slight instability in bank slope. The grey colour indicates poorly-drained flood plain or inundation for a long time that creates anoxic swamp condition. Therefore, the lithofacies represents vertical accretion in channel margin to narrow floodplain or island in braiding river system (Walker, 1976). Its erosion to an inter-bar mudstone or thin horizontal/ ripple laminated sand is therefore, attributed to rapidly shifting channel in a typical braiding river.

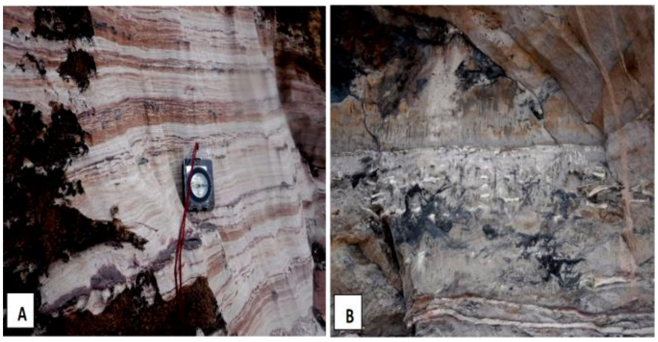

**Figure 7:** (A) Shows the characteristics of heterolithic sandstone/mudstone lithofacies (Fsm). (B). Shows interbedded sandstone and mudstone grading upward to an interval characterized by mud films and carbonaceous or coaly material and overlain by laterally accreted sand bars with sharp/erosive basal contact.

### 4.1.6 Horizontal stratified sandstone (Sh)

Flat thin bedded (1cm) to horizontal laminated (< 1cm) very fine- to fine-grained sand. It is very rare with gross thickness not more than 4cm such that it can easily be unnoticed. It overlain, with sharp contact, either trough or planar cross bedded sand, especially in ridge L2 (Figure 8). *Interpretation:* Horizontal stratification indicates upper plane bed deposition formed by the washing out of dunes and ripples at upper flow regime (Fielding, 2000). Overlying trough cross beddings (*St*) indicates channel aggradation, while overlying planar cross bedding (*Sp*) suggest sand flat accretion in braiding river system (Cant and Walker, 1978).

**Figure 8:** Trough cross bedding of 3D dune phase condition abruptly transitioned upward into horizontal stratification of plane bed conditions and abruptly truncated by overlying planer cross stratifications of 2D dune phase condition. It indicates cycles of long and short periods of lower and upper flow regimes respectively in channel deposition in L2. The hammer is 35cm long.

### 4.1.7 Cross ripple laminated sandstone (Sr)

It is characterised by planar cross laminations, very fine-grained sands and sharp basal and top contacts (Figure 9). It overlays either trough cross bedded sandstone or planar cross bedded sandstone. *Interpretation:* The ripple laminations generally indicate current ripple migration in a weak current, but planar cross laminations indicates migration of straight crested ripples formed under rapid fallout of large quantities of sand from near-bed suspension (Fielding, 2000; Nichols, 2009). Its occurrences on top of planar cross bedded sands suggest active transverse bar surface small scale bed forms, while on top of a trough cross bedded sand sandstone indicates small bed forms by waning current in a channel (Smith, 1971).

**Figure 9:** Sets of fining upward planar-tabular cross bedded sandstone grading upward to very fine grained planar cross rippled laminated sands indicating discharge fluctuations and waning flow in sandy bar deposition in L2. Length of measuring tape is 24 cm.

### 4.1.8 Reddish muddy sand (Fl)

Inter-bedded very fine grained-sandstone and silty claystone (mudstone) grading upward to more reddish coloured massive muddy sand (Figure 10). The topmost of the facies sequences in the two studied outcrops locations. It is unconsolidated and has vegetated top soil horizon.

*Interpretation:* Topmost in the facies sequences and very fine grain texture suggest channel abandonment, the zone of deposition and preservation is highly oxidizing or the fill of a channel above average water level. Therefore conversion of ferrous ion ($Fe^{2+}$) in meteoric fluid to ferric ion ($Fe^{3+}$). It is commonly described as lateritic crust. The clay layers are kaolin with the same characteristics as that of Fm facies. The vegetated soil horizon indicates environmental equilibrium, where there is no more erosion and sediment deposition.

**Figure 10:** Inter-bedded sandstone and mudstone grading upward to more reddish coloured massive muddy sand or lateritic soil.

### 4.1.9 Siltstone (Ssm)

Massive siltstone characterized by very fine lithology, branching burrows, lack of paleocurrent indicators and light to brownish grey colour grading upward to light brown of very fine-grained clayey sandstone. The clayey sandstone is truncated by ferruginized firm clast strewed surface (Figures 2 and 11). *Interpretations:* Very fine lithology indicate settling of suspended fines in a low energy environment. The upward gradation of siltstone to clayey sandstone indicate sediment progradation in shelf or deltaic depositional setting (Oyanyan and Oti, 2015). The lack of paleocurrent indicators and the branched burrows indicate marine deposition. The branched burrows are *Thalassinoides* burrows associated with cruziana ichnofacies in lower shoreface to offshore of marine environment (IRG, 1999). The ferruginized firm clast strewed surface indicates an erosive unconformity surface- a time interval of erosion and non-deposition which gave room for surface iron mineralization (Nichols, 2009).

**Figure 11: (A)** Shows ferruginized lag-strewn scoured surface that separates the basal sandstone of Ajali Formation from an underlying clayey sandstone of Mamu Formation characterized by *Thalassinoides* burrows. (B) Shows *Thalassinoides* burrow in siltstone. Length of pen is 14.3cm.

### *4.1.10 Shale (Fsh)*

Fissile sedimentary fines. The colour ranged from dark grey in fresh surfaces to brownish grey in weathered surfaces (Figure 12). It is gradationally overlain by siltstone facies (*Ssm*). *Interpretation:* Shale deposit is an indication of suspension settling during slack water condition (Oyanyan and Oti, 2015). The brownish grey colouration of weathered surface is as a result of the oxidation of disseminated particles of iron sulphide (pyrite) which was deposited along with marine mud in reducing or anoxic and low energy condition (Nichols, 2009). The dark grey colour indicates high organic matter deposition typical of marine environment.

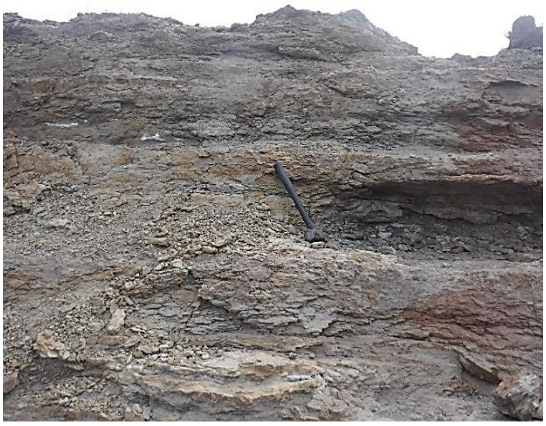

**Figure 12:** Dark grey coloured Shale characterized by fissility and brownish grey weathered surfaces. The length of the hammer is 35cm.

## 4.2 Fluvial Sedimentary Architecture

Fluvial sedimentary architecture is defined by architectural elements, as building blocks, bounded by surfaces (Miall, 1985). Five order bounding surfaces were identified. First and second-order bounding surfaces characterizes micro- and meso-forms bed forms respectively, while third-order surfaces (reactivation surfaces) indicate bar vertical increment or growth. The fourth order surfaces indicate macroform bed forms or geomorphic products. The fourth-order surface was divided into two types: accretionary (4a) and erosional (4e) surfaces (Tedeco et al., 2010). But in this study, 4a correspond to the lateral boundaries of macroforms, while 4e corresponds to the erosional bases of dominant shallow or second and third order channels on a major or whole river channel (Bristow and Best, 1993). The fifth order surface is an erosional surface that defines the base of a whole or first order channel floor fill or channel complex in which 4e surfaces are defined up the sequence. Based on the bounding surfaces and lithofacies associations, four fluvial sedimentary architectural elements were identified (Figures 13 and 14). They are as follows:

### *4.2.1 Channel-fill (CH)*

It is the depositional architectural element with erosional basal contact. It is divided into two parts, viz. 1. Whole or first order channel floor-fill (CH1) depositional elements consisting mainly of *St* lithofacies and occurs at the base of the generalized sequence (Figures 13 and 15). Where it is exposed at L1, it is characterized by thickness that ranged from 0.5 to 1.5m and clast or gravel lagged erosion surface taken as fifth order bounding surface. In L2, the lithofacies St grades upward to Sh indicating decrease in current velocity (Figure 15). 2. Shallow or second order channel-fill (CH2) consisting of small-scale *St, SSp, Sh, Sr* and *Fm* with thickness that ranged from 0.35 to 1m and overlain erosional surface on lenticular mud bed.

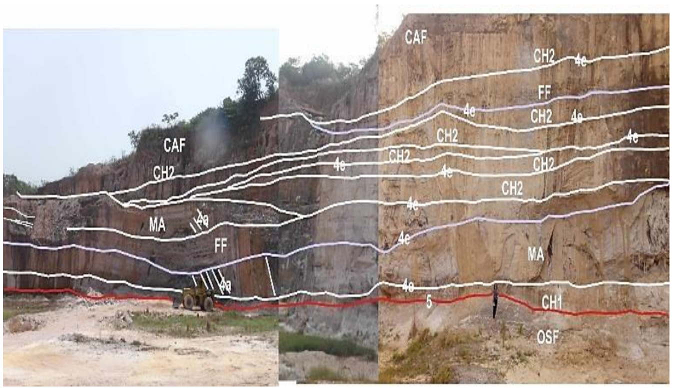

**Figure 13:** The profile of quarried ridge at location 1 (L1) showing architectural elements, bounding surfaces and sheet dominated alluvial architecture. The profile reveals a combination of internal almagamated geometry (at the middle) and semi-amalgamated geometry (at top and bottom). The height of the lady on the right side of the Figure is 1.6m.

**Figure 14:** The profile of quarried ridge at location 2 (L2) showing architectural elements, bounding surfaces and sheet dominated alluvial

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architecture. It shows the dominance of semi-amalgamated geometry.

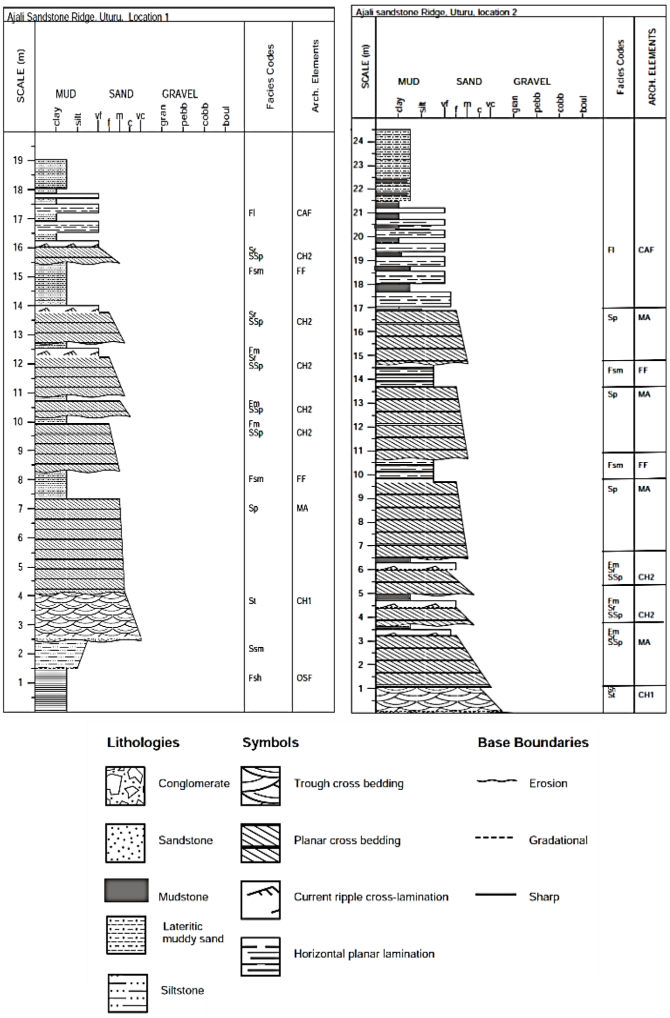

**Figure 15:** Sedimentary log of the right end of the two studied ridges, showing facies distribution, bounding surfaces, architectural elements and sedimentary successions.

### 4.2.2 Macroforms Accretion (MA)

Accreted macroforms of mid channel sandy bars or sheets of sand bars bounded laterally by steep dipping ferruginized accretion surfaces (4a) and vertically by erosive surfaces (4e) and consist mainly of planar-cross bedded sandstone (*Sp*) (Figures, 13, 14, 15 and 16). It can be regarded as third order channel or cross-channel bar deposit (Cant and Walker, 1978; Bristow and Best, 1993). It overlain the basal or whole channel floor fill depositional element (CH1) in the two Ajali Formation ridges, L$_1$ and L$_2$. It has thickness that ranged from 1 to 5m. The accretionary macroform successions with lateral accretion surfaces were identified at L1 and in L2. Though the bars accretion is lateral, the dominance of planar cross beddings, steep angles of dip ($\sim 65^{o}$) of accretion surfaces, abrupt flat top and rare to absence of mud drapes on accretion surfaces differentiated it as braiding river bars accretion from that of meandering river point bar. Point bar is characterized by rare planar cross beddings and low angle (1 to $25^{0}$) dipping epsilon beddings or accretion surfaces lined with millimetre to centimetres thick mud (Ethridge, 1982; Willis, 1993). It is also characterized by transitional top and upward fining and decrease in bed form size (Bristow, 1993). Therefore, this MA is mid-channel bar in origin and its formation can be attributed to dissected transverse or cross-channel bar margin shifting in correspondence to the shifting of adjacent channel with currents that erodes previous bar at every other low stage and the presence of unstable bank (Smith, 1971). The long period of low stage gave room for the ferruginization of the erosional bar margin surface. According to a study, irregular and lobate shapes assumed by transverse bars usually result in some margins becoming aligned parallel to currents in adjacent channels such that ripples and dunes formed by these parallel side currents are oriented more or less perpendicular to the bar margin (Smith, 1972). Therefore, the ferruginized lateral accretion surfaces indicate episodes of sand accretion to mid-channel bars in braiding river system.

**Figure 16:** Red arrow indicates accretionary macroforms architectural element with ferruginized steep angle accretion surfaces while the double blue arrow indicates flood-plain fines element. The height of the lady in the Figure is 1.6m

### 4.2.3 Flood-Plain Fines (FF)

It is a vertical accretion depositional element in a swamp or poorly drained depositional environment adjacent to an active channel. It consists dominantly of lithofacies *Fsm* (Figure 15). Its thickness ranged from 1.5 to 0.3m, but its percentage of occurrence is low compare to the channel and accreted macroforms elements (Figures 13, 14 and 15). Some channel fill elements pinch out to it (Figure 17). Its narrowness and limited zones of occurrence in the sandstone ridges indicates braiding river system normally characterized by narrow flood plain (Miall, 1981; Ethridge, 1982).

**Figure 17:** Shows pinch out of channel fill elements into flood plain-fines

### 4.2.4 Channel Abandonment Fines (CAF)

This is a depositional element that represents deposition in channel margin above the general water table level and channel abandonment. It consists mainly of lithofacies *Fl* and *Fm*. It overlain the shallow channel (CH2) elements at abandonment stage (Figure 15). Reddish colouration and absence of carbonaceous or coaly layers differentiated it from the flood-plain fine architectural element, though they are both vertical accretion deposits.

## 4.3 Marine Sedimentary Architectural Element

### 4.3.2 Offshore-shoreface fines (OSF)

The vertical successions of lithofacies *Fsh* and *Ssm* indicate Offshore-shoreface fines (OSF) depositional element of marine progradational architecture (Figure 15). The marine lithofacies assemblage is similar to the distal part of lithofacies assemblage described for Mamu Formation which consists mainly of fine grained and well sorted sandstones, siltstones and shales (Onyekuru and Iwuagwu, 2010). The cast or lag strew erosion surface that truncated the element can therefore, be described as a sequence boundary that separates Mamu Formation of marine deposition from the overlying Ajali Sandstone of fluvial deposition (Figure 11).

## 5. DISCUSSION

### 5.1 Paleodeposition Processes and Sedimentary Architecture/ Geometry

The observed sedimentological characteristics of the two quarried Ajali sandstone ridges at Uturu can be attributed to the mode of deposition, while the geomorphology of the terrain can be attributed to differential weathering. The erosive surface between the offshore-shoreface fines (OSF) element and overlying channel fill (CH1) element indicate abrupt replacement of marine depositional system, in which Mamu Formation was deposited, with continental-fluvial depositional systems in which the Ajali sandstone Formation was deposited. Lithofacies characteristics, facies associations or architectural elements of the Ajali sandstone ridges indicate that transverse bars formation in a low sinuosity river that cut into Mamu Formation was a precursor for the formation and evolution of the two ridges. According to a study, "transverse bars which dominantly comprise of planar cross bedded fine- to medium -grained in sandy braided fluvial system is developed when sand moving along the stream bed encounters a depression that results in the sudden increase in water depth (Smith, 1971).

The river will deposit its bed-load if the depth increase is sufficient to lower the current speed below the critical value needed for traction transport. The sediments will then build up from the floor of the depression in the cross-section form of a small ridge or delta, retarding flow until a critical depth and velocity are attained once again. When the critical depth and velocity are attained, bar top will then become the new channel floor over which sediment is transported". Therefore, the discontinuity of some of the sandstone ridges suggests sandy braided fluvial successions and their evolvement in locations where depressions as a result of differential tectonic subsidence occurs along NW- SE trending fluvial channels that cut into the pre-existing marine deposit called Mamu Formation. Paleocuurent data shows that ridge L1 is located at eastern position or fairly downstream of ridge L2 (Figure 1). The profiles of the two ridges (Figures 13 and 14) shows that Ridge L2 is dominated by semi-amalgamated geometry, with intercalating floodplain deposits, while Ridge L1 consist of both internal amalgamated and semi-amalgamated geometry.

The downstream increase in amalgamation of channel sand body types suggest incision river system which is mostly low sinuosity river system where braiding of bars is common, and not distributary river system (Owen et al., 2019). The profiles of the two studied ridges (Figures 13 and 14) also show vertical aggradation of channel deposits and dominance of sheet alluvial architecture and absence of ribbon structure (Hirst, 1991). These characteristics indicates high stream power, unstable channel and high sediment supply resulting in higher channel lateral migration over channel avulsion (Hirst, 1991). The low cohesiveness of siltstone facies in the upper sequence of Mamu Formation that the paleo-stream cut into could be responsible for the unstable channel, and consequently the braiding of the paleo-channel belt.

The absence of complete isolated sand body geometry indicate absence of both frequent avulsions and rapid aggradation (Hirst, 1991; Bristow and Best, 1993). Avulsion frequency however appears to increase with high rates of sediment accumulation (Bridge and Leeder 1979). Therefore, low rate of channel avulsion, moderate rate of lateral channel migration, moderate rate of channel aggradation, variable discharge rate, high rate of sediment supply, high rate of subsidence and narrow flood plain in a typical braided river system are considered as factors that controlled the deposition, preservations and vertical amalgamation of sand units in the two studied ridges. However, apart from rate of sediment supply, all other factors seem to be higher in the deposition and preservation of sands units in ridge L1 which resulted in the formation of multilateral/multi-storey sheet sand bodies.

### 5.2 Typical deposition Model

The successions of First order channel (CH1), accretionary macroform, floodplain and shallow channel (CH2) elements is typical of braiding stream systems and is similar to successions of in-channel, cross-channel bar, channel aggradation and vertical accretion deposits in sand-flat evolution in the sandy braided South Saskatchewan River fluvial processes (Miall, 1978; Cant and Walker,1978; Kelly, 2006). It therefore suggests that the two studied Ajali Formation ridges evolved through sandflat deposition and accretion as well as channel aggradation in sandy braided river. Ridge L1 was however more dominated by channel aggradation than Ridge L2 that is more dominated by sand flat accretion. The architectures of the two ridges show limited preservation of vertical accretion deposits in flood-plain/overbanks environments, which is typical of braided channel depositional system.

### 5.3 Implication for Hydrocarbon Exploration and Production

Braided stream sand deposits are reservoirs for oil and gas in some petroleum provinces of the world. Outcrop analog study is one of the techniques of acquiring its vertical and aerial characteristics. It enables the understanding of its internal architecture and depositional setting-paleochannel geometry and mode of paleochannel movement (Bridge and Tye, 2000). Therefore, this study has provided an understanding of facies relationships, mesoscopic heterogeneities in internal architecture and compartmentalization style inherent in sandy braided fluvial depositional system in tropical region, which is necessary for optimal recovery of hydrocarbon from sandstone reservoirs (Tyler and Finley 1991). Most of the documented popular models of braided channel depositional systems such as sandy braided South Saskatchewan River are not of tropical climate. It is an acceptable fact in sedimentology that climate is one of the factors that affects the processes of sediment deposition and preservation in a basin. Therefore, this study can be used as analog model for the development of hydrocarbon bearing sandy braided channel reservoirs in tropical regions of the world.

According to a study, braided stream deposits are characterized by high lateral and moderate vertical heterogeneities respectively (Tyler and Finley, 1991). The vertical heterogeneity can be attributed to the horizontal accretionary macroforms and channels' bounding surfaces and lenticular mudstones of flood-plain and channel abandonment fines. Whereas, the lateral heterogeneity can be attributed to the ferruginized accretion surfaces in accreted macroforms and lateral thins out of some architectural elements. The ferruginized accreting surfaces can act as baffles or barriers to horizontal flow of hydrocarbon in the accreted macroforms reservoir deposits which can results in the laterally by-passed of non-residual or mobile oil in uncontacted oil-bearing compartment if developed with vertical well (Tyler and Finley, 1991). The lenticular mudstone in the internally amalgamated channel sand bodies can act as vertical barrier to hydrocarbon flow resulting in vertical compartmentalization. Therefore, hydrocarbon in the accreted macroforms and the internally amalgamated channel sand bodies can be drained successfully with horizontal and vertical wells respectively.

## 6. CONCLUSION

The analysis of Lithofacies and architectural elements exposed in two ridges at Uturu being quarried for constructions sands revealed the followings:

1. The Ajali sandstone and Mamu Formation comprised of fluvial and Marine sedimentary architectures respectively.

2. The ridges were the infilling of the braided fluvial channels that cut into the then pre-existing and now underlying marine Mamu Formation. This assertion is buttressed by the fact that the successions of architectural elements which include first order channel (CH1), accretionary macroform, floodplain and shallow channel (CH2) elements is similar to successions of in-channel, cross-channel bar, channel aggradation and vertical accretion deposits in sandflat evolution in the sandy braided South Saskatchewan River fluvial processes. The sedimentary structures in the sandstone successions comprised trough cross stratification, ubiquitous planar cross stratifications, very rare horizontal stratifications, few current ripples and lenticular mudstones.

3. The profile of the two ridges is characterized by vertical aggradation/amalgamation of channel deposits and dominance of sheet alluvial architecture. Low rate of channel avulsion, moderate rate of lateral migration and aggradation, variable discharge rate and high rate of sediment supply and subsidence can be considered as factors that controlled the deposition and preservations of sand units.

4. The understanding of facies relationships, mesoscopic heterogeneities in internal architecture and compartmentalization style inherent in sandy braided fluvial depositional system. Therefore, this study can be used as analog model for the development of hydrocarbon bearing sandy braided channel reservoirs.

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## REFERENCES

Adekoya, J.A., Aluko, A.F., Opeloye, S.A., 2011. Sedimentological characteristics of Ajali sandstone in the Auchi environs of Anambra basin, Nigeria. Ife J. Sci., 13 (2), Pp. 52-67.

Akande, S.O., Egenhoff, S.O., Obaje, N.J., Erdtmann, B.D., 2011. Stratigraphic Evolution and Petroleum Potential of Middle Cretaceous Sediments in the Lower and Middle Benue Trough, Nigeria: Insights from New Source Rock Facies Evaluation. Petr. Tech. Dev. J.: An Int. J., 1, Pp. 1 – 34.

Allen, J.R.L., 1983. Studies in fluviatile sedimentation: bars, bar complexes and sandstone sheets (low-sinuosity braided streams) in the Brownstones (L. Devonian), Welsh Borders. Sedim. Geol., 33, Pp. 237-293.

Amajor, L.C., 1987. Paleocurrent, petrography and provenance analyses of the Ajali Sandstone (Upper Cretaceous), southeastern Benue Trough, Nigeria. Sedim. Geol., 54, Pp. 47–60.

Ashley, G.M., 1990. Classification of large-scale subaqueous bedforms: a new look at an old problem. J. Sedim. Petrol., 60, Pp. 160-172. https://doi: 10.2110/pec.75.23.0193

Benkhelil, J., Mascle, J., Guiraud, M., 1998. Sedimentary and Structural Characteristics of the Cretaceous Along the Côte D'ivoire-Ghana Transform Margin and In the Benue Trough: A Comparison. In Mascle, J., Lohmann, G.P., and Moullade, M. (Eds.), Proc. Ocean Drill. Program, Sci. Results, 159, Pp. 93 -99.

Bridge, J.S., Leeder, M.R., 1979. A simulation model of alluvial stratigraphy. *Sedimentology,* 26, Pp. 617-644.

Bridge, J.S., Tye, R.S., 2000. Interpreting the Dimensions of Ancient Fluvial Channel Bars, Channels, and Channel Belts from Wireline-Logs and Cores. Am. Assoc. Petr. Geol. Bull., 84 (8), Pp. 1205–1228.

Bristow, C.S., 1993. Sedimentology of the Rough: A carboniferous braided river sheet sandstone in Northern England. Geo. Soc. Spec. Publ., London., 75, Pp. 291 -304.

Bristow, C.S., Best, J.L., 1993. Braided rivers: perspectives and problems, *In* Best, J. L. & Bristow, C. S. (eds), *Braided Rivers.* Geo. Soc. Spec. Publ., 75, Pp. 1- 11.

Burke, K.C., Dessauvagie, Y.F.J., Whiteman, A.J., 1972. Geological history of the Benue valley and adjacent areas. In. T.F.J. Dessauvagie and A. J. Whiteman (Ed) African Geology university of Ibadan press, Ibadan, Pp. 187 – 205.

Cant, D.J., and Walker, R.G., 1976. Development of a braided-fluvial facies model for the Devonian Battery Point sandstone, Quebec. Can. J. Earth Sci., 13, Pp. 102-ll9.

Cant, D.J., Walker, R.G., 1978. Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada. *Sedimentology,* 25, Pp. 625-648.

Collinson, J.D., 1996. Alluvial sediments. In: Sedimentary environments and facies (Ed Reading, H.G.), Pp. 37-82.

Ethridge, F.G., 1982. The fluvial system with applications to economic geology: Fort Coll ins, Colorado State University, Department of Earth Resources, Pp. 328.

Fielding, C.R., 2000. Upper flow regime sheets, lenses and scour fills: Extending the range of architectural elements for fluvial sediment bodies. Sedim. Geol., 190 (1-4), Pp. 227–240.

Fitton, J.G., 1980. The Benue trough and Cameroon line - A Migrating Rift System in West Africa. Earth Planet. Sci. Lett. Elsevier Scientific Publishing Company, Amsterdam, 51, Pp. 132-138.

Guiraud, M., 1993. Late Jurassic-Early Cretaceous rifting and Late Cretaceoustranspressional inversion in the Upper Benue basin (NE Nigeria). Bull. Cent. Rech. Explor. —Prod. Elf-Aquitaine, 17, Pp. 371–383.

Herbert, C.M., Kathryn, J., Amos, K.J., Fielding, C. R., 2020. Unit bar architecture in a highly-variable fluvial discharge regime: Examples from the Burdekin River, Australia. Sedimentology, 67, Pp. 576–605. https://doi: 10.1111/sed.12655

Hirst, J.P.P., 1991. Variations in Alluvial architecture across the Oligo-Miocene Huesca Fluvial System, Ebro Basin, Spain, *in* Miall, A. D. and Tyler, N. eds., The three-dimensional facies architecture of terrigenous classic sediments and its implication for hydrocarbon discovery and recovery, Soc. Econ. Paleontol. Mineral. Pp. 111-121.

Hoque, M., Ezepue, C. M., 1977. Petrology and Paleogeography of Ajali Sandstone. J. Niger. Min. Geosci. Soc., 14, Pp. 16 – 22.

IRG (Ichnology Research Group), 1999. Ichnology Atlas, Version 1.2.

Kelly, S., 2006. Scaling and hierarchy in braided rivers and their deposits: examples and implications for reservoir modelling *In* Gregory H. Sambrook Smith, James L. Best, Charlie S. Bristow and Geoff E. Petts, eds., Braided Rivers: Process, Deposits, Ecology and M anagement eds., Sedimentology, Pp. 75 -106. ISBN: 978-1-405-15121-4

Miall, A.D., 1978. Lithofacies types and vertical profile models in braided rivers: a summary; *in* A.D. Miall, ed., Fluvial Sedimentology; Can. Soc. Petrol. Geol. Mem., 5, Pp. 597-604.

Miall, A.D., 1981. Analysis of Fluvial Depositional Systems. Originally presented at the Am. Assoc. Petr. Geol. Fall Education Conference Calgary, Pp. 76.

Miall, A.D., 1985. Architectural-element analysis: a new method of facies analysis applied to fluvial deposits. Earth Sci. Rev., 22, Pp. 261-308.

Miall, A.D., 1996. The geology of fluvial deposits: sedimentary facies, basin analysis and petroleum geology. Berlin, Springer-Verlag, Pp. 582.

Nichols, G., 2009. Sedimentology and Stratigraphy. Wiley and Blackwell Publ. (second edition), Pp.432.

Ofoegbu, C.O., 1990. (ed.) The Benue Trough: Structure and Evolution. Friedr Vieweg and Sohn, Braunschweig, Weisbaden, Pp. 359.

Onyekuru, S.O., Iwuagwu, C.J., 2010. Depositional Environments and Sequence Stratigraphic Interpretation of the Campano-Maastrichtian Nkporo Shale Group and Mamu Formation Exposures at Leru-Okigwe Axis, Anambra Basin, Southeastern Nigeria. Aust. J. Basic & Appl. Sci., 4 (12), Pp. 6623-6640.

Onyekuru, S.O., Okoro, Eze, M., Opara, K.D., Agumanu, A.E., Ikoro, D.O., 2017. Paleoenvironment and Provenance Studies of Ajali Sandstone in Igbere Area, Afikpo Basin, Nigeria. The Int. J. Eng. & Sci. (IJES), 6 (2), Pp. 19-30.

Owen, A., Hartley, A.J., Ebinghaus, A., Weissmann, G.S., Santos, M.G.M., 2019. Basin-scale predictive models of alluvial architecture: Constraints from the Palaeocene–Eocene, Bighorn Basin, Wyoming, USA. Sedimentology, 66 (2), Pp. 736-763. http://dx.doi.org/10.1111/sed.12364

Oyanyan, R.O., Oti, M.N., 2015. Sedimentology and Ichnology of Late Oligocene Delta Front Reservoir Sandstone Deposit, Greater Ughelli Depobelt, Niger Delta. Am. J. Geosci., 5 (1), Pp. 12-25. https://doi: 10.3844/ajgsp.2015.12.25.

Reyment, R.A., 1965. Aspect of the Geology of Nigeria. Ibadan University Press, Pp. 145.

Selly, R.C., 2000. Applied Sedimentology (second edition). Academic press publication, Pp. 543.

Simpson, A., 1954. The Nigerian coal fields and the geology of part of Onitsha, Owerri and Benue provinces. *Geol.* Surv. Nig. Bull. 24, Pp. 85.

Smith, N.D., 1970. The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians. Geo. Soc. Am. Bull., 81, Pp. 2993-3014.

Smith, N.D., 1971. Transverse Bars and Braiding in the Lower Platte River, Nebraska. Geo. Soc. Am. Bull. 82, Pp. 3407-3420. https://doi: 10.1130/0016-7606(1971)82[3407: TBABIT]2.0.CO;2.

Smith, N.D., 1972. Some Sedimentological Aspects of Planar Cross-Stratification In A Sandy Braided River. J. Sedim. Petrol., 42 (3), Pp. 624-634.https://doi:10.1306/74D725E0-2B21-11D7 8648000102C 1865D

Smith, N.D., 1974. Sedimentology and Bar Formation in the Upper Kicking Horse River, a Braided Outwash Stream. The J. Geol., 82 (2), Pp. 205-223. https://doi: 10.1086/627959

Tedesco, A., Ciccioli, P., Suriano, J., Limarino, C.O., 2010. Changes in the architecture of fluvial deposits in the Paganzo Basin (Upper Paleozoic of San Juan province): an example of sea level and climatic controls on the development of coastal fluvial environments. Geol. Acta, 8 (4), Pp. 463 - 482. https://doi: 10.1344/105.000001583

Tyler, N., Finley, R.J., 1991. Architectural controls on the recovery of hydrocarbons from sandstone reservoirs, in Miall, A. D., and Tyler, Noel, eds., The three-dimensional facies architecture of terrigenous clastic sediments and its implications for hydrocarbon discovery and recovery. Concepts in Sedimentology and Paleontology. Soc. Econ. Paleontol. Mineral., 3, Pp. 1-5.

Uzoegbu, M.U., Ikwuagwu, C.S., 2016. Sedimentological characteristics of Ajali sandstone at Okigwe, Anambra basin, SE Nigeria. Int. J. Geol. and Mining, 2 (1), Pp. 038-052.

van Wagoner, J.C., Mitchum, R.M. Jr., Campion, K.M. and Rahmanian, V.D., 1990. Siliciclastic Sequence Stratigraphy in Well Logs, Cores and Outcrops: Concepts for High-Resolution Correlation of Time and Facies. 1st Edn., Am. Assoc. Petr. Geol. Tulsa, Pp. 55. ISBN-10: 0891816577.

Walker, R.G., 1976. Facies Models 3. Sandy Fluvial System. Geosci. Can., 3 (2), Pp. 101-109.

Whiteman, A., 1982. Nigeria: Its Petroleum Geology, Resources and Potentials. Vol. 1 & 2. Graham and Trotman Ltd.: London. UK.

Willis, B.J., 1993. Bedding Geometry of ancient point bar deposit. In Marzo, M., Puigdefabregas. C. (Eds). Alluvial Sedimentation. Sedimentology, Spec. publ., Pp. 17.

Worden, R.H., Burley, S.D., 2003. Sandstone Diagenesis: The evolution of sand to stone, In Burley, S. D., Richard H. and Worden, R. H. (Eds). sandstone diagenesis: Recent and Ancient. Sedimentology, Pp. 3- 44.

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