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Paleodepositional Environment and Sequence Stratigraphy of Outcropping Sediments in Parts of Southern Middle Niger Basin, Nigeria

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Abstract
The determination of paleodepositional environment and sequence stratigraphic framework within which geologic factors interplayed to create the sedimentary facies present in outcropping sediments in parts of the Southern Middle Niger Basin, in order to establish sedimentary architectures and chronostratigraphically significant surfaces; erecting a stratigraphic framework through quantitative palynological and sedimentological analysis of sediments by detailed field mapping and laboratory techniques, forms the focus of this study. The Lokoja Formation was mapped on outcrops exposed in Robinson Street, Mount Patti, Banda and Filele in Lokoja area, while the Patti Formation was mapped in Ahoko, Gegu Beki, Gegu Egba, Adabor, Orehi and Akpasi along the Lokoja-Abuja express way. The study area lies within Latitude N 07^0 81' and N 08^0 30'; Longitude E 006^0 73' and E 006^0 86'. Three main lithofacies, sand, shale and silt were defined with seven subfacies as silty sand, fine-grained sand, medium-grained sand, coarse-grained sand, clayey siltstone, silty clay, and sandy silt. Sorting ranged from 0.72 – 1.29, indicating poor – moderate sorting for the Lokoja Formation. Depositional environments defined by values of binary plots of skewness versus standard deviation and mean versus standard deviation for samples obtained from the Lokoja area, confirmed by binary plot of skewness versus median for same samples indicate a continental fluvial and shallow marine to transitional paleodepositional environment for the Lokoja Formation and the Patti Formation respectively.
Three systems tracts, LST, TST and HST, were established in the study with the Lokoja Formation as an LST, the lower section of the Patti as a TST and the upper section as an HST. An SB and a candidate MFS of probably Late Cretaceous age was established at the base of the Lokoja Formation and in the Patti Formation respectively. Age-significant Cretaceous palynomorph species recovered from the Patti Formation which includes *Cyathidites sp., Monocolpopollenites spheroidites, Proteacidites dehanni, P. longispinosus, Cingulatosporites ornatus, Echitriporites triangulatus, Baculatisporites sp., Longapetites veneendenburgi, and Monocolpites marginatus indicate and confirm a Late Cretaceous age for the Patti Formation.*
Keywords: Sequence stratigraphy, Middle Niger Basin, Patti Formation, Lokoja Formation, Depositional Environment.

1. INTRODUCTION

The southern Middle Niger Basin is constituted of three Late Cretaceous formations, the Lokoja Sandstone Formation, Patti Formation and the Agbaja Formation (Jones, 1958). The Late Cretaceous formation of the southern Middle Niger Basin has been described by some authors as the Lokoja Sandstone (Jan du Chene et al., 1978, Idowu and Enu, 1992). In the study, the authors upholds the nomenclature of Jones (1958) as it is pointed in this study that the formations were formed by different depositional phenomenon.
Some studies have been carried out on the Late Cretaceous sediments of the Southern Middle Niger Basin. These studies have centered mainly on the sedimentology (Adeleye Dessauvagie, 1972), biostratigraphy and biozonation (Jan du Chene et al., 1978; Oloto, 1994), paleodepositional environment (Akande et al., 2005; Agyingi, 1993; ojo and Akande, 2006, 2008), tectonics (Kogbe et al., 1983; Ojo and Ajakaiye, 1976, 1989), hydrocarbon generation potential (Idowu & Enu, 1992, Obaje et al., 2011). Some previous studies have lumped the Patti and Lokoja Formations as one, while other have correlated the Patti Formation with the Ajali or Mamu Formations of the adjourning Anambra Basin leading to some level of confusion among geoscientists in Nigeria. This situation is because the sequence stratigraphic framework of the sedimentary pile in the basin has not been evaluated. Thus in this study, the authors views the sedimentary pile from a process sedimentology aspect in order to build a valid sequence stratigraphic framework for the Late cretaceous sequences deposited in this part of the Middle Niger basin.
Sequence stratigraphy is a recent revolutionary paradigm in the field of sedimentary geology. The broad concepts embodied by this discipline have resulted in a fundamental change in geological thinking and in particular the methods of vertical and lateral facies and stratigraphic analysis. Sequence stratigraphy is the study

of rock relationships within a time – stratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or non-deposition; or their correlative conformities, (Van Wagoner, 1995). It attempts to link subdivided sedimentary deposits into unconformity bound units on a variety of scales and explains these strata units in terms of control by relative sea – level changes and variations in sediments supply.

Over the past twenty years, this approach has been embraced by earth scientists as the preferred method of stratigraphic analysis, which has served to tie together observations from many disciplines. It blends the insights from a range of disciplines like biostratigraphy, lithostratigraphy, seismic stratigraphy, sedimentology etc., which invariably leads to a more robust interpretation and consequently scientific progress. Thus, the sequence stratigraphic approach has led to improved understanding of how stratigraphic units, facies tracts and depositional elements relate to each other in time and space within sedimentary basins.

Nevertheless, the application of sequence stratigraphy range widely, from predictive exploration for petroleum, coal and placer deposits, to improved understanding of earth's geological record of local to global changes. Its strong sedimentological component emphasizes on the facies-forming processes within the confines of individual depositional systems, particularly in response to changes in base level. At this scale, sequence stratigraphy is generally used to resolve and explain issues of facies cyclicity, facies associations and relationships, and reservoir compartmentalization.

In this paper we report the results of a detailed field and laboratory analysis of paleodepositional environment of outcropping sediments in parts of the Lower Middle Niger Basin, within a sequence stratigraphic framework.

2. GEOLOGICAL AND PHYSIOGRAPHIC SETTING OF THE SOUTHERN MIDDLE NIGER BASIN

The Middle Niger Basin (also known as the Nupe or Bida Basin) is a NW-SE trending intracratonic basin extending from Kotangora (in the North) to just south of Lokoja (in the south). It stretches from south of the confluence of Niger and Benue Rivers to the dam lake of Kainji, where basement rocks separate if from the Sokoto Basin. Generally three physiographic units are recognized in the basin (Adeleye, 1972). These are:

a. The Niger River with its flood plain and distributaries,
b. A belt of mesas and buttes, and
c. The plains.

The Niger River runs ESE in the southern marginal area of the basin. Its flood plains are broad and marked in most areas by a series of elongated ponds running parallel to the river. The belt of discontinuous mesas runs from an area about 16 km east of Mokwa to Lokoja and SW Dekina covering about 10% of the basin. The top lies between 260 and 500 meters around the Niger/Benue confluence areas. Flat lying to gently rolling plains covers about 70% of the basin. The plains lie between 60 and 180 meters above sea level in the Lokoja area. Sediment thickness in the Middle Niger Basin is estimated to be between 3000 and 3500 meters (Whiteman, 1982; Braide, 1992).

The basin occupies a gently down warped trough. The epeirogenesis responsible for the basin genesis seems closely connected with the Santonian tectonic crustal movements which mainly affected the Benue Basin and SE Nigeria. The buried basement complex probably has a high relief (Jones, 1955) and the sedimentary formations have been shown to be about 2000 metres thick by gravity survey (Ojo and Ajakaiye, 1976), constituted of post-tectonic molasse facies and thin marine strata, which are all unfolded. Borehole logs, Landsat images interpretation, and Geophysical data across the basin suggest that it is bounded by a NW-SE trending system of linear faults (Kogbe et al., 1983). Gravity studies also confirm central positive anomalies flanked by negative anomalies (Ojo, 1984; Ojo and Ajakaiye, 1989). This pattern is consistent with rift structures as observed in the adjacent Benue Trough/Basin. A detailed study of the facies indicates rapid basin-wide changes from various alluvial fan facies through flood-basin and deltaic facies to lacustrine facies (Braide, 1990). Consequently, a simple sag and rift origin earlier suggested may not account for the basin's evolution. According to Braide (1990) paleogeographic reconstruction suggests lacustrine environments were widespread and elongate. Lacustrine environments occurred at the basin's axis and close to the margins. This suggests that the depocenter must have migrated during the basin's depositional history and subsided rapidly to accommodate the 3.5 km thick sedimentary fill.

The basin's strata are Late Cretaceous (Campanian –Maastrichtian) in age and were named the Nupe Sandstone by Russ (1930). However, the Sandstone is referred to by Adeleye and Dessauvagie (1972) as a Group (instead of a formation). Adeleye (op. cit.) sub-divided the Group into four formations: Bida Sandstone (oldest), Sakpe Ironstone, Enagi Siltstone and Batati Ironstone (youngest). A lateral facies variation occurs in the basin. Around Lokoja, the sequence was usually referred to as the Lokoja Sandstone (Jan du Chene et al., 1978; Idowu and Enu, 1992). However, the Sandstone is only partly equivalent to the Nupe Sandstone (Dessauvagie, 1975) and is overlain by Patti Formation (Jones, 1958). The Bida area and Lokoja area are considered separately as the stratigraphy are different. The Lokoja, Patti and Agbaja Formations occur as the three formational units in the southern Middle Niger basin. The Lokoja Formation consists of pebbly clayey grit and sandstone, coarse-grained cross bedded sandstone, and few thin oolitic iron stones. A basal conglomerate of well-rounded quartz pebbles in a matrix of white clay is rarely exposed. Its thickness depends on the relief of the underlying Basement Complex floor and varies between 100 and 300 metres (Dessauvagie, 1975)

The Patti Formation is a sequence of fine to medium-grained, grey and white sandstones, carbonaceous siltstone, clay stone, shale and oolitic and Concretional ironstone. Thin coal seams may be present and white gritty clays are common. The maximum exposed thickness is 70 m (Jones, 1958), while the oolitic ironstones ranges from 7-16 m thick. A Maastrichtian (and possibly Senonian) age was thus assigned to it based mainly on correlation with other formations e.g. the Nupe Sandstone and Enugu Shale of Campano-Maastrichtian age. Adediran and Jan du Chene (1979) and Petters (1979) have recorded a palynomorph assemblage and a foraminifera fauna respectively from the Lokoja area. The micro fauna is considered to be a marsh assemblage.

The palynomorphs are made up mainly of pollen and spores, the assemblage of which is indicative of a Maastrichtian age (Adediran and Jan du Chene, op. cit.). Dessauvagie (1975) indicates that Patti formation yielded fossil plants (from the carbonaceous beds) and dates the formation as Campanian to Maastrichtian. More recently, Ojo (2009) reported a rich and well preserved palynomorph assemblage from the black shale outcrop samples of the Patti Formation collected between Kotonkarfi and Abaji and between Lokoja and Agbaja. The outcrop is constituted by marine dinocyst and the more copious continental sporomorphs. Ojo (2009) reasoned that the assemblage is a confirmation evidence for the Late Cretaceous Tethys – South Atlantic connection through the Nupe Basin. The Agbaja Formation consists of oolitic ironstone and occurs as the topmost stratigraphic sequence in the Agbaja Plateau, on mesas around the southern part of the basin and the Lokoja area.

3. *MATERIALS AND METHODS OF STUDY*

The southern Middle Niger Basin characteristically lacks exploratory well or well preserved borehole sample, thus leaving us with the option of outcrop samples. Based on lateral and vertical facies changes, and bed thickness a systematic sampling of outcropping sediments was carried out to obtain samples within latitude N 07^0 81´ and N 08^0 30´; and longitude E 006^0 73´ and E 006^0 86´. Thirty two (32) outcrop samples [Nineteen (19), shale and thirteen (13), sand] obtained from the Patti Formations in Ahoko exposed in road cuts and quarry sites and in the Lokoja Formation exposed in road cuts in the Lokoja area: Robinson Street Lokoja, Felele, Banda and Mount Patti. Samples were lithologically described and subjected to further sedimentological analysis and palynological processing. The siliciclastic samples were air dried, crused, and mixed and 50g of each sample was sieved in an automated sieve shaker for 10mins to obtain quantitative data set for further statistical analysis including the Graphic Mean (Mz), Inclusive Graphic Standard Deviation (σ_1), Inclusive Graphic Skewness (SK) and Graphic Kurtosis (K_G)

Shale samples were processed by standard method described by Traverse (1988). These samples were subjected to various stages of acid treatment followed by sieving, density separation and concentration of organic matter through centrifuging, staining with appropriate dye (Safranin O), mounting on slides with mounting medium (Norland) and then covering with cover slips. The slides were analyzed using an Olympus MGN binocular transmitted light microscope. A total of 19 slides were analyzed under the microscope and the various palynomorphs observed were captured by means of a SONY 12.1 MEGA PIXELS digital camera with optical zoom of 4×. The Palynomorphs were speciated standard published palynological references and catalogs.

4. *RESULTS*

Table 1shows a summary of the results of sieve analysis carried out on thirteen field samples obtained from parts of the Lokoja Formation, exposed in Robinson Street, Felele, Banda and the basal section of Mount Patti. The graphical presentation of the results for the determination of relevant sedimentological parameters (mean, standard deviation, skewness and kurtosis) is shown in figure 2 A-L.

Four main facies types (sandstone, siltstone, claystone and shale) and six sub-lithofacies (fine-grained sand, medium-grained sand, coarse-grained sand, sandy siltstone, dark grey shale and light grey shale) were defined. The various sandstone facies of the Lokoja Formation are generally feldsparthic. The sand facies characterizes the Lokoja Formation while the shale and silt facies are characteristic of the Patti formation. Shale strata of the Patti Formation are intercalated by ferruginous and Concretional ironstone beds. The shale member of the Patti Formation was mapped in two outcrop locations at Ahoko. Location one is a quarry site off the Lokoja-Abuja highway, north of Ahoko town, while location exposure 2 is a road cut exposure along the Lokoja-Abuja express road. The outcrops from these two locations are shown in figure 12, while the lithologic logs drawn for the exposures are shown in figures 5 and 6.

Field relationship shows that the Lokoja Formation unconformably rests on the Precambrian Basement Complex. This contact is visible at Filele along the Lokoja-Abuja express way (fig. 3)

These sediments exhibits high angle cross bedding, fining-upward (fig. 4) sequence underlain by very poorly sorted, medium to cobbly conglomeratic sands (fig. 3). Thin ferrugenous beds occur discontinuously within the sandstone beds. The sorting values of samples range from 0.72 – 1.29.

The palynological assemblage recovered from shale samples of the Patti Formation consists dominantly of pollen and spores (fungal and pteridophytic), with a complete absence of dinocysts. Sporomorphs dominate the recovered palynoflorules and consists mainly of trilete and monolete species. The pollen grains which are subordinate in the in the recovered palynoflorules, are dominated by few species of triporates and monocolporates. The palynomorphs are well preserved and characteristically of low diversity. The highest number of palynomorph count was from bed 7 in AHOKO 1 and bed 1 in AHOKO 2 (Tables 2 and 3).

5. DISCUSSION

5.1 Depositional Environment

On bases of environment and processes of deposition which in turn defines the lithologic and paleontologic characteristics of the deposits, three basic sedimentary facies are defined in the outcropping sediments of the study area. These are fluvial facies, shallow marine and transitional facies. The facies of the Lokoja Formation which exhibits high angle cross bedding, fining-upward sequence (fig. 4), underlain by very poorly sorted, medium to cobbly conglomeratic sands (fig 3) are interpreted as channel lag deposits and characteristic of point bar deposits. The occurrence of thin ferrugenous beds discontinuously within the sandstone beds indicate subaerial exposure of depositional surfaces through time characteristic and evident of a regressive phase in the basin. The dominantly poor sorting (0.72 – 1.29, Table 14), high angle cross bedding, fining-upward sequence and a general absence of fossils, exhibited by the sand facies, is indicative of deposition in a fluvial setting, (Friedman, 1961), and implying deposition during a regressive out-building in the Middle Niger Basin.

To further establish the fluvial facies defined for the Lokoja Formation using the sorting values (Table 14), binary plots (figs. 5 - 7) with boundaries modified after Friedman (1967), Moiola and Weiser (1968), and Stewart (1958) was done for the samples using the skewness, standard deviation, median and mean values generated from the sedimentological sieve analysis (Table 1). All values plotted falls within the fluvial domains.

Overlying the Lokoja Formation is the Patti Formation which is observed to be constituted of shales parasequences, Concretional ironstone and silt stones, at the lower to middle part of the Formation, with clay stones, silt and very fine sands at the upper part of the Formation.

The Ahoko outcrops exhibits colour variation ranging from dark grey at the bottom to light grey at the top, suggesting a quantitative variation in organic matter content that may have been caused by a change from a relatively anoxic to oxic paleoenvironment conditions.

Previous studies on the Patti Formation have shown the presence of marine palynomorphs species, (Jan Du Chene *et al.,* 1978; Agyingi, 1993 and Ojo and Akande, 2005). Although the samples from the Ahoko section in this study yielded no marine palynomorph element, a detailed evaluation of the sedimentologic attributes and palynologic components of the shales, indicates depositional of the sediments in a shallow marine paleoenvironment.

Palynological data have been applied to interpret paleodepositional systems (Van Bergen *et al.,* 1990; Ibrahim and Schrank, 1996; Vadja Santinavez, 1998, Helenes *et al.,* 1998; Rull, 2002 and Ojo and Akande, 2005). In these studies, Palynological Marine Index (PMI) values, which are the abundance of marine to terrestrially derived palynomorphs, are calculated. Null values of PMI indicate samples without marine palynomorphs and represents freshwater environment. Low values of PMI are interpreted as indicative of brackish water environment, while high values of PMI are indicates deposition under marine conditions. These sequences would ordinarily be interpreted as continental deposits based on the absence of marine palynomorphs, but the occurrence, frequencies and abundance of the brackish-water palm species *Spinizonocolpites baculatus,* the back-mangrove palms species, *Psilamonocolpites sp.* and ferns *Deltoidospora sp.* (Rull, 2000), at different stratum in the outcrops, and the occurrence of concretional ironstone strata within the shale facies suggests a rhythmic and fluctuating paleosea conditions during which time continental domains were occasionally inundated creating brackish water swamp conditions in which the fern species *Deltoidospora* thrived. *Deltoidospora* is a representative of wetland species behind mangroves forests near the limit of tidal influence (Rull, 1992, 1997a, b, 1998), which can be transported to near shore environments as presented by Muller, 1959, in a modern analogue study. This species possibly flourished in this area due to favorable paleoecologic conditions created by the Late Cretaceous Sea which flooded the land area, providing saline water conditions in which the species thrived, but later transported into shallow marine paleoenvironments and preserved in the fine-grained shale facies of the Patti Formation. This interpretation coupled with the dark grey coloration of the shale points to deposition in a marine paleoenvironment.

5.2 *BIOSIGNALS AND SEQUENCE STRATIGRAPHY*

The frequency distribution of palynomorphs recovered from the Patti Formation around the Ahoko area is shown in Tables 2 and 3. The samples are dominated by miospores with a complete absence of dinocysts species, composed mainly of trilete, baculate and monolete spore, and triporate echinate forms. The shales yielded age-significant Late Cretaceous palynomorph taxa such as *Proteacidites dehanni, Buttina andreevi, Cyathidites sp., Baculatisporites sp., Spinizonocolpites baculatus, Echitriporites trianguliformis, Cingulatisporites sp., Longapertites veneendenburgi, L. marginatus,* and *Buculatisporites sp.* These species have been used to age-date Upper Cretaceous sediments in Nigeria, (Jan du Chene, 1978; Jan du Chene and Salami, 1978; Evamy *et al*., 1978; Oloto, 1994; Ojo, 2008), and in South America, Germeraad *et al*., (1968). The occurrence of these forms in the samples indicates a Late Campanian-Mid Maastrichtian age for the outcropping sediments in the Ahoko area and thus correlates with the Upper Cretaceous Patti Formation in the Middle Niger Basin.

Graphical distribution of forms shows that bed 7 and 9 in AHK 1 and 2 has the highest total spore and paly population respectively, while the highest population of pollen is observed in bed 9 and 1 in both outcrops (Tables 2 and 3, Fig. 10), with the general pollen population less than the spore population.

5.3 *Sequence Stratigraphic Surfaces*

Two major sequence stratigraphic surfaces, a maximum flooding surface (MFS) and a sequence boundary (SB), where defined in the study area. The sequence stratigraphic interpretation of the sediments is based on the integration of lithofacies and biosignal characteristics. This approach enabled the definition of three systems track, one maximum flooding surface (MFS) and one sequence boundary (SB). Beds or stratum with the highest pollen count is conventionally used to establish the maximum flooding surface (MFS) (Pomout, 1989, Osokpor, 2002). The use of highest pollen count for the establishment of the MFS is a phenomenon that is easily recognized in marginal basins where mangrove swamp vegetation is well established (Osokpor, 2002). In these settings, the pollen population is enhanced by large inputs from mangrove forest species and freshwater forest swamp species (FWFS) from back swamps. *Zonocostites ramonae* (*Rhizophora* sp.) is a mangrove species which evolved in Nigeria in the Oligocene (Kuyl *et al*., 1955). Other known constituents of the mangrove swamp forest include *Deltoidospora spp.* A saline water fern, *Spinizonocolpites baculatus/echinatus* (*Nypa fruticans*) with an age range of Maastrichtian-Paleocene. Of all the mangrove forest species mentioned so far, only *Zonocostites ramonae* was not recovered from these sediments due to the older age of the sediments. *Spinizonocolpites baculatus* and *Deltoidospora* sp. was recovered. *Nypa* is a palm that inhabits coastal mangrove swamps characterized by hot, wet and humid climatic conditions. Global warm humid climatic conditions cause deglaciation of polar ice sheet leading to the release of melt waters into the ocean. This conditions cause a corresponding rise in sea level with a transgression and inundation of continental coastal domains, establishing brackish water swamps where salt water-loving plant species such as *Nypa* and *Deltoidospora* thrived, hence the biosignal presented by these species have used herein to recognized a transgressive systems tract, while the bed hosting the highest abundance, as the MFS.

Bed 7 in AHK 1 and Bed 1 in AHK 2 (figs. 10 and 11) which presents the highest counts of these two species, consists of very fine shale lithofacies, that have been likely deposited in distal marine settings far from the influence of terrestrial sediment input, possibly occasioned by flooding of the paleo coastal land area. Based on sedimentological and biostratigraphic attributes the MFS is thus established in these horizons.

The lithofacies characteristics and stratigraphic position of the Lokoja Formation depicts deposits of lowstand systems tract (LST). The Lokoja Sandstone is a continental siliciclastics formed during the progradative out-building of sediments in the Middle Niger Basin in the Late Cretaceous and rest unconformably on the western Basement Complex sequence. The contact between the formation and the basement characterized by very poorly sorted sediments, composed of pinkish clay derived from the weathering and disintegration of intraformational feldspars, very fine sands to large boulders is here defined as a sequence boundary (Fig. 3).

5.4 *Systems Tracts*

Three systems tracts an LST, TST and HST were defined based on lithofacies and biosignal characteristics identified above. From the sedimentological attributes presented above, outcropping sediments of the Lokoja Formation mapped at Robinson Street, Filele, Banda and the base of Mount Patti all show the characteristics of a lowstand system tract (LST). Three basic types of deposits are recognized in an LST, these are slope fan (SF), basin floor fan (BFF) and lowstand prograding wedge (LPW) (Catuneanu, 2006). Generally fan deposits are indicative of marine regression (Catuneanu, 2006), a shift of shore line basinward and prevalence of high fluvial activities. The Lokoja Formation is defined solely as an LST depicting a lowstand prograding wedge.

Outcrops I (AHK1) and 2 (AHK 2) in the Ahoko area (figure 12), exhibit sedimentological characteristics depicting deposits of a transgressive system tract (TST). Transgressive system tract (TST) is characterized by a net rise in relative sea level, during which time finer grained sediments like shales and silts are deposited indicative of transgression or landward shift in Shoreline (Catuneanu, 2006; Reading, 2008). The shale and silt sequences exposed in these outcrops are here interpreted as deposited during the Late Campanian-Mid

Maastrichtian marine transgression that affected the Mid Niger Basin. The evidence of a net rise in relative sea level is observed from the steady increase in the thickness of the dark colored shales as shown in figure 8 and 9. A careful analysis of the lithologic log shows a steady decrease in the thickness of the iron stone concretion toward the top of outcrops where they occur. This strongly suggests increasing marine influence in the basin with a corresponding decline in continental facies. Deposits of the Patti Formation mapped at Orehi, Achabo, Gegu Beki, Gegu Egba, Akpasi, Ahoko, Adabor and Adanya are grouped under a highstand system tract (HST) as shown in figures 11, 13 and 14. This sequence stratigraphic arrangement is strongly riveted on the sedimentologic and Palynologic interpretation as summarized in figures 13 and 14.

The environment of deposition of the Patti Formation has been a subject of interest and discussion by various authors (Braide, 1992; Agying, 1991). These authors suggested a non-marine environment for the argillaceous rocks (shale – clayey member of the Patti Formation) (Braide, 1992; Agying, 1991). Nevertheless, recent investigation of Ojo and Akande (2006) and Akande et al, (2005) recognized and reported certain striking marine sedimentological features in these sediments.

However, from the biostratigraphic analysis of the shales within the Patti Formation as mapped in Ahoko 1 and 2, the presence of miospores produced by saline water flora species is indicative of deposition in a marine-transitional paleoenvironment characterized by salt water swamps influenced by marine inputs in the marginal/shore line settings. Adediran and Jan du Chene, 1979; Ojo, 2009, concluded and correlated the Patti Formation with the Ajali Sandstone Formation in the adjourning Anambra Basin, explaining that in the late Cretaceous when the Benue Trough was experiencing a regressive phase and the Ajali Formation was being laid down in the Anambra Basin, some of the waters from the regressing sea emptied into the Middle Niger Basin and moved northwest ward as a transgressing system, thereby creating a marine depo system in the area during which time marine shale of the Patti Formation were deposited. The regressive phase in the Benue Trough led to an increased transgressive phase in the southern part of the Mid Niger Basin, as the basin appears to have experienced further subsidence. This conclusion and correlation are incorrect as these posses more questions than answers. Similar tectonic event created the Middle Niger and the Benue Trough of which the Middle Niger Basin exist as a failed arm in a triple junction. Hence transgressive conditions would be expected to affect the basin like the adjacent areas. The Mama Formation in the Anambra Basin is a transgressive and highstand deposit. On the basis of chronostratigraphy (fig. 14), the Patti Formation is a lateral equivalent of the Mamu Formation. In the Late Cretaceous, Southern Nigeria basins including the Anambra Basin which adjourns the Middle Niger Basin, experienced widespread transgression which created transgressive marine sediments in all the southern basins. The Late Cretaceous transgression affected the Middle Niger Basin leading to localized wet conditions along the marginal areas as evident by the presence of marginal saline swamp species such as *Deltoidospora sp.* and *Spinizonocopites sp.* In the Benin Flank which is the western arm of the Anambra Basin, the Mamu Formation is seen to also rest unconformably on the Lokoja Formation (on-going outcrop studies) as a transgressive sequence. With these chrono-correlation and analogy, it is obvious that the Late Cretaceous transgression that affected the Anambra Basin also affected the Southern Middle Niger Basin leading to the deposition of the Patti Formation.

Integrating the sedimentological and biostratigraphic evidences, it is suggested that the shales of the Patti Formation mapped in Ahoko 1 and 2 were deposited in a shallow marine to brackish water environment where anoxic bottom water conditions was prevalent, while sediments of the Patti Formation mapped at Orehi, Achabo, Gegu Beki, Gegu Egba, Akpasi, Adabor and Adanya exhibits sedimentological characteristics of a high stand system tract (HST) (fig. 13). HST is generally known to be characterized by aggradational deposits. These deposits are usually better sorted, laterally extensive in contrast with fluvial facies that exhibits rapid lateral and vertical facies change, (Reading, 1978). The lower section of the Patti Formation characterized by dark grey shale sequences constitutes the TST (fig. 13, Table 4), while the upper section composed of siltstones and clays constitute an HST.

6. CONCLUSION

The suits of lithofacies (sand, siltstone, ironstone, clay and shale) recognized and their sedimentological characteristics suggests that sediments in the Lokoja Formation were formed in high energy fluvial settings while sediments in the Patti Formation were formed in low energy shallow marine and probably sheltered coastal settings like estuaries, bays and lagoons.

The Lokoja Formation with its characteristic coarse-grained continental regressive sequences typifies a lowstand systems tract. The lower section of the Patti Formation the yielded saline swamp miospore species with its characteristic dark grey and black shale sequence typifies a transgressive systems tract, while the upper section characterized by laterally extensive sequences of siltstone and sandy siltstone devoid of palynoflorules typifies a high stand systems tract and correlates with Mamu Formation in the Anambra Basin.

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TABLES

TABLE 1: Quantitative graphical analytical values of sieve analysis for the Robinson Street, Filele, Banda and Mt. Patti outcrops.

Sample	(Mz)	Grain class	σ_1	Sorting class	SK_I	Skewness
Robinson St. Bed 1	0.64	Coarse sand	1.26	Poorly sorted	0.04	Nearly symmetrical
Robinson St. Bed 2	0.59	Coarse sand	0.72	Moderately sorted	-0.23	Coarse skewed
Robinson St. Bed 3	-0.09	Very coarse sand	1.22	Poorly sorted	-0.09	Coarse skewed
Robinson St. Bed 4	0.73	Coarse sand	1.29	Poorly sorted	-0.17	Coarse skewed
Robinson St. Bed 5	-0.70	Very coarse sand	-	-	-	-
Banda Bed 1	0.75	Coarse sand	0.73	Moderately sorted	0.14	Fined skewed
Banda Bed 2	1.17	Medium sand	1.02	Poorly sorted	0.10	Fined skewed
Banda Bed 3	-0.27	Very coarse sand	-	-	-	-
Filele1 Bed 1	0.93	Coarse sand	0.89	Moderately sorted	-0.07	Nearly symmetrical
Filele 1 Bed 2	0.60	Coarse sand	1.10	Poorly sorted	-0.07	Nearly symmetrical
Filele 2 Bed 1	0.21	Coarse sand	1.11	Poorly sorted	0.14	Fine skewed
Mount P. Bed 1	0.30	Coarse sand	1.26	Poorly sorted	0.17	Fine skewed
Mount P. Bed 4	0.54	Coarse sand	-	-	-	-

Mz = Mean Grain size, σ_1= sorting, SK_I = Skewness

Table 2: Total Pollen and spore population in Ahoko 1 (AHK 1)

BEDS	TOTAL PALY	TOTAL POLLENS	TOTAL SPORES
Bed 17	-	-	-
Bed 15	-	-	-
Bed 13	-	-	-
Bed 11	27	2	25
Bed 9	37	**7**	30
Bed 7	**66**	**5**	**61**
Bed 5	23	2	21
Bed 3	24	3	21
Bed 1	19	2	17

Table 3: Total Pollen and spore population in AHOKO 2 (AHK 2)

BEDS	TOTAL PALYS	TOTAL POLLENS	TOTAL SPORES
Bed 7	-	-	-
Bed 6	6	-	6
Bed 4	17	2	15
Bed 3	5	-	5
Bed 1	**48**	**4**	**44**

Table 4: System tracts and palaeodepositional environments of the locations under study.

LOCATION	*FORMATION*	*SYSTEM TRACT*	*ENVIRONMENT OF DEPOSITION*
Orehi	*Patti*	*HST*	*Transitional/ lagoonal*
Achabo	*Patti*	*HST*	*Transitional / lagoonal*
Gegu Beki	*Patti*	*HST*	*Transitional / lagoonal*
Ahoko	*Patti*	*HST*	*Transitional/ lagoonal*
Gegu Egba	*Patti*	*HST*	*Transitional / lagoonal*
Akpasi	*Patti*	*HST*	*Transitional / lagoonal*
Adabor	*Patti*	*HST*	*Transitional / lagoonal*
Adanya	*Patti*	*HST*	*Transitional /lagoonal*
Ahoko (shale)	*Patti*	*TST*	*Shallow marine to brackish*
Filele	*Lokoja*	*LST*	*Continental*
Banti	*Lokoja*	*LST*	*Continental*
Mount Patti	*Lokoja*	*LST*	*Continental*
Robinson Street	*Lokoja*	*LST*	*Continental*
Banda	*Lokoja*	*LST*	*Continental*

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FIGURES

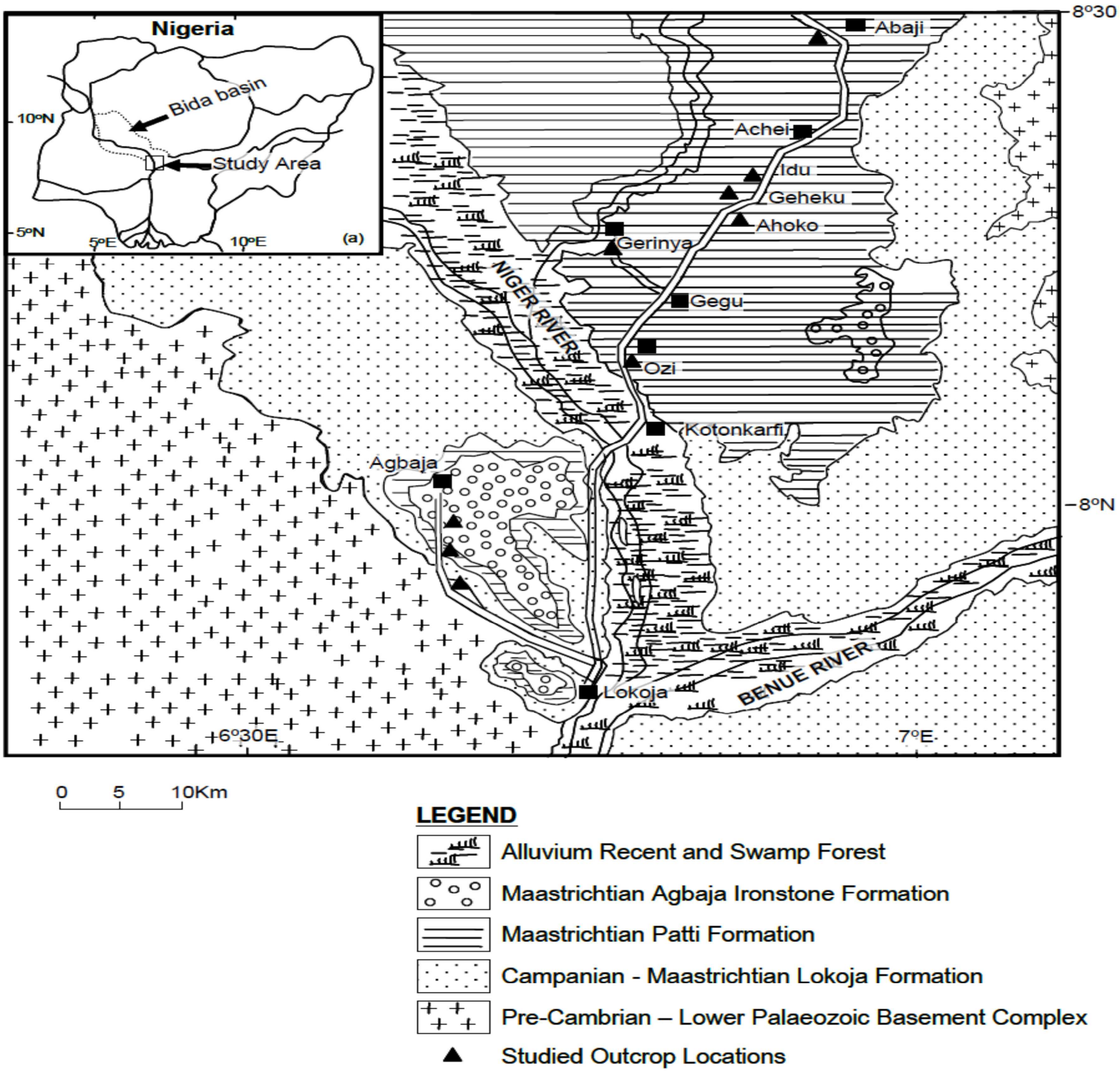

Figure 1: Map of study area. (*Modified from Ojo, 2009*)

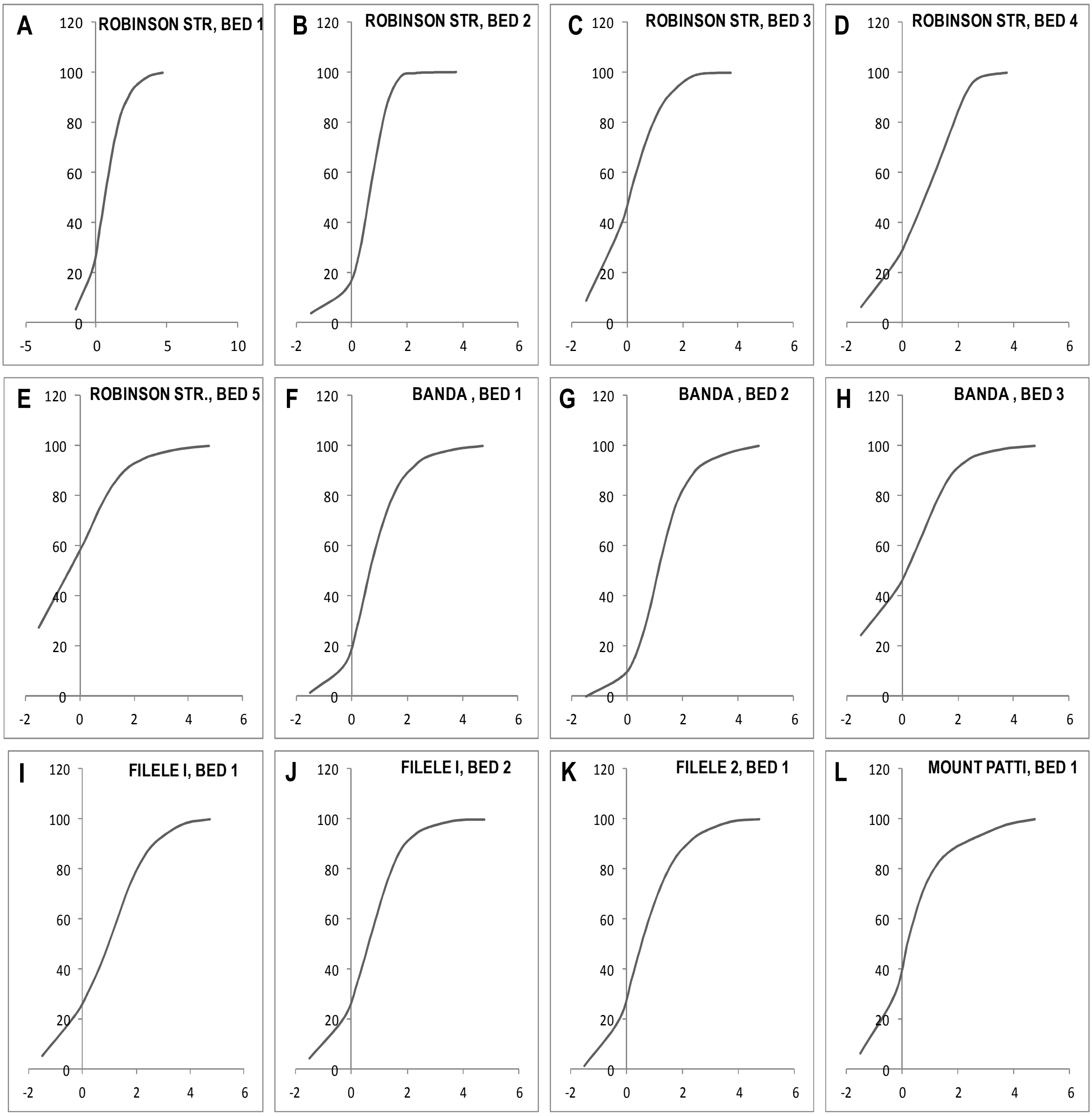

Fig. 2: Graphical plots of statistical data sets derived from sieve analyses for various sample locations.

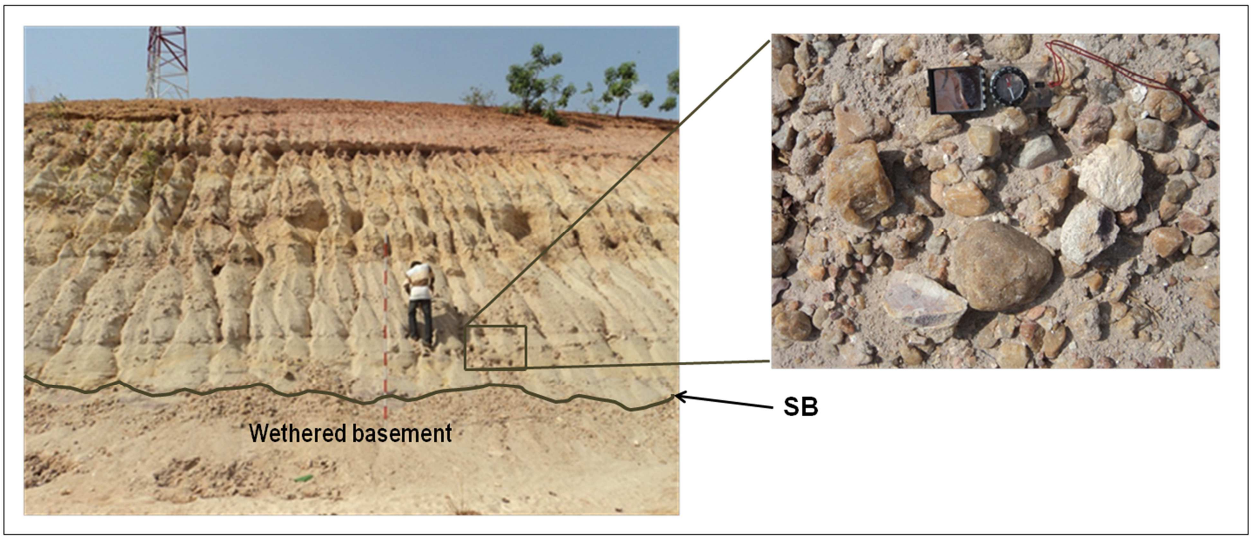

Fig. 3: A road cut exposure of the highly feldsparthic Lokoja Sandstone formation along the Okene-Lokoja highway at Filele showing the sediment-basement contact and the characteristic sedimentary constituents.

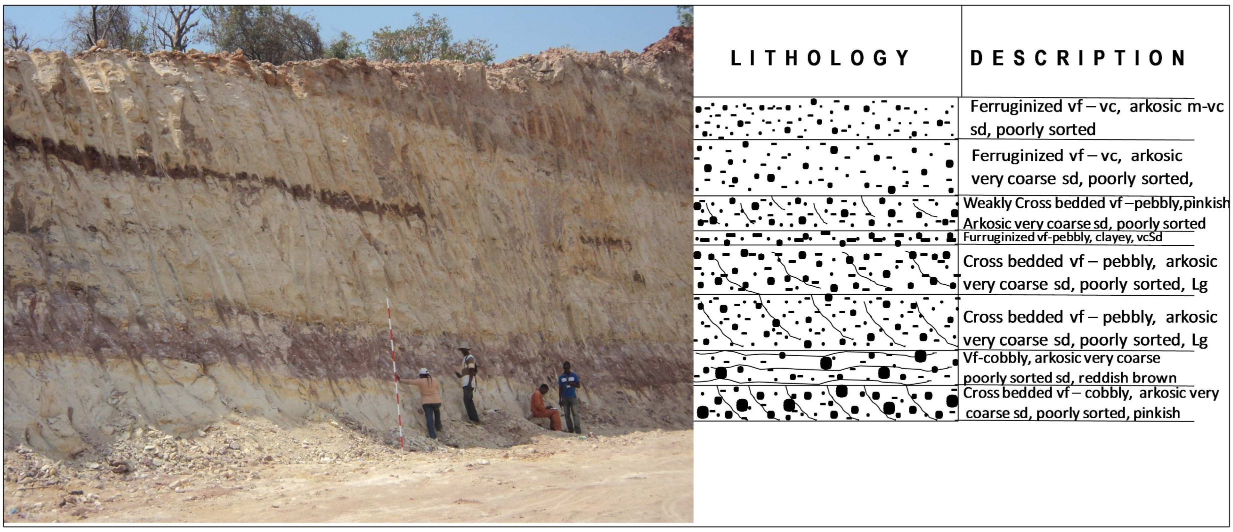

Fig. 4: A section of the Lokoja Formation showing feldsparthic poorly sorted cross bedded sandstone sequences along the Lokoja-Abuja highway at Banda near Lokoja town.

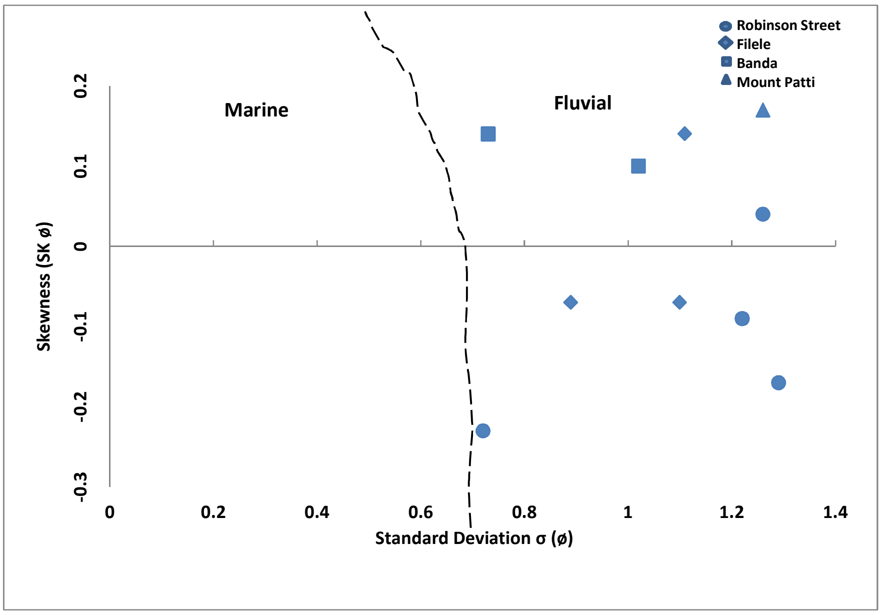

Figure 5: Binary plots of Skewness versus Standard Deviation for sand facies from the Lokoja area (boundary modified after Friedman, 1967)

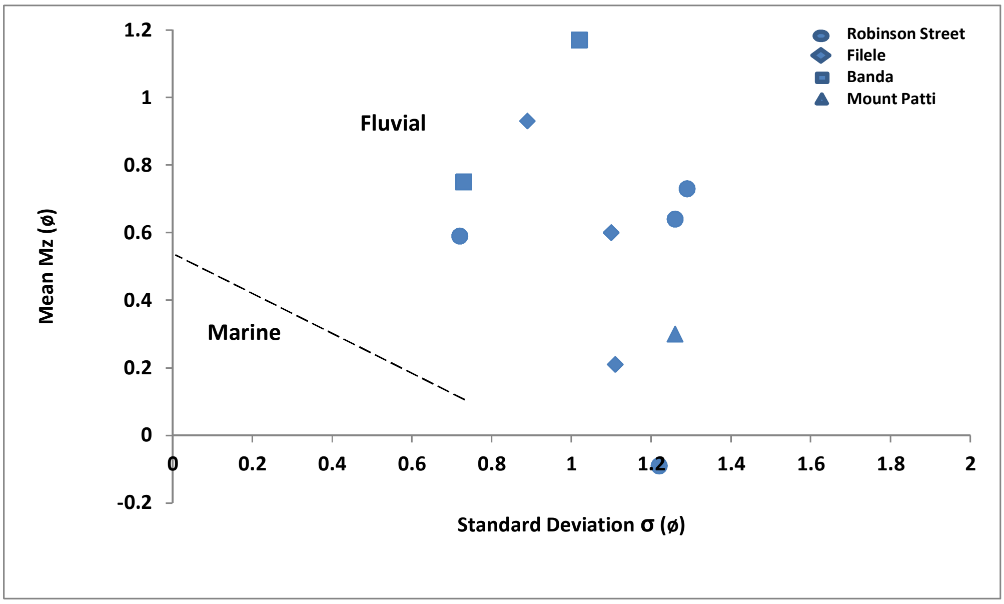

Figure 6: Binary plots of Mean versus Standard Deviation for sand facies from the Lokoja area (boundary after Moiola and Weiser, 1968)

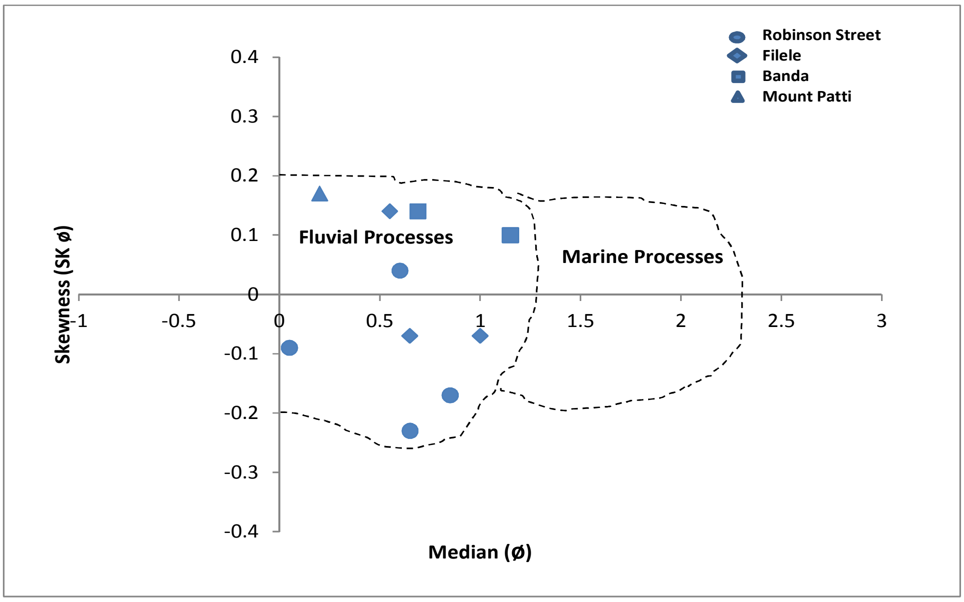

Figure 7: Plot of Skewness against Median for sand facies from the Lokoja area (boundary modified after Stewart, 1958)

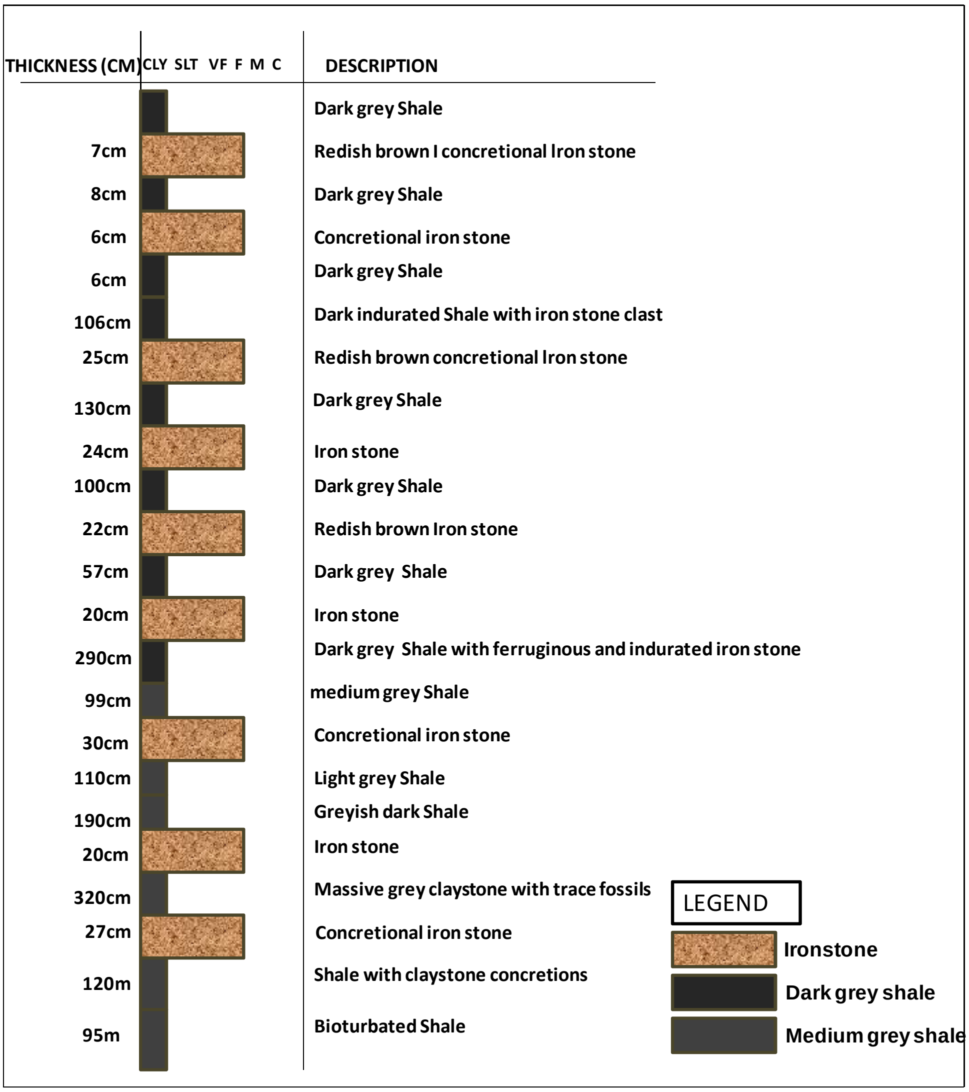

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Fig. 8: Lithologic log of the Patti Formation mapped at Ahoko, exposure 1.

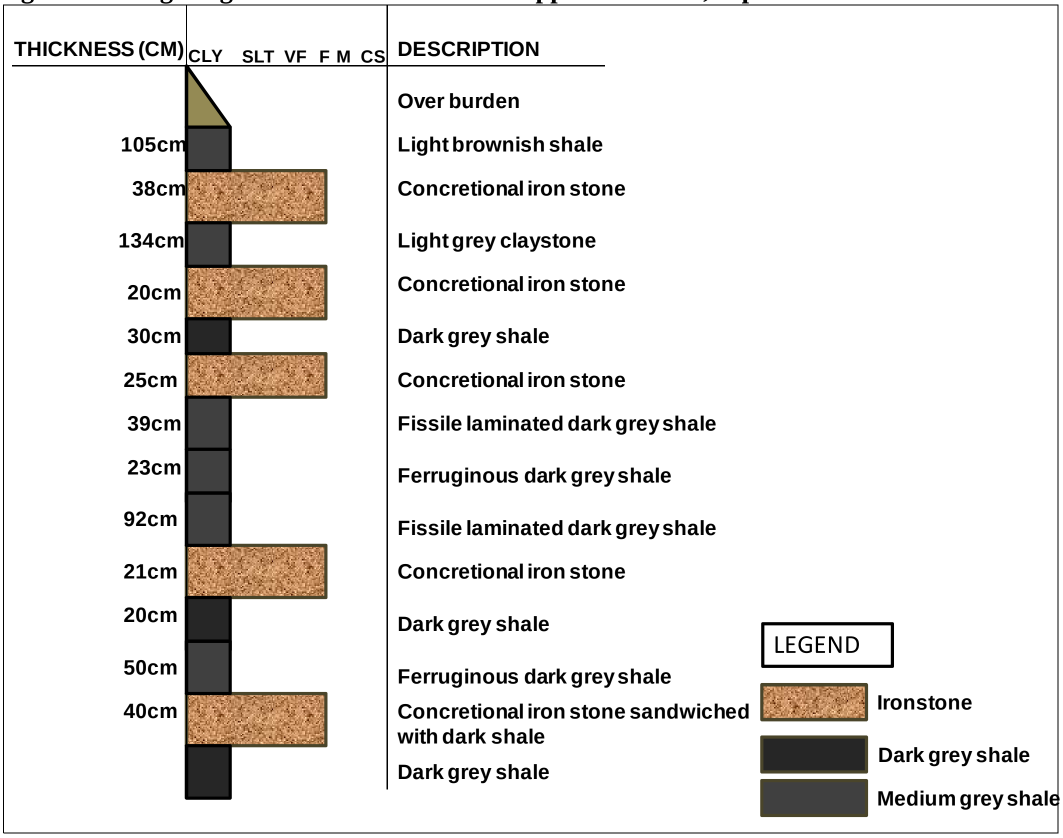

Fig. 9: lithologic log of the Patti Formation mapped in Ahoko exposure 2.

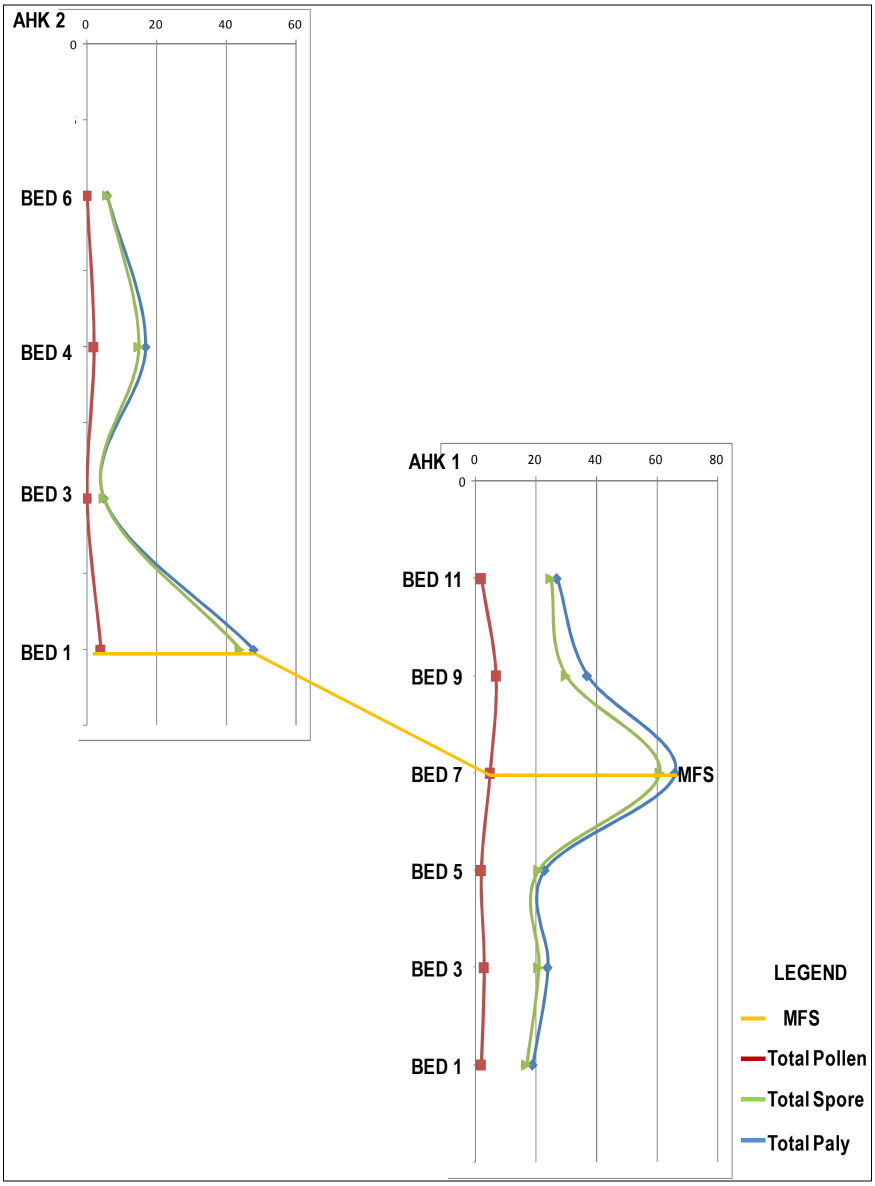

Figure 10: Correlation of Ahoko 1and 2 with established MFS

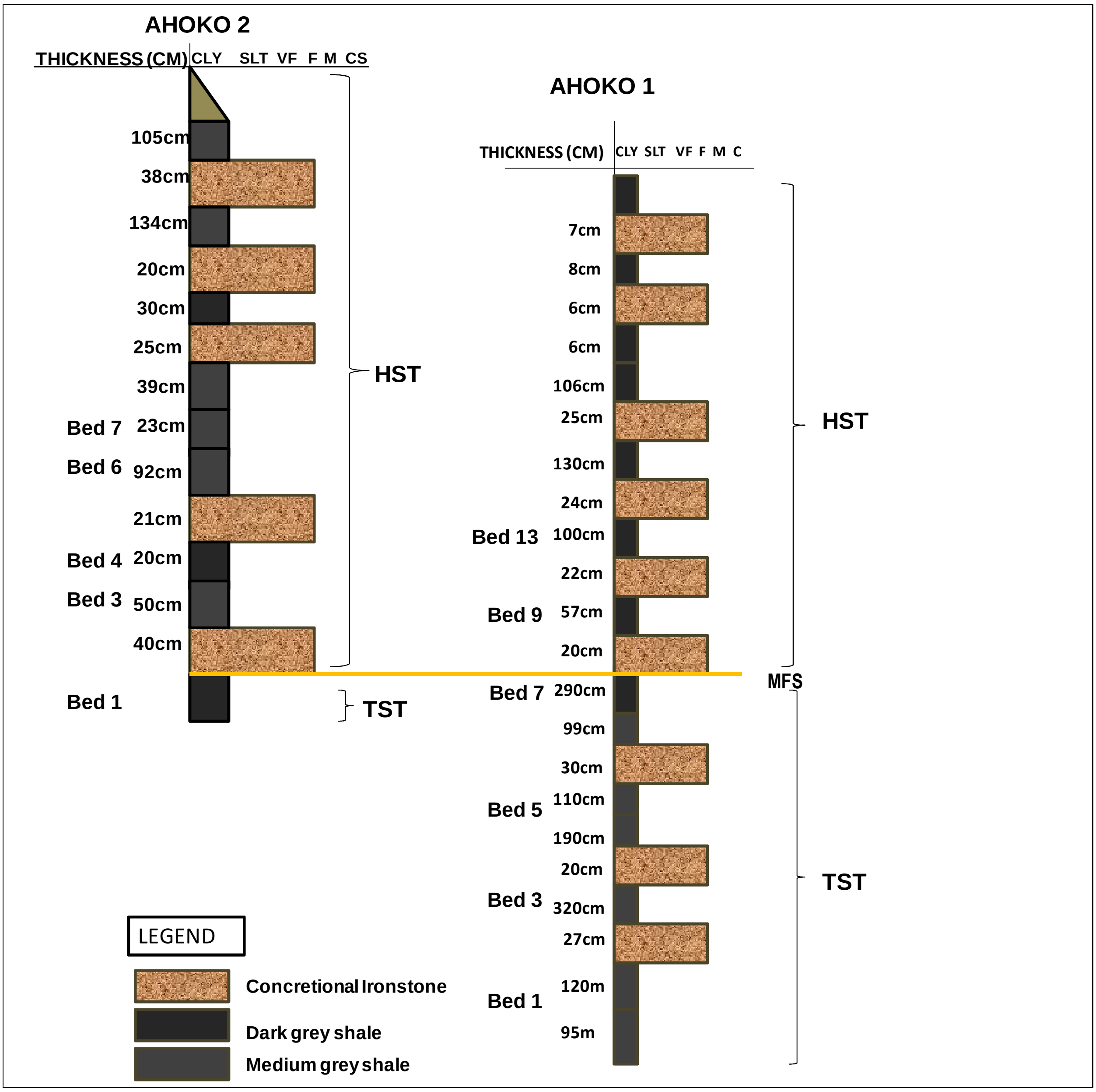

Figure 11: Sequence stratigraphic correlation panel of Ahoko 1 and Ahoko 2 on lithologic log showing various sequence stratigraphic elements on both sections.

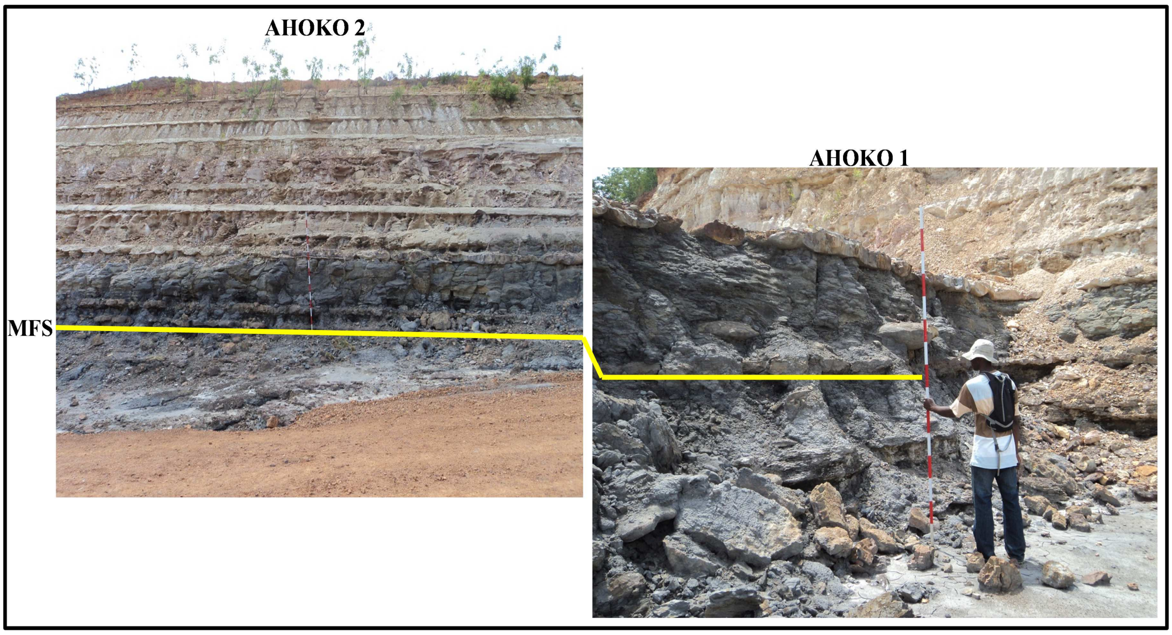

Fig. 12: Defined and correlated MFS established on outcrop sections.

Location	Elevation (ASL)	Thickness (m)	Cly Slt VFS FS MS CS Pb Cb	Description	System Tract
Gegu Beki	177	6.5		Very fine Sand. Ferrogenised and indurated. Well sorted	HST
Orehi	145m	4		Clayey Silt stone. Bioturbated. Well sorted	
Achabo	137m	3		Very fine to Silty Sand. Bioturbated with ferrogenised beds. Well sorted.	
Adabor 2	136m	3		Clayey Silt, with bands of Ironstone concretions. Well sorted	
Adanya	135m	5		Clayey Silt, with bands of Ironstone concretions. Well sorted	
Ahoko	132m	0.3		Silty Clay. Well sorted	
Gegu Egba	128m	3.5		Very fine to Sandy Silt. Well sorted	
Akpasi	125m	6		Clayey Silt, well sorted	
Adabor 1	119m	4		Clayey Silt, well sorted.	
Ahoko 2	96m	6.37		Shales with ironstone concretions	TST
Ahoko 1	90m	18.12		Shales with ironstone concretions	
Robinson	82m	2.5		Coarse to Pebbly Sandstone. Poorly sorted. Mineralogically immature.	LST
Banti	62m	10.5		Pebbly Sandstone. Poorly sorted. Mineralogically immature.	
Banda	47m	12.10		Coarse to Pebbly Sandstone. Poorly sorted. Mineralogically immature.	

Legend

Coarse sandstone
Pebbly sandstone
Clayey silt
Fine sandstone
Silty clayey
Shale

Cly – clay, **Slt** - silt, **VFS** – very fine sand

FS – fine sand, **MS** – medium sand, **CS** – coarse Sand

Pb – Pebbly, **Cb** - Cobble

Figure 13: Stratigraphy of the combined locations

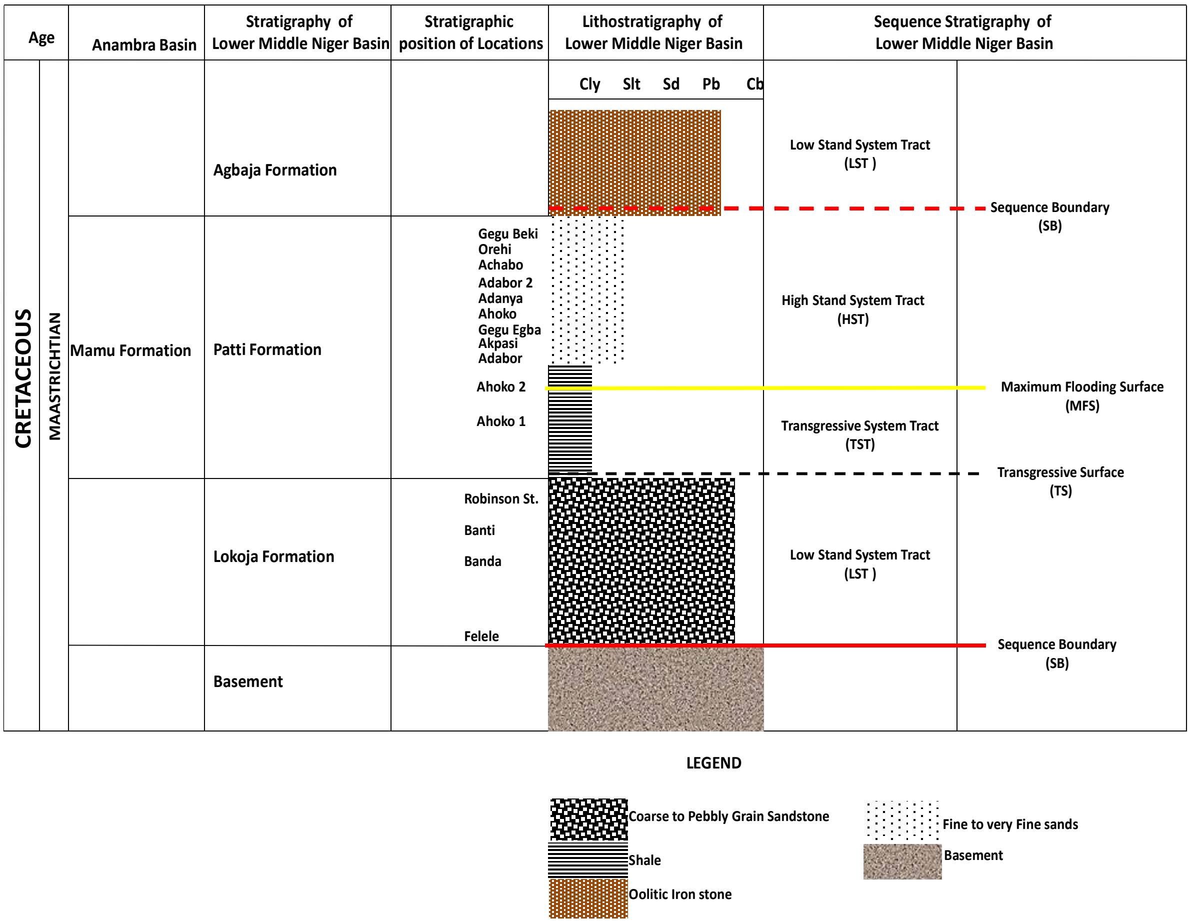

Figure 14: Sequence Stratigraphy of the Lower Middle Niger Basin as mapped in the various locations stated above