# Depositional Enviroment And Origin Of Deformation Structures In The Upper Cretaceous Facies Of Enugu Area, South Eastern Nigeria

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**ABSTRACT : -** The Upper Cretaceous facies of Enugu Area are part of the sequence in the Anambra Basin of Southeastern Nigeria. These include the Enugu Shale, Mamu Formation, Ajali Sandstone and Nsukka Formation. The deformation structures within the Upper Cretaceous in Enugu area were dominant to sandstones of the Marnu Formation. The white silty fine sandstone, muddy fine sandstone and heteroliths of this formation show various degrees of deformation which were penecontemporaneous with the deposition of the lithologies. The deformation structures include convolute bedding, load and flame structures, slump structures, gravity faults, water escape structures. Other sedimentary structures in the area are wave ripple lamination, hummocky cross stratification, parallel lamination, current ripples, flaser and lenticular bedding, channeling, water level marks, tabular and lenticular sandstone, mudcrack etc. The vertical, inclined and horizontal burrows of Ophiomorpha, Thalassinoides and Skolithos constitute the biogenic structures. Studies have shown that these deformation structures in the area originated from several processes which include the instability of the over steepened depositional slopes, overloading and unequal loading by sediment which produced both vertical and lateral movement (differential liquefaction and thixiotropic transformation) and rapid sedimentation under gravity. Diagenetic and textural studies indicate that the sandstones are now well compacted and lithified. The presence of these inorganic and biogenic sedimentary structures and the general stratigraphy of the area indicate that the sandstones were deposited in a storm dominated and low wave energy marine shoreline environments.
**Kewords;** Depositional, Structures,enviroment

## 1. INTRODUCTION

The evolution of the Anambra Basin began in the Santonian epoch due to the tectonic episode of uplifting and folding of the Pre-Santonian sediments of the Abakaliki- Benue Trough. The Upper Cretaceous facies of Enugu area are part of the sequence in the Anambra Basin of Southeastern Nigeria. The main Geologic rock systems here are the Enugu Shale (Campanian), Mamu Formation (Maastritchian), Ajali Sandstone (Mid Maastritchian) and Nsukka Formation (Upper Maastritchian) (Simpson, 1954; Reyment, 1965; Murat, 1970). The Enugu Shale comprises the dark parallel laminated shale which is intercalated with thin beds of siltstone. According to Nwajide and Reijers (1996), the formation is of open marine setting and the dark colour of the shale is an indication of bottom anoxia perhaps due to density stratification and poor circulation. However, the deformation structures are confined to Mamu Formation which overlies the Enugu Shales. Although a lot of work has been done on this formation, the deformation structures have not been well studied. Mamu Formation is composed essentially of shale, unconsolidated quartz arenite, coal, sandstonesheteroliths, mudstone, siltstone and claystone.


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Sedimentary structures include wave ripple lamination, hummocky cross stratification, parallel lamination, current ripple lamination, micro cross stratification, flaser and lenticular bedding, water level marks, channel, mudcrack, joints, soft sediment deformation structures such as dump structures, load and flame structures, convolute bedding, gravity faults, water escape structures. Trace fossils include the vertical, inclined and horizontal cylindrical burrows of Ophiornorpha, Thalassinoides and Skolithos which are abundant. Ferruginized sandstone has iron oxide coating around the grains. Silica and clay mineral cement are also present on the sandstone. Mineralogically, the sandstone is mature but texturally sub mature. Mamu Formation is transitional between the clearly marine Campanian Enugu Shale and marginal marine (largely tidal) Ajali Sandstone. Thus many facies belts representing different environment and sub environments are found in Marnu Formation which can be interpreted as shoreface facies, transitonal zone facies, and tidal flat facies.

## II. RESEARCH OBJECTIVES

The primary objectives of the study are:

1. To identify and study the Geologic structures in this area
2. To determine those structures that are contemporaneous with sedimentation when sediments were still soft.
3. To determine how these structures were formed and their tectonic significance with reference to the geologic history of the area.
4. To determine the Depositional environment of the study Area.

**Location of study area** The study area lies between latitudes 6°41'N and 7°06' N and longitude 7°21'E and 7°54' E. It is bounded in the west by an escarpment, and in the east by the Cross River plains. Enugu is linked to other parts of the country and the outside world by expressways, minor tarred roads and an airport.

**Geologic Setting of the Study Area** Anambra Basin of southeastern Nigeria developed due to tectonic episode of uplifting and folding of Pre-Santonian sediments of the Abakaliki-Benue Trough. (Reyment, 1965; Murat, 1970; Kogbe, 1976; Wliiternan, 1982; Benkhelil, 1988). More than 30,000ft of sediment accumulate in the basin after its evolution (Whiteman, 1982) which may be of Late Santonian and Maastrichtian age with the rising fold system (Abakaliki Anticlinorium) and the flank being the sediment source. The Upper Cretaceous facies of Enugu area are part of the sediment in the Anambra Basin. It include the Enugu Shale (Campanian- Maastritchian) consisting chiefly of blue or dark grey friable shale with occasional thin beds of sandy shale and white sandstones. It passes upward into the so called "lower coal measures" of Simpson (1954) called the Mamu Formation consisting of sandstones which are fine medium grained, yellow in colour. The shale and mudstone are dark blue or grey and frequently alternate with the sandstone to form a characteristically stripped rock.

## III. METHODOLOGY

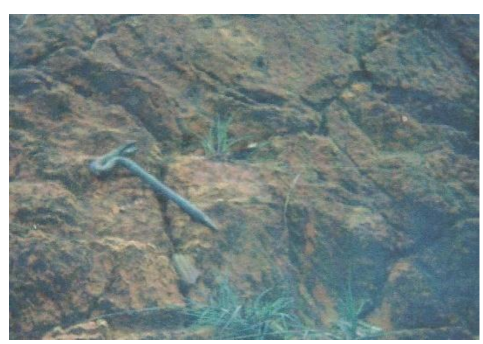
Much of the information preserved in sedimentary rocks can be observed and recorded in the field. The amount of detail which is recorded will vary with the of study and the amount of time and money available. However, for the sedmenentological aspect of the sedimentary rocks, the aims are mostly interpretation of depositional enviromnents and stratigraphic correlation but the geometry of the diagonistic sedimentation structures can be very useful in the reconstruction of the directions of transport of the sediment depositing current as well as determining the polarity (normal or overturned) of the beds. This research work aims at identifying structures determining the ones which are penecontemporaneous with sedimentation, their origin as well as their tectonic significance. Topographic map used to delineate the geological boundaries while making traverses in the field information were recorded at selected localities within the sedimentary formations in every well exposed areas and representative samples collected for laboratory analysis

**(a) Field procedures** The main thrust of the study of sedimentary rocks/outcrops is interpretation or reconstruction of ancient depositional enviromnents, stratigraphic correlation and possibly reservoir characteristics (Tucker, 1988; Miall, 1990). The systematic description of accurately located exposures is the first objective in the field mapping, and involves observation and recording of data while data collection programme depends on the aims of the investigation and the amount of time available for field work. A day reconnaissance survey of the area was carried out before detailed mapping in order to get familiar with the geographical features, as well as the rock types and styles of the structures which are to be mapped. Samples were collected from each locality for further study in the laboratory. In this study, exposure measurements were made by the direct contact of a compass clinometer held normal to both strike and dip and in measuring vertical sections with the use of a tape. Graphic logs which are diagrams of measured vertical section through sedimentary rock units were made in the field to record a number of observations to show the type of succession, contacts, grain size, the distribution of sedimentary structures which include soft sediment deformation structures, and other structures of sedimentary origin. The thickness of each lithofacies were also taken. The technique used in the study of outcrops include the following:

1. ***The lithologic identification and description:*** Each lithofacies found in the area at different localities were properly identified and well described with their contacts placed.
2. ***Textural characteristics:*** Each lithofacies which include their grain sizes, grain shape (roundness and sphericity), sorting and fabric (preferred grain orientation, grain matrix relation etc) were studied.
3. ***Sedimentary structures:*** These were recorded as they were found with the photographs of the structures taken. The sedimentary structures found include wave ripple lamination, hummocky cross stratification, parallel lamination, micro cross stratification, load and flame structures, slump structures, convolute bedding, gravity faults, water escape structures, flaser and lenticular bedding, joints, fractures, mudcrack, water level marks etc.

Symmetrical wave ripple lamination onyeama mines

Water level markings, opposite Onyeama mines



Hummocky cross stratification with Gravity faults-location 1

Convolute bedding-opp. Onyeama

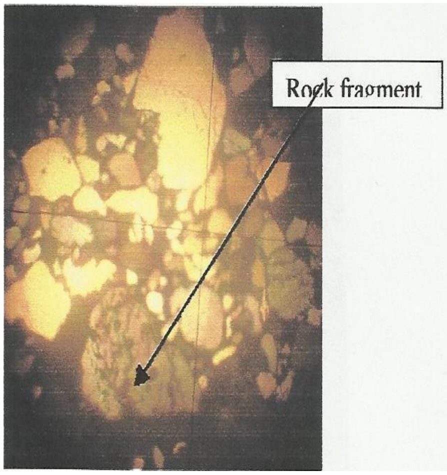
Erosiona channels-loc.2

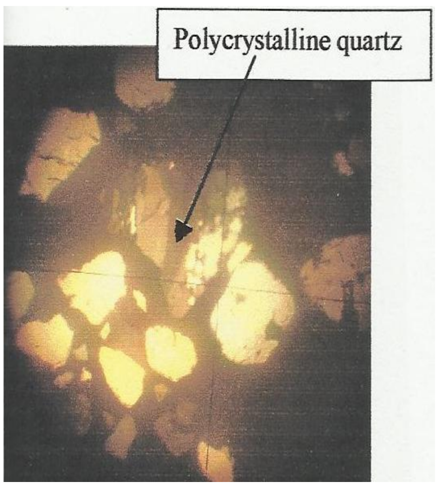
4. ***Beds:*** The designation of the beds and bedding planes.
5. ***Fossils:*** The fossil content of the lithologies were studied based on types, modes of occurrence abundance, body or trace fossils taking particular interest to note whether they are vertical, inclined or horizontal. The preliminary field interpretation was established based on the features recorded
6. ***Collection of Sarnples*:** Samples were collected at each of the locations for detailed laboratory analysis.

**(b) labolatory method:.**

**(i)** ***Grain size analysis*** The size of the component particle is one of the fundamental textural characteristics of all fragmentary deposits and their lithified equivalents and the size of particles is a measure of the dimensions which best describe a specific group of particles. The methods used in determination of size vary widely from calipers on D coarsest fragments, through sieving (Tucker, 1988). Therefore, the primary purpose of the analysis is to determin particle size distribution in sands which has to do with availability of different sizes of particles present, processes operating where sediments are deposited and at time of deposition e.g competency of the flow and concentration of particles in suspension (Friedman, 1979; Lewis). The method of sieving was used as the particles are in the pebbles and sand ranges (particles coarser than 0.063). The dry sieving method was employed whereby the samples were first oven dried. The mechanical shaker (Ro — Tap) was arranged such that coarsest sieve required was at the top of a nest of sieves in which the screen openings become progressively smaller downwards with a pan placed beneath the lowest sieve to the fines that pass through the entire column. The dried sample for testing was on the uppermost sieve after weighting, the retaining lid closed and the nest sieves were shook for fifteen minutes. The material retained in each successive eve was weighed. From the analysis, the cumulative frequency curve was plotted for the fifteen samples and the values of the parameters such as graphic mean, median, mode, inclusive graphic standard deviation, graphic inclusive skewness and graphic kurtosis were calculated. The values of these parameters permit characterization of the curves, and enable numerical comparison to be made between samples (Tucker, 1988). The bivariate plots of Friedman (1961) was helpful in environmental interpretation.

**(ii)** ***Petrographic studies*** Petrographical studies of thin section form the basis of much modern research on sedimentary rocks and the information gained can greatly supplement data from or core based studies, including facies analysis and construction of depositional models (Tucker, 1988). The information required in petrographic studies determine kinds of sample preparation to be employed. The sand samples for the thin section were selected and oven dried. The samples were poured inside a cut glass tubes before heating and this was followed by impregnation using epoxy under vaccum and the small samples were cast into blocks which were more convenient for the sawing and hand holding while grinding the face on abrasive paper. Selected areas of the faced samples were marked with water insoluble felt tip pen before cutting and trimming to avoid rock overhanging slide. The slices then mounted on chuks with a sponge backing to accommodate different thickness and irregular specimens. Coarse abrasives were completely omitted as the faces of the samples were grinded with 600F carborundurn powder with water as a lubricant for thirty- five minutes when the faces approaches optical flatness. At this stage, the slices destined to become standard thin sections were removed and resin bonded to glass using epoxy resin.




## IV. PRESENTATION AND INTERPRETATION OF RESULT

### (A) OUTCROP DESCRIPTION

**1. Outcrop description of location one** This is a well exposed outcrop of about 20m thickness situated farther west of Onyeama mine at road bend along Enugu -Onitsha expressway, about 2.8km from Kings pet petrol station, Enugu. The outcrop has the dip direction of 300°NW. The logic unit in this location is Mamu Formation consisting of white silty fine sandstone, the reddish brown muddy fine sandstone and the heteroliths. The contact between the lithologies at some point is sharp and gradational at some other areas within the locality. The heteroliths show the gradational contact. Very thick white very fine sandstone overlying the muddy fine sandstone was intensely deformed, broken down into smaller rectangular blocks at some points with gravity faults and is also evidence of the white silty fine sandstone falling down into the muddy sandstone layer. Most of the sedimentary structures and soft sediment deformation structures in this location are mostly on the white silty fine sandstone and include hummocky cross stratification which is dominant, a lot of gravity faults, parallel lamination, load and flame structures, water escape structures. The bioturbation are more on the white silty fine sandstone with the horizontal cylindrical burrows dominating. The burrows are more towards the top of the white silty fine sandstone.

**Lithofacies Description**.

- **(a)** ***White silty fine sandstone with both parallel lamination and hummocky cross gratification:*** This lithofacies is about 4m thick forming the base of the outcrop on the western part. At the bottom is inclined parallel laminated white silty fine sandstone which was followed upwards by hummocky cross stratification and then horizontal parallel lamination towards the top of the facies.
- **(b)** ***Highly deformed white silty fine sandstone*:** This lithofacies has many formation structures such as gravity faults, load and flame structures as it was underlain by muddy fine sandstone. Some other structures include hummocky cross stratification, wave ripple lamination, parallel lamination and horizontal burrows. This lithofacies is about 9.6mn thick.
- **(c)** ***Deformed muddy fine sandstone:*** This layer is about 5.4mn thick and was underlain by white silty fine sandstone. Towards the top of this lithofacies is the load and flame structures.

**2. Outcrop description of location Two** This location is situated still west of Onyeama mine at about 2.6km fiom Kings station, Enugu. The thick white silty fine sandstone, muddy fine sandstone and heterolith of Mamu Formation were exposed on the opposite sides of the expressway. The dip of the outcrop recorded 82°NE. The white silty fine sandstone on the western part of the outcrop was heavily deformed by the overlying coarse muddy sandstone even with boulders but with sharp contact separating the two lithologies. The central and eastern part of the outcrop show a well deformed white fine sandstone, muddy fine sandstone and heteroliths of about 30m thick. The outcrop were deposited in cycles with the middle layer towards the top revealing evidence of collapsing on the lower layer. The topmost part of the outcrop is the deformed muddy fine sandstone. Sedimentary structures found in this location include parallel (inclined and horizontal ) lamination, wave ripple lamination, hummocky cross stratification, load and flame structures, slump structures, gravity faults, convolute bedding, channel, flaser and lenticular bedding, vertical and horizontal cylindrical burrows.

**Lithofacies Description**

- ***(a) White silty fine sandstone facies:*** This is at the base of the outcrop which is about 9m thick undeformed but parallel laminated (both inclined and horizontally) and hummocky cross stratification also present. At some point, few wave ripple lamination were found still on the same lithofacies. This facies is overlain by muddy fine sandstone
- ***(b) Muddy fine sandstone facies:*** This facies is well deformed and structures found on it include slump structures, load and flame structures and burrows. It is about 3.2m thick. In an undeformed area, mudcrack is seen.
- ***(c) Highly deformed white silty fine sandstone facies*:** This lithofacies is about 8m thick. At the base of the facies, hummocky cross stratification and gravity faults were found. Slump structures occur at the center with parallel lamination and wave ripple lamination can be seen at some points. Convolute bedding occurred at the top of the lithofacies. The

bedding shows parallel lamination. The lithofacies is burrowed with vertical cylindrical burrows dominating.

***(d)*** ***Heteroliths*****:** This lithofacies is about 3.2m thick consisting of the white sandstone with the lenses or stripes of the muddy sand. The facies is wave ripple laminated and shows gradational contact between the white silty fine sandstone and the muddy sandstone. Vertical burrows are dominant.

**3. Outcrop description of location Three:** This location is exactly opposite Onyeama mine administrative building about 2.3km to Kings petrol station, Enugu. The geologic unit is still Marnu Formation, about 60rn thick consisting almost entirely of white silty fine sandstone with lateritic top soil. The thick outcrop also.shows deposition in cycles denoting series of events. The white silty fine sandstone was also deformed. The middle part shows very thin bed of shale intercalation with the parallel laminated white silty fine sandstone (lenticular sandstone). This unit is above hummocky cross stratified tabular sandstone. The lithofacies exhibit colour variation which differentiated it into upper and lower layer. It has a lateral extent of about 31m**.** The contact between the two layers of the lithofacies is sharp as it can be clearly seen and differentiated. The upper part is more shally and dark in colour while the lower layer is bluish grey to cream colour. This middle part is also compacted in between the lower and upper sandstone. Sedimentary structures and soft sediment deformation structures here are as follow: Wave ripple lamination, hummocky cross stratification, parallel (inclined and horizontal) lamination, channels, water level marks, water escape structures, biogenic structures etc. The azimuth of the general outcrop recorded 58°.

**Lithofacies Description**

***(a)*** ***White silty fine sandstone with little deformation:*** This facies is about 8.3 m thick and found at the base of the outcrop. Both parallel and wave ripple laminations with hummocky cross stratification are found at different point within this lithofacies. It is moderately bioturbated.

***(b)*** ***Lenticular sandstone facies*****:** This facies was found associated with the second cycle sediment. It consists of thin beds of shale intercalation with the white silty fine sandstone. The facies is distinguished into two. The upper layer is dark in colour and contain more shale while the lower layer is bluish grey to cream in colour. The thickness of the silty sandstone intercalating the thin bed of shale increases towards the top of the facies.

***(c)*** ***Tabular sandstone facies:*** This lithofacies is about 7m thick and has a lot of tabular structures. The sandstone was broken down in a tabular form without any matrix in between the blocks. Beneath this is a hummocky cross stratified undeformed silty sandstones.

**4. Outcrop description of location four:** The area is Aguabo Ribado mine. The Marnu Formation in this location consists of claystone, shale and coal. The shale is bluish grey in colour and fissile. Beneath shale is a thin bed of coal of about 0.3m thick which has planar arrangement. This coal was underlain by mudstone. The dip direction of the outcrop $34^0$ NE. Ribado stream exposes the fine to medium sand which are well sorted to moderately sorted with reddish brown stripes of iron oxide. The sand is deeply burrowed. Sedimentary structures here include parallel lamination and micro cross stratification.

**Lithofacies Description**

***(a)*** *Mudstone/coal/shale/claystone facies:* The unit is about 3.2m thick consisting of mudstone overlain by thin coal bed of about 0.3m thick which was followed upwards by dark fissile parallel laminated shale and then claystone. The coal has planar arrangement and the mudstone is deeply fractured.

***(b)*** *Parallel and ripple laminated sand facies*: This unit is made up of light brown consolidated fine sand of about 2m thick. The sand has parallel stripes of iron banding, well sorted and burrowed with inclined cylindrical burrows dominating.

***(c)*** *Micro-cross-stratified medium to coarse sand:* This facies consists of poorly sorted medium to coarse unconsolidated sand which is light brown in colour. The unit is about 3.6m thick.

**5. Outcrop description of Location five** This location lies in between Ekulu Pottery village and Proda dilapidated building. Outcrop of Ajali in this locality consists of fine to coarse unconsolidated sand of about 20m thick. The dip of the outcrop is 74° NE. At some points within the location, the sand has occasional clay pebbles and there is lateral variation in grain sizes. The outcrop also shows repeated cycles of deposition of fine and medium sand which are evenly laminated with horizontal bedding. The lamination is marked by alternating layers of fine and medium grained sizes with colour variation indicating different mineral content. Sedimentary structures found here include parallel lamination, current ripple lamination, micro cross stratification, horizontal and inclined cylindrical burrows.

**Lithofacies Description**

Apart from mudstone/coal/shale/claystone facies, the units are the same as in four consisting of the ripple and parallel laminated well sorted fine sand poorly sorted micro cross stratified medium to coarse sand.

**Location Six**

This is a well exposed outcrop about 300m from Kings petrol station along Enugu Onitsha expressway, Enugu. The outcrop consists of white fine sandstone, siltstone, shale and heteroliths (shale with lenses of sand) of Mamu Formation. The shale is dark in colour. The sand content of the heteroliths increases up, the exposure outcrop was more sandy at the top. The white sandstone and siltstone at the base are wave ripple laminated and jointed, the shale is parallel laminated and the heterolith is also wave ripple laminated, burrowed with horizontal burrows dominating. The dip of the outcrop recorded 36° NE.

**Lithofacies description**

- ***(a) Heterolithic facies:*** This unit consists of sandy heteroliths (shale with lenses of sand). They generally show parallel lamination. The facies is about 5.2m thick, burrowed and jointed.
- ***(b) Wave rippled white fine sandstone facies:*** This facies underlain the heteroliths and consists entirely of burrowed white fine sandstone.

**7. Outcrop description of Location seven** This is the Ekulu river section (quarry site) about 200m to Kings petrol station, at flyover of Enugu-Onitsha expressway, Enugu. The outcrop of this location consists of dark fissile shale, mudstone and unconsolidated fine to medium grained sand. In some area within the location, repeated cycles of fine and medium grained sand were deposited, whitish to yellowish brown in colour with stripes of iron oxide. In other area, a ferruginized coarse and pebbly sand was deposited. The outcrop shows both lateral and vertical variations. The fine sand is well to moderately sorted, fine to coarse sands are poorly sorted. The dip of the outcrop as recorded was $60^0$ NE. Sedimentary structures found are parallel lamination, wavy lamination, planar bedding and micro cross stratification.

**Lithofacies description**

- ***(a)*** *The fine sand and the medium to coarse unconsolidated sand facies* here are the same as in location five. Ripple and parallel laminated, well sorted to moderately well sorted fine sand. The medium sand is micro cross stratified.
- ***(b)*** *Parallel laminated shale facies:* The unit is about 5m thick consisting of dark fissile shale which was underlain by medium grained sand.

### (B) Mineralogical composition sandstones

The Ajali sand is mainly fine to coarse, well to poorly sorted quartz arenites that lack detrital matrix (grain supported). Feldspar and rock fragment are very little to rare. The Mamu sandstones are fine grained, very well sorted and contain both sillica, clay mineral and iron oxide cement. Quartz grains in each case are mainly angular to subrounded, with monocrystalline quartz which shows straight extinction dominating over polycrystalline quartz which is slightly undulose. Pyrite, muscovite and biotite were also found on this sand but occur as accessory minerals.

### (C) Diagenesis

Diagenesis include all the processes physical,chemical and biological which occur from deposition of a sediment during and after lithification but before metamorphism (Pettijohn et al, 1972). The accumulation of sediment at a point results in the earlier deposits being overlain by younger material which exerts a pressure on it. This overburden pressure acts vertically on a body of sediment and increases as more sediment, and hence more mass is added on top. Diagenetic fabrics result from processes which occur after deposition of the sediment which include compaction, cementation, mineral replacement and dissolution of pre-existing phases. The diagenetic fabrics of the Mamu sandstones can be subdivided into two major types those due to compaction and those due to chemical alteration. The fabric can be important indicators both of the depositional environment of the sediment and the chemistry of a variety of fluids which have been flushed through the sediment during burial.

### (D) Compaction

Loose aggregates of sand changes the initial packing arrangement in response to overburden pressure. This causes reduction in the volume of the sediment body as the volume of the pore water is expelled from the sediment and the individual grains are being brought in contact with each other. Under thick piles of sediment the overburden pressure may be high enough to result in more extreme physical changes in the sediment. Weaker grains deformed or broken by the pressure exerted by stronger grains around them. At grain contact pressures are concentrated at the points where grain touch (high pressure points) resulting into minerals going into solution in the encompassing pore water (pressure solution or pressure dissolution). The degree of compaction is determined by looking at the nature of the grain contacts. The quartz grain of Mamu sands and sandstones exhibit point, long and concavo convex contact and differential compaction was also evidenced from lateral changes in sediment types as seen on mud and sand of location one and two.

### (E) Cementation

Cement is a mineral precipitated within pore spaces during diagenesis. In Mamu sandstone, silica cement is common with minor iron oxide cement. Clay mineral cement was found in abundance in the muddy fine sandstone. There was also lots of quartz overgrowth associated with the sands. The iron oxide cement may have formed by precipitation around the sediments due to weathering, transportation and deposition of amorphous iron compounds. It might also have arisen through a purely diagenetic origin where by the iron is supplied by intrastratal solution of phyllosilicates. The quartz overgrowths observed around these detrital quartz grains are as a result of the cement and the adjacent detrital quartz grains being of the same chemical composition.

### (F) Mineralogical maturity

The mineralogical maturity of sand is expressed by quartz content or by the quartz-feldspar ratio. The analytical evidence from the mineralogical composition studied shows that the most abundant stable mineral in the sand is quartz with a total average of 94 % to 99 **%.** Thus forming the entire framework. This criterion infers that the sands is mineralogically mature.

### (G) Textural maturity

The three stages of the textural maturity of sands according to Pettijolin et a1 (1972) are based on the idea that in transport, clay is first removed, then the framework grains are sorted and much later they are finally rounded (that is winnowing and abrasion by currents to sorting and rounding). The sands is texturally submature. This is judged based on the relatively very low clay content of less than 1 % except in muddy fine sandstone. The standard deviation (sorting measure) in phi scale averaged 1.26 (poorly sorted) and the mean roundness of 0.38 (subrounded).

**(H) Depositional environment of Mamu Formation**

The physical, biological and chemical characteristics of the Mamu Formation aids in the Paleoenvironmental reconstruction because they gave rise to the various sedimentary facies. However, sedimentary facies being a mass of sedimentary rock that can be distinguished from others by its geometry, lithology, sedimentary structures, paleocurrent pattern and presence or absence of body fossils or trace fossils is a product of a depositional environment. Mamu Formation shows deposition in different environments with varying energy levels. The general stratigraphy of the facies of the area shows a pattern of repetition of the various lithofacies which are the representation of the tidal flat and the shoreface environments. These reveal transgressive and regressive cycles in the deposition with fining upward sequence at some area and it is also an indication of fluctuating energy. The hummocky cross stratification, symmetrical wave ripple lamination and parallel lamination with lenticular and tabular sandstone structures as found on the white silty fine sandstone indicates storm dominated low wave energy shoreface environment. The slump structures and gravity faults show instability of the oversteepened depositional slope and rapid sedimentation. The water level marks indicate fall in the water level (regression) aid presence of convolute bedding denotes subaerial exposure of the sediment and differential loading. The wave ripple laminated heteroliths show low energy transitional environment. Coal deposit is an indication of intermittent swamp conditions and this is followed upwards by parallel laminated shale denoting a change in the environment of deposition. The sea must have transgressed too fast for the barrier sands to form which may have been caused either by shortages of land derived sediment, or by extremely rapid rises of sea level or subsidence of land. lenticular and flaser beddings as seen on the sands are indication of tidal environment with fluctuating energy. The burrows of trace fossils are mostly horizontal, inclined and vertical cylindrical burrows of Ophiomorpha, Skolithos and Thalassinoides. The Ophiomorpha burrows are formed by high energy suspension feeders. Vertical burrows are indicative of high energy, horizontal burrows indicate low energy while inclined burrows show moderate energy depositional environment. A general gradation from the vertical to horizontal burrows suggest shallow water deposit to deeper water deposits respectively. Also intensely bioturbated intervals alternating with intervals showing inorganic structures as seen on the outcrop is an indicative of episodic sedimentation. Based on the composition (mineralogical and textural), sedimentary structures, trace fossils and the internal arrangement of the various units observed in the study area, Mamu Formation is proposed to consists of shoreface, transitional, tidal i.e paralic shallow marine depositional environment with relatively short lasting paludal intermission.

## V. DISCUSSION OF RESULT

The sieve analysis data of the sand bodies within the Ajali sand show that the grain size distribution of the sediments is a mixture of three different populations (Visber,1969) which indicates that three modes of transport were involved in the deposition of the sands . These include traction or rolling, saltation and suspension with the greater percentage being transported by saltation. Friedman (1979) attributed the coexistence of the three sub populations to the availability of different particle sizes in a parent material, processes operating in a depositional environment particularly the competency of the flow and the concentration of particles in suspension. The sand is fine to coarse grained (0.02-2.09) with an average mean value of 0.85 (coarse), well sorted to very poorly sorted (0.48-2.15) with the average sorting value being I .26 (poorly sorted). Skewness ranges from very positive to very negatively skewed (-0.42 to +0.46) and very platykurtic to very leptokurtic (0.56 to 1.57) with the average being mesokurtic (0.97). The mean grain size in a sediment is largely a function of energy of the processes controlling transport and deposition, that is the particles are segregated according to their hydrodynamic behaviour which depends on size, specific gravity and shape. According to Reineck and Singh (1980), coarser sediments are of higher energy and finer sediments are of lower energy depositional setting. The recognition of the various sub populations i.e the suspension, population and traction is an indication of fluctuating (pulsating) energy condition of the depositional environment. The average value for the standard deviation which defines the degree of sorting of the sediments is 1.26 (1) (poorly sorted). The poorly sorted nature shows dominance of higher energy over lower energy and so fluctuation in energy condition as finer sands tend to settle at lower energy. The average skewness shows a negative value thus a tail to the left which is an indication of excess of coarse fraction (Tucker, 1988). The plot of skewness against kurtosis for the fifteen analysed samples shows a departure from normality and thus the curves of the sands are generally less peaked than that of the normal curve. The plot of skewness and standard deviation (sorting) of Friedman (1961) shows that majority of the sands is river deposit but with few falling on the beach side. This might be the cause of the sands being generally poorly sorted, negatively skewed and mesokurtic. The undulatory current ripples which are asymmetrical represent transition between low- energy straight- crested small ripples and higher energy lingoid small ripples (Reineck and Singh, 1980). Micro cross stratification shows that there was periodic rapid accumulation of sediment in the environment. The inorganic sedimentary structures found in the sandstones of the Mamu sandstones in the study area include the hummocky cross stratification, wave ripple lamination, both horizontal and inclined parallel lamination, current ripples, micro cross stratification, lenticular and flaser bedding, water level marks, channels, joints, mudcrack etc and soft sediment deformation structures such as slump structures, gravity faults, load and flame structures, convolute bedding and water escape structures. The hummocky cross stratification is an indicative of deposition between storm wave base and normal wave base (Bourgeois,1980; Dott and Bourgeois, 1982; Duke, 1985). The wave ripple lamination is associated with storm-dominated processes and are common in many shallow water environments affected by oscillatory waves. The symmetrical nature of the wave ripples is an indicative of the orientation of wave fronts. Parallel laminations generally record deposition below wave base (quiet or low energy water) and its preservation indicates either very rapid deposition or toxic bottom conditions. These laminations arise as a result of variations in the rate of supply or deposition of different materials (alternations of coarse and fine particles) have been attributed to the fortuitous shift in the depositing rent, to climatic causes and also to a periodic storms or floods (Pettijohn, 1975). Flaser and lenticular bedding indicate current activity alternating with periods of quiescence (Reineck and Singh, 1980). The water level marks are good indicators of sinking water level in an area exposed intermittently subaerially . The soft sediment deformation structures are penecontemporaneous with the deposition of the white silty fine sandstone, muddy fine sandstone and the heteroliths. The slump structures and gravity faults are indication of the instability of an oversteepened depositional shoreface slope and rapid fall of sediments under gravity. The water escape structures and convolute bedding are as a result of unequal loading and over loading of sediments with subaerial exposure of the sediments at low tide. Load and flame structures show deposition of sand over a hydroplastic mud layer. Pettijohn et al 1972). Channels which are post depositional were created by water owing over the soft sediments. The simple straight and u-shaped burrows of suspension feeders which include the vertical, inclined and horizontal burrows of Ophiomorpha, Thalassinoides and Skolithos are dominant trace fossils. Ophiomorpha burrows are formed by different organisms which are high energy suspension feeders and so also is Skolithus. Vertical burrows are dominant in high energy conditions which keep surfacial sediment mobile and horizontal burrows are dominant where the energy condition are low and nutrients are abundant within the substrate. A general gradation from vertical burrows to horizontal and increasing patterned burrows suggest shallow- water deposit to deeper water deposits. Bioturbation density are mainly affected by oxygen content of the water, the availability of food, conditions of sedimentation and grain size which is a function of hydraulic condition (Lewis and MacConchie, 1994). Also intensely bioturbated intervals alternating with intervals showing inorganic structures as seen in some locations of the study area is an indication of episodic sedimentation. Both Ophiomorpha and Skolithus are diagnostic of shallow marine depositional environment. The presence of some lithologic units such as coal beds which were followed upwards by parallel laminated dark fissile shale is an indication of intermittent swamp conditions punctuated by sea transgression. Thus a shallow marine shale overlies a coal swamp facies (Selly, 1982). The alternation of fine, medium and coarse sands even with shale and mud as seen in some locations indicates fluctuation (low to high) energy and they must have been deposited as mud flat, mixed flat, sand flat and sub tidal in tidal shallow marine environment. The hummocky cross stratified white silty fine sandstone, tabular and lenticular sandstone facies are all indication of deposition in storm dominated low wave energy marine shoreface. The wave ripple laminated heteroliths of the muddy fine sandstone and the white silty fine sandstone also indicate a low energy transitional zone deposit in shallow marine environment. The sphericity of the grains studied using a visual comparison chart of Power (1982) showed a range of 2.5mm to 4.5mm. The relative high value of sphericity suggests that the sediments must have been reworked which is also an indication of multicycle origin. The degree of the grain rounding which was studied using the visual comparison chart for estimating roundness and sphericity from Power (1982) shows that the range of roundness for Mamu sands is 0.25mm to 0.49mm with the midpoint of 0.37mm (subrounded). This indicates that the sediment has been transported farther away from the source area to the depositional environment . Roundness of a detrital particle is dependent on its size, physical characteristics and history of abrasion. The grain contacts as seen under the microscope are generally point, long and concavo - convex contacts suggesting that the sediment has been subjected to various degrees of environmental stress from little overburden pressure to formation of pressure solution whereby one grain dissolved at the point of contact with another. This is also an evidence of diagenesis (compaction). Also the ferruginized sand has iron oxide coating around the grains. Surface texture as observed shows that the quartz grains exhibit dull and opaque appearance and have thin hard coatings of iron oxide and silica which are product of chemical actions. The general absence of breakage of the quartz grains shows that high velocity currents were involved in the transportation. Mineralogically, the sands and sandstones are quartz arenites consisting of almost entirely quartz with very little to no feldspar. The monocrystalline quartz with straight extinction dominated over the polycrystalline quartz which is slightly undulose. Pyrite, muscovite and biotite occur as accessory minerals. The absence of feldspar indicates an intense chemical weathering in a warm humid climate. The dominance of quartz shows that Mamu sand is mineralogically mature. Textural studies also showed them to be submature. Based on the general stratigraphy of Marnu Formation, sedimentary structures observed, composition, trace fossils etc a shallow marine paralic depositional environment with relatively short lasting paludal intermission has been assigned to Mamu Formation.

## VI. CONCLUSION

Mamu Formation comprises of shales, mudstones, claystones, coal, sandstones and heteroliths. The loose friable and unconsolidated sands which are coarse grained, generally pooriy sorted, positively to negatively skewed and mesokurtic are of Ajali Sandstone. The sandstones are fine grained quartz arenites which has Silica as a dominant cement. Quartz grains are mostly monocrystalline with straight extinction, quartz overgrowth and inclusions. The sedimentary structures studied in the area include hummocky cross stratification, wave ripple lamination, current ripples, parallel laminations, micro cross stratification, lenticular and flaser bedding, water level marks, channels, mudcrack and joints. The soft sediment deformation structures are dominant in the sandstones of Mamu Formation and are penecontemporaneous with the deposition of these fine sands which was later lithified due to loading (increased over burden pressure). These deformation structures include slump structures and gravity faults which results from rapid fall of the sediment under gravity in an oversteepened shoreface depositional slope. The water escape structures and convolute bedding are the indications of overloading and unequal loading. The load and flame structures resulted from the deposition of sands over a hydroplastic mud layer. The vertical, inclined and horizontal cylindrical burrows are the dominant trace fossils. Based on the data obtained in this study, the Marnu Formation is hereby considered to be shallow marine paralic deposit which was interrupted by relatively short lasting paludal intermission. The presence of coal swamp facies, tidal flat facies, shoreface facies and transitional zone facies are all evidence to support this.

## VII. REFERENCES


[1]. **Allen, J.R.L. 1963.** The classification of cross stratified units, with notes on their origin.Sedimentology 93 — 114.

[2]. **Allen ,J.R.L.,1967.** Notes on some fundamentals of paleocurrent analysis with reference to preservation potential and sources of variance. Sedimentology Vol 9 pp.75—88.

[3]. **Allen, J.R.L.,1968.** Current Ripples. Elsevier, Amsterdam, 433p.

[4]. **Allen, J.** R. L., 1971. Traverse erosional marks of mud and rock their physical basis and geological significance. Sediment Geol. Vol. 5.pp.167- 385.

[5]. **Allen, J. R.** L., 1982. Sedimentary structures: Their character and physical Basis. Developments in sedimentology 30A. Elsevier, Amsterdam, 593 p.

[6]. Andressen, A., and L. Bjerrum, 1967. Slides in subaqueous slopes in loose sand and silt. In A. F. Richards (ed), Marine Geotechnique, university of Illinois press, Urbana, pp. 221-39.

[7]. Benkheil, **J.,** 1988. Structure and geodynamic evolution of the intracontinental Benue Trough (Nigeria). Bull center rech . Explor. prod. Elf-Acquitaine 12.

[8]. Boersnia, **J.** R., 1970. Distinguishing features of wave ripple cross stratification and morphology. Doctoral Thesis, university of Utrecht. 65p.

[9]. Bourgeois, **J.,** 1980. A transgressive shelf sequence exhibiting hummocky stratification — the cape Sebastian sandstone (Upper Cret), southwestern Oregon. Journal of sedimentary petrology Vol 50 pp. 681 -702.

[10]. Bourgeois, **J., and E. L.** Leithoid,1984. Wave worked conglomerates — depositional processes and criteria for recognition. In sedimentology of gravels and conglomerates (ed byE. H. Koster and R.J.Steel), pp .331 — 343; mem. Can. Soc. Petrol. Geol, 10, Calgary. 6.2.3,6.5.4,7.7.2.

[11]. **Bridges, PH.,** 1972.The significance of tool marks on a Silurian erosional burrow. Geol. mag., Vol. 109, pp. 405-410

[12]. **Bromley, R. G., 1991.** Ti-ace fossils, Biology and Taphonorny. Unwin Hyman, London, 280 p.

[13]. **Brush, L .M., 1965.** Sediment sorting in alluvial channels. In: Middletoii, G.V., ed. Primary sedimentary structures and their hydrodynamic interpretation, special publication Vol 12. 25-33. Tulsa Oklahoma: soc. Econ. paleonti. minera.

[14]. **Bucher,** W. II., 1919. On ripples and related sedimentary surface forms and paleogeographic interpretations. Am. J. sci. Vol. 47, pp. 149 -210,

[15]. **Budd,** D. A, **and** R. D. Perkins, 1980. Bathymetric zonation and paleoecological significance of rnicroborings in Puerto Rican shelf and slope sediments. Jour. of sedimentary petrology Vol. 50. Pp. 881-904.

[16]. **Burke,** K. C. B. 1972. Longshore Drift, submarine canyon and submarine fans. Amer. Assoc. petol. Geol. Bull. 56 (ID).

[17]. Carriker, M. R., L. H. Smith, **and** E. T. Wlice (eds), **1969.** Penetration of calcium carboaate substrates by lower plants and invertebrates. American zoologist Vol.9 pp 629 -1020.

[18]. Casey, **0.** P. **and** A. M. **de** Swardt, **1963.** Coal Resources of Nigeria. Geol. Surv. Nig. Bull. No. 28, pp. 1 —15. Cheel, R. **J, and D.** A. Leckie, **1993.** Hurninocky crOss stratification. In: V. P. Wright, (ed), Sedimentology Review, vol, p.103-122.

[19]. **Coleman, J.** M., 1969. Brahmaputra River: chaimel processes and sedimentation. Sediment. Geol. 3. 129- 239. Collinson, **J.** D., and D. B.Thompson, 1982. Sedimentary Structures. 2' ed. Chapman and Hall, London

[20]. Conybeare, C. E. B, and K. A. W. Crook, 1968. Manual of sedimentary structures. Bureau of mineral Resources, Geology and Geophysics Bulletin 106 of grain size parameters. In sedim. petrol. vol. 27. Pp. 326.

[21]. Franki, E. **J. and Cordry, E. A., 1967.** The Niger Delta oil province: Recent Developments onshore, offshore, proc. 7th World petroleum Congress, vol. 2 pp. 125—209.

[22]. **Frey, R. W., 1973.** Concepts in the study of biogenic sedimentary structures. Journal of sedimentary petrology 43 Vol.43 pp 6-19

[23]. Frey, R. W. **and S. G. Pcmberton** 1987. Trace fossil fades models. In: facies models (Ed. by R. G. Walker), pp 189-207. Geol. Assoc. Can., Waterloo, Ontario.

[24]. Friedman, G. M., 1961. Distinction between dune, beach, and river sands from their textural characteristics. J. sediment, petrol: Vol. 31, pp. 514- 529.

[25]. **Friedman,** G. M., 1979. Differences in size distributions of populations of particles among sands of various origins. Sedimentology, vol. 26. Pp. 33-32.

[26]. Hantzschel, W. F. el — **Baz, and G. C. A mstutz, 1969.** Coprolites, an annotated Bibliography. In:

Reineck and singh (ed), Depositional Sedimentary Environments, Springer-Verlag, .Newyork.

[27]. **Harms, J. C., J. B. Southard, and R. G. Walker,** 1982. Structures and sequences in elastic rocks. SEPM sort course 9.

[28]. Hendry,H. E., 1973. Sedimentation of deep water conglomerates in lower Ordovician rocks of Quebec composite bedding produced by progressive liquefaction of sediment. Journal of sedimentary petrology Vol. 43 pp. 125-36.

[29]. **Hofmann, H.** 1., 1973. Stromatolites: characteristics and utility, Earth science Reviews Vol. 9 pp. 339-73.

[30]. **Kaye, C. A., and Power, W. R., 1954.** A flow cast of very recent date from northeastern Washington. Am. J. sci. Vol. pp. 252, 309 -310.