CAMPANO-MAASTRICHTIAN SUCCESSION AND PALEO ENVIRONMENT OF THE SOUTHERN BIDA BASIN,

CENTRAL NIGERIA

BY

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Declaration

I declare that the work in this dissertation entitled CAMPANO-MAASTRICHTIAN SUCCESSIONS AND PALEOENVIRONMENT OF THE SOUTHERN BIDA BASIN, CENTRAL NIGERIA" has been carried out by me and is a record of my own research work under the supervision of Dr. T. Najime and Dr. H. Hamza. All the information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

Name of Student	Signature	Date

Certification

This dissertation entitled “CAMPANO-MAASTRICHTIAN SUCCESSIONS AND PALEOENVIRONMENT OF THE SOUTHERN BIDA BASIN, CENTRAL NIGERIA” by Adukwu Fabian OHIEMI meets the regulations governing the award of master’s degree in Geology (Paleontology and Stratigraphy) of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Dr. T. Najime Chairman, Supervisory Committee	Signature	Date
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Abstract

The determination of paleodepositional environment within which geologic factors interplayed to establish the sedimentary facies present in outcropping sediments in parts of the Southern Bida Basin, in order to establish sedimentary facies through sedimentological analysis of sediments by detailed field mapping and laboratory techniques, forms the focus of this study. The study area is bounded by latitudes 7° 51' and 8° 30' N and longitudes 6° 40' and 6° 57'E.

The southern Bida Basin contains a stratigraphic succession comprising of Lokoja Sandstone, Patti Formation and Agbaja Ironstone. The Lokoja Sandstone consists of conglomerate, sandstone and claystone facies. The conglomerate facie is subdivided into massive, matrix to grain supported subfacies. The sandstone facies is also subdivided into medium, pebbly grained and bioturbated sandstone subfacies. The result of the grain size analyses show that the Lokoja Sandstones are generally poorly sorted, medium to coarse grained in texture

The Patti Formation in the study area consists of conglomerate, sandstone, and siltstone-shale-claystone facies with sand,fine-grained sand, medium-grained sand, coarse-grained sand, clayey siltstone, silty clay, and sandy silt hummocky cross stratified and bioturbated sandstones subfacies. Herringbone cross-stratification, bioturbation and wave ripples associated with the sandstones of the Patti Formation. The result of grain size analysis of sandstones from Patti Formation shows that it is medium to coarse grained, poorly sorted

The Agbaja Ironstone consists of oolitic, concretional and massive ironstone bed interbedded sandstone and claystone. Depositional environments defined by values of bivariate plots of skewness versus standard deviation and mean versus standard deviation for samples obtained from part of Lokoja Sandstone and Patti Formation confirmed by bivariate plot of skewness versus median for some samples indicate a continental fluvial and shallow marine to transitional paleodepositional environment.

The depostional environment for the Campano-Maastrichtian successions in the southern Bida Basin evolved from proximal alluvial fans through braided stream into shallow marine conditions

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CHAPTER ONE

INTRODUCTION

1.1 GENERAL STATEMENT

The Bida Basin (otherwise known as the Middle Niger or Nupe Basin) is one of the least investigated sedimentary basins in Nigeria. It is a linear intracratonic sedimentary basin located in central Nigeria. The basin is about 350 Km long and 75Km to 150 Km wide trending NW-SE and extending from Kontagora (in the north) to just south of Lokoja (in the south) and is aligned approximately orthogonal to the Benue Trough (Fig.1). It is separated from the basal continental beds of the Sokoto Basin by a narrow outcrop of the crystalline basement rocks in the west and it iscontiguous with the Anambra Basin in the east. Due to its large areal extent, the basin has beendivided into two sectors i.e. northern and southern Bida Basins, probably due to rapid facies changes across the sub- basins.

A wide range of investigations have been carried out in the Bida basins. Most of these have focused on the sedimentology and depositional environments of the sediments in the northern Bida Basin with little been done in southern part of the basin.However, detailed lithological mapping and sedimentological characterization must be carried out with the regard to depositional environment.

1.2 AIM AND OBJECTIVES OF STUDY

The aim of the present study is to improve on the existing knowledge of the study area by carrying out detailed geological investigation such as lithological, sedimentological and to determine paleoenviroment of deposition of the succession in the area with the specific given to the outcrop along Abaji-Lokoja –Agbaja road.

1.3 LOCATION, EXTENT AND ACCESIBILITY

The study area lies within parts of the (FCT) and Kogi State. The field study was carried out in part of southern Bida Basin from Abaji which is in Kotonkarfi Sheet227 to Agbaja in the Lokoja Sheet 247.The study area is bounded by latitudes 7° 51’ N to 8° 30’ N and longitudes6° 40’ E to 6° 57’E.

The area is accessible from Abuja via Abuja-Lokoja highway through Abaji - Ahoko and through Kotonkarfi - Lokoja – Agbaja road. Accessibility to the area from the western part is through Kabba and from the east through Ajaokuta to Lokoja and Agbaja. The area is also accessible by network of secondary roads,footpaths and stream channels linking the different parts.Accessibility is much better during the dry season when grasses are usually dried.

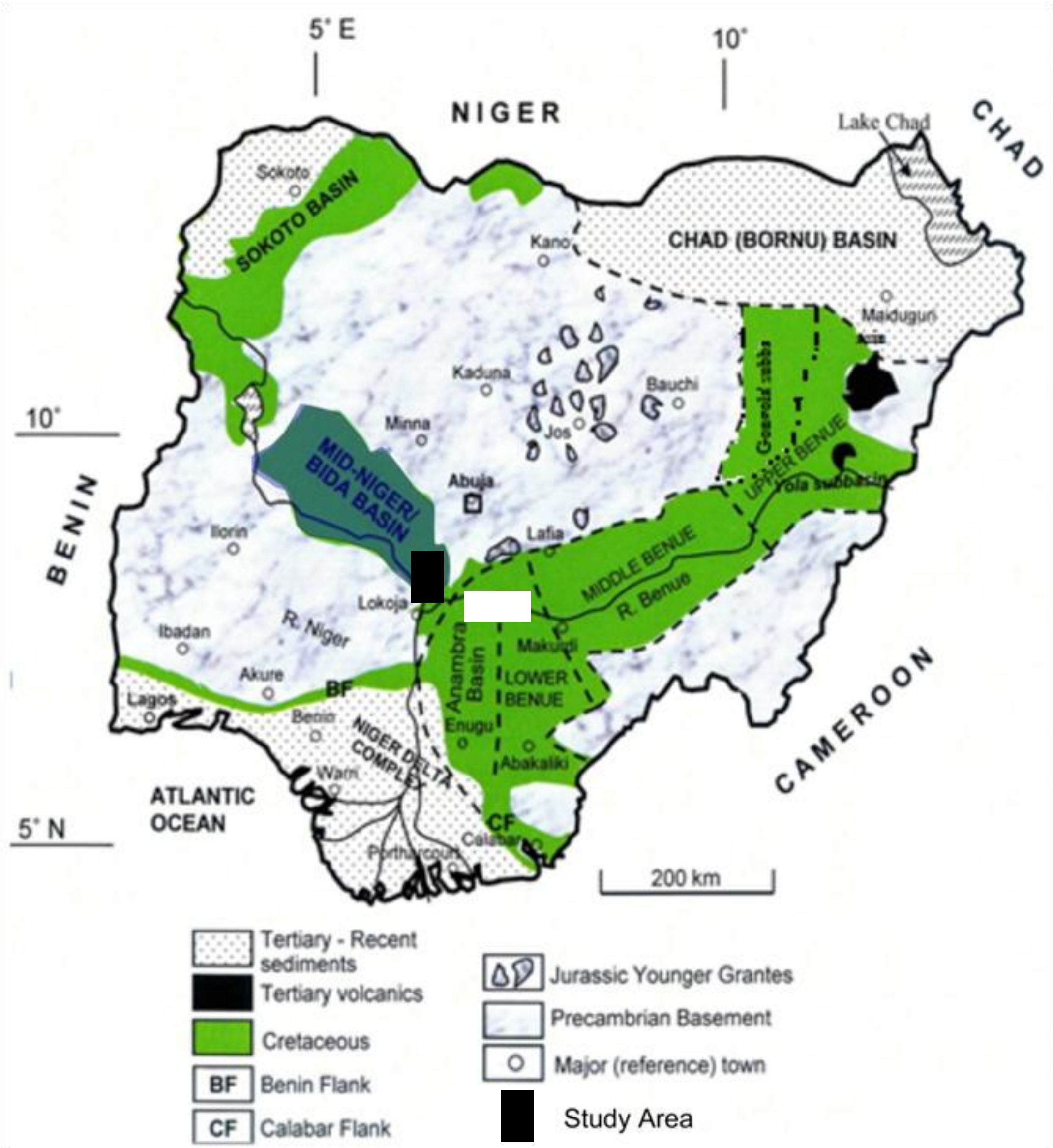


Figure 1**:**Geological map of Nigeria showing the location of the study area (After Obaje *et al*., 2004).

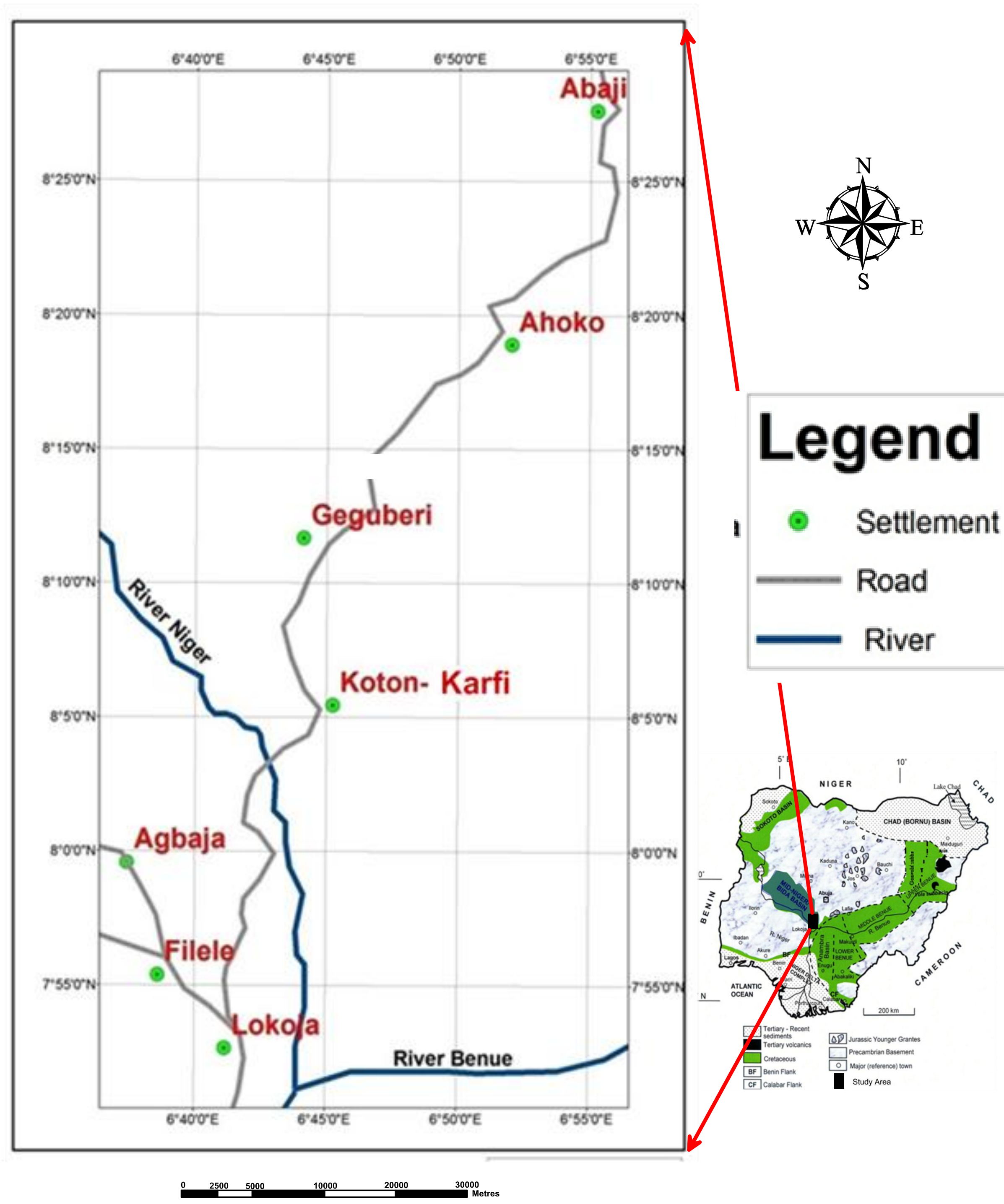


Figure. 2: Accessibility map of the study area.

1.4 CLIMATE

The southern Bida Basin lies within the tropical climate marked bywet and dry seasons. The dry season sets in during November and lasts until March. It is followed by a wet or rainy season from April to October with maximal rainfall in June and September. The annual amount of rainfall within the area is between 1200 and 1500 mm. Relative humidity is about 90 percent in the morning and drops to about 80 percent in the dry season. The annual temperature range between 16°C and 37°C. During the rainy season, the area is under the influence of moisture-laden southwest trade winds which give way to the dry and sometimes dusty northeast winds (harmattan) during the dry season.

1.5 VEGETATION

The southern Bida Basin lies within the Guinea Savannah vegetation beltcharacterized by trees and grasses with numerous trees in sparsely settled area. There are heavy forests along the river valleys. However, the original vegetation has been, in most cases, tempered with through human activities.Examples of trees in the study area include *Afezilia africana*,*Uapacatogoenesis, Daniella oliveri (*locust bean*), Buttryospenum paradoxim, (*sheabutter*), Montes kerstingi* and *Isoberlina dalzieli* .The dominant grasses include Elephant grass (*Axonopus Comprssors),* Pine grass (*L. Penisefum* SPP), species of Devil bean stems with delicate, offensive, adhesive hairs that produce unpleasant irritation when in contact with the skin are also common.

1.6 RELIEF

The southern Bida Basin is characterized by undulating terrain with limited flat terrain. This is typical of Patti hill and Agbaja Plateauwhich are the two main hills in Lokoja area. Patti hill attains an elevation of 1500 m. Falconer (1911) andKogbe (1981) described Mount Patti as linear

NW-SE ridge parallel to Agbaja Plateau with an altitude of about 1450 mboth following the basin trend perpendicular to the main axis of the Benue Trough These high lands are capped by indurated and ferruginous sandstone. This hill also extends across the Niger River toward Bassa and terminating around Gboloko-Monzum area.

1.7 DRAINAGE

The geomorphological features in the southern Bida Basin consist of River Niger, its flood plain and tributaries characterized by belt of mesas and plains. The area is being drained by Rivers Niger and Benue.

Other minor rivers and streams like River Mimi flowing southward into River Niger exactly at the confluence. Patti stream which is more or less a flow of connate water gushing out of sediment and flowing into River Niger in southeastern direction. River Abaji also flows in southeastern direction into River Niger. Most of these streams are intermittent and thus dry off at the peak of dry season. Generally, the drainage pattern is simply dendritic where many tributaries join the major river (Fig.4).

1.8SOIL AND AGRICULTURE

Predominantly, the soil is mainly sandy clay in Lokoja up to Kotonkarfi and clay soil in Ahoko and Abaji. The variation in colour is due to the original composition of the rock which they were formed and organic matter present.The land use is basically for agriculture andthe agricultural practices include fishing along River Niger and cultivation of yam, rice, cassava and sweet potatoes. Excavation and molding of clays is carried out by the people in the area. They mold clay blocks which are used in building houses

.1.9SETTLEMENT

The distribution of settlements in the study area depends on the geology, topography and the availability of water and arablefarm lands. The settlement pattern is nucleated in some parts and linear in other areas. (Fig.3).

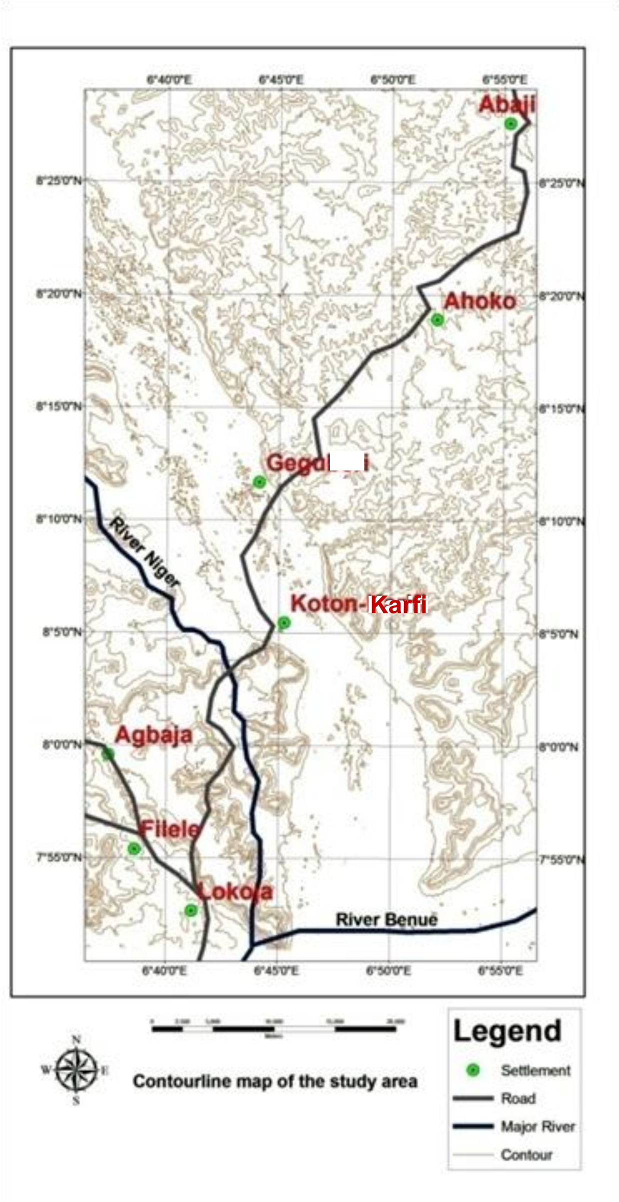


Figure 3:Relief and settlements map of the study area.

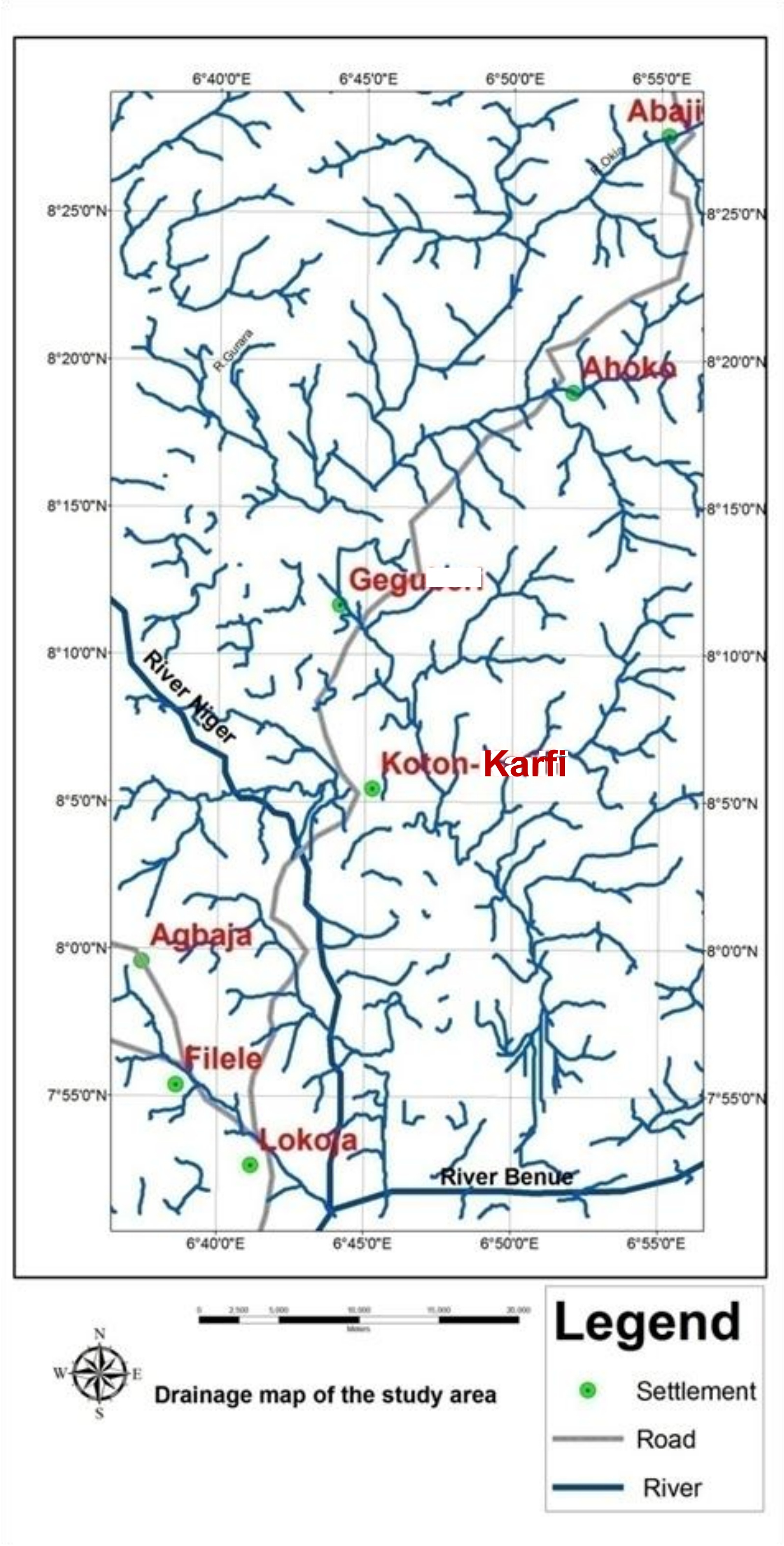


Figure 4:Drainage map of the study area.

CHAPTER TWO

2.1LITERATURE REVIEW

The northwest - southeast trending Bida Basin forms one of the major inland sedimentary basins in Nigeria (Fig.1). Falconer (1911) was among the first authors that described and investigated the upper Cretaceous rocks in the basin. Jones (1958) divided the series in to southern Lokoja sub-basin and central Bida sub-basin which are lateral equivalent in age.Russ (1930); Adeleye and Dessauvagie (1972)used the term Nupe Group collectively for the stratigraphic succession in both northern and southern Bida Basin. Russ (1957); Adeleye and Dessauvagie (1971); Jones (1958) and Obaje (2009) described the general stratigraphy of the basin. Lokoja sub-basin was subdivided into basal Lokoja Sandstone which is overlained by Patti Formation and capped by Agbaja Ironstone. The northern or central Bida sub-basin comprises of Bida Sandstone overlained by Sakpe Ironstone and Enagi Siltstone and capped by Batati Ironstone Ojo (1992);Jan Du Chene *et al.* (1978) and Whiteman (1982) carried out the palynological studies on the Lokoja Formation revealing about 70-80% pollens and spores of the total microfossils. Jones(1958); Adeleye (1971, 1973, 1974) andJan Du Chene *et al.* (1978) reported the occurrence of upper Cretaceous palynomorphs in the basin. On the basis of palynofossils recovered from road side exposures north of Lokoja, a Maastrichtian age was assigned Jan Du Chene *et al.* (1978) while Mebradu*et al.* (1986) also suggested a Maastrchtian age for the same or at least nearby exposures, using palynofossils.

Braide (1992a); Olaniyan and Olobaniyi (1996); Olugbemiro and Nwajide (1997) described some aspect of some sedimentological charecteristics of Lokoja and Bida Sandstones which they interpreted as continental deposits and are of lateral equivalents. The ironstone deposit of theAgbaja was first reported by Falconer (1911) who suggested that the ironstone is of sedimentary origin and formed in a non- marine environment in view of its unfossilliferous nature. Dupreez (1954) postulated an *in situ* lateritic origin for the ooidal and pisoidal ironstone. Ladipo *et al.* (1994), Abimbola (1997) described the genesis of the Agbaja Ironstone on the basis of the petrography, lithologic characteristics and field relationships. Vibkal *et al.* (1999) reported the hydraulic features of the upper Cretaceous sandstone facies in the southern Bida Basin.Russ (1930);Jones (1958, 1965);Adeleye (1971, 1973); Ojo and Ajakaiye (1989) and Obaje *et al.* (2011) concluded that the Bida Basin is a shallow downwarped trough filled with Campanian-Maastrichtian non marine and marine sediments deposited on the Precambrian Basement Complex.

Ladipo (1988) reported petrological characteristics of the Lokoja Sandstone. Adeleye and Dessauvagie(1972);Jones (1958) described the pebbly and conglomeratic sandstone of the Bida Basin as composed of well rounded quartz pebbles in the matrix. Akande*et al.* (2005) analyzed the sandstone and siltstone facies and revealed quartz, feldspar, mica and other accessory minerals. They reported that the sandstones range from rounded to well rounded and mineralogically immature. Olaniyan and Olabaniyi (1996) identified the unconformity sequence about 7 km west of Filele town representing erosive contact between conglomeratic sandstone overlying the weathered basement. Allen (1982) reviewed the origin and classification of the recent alluvial sediment along River Niger in terms of its heavy mineral composition.

Akande*et al.* (2005) carried out paleontological and sedimentological analysis of the exposed Patti Formation along Kotonkarfi and Abaji road and identified a kerogenous organic matter in the shale facies with the total organic content (TOC) 0.43wt%. Braide (1990) hinted on the possibility of occurrence of gas and condensate in the southern part of the basin.

Recently, however investigations have also been carried out on the petroleum potentials of the Bida Basin by Obaje *et al.* (2011) who the potential source rocks in the BidaBasin are gas-prone.These authors also noted that reservoir rocks in the basin include fluvial sandstones in the Lokoja Formation and well-sorted shelf and flood plain sandstones in the Patti Formation while shales and claystones of the Patti and Agbaja Formations may provide regional seals in the Southern Bida Basin.

2.2 ORIGIN OF THE BIDA BASIN

The Bida Basin is a NW-SE trending linear intracratonic structure about 350 km in lengthextending from Kontagora in the northwest to Lokoja in the southeast. Its width ranges between 75 km to 150 km. Several authors have expressed their views as regard the evolution of the basin.King (1950)and Kennedy (1965) described it as a rift bounded tensional structure produced by faulting associated with the Benue Trough system and drifting apart of African and Brazilian Plates.

Adeleye (1976) regarded the Bida Basin as having originated as simple sag structure subsequent to Santonian folding in the Benue Trough. In a different model, Ojo and Ajakaiye (1989) relates the origin of the basin to have been associated with isostatic readjustments and gentle down warping of the basement which resulted mainly from the removal of material during the emplacement of “Younger Granites” in the Jurassic times.

Whiteman (1982) noted that the gravity and aeromagnetic data could be taken to indicate a rift origin for the Bida Basin but on the basis of field relationship and lack of fault scarps favoured a simple, post- Santonian sag origin. Aeromagnetic data suggesting sedimentary infill in excess of

3000 m. Adeleye and Dessauvagie (1972) estimated a thickness of about 2-3 km, and Ojo (1990) not more than 2 km.

Fairhead and Okereke (1987) have shown that a positive regional gravity anomaly decreasing in amplitude to the west characterizes the Bida Basin. Although the precise shape of the anomaly was uncertain a crust thickening from about 20km in the east to 28km or more below the central part of the basin was suggested. Removal of this positive anomaly allowed a well defined negative anomaly to be identified over the basin representing the low sedimentary infill but no thickness estimate was made for it.

Interpretations of landsat images and borehole logs, as well as geophysical data across the entire Bida Basin suggest that the basin is bounded by a system of linear faults trending NW/SE(Kogbe,1981; Ojo, 1984; Ojo and Ajakaiye, 1989). Kogbe *et al*. (1983) interpreted the course of the River Niger and its valley margin to be controlled by faults with the same trends. Coupled with the field data, these relationships were used to infer that the Bida Basin is a rift basin. Gravity studies point to a series of central positive anomalies flanked by negative anomalies, similar to the adjacent Benue Trough and typical of rift structures (Ojo, 1984; Ojo and Ajakaiye, 1989). Gravity studies in the Bida Basin put the maximum thickness of the sedimentary successions at about 3.5 km in the central axis(Ojo, 1984).

Although no outcrops of volcanic rocks have been reported yet, Ojo (1990) on the basis of aeromagnetic anomalies, inferred the presence of E-W trending mafic and ultramafic intrusive at depths of 4-6km in the Bida Basin thussuggest that the basin may have originated as a rift associated with mantle upwelling. Subsequent cooling and subsidence led to concealment of the rift zone below younger sediments.

Agyingi (1991) stated that both surface and subsurface information is suggestive of post-Santonian origin for the Bida Basin as its sediments are generally undisturbed. A maximum sedimentary pile of 3300 m was postulated from the aeromagnetic interpretation.Adeniyi (1985) through aeromagnetic studies outlined the Bida Basin configuration. Arecent spectral analysis of the residual total magnetic field in different sections of the basin showed that the average depth to basement is about 3.4 km, with sedimentary thicknesses of up to 4.7 km in the central and southern parts of the basin (Udensi and Osazuwa, 2004). Braide (1992a) suggested a wrench fault tectonic model for the origin of Bida Basin based on the sedimentary cycles; that the weight of these sediments may have contributed to the subsidence of granitic floor of the basin. Braide (1992b) added that the development of central and southern sub-basin was attributed to the wrench fault movement associated with the tectonic frame work of Nigerian sedimentary basins. According to Ojo and Akande (2012), Bida Basin could be considered as a graben developed at an angle to the strike-slip principal fault movement along the Benue Trough.Obaje *et al.* (2011) suggested that the basin is a gently downwarpedtrough whose genesis may be closely connected with the Santonian orogenicmovements of southeastern Nigeria and the Benue Trough. Likkason (1995) suggested that Bida Basin was initiated during the Campano-Maastrichtian but related its origin to a postulated mantle plume occurring close to the confluence of the River Niger and Benue.

The Bida Basin lies along the line extending NW through southern part of the Sokoto Basin(where early Cretaceous or late Jurassic sediment of similar lithological characteristics to those in the northern Bida Basin occurs) and along the southwestern margin of the Iullummeden Basin to the Gao-Trough. The Gao-Trough is a half graben, faulted along its southern-western margin (Guiraud *etal*., 1987) and active during Early Cretaceous times (Popoff, 1988; Guiraud and Maurin, 1990).Genik (1993) regarded the Bida Basin-Gao Trough line as possible major fault zone or “crustal block boundary” along which both structures originated during the Early Cretaceous. It is possible that the Bida Basin originated earlier than it is generally assumed, perhaps by translation of strike- slip movement along the Benue Trough into extensional stresses that favours post-Santonian origin due to apparent absence of mid-Cretaceous marine beds and the relatively undeformed nature of the sediments (Zaborski, 1998).

2.3 STRATIGRAPHY

The sedimentation andstratigraphy of the upper Cretaceous sediments of the Bida Basin were documented by several workers including Adeleye (1973, 1974); Ladipo (1988); Abimbola(1997); Braide (1992b); Obaje (2009) and Obaje *etal.*(2011). Four mapable stratigraphic units and their equivalence were recognized from the north to the southern part of the basin as delineated by Adeleye and Dessauvagie (1972). The stratigraphic succession of the Middle Niger Embayment collectively referred to as Nupe Group (Adeleye,1974; Obaje, 2009) comprises a two-fold subdivision of northern Bida and Lokoja sub- basin. The Bida Basin strata are Late Cretaceous (Campanian–Maastrichtianin age and were named the Nupe Sandstone by Russ (1930).   .

According to Jones (1958) the southern Bida Basin contains the Campanian Lokoja Sandstone (mainly conglomerate and sandstone), the Maastrichtian Patti Formation (shale, claystone and sandstone) and the Agbaja Ironstone according to Adeleye and Dessauvagie (1972). Their lateral stratigraphic equivalents in the northern Bida Basin consists of the basal Bida Formation (conglomerate, sandstone), Enagi Formation (siltstone, claystone and sandstone) and Batati Formation(Fig.5)

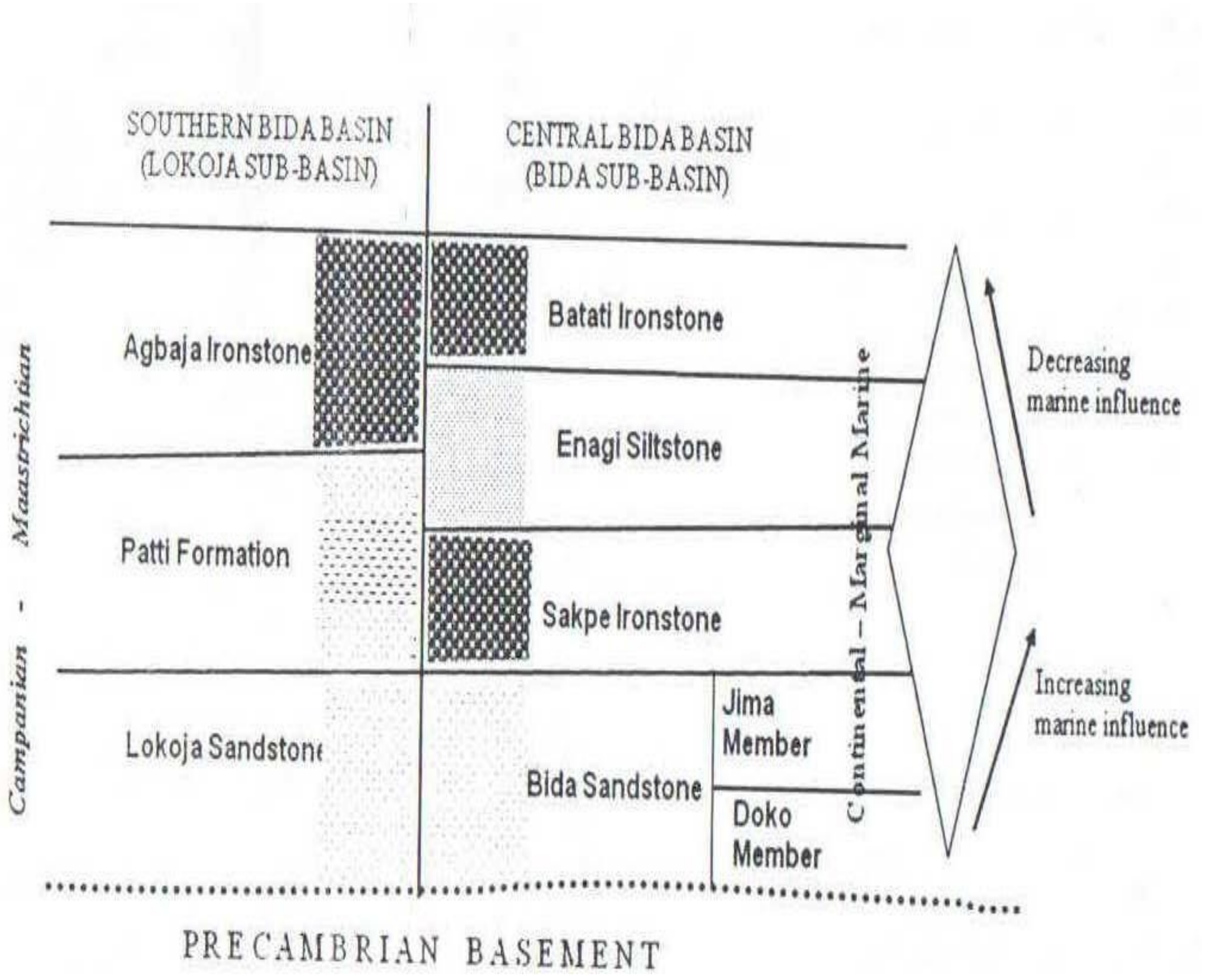


Figure5:Stratigraphic succession in the Bida Basin (After Obaje, 2009)

2.4NORTHERN BIDA BASIN (BIDA SUB-BASIN)

The stratigrahic units identified by Adeleye and Dessauvagie (1972) include Bida Sandstone (oldest), Sakpe Ironstone, EnagiSiltstone and Batati Ironstone (youngest).A lateral facies variation occurs in the southern part of the basin.

2.4.1The Bida Sandstone

The term "Bida Sandstone" was proposed by Adeleye and Dessuvagie (1972). It overlies unconformably the Basement Complex and it is the lateral equivalent of the Lokoja Sandstone to the south.These authors divided the formation into a basal Doko Member and Jima Member. The Doko Member estimated to be at least 183 m thick and of probable braided river origin. It consists mainly of very poorly sorted, pebbly arkoses, sub-arkoses and quartzose sandstones and is thought to have been deposited in alluvial fan setting. The Jima upper member is estimated to be at least 90 m thick and of meandering river origin. It is dominated by cross-stratified quartzose sandstones, siltstones and claystones. The source area for the Bida Sandstone is believed to have been the crystalline Basement Complex of south-western Nigeria(Adeleye and Dessuvagie, 1972).

2.4.2 The Sakpe Ironstone

The term "Sakpe Ironstone"wasproposed by Adeleye and Dessauvagie (1972). It lies between the Bida Sandstone and Enagi Siltstone. It is made up of dark yellow to dark brown ooidal, geothitic and pisolitic ironstones with a matrix of brownish yellow or white clay or fine- grained sand. The Ironstone form the prominent break of slope along the "mesa" walls in the Bida area (Adeleye, 1971).According toAdeleye and Dessauvagie(1972)the formation containspoorly preserved marine molluscs suggesting Massstrichtian age. Lamination and thin to thick flat bedding are most common structures of the ironstone (Adeleye, 1973).

2.4.3 The Enagi Siltstone

The "Enagi Siltstone" directly overlies the Sakpe Ironstone and the name was proposed by Adeleye and Dessauvagie (1972).It iscomposed of laminated siltstones with subordinate finegrained and kaolinitic claystones. Themineral assemblages consist mainly of quartz, feldspars and clay minerals.Fossil leaf impressions and rootlets have been found within the formation. The formation ranges in thickness from 30 m to 60 m. This argillaceous rock is referred to as the Enagi Siltstone Formation (Adeleye, 1971).

2.4.4 The Batati Ironstone

The Batati Ironstone overlies the Enagi Siltstone and is the uppermost unit of the Nupe Group and the name was proposed by Adeleye and Dessauvagie (1972). It is made up of oolitic ironstones consisting of brown, yellow to white geothitic oolites in a yellow limonitic matrix. Due to erosion, the formation varies from 0.3m to 15 m in thickness. Adeleye and Halstead (1972) indicated that the formation is of Maastrichtian based on a marine fauna of molluscs and worms recovered from it.

2.5SOUTHERN BIDA BASIN (LOKOJA SUB-BASIN)

Three formations are recognized in the southern Bida Basin (Fig.5) all of which are Campanian to Maastrichtian in age (Adeleye, 1971; Adeleye and Dessauvagie, 1972; Agyingi, 1991). The formations are the basal Lokoja Sandstone,Patti Formation and the uppermost Agbaja Ironstone.

2.5.1 The Lokoja Sandstone

The Lokoja Sandstoneunconformably overlies the Precambrian basement rocks and the name was proposed by Adeleye and Dessauvagie (1972). Falconer (1911) described the Upper Cretaceous sedimentary rocks around Lokoja as the Lokoja series. It is the lateral equivalent of Bida Sandstone (Fig.5). The formation comprises of basal conglomerates and sandstone finely interbedded with siltstone and claystone. They are generally poorly sorted, feldspathic sandstones with interbedded siltstone and claystone.

The basal conglomerate consists of subrounded to well-rounded pebbles and cobbles of quartz and feldsparsembedded in a whitish clay matrix. The sandstonesshow fining upwardssequence.The sandstones and conglomerates were interpreted to have been formed in continental environment dominated by alluvial and braided stream process(Akande *et al.,* 2005).

2.5.2Patti Formation

The term Patti Formation was proposed byAdeleye and Dessauvagie (1972). The formation directly overlies the Lokoja Sandstone and consists of fine to medium- grained, grey and white sandstones, clays and carbonaceous silts and shales, oolitic ironstone and thin impure coal seams. The argillaceous rocks (shale, siltstone and claystone) in this formation are well exposed between Kotonkarfi and AbajiObaje *et al*. (2011)The siltstones of the Patti Formation commonly have parallel laminae and may show occasional wavy ripples of soft sediments deformational structures (e.g. slumps), convolute laminations, load structures. Trace fossils (especially*Thalasinoides*) are frequently preserved. The interbedded claystones are generallymassive and kaolinitic.The maximum exposed thickness is 70 m (Jones, 1958), while the oolitic ironstones range from 7 to 16 m in thickness.Agyingi (1993) recorded a thickness of up to 220 m for these sediments and inferred a meandering river depositional environment. Thetype locality is in Mount Patti near Lokoja. It is the lateral equivalent of the Enagi Sandstone in the northern Bida Basin. The sandstone of the Patti Formation is in large part moremineralogically maturethan those of the Lokoja Formation Akande*et al.*(2005). On the basis of palynofossils recovered from the road side exposure north of Lokoja, a Maastrichtian age was assigned by Jan Du Chene *etal.* (1978). Mebradu (1986) also suggested a Maastrichtian age for the same or at least nearby exposures, using palynofossils and foraminifers. Jan Du Chene *et al.*

*(*1978) inferred fluviatile to shallow lacustrine environments of deposition and identified lateritic soil profiles at several horizons.

The predominance of argillaceous rocks, (siltstone, shale, and claystone) in the Patti Formation suggests low energy environments probably restricted bodies of water(Braide, 1992b). The abundance of land plant materials suggests prevailing fresh water conditions.

2.5.3 The Agbaja Ironstone

Adeleye and Dessauvagie (1972) proposed the name Agbaja IronstoneThis. formation forms a persistent cap for the Campanian – Maastrichtian sediments in the southern Bida Basin and is a lateral equivalent of the Batati Ironstone on the northern sub-basin. It consists of sandstones and claystones interbedded with oolitic, concretionary and massive ironstone beds. The sandstones and claystones were interpreted as abandoned channel sands and over bank deposits that were subjected to marine reworking forming the massive concretionary and oolitic ironstones (Ladipo *et al*., 1994).Minor marine influences were also reported to have affected the dominantly continental environment of the upper parts of the Lokoja Sandstoneand the Patti Formation (Braide, 1992b; Olaniyan and Olobaniyi, 1996). The marine inundations appear to have continued throughout the period of deposition of the Agbaja ironstones in the southern Bida Basin (Ladipo *et al.*, 1994).

Abimbola (1997) recognized three facies within the Agbaja Ironstone. These are:

(i) At the top, a breccia mud- ironstone comprising kaolinitic matrix with angular to sub-angular detrital grains and angular clasts mostly made up of kaolinitic false ooids with faint replacement goethite rings.

(ii) Pisoidal pack-ironstone consisting of poorly sorted, loosely packed pisolites made up of goethite, minor haematite and relict kaolinite with core of goethite with an outer rim of haematite. The matrix is composed kaolinite.

(iii) At the bottom, ooidal pack-ironstone comprising spherical ooids, made up of kaolinite, kaolinite goethite or haematite within kaolinite matrix.

Adeleye (1973) suggested that the ooidal and pisolitic ironstones were similar to Minette-Type deposits, having formed within high-energy, subtidal shore line environments encroaching into fluviatile and swamp area.

CHAPTER THREE: METHODOLOGY

3.1. INTRODUCTION

The methods employed in the present study include field work, sample collection and laboratoryanalysis. The laboratory analysis included petrographic studies, granulometric analysis and micropalaeontological analysis.

3.1.2 FIELD WORK

The field mapping was conducted during the dry season on a scale of 1:50,000 by traverse exposure mapping. During the field survey, traverses were taken with the aid of compass in southern Bida Basin from Kwaita through Abaji to Lokoja to locate the outcrops of the Campanian -Maastrichtian Lokoja Sandstone, Patti Formation and Agbaja Ironstone in the study area (Fig.6). The sections were logged, described and correlated (Figs 7-26 and 28) with special attention paid to the sedimentary structures.

Systematic logging technique was adopted and this involved measuring the thickness of the beds using measuring tape, location of different lithofacies boundaries along section with the aid of Global Positioning System and sample were collected for laboratory analysis. Lithologic logs were drawn with the help of Sedlog (3.0) and Corel Photo-paint (X5) software.The paleoenvironmental interpretation was attempted based on integration of facies association, sedimentary structures, textures and petrography.

Nineteen sections were logged within the study area.The lithofacies encountered in the study locations comprise of conglomeratic sandstone,ironstone, sandstones, siltstone, carbonaceous shale and claystone.

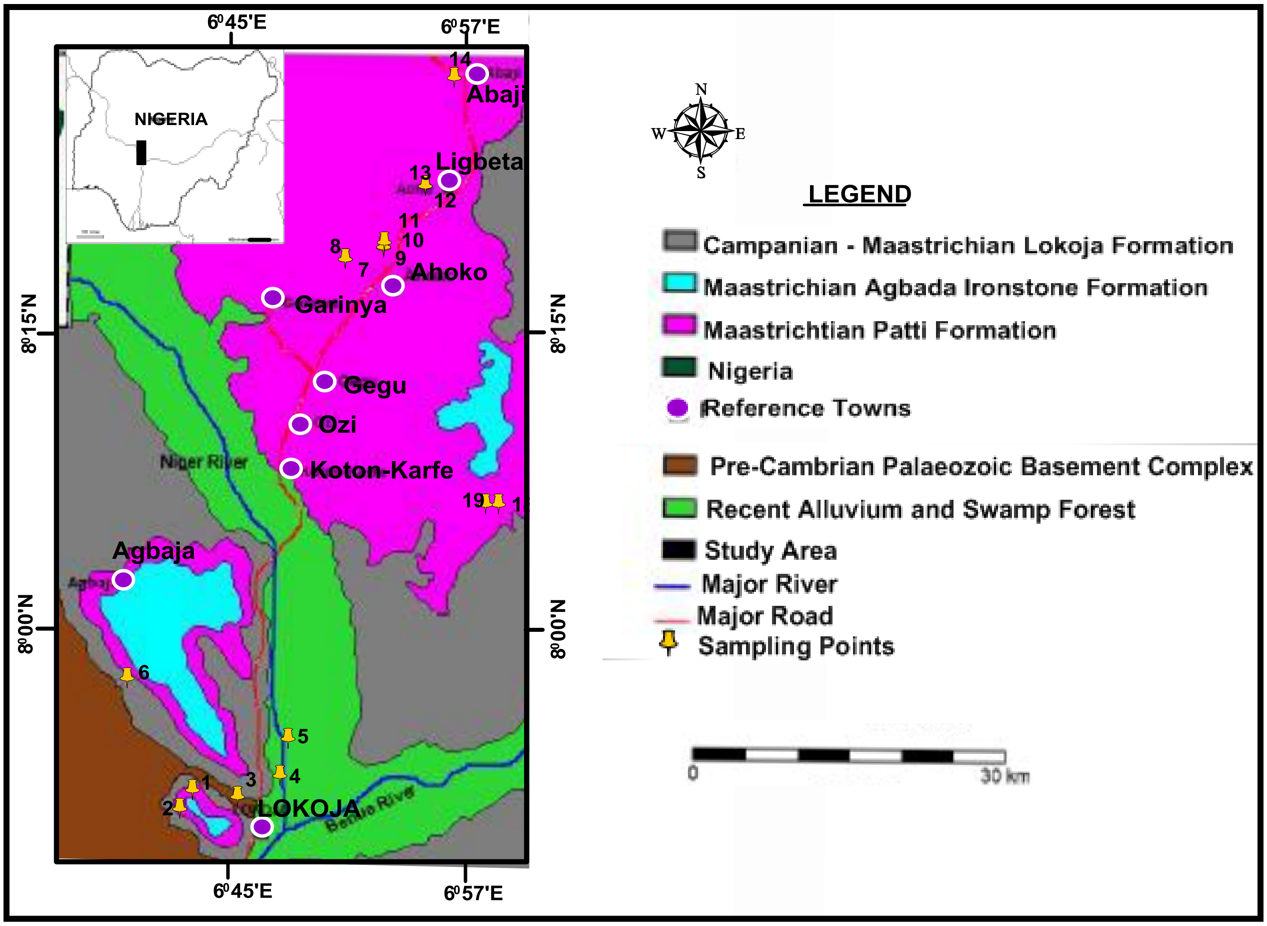


Figure 6:Geological map of the study area (Modified from Atabo *et al.*, 2015)

3.2 LABORATORY SAMPLE PREPARATION AND ANALYSIS

3.2.1 Granulometric Analysis

Granulometric analysis (sieve analysis) was carried out on samples from Lokoja Sandstone and Patti Formation in the Department of Geology Ahmadu Bello University, Zaria.The primary aim of sieve analysis is to determine particles size distribution and other grain size parameters like sorting, skewness, mean and kurtosis. A total of sixteen samples from Lokoja Sandstone and Patti Formation were selected from different locations for sieve analysis.

Samples were carefully disaggregated with the use of rubber paddedpestle and mortar. The weight of the selected empty sieves (2.0mm 1mm, 500µm, 250µm, 125µm, 63µm, and pan) were obtained using weighing balance. The required sieves were arranged according to decreasing mesh sizes with the smallest opening at the bottom and the panwhich collects the finest grainand the top is covered with lid. The sieves and the bottom pan were fastened to the mechanical shaker, and 100g of the samples was poured into the upper sieve. The machine was allowed to shake for ten (10) minutes. The sediments retained in each of the sieve and the bottom pan were weighed and their weight recorded.

During the process of the sieve analysis care was taken in the separation of the sieves to avoid the spillover of the sediments after shaking.Care was also taken when disaggregating the samples to avoid crushing and grinding in order not to distort the original shape of the grains. The results of the sieve analysis are presented in (Tables 1 and 2).

The cumulative frequency curves resulting from the analysis are shown in(Appendix 2). From the cumulative frequency curve, critical percentiles (Table 2) (φ5, φ16, φ25, φ50 φ75 φ84 φ95) were obtained and used in the calculation of grain size parameters such as; graphic mean, sorting (graphic standard deviation), graphic skewness and graphic kurtosis; the results of these parameters for each of the samples are tabulated as shown in (Table2)

The statistical parameters of the grain size frequency distribution were obtained and computed by the method of Folk and Ward (1957). Thegrade fraction plotted against the size grade distribution curve shows distribution range (sorting measure), symmetry parameter and least or most frequently occurring grain size range.

3.2.2Petrographic studies

Thin sections made fromthree representative samples collected from Lokoja Formation were analyzed using petrological microscope at the Department of Geology Ahmadu Bello University Zaria.The petrographic studies involved the identification of the framework materials such asmatrix, cement, determination of grain size, sorting, roundness, nature of contact of the framework elements and preserved porosities.

3.2.3Micropalaeontological Analyses

The micropalaeontological analysis involved washing of the argillaceous samples in order to extract microfossils from the samples. Ten samples of carbonaceous shale were collected from the section at Ahoko along Lokoja-Abuja express way in the central part of the basin. 100g of eachsample of shale were disaggregate and then poured into a beaker. They were further treated with hydrogen peroxide for about 20 minutes to bedisaggregatedand then washed with a jet of water through a 63µm sieve mesh. After washing, the remaining residue was poured into a beaker and placed in an oven for drying at the temperature of 20°C. During the picking, no foraminiferal species was recovered.

CHAPTER FOUR

4.0 RESULTS

4.1 Lithostratigraphic sections

The lithostratigraphic sections in the study area are presented in Figs.6-25.

4.1.1.1 Filele Section at (7°51'10.7"N 6°43'01.3”E)Fig.7.

i) F/01, a 0.6 m thick grain supported conglomerate angular (pebbles) to subrounded quartz, rock fragment and feldspar.

ii) F/02, a 0.8m thickferruginized weakly stratified pebbly sandstone.

iii) F/03, a 1.0 m thick massivematrix supported conglomerate sub-facies with

sharpcontact with the overlying pebbly to coarse grained sandstone.

iv) F/04, 1.5 m thick milky white pebbly sandstone

iii) F/05, a1.0 m thick coarse to medium grained sandstone.

iv) F/06, overlying the coarse to medium grained sandstone is a 3 m thick matrix supported conglomerate. In this sub-facies (F/06), the pebble to cobble size clasts of quartz and feldspar are embedded within reddish brown sandy to clay matrix.

v) F/07, a 2 mthick massive ferruginized claystone.

vi) F/08, a1.5 m thick of dark to reddish-brown lateritic overburden forming the capping.

Plate I: Matrix supported conglomerate at Filele Lokoja (7°51'10.7"N, 6°43'01.3"E)

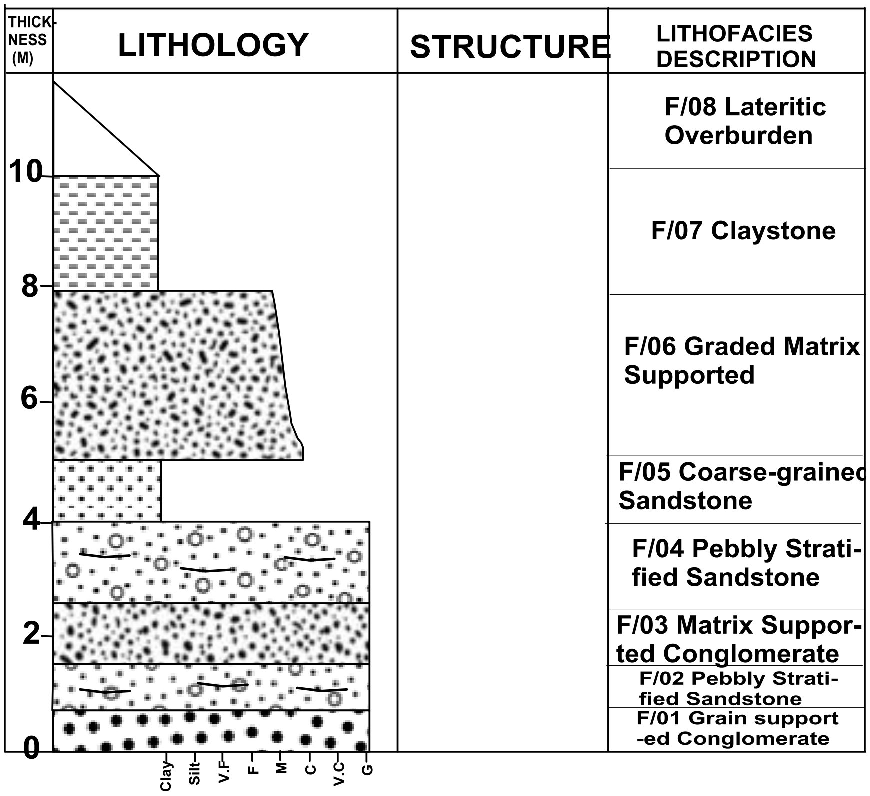


Figure 7: Lithostratigraphic log of Lokoja Sandstone exposed at Filele in Lokoja . (7°51'10.7"N6°43'01.3"E)

Plate II: Grain supported quartzose conglomerate facies characterized by rounded clasts at Lokoja(7°51'10.7"N6°43'01.3"E)

4.1.2 Section near Filele(7°50'12.7"N,6°42'22.3"E)Fig.8.

i) F2/01, a 2 m thick claystone

ii) F2/02, a 1.5 m thick medium grained sandstone

iii) F2/03, a 1.0m thick claystone

iv) F2/04, a 2.0 m thick pebbly to coarse grained sandstone

v) F2/05, a 1.0 m thick claystone.

vi) F2/06, a 2 m thick trough crossbedded conglomeratic sandstone.

F2/07, a1 m thick coarse grained sandstone with pebbles

F2/08, a 2 m thick sandy claystone

F2/09, a 1.0 m thick lateritic overburden which forms topographic surface.

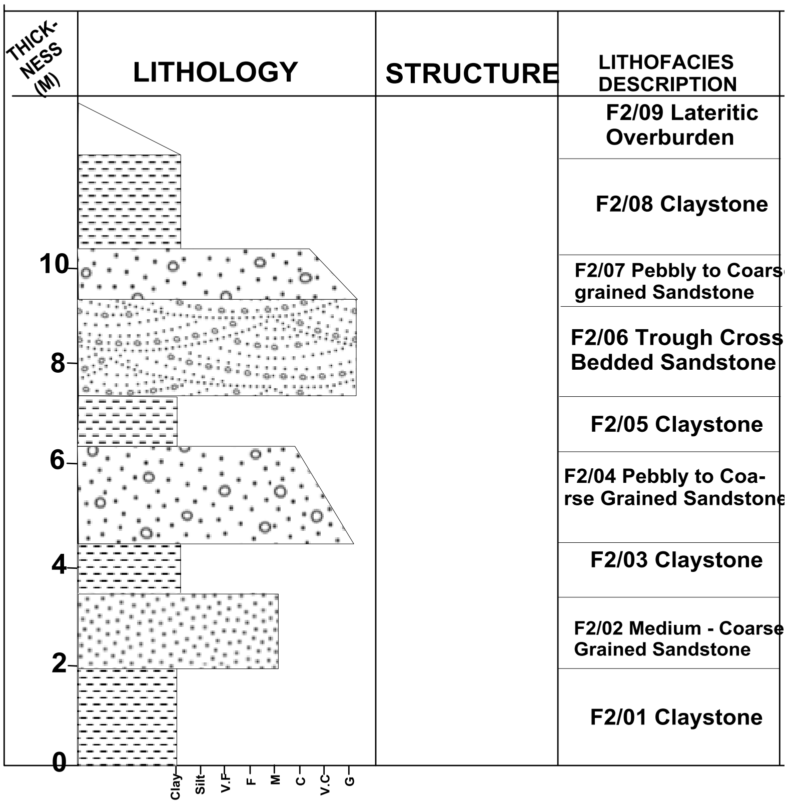


Figure 8: Lithostratigraphic log of Lokoja Sandstone exposed near Filele in Lokoja (7°50'12.7"N and 6°42'22.3"E)

4.1.3 Section at 1.2 km north of Lokoja(7°50'49.9"N and 6°45'19.6"E.)Fig.9

This section has a total thickness of about 20 m consisting of the following

i) N/01, a 2.5 m thick matrix supported conglomerateswithsegregated bands of clasts.

ii) N/02, a2.2 m thick whitish sandy claystone.

iii) N/03, a 1.5 m thick massive pebbly sandstone.

iv) N/04,a4.0 m thicktrough cross-bedded conglomeratic sandstone with a sharp erosive base.

v) N/05 -2 m thick massive poorly sorted coarse grainedsandstone with the thickness of about 2.0 m

vi) N/06, a 3.5 m thick troughs cross bedded conglomeratic sandstone.

vii) N/07, a 2.0 m thick massive ferruginized claystone.

viii) N/08, a 2.8 m thick of lateritic overburden forming the topographic surface.

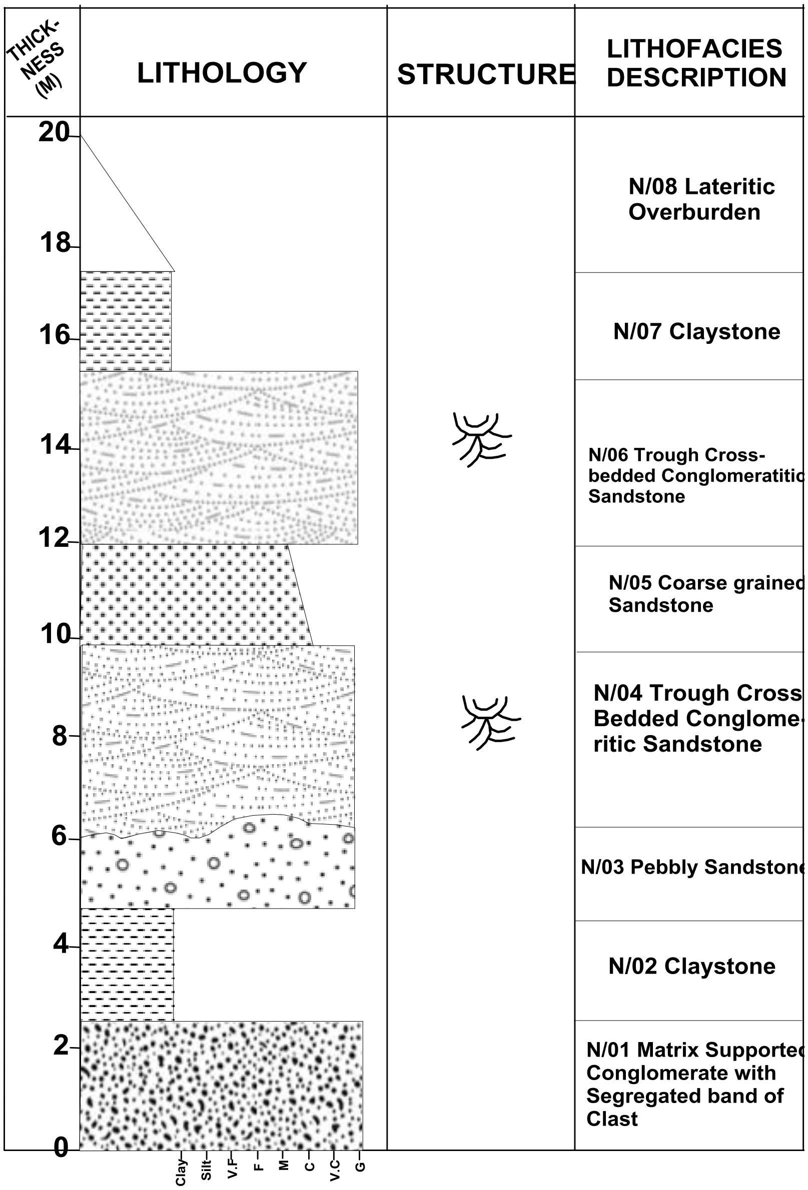


Figure 9: Lithostratigraphic log of Lokoja Sandstone exposed at Nataco km 1.2. (7°50'49.9"N, 6°45'19.6"E).

4.1.4: Section at Nataco km 1.8 (7°51'54.9"N and 6°47'29.6"E)Fig.10

i)N2/01, a 3.7 m thick conglomeratic sandstone with poorly preserved trough cross-beddings and burrows

ii)N2/02, a 3.0 m thick coarse grained sandstone.

iii)N2/03, a 2 m thick conglomeratic sandstone.

iv)N2/04, a 2 m thick massive pebbly coarse grained sandstone.

v)N2/05, a 4 m thick massive claystone

vii)N2/06, a 2.5 m thicklateritic overburden forming the capping.

PlateIII:Road section of the Lokoja Sandstone showing feldsparthic poorly sorted cross bedded sandstone at km 4.5 along Lokoja-Abuja express way.(7°51'54.9''N and 6°47'29.6''E)

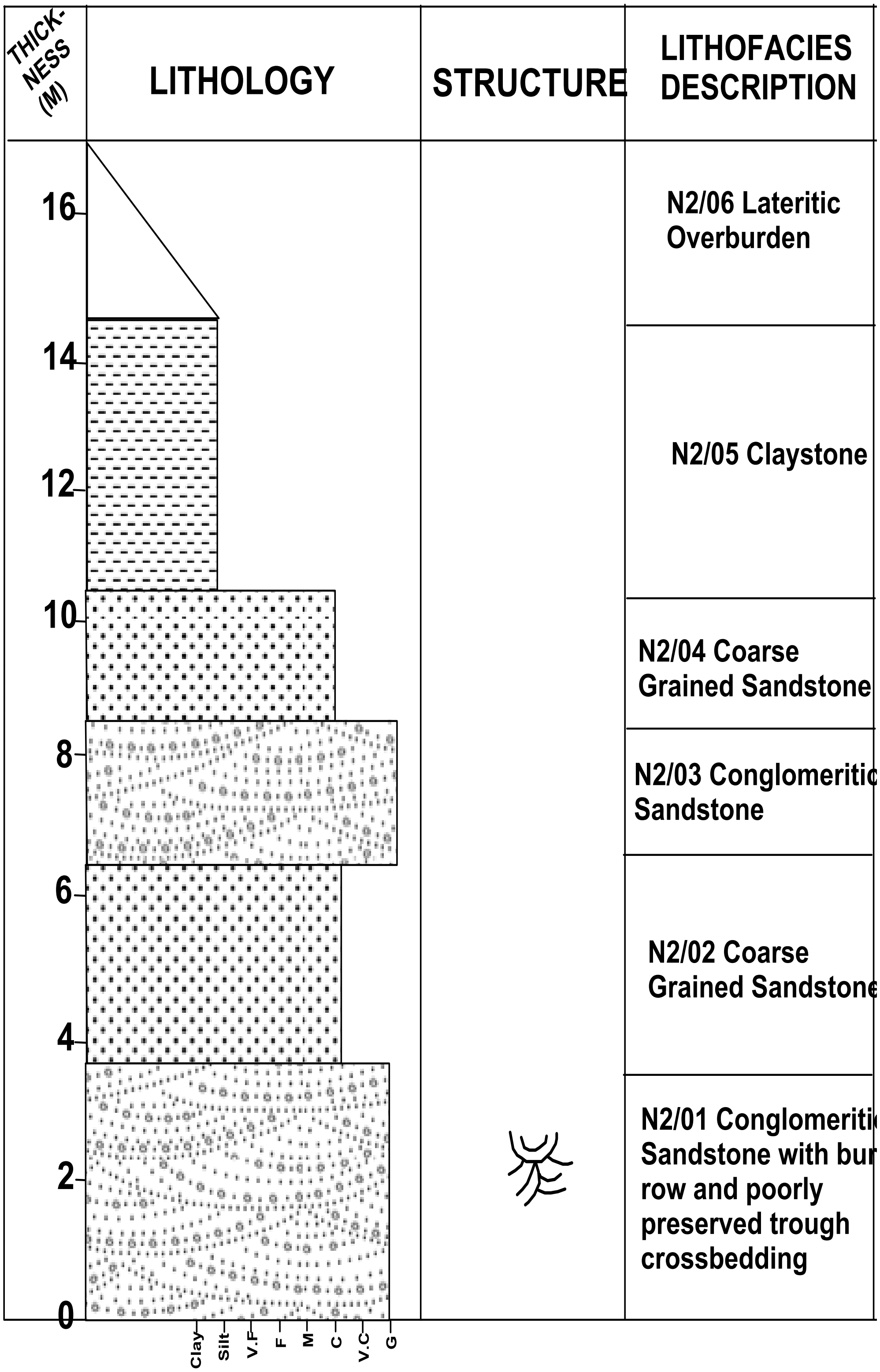


Figure 10:Lithologic section of Lokoja sandstone at Nataco km 1.8 along Lokoja and Abuja express way(7°51'54.9"Nand 6°47'29.6"E).

4.1.5 Section at Nataco km 4.5 (7°53'49.12"N and 6°47'54.6"E)Fig.11

i)N3/01, a 1.5 m thick grain supported conglomeratic sandstone.

ii)N3/02, a 3.2 m thick matrix supported conglomeratic sandstone

iii)N3/03, 4 m thick conglomeratic sandstone with herringbone stratification

iv)N3/04, 2 m thick coarse grained sandstone

v)N3/05, a 1 m thick fine grained sandstone

vi)N3/06, 2 m thick very coarse grained sandstone

vii)N3/07, 2.5 m thick coarse grained sandstone

viii)N3/08, a 1.5 m thickclaystone

ix)N3/09, a 1.0 m thick coarse grained sandstone

x)N3/10, 1 m thick conglomeratic sandstone

xi) N3/11, a 2m thick medium grained sandstone

xii)N3/12, a1.5 mthick sandy claystone

xiii) N3/13 lateritic overburden forming the topographic surface.

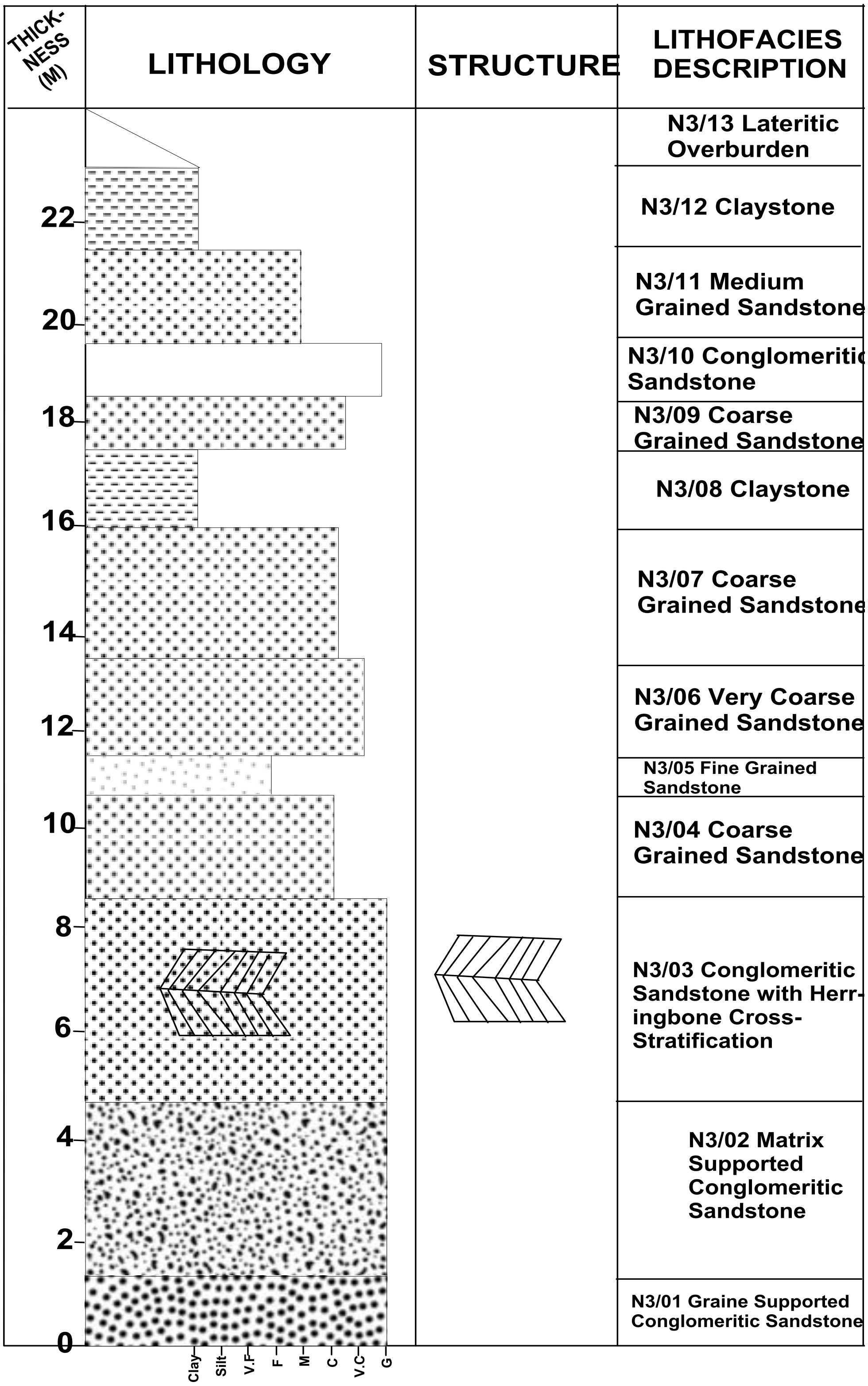


Figure11: Lithologic section of Lokoja sandstone at Nataco k m 4.5 along Lokoja –Abuja expressway (7°53'49.12"N and 6°47'54.6"E).

4.1.6Agbaja section (7°56'56.5"N and 6°39'41.0".E)Fig.12

The section consists of the following from top to bottom

i) AGB/O1, a 1 m thick matrix supported conglomerates.

ii) AGB/02, a 1.2 m thick matrix supported conglomerate.

iii) AGB/03, 1.2 m thick pebbly sandstone.

iv) AGB /04, a 2.5 m thick matrix supported conglomeratic sandstone

v) AGB/05, 1.8 m thick pebbly sandstone

vi) AGB/06, a 3.0 m thick matrix- supported conglomerates.

vii) AGB/07, a 7 m thick conglomeratic sandstone with cobble and pebble- sized conglomerate sandstone angular to well rounded.

viii) AGB/08, a 1.4 m thick conglomerate sandstone with graded bedding.

ix) AGB/09, a 4 m thick fine grained sandstone withclay drapes

x) AGB/10, a 2.8 m thick sandy claystone.

xi) AGB/11, a3 m thick medium- coarse grainedsandstone

xii) AGB/12, a 2.5 m thick sandy claystone

xiii) AGB/13, a 3.5 m thick well sorted fine-grained sandstone with herringbone structure

xiv) AGB/14, a 3.5 m thick ferruginized sandy claystone.

xv) AGB/015, a 8.5 m thick medium grainedsandstonewith herringbone cross-bedding

xvi) AGB/16, a 3.8 m medium grained sandstone.

xvii) AGB/17, a 3 mthick hummocky cross-bedded sandstone

xvii) AGB/18, a 3.5 m thick medium grained sandstone with burrows

xix) AGB/19, a 9.5 m thick oolitic ironstone.

xx) AGB/20, a 3.2 mthick concretional ironstone forming the capping.

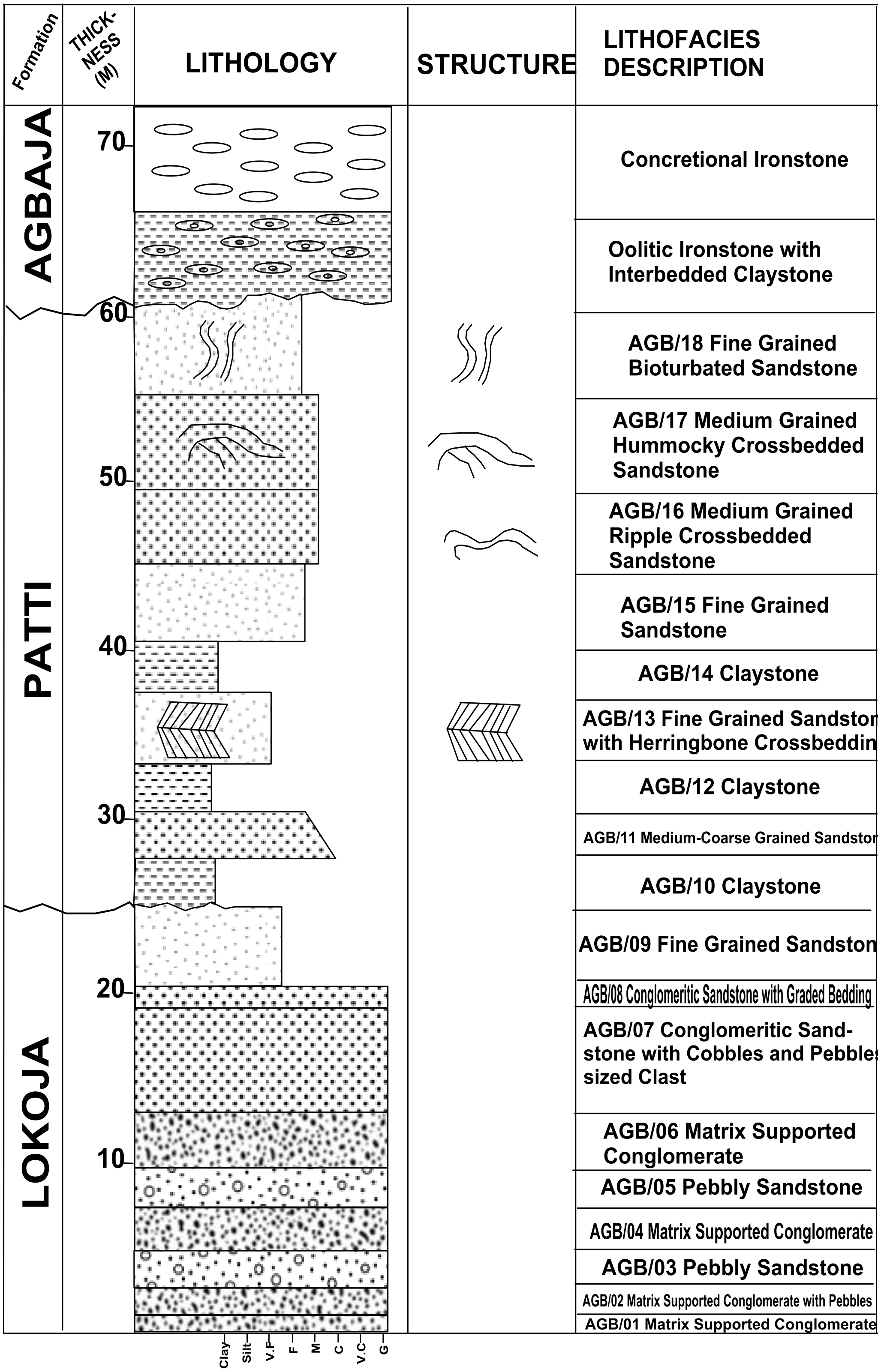


Figure 12: Lithologic Section of Lokoja , Patti and Agbaja formations exposed at Agbaja plateau .(7°56'56.5"N and6°39'41.0".E).

Plate IV: Wavy laminated sandstone facies at Agbaja interbedded with ironstone band (Agbaja Ironstone) at the middle to the top of the section(7°56'56.5''N and 6°39'41.0''.E).

4.1.7:Section near Ahoko(N8°18' 04.0"and E6°51'529.7") Fig.13

i) B1, a 4m thick ferruginized sandstone fine grained sandstone

ii) B2, a 6m thick clayey siltstone

iii)B3, 10m thick medium grained sandstone interbedded with purplish mudstone

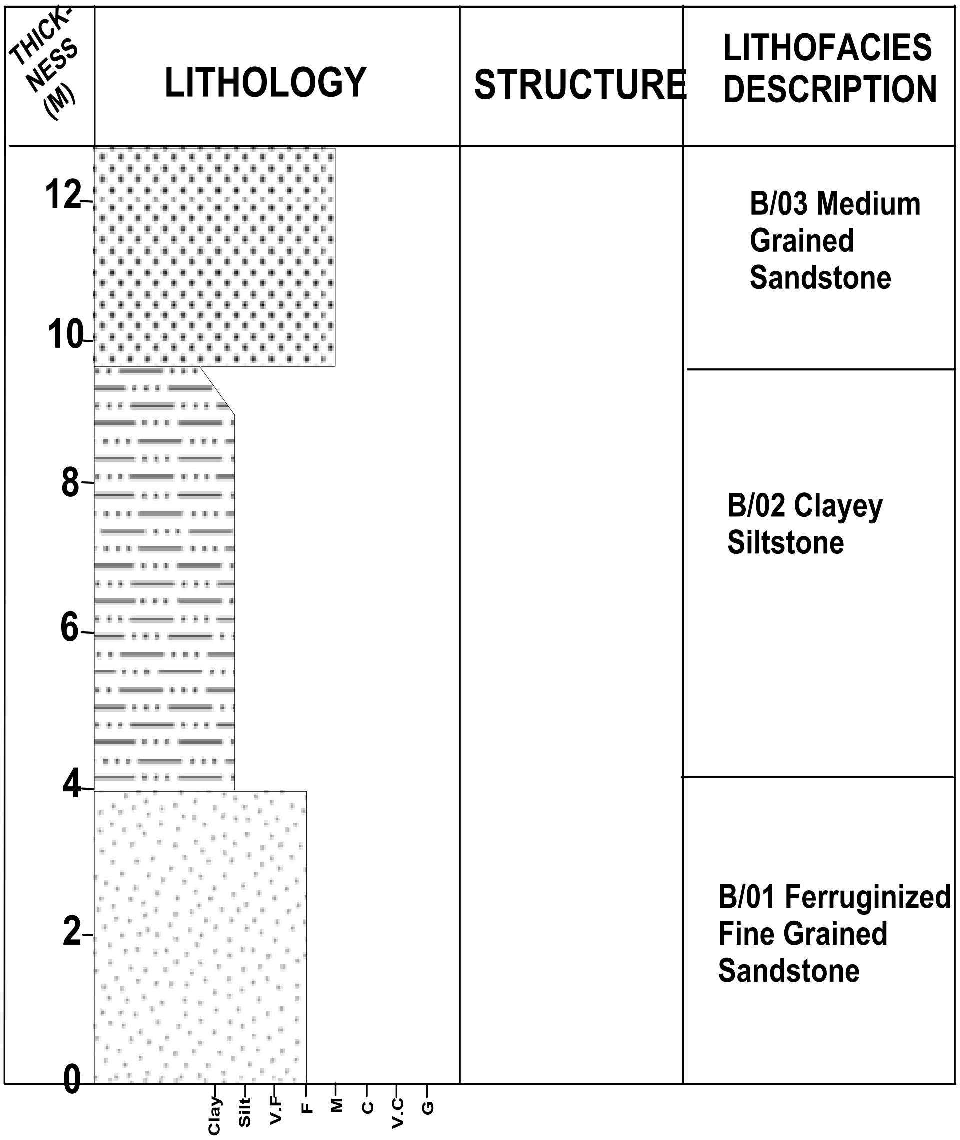


Fig. 13:Lithostratigraphic log of Patti Formation exposed near Ahoko .(8°18' 04.0"Nand 6°51'529.7"E.)

4.1.8Section at Ahoko village (8°18'32.1""Nand 6°50'50.2"E) Fig.14

The section is about 25 m thick of sediments.

i)AH2/01, a 2.5 m thick dark shale interbedded with ferruginous siltstone.

ii) AH2/02, a 0.8 m thick light grey shale interbedded with concretional ironstone

iii)AH2/03, a 2 m thick carbonaceous shale with plant remains interbedded with concretional ironstone

iv) AH2/04, a1.7 m thick siltyshale with burrows.

v) AH2/05, a 2.8 m thick whitish claystone.

vi) AH2 /06, a 0.5 m thin bedded siltstone with horizontal burrows.

vii) AH2/07, a 2.7 m of light grey silty shale with plant remains interbedded.

viii) AH2/08, 2.5 m thick dark grey shale with abundant woody fragments.

ix) AH/09 , a 0.5 m thick silty shale.

x) AH2/10, a 2.5 m thick light grey shale with plant remains.

xi) AH2/11, a 0.8 m thicksilty shale and bioturbated ironstone.

xii) AH2/12, a 1.8 m thick silt stone.

xiii) AH 2/ 13, a 1.5 m thickfine grained claystone withhorizontal burrows

xiv) AH2/ 14, a 2.5 m thick lateritic overburden forming the capping.

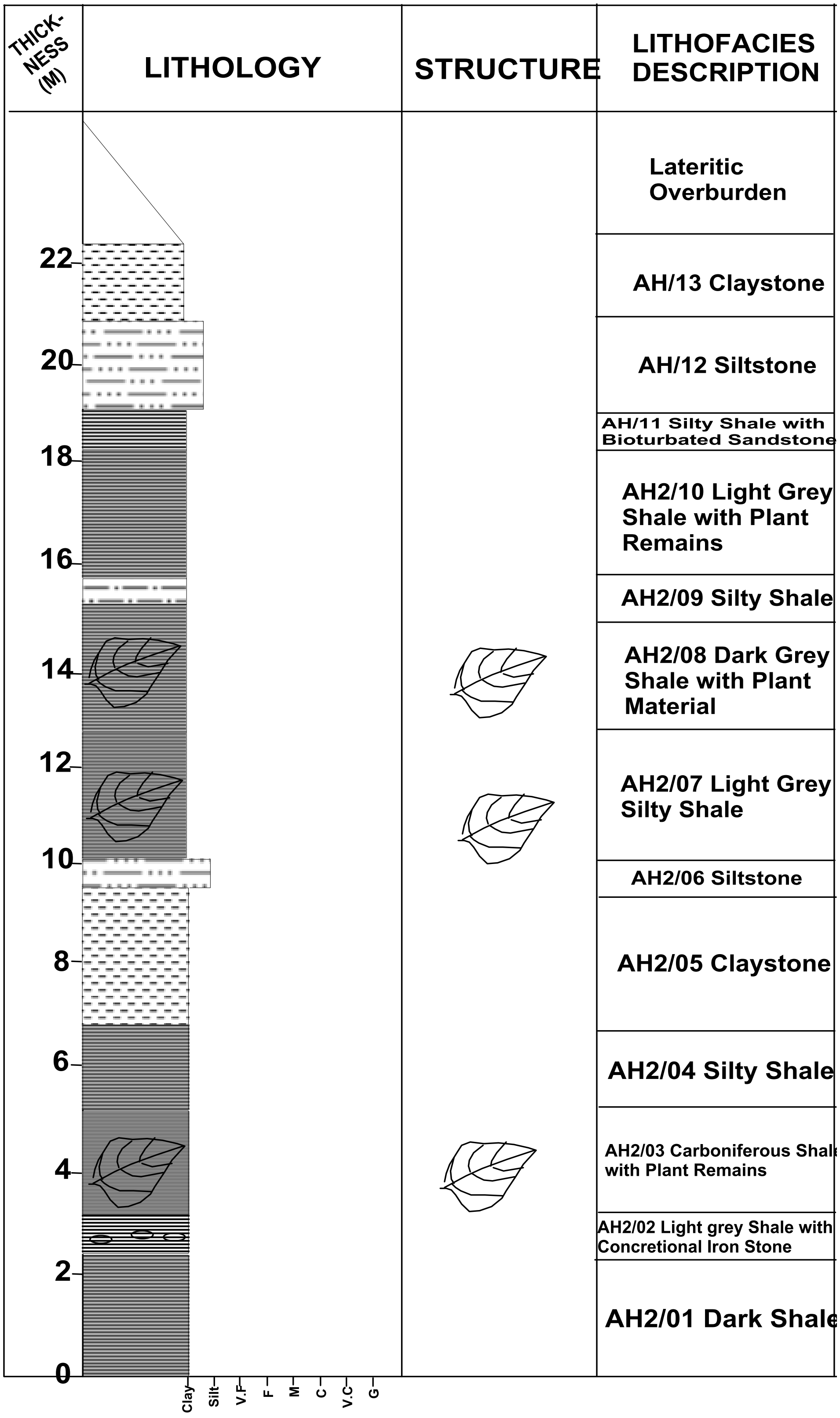


Figure 14:Lithostratigraphic log of Patti Formation exposed at Ahoko village.(8°18'32.1"Nand 6°50'50.2"E)

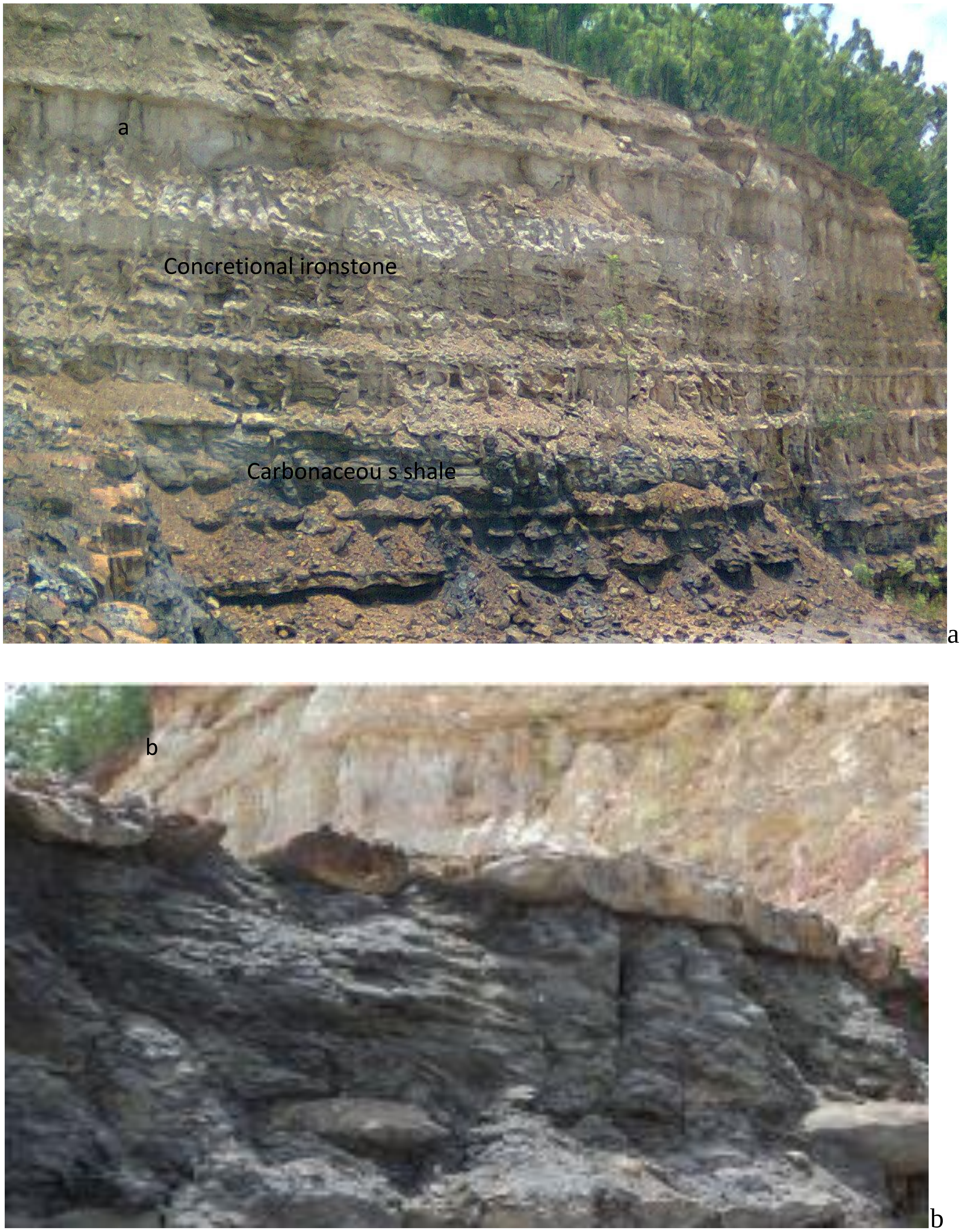


Plate Va and b: Lithologic sections of Patti Formation at Ahoko (08°19'07.2''N and 006°52'48''E) showing shales and siltstones which are rhythmically interbedded with concretional to massive, bioturbated ironstones .

4.1.9: Section at Ahoko along Abuja – Lokoja express way(8°19'07.2"N and 6°52'48.0"E) Fig. 15

i) AH/01, a 2.0 m thick dark shale with ferruginous silt stone interbedded.

ii) AH/02, a 1.2 m thick light grey shale.

iii) AH/03, a 1.7 m thick carbonaceous shale with plant remains and interbedded concretional ironstone

iv) AH/04, a 2.5 m thick claystone.

v) AH/05, a 0.5 m thin bedded siltstone with horizontal burrows.

vi) AH/06, a 3.0 thick light grey silty shale with ferruginous layer and plant remains.

vii) AH/07, a 2.5 m thick light grey shale with abundant woody fragments.

viii) AH/08, a 1.0 m thick silty shale with plant remains.

ix) AH/09, a 2.5 m thick light grey shale with plant remains.

x) AH/10, a 0.8 m thick silty shale with bioturbated concretional ironstone.

xi) AH/11,a 1.8 m thick siltstone.

xii) AH/12, a 2.0 m thick whitish fine grained claystone.

xiii) AH/13, a 2.0 m thick lateritic overburden forming the lateritic capping.

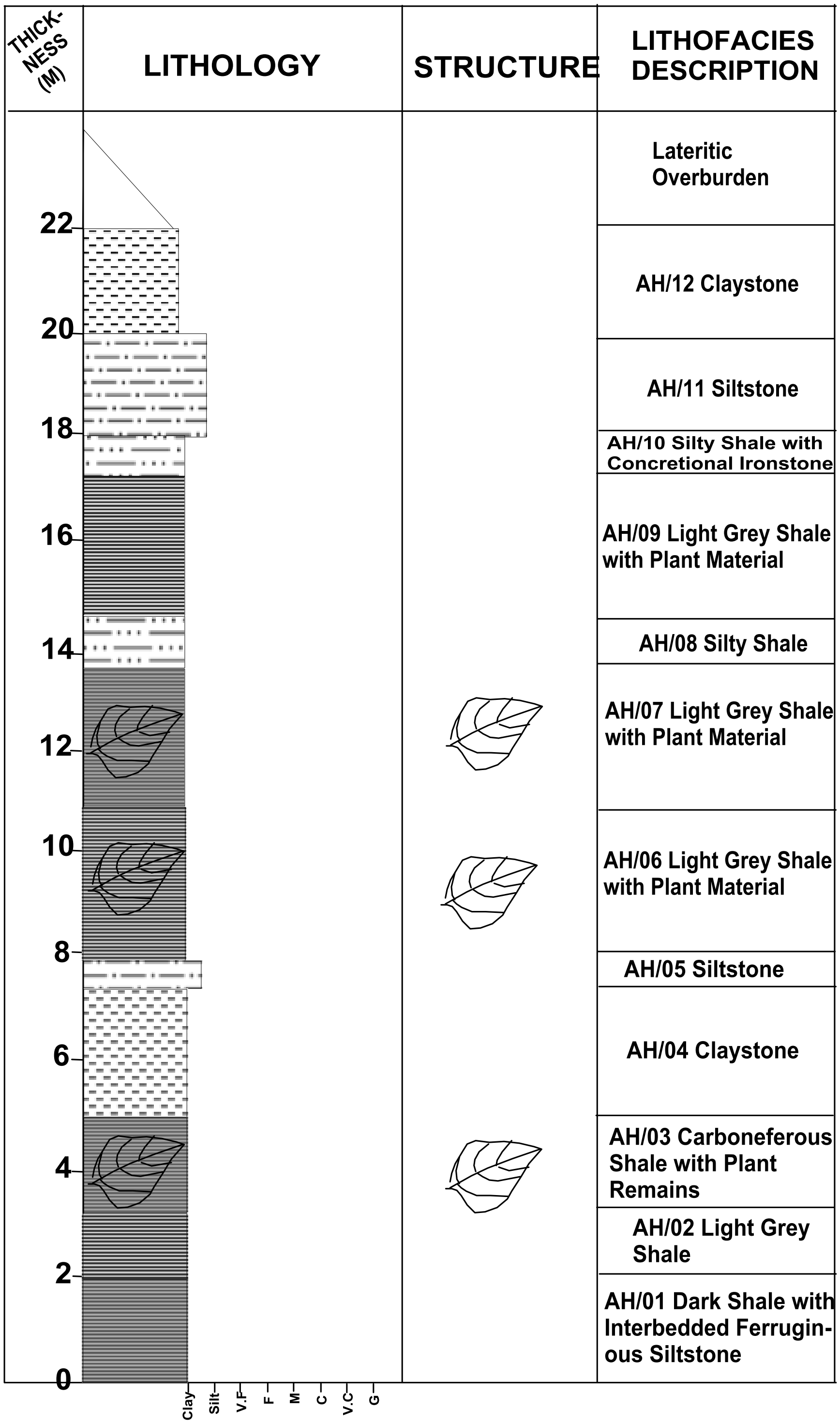


Figure 15:Lithostratigraphic log of Patti Formation exposed at Ahoko Lokoja –Abuja express way (8°19'07.2"Nand 6°52'48.0"E.)

4.1.10Section at Ahoko - Lokoja –Abuja express way (8°19'10.09"N and 6°52'47.8"E)Fig.16

i)C1, a 2 m thick siltstone

ii)C2 a 4m thick dark mudstone layer with plant remains

iii)C3, a 2m thick claystone

iv)C4, a 3m thick clayey siltstone

V)C5, a 3m thick siltstone

vi) C6,a 4m thick clayey siltsone

vii) C7,a 4m thick siltstone which passes into lateritic overburden.

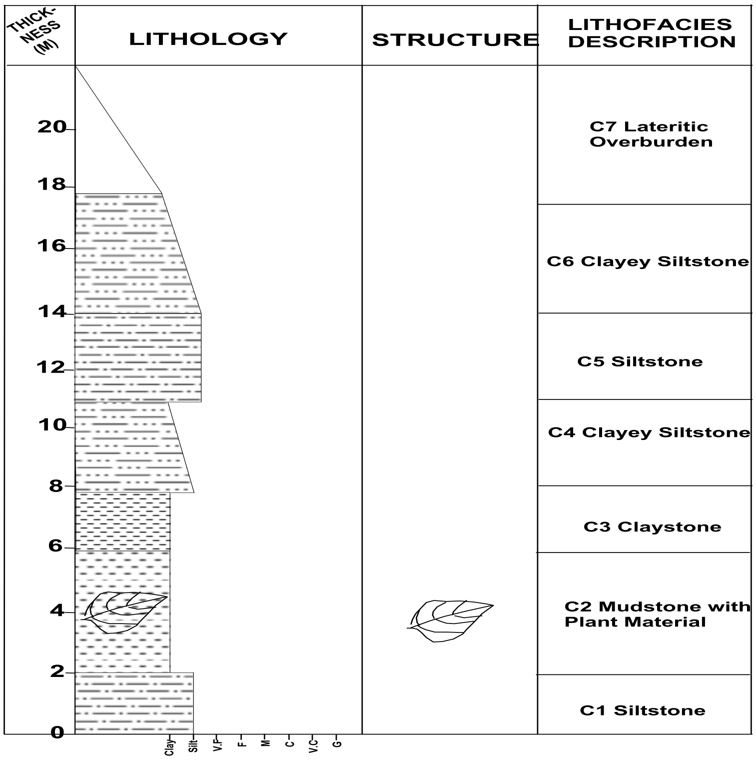


Figure 16: Lithostratigraphic log of Patti Formation exposed at Ahoko 1 Lokoja –Abuja express way (8°19'010.09"N and 6°52'47.8"E)

4.1.11:Section at Clay Quarry at Ahoko(8°19'24.27"N and 6°52 49.9"E) Fig.17

i) D/01, a 7m thick mudstone changing gradually to dark shally mudstone with glauconitic (greenish) mineral dipping at about 20° NE ward.

ii) D/02,a 3m thick ferruginous siltstone.

iii)D/03, a 5 m thick of claystone which passes into lateritic overburden.

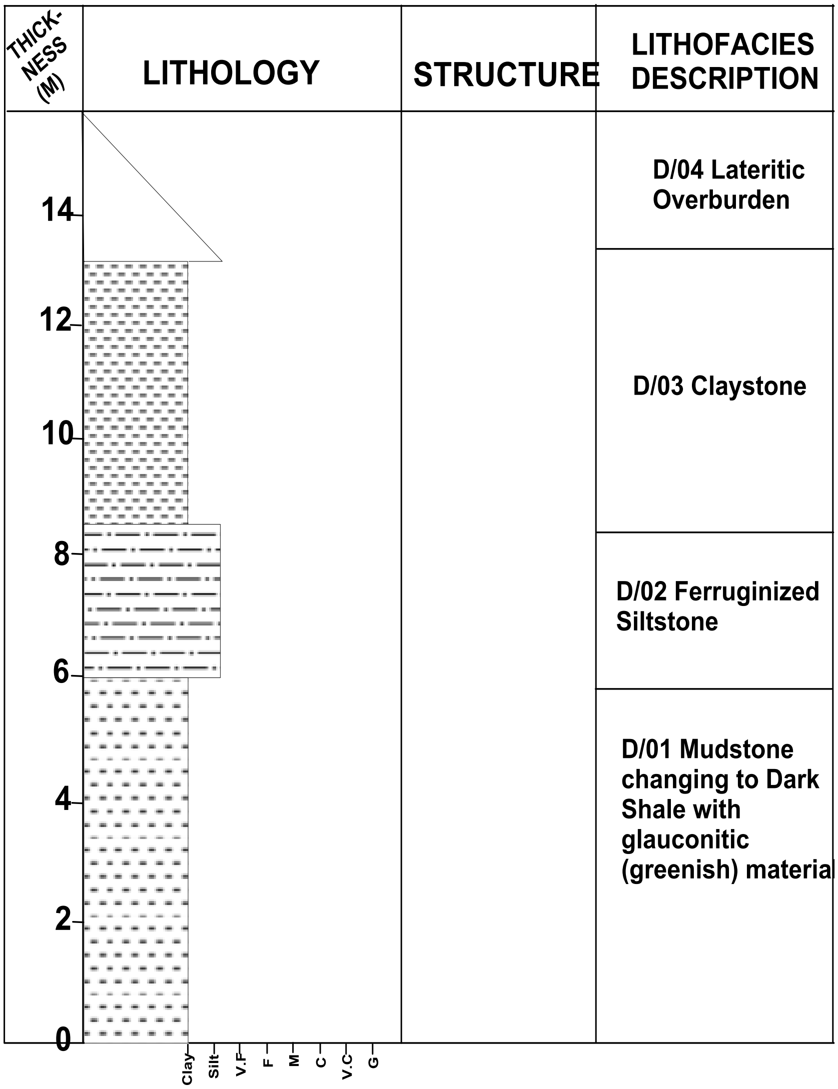


Figure 17:Lithostratigraphic log of Patti Formation of Patti Formation exposed at clay quarry in Ahoko along Lokoja –Abuja -express way.(8°19'24.27''N and 6°52 49.9''.E)

Plate VI a and b: Claystone and siltstone deposits of Patti Formation exposed at Ahoko clay quarry along Lokoja –Abuja -express way.(8°23'12.2"N and 6°55'56.0".E)

4.1.12:Section at Ligbeta village, Lokoja –Abuja express way, Fig18

L/01, a 2 m thick graded siltstone

L/02, a 3 m thick sandy siltstone with parallel to wavy lamination

L/03, a 2.5 m thick claystone

L/04, a 1 m thick ferruginous siltstone

L/05, a 2 m thick claystone

L/06, a 2 m thick lateritic overburden

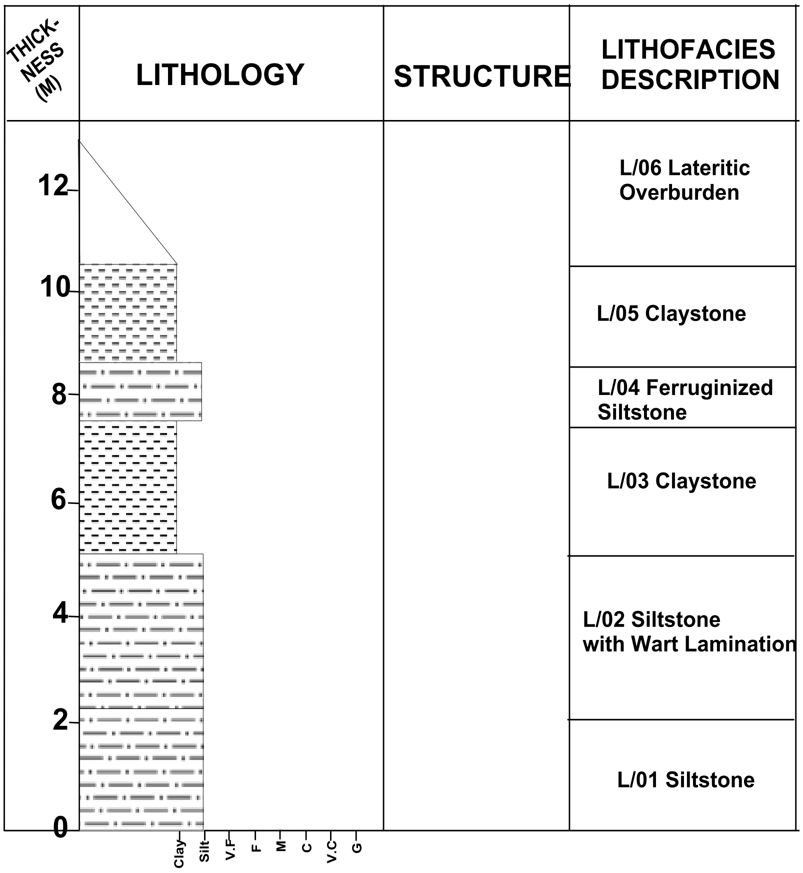


Figure18: Lithostratigraphic log of Patti Formation exposed at Ligbeta Lokoja – Abuja express way (8°22'12.2"N and 6°55'5.0".E)

4.1.13: Section of Patti Formation exposed after Ligbeta village Lokoja – Abuja express way (8°22'18.24"N and 6°54'55.7"E) Fig.19

i) G1, a 2m thick of siltstone.

ii) G2, a 4.5 mthick light grey siltstone interbedded with brown siltstone and purplish siltstone.

iii) G3, a 5 m thick claystone interbedded with sandy clay stone passing upward into white claystone.

iv) G4, a 5m thick grit with blocky surface forming the topographic surface.

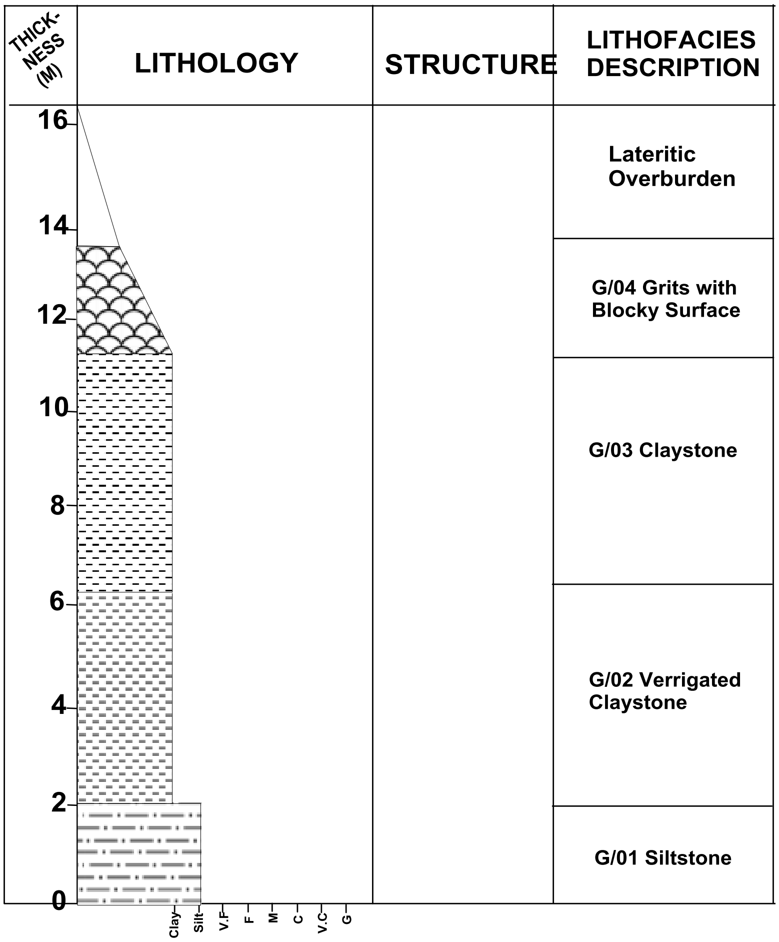


Figure19:.Lithostratigraphic log of Patti Formation exposed after Ligbeta village Lokoja – Abuja express- way. (8°22'18.24"N and 6°54'55.7".E)

4.1.14 Section at Abaji (8°27'52.8"N and 6°56'24.3"E) Fig. 20

The section at Abaji (Fig, 22) exposes the Patti Formation.

The section at Abaji is about 24 m thick consisting of fining upward cycle from the base

i) ABJ/01, a 2.2 m thick of poorly sorted massive conglomeratic sandstone

ii) ii) ABJ/02, a 2.5 m thick conglomeratic sandstone, cross stratified with pebble to cobble layer

iii) ABJ/03, a 3.5 m thick poorly sorted, very coarse grained sandstone with herringbone cross bedding

iv) ABJ/04, a 1.5 m thick poorly sorted medium grained sandstone.

v) ABJ/05, a. 1 m thick poorly sorted pink coarse grained sandstone.

vi) ABJ/06, a2 m thick medium grained sand stone.

vii) ABJ/07, a1 m thickvery poorly sorted milky very coarse grained sandstone.

viii) ABJ/08, a0.6 m thick moderately sorted medium grained sandstone

ix) ABJ/09, a1.5 m thick claystone.

x) ABJ/10, aa 1.9 m thick coarse grained sandstone.

xi) ABJ/11, 2.5 m thick massive conglomeratic sandstone.

xii) ABJ/12, a 1.5 m thick fine grained sandstone.

xiii) ABJ/ 13, a 1 m thick sandy claystone.

xiv) ABJ/14, a 1.5 m thick lateritic overburden.

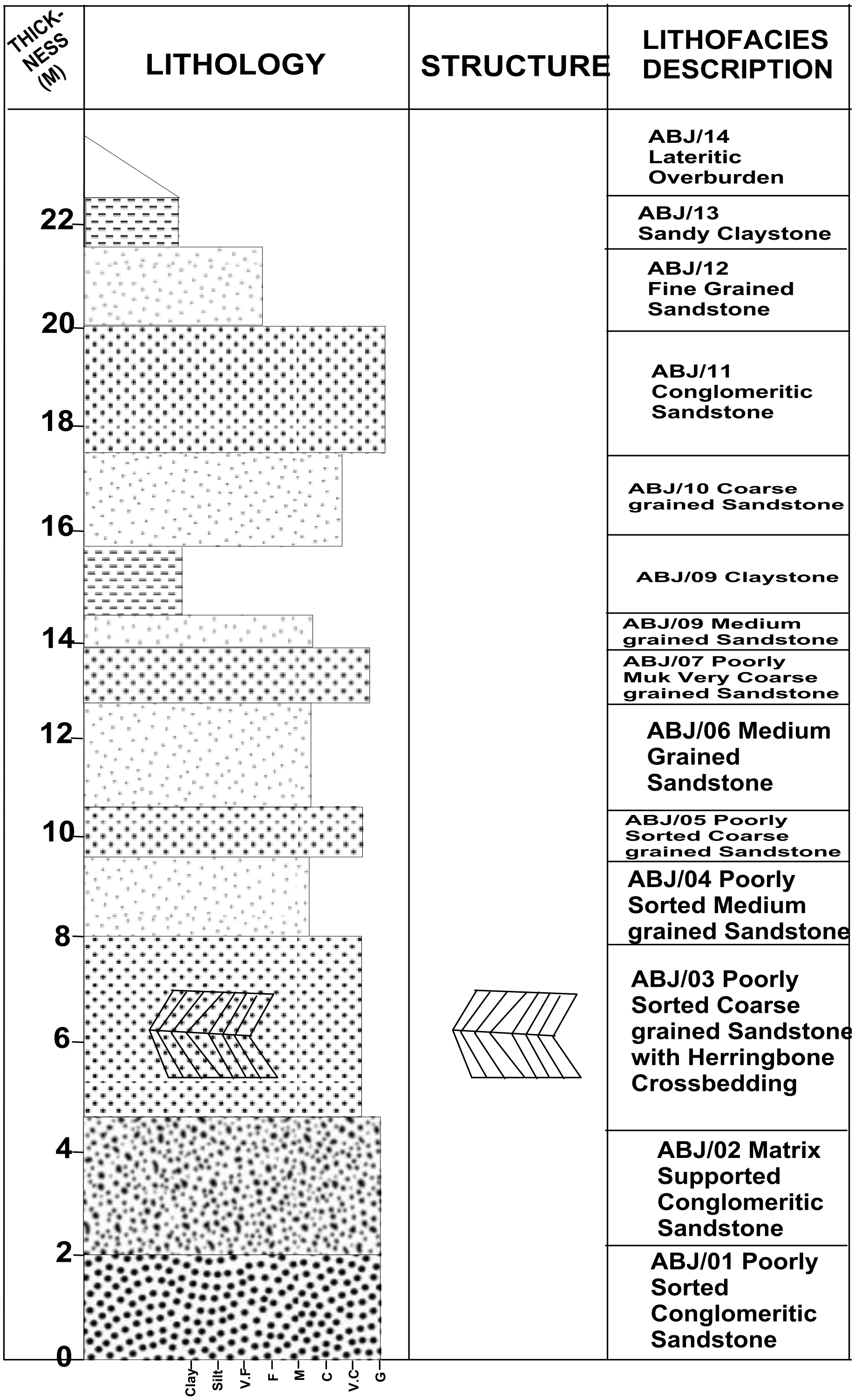


Figure 20: Lithostratigraphic log of Patti Formation exposed at Abaji.(8°27'52.8"N and 6°56'24.3"E).

Plate. VII:Channel sandstone of Patti Formation exposed at Abaji characterized by sandy claystone at the top. . (8°27'52.8"N and 6°56'24.3"E).

4.1.15: Section exposed close to Kwaita village (.8°36'44.28"N and 6°54'52.8."E) Fig.21

i) Y/1, a 6m thick dark mudstone interbeded with grey mudstone

ii) Y/2, a 5m thick of silty clay comprises of variegated colours. A succession shows light grey siltstone overlain by purplish siltstone and white siltstone.

iii) Y/3, a 4m thick grit showing blocky surface forming lateritic capping.

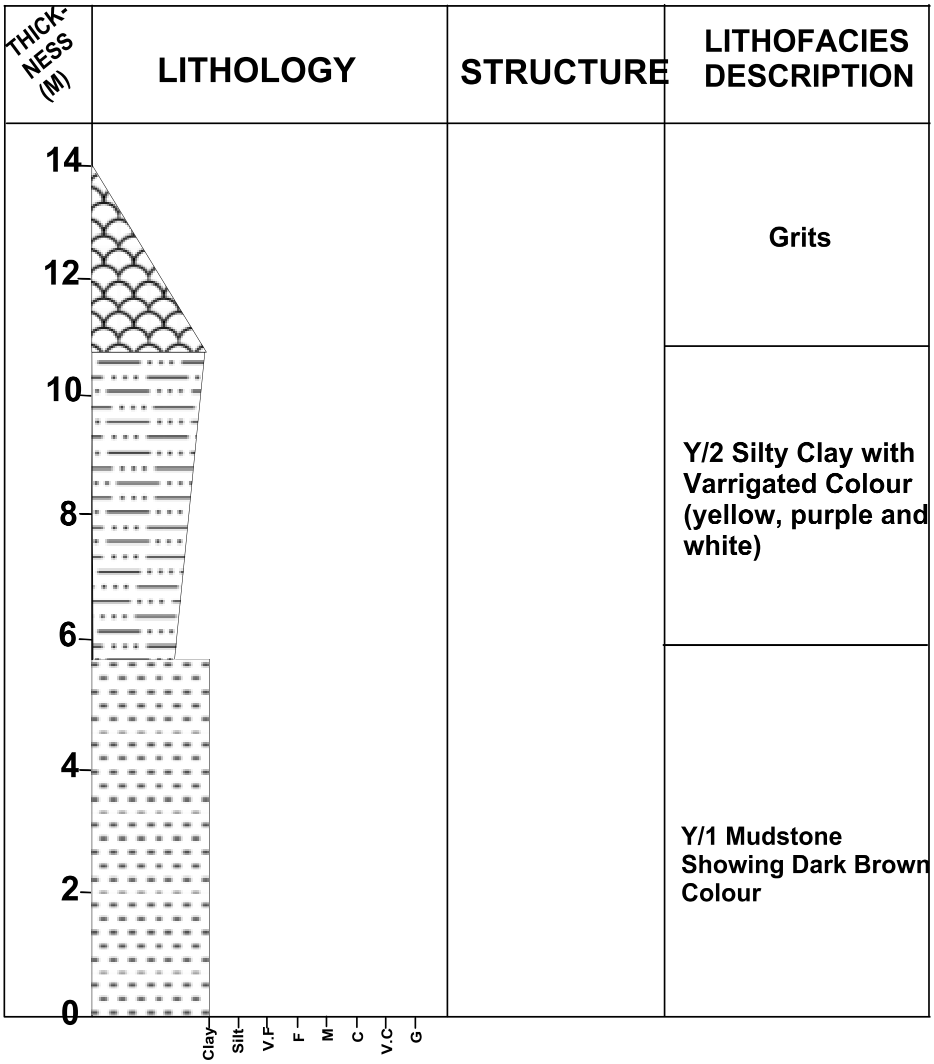


Figure 21: Lithostratigraphic log of Patti Formation exposed close to Kwaita village. (8°36'44.28"Nand 6°54'52.8.".E)

4.1.16:Sectionexposed close to Kwaita village (8°36'44.8"N and 6°54'51.8."E) Fig.22

i) J/1, a 6m thick claystone

ii) J/2, a 4m thick of mudstone comprises of variegated colours which is pinching out with the area.

iii) J/3, a 5m thick of siltstone with variegated colours. It comprises of light grey siltstone, purplish siltstone with solution cavities.

iv) J/4, a 4m thick grit with the blocky surface forming the cap.

Plate**VIII:**Massive mudstone of Patti Formation exposed close to Kwaita village showing solution cavity. (8°36'44.8"N and 6°54'51.8."E).

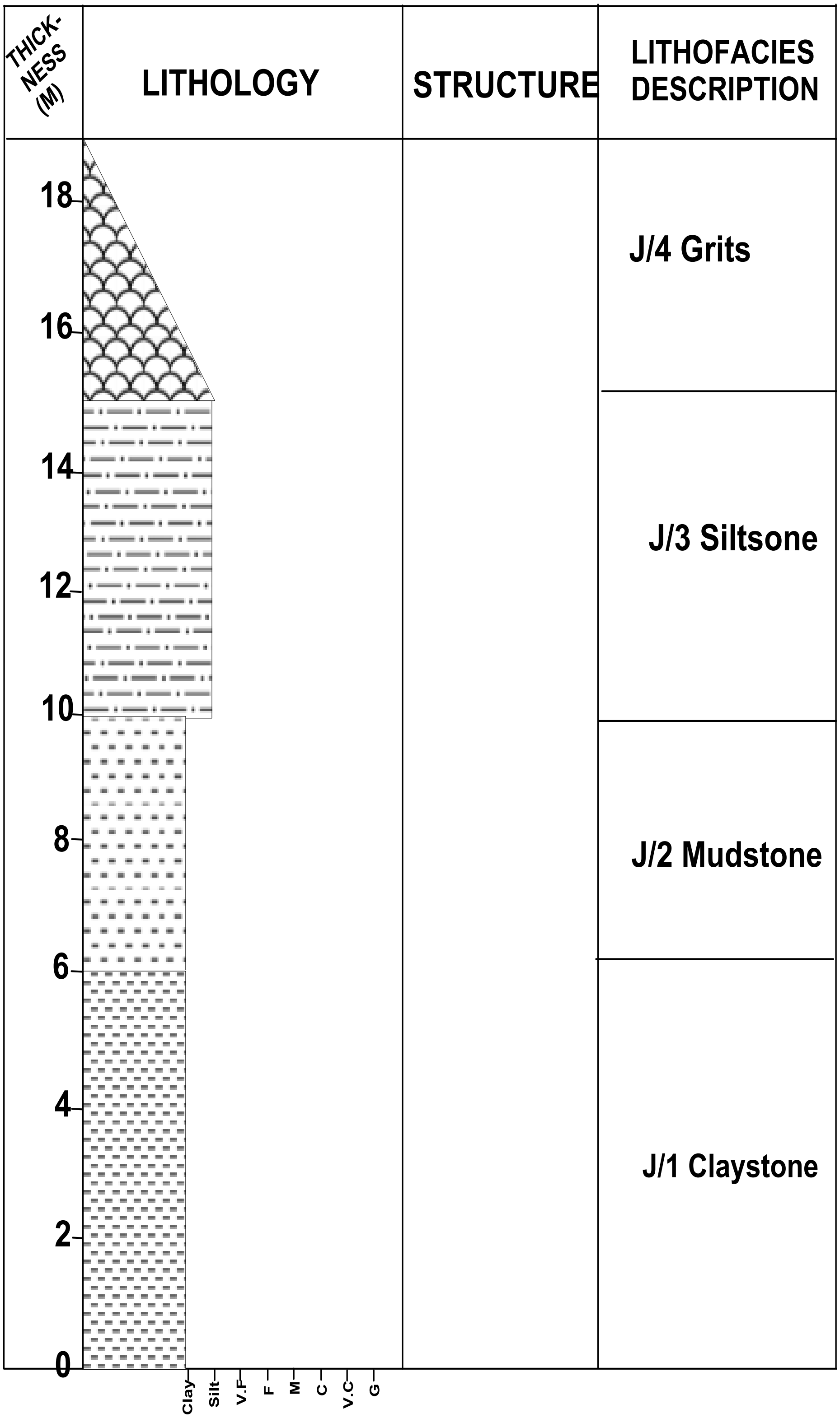


Figure 22:.Lithostratigraphic log of Patti Formation exposed close to Kwaita village . (8°36'44.8''N and 6°54'51.8.''.E)

4.1.17: Section exposed at Kwaita village. (8°38'45.6"N and 6°55'15.14.".E) Fig.23

i) Z/1, a 2m thick of whitish mudstone at the base of the succession

ii) Z/2, a 2m thick comprise of variegated mudstone. A succession of grey mudstone interbededwithpurple and light grey mudstone

iii)Z/3, a 10m thick of fine grained sandstone showing angular relationship with clay and mudstone passing upward into a dominantly parallel laminated fine grained sandstone

iv)Z/4, a 8m thick grit showing blocky surface which forms the topographic surface

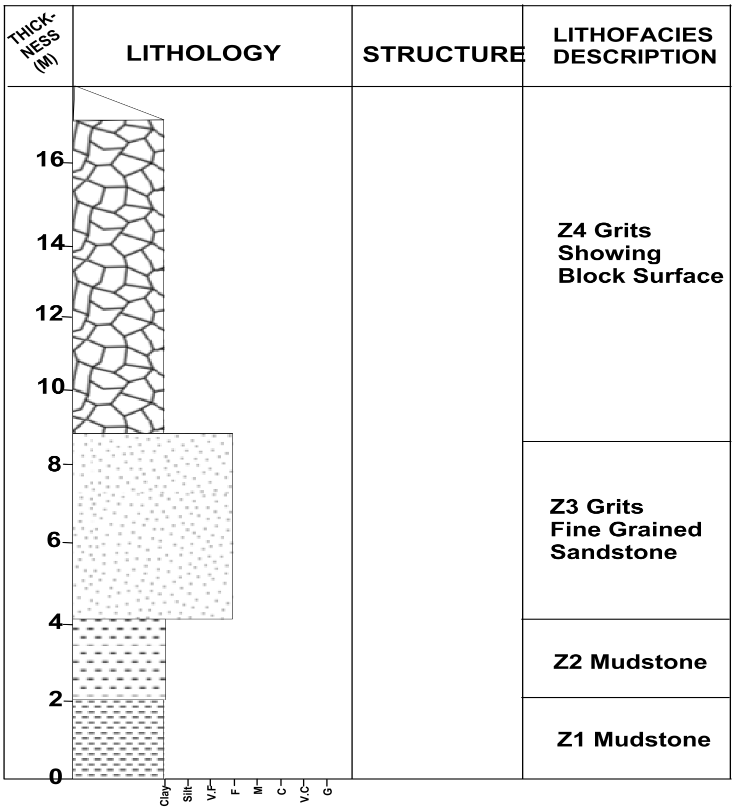


Fig. 23: Lithostratigraphic log of Patti Formation exposed at Kwaita village (8°38'45.6"N and 6°55'15.14.".E)

4.1.18:Sectionsafter Kwaita village.(8°36'41.17.4"N and 6°55'55.8.".E) Fig.24

i) P/1, a 2.5m thick of exposed schist/phyllite

ii) P/2, 2m thick of angular to rounded agglomerate forming the basal deposits

iii)P/3, a 3m thick variegated (yellow, brown and white) mud stone with erosional stripe

iv) P/4, a 6m thick grits showing blocky surface. The grits are exposed extensively and within the gritsis agglomerate which is becoming very thick making up a hill within the area

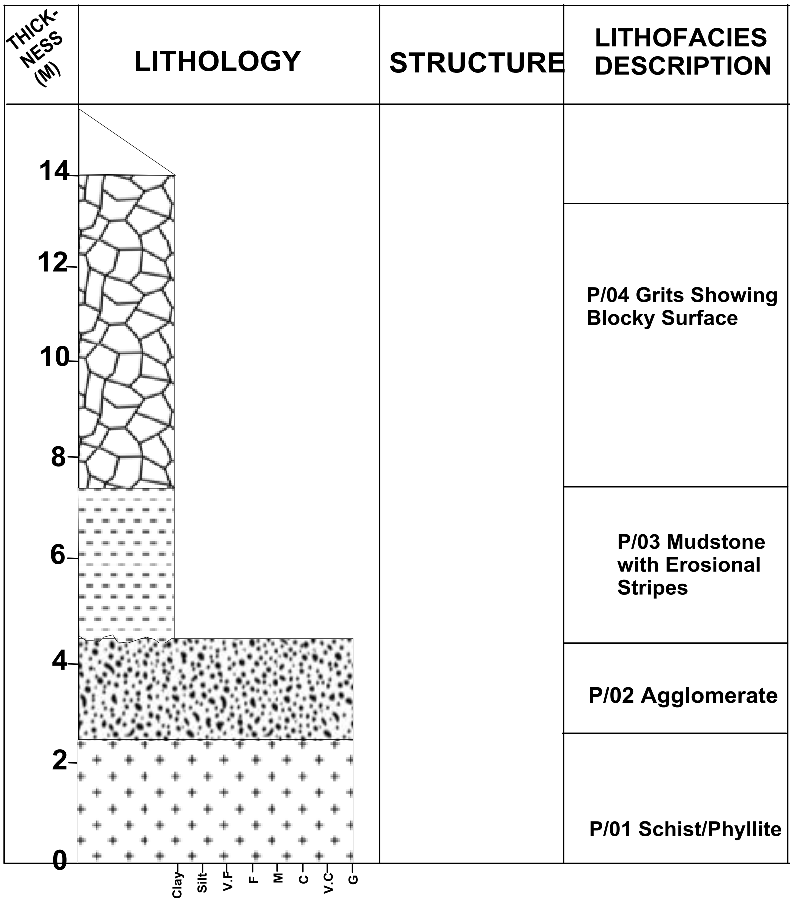


Fig. 24.Lithostratigraphic log of Patti Formation exposed after Kwaita village. (8°36'41.17.4"N and 6°55'55.8.".E)

4.1.19: Sectionafter Kwaitavillage (8°05'53.8"N and 6°58'40.05.".E) Fig.25

i) Q/1, a 3m thick of schist/ phyllite which is the point of basement and sedimentary contact aroundKwaita along Abuja – Lokoja express way.

ii) Q/2, a 1.5m thick of conglomerate with segregated band of clasts

iii) Q/03, a 8m thick of massive mudstone comprises of grey mudstone interbeded with dark to whitemudstone.

Plate I**X:**Unconformity between sedimentary andbasement rocks (Phyllites) around Kwaita .(8°05'53.8"N and 6°58'40.05.".E)

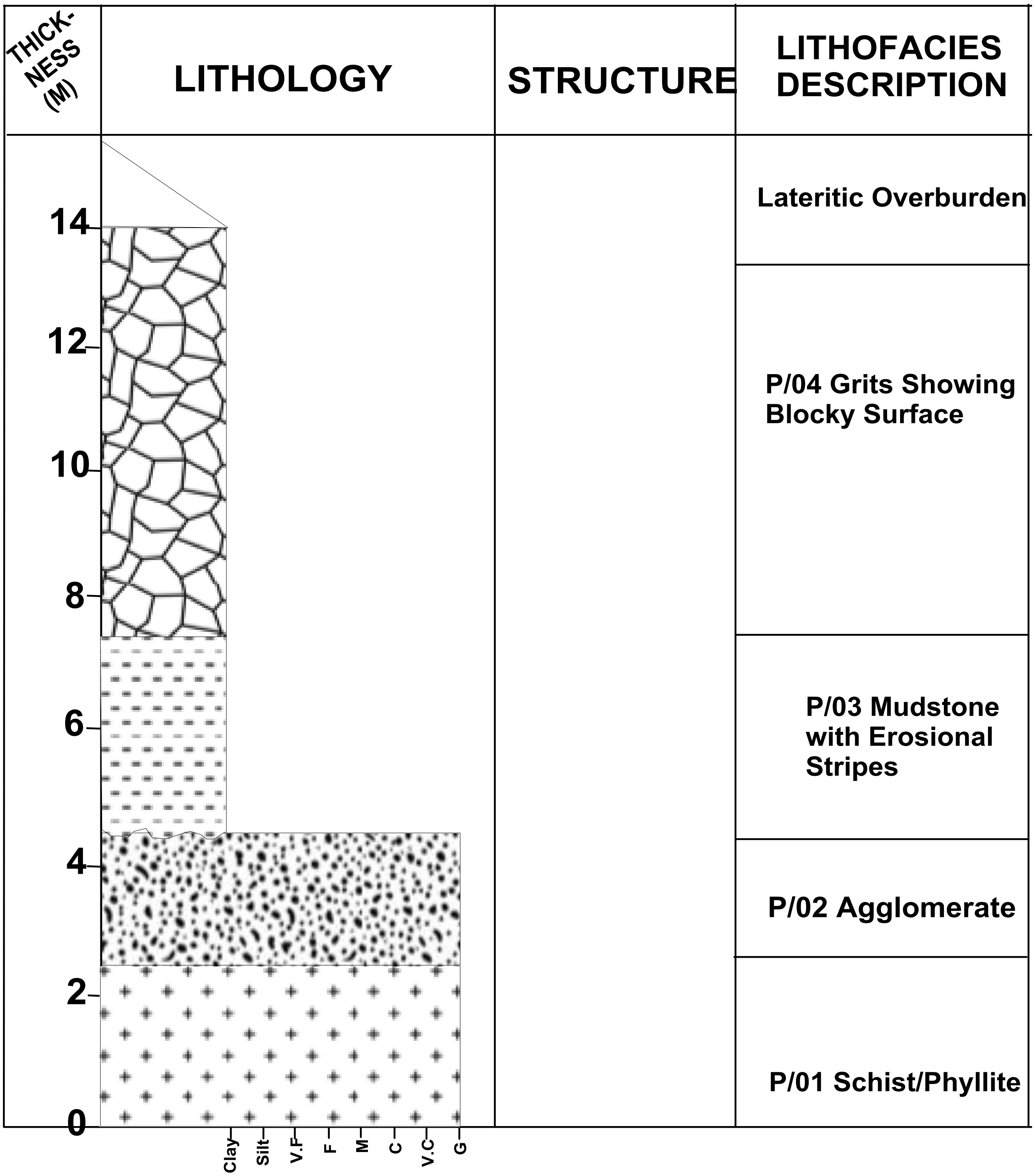


Figure 25.Lithostratigraphic log of Patti Formation exposed after Kwaita village. 8°05'53.8''N an6°58'40.05.''.

4.3:.Stratigrahic correlation of the studied sections:

An attempt at correlating the stratigraphic sequence of beds of the studied area from the exposed road sections was difficult due to lack of fossils, so lithology became major correlating factor. As it can be seen in (Fig. 26a)which correlate the sections in Lokoja area and (Fig.26b) which correlate sections between Ahoko through Abaji to Kwaita .

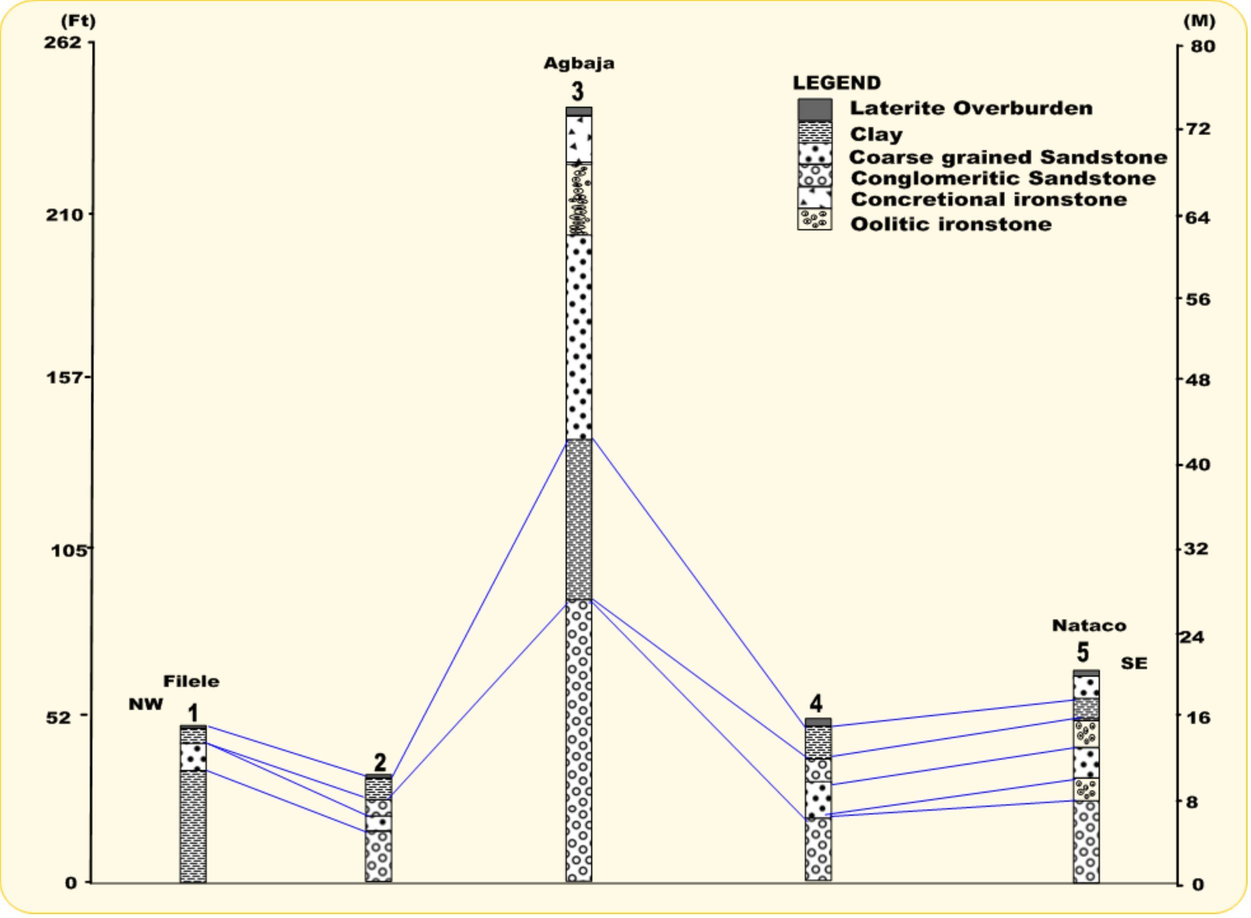


Fig. 26a.Lithostratigraphic correlation of the studied sections in the Lokoja area

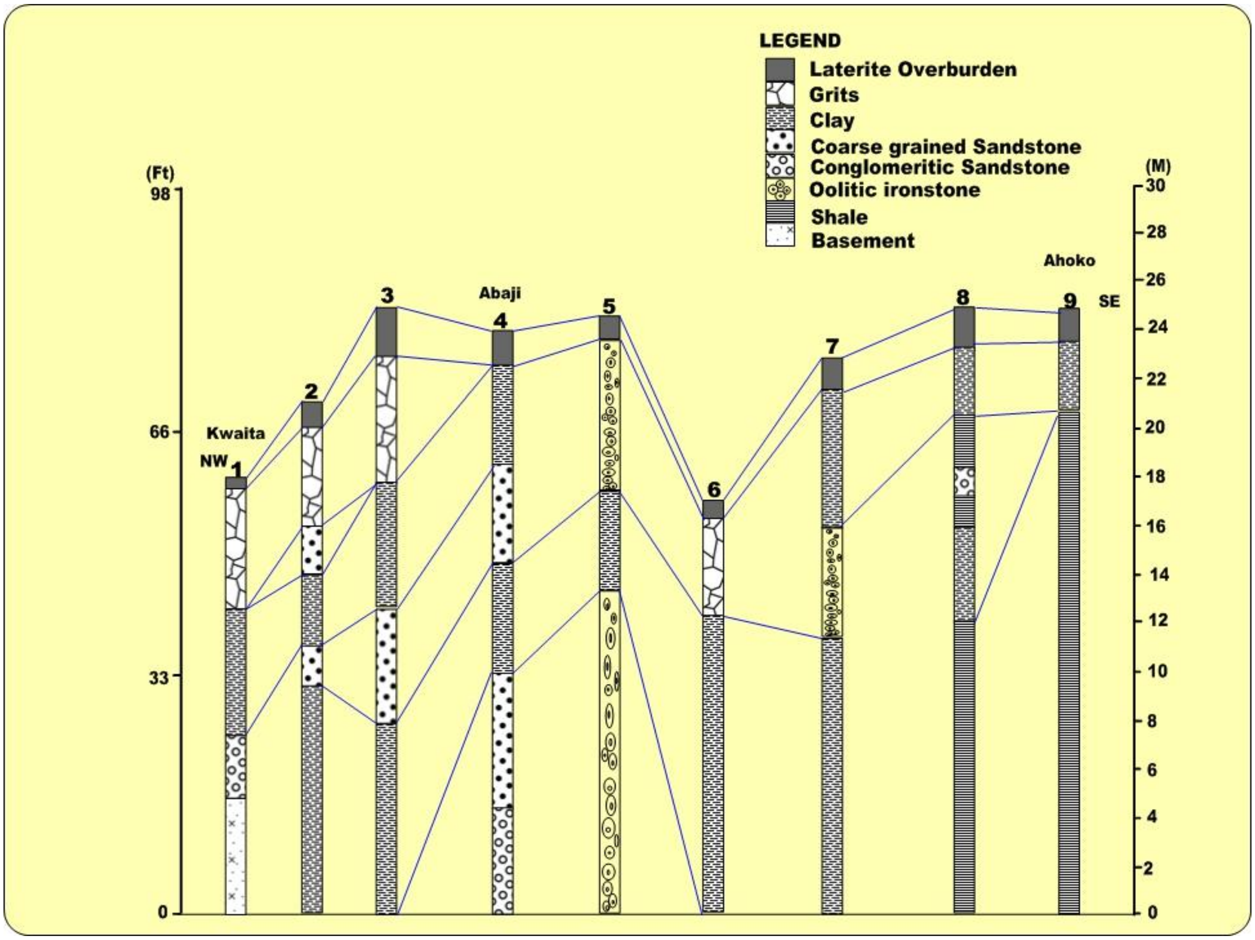
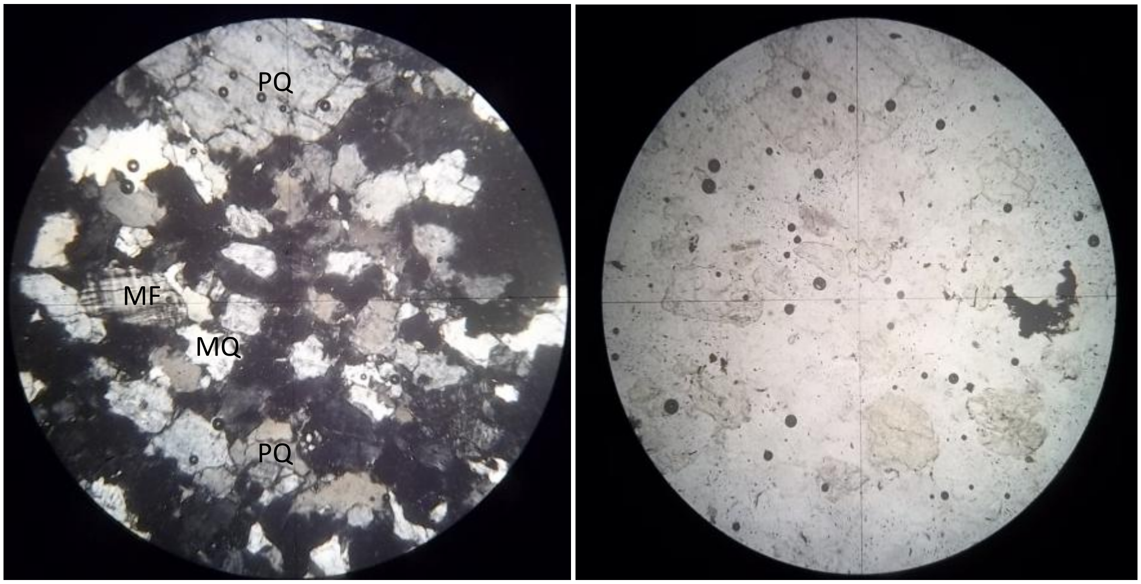


Figure 26b. Stratigraphic correlation of the studied sections in Kwaita, Abaja and Ahoko area.

Correlation of sections studied in the Lokoja area Fig.26a shows that the lowermost bed made up of conglomerate and overlain by bed of alternating clay and sandstone Fig. 7, 8, 9,10 and 11 and capped by lateritic overburden. The Basement Complex represents the point of basement sediment contact at Kwaita. (8°05'53.8''N and 6°58'40.05.''E). Correlation of beds of sections of bed studied in the Ahoko through Abaji to Kwaita area Fig.26b shows that beds are made up of conglomeratic sandstone and these sandstones are overlain by alternating clay sandstone, carbonaceous shale and are capped by grits and lateritic overburden.

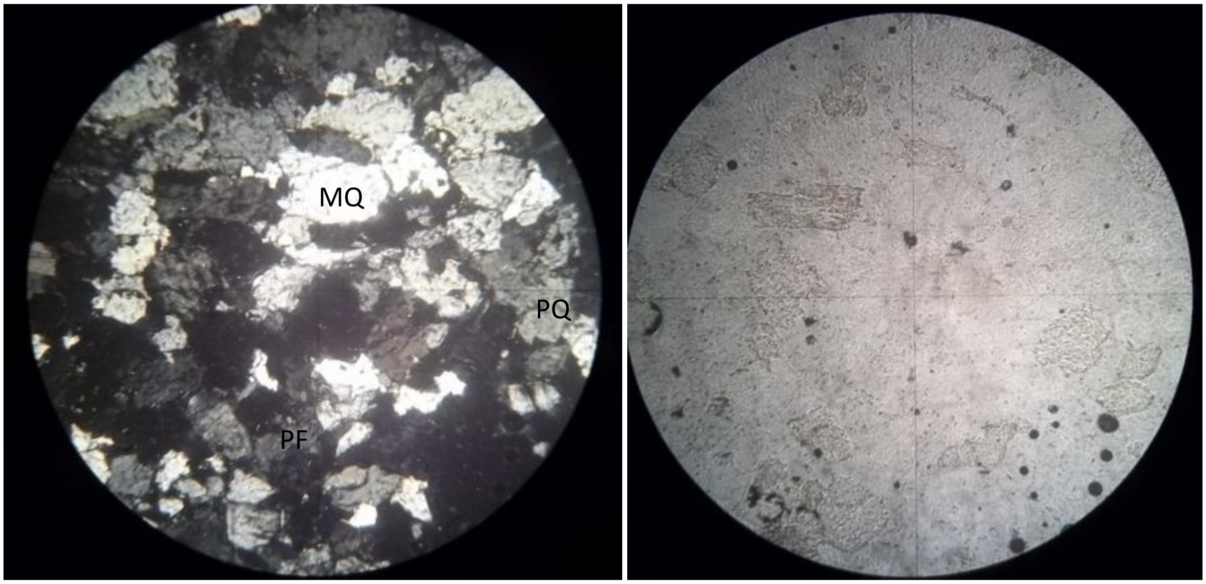
4.4. Petrographic Study

The results obtained from petrographic analysis of rocks in the study area are presented below:



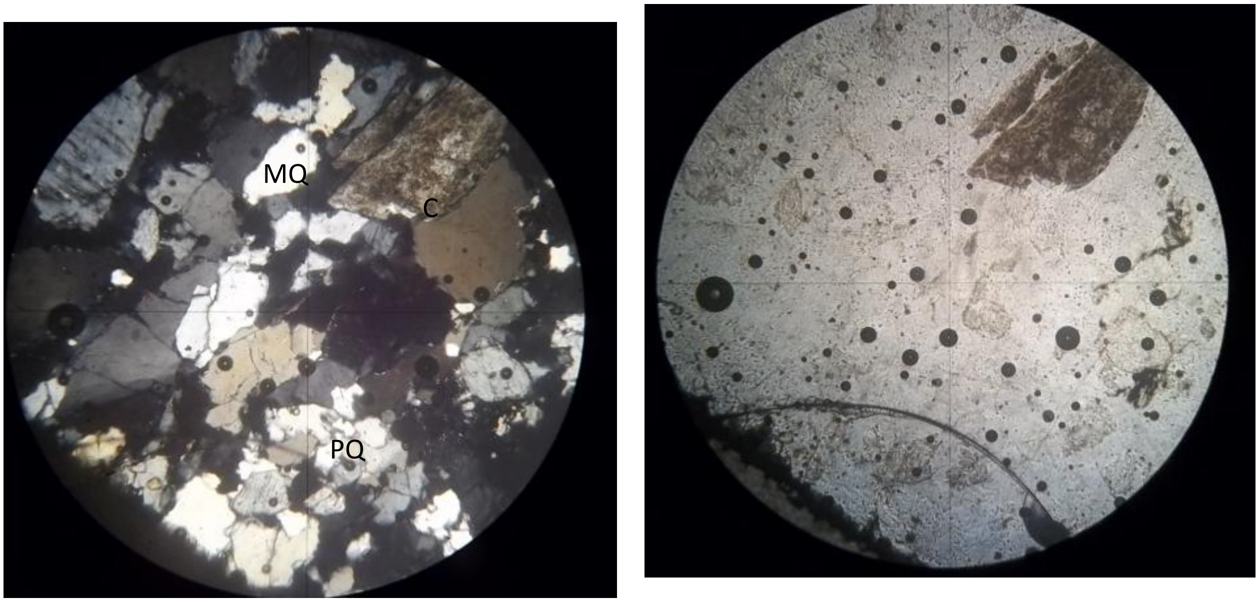
XPL Mg-×10 PPL

Plate X: Photomicrograph ofLokoja Sandstone at Filele making up unit (F/01) of (Fig.6)
MQ- monocrystalline quartz; PQ-polycrystalline quartz MF –microcline feldspar PF-plagioclasefeldsper.



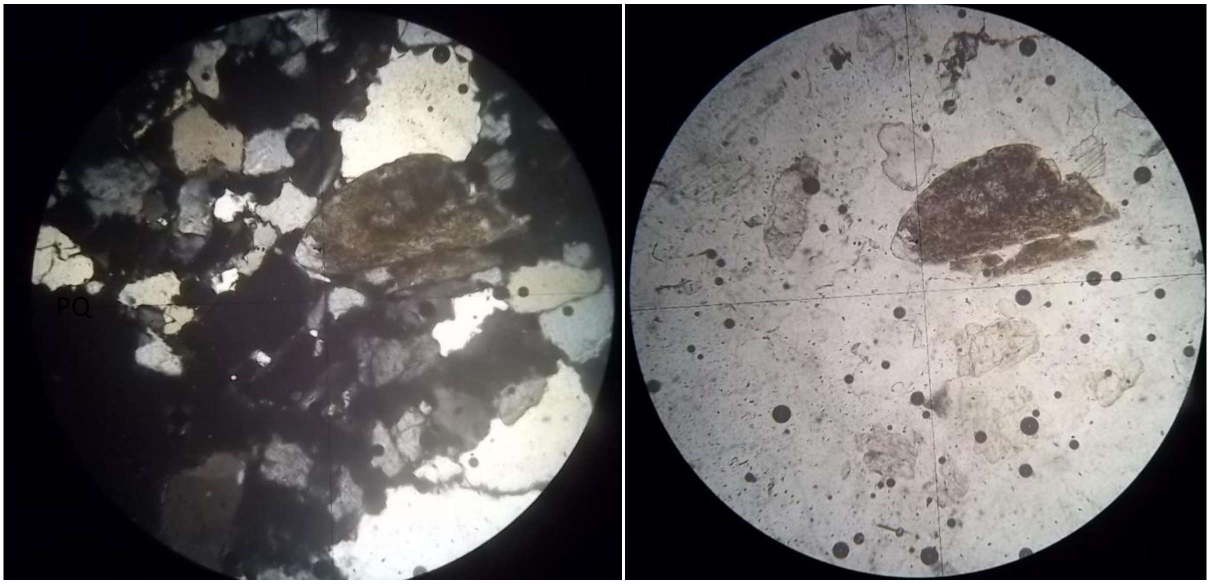
XPLMg ×10 PPL

Plate XI: Photomicrograph ofLokoja Sandstone at Filele section making up unit (F/01) of MQ-monocrystalline quartz; PQ-polycrystalline quartz MF –microcline feldspar PF-plagioclase feldsper.



XPL Mg ×10 **PPL**

Plate XII: Photomicrograph of Lokoja Sandstone at Natacosandstone making up unit N2/03 of MQ-momcrystalline quartz; PQ-polycrystalline quartz F –feldspar.



XPL Mg×10PPL

Plate XIII: Photomicrograph ofLokoja Sandstone at Nataco sandstone of sandstone making up unit N302/02.MQ-monocrystalline quartz; PQ-polycrystalline quartz
. C-ferruginized kaolinite cement.

The observation shows that thin section photomicrograph of sandstone from the study area consists mainly of quartz, feldspar, clay matrix and cement of varying compositions filling the void. The quartz crystals are generally colourless and clear as opposed to feldspars which are cloudy. Some of the quartz grains exhibit normal extinction while others show undulous extinction. Moncrystalline quartz is dominant while polycrystalline quartz occurs in some of the samples studied (Plate X-XII). Quartz comprises an average of 73%of the framework ofthe sandstone. The next most abundant mineral is feldspars (about 5% – 15%). The feldspar rcrystals are generally quite distinct from quartz grains as they exhibit low relief, and are cloudy (Plate X-XII). The feldspar is mainly microcline with little plagioclase. Microcline shows cross-hatched twinning under cross polarized light while plagioclase feldspar show albite twinning (Plates xii and xiv) with narrow twin laminae under cross polarized light.

The iron oxide, hematite occurs as redish-brown cement coating the grain while calcite cement bonded the grain together in white conglomeratic sandstone. The matrix is about 15% in conglomeratic sandstone. The iron oxide cement is produced by deposition in an oxidizing environment while carbonate cements are product of chemical precipitation during clastic sedimentation and recrystallisation of organic carbonate materials

Using Folk's (1957) sandstone classification, Lokoja Sandstone ranges from subarkose to quartzarenite.

4.5: Granulometric Studies.

4.5.1 Grain size and statistical parameters

The mean grain size in a deposit is generally a function of the energy of the processes controlling transport and deposition. The sediments are segregated according to their hydrodynamic behaviour which depends on the size, specific gravity and shape. In contrast, the degree of sorting of grains in a deposit is a function of the persistence and stability of the energy condition by availability of grains that can be deposited in the environment.

Sixteen samples were sieved and statistical parameters of each of the sandstone samples are presented in (Table 1).The cumulative curves plotted for various sample are presented in(Appendix 2)

Quantitative graphical values of percentile from various sample obtained from the cumulative frequency curve in(Appendixes 1 and 2) are presented in (Table 2)

The following graphical parameters were obtained by using Folk and Ward's (1957) formulae

1 Graphic mean (M) = $\frac{\phi 16+\phi 50+\phi 84}{3}$

2. Graphic Standard Deviation (sorting) (I) = $\frac{\phi 84 - \phi 16}{4} + \frac{\phi 95- \phi 5}{6.6}$

3. Inclusive Graphic Skewness (Ski) = $\frac{\phi84+\phi16-2\phi50}{2(\phi84-\phi16)} + \frac{\phi95+\phi5-2\phi50}{2(\phi95-\phi5)}$

4. Graphic Kurtosis (K_G) = $\frac{\phi95-\phi5}{2.44(\phi75-\phi25)}$

M: Graphic mean standard values

Phi (ϕ) value	**Sizeclass (Wentworth, 1922)**
-1.0 to 0.0	Verycoarsegrainedsand
0.0 to 1.0	Coarsegrained sand
1.0 to 2.0	Medium grained sand
2.0 to 3.0	Finegrained sand
3.0 to 4.0	Veryfinegrained sand
4.0 to 8.0	Silt
8.0 to 14.0	Clay

I: values Graphic phi standard deviation

Phi standard deviation	**Verbal sorting**
<0.35	Verywell sorted
0.35 to 0.50	Well sorted
0.50 to 0.70	Moderatelywell sorted
0.70 to 1.00	Moderately sorted
1.00 to 2.00	Poorly sorted
2.00 to 4.00	Verypoorlysorted
>4.00	Extremelypoorlysorted

Ski: Graphic skewness standard values

Calculatedskewness	**Verbalskewness**
> +0.30	Stronglyfine skewed
+0.30 to +0.10	Positively skewed
+0.10 to –0.10	Nearsymmetrical
–0.10 to –0.30	Negatively skewed
< −0.30	Strongly coarseskewed

K_G: Graphic kurtosis standard values

CalculatedKurtosis	**Verbal Kurtosis**
<0.67	Veryplatykurtic
0.67– 0.90	Platykurtic
0.90–1.11	Mesokurtic
1.11-1.50	Leptokurtic
1.50 -3.00	Veryleptokurtic

Table 1. Percentile value from cumulative curve plots of sandstones samples in the study area.

Sample	ϕ5	ϕ16	ϕ50	ϕ84	ϕ95	ϕ25	ϕ75	ϕ64
ABJ/03	-1.9	-1.7	-0.8	0.4	2.4	-1.5	-0.1	0.3
ABJ/04	-0.2	0.3	1.3	2..3	2.8	0.5	2	1.7
ABJ/05	-0.1	0.4	1.3	2.1	2.9	0.7	1.8	1.6
ABJ/06	-1.3	-0.9	0.9	2.8	3.6	-0.2	2.1	1.5
ABJ/07	-0.1	0.7	1.6	2.5	2.8	1.0	2.2	1.9
ABJ/08	-2.0	-1.2	0.5	2.1	3	-0.75	1.7	1.2
ABJ/09	0.9	1.3	2	2.8	3.2	1.5	2.5	2.3
ABJ/11	-0.2	0.4	1.3	2.1	3.2	0.7	1.8	1.6
AGB/06	0.2	0.5	1.3	2	2.5	0.8	1.8	1.6
AGB/12	1.8	2.1	2.5	2.9	3.1	2.3	2.8	2.7
AGB/18	-0.2	0.3	1.3	3.2	3.8	0.6	1.9	1.6
F/02	-0.1	0.4	1.4	2.8	4.2	0.7	2.2	1.8
F/04	-1.4	0.1	1.6	4.1	4.7	0.5	3.5	2.6
F/05	-0.59	-0.1	0.8	2.2	3.5	0.2	1.7	1.4
N/02	-1.3	0.1	0.7	1.8	2.8	0.1	1.4	1
N/05	-0.7	0.2	0.6	1.8	3	0.1	1.4	1

Table 2: Grain size distribution and quantitative parameters of sandstone samples in the study area.

SAMPLE ID	Mean (mm)	GRAPHIC STANDARD DEVIATION (SORTING)φ	GRAPHIC SKEWNESS (SKI)φ	GRAPHIC KURTOSIS (KG)φ
ABJ/03	-0.7 Very coarsegrained	1.23 Poorly sorted	-0.127 Negatively skewed	1.3 Leptokutic
ABJ/04	1.3 Mediumgrained	0.95 Moderately sorted	0.00 Near symmetrical	0.82 Platykurtic
ABJ/05	1..3 Mediumgrained	0.9 Moderately sorted	0.0058 Near symmetrical	1.2 Lleptokurtic
ABJ/06	0.9 Coarse grained	1.7 Poorly sorted	0.0645 Near symmetrical	0.9 Platykurtic
ABJ/07	1.6 Mediumgrained	1.6 Poorly sorted	-0.86 Strongly coarse skewed	1 Mesokurtic
ABJ/08	-0.5 Coarse grained	1.28 Poorly sorted	-0-015 Near symmetrical	0.8 Platykurtic
ABJ/09	2.0 Mediumgrained	0.72 Moderately sorted	0.05 Near symmetrical	0.94 Mesokurtic
ABJ/11	1.3 Mediumgrained	1.0 Poorly sorted	-0.41 Strongly coarse skewed	1.3 Mesokurtic
AGB/06	1.27 Mediumgrained	0.72 Moderately sorted	0.06 Near symmetrical	0.94 Mesokurtic
AGB/12	2.5 Finegrained	0.396 Well sorted	-0.384 Strongly coarse skewed	1.06 Mesokurtic
AGB/18	1.6 Mediumgrained	1.33 Poorly sorted	0.3 Positively skewed	1.26
F/02	1.5 Mediumgrained	1.25 Poorly sorted	0.23 Positively skewed	1.17 Leptokurtic
F/04	1.93 Mediumgrained	1.92 Poorly sorted	0.13 Positively skewed	0.83 Platykurtic
F/05	0.96 Coarsegrained	1.19 Poorly sorted	0.26 Positively skewed	1.18 Leptokurtic
N/03	0.86 Coarsegrained	1.04 Poorly sorted	0.159 Positively skewed	1.29 Leptokurtic
N/05	0.86 Coarsegrained	0.24 Very well sorted	0.25 Positively skewed	1.7 Very leptokurtic

4.5.2. Univariate grain size parameters

The samples display a wide variety of grain sizes i.e. they range from medium to coarse grained sizes. Most of the samples have their peaks between 1.10φ and 2.45φ which is the equivalent to medium to fine grained classes of the Wenthworth (1922) scale.

a) Median:

The median grain is the grain size that separates 50% of the sample (by weight) from other 50%. It thus corresponds to φ_{50} (that is, the φ value for the 50th percentile). It corresponds to certain grain size in mm.

The true mean would be the average size of all the grains present. We cannot possibly do such a calculation so the graphic mean is conventionally quoted. The average size is generally controlled by the strength of the depositing current, the initial grain size and source of the material (Folk and Ward, 1957; Pettijohn 1975). The graphic mean for various sizes for the various samples is presented in (Table 2)

Lokoja Sandstone ranges from coarse to medium grained sand (N/05, 02 to F/05, 04 and 02) (Table 2.)while samples from Patti Formation range from medium (ABJ/11, 0 9, 07, 05 and 04 AGB/18, 12 and 06) to coarse (ABJ/8) very coarse grained (ABJ/ 3). (Table 2.).

The mean size of a grain still has no definite trend to support any environmental interpretation. Friedman (1967) pointed out that the average mean size is not sensitive as an environmental indicator

b) Inclusive Graphic Standard Deviation (Sorting)

The degree of sorting in sandstones generally depends on the sediment source, grain size and the depositional regime. It is indicative of hydrodynamic condition (i.e. range of velocities and degree of turbidity) operating within the transporting medium and to some extent it is suggestive of the distance traveled (Krumbein and Sloss, 1963).The value of the standard deviationtends to show most of the samples are poorlysorted with few very poorly and moderately sorted (Table 2). Samples from Lokoja Sandstone are pooly sorted (F/05, 04, 02,N/02) to very well sorted (N/05) while samples from Patti Formation ranges from poorly sorted (ABJ/11,08,07, 06, 05, 03 and AGB/18) to moderately sorted (ABJ/9) (AGB/06) (Table 2)

Generally, the poorly sorted medium to coarse grained indicating less winnowing and short distance of travel reflecting fluvial setting.

However, diagenesis may introduce secondary clay to sandstone thereby disrupting the degree of sorting that would be obtained from the sieve analysis. Therefore itis the measure of scatter of grain size about the mean and corresponds with the standard deviation.

c) The (graphic) Skewness

It is the measure of the symmetry or bias in the grain size distribution towards the coarser or finer-grained end of the size range and it is a very useful descriptive term for the depositional processes of the sediments. Positively skewed samples have an excess of fine grains, negatively skewed sample ofcoarse grain. The samples analyzed have skewness values ranging from -.0.015 to 0.3 from negatively skewed, nearly symmetrical to positively skewed.(Table 2).The result shows that Lokoja Sandstone is positively skewed (N/05,and 02, F/02,04 and 5 while samples from Patti Formation in the study area is mainly near symmetrical (ABJ/, 8, 07, 05 and 04 AGB/,0 6) (Table 2.)

d) The (graphic) Kurtosis

Kurtosis is the measure of the flatness of grain size distribution as it will appear on the simple frequency curve. Flat distributions are platykurtic and peaked distributions are leptokurtic.

The various samples analyzed (Table 2) shows that samples from Lokoja Sandstone are leptokurtic (N/02, F/02, 05) while samples from the Patti Formation are mesokurtic (ABJ/11,09,07 and AGB/06) to platykurtic (ABJ/08, 04). Little geological information can be derived from the value of kurtosis (Pettijohn 1975).

4.5.3 Bivariate grain size parameters

Mean grain size, standard deviation (Sorting) skewness, and median are parameter needed to separate sand based on origin according to standard plots of various workers. These are bivariate plots versus first percentile (Friedman, 1979), standard deviation versus skewness (Friedman, 1961, 1967, 1979) and Moiola and Weiser (1968). These plots are presented below.

a) Standard Deviation Versus skewness

The bivariate plots of standard deviation versus skewness are based on the work of Friedman (1961, 1967, and 1979) and Moiola and Weiser (1968). Most of the studied samples plotted within the river field (Fig 27a-l.).

The plots based on Friedman (1979), showed that 100% of the samples plotted falls within the river field environment for samples from Lokoja Sandstone and 99% of the sample plotted within the river field environment for sample from Patti Formation (Fig.27a and b.).The plots based on Moiola and Weiser (1968) showed that 99.9% of the studied samples plottedwithin river field environment for the whole samples from Lokoja Sandstone and Patti Formation (Fig.27c and d).Using the distinction of Friedman (1961), 99% of samples plotted are within fluvial environment for the samples from Lokoja Sandstone and Patti Formation (Fig.27e and f)

b) Standard Deviation versus Mean Size

The plot of standard deviation versus mean size based on the Friedman (1979) shows that 100% of sample from Lokoja Sandstone falls within river sand field while 99% of sample of Patti Formation falls within river sand field and 1% falls within inland dune sand field(Fig. g and h).

Using Moiola and Weiser, (1968), 100% of samples studied for both Lokoja Sandstone and Patti Formation plotted within river field. (Fig.27 i and j) while Friedman (1967) plot Fig.27 k. and l shows the distribution of sand parameters between river and beach environment, from the plots, 100% the samples fall within river field environment for samples from Lokoja Sandstone while 99% fall within the river sand field environment for samples from Patti Formation.

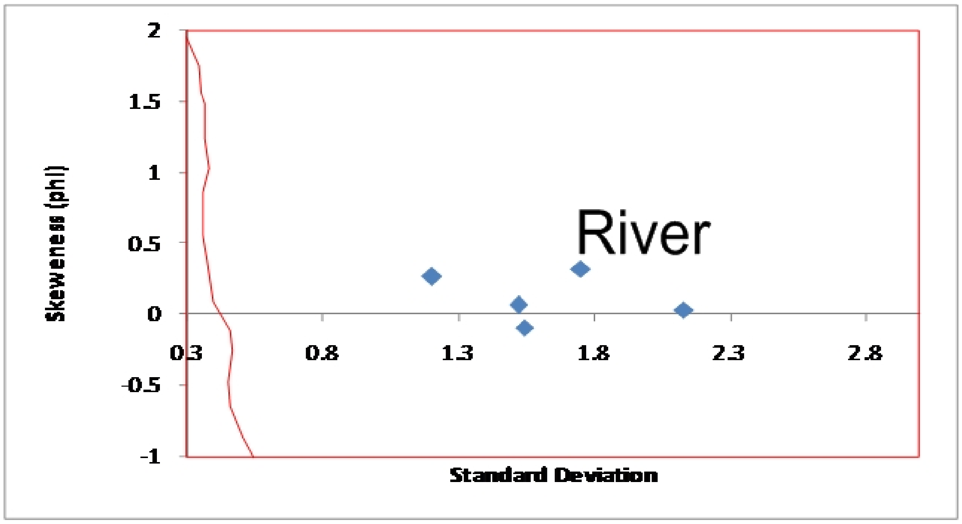


Figure 27a: Bivariate plot of standard deviation vs skewness for the whole samples from Lokoja Sandstone (Adapted from Friedman, 19 79)

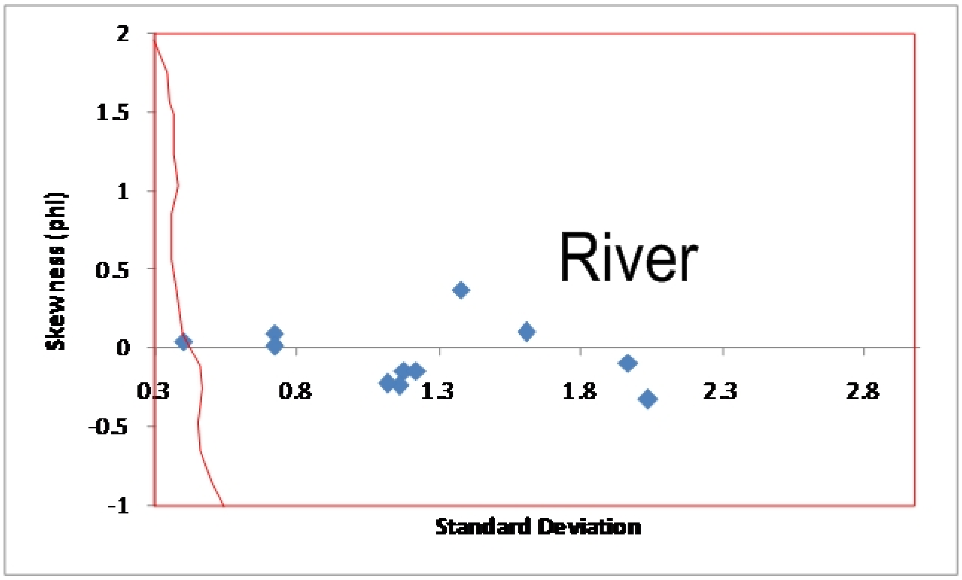


Figure 27b: Bivariate plot of standard deviation vs skewness for the whole samples from Patti Formation (Adapted from Friedman, 19 79)

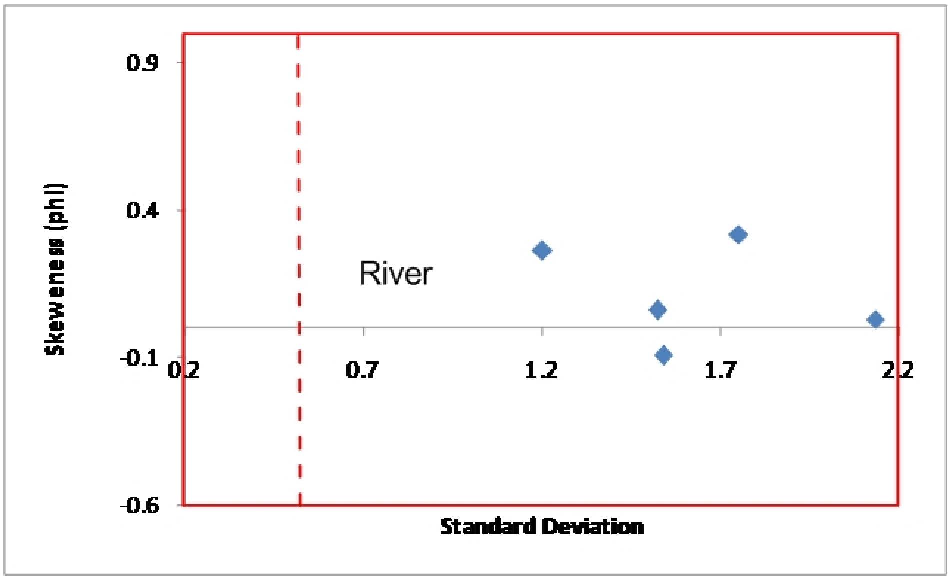


Figure 27c: Bivariate plot of standard deviation vs skewness for the whole samples from Lokoja Sandstone (Adapted from Moiola and Weiser, 1968).

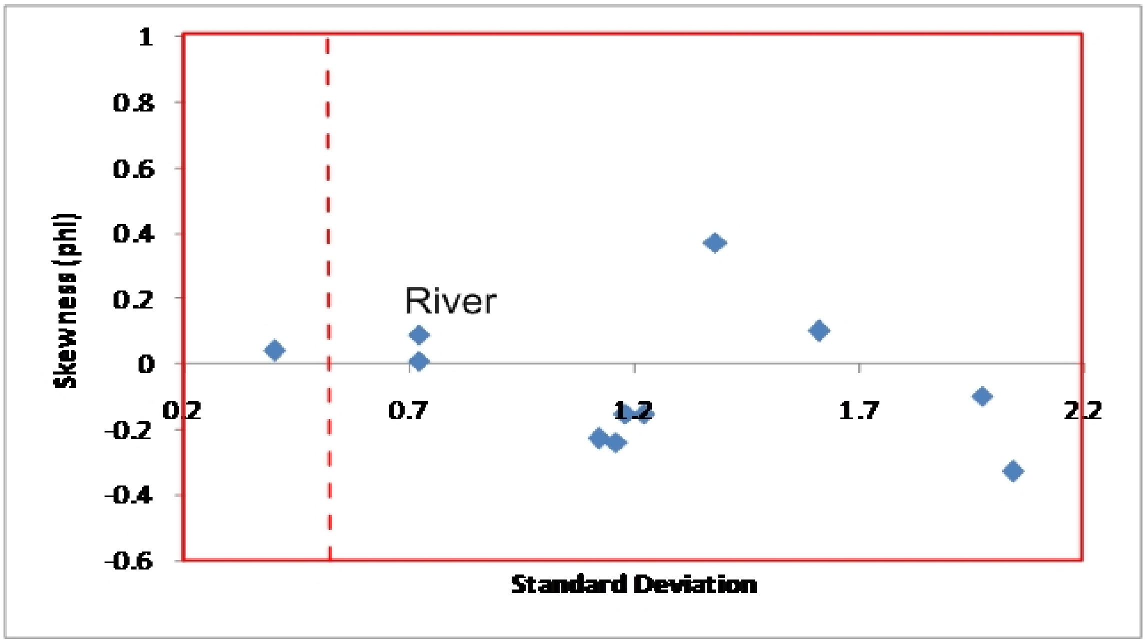


Figure.27d: Bivariate plot of standard deviation vs skewness for the whole samples from Patti Formation (Adapted from Moiola and Weiser, 1968).

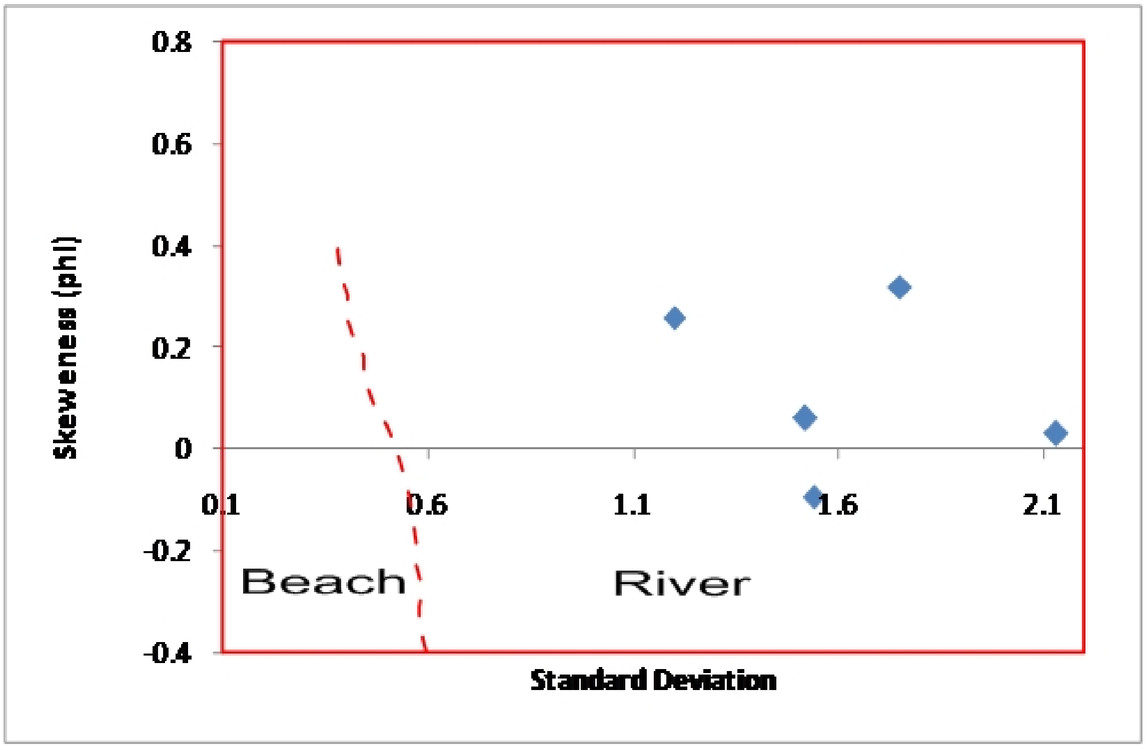


Figure 27e: Bivariate plot of standard deviation vs skewness for the whole samples from Lokoja Sandstone (Adapted from Friedman, 1961)

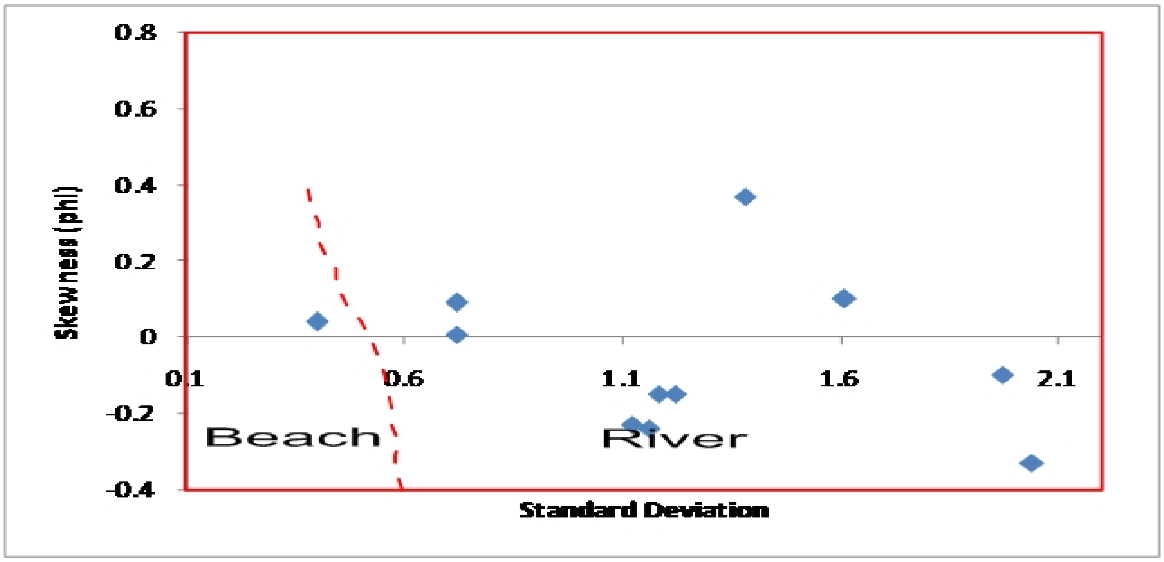


Figure 27f: Bivariate plot of standard deviation vs skewness for the whole samples from Patti Formation (Adapted from Friedman, 1961).

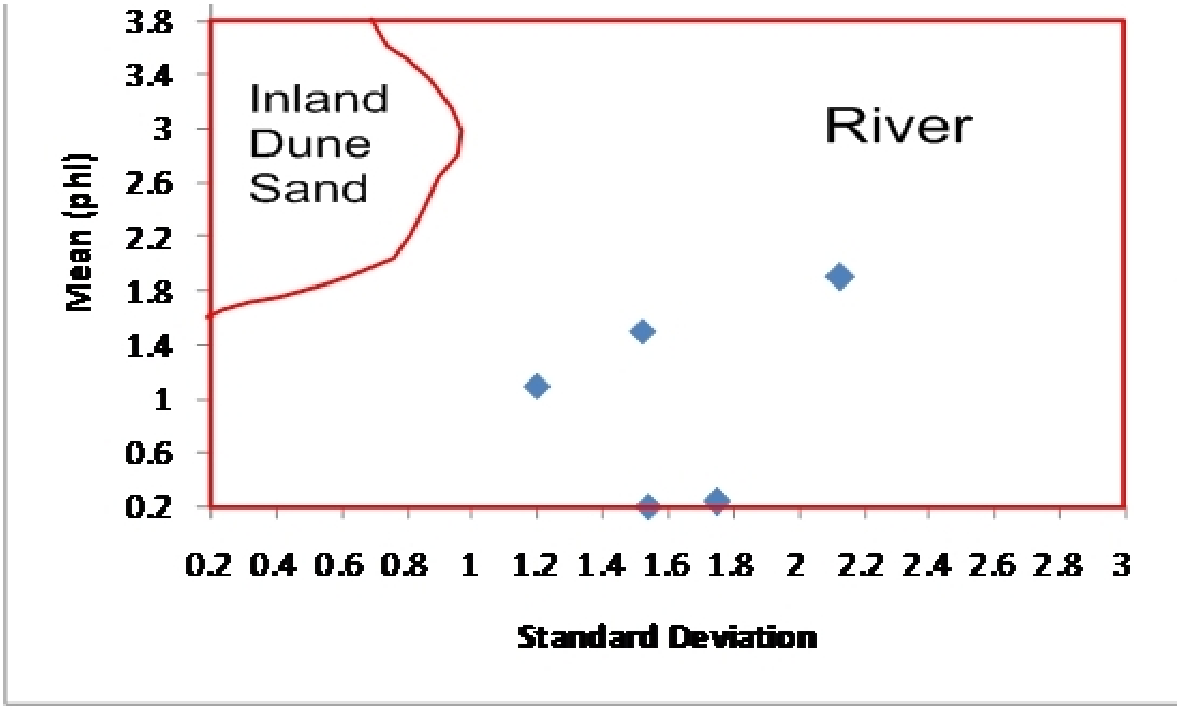


Figure 27.g: Bivariate plot of standard deviation vs skewness for the whole samples from Lokja sandstone (Adapted from Friedman, 1979).

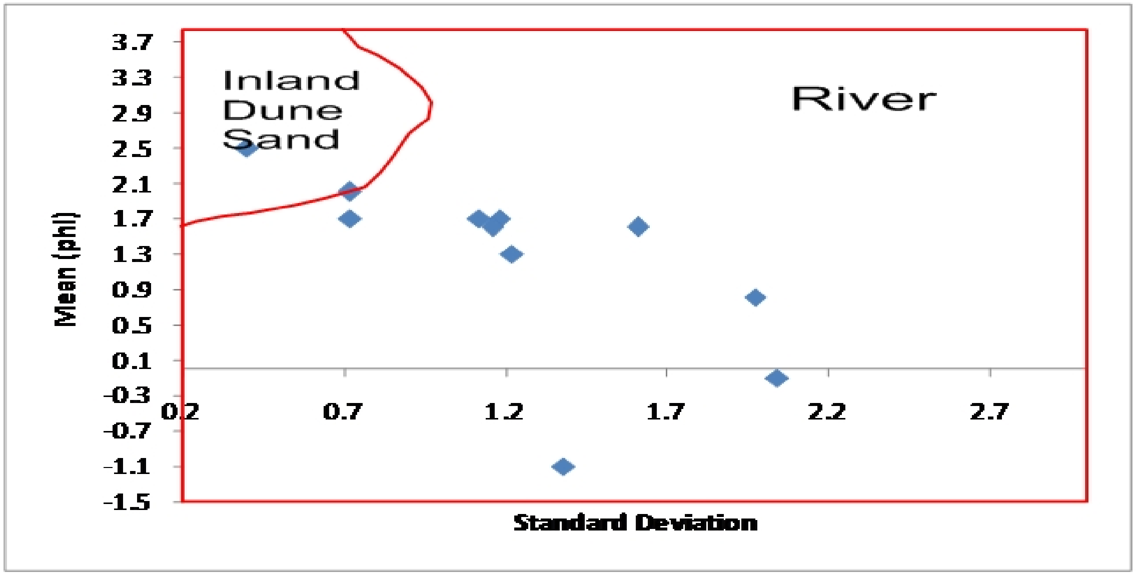


Figure 27 h: Bivariate plot of standard deviation vs skewness for the whole samples from Patti Formation (Adapted from Friedman, 1979).

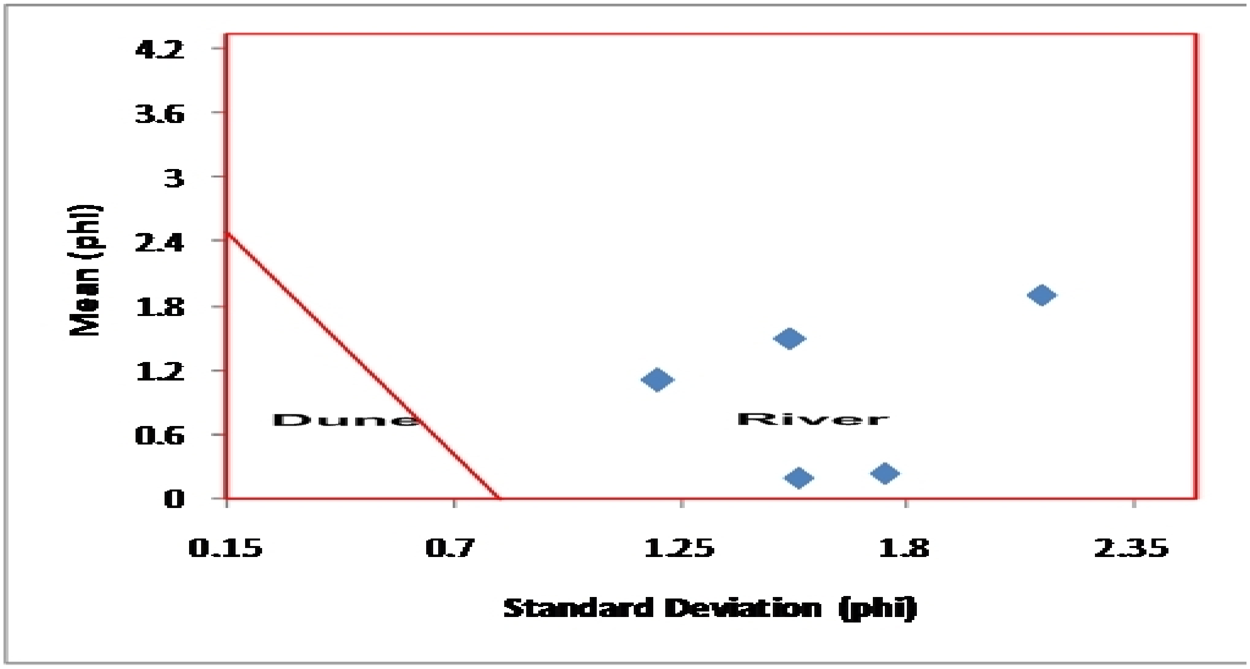


Figure 27i: Bivariate plot of standard deviation vs mean for the whole samples from Lokoja Sandstone (Adapted from Moiola and Weiser, 1968).

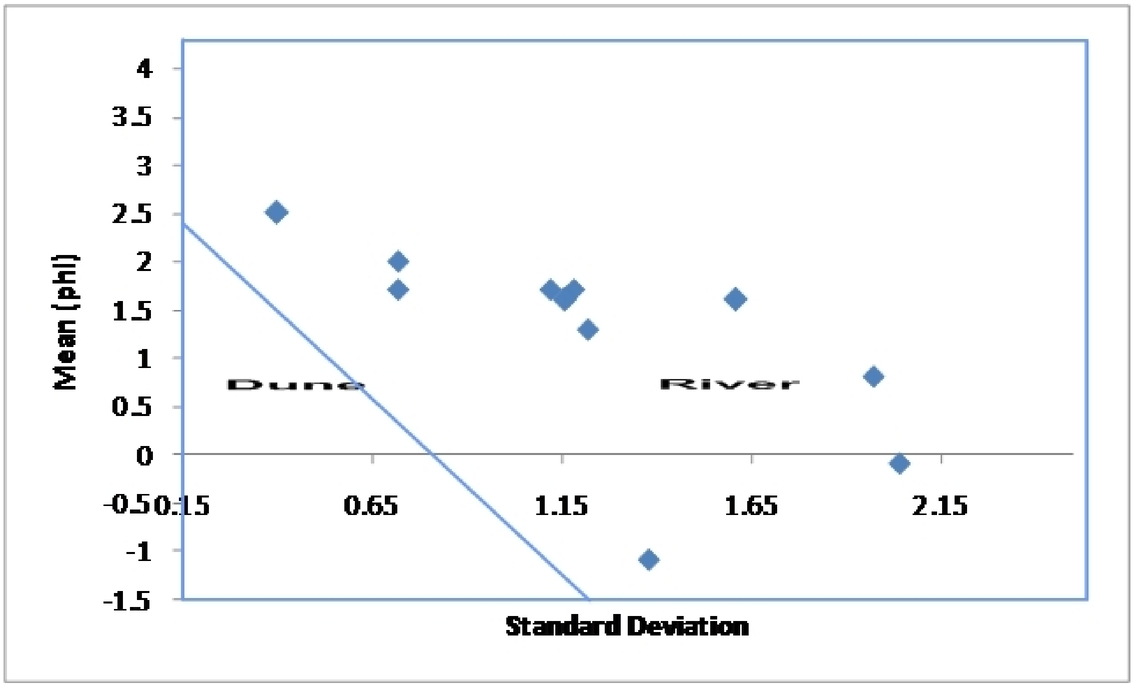


Figure 27j:. Bivariate plot of standard deviation vs mean for the whole samples from Patti Formation (Adapted from Moiola and Weiser, 1968).

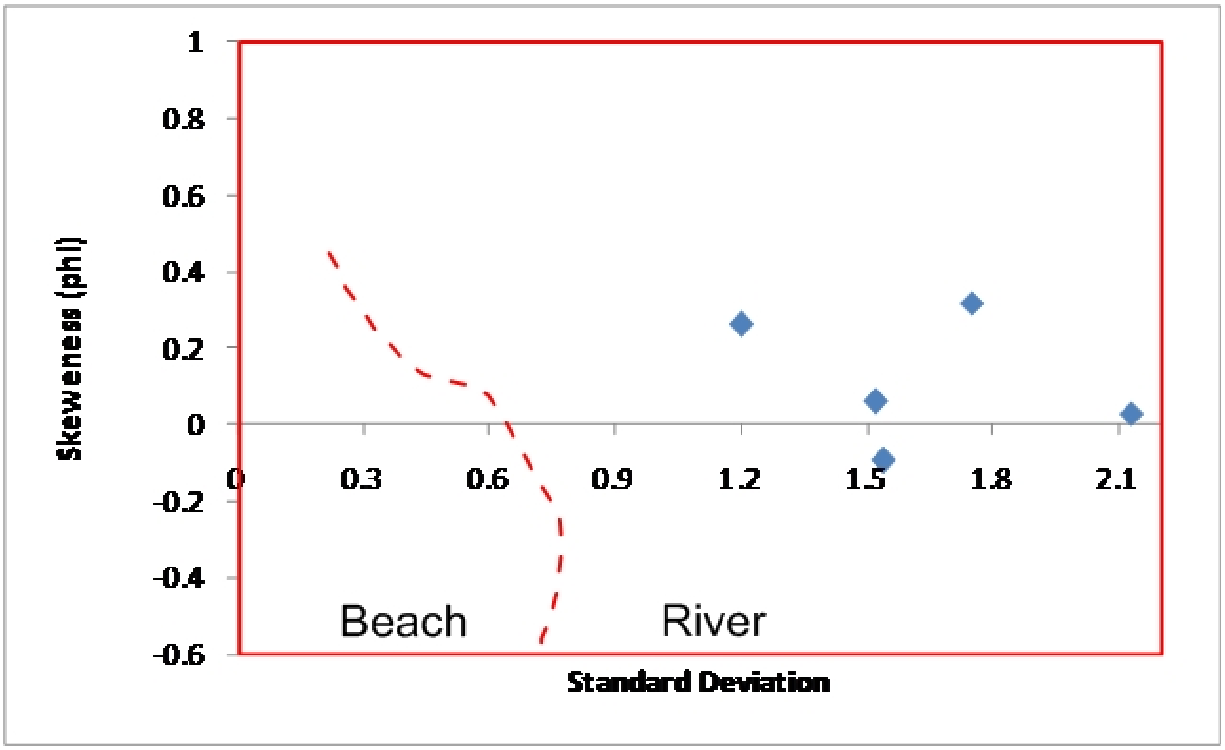


Figure 27k. Bivariate plot of standard deviation vs skewness for the whole samples from Lokoja Sandstone (Adapted from Friedman, 1967).

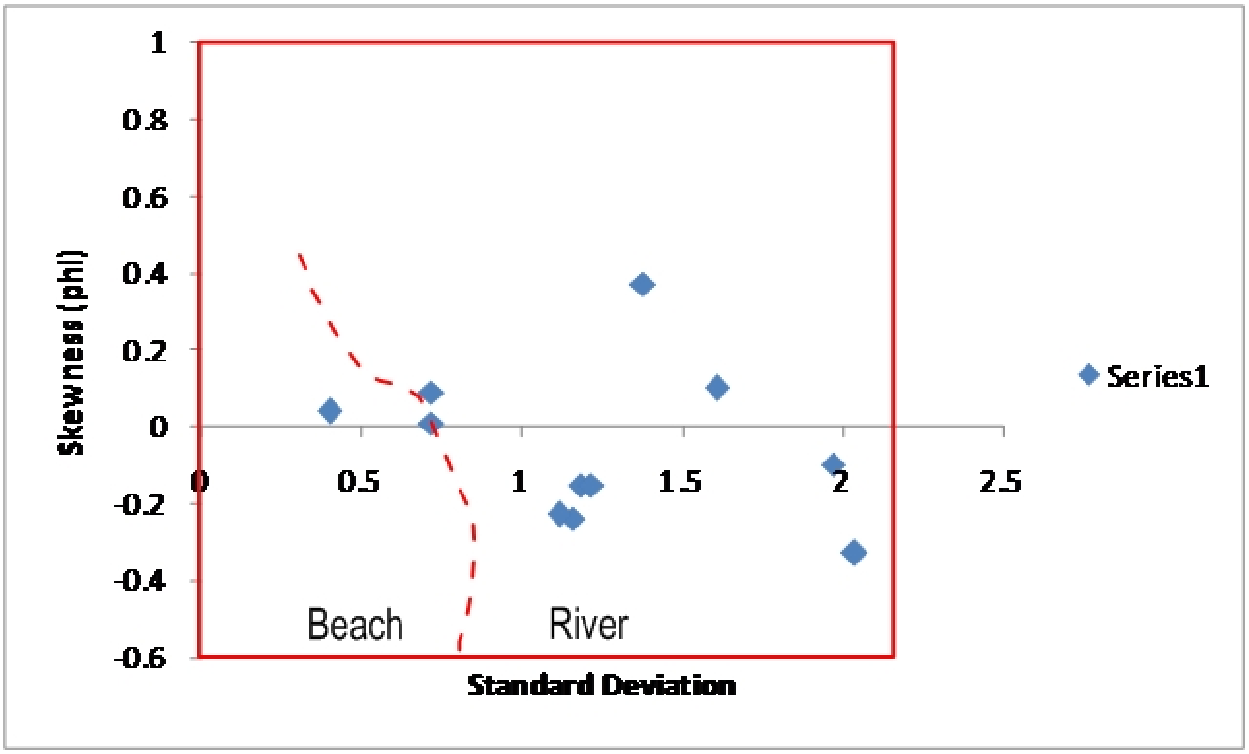


Figure 27l: Bivariate plot of standard deviation vs skewness for the whole samples from Patti Formation (Adapted from Friedman, 1967).

4.6.Paleontology

Ten samples of shale, mudstone and claystone were collected from of Patti Formation at Ahoko. These samples were all treated with 30% (W/V) hydrogen peroxide and then washed using 63µm sieve .After drying, these samples were all subjected to thorough microscopic studies, but no foraminifera or ostracod was seen. Bioturbated sandstone containing *ophiomorpha* and *thalassinoid* burrows were observed at Natako km 1.2 N/01 and Agbaja AGB/18.

CHAPTER FIVE: DISCUSSION

5.1 SEDIMENTARY FACIES DESCRIPTION AND DEPOSITIONAL ENVIRONMENTS

Detailed descriptions of measured outcrop sections in the southern Bida Basin indicate that the formations were deposited in a wide range of environments. Generally, the facies associations (conglomerate, sandstone, siltston-claystone and shale-claystone –siltstone facies) and peculiar sedimentary features such as wavy laminations and bioturbation in the study area are indicative of alluvial deposits which might have prograded through braided streams to near marine condition (Fig. 28)

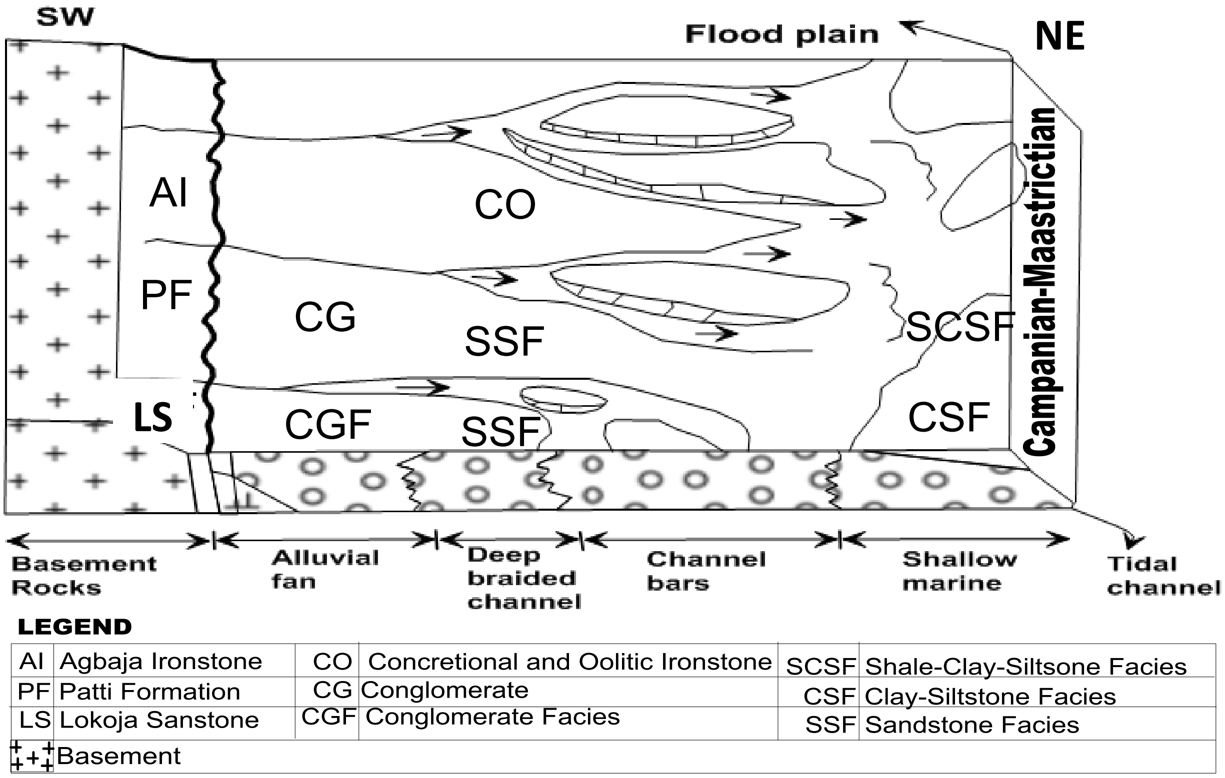


Figure 28: Schematic diagram showing the depositional model of Lokoja Sandstone, Patti Formation and Agbaja Ironstone in the study area (modified from Ojo and Akande, 2003).

Based on sedimentary structures and texture, the following sedimentary facies of the southern Bida Basin arerecognized in the study area.

5.2. LOKOJA SANDSTONE

The Lokoja Sandstone in the study area consists of three facies associations. These are the conglomerate facies, sandstone facies and siltstone-claystone facies.

I. Conglomerate Facies

The conglomerate facies can be distinguished into subfacies: the grain supported conglomerate F/01 and N3/01(Fig.7 and11), graded matrix supported conglomerate F/06 and the matrix supported conglomerate F/03,and N/01were observed in the measured section at Filele (Fig.7) and Nataco (Fig 9).

The matrix supported conglomerate subfacies also varies in terms of their composition. At the measured section at Filele (Fig.7) and Nataco (Fig.9) Km 1.2, the matrix supported conglomerates are massive and poorly sorted muddy to sandy matrix. Their pebbles and cobbles include rounded to angular quartz. The grain supported conglomerate subfacies F/01 overlies the Basement Complex non- conformably, it is massive and make sharp contact with overlying pebbly to coarse grained sandstone (Fig.7). Overlying this succession is a matrix supported subfacies F/03, the pebble to cobble sized clasts of quartz are embedded within the sandy to clayed matrix. The graded matrix supported conglomerate subfacies F/06 occur towards the upper part of the measured section at Filele (Fig. 7) and at the base of the section at Nataco Km 1.2 (Fig.9)

II. Sandstone Facies

The sandstone facies occurs in most of the sections studied in the Lokoja Sandstone can be distinguished into medium grained and pebbly sandstone subfacies. The medium grained and pebbly sandstone subfacies is well represented in the section at Nataco (Figs. 7- 9). Generally, they are poorly sorted and felspathic. In most of the sections they are massive and occur in repeated upward cycle were passed upward to conglomerates. The clasts pebble to cobble sized are oriented parallel to the sets defining the sets and the bounding surfaces. They make erosive contact with the lower bed (Fig.9 N/04). The prominent sedimentary structure is trough cross bedding (Figs. 8 - 10). Herringbone cross bedding is well displayed in a section located at Nataco Km 4.5 (Fig .11). The bioturbated sandstone subfacies are also observed at the measured section at Nataco Km 1.8 N2/01 (Fig.10). This subfacies is strongly bioturbated containing *ophiomorpha*and *thalassinoids* burrows. This unit also contains weakly preserved cross-stratification.

III. Claystone Facies

This facies is made up of claystones which occurs in the top most part of the measured section in Lokoja Sandstone(Figs. 7 - 11) and consist of massive, laminated ferruginized claystones. They are micaceous and sandy at intervals and often passing into lateritic overburden.

5.2.1.DEPOSITIONAL ENVIRONMENT OF LOKOJA SANDSTONE

On the basis of environment and processes of deposition which in turn defines the lithologic and palaeontologiccharacteristics of the deposits, the conglomerate facies comprising of massive, grain supported conglomerate subfacies (F/01,N3/01), graded matrix supported conglomerate (F/06)subfacies and matrix supported conglomeratesubfacies(N/01,F/03) (Figs.7 and 9) in the study area contain features that indicate a continental environments dominated by alluvial and braided stream processes. Comparison of the sedimentary features of these conglomerate bedswith well known and documented conglomerates in various parts of the world suggest that the grain to matrix supportedconglomerates in the study area suggest debris flow sediments deposited from dense andviscous fluids (Hampton, 1979; Collinson, 1996; El – Arabi and Abdel Motelib, 1999). The massive immature matrix to grain supported conglomerate subfacies can be ascribed to debris flow in alluvial fan setting (Ojo and Akande,2003). Guiraud (1990) and Ojo and Akande (2003) interpreted similar conglomerates characterized by poor sorting, lack of internal organization and non imbricated clasts in the Upper Benue Trough and southern Bida Basin respectively as gravity induced proximal alluvial fan deposits.The occurrence of graded - matrix supported conglomeratetowards the middle part of Filele section (Fig.7) and Nataco section (Fig.11) in part of Lokoja Formationsuggests a change in texture and, consequently, the flowsystem.

The sandstone facies comprising of thecross- stratified to massive conglomeratic sandstone and medium to coarse grained sandstonesubfacies (Figs.7-10) in the Lokoja Formation is interpreted as braided fluvial deposits. The braided fluvial origin is indicated by absence of trace fossil, alternating thick sequence of conglomeratic and pebbly to coarse grained sandstone and overbank fine sediment (Brown and Plint, 1994; Amireh and Abed, 1999; Ojo and Akande, 2003, 2012). Braided fluvial systems are subject to rapid fluctuations in flow velocity and cause sediment to be deposited mainly in form of channel bar (Wycsk, 1990: Ojo and Akande, 2003).The frequently interbedded conglomeratic sandstone and medium – coarse grained sandstone in the studyarea (Figs. 8-11) is suggestive of development of low sinuosity channel bars arising from high discharge, channel switching,and lack of point bar sedimentation (Allen, 1982; Selley, 1985; Blair, 1987;Ojo and Akande, 2012).The massiveconglomeratic sandstones were probably deposited rapidly from a high velocity current while the graded andtrough cross stratified conglomerate sandstones (Figs.7-9) in part of the Lokoja Formation developed from downstream migration of dunes of possiblystraight crested bedforms in a low flow regime conditions (Cant, 1982; Miall, 1988, 1990; Amireh *et al*., 1994Ojo and Akande, 2012).The thinly bedded medium to coarse grained sandstone subfacies (Fig.8) in the Lokoja Formation is howeverinterpreted as mid to distal channel bars deposited in upper flow regimes (Cant and Walker, 1978;Ojo and Akande, 2012).

The bioturbated and herringbone cross-stratified conglomeratic sandstone subfacies (Figs.9 and 10) reflect shallow to near shore marine environment (Nwajide, 1990).The bioturbated conglomeratic sandstone with abundant burrows support occasional shallow marine.The fine grained sandstone, siltstone and claystone facies of Lokoja Formation are interpreted as flood plain deposits resulting from deposition out of suspension in upper flow regime during flood plain stage.(Akande,2003).

The facies association and the sedimentary structures of the Lokoja Sandstone in the study area are indicative of alluvial deposit which might have prograded through braided stream to near shore marine Fig.28

The result of the grain size analyses (Table 2) show that the Lokoja Sandstones are generally poorly sorted, medium to coarse grained in texture,indicating less winnowing and abrasion. Consequently, the grains probably retained original configuration and texture. This is an indication of rapiddeposition and short distance of transportation reflecting a fluvial setting (Friedman 1979).

The result of the thin section shows that occurrence of monocrystallinequartz, polycrystallinequartz and feldspar may suggest input mainly from alkaline igneous or metamorphic rock (Boggs, 1995)

The bivariate plot of Friedman's (1961, 1967, 1979) for skewness versus standard deviation and Moiola and Weiser (1968) for skewness versus standard deviation and mean versus standard deviation suggest a fluvial origin for Lokoja Sandstone.

5.3.PATTI FORMATION

The Patti Formation in the study area consists of conglomerate,sandstone, siltstone-claystone-shale and facies subfacies

(i) Conglomerate

This facies consists ofconglomeratic sandstone, medium grained to very coarse grained sandstone, and minor fine grained sandstone (Fig. 20). The sandstone generally fines upward with channel lag deposits on erosional surface and through a medium to coarse grained sandstone, and terminates with siltstone and claystones

(ii) Sandstone Facies

The sandstone facies of the section studied in Patti Formation can be distinguished into medium grained which iswell sorted,(Table 2 AGB,12,and 6)cross stratified, and bioturbated. This facies is well represented at the Agbaja sections(Fig 12).Cross stratified sandstone facies appears at the middle part of the section and the massive bioturbated sandstone facies occur towards the upper parts of the Agbaja sections. In these locations, the beds show varying degrees of bioturbations. At Agbaja, (Fig.12). The sandstones show herringbone cross-bedding and wavy lamination.

iii) Shale-claystone-siltstone Facies

This facies is made up of dark shale and claystone subfacies occur in the lower part of the measured section at Ahoko (Figs. 14 and 15) and consist of massive to laminated ferruginous siltstone. At Ahoko,the argillaceous unit consists predominantly of shales and siltstones which are rhythmically interbedded with concretional and bioturbated ironstones. (Figs.14 and 15). The shales are dark to light grey, carbonaceous and fissile. The silty shale unit within depth interval contains abundant woody fragments and plant remains. The claystone subfacies occur in almost all the studied sections as capping in the lithologic successions (Figs.13-25). It is partly ferruginized often passing to lateritic overburden. A very thick bed of claystone occurs at Ahoko and Ligbeta and Kwaita (Fig 14, 16- 18, 22a and b, 23- 25).The dirty to white claystone beds are massive and show shrinkage crack features. The clay is being mined local miners. This may be due to its suitability as raw material for ceramic and potteries.

5.3.1. DEPOSITIONAL ENVIRONMENT OF PATTI FORMATION

The sandstone facies associations of the Patti Formation interpreted as tidal- shoreface in the study area are fine to medium grained which is well sorted, hummocky cross- stratified, and bioturbatedsandstones (Figs.12 and 20). According to Walker (1990), hummocky cross stratification is widely interpreted as product of strong oscillatory process, often with variable but subordinate superimposed unidirectional flow which forms during intense storms. The structure is commonly preserved between fair weather and storm wave base. Harms *et al.* (1982) suggested that this structure is formed by strong surges of varied direction (oscillatory flow) that is generated by relatively large storm waves. Strong wave action first erodes the sea bed into low hummock and swale that lack any significant orientation. Duke*et al.* (1991) suggest that hummocky stratifification originates by the combination of unidirectional and oscillatory flow related to the storm activity.

Herringbone cross-stratification,bioturbation and wave ripples associated with the sandstones (Fig.12) in the study area indicate shallowmarine conditions and tidal channels (Pettijohn, 2004)

Herringbone cross beddings observed in the Patti Formation (Fig.12) indicate reversalsin current direction typical of tidal regimes Klein, (1970). Reactivation surfaces have also been described from tidal environments as a result of lee-face modification of the bedforms by subordinate tidal currents (Ladipo, 1986).

Other associated sedimentary structures observed in this facies association (Fig.12) include convolute beddings, wave ripplesand horizontal laminations. According to Taylor and Lovell (1991), such parallel laminated sandstones may indicate that the grain size of the sands being moved and reworked on the sea-floor below the fair-weather wave base was too large to form hummocky cross stratification under storm wave influence, thus forming upper flow regime, parallel laminated sands instead. This facies association is generally interpreted as transgressive fill of incised valley (Castle, 2001). The fine grained sandstone and interbeds of siltstone and claystones may represent low energy deposition under the influence of wave in shallow marine environments.

The predominant argillaceous and fine grained strata in this facies association (Figs.13-25) indicate a low-energy environment. Absence of marine fossils coupled with the abundance of structured vegetal remains, which are land-derived in the shale and siltstones, (Figs.14-15) suggest prevalence of fresh water in this low-energy environment. The bioturbated ferruginous subfacies with *ophiomorpha* burrow shows inundation of the basin by marginal to brackish water. The ferruginized siltstone and ironstone is the diagenetic product of iron rich mud deposited in shallow marine conditions.The claystones are interpreted as overbank deposits

The Ahoko outcrops (Figs.14 and 15) 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 arelatively anoxic to oxic paleoenvironmental conditions.

The result of grain size analysis of sandstones from Patti Formation shows that the samples (Table 2) are medium to coarse grained sandstone and are poorly sorted. The bivariate plot of Friedman’s (1961, 1967, and 1979) for skewness versus standard deviation and Moiola and Weiser (1968) for skewness versus standard deviation and mean versus standard deviation suggest a fluvial origin for the Patti Formation.

5.4. AGBAJA IRONSTONE

The Agbaja Ironstone consists of oolitic, concretional and massive ironstone bed with interbedded sandstone and claystone. (Fig.12)

5.4.1.DEPOSITIONAL ENVIRONMENT OF AGBAJA IRONSTONE

Agbaja Ironstone was deposited was deposited in the shallow marine estuarine waters by the reaction between run-off from lateritic weathering and marine water resulting from regional transgression. The clastic sediments interbedded with the ironstone were probably deposits of muddy fluvial and deltaic environment.

The sandstone and claystone are interpreted as abandoned channel sands and overbank deposits influenced by marine reworking to form concretionary and oolitic ironstone as confirmed in some details by (Ladipo *etal.*, 1994, Obaje *et al.*, 2011). According to Braide(1992b); Olaniya and Olabaniyi(1996) minor marine influences have inundated the initial continental environment of the upper part of the Lokoja Sandstone and Patti Formation. This marine inundation is believed to have continued throughout the period of deposition of Agbaja Ironstone in the southern Bida Basin.

CHAPTER SIX

6.1. SUMMARY AND CONCLUSION

The stratigraphic succession in the southern part of Bida Basin comprises of Lokoja Sandstone, Patti Formation and Agbaja Ironstone.

The following results and conclusions are drawn from the study.

The Lokoja Sandstone, within the study area comprising of conglomerate, sandstone, silt-claystone facies displaying lithological characteristics, variations in texture and sedimentary structures that defined the depositional environments .

In the Lokoja Sandstone, alluvial fan is represented by massive to immature, matrix to grain supported conglomerate subfacies deposits. The conglomeratic sandstone subfacies, massive cross-stratified and graded subfacies represent the deep braided channels. The shallow marine to near shore marine is represented by herringbone cross- stratified and bioturbated conglomeratic sandstone. The presence of burrows structure belonging to *thallassinoides* suggests shore face and tidal channel deposits. The flood plain is represented by siltstone and claystone.

The granulometric analysis of sandstone subfacies shows that Lokoja Sandstone is poorly sorted, medium to coarse grained sandstone. The Patti Formation within the study area comprising of conglomeratic sandstone sandstone silt-claystone, shale subfacies.The sedimentary depositional facies comprises of shore face, tidal channel, and fluvial channel overbank and tidal to marsh to coastal swamp facies association

The shore face facies is represented by medium grainedhummocky cross-stratified and bioturbated sandstone. The tidal channel facies are represented by well sorted to moderately sorted medium grained sandstone and few coarse to very coarse grained sandstone characterized by bi-directional current features. The fluvial channel facies is represented by medium grained to a very coarse grained, conglomeratic sandstone and minor fine grained sandstone while the tidal to marsh to coastal swamp facies association consist of shale- claystone member at Ahoko (Fig. 14 and 15).The granulometric analysis of Patti Formation shows that the sandstones are predominantly medium grained poorly sorted and negatively skewed.The AgbajaIronstone within the study area comprises of oolitic, concretional and massive ironstone bed with interbedded sandstone and claystone. Agbaja Ironstone was deposited was deposited in the shallow marine estuarine waters by the reaction between run-off from lateritic weathering and marine water resulting from regional transgression. The clastic sediments interbedded with the ironstone were probably deposits of muddy fluvial and deltaic environment.

The interbedded clay represents the overbank while the oolitic and concretional ironstone represent the products of marine reworking. The bivariate plot of Friedman's (1961, 1967, and 1979) for skewness versus standard deviation and Moiola and Weiser (1968) for skewness versus standard deviation and mean versus standard deviation suggest a fluvial origin for the sediments in the southern part of the basin.

6.2 CONTRIBUTION TO KNOWLEDGE

The Campano-Maastritian successions in the southern Bida Basin consist of Lokoja Sandstone, Patti Formation and Agbaja Ironstone. The following contributions were drawn from the present study.

i) The suits of lithofacies (conglomerate, sandstone, siltstone, ironstone, clay, shale and grit) recognized in the study area 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 and sediments in Agbaja Ironstone were deposited in shallow marine.

ii) Updating the geological map of the study area.

iii) Mapping and description of Basementand Sedimentary contactat Kwaita.

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APPENDIX I

DATA SHEETS FOR SIEVE ANALYSIS

Table.3 Sample ABJ/11

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	465	0	0	0
1mm	0	360.61	368.05	7.44	7.45	7.45
500µm	1	313.57	342.26	28.69	28.71	36.16
250µm	2	317.61	362.74	45.13	45.16	81.32
125µm	3	300.93	312.33	11.4	11.41	92.73
63mic	4	268.24	274.6	6.36	6.36	99.09
Pan	5	272.84	273.75	0.91	0.91	100
				99.93	100	

Table 4.Sample ABJ/09

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained(g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	465	0	0	0
1mm	0	360.61	360.8	0.19	0.19	0.19
500µm	1	313.57	320.5	6.93	6.94	7.13
250µm	2	317.61	360.47	42.85	42.91	50.04
125µm	3	300.93	341.8	40.87	40.93	90.97
63mic	4	268.24	276.7	8.46	8.47	99.44
Pan	5	272.84	273.4	0.56	0.56	100
				99.86	100	

Table5. Sample ABJ/08

Sieve	Phi Scale	Weight	Weight	Weight	% weight of	Cumulative

Size (mm)	(φ)	of sieve (g)	of sieve + Sample retained (g)	of Sample (g)	Sample	Weight%
2mm	-1	465	484.08	19.08	19.14	19.14
1mm	0	360.61	402.67	22.98	23.05	42.19
500µm	1	313.57	329.65	16.08	16.13	58.32
250µm	2	317.61	341.7	24.09	24.16	82.48
125µm	3	300.93	313.38	12.45	12.49	94.97
63mic	4	268.24	272.46	4.22	4.23	99.2
Pan	5	272.84	273.64	0.8	0.8	100
				99.7	100	

Table.6 Sample ABJ/07

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	465	0	0	0
1mm	0	360.61	366.5	5.89	5.92	5.92
500µm	1	313.57	331.6	18.03	18.11	24.03
250µm	2	317.61	360.46	42.85	43.05	67.08
125µm	3	300.93	332.78	31.85	32	99.08
63mic	4	268.24	269	0.76	0.76	99.84
Pan	5	272.84	273	0.16	0.16	100
				99.54	100	

Table.7 Sample ABJ/06

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	475	10	10.04	10.04
1mm	0	360.61	395	24.39	24.48	34.52
500µm	1	313.57	330.53	16.96	17.02	51.54
250µm	2	317.61	340.21	22.6	22.68	74.22
125µm	3	300.93	312.7	11.77	11.81	86.03
63mic	4	268.24	281	12.76	12.81	98.84
Pan	5	272.84	274	1.16	1.16	100
				99.64	100	

Table.8 Sample ABJ/05

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	465	0	0	0
1mm	0	360.61	366.26	5.65	5.66	5.66
500µm	1	313.57	344.22	30.65	30.7	36.36
250µm	2	317.61	362.56	44.95	45.02	81.38
125µm	3	300.93	317.65	16.72	16.75	98.13
63mic	4	268.24	269.95	1.71	1.71	99.84
Pan	5	272.84	273	0.16	0.16	100
				99.84	100	

Table.9 Sample ABJ/04

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	465.15	0.15	0.15	0.15
1mm	0	360.61	368.25	7.49	7.54	7.69
500µm	1	313.57	346.3	32.73	32.94	40.63
250µm	2	317.61	351.32	33.71	33.92	74.55
125µm	3	300.93	323.82	22.89	23.04	97.59
63mic	4	268.24	270.48	2.24	2.25	99.84
Pan	5	272.84	273	0.16	0.16	100
				99.37	100	

Table.10 Sample ABJ/03

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	506.76	41.76	42.08	42.08
1mm	0	360.61	438.61	36.24	36.51	78.59
500µm	1	313.57	321.8	8.23	8.29	86.88
250µm	2	317.61	322.8	5.19	5.23	92.11
125µm	3	300.93	307.84	6.91	6.96	99.07
63mic	4	268.24	269	0.76	0.77	99.84
Pan	5	272.84	273	0.16	0.16	100
				99.25	100	

Table.11 Sample F/05

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	466.28	1.28	1.29	1.29
1mm	0	360.61	379.68	17.79	17.91	19.2
500µm	1	313.57	349.5	35.93	36.17	55.37
250µm	2	317.61	342.55	24.94	25.11	80.48
125µm	3	300.93	312.54	11.61	11.69	92.17
63mic	4	268.24	273	4.76	4.79	96.96
Pan	5	272.84	275.86	3.02	3.04	100
				99.33	100	

Table.12 Sample F/04

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	473.38	8.38	8.42	8.42
1mm	0	360.61	375.65	6.66	6.69	15.1
500µm	1	313.57	335.42	21.85	21.94	37.04
250µm	2	317.61	336.1	18.49	18.57	55.61
125µm	3	300.93	314.22	13.29	13.35	68.96
63mic	4	268.24	280.99	12.75	12.8	81.77
Pan	5	272.84	290.99	18.15	18.23	100
				99.57	100	

Table13. Sample F/02

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	465	0	0	0
1mm	0	360.61	367.64	7.03	7.09	7.09
500µm	1	313.57	341.64	28.07	28.29	35.38
250µm	2	317.61	350.56	32.95	33.21	68.59
125µm	3	300.93	318	17.07	17.21	85.8
63mic	4	268.24	275.8	7.56	7.62	93.42
Pan	5	272.84	279.37	6.53	6.58	100
				99.21	100	

Table.14 Sample N/05

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	465.26	0.26	0.26	0.26
1mm	0	360.61	382	21.13	21.19	21.45
500µm	1	313.57	357.12	43.54	43.66	65.11
250µm	2	317.61	340.11	22.5	22.56	87.67
125µm	3	300.93	308	7.07	7.09	94.76
63mic	4	268.24	271.52	3.28	3.29	98.05
Pan	5	272.84	274.78	1.94	1.95	100
				99.72	100	

Table15. Sample N/02

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	472.44	7.44	7.48	7.48
1mm	0	360.61	380	11.95	12.02	19.5
500µm	1	313.57	356.75	43.18	43.42	62.92
250µm	2	317.61	341.76	24.15	24.29	87.21
125µm	3	300.93	309.22	8.29	8.34	95.55
63mic	4	268.24	271.25	3.01	3.03	98.58
Pan	5	272.84	274.25	1.41	1.42	100
				99.43	100	

Table.16 Sample AGB/18

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	468	3	3.02	
1mm	0	360.61	368.13	4.52	4.56	7.58
500µm	1	313.57	344.12	30.53	30.78	38.36
250µm	2	317.61	356.11	38.5	38.81	77.17
125µm	3	300.93	303.62	2.69	2.71	79.88
63mic	4	268.24	285.92	17.68	17.82	97.7
Pan	5	272.84	275.12	2.28	2.3	100
				99.2	100	

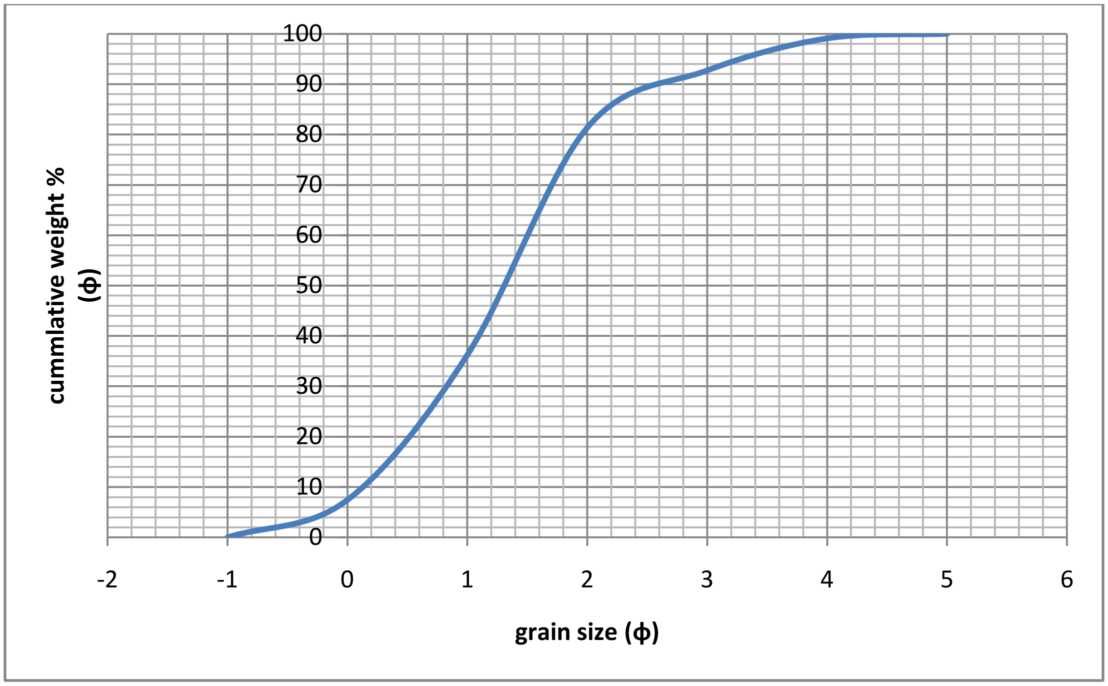
Table. Sample AGB/12

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	465	0	0	0
1mm	0	360.61	360.64	0.03	0.03	0.03
500µm	1	313.57	314.38	0.81	0.81	0.84
250µm	2	317.61	324.56	6.95	6.99	7.83
125µm	3	300.93	381.68	80.75	81.2	89.03
63mic	4	268.24	278.8	10.56	10.62	99.65
Pan	5	272.84	273.19	0.35	0.35	100
				99.45	100	

Table. Sample AGB/06

Sieve Size (mm)	Phi Scale (φ)	Weight of sieve (g)	Weight of sieve + Sample retained (g)	Weight of Sample (g)	% weight of Sample	Cumulative Weight%
2mm	-1	465	465	0	0	0
1mm	0	360.61	362	1.39	1.39	1.39
500µm	1	313.57	344.68	31.11	31.2	32.59
250µm	2	317.61	370.12	52.51	52.66	85.25
125µm	3	300.93	314.1	13.17	13.21	98.46
63mic	4	268.24	269.76	1.52	1.52	99.98
Pan	5	272.84	272.86	0.02	0.02	100
				99.72	100	

APPENDIX II



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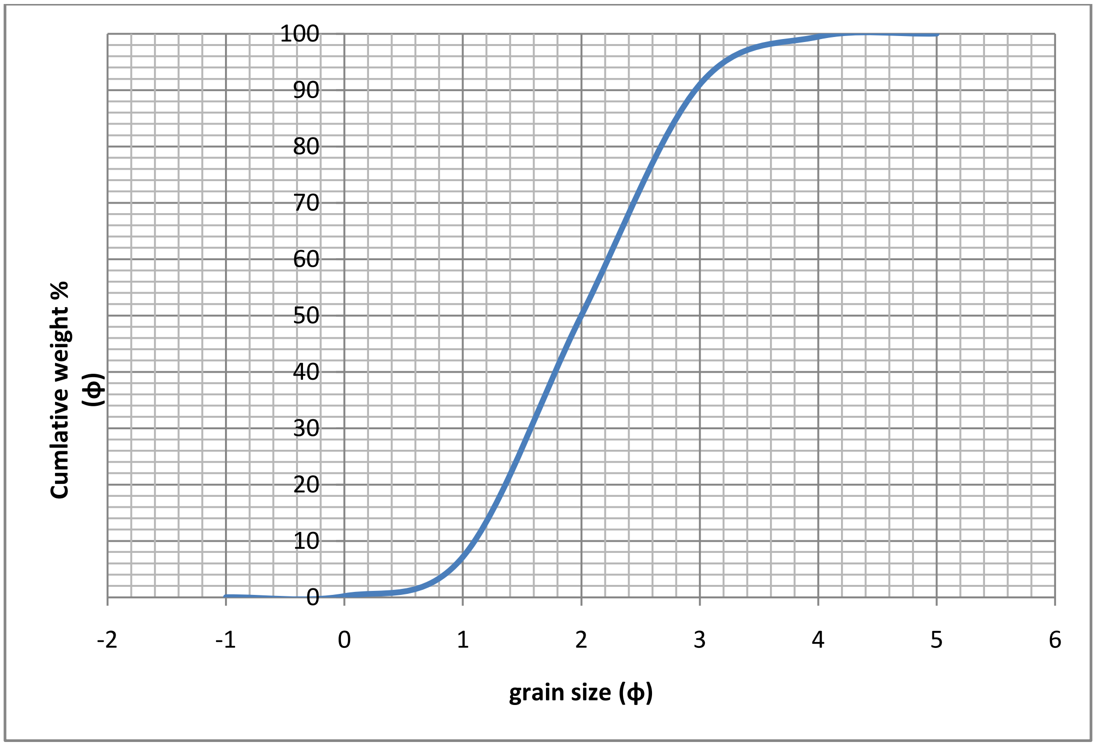

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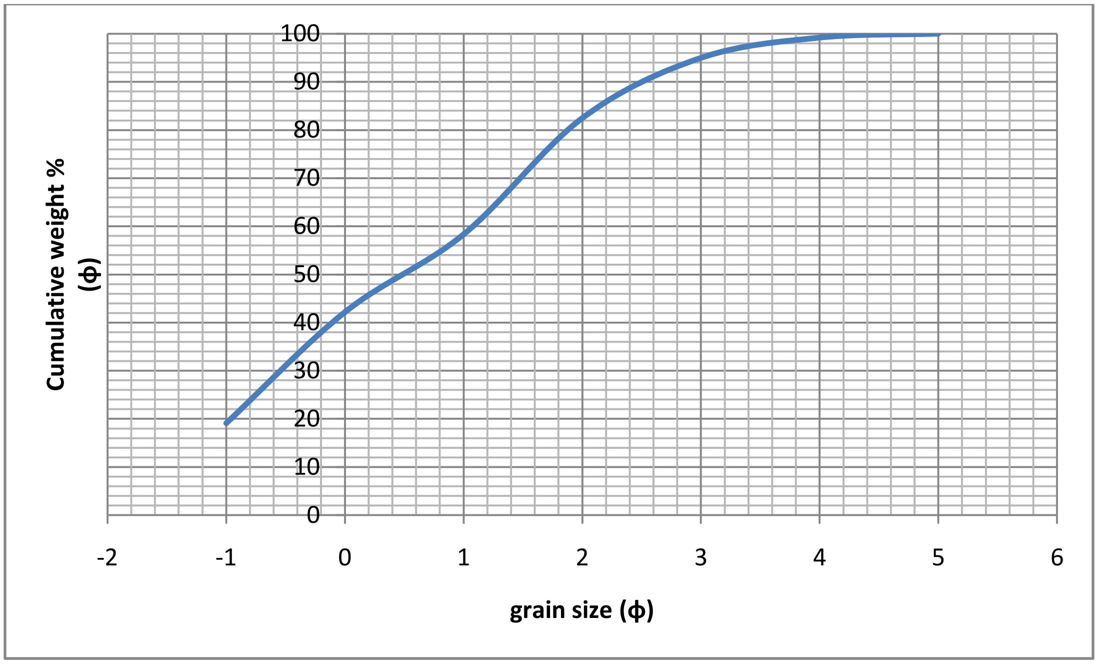

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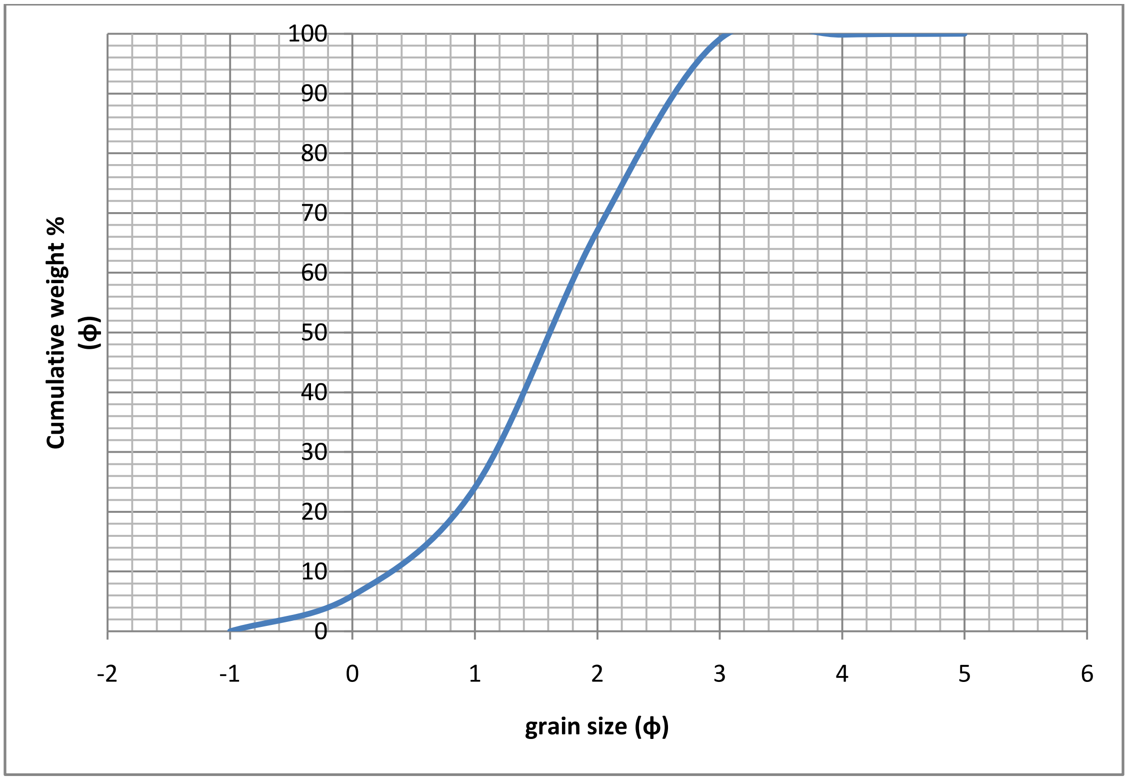

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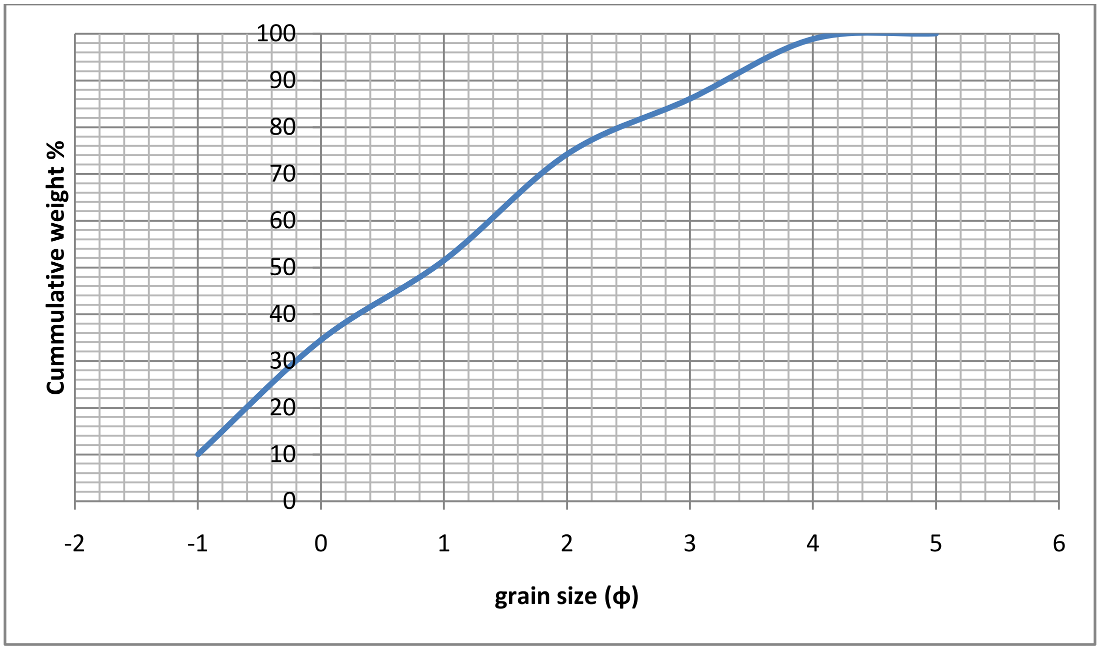

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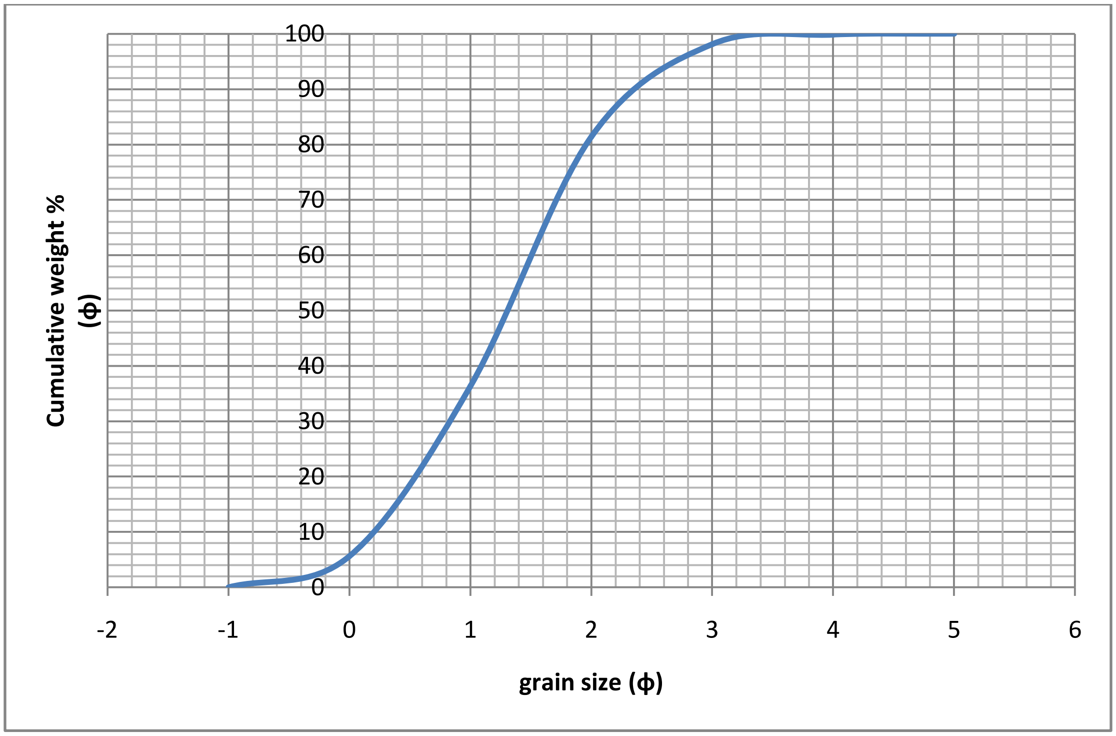

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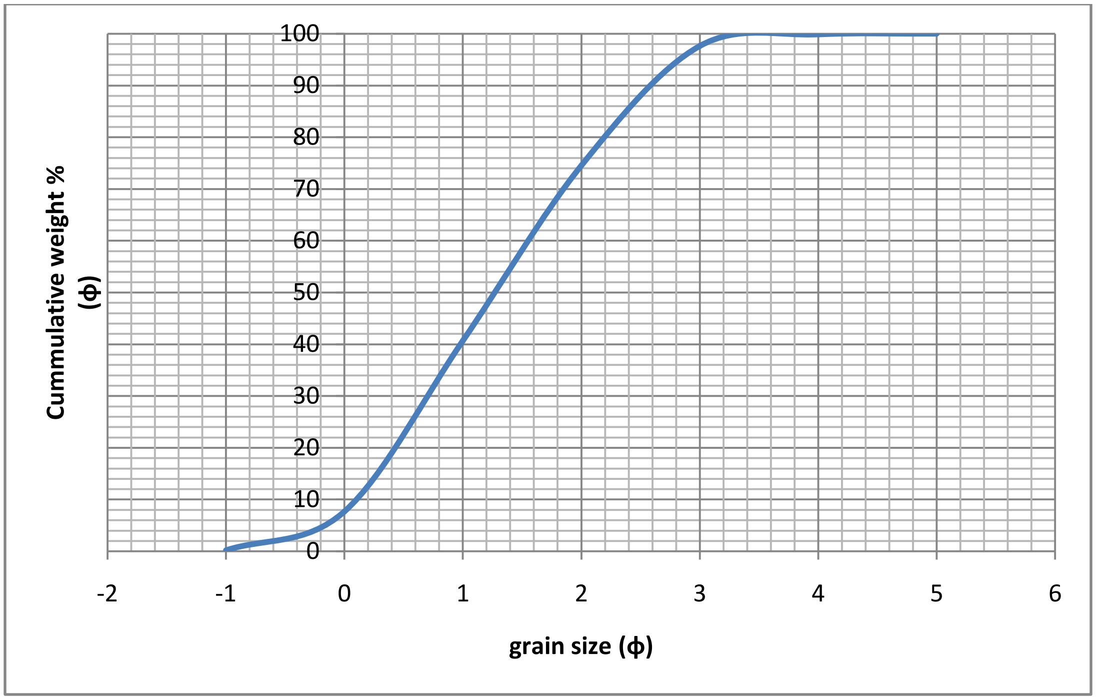

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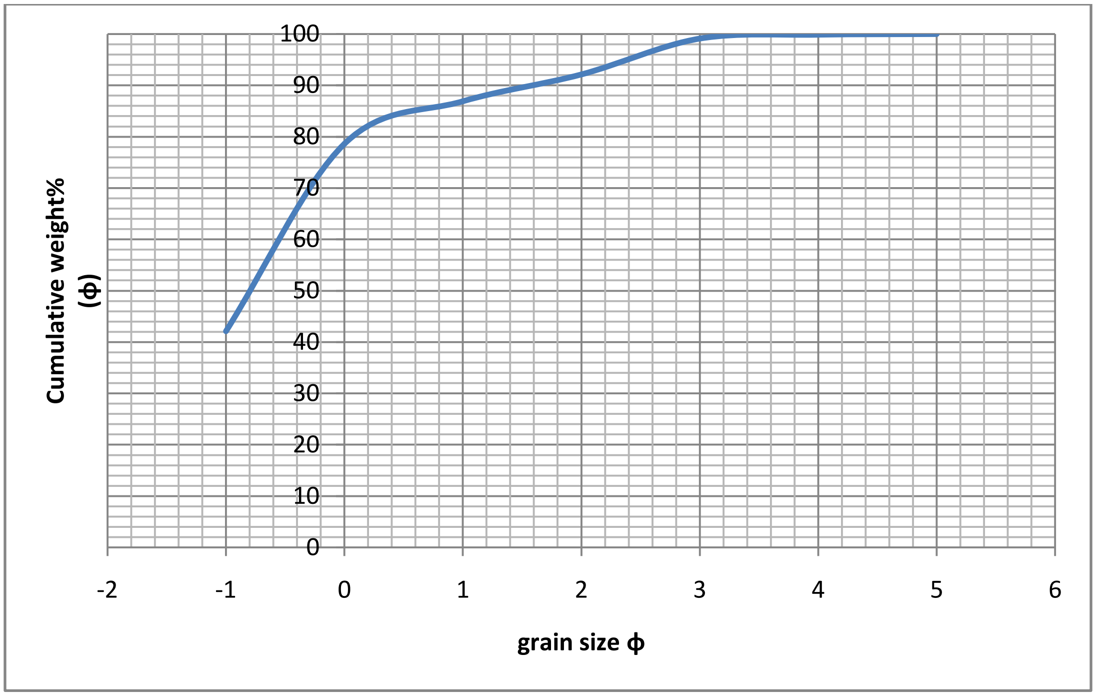

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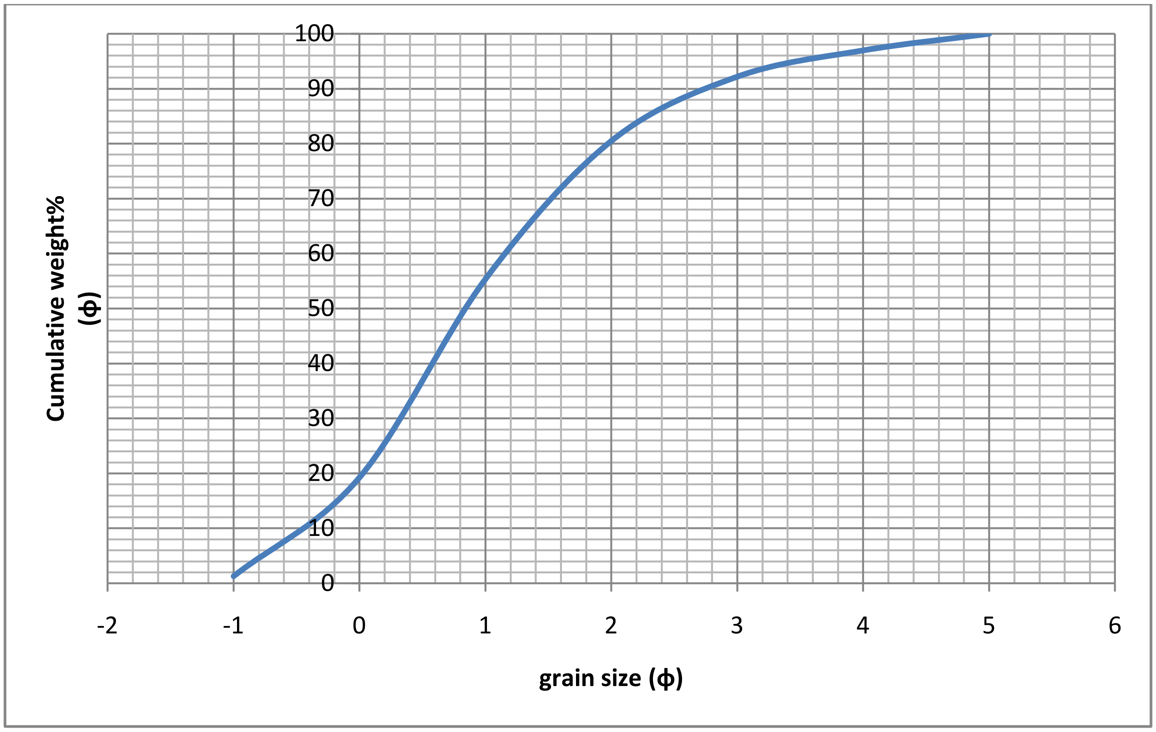

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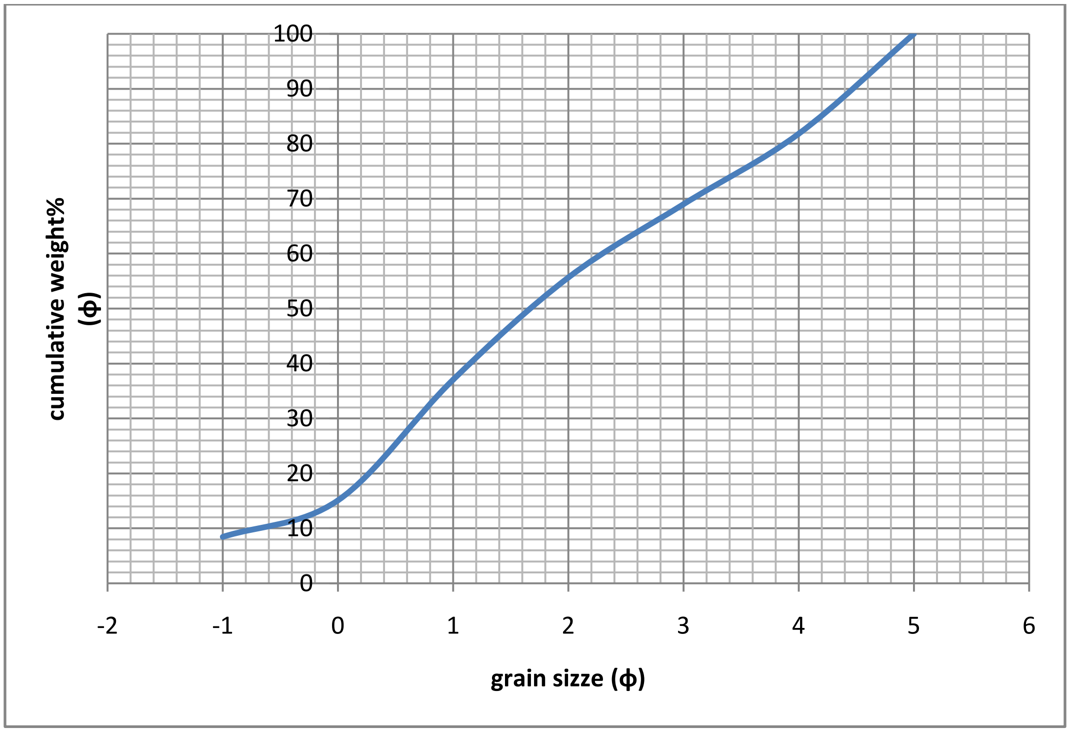

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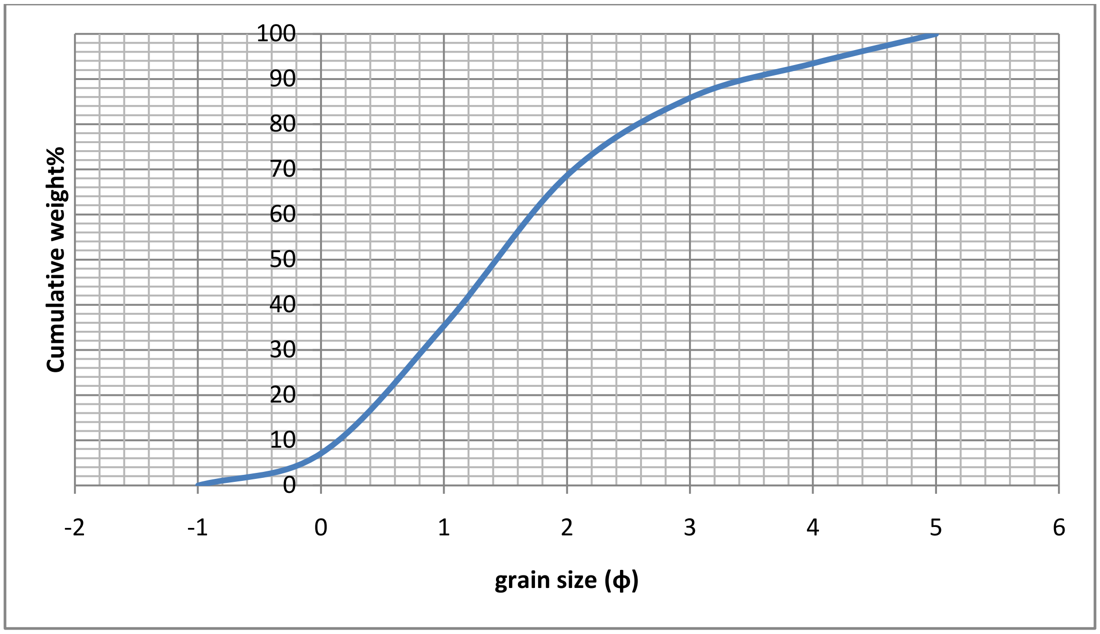

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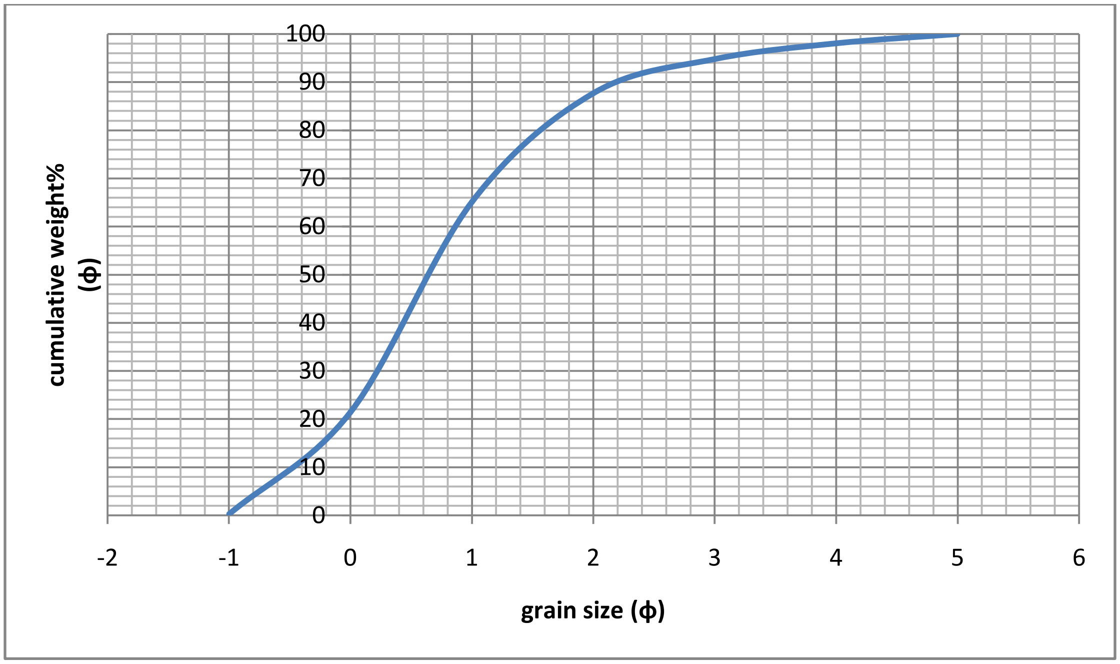

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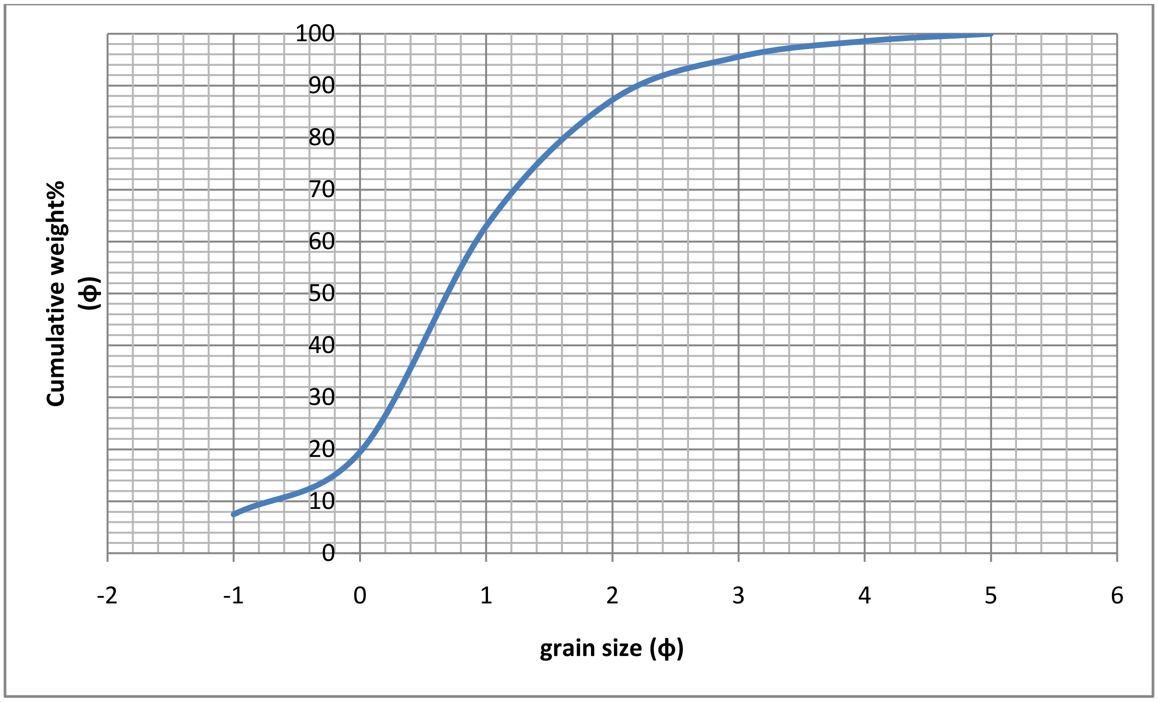

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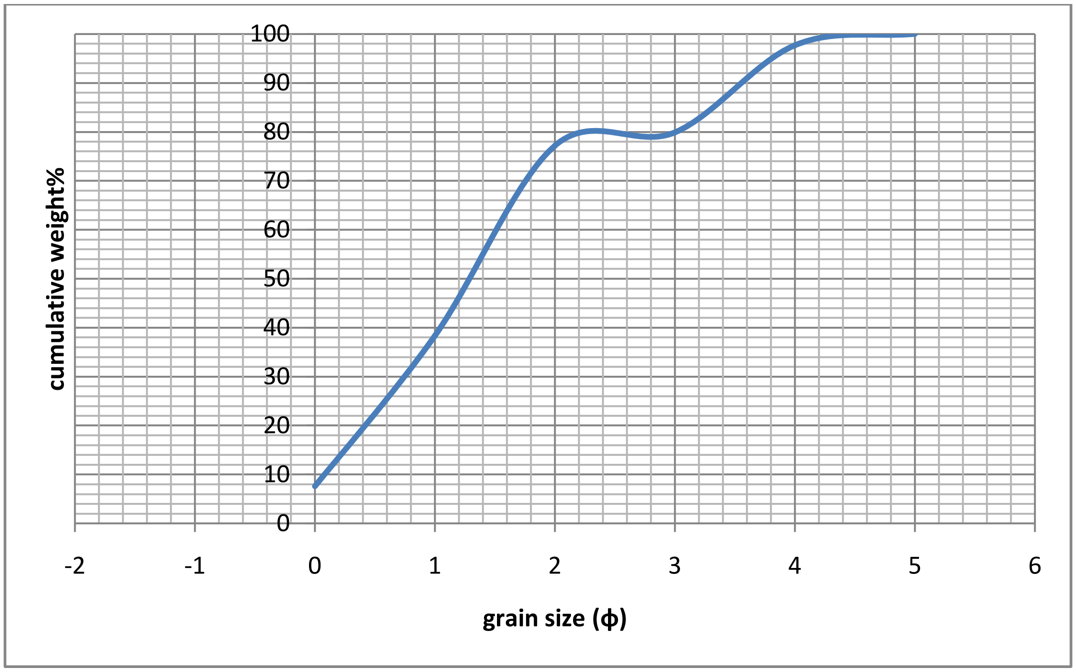

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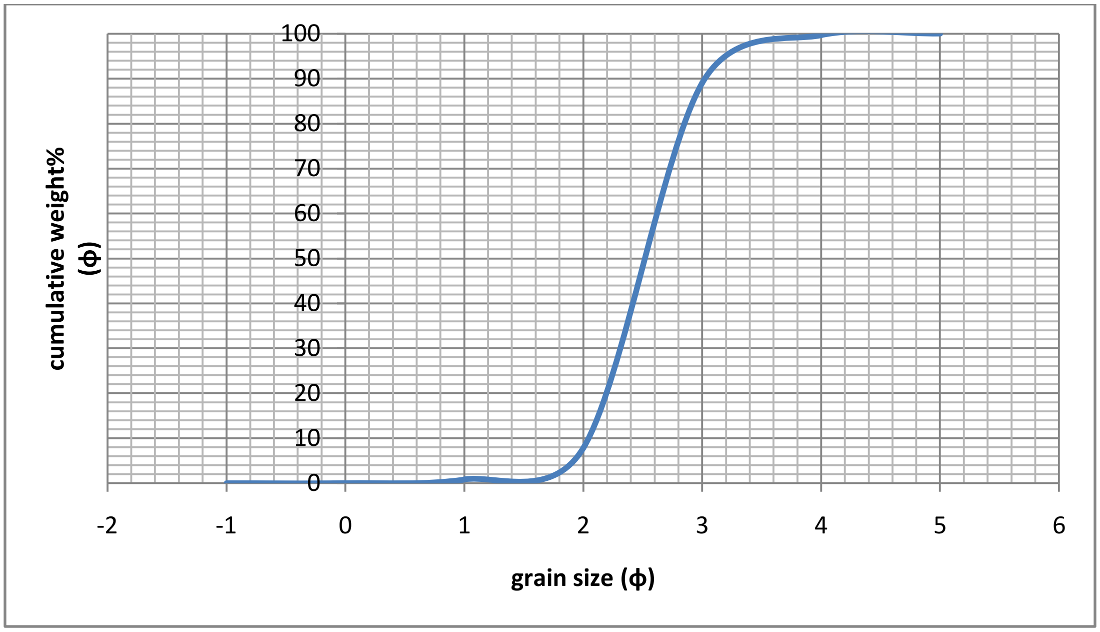

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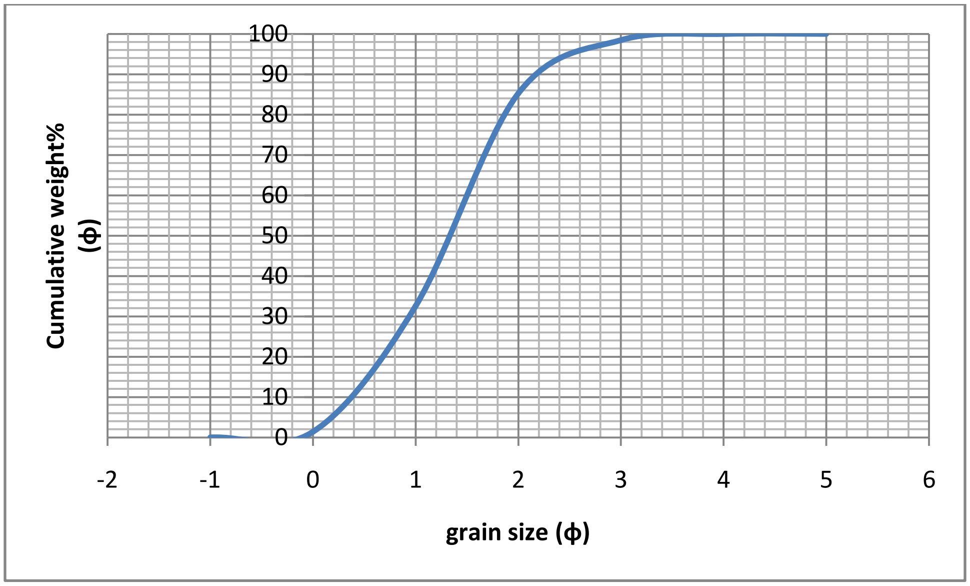

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