PETROLOGY AND PROVENANCE OF THE LOKOJA FORMATION, SOUTHERN BIDA BASIN

by

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BEING A PROJECT SUBMITTED TO THE DEPARTMENT OF GEOLOGY, FACULTY OF SCIENCE, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE DEGREE (B.Sc.) IN GEOLOGY, FEDERAL UNIVERSITY, OYE EKITI, EKITI.

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Certification

This is to certify that the research project on the Petrology and provenance study of the Lokoja Formation, Southern Bida Basin was actually carried out by Akinyemi Ayobami with matriculation number GLY/14/2252 under the supervision of Mrs Ndukwe

The work has been approved as meeting the required standard for the award of Bachelor of Science (B.Sc.) Degree of the department of Geology, Faculty of Science, Federal University Oye-Ekiti, Ekiti State, Nigeria.

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DEDICATION

I dedicate this work to Almighty God, who gave me this privilege to be able to put up a thesis such as this and also to my supervisors Prof. O. J Ojo and Mrs Ndukwe, O. S. , for taking their time to put me through this thesis.

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First of all, I will like to give thanks to the Almighty, for seeing me through this research; all praise and gratitude are due to Him. I will also like to give thanks to my parents for their love and support. A very sound gratitude goes to my supervisors Professor Olusola Ojo for his persistence and help during the course of the research and Mrs Ndukwe O.S, for her tutorship and mentorship over the period of the research. I must not fail to acknowledge my colleagues who helped during the field mapping, to my siblings for their love and to everyone who contributed in a way or two towards the success of this project.

ABSTRACT

Sandstone samples from Lokoja Formation in Southern Bida basin were studied to determine the provenance, depositional environment, mineralogical and textural characteristics of the Lokoja Sandstone. The Granulometric studies of the deposit are medium to coarse-grained, poorly sorted, dominantly leptokurtic and platykurtic and positively skewed, indicative of river laid sediments. The mean grain size (0.85) suggests medium to high energy depositing stream for the sediments. Morphometric studies of pebbles showed variations in environment of deposition from fluvial to marine settings for the Lokoja Sandstone. The scatter plots of maximum projection sphericity index (MPS.I) versus oblate – prolate index (O.P.I.) indicate river origin for the pebbles. The roundness versus elongation ratio (E.R) shows the same fluvial source. The mean roundness value (0.3) reflects angular to subrounded pebbles and short transportation history. Heavy mineral analysis revealed the presence of zircon, rutile, tourmaline, chloritoid and opaques indicative of igneous and metamorphic sources, probably the southwest and north central Basement Complex terrains.

Petrographic analysis showed that sandstones from Lokoja Formations are composed of mostly quartz, feldspar and lithic fragment; hence the studied samples are said to be mineralogically immature sediments. The depositional environment of the study area is fluvial- marine.

The geochemical data shows that the enrichment of other major oxides which are CuO, NiO, V_2O, PbO, BaO in the Lokoja is related to the enrichment of ferromagnesian minerals and feldspars probably due to short transportation of the source material and also provenance of the sediment to be mafic igneous provenance.

Pebbles morphometry and grain size analysis on the Lokoja Formation indicate a fluvial setting for the associated sandstones and pebbles.

TABLE OF CONTENTS

Chapter Four

Results and Discussion

Chapter Five

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 General Statement

The northwest southeastern trending Bida Basin forms one of the major inland sedimentary Basins in Nigeria. It is a shallow, linear depression with sedimentary fill of about 3,000m thick (Udensi and Osazuwa, 2004). Geological developments in the basin in terms of basin evolution and structural features have been discussed by many authors. King (1950) and Kennedy (1965) described the Bida Basin as a rift bounded tensional structure produced by faulting associated with Benue Trough system and break up of the Gondwana.

Landsat imageries analysis by Kogbe et al. (1981) indicates that the southern Bida Basin is controlled by NW-SE trending faults which support a rift model. The existence of a deep seated central positive anomaly flanked by negative anomalies typical of rift structure was confirmed by the geophysical study (Ojo and Ajakaiye, 1989). The authors proposed that Bida Basin as a post-Santonian shallow cratonic sag while Braide (1992) suggest the idea of pull-apart origin for Bida Basin.

1.2 Location of the Study Area:

Lokoja sub – basin of the Bida basin is a NW – SE shallow, downwarped trough which resulted from the wrench fault movement associated with the tectonic framework of the Nigerian sedimentary basins (Ojo and Ajakaiye 1989). The study area falls within latitudes 7^0 48- 7^0 57 N and longitude 6^0 42- 6^0 45 E as shown in Figure 1.

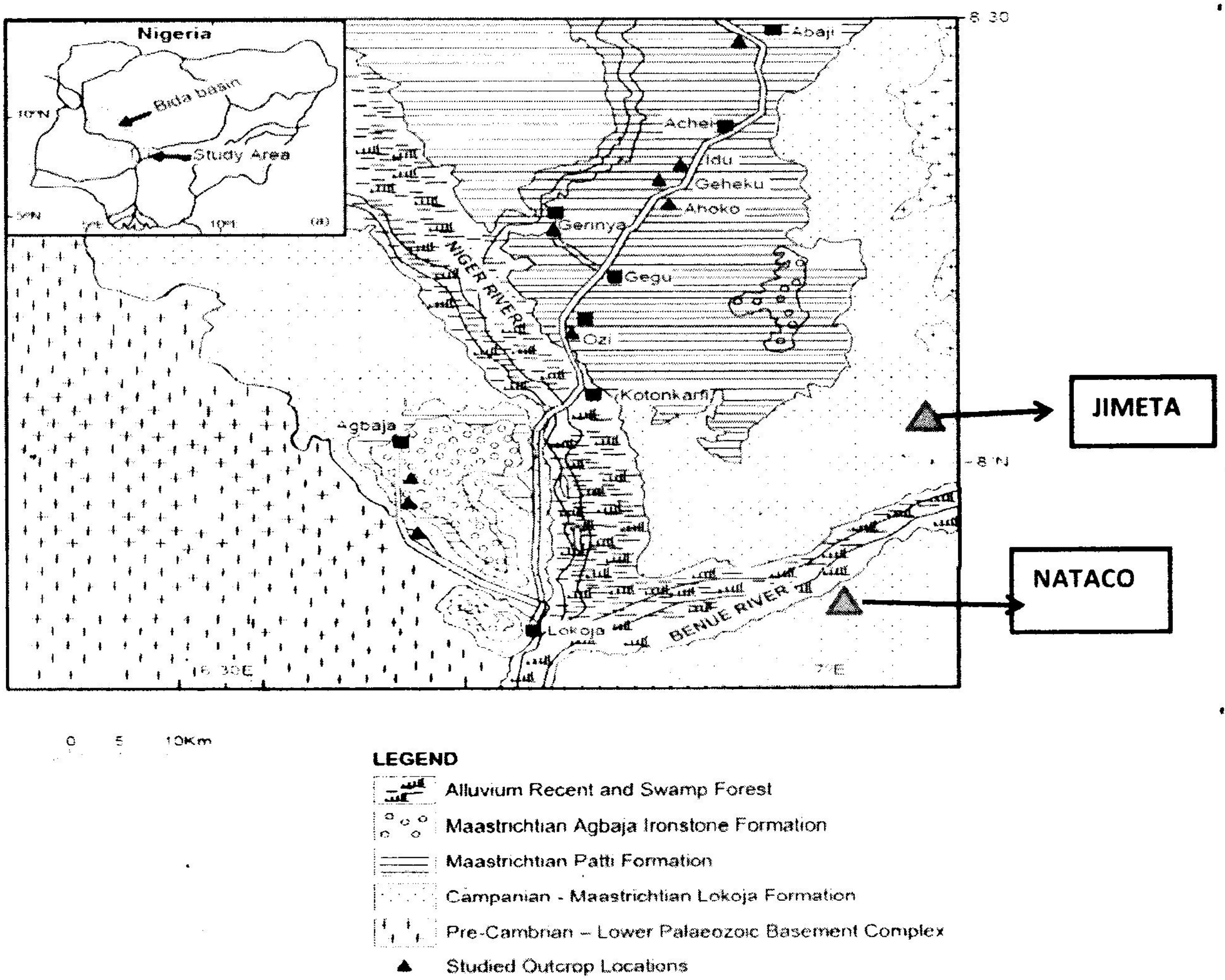


Figure 1: Location Map of the study area. (Modified from Ojo, 2009)

1.3 Aim and objectives of research

This research will help to improve on the existing knowledge of the study area via lithological, sedimentological, petrographic/ geochemical studies and to determine paleoenvironment of the succession in the area with where the outcrop are exposed. The following objectives are to ;

1. To establish the source (provenance) of the sediments
2. The determine the facies and facies association in the study area
3. To establish the maturity and transportation history of the sediments
4. To establish the paleoenvironment of the sediments.
5. To assess the depositional environments of the sediments

1.4 Physiography

Lokoja lies about 7.8023° N of the equator and 6.7333° E of the meridian. It is about 165km SW of Abuja as the crow flies and 390km NE of Lagos by same measure. The city has various suburbs such as Felele, Adankolo, Otokiti and Ganaja. The town is situated in the tropical wet and dry savanna climate zone of Nigeria and temperature remains hot all year round. The various sedimentary rock groups extends along the banks of River Niger and Benue and southeast wards through Enugu and Anambra state to join the Udi plateau.

1.4.1 Relief and drainage

The land rises from about 300m along the Niger Benue conflute, to the heights of between 300m and 600m above sea level in the upland. The state is drained by the Niger and Benue River and their tributaries. The confluence of Niger and Benue which could be viewed from Mount Patti is located within the state.

1.5 Climate

The southern Bida Basin lies within the tropical climate marked by wet 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 (Ayoade, 1974; Adefolalu, 1988). 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 (Odekunle, 2006).

1.6 Vegetation

The vegetation of the study area is classified as Guinea savanna of Nigeria. It is characterized by the presence of tall grasses and scattered short deciduous trees. Arrival of rainfall in the area marks the beginning of the growth of grasses in the area

1.7 Previous work done on geology of Bida Basin

Previous studies on the geology of the Bida Basin were reported in Adeleye (1973) and the micropaleontological studies of Jan du Chene et al. (1979) which documented the palynomorph-foraminiferal associations including the interpretation of the paleoenvironments of the Lokoja and Patti Formations. Akande et al. (2005) interpreted the paleoenvironments of the sedimentary successions in the southern Bida Basin as ranging from continental to marginal marine and marsh environments for the Cretaceous lithofacies. Whereas the origin of the oolitic ironstones in the Bida Basin has been a principal subject of several workers (e.g.Adeleye,1973; Ladipo et al., 1994; Abimbola, 1997), only few investigations have been made on the hydrocarbon prospectivity of the basin.

Jerry and Jahsmill, 2013 worked in the basin to know the sedimentological and paleodepositional studies of outcropping sediments in parts of Southern Middle Niger Basin. The field and laboratory analysis of siliciclastics sediment samples from outcrops of the Lokoja Formation enabled the discrimination of various subfacies formed in continental paleodepositional settings of dominantly fluvial systems during the Late Cretaceous out-building of sedimentary sequences in the Southern Middle Niger Basin and signaled as lowstand systems tract architecture.

Sanni, et al. 2016 worked in the area (Lokoja Formation) to determine provenance studies through petrography and heavy mineral analysis of part of Agbaja-Lokoja Formation, bida basin, NW Nigeria, they conclude that Bida Basin comprises three sedimentary facies assemblages characterised the sediments of Lokoja and Agbaja Formations. They are the conglomerate, sandstone/siltstone and claystone facies. The conglomeratic facies are expressed as massive grain-matrix support conglomerate, graded conglomerate as well as cross stratified to massive sandstones with implications of debris flow, alluvial fan, braided channel and stream deposits respectively.

The fine-grained/siltstone as well as the herringbone and bioturbated sandstone sub-facies clearly present the extension of the fluvial sedimentation into the flood plain and shallow marine area where tidal effect held sway. Most of the outcrops were road cuts which represent the different lithofacies of the formations.The laboratory analyses include textural, geochemical, petrographic and heavy minerals analyses for the sandstone samples.

The textural assessment of Lokoja Sandstone revealed poorly sorted sub-arkose immature sandstone with the quartz showing both monocrystalline and polycrystalline crystal forms with more of the undulatory forms which depict its derivation mainly from metamorphic origin Abimbola, (1997)

Madukwe, et al (2014) worked on geochemical and petrographic Studies of Lokoja Sandstone: implications on source area weathering, provenance, and tectonic setting, they conclude that the composition, provenance, weathering, tectonic setting and redox proxy of the Lokoja sandstone, Middle Niger basin has been assessed using integrated petrographic, granulometric and geochemical approach. Major elements geochemistry and their ratios revealed that the Lokoja sandstone is mostly mature lithic arenites including sub-greywacke and protoquartzites influence of felsic igneous provenances on the passive basin. The heavy mineral suites are indicative of igneous and metamorphic sources, perhaps, the southwest and north central Basement Complex terrains. The calculated mineral maturity index (MMI) and ZTR indices suggest mineralogically immature to sub mature sediments. The grain size distribution results suggest medium to coarse grained sediments were positively coarsely skewed and leptokurtic. Accordingly implying river deposited sediments under low energy current.

Ojo, (2009), previous work on sedimentology and deposition environments of the Maastrichtian Patti formation,southeastern Bida Basin, Nigeria. Also concluded that the Maastrichtian Patti formation in the southern Bida Basin consists of sandstone and shale-claystone members deposited in a wide range of environment ranging from fluvial to marine.

CHAPTER TWO

REVIEW OF THE OF GEOLOGY OF BIDA BASIN

2.1 Origin of Bida Basin

The Mid-Niger Basin otherwise known as the Bida Basin or the Nupe Basin is a NW–SE trending intracratonic sedimentary basin extending from Kontagora in Niger State of Nigeria to areas slightly beyond Lokoja in the south.

The study area is part of the southern Bida Basin of Nigeria. The Bida Basin is a northwest - southeast trending depression perpendicular to the main axis of the Benue Trough. The basin is subdivided geographically into the northern, central and southern Bida basins referred to as sub basins.

The Bida Basin, located at central Nigeria, is one of the hinterland sedimentary basins in Nigeria, having a sedimentary fill of about 4km (Ojo, 1984; Udensi & Osasuwa, 2004). It is a northwest-southeast trending intracratonic structural depression adjacent and contiguous with Sokoto and Anambra Basins in the northwest and southeast respectively. The Bida Basin is subdivided into the northern and southern sub-basins to accommodate the fast and wide facies changes across its long and large areal extent The study area lies within the southern basin It is delimited in the northeast and southwest by the basement complex while it merges with Anambra and Sokoto basins in sedimentary fill comprising post orogenic molasse facies and a few thin unfolded marine sediments (Adeleye, 1974). The basin is a gently down warped trough whose genesis may be closely connected with the Santonian orogenic movements of southeastern Nigeria and the Benue valley, nearby.

It is frequently regarded as the northwestern extension of the Anambra Basin, both of which were major depocentres during the third major transgressive cycle of southern Nigeria in Late Cretaceous times. Interpretations of Landsat images, borehole logs, as well as geophysical data across the entire Mid-Niger Basin suggest that the basin is bounded by a system of linear faults trending NW–SE (Kogbe et al., 1983). Gravity studies also confirm central positive anomalies flanked by negative anomalies as shown for the adjacent Benue Trough and typical of rift structures (Ojo, 1984; Ojo and Ajakaiye, 1989).

The Southern Bida basin is located in central Nigeria and is a major sedimentary area with a 3.5-km-thick sedimentary fill. However, it is the least understood of Nigeria's sedimentary basins because serious oil and gas exploration has not been undertaken in the basin. The surrounding Precambrian basement rocks experienced severe deformation during the Late Panafrican phase (600 {plus minus} 150 m.y.), and developed megashears that were reactivated during the Late Campanian-Maestrichtian. The ensuing wrenchfault tectonics formed the basin. The sedimentary fill, which comprises the Lokoja Formation are chiefly, if not wholly, nonmarine clastics. These have been characterized into facies that rapidly change from basin margin to basin axis, and have undergone only relatively mild tectonic distortion. Subsurface relations of the Lokoja Formation are postulated from outcrop study. (Akande et al, 2006)

Investigations on the stratigraphy and sedimentation of the Upper Cretaceous sequences of the Bida Basin reveal that the Bida Basin has four recognizable mappable stratigraphic units with each of the units having a lateral equivalent (Adeleye 1971, 1973, Braide 1992a and 1992b; Ladipo et al. 1994 and Abimbola et al, 1999). The units include the Bida Sandstone (with the Doko and Jima members) overlain by the Sakpe Ironstone, followed by the Enagi Siltstone which in turn is overlain by the Batati Ironstone. The respective lateral equivalents of these units to the south (Lokoja sub basin) are the Lokoja Formation (lateral equivalent to Bida sandstone), the Patti Formation (lateral equivalent of the Sakpe Ironstone and the Enagi Siltstone) and the Agbaja Formation (lateral equivalent of the Batati Ironstone). The correlation of the stratigraphic successions across the northern and central portions of the basin into the Lokoja area to the south is largely based on the lithologic and depositional characteristics and has been extended into the Anambra Basin to the south. The lateral equivalents represent continuous depositional phases from the south to the north and northwest, controlled by the major sea level rises and falls of the uppermost Cretaceous (Akande et al, 2006) as seen in the figure 2.1.

Initial gravity studies in the Bida Basin put the maximum thickness of the sedimentary successions at about 3.5 km (Ojo, 1984) in the central axis. Although the hydrocarbon potential of the basin has not been fully tested with seismics and the basin remains undrilled, both ground and aeromagnetic studies by several workers have outlined the basin configuration (Adeniyi, 1985; Udensi and Osazuwa, 2004). A recent spectral analysis of the residual total magnetic field values over several sections of the basin reveals an average depth to the basement rocks to be ca. 3.4 km with sedimentary thickness of up to 4.7 km in the central and southern parts of the basin (Udensi and Osazuwa, 2004). In general, sediment thickness decreases smoothly from the central portion to the flanks

Previous studies on the geology of the Bida Basin were reported in Adeleye (1973) and the micropaleontological studies of Jan du Chene et al. (1979) which documented the palynomorph-foraminiferal associations including the interpretation of the paleoenvironments of the Lokoja and Patti Formations. Akande et al. (2005) interpreted the paleoenvironments of the sedimentary successions in the southern Bida Basin as ranging from continental to marginal marine and marsh environments for the Cretaceous lithofacies. Whereas the origin of the oolitic ironstones in the Bida Basin has been a principal subject of several workers (e.g. Adeleye,1973; Ladipo et al., 1994; Abimbola, 1997), only few investigations have been made on the hydrocarbon prospectivity of the basin.

2.2 Stratigraphic Setting and Paleogeography

The stratigraphic succession of the Mid-Niger Basin, collectively referred to as the Nupe Group (Adeleye, 1973) comprises a two-fold Northern Bida Basin (Sub Basin) and Southern Bida Sub-Basin or Lokoja Sub-Basin. The Bida Basin is assumed to be a northwesterly extension of the Anambra Basin (Akande et al., 2005). The basin fill comprises a north west trending belt of Upper Cretaceous sedimentary rocks that were deposited as a result of block 'faulting, basement fragmentation, subsidence, rifting and drifting consequent to the Cretaceous opening of the South Atlantic Ocean. Major horizontal (sinistral) movements along the northeast-- southwest axis of the adjacent Benue Trough appear to have been translated to the norths-south and northwesterly trending shear zones to form the Mid-Niger Basin perpendicular to the Benue Trough (Benkhelil, 1989). Although the sedimentary fill of the Benue Trough consists of three unconformity-bounded depositional successions (Petters, 1978), the Bida and Anambra geographical regions were platforms until the Santonian. Pre-Santonian sediments are recorded principally in the older Benue Trough and parts of the southern Anambra Basin. The collapse of the Mid-Niger and Anambra platforms led to the sedimentation of the Upper Cretaceous depositional cycle commencing with the fully marine shales of the Campanian Nkporo and Enugu Formations which may have some lateral equivalents in the Lokoja Formation of the Bida Basin. Overlying the Nkporo Formation is the sedimentary units of the Mamu Formation. These consist of shales, siltstones, sandstones and coals of fluvio-deltaic to fluvio-estuarine environments whose lateral equivalents are the conglomerates, cross-bedded and poorly sorted sandstones and claystones of the Lokoja and Bida Formations in the Bida Basin.

The Mamu Formation is succeeded by sandstones of the Lower Maastrichtian Ajali Formation laterally equivalent to the Patti, Sakpẹ and Enagi Formations of the Bida Basin. These sandstones are well sorted, quartz arenite that are commonly interbedded with siltstones and claystones and similar in part to the lithologies of the Patti and Enagi Formations. The Patti and Enagi Formations are overlain by the Agbaja and Batati Formations (lateral equivalents) of Upper Maastrichtian age as seen in the figures 2.1.

These consist of oolitic, pisolitic and concretionary ironstones deposited within a continental to shallow marine setting. The Upper Cretaceous sedimentary sequences in the Bida Basin suggest that fully marine conditions was not established compared with the initial marine sedimentation established for the Campanian Nkporo Formation in the adjacent Anambra Basin during that transgressive cycle. A comparison of the sediment thicknesses in the two basins indicate that the successions of the Anambra Basin reached up to 8 km thickness compared with an average of 3.4 km sediment thickness in the Bida Basin (Akande and Erdtmann, 1998).

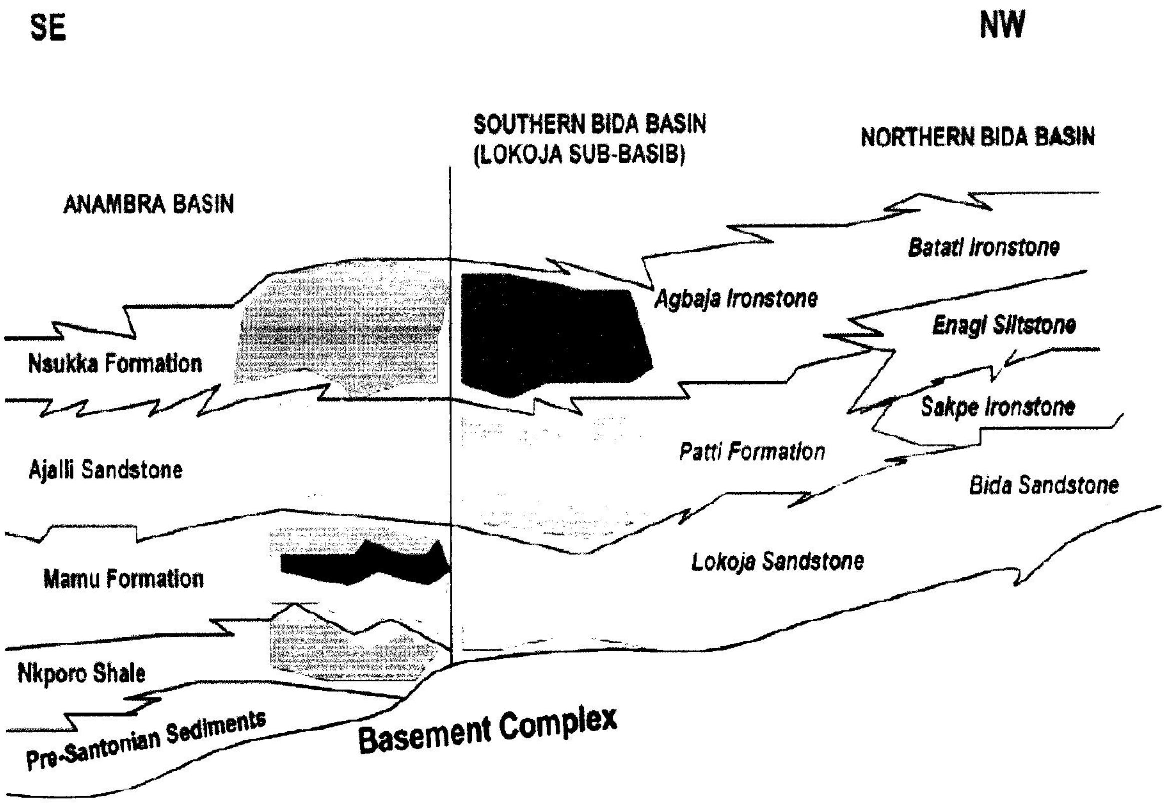


Fig 2.1: The formations in the Northern and Southern Bida Basin in correlation with Anambra basin (Obaje 2011).

Lithostratigraphy and Depositional Environments

The stratigraphy and sedimentation of Upper Cretaceous succession of the Bida Basin have been documented by Adeleye and Dessauvagie (1972) in the central parts of the basin around Bida. Four mappable stratigraphic unites are recognized in this area, namely, the Bida Sandstone (divided into the Doko Member and the Jika Member), the Sakpe Ironstone, the Enagi Siltstone, and the Batati Formation. These are correlatable with the stratigraphic units in the Southern Bida Basin.In the southern Bida Basin (which has been best studied), exposures of sandstones and conglomerates of the Lokoja Formation (300 m thick) directly overly the Pre-Cambrian to Lower Paleozoic basement gneisses and schists. This is over lain by the alternating shales, siltstones, claystones and sandstones of the Patti Formation (70–100 m) thick in the Koton-Karfi and Abaji axis and succeeded by the claystones, concretionary siltstones and ironstones of the Agbaja formation.

Southern Bida Basin

The southern part of the study area is characterized by formations with the following lithology: weathered laterite, sandy clay/clayey sand, fractured basement and fresh basement rocks. Generally the rock units in this region are suggested to be highly characterized by intercalations of clay stone, siltstone, silt, clay and weathered bedrock (Braide, 1990; Akande et al., 2005). These geological materials are usually liable to form aquifer and permeable zones to the bedrocks in both the sedimentary terrain and the crystalline basement complex existing in this area. During Campanian–Maastrichtian, the South Atlantic–Tethys seaway was routed through the Mid-Niger Basin and it has been most frequently regarded as,the northwestern extension of the Anambra basin (Ladipo et al., 1994; Akande and Ojo, 2002), both of which were major depocentres during this transgression. Sediment thickness in the Mid-Niger Basin is estimated to be between 3000–3500 m (Whiteman, 1982; Braide, 1990).

The Lokoja Formation

Lithologic units in this formation range from conglomerates, coarse to fine grained sandstones, siltstones and claystones in the Lokoja area. Subangular to subrounded cobbles, pebbles and granule sized quartz grains in the units are frequently distributed in a clay matrix. Both grain supported and matrix supported conglomerates form recognizable beds at the base of distinct cycles at outcrop. The sandstone units are frequently cross-stratified, generally poorly sorted and composed mainly of quartz plus feldspar and are thus texturally and mineralogically immature. The general characteristics of this sequence especially the fining upward character, compositional and textural immaturity and unidirectional paleocurrent trends, suggest a fluvial depositional environment dominated by braided streams with sands deposited as channel bars consequent to fluctuating flow velocity. The fine grained sandstones, siltstones and clays represent flood plain overbank deposits. However, Petters (1986) reported on the occurrence of some diversiy arenaceous foraminifera from clayey interval of the Lokoja Formation indicating some shallow marine influence. These foraminiferal microfossils identified by Petters (1986) are however more common in the overlying Patti Formation where shallow marine depositional conditions are known to have prevailed more.

The Patti Formation

The formation extends from Koton-Karfi and Abaji. This formation consists of sandstones, siltstones, claystones and shales interbedded with bioturbated ironstones. Argillaceous units predominate in the central parts of the basin. The siltstones of the Patti Formation are commonly parallel. The Formation was deposited in marginal shallow marine to brackish water condition.(Ladipo et al., 1994)

The Agbaja Formation

This formation forms a persistent cap for the Campanian – Maastrichtian sediments in the Southern Bida Basin as a lateral equivalent of the Batati Formation on the northern side of the basin. It consists of sandstones and claystones interbedded with oolitic, concretionary and massive ironstone beds in this region. The sandstones and claystones are interpreted as abandoned channel sands and overbank deposits influenced by marine reworking to form the massive concretionary and oolitic ironstones observed (Ladipo et al., 1994). Minor marine influences were also reported to have inundated the initial continental environment of the upper parts of the Lokoja Sand stone and the Patti Formation (Braide, 1992; 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)

CHAPTER THREE

METHODOLOGY

3.1. Materials

Materials: The materials used includes the following:

Geographical Positioning System GPS: The GPS is a sophisticated technology which is basically used in determining the exact position of any sampling point on the map and also used to get the actual Longitude and Latitude. Modern GPS is also used to know the exact distance from one sampling point to another.

Compass/Clinometer: The compass was used in the field for accurately determining the bearing from any feature and also used in measuring the trend of geologic features like faults, joints, intrusions, foliations etc. The clinometer on the other hand was used in measuring the amount and direction of inclination on necessary geologic features observed.

Hammer: Hammer as a hand-held instrument, was used to break down rocks mechanically to get fresh samples of rocks.

Field note: it was used to take detailed record of all activities on the field

Masking tape and marker pen: They were used for sealing the samples bags and to label the samples.

Sample bag: The sample bag is normally used in the field to store any collected rock sample.

This also allows the sample to be perfect condition before it is being taken to the laboratory for analysis.

3.2 Methods used

Exposed outcrops were sampled by the method of spot sampling and samples were collected

Fifteen (15)Sandstone samples were collected for the purpose of re-sampling if the need arises without having to return to the outcrops. Labeling of the samples were performed on each location right on the point of collection using a marker pen indicating the following: sample number/location, rock unit, locality. These information were placed on the outside of the sample bag and on a masking tape on the bag. At the same time, relevant data were entered into the field note book.

Sampling Technique

The sections were logged, described and correlated 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 Corel Photo-paint (X5) software.The paleoenvironmental interpretation was attempted based on integration of facies association, sedimentary structures, textures and petrography. Thirteen (13) sections were logged within the study area. The lithofacies encountered in the study locations comprises of conglomeratic sandstone, ironstone, sandstones, siltstone, carbonaceous shale and claystone.

Field work

Samples for the field exercise were collected during the field trip to Lokoja. The field mapping was done by navigating through a system of grid patterns which is basically known as traversing. Here, movement around various outcrops is done by automobile or foot and so as to examine as many outcrops as possible. Navigation is being done from one location to another with the aid of the geographical positing system GPS device and the compass/clinometer. The compass/clinometer is essentially used to measure all observed geologic structure, be it ductile or brittle. The GPS is used essentially to know the exact position on the field map. During traversing, every grid on the map is being walked across with the aim studying every outcrop that falls within such grid. When walking across the grids, necessary geologic information is collected in any outcrop encountered; such information includes description of the outcrop, description of the lithology, measurement of the thickness of each beds in the particular outcrop, Finally a very good representative sample is collected from the outcrop.

3.2.2 PROCESSING AND ANALYSIS OF THE SAMPLES

3.2.2.1 Grain Size Analysis

Grain size analysis (sieve analysis) was carried out on Nataco and Jimeta from Lokoja Formation in the Department of Geology laboratory in Federal University Oye Ekiti. 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 fifteen (15) samples from Lokoja Formation and were collected from different locations for sieve analysis. Samples were carefully disaggregated with the use of rubber padded pestle and mortar. The weight of the selected empty sieves (4.0mm, 3.35mm, 2.0mm, 1.18mm, 600µm, 425µm, 150µm, 75µm, 63µm and pan) were obtained using weighing balance. The required sieves were arranged according to decreasing mesh sizes of 63µm at the bottom and the pan which collects the finest grain while the top is covered with a lid. The sieves and the bottom pan were fastened to the mechanical shaker, and 100g of the samples was poured into the upper sieve (4.0mm). 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.

From the cumulative frequency curve, critical percentiles (Table 4.5) (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 statistical parameters of the grain size frequency distribution were obtained and computed by the method of Folk and Ward (1957). The grade fraction plotted against the size grade distribution curve shows distribution range (sorting measure), symmetry parameter and least or most frequently occurring grain size range

3.2.2.2 Heavy mineral Analysis

Heavy mineral analysis were done on eleven (11) representative samples collected from Lokoja Formation using petrological microscope. Separation of heavy minerals particles by gravity is accomplished using a so-called heavy liquid and two superposed separatory funnel. In order to serve as a suitable medium for gravity must be: liquid at room temperature, of low viscosity, transparent, chemically inert, readily available, chemically stable, easily handled and recovered, inexpensive and non-poisonous. All procedures must be carried out under a well ventilated lab using tetrabromoethane($C_2H_2Br_4$), which has specific gravity at 20^0C of 2.96; bromoform ($CHBr_3$) is also used as a heavy liquid. The petrographic studies involved the identification of the mineral and provenance interpretation of those minerals.

3.2.2.3 Pebbles Morphometry

A total of on e hundred and sixty(160) pebbles were collected from two (2) locations which are Natakol and Natako 2. The pebbles were washed and dried. Broken pebbles were removed. Pebble morphometric measurement using vernier caliper after Krumbeins(1941) method was used. The long (L), intermediate(I) and short (S) axes of the pebbles were measured. Pebble indices such as flatness ratio (FR), flatness index (FI), elongation ratio (ER) maximum projection sphericity index (MPSI) and oblate prolate index (OPI) with the visual estimation of pebbles roundness using roundness chart.

3.2.2.4 Petrographic studies

Thin sections are made from Eight (8) representative samples collected from Lokoja Formation were analyzed using petrological microscope. The petrographic studies involved the identification of the mineral and provenance interpretation of those minerals. The selected samples were cut with a micro-cutting machine into slices of 3 to 4mm, these cut samples were polished on a glass plate using carborundum. After polishing, the samples were subjected to an immense heat at a temperature of about 80^0C to 90^0C after which a small quantity of araldite is added to the heated sample. Prior to the heating, the thin perfectly smooth surface rock samples air bubbles and impurities were removed. The prepared thin section were examined under a petrological microscope to identify the mineral assemblage, morphology and other properties were studied under a plane polarized light and cross polarized light of the petrological microscope.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Lithologic Description

4.1.1 Conglomerate Facies

Conglomerate facies occur in most of the studied locations. The conglomerate facies can be distinguished into matrix supported conglomerate and clast supported conglomerate subfacies. The composition of this subfacies also varies from one location to the other. At Natako1,Natako2 and Jimeta. The matrix supported conglomerates are reddish massive, friable and poorly sorted grain with muddy to sandy matrix. Their pebbles and cobbles include rounded to angular quartz, feldspars and fragments of quartzite, schist and granite. Generally, this subfacies is non-imbricated and lack any internal organization and they commonly grade upward into conglomeratic sandstone i.e fine upward. This conglomerate bed appears to have less matrix and the pebbles mostly of well rounded quartz are well indurated. The beds with average thickness of 2m are massive and bioturbated. Generally, the conglomerates are immature. The proximal alluvial fan processes were preserved in the stratigraphic record as conglomerates in various parts of the study area (Ojo & Akande, 2011). Both the matrix supported and grain - matrix supported conglomerate subfacies contain features that are indicative of continental environments dominated by gravity induced alluvial processes (Ojo & Akande, 2011).

4.1.2 Sandstone Facies

This facies, widely distributed in the study area comprises conglomeratic sandstone, medium to pebbly sandstone, and fine grained sandstone subfacies. The conglomeratic sandstone sub facies are well represented in the sections exposed at Natako 1, Natako 2 and Jimeta (Figures 4.1-4.3). Generally, they are friable and feldspathic, that is, some of the pebbles embedded within the clay and sand matrix are feldspars. The thickness ranges from 0.5 to 2m averaging 1m. In most sections, they are massive and occur as localized cycles of coarsening upward sequences, and commonly pass upward into conglomerate bed. Occasionally, the pebbly clasts form irregular bands on the erosional surface defining a bounding surface between it and the lower bed. A variant of this is graded bedded and stratified conglomeratic sandstone, The trough cross bedding type is most common occurring in most of the sections, with the sets varying in thickness from 0.4 to 1m. The medium to coarse grained sandstone subfacies is the next in terms of size of grains to common occurring in most of the sections, with the sets varying in thickness from 0.4 to 1m. The medium to coarse grained sandstone subfacies is the next in terms of size of grains to conglomeratic sandstone subfacies in the study area. They are composed mainly of sands, minor silts and pebbles and their thickness range from 0.3 to 1m.

4.1.3 Claystone Facies

This facies is made up of claystone and siltstone. A very thin bed of the claystone occurs at Natako where it reaches a thickness ranging from 0.2 to 0.5m.

The argillaceous nature of the claystone facies coupled with the thin lamination suggest a low energy depositional system within floodplain or overbank environment. Lack of association with any marine fauna or sedimentary features suggest a non marine floodplain or ox bow lake environment adjacent to the braid channels (Miall, 1990; Ojo & Akande, 2011).

4.2 Lithostratigraphic sections

The lithostratigraphic sections in the study area are presented in Figs.(4.2,4.4 and 4.6).

4.2.1 Natako Section at 1.2 km north of Lokoja (7°51'49.9"N and 6°45'14.6"E.)

At Natako 1 (07° 51' 49" N , 006° 45' 14" E). This section has a total thickness of about 18.38m we have several beds starting from the base are massive coarse grained conglomeratic sandstone, fine clayish sandstone, cross-stratified coarse sandstone, pebbly sandstone, massive conglomeratic sandstone and oolitic ironstone.

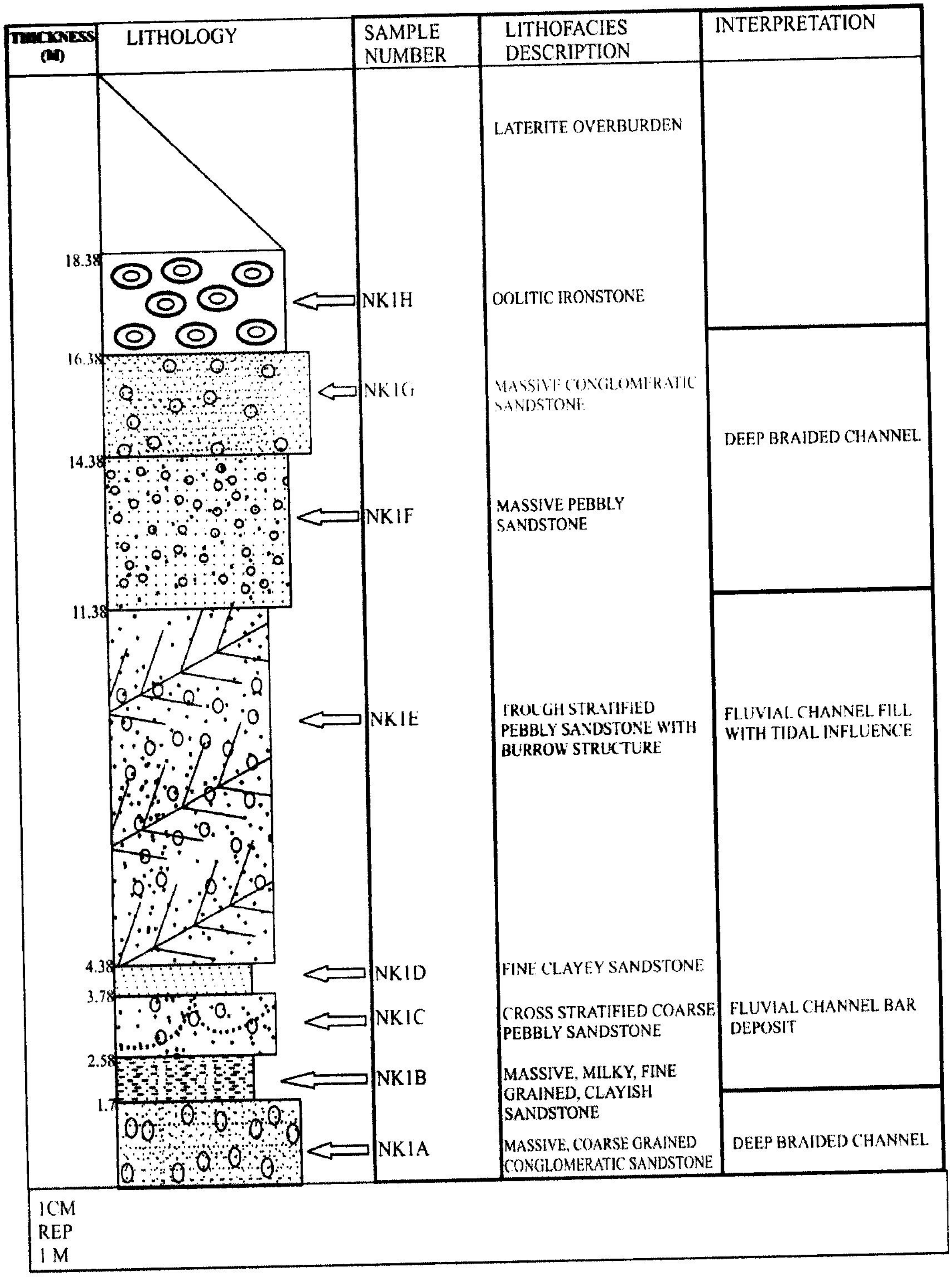


Figure 4.2.1: Lithological log of Lokoja Sandstone exposed at Natako 1 km 1.2 (7°51'49.9"N and 6°45'14.6"E.)

4.2 : Section at Natako2 (7°51'54.9"N and 6°47'29.6"E)

At Natako 2 (07° 41' 51" N , : 006° 45' 33" E), The lithologic units here are milky medium to coarse sandstone, coarse sandstone with cross stratification,fine to medium sandstone, purplish coarse sandstone and coarse conglomeratic sandstone This section has a total thickness of about 10m as seen in fig 4.2.2

4..3 : Section at Jimeta (8°2'54.0"N and 6°45'57.0"E)

:At Jimeta (08° 2' 54" N , 006° 45' 57" E), here we have coarse pebbly sandstone, very coarse to pebbly sandstone cross-stratified, pebbly sandstone,brownish to mikly sandstone and oolitic irontone. This section has a total thickness of about 10.85m as seen in figure 4.2.3

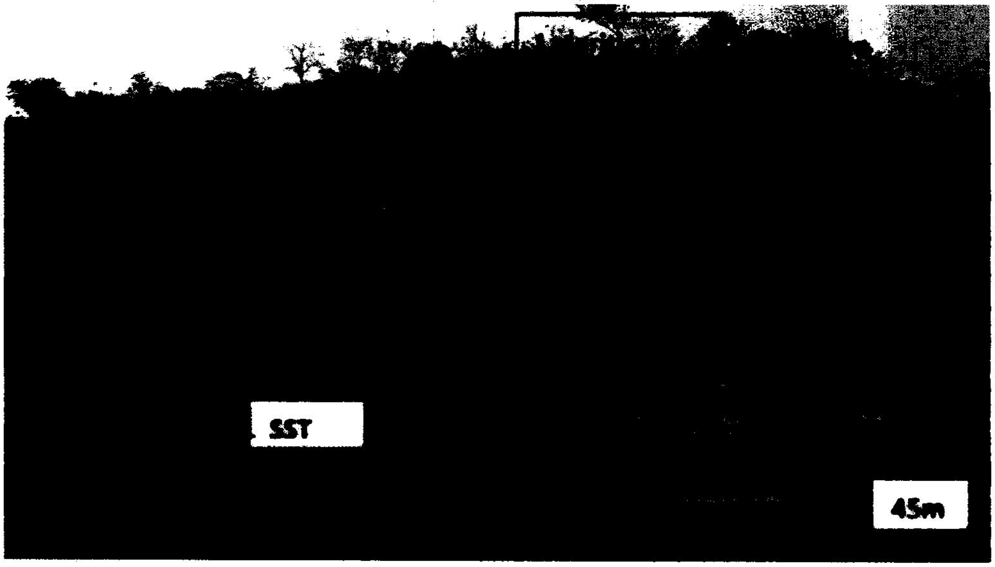


Figure 4.2.2 : Field photograph showing section of the Lokoja Sandstone showing feldsparthic poorly sorted sandstone at km 4.5 along Lokoja-Abuja express way.(7°41'51.9"N and 6°45'32.6"E).

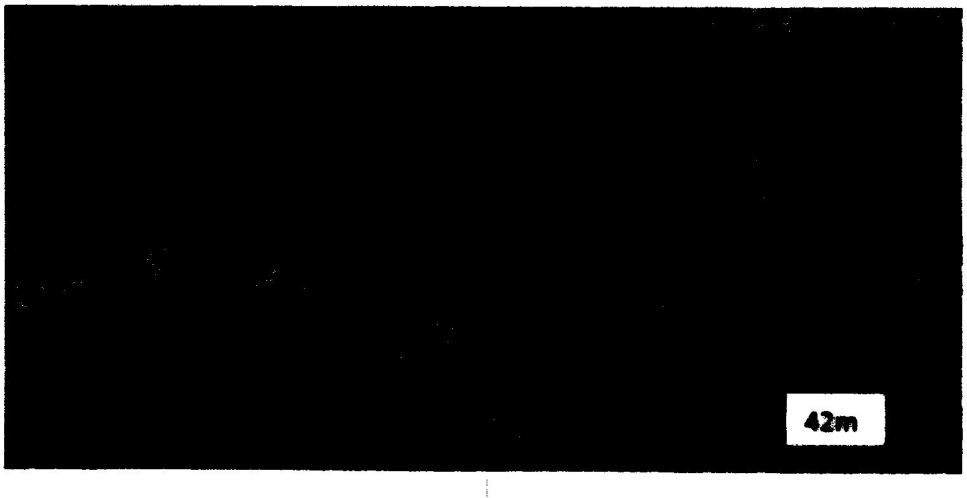
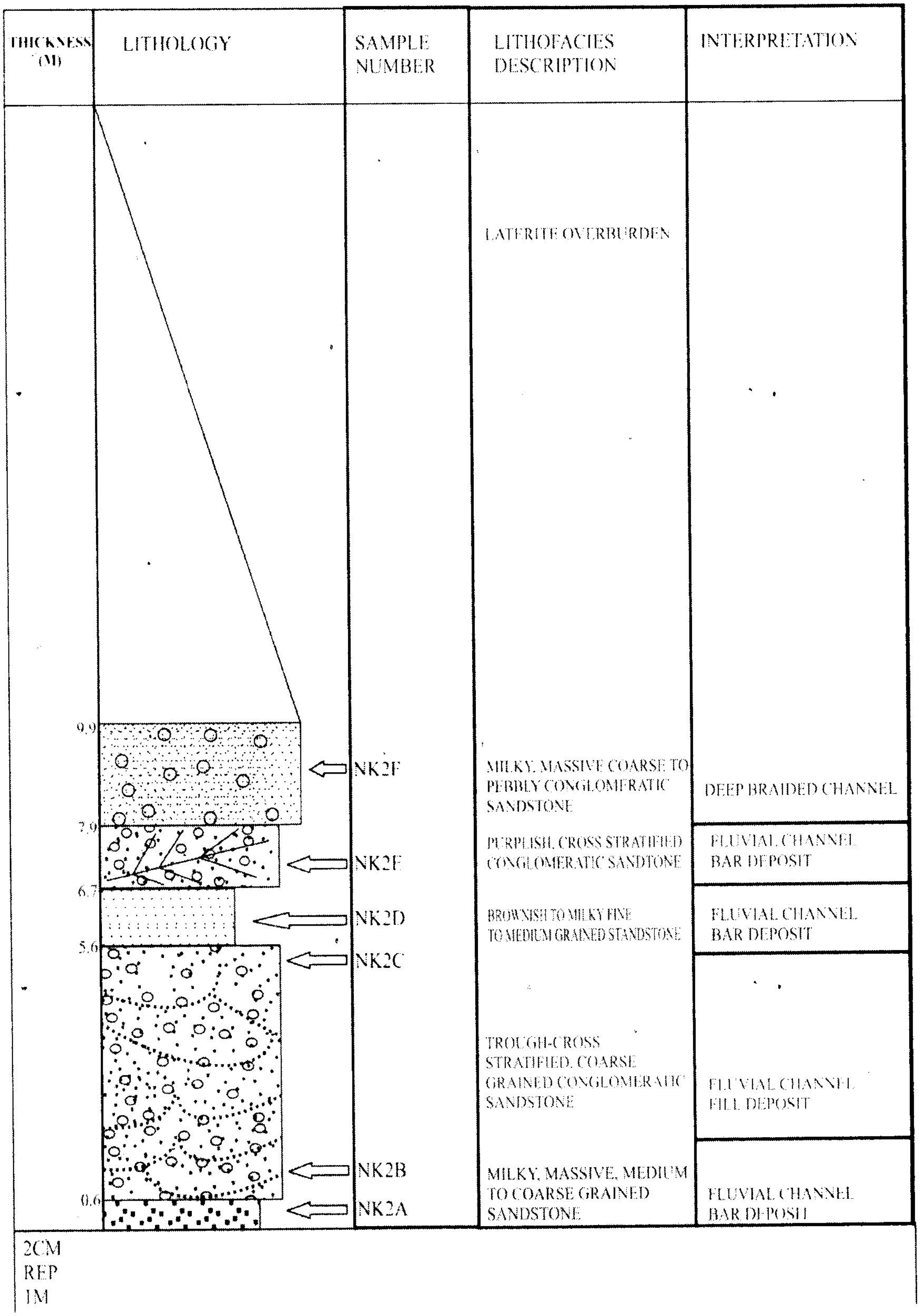


Figure 4.2.3: Field photograph of exposed sandstone and ironstone unit of the Lokoja Formation at Jimeta.(8°2'54.0"N and 6°45'57.0"E).



THICKNESS (M)	LITHOLOGY	SAMPLE NUMBER	LITHOFACIES DESCRIPTION	INTERPRETATION
			LATERITE OVERBURDEN	
9.9		NK2F	MILKY, MASSIVE COARSE TO PEBBLY CONGLOMERATIC SANDSTONE	DEEP BRAIDED CHANNEL
7.9		NK2F	PURPLISH, CROSS STRATIFIED CONGLOMERATIC SANDTONE	FLUVIAL CHANNEL BAR DEPOSIT
6.7		NK2D	BROWNISH TO MILKY FINE TO MEDIUM GRAINED STANDSTONE	FLUVIAL CHANNEL BAR DEPOSIT
5.6		NK2C	TROUGH-CROSS STRATIFIED, COARSE GRAINED CONGLOMERATIC SANDSTONE	FLUVIAL CHANNEL FILL DEPOSIT
0.6		NK2B NK2A	MILKY, MASSIVE, MEDIUM TO COARSE GRAINED SANDSTONE	FLUVIAL CHANNEL BAR DEPOSIT

2CM
REP
1M

Figure 4.2.4: Lithologic section of Lokoja Formation at Nataco km 1.8 along Lokoja and Abuja express way(7°41'51.9"N and 6°45'32.6"E).

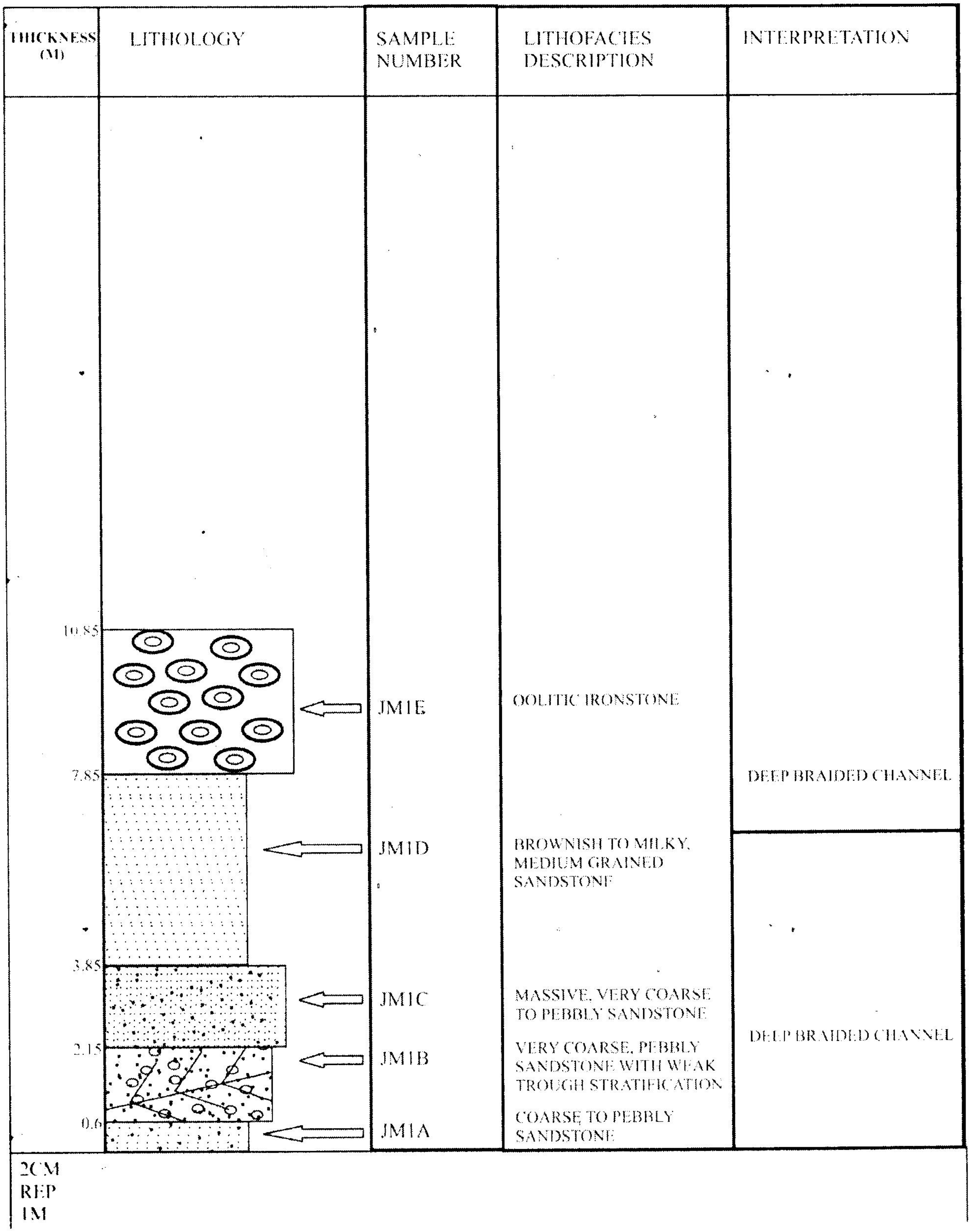


Figure 4.2.5 : Lithologic section of Lokoja Formation at Jimeta (8°2'54.0"N and 6°45'57.0"E).

4.3 Granulometric Studies.

4.3.1 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. thirteen samples were sieved and statistical parameters of each of the sandstone samples are presented in (Table 4.5). The following graphical parameters were obtained by using Folk and Ward's (1957) formulae

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

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

$$\text{Inclusive Graphic Skewness (Ski)} = \frac{\phi 84+\phi 16-2\phi 50}{2(\phi 84-\phi 16)} + \frac{\phi 95+\phi 5-2\phi 50}{2(\phi 95-\phi 5)}$$

$$\text{Graphic Kurtosis (KG)} = \frac{\phi 95-\phi 5}{2.44\,(\phi 75-\phi 25)}$$

Table 4.1: Graphic mean standard values according to Wenthworth, 1922

Phi (ϕ) value	Size class (Wentworth, 1922)
-1.0 to 0.0	Very coarse grained sand
0.0 to 1.0	Coarse grained sand
1.0 to 2.0	Medium grained sand
2.0 to 3.0	Fine grained sand
3.0 to 4.0	Very fine grained sand
4.0 to 8.0	Silt
8.0 to 14.0	Clay

Table 4.2: Standard deviation of the assessed Sandstone

Phi standard deviation	sorting
<0.35	Very well sorted
0.35 to 0.50	Well sorted
0.50 to 0.70	Moderately well sorted
0.70 to 1.00	Moderately sorted
1.00 to 2.00	Poorly sorted
2.00 to 4.00	Very poorly sorted
>4.00	Extremely poorly sorted

Table 4.3: Graphic skewness standard values

Calculated skewness	skewness
> +0.30	Strongly fine skewed
+0.30 to +0.10	Positively skewed
+0.10 to -0.10	Near symmetrical

–0.10 to –0.30	Negatively skewed
< –0.30	Strongly coarse skewed

Table 4.4: Graphic kurtosis standard values

Calculated Kurtosis	Kurtosis
<0.67	Very platykurtic
0.67– 0.90	Platykurtic
0.90–1.11	Mesokurtic
1.11-1.50	Leptokurtic
1.50 -3.00	Very leptokurtic

Table 4.5: Grain size distribution and quantitative parameters of sandstone samples in the study area.

SAMPLE NO.	MEAN	MODE	MEDIAN	STANDARD DEVIATION	SKEWNESS	KURTOSIS
NK1A	0.4	Φ2	0.4	1.3	-0.1	1.1
NK1B	0.3	Φ2	0.8	1.5	0.1	1.1
NK1C	0.5	Φ3	0.6	1.3	0.3	0.7
NK1D	0.3	Φ1	0.4	1.5	0.1	0.8
NK1E	0.6	Φ1	0.6	1.0	0.3	0.73
NK1G	0.2	Φ-2.2	-0.6	1.0	1.5	0.4
NK2A	0.1	Φ-2.2	-0.4	0.71	1.0	0.98
NK2B	-0.1	Φ1	0.2	0.9	0.6	0.4
NK2C	1.4	Φ1	0.4	1.0	O.1	1.49
NK2D	0.4	Φ-2.2	-0.6	0.92	1.5	0.72
JM1A	0.1	Φ1	0	1.4	0.1	0.95
JM1B	-0.1	Φ0	-0.1	1.11	-0.1	1.2
JM1D	0.1	Φ1	0.45	1.1	0.1	0.5

Table 4.6: Grain size distribution and quantitative parameters of sandstone samples in the study area.

SAMPLE NO	MEAN	STANDARD DEV	SKEWNESS	KURTOSIS
NK1A	COARSE GRAINED	POORLY SORTED	NEAR SYMMETRICAL	LEPTOKURTIC
NK1B	COARSE GRAINED	POORLY SORTED	POSITIVE SKEWED	LEPTOKURTIC
NK1C	COARSE GRAINED	POORLY SORTED	POSITIVE SKEWED	VERY PLATYKURTIC
NK1D	COARSE GRAINED	POORLY SORTED	NEAR SYMMETRICAL	PLATYKURTIC
NK1E	COARSE GRAINED	POORLY SORTED	POSITIVE SKEWED	PLATYKURTIC
NK1G	COARSE GRAINED	POORLY SORTED	STRONGLY POSITIVE SKEWED	VERY PLATYKURTIC
NK2A	COARSE GRAINED	MODERATELY SORTED	STRONGLY POSITIVE SKEWED	MESOKURTIC
NK2B	VERY COARSE GRAINED	MODERATELY SORTED	STRONGLY POSITIVE SKEWED	VERY PLATYKURTIC
NK2C	MEDIUM GRAINED	POORLY SORTED	NEAR SYMMETRICAL	LEPTOKURTIC
NK2D	COARSE GRAINED	MODERATELY SORTED	POSITIVE SKEWED	PLATYKURTIC
JM1A	COARSE GRAINED	POORLY SORTED	NEAR SYMMETRICAL	LEPTOKURTIC

JM1B	**VERY COARSE GRAINED**	**POORLY SORTED**	**NEGATIVE SKEWED**	**LEPTOKURTIC**
JM1D	**COARSE GRAINED**	**POORLY SORTED**	**NEAR SYMMETRICAL**	**VERY PLATYKURTIC**

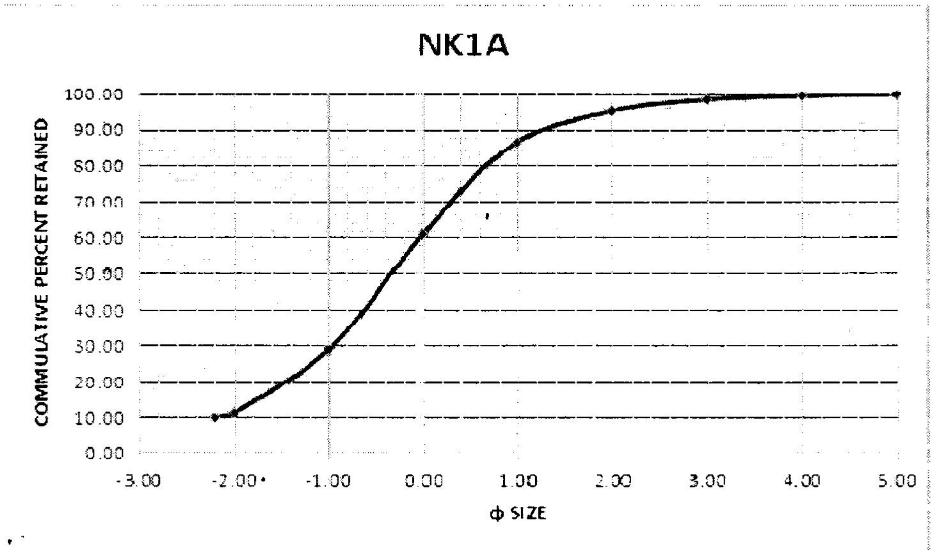


Figure 4.3.1 particle size analysis curve for sample NK 1A

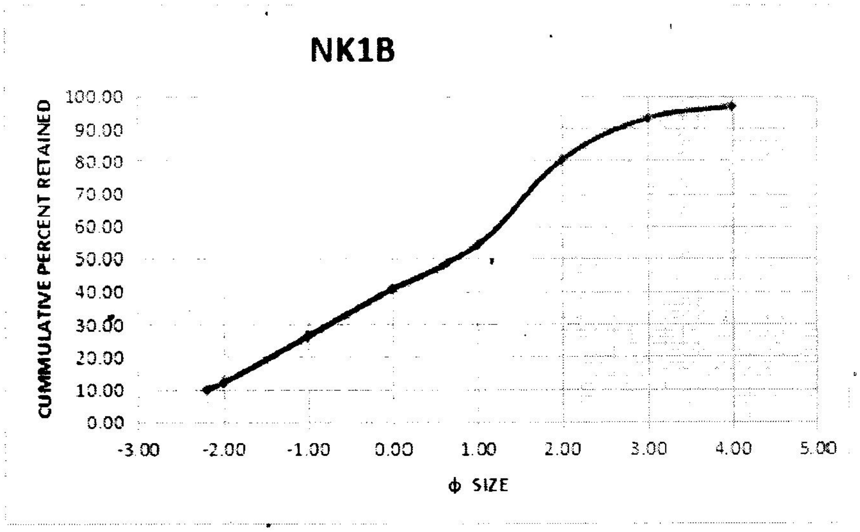


Figure 4.3.2 particle size analysis curve for sample NK 1B

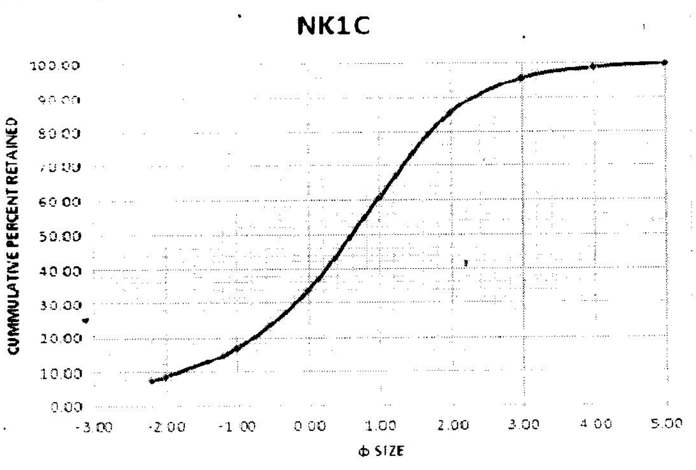


Figure 4.3.3 particle size analysis curve for sample NK 1C

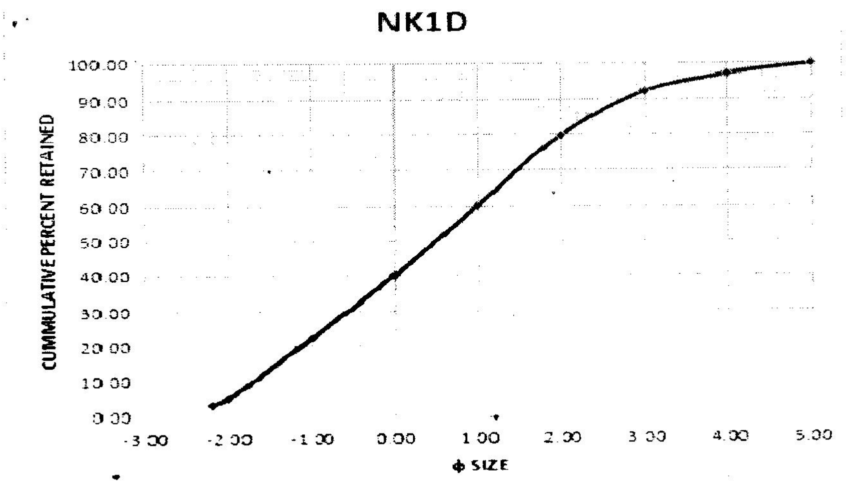


Figure 4.3.4 particle size analysis curve for sample NK 1D

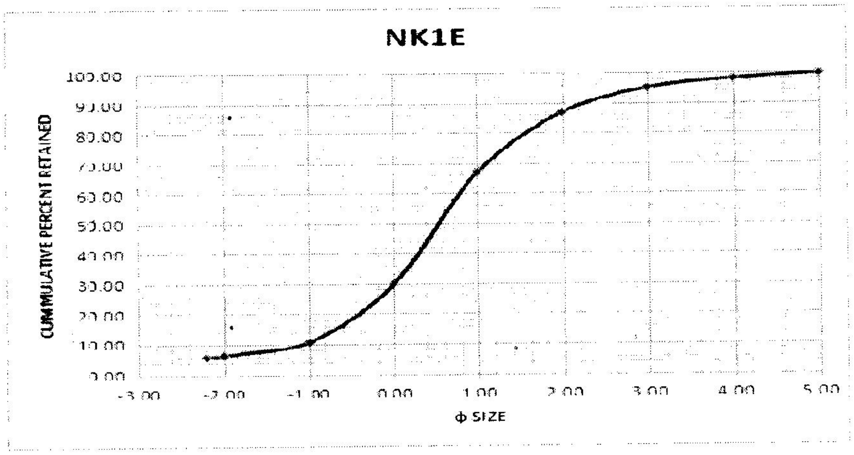


Figure 4.3.5 particle size analysis curve for sample NK 1E

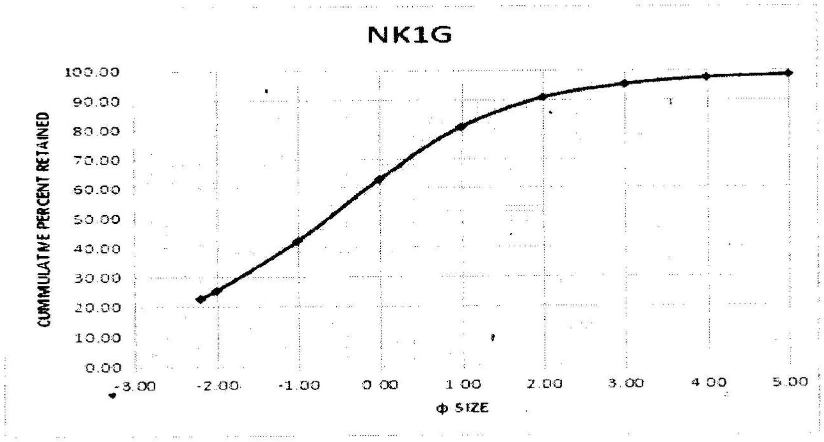


Figure 4.3.6 particle size analysis curve for sample NK 1G

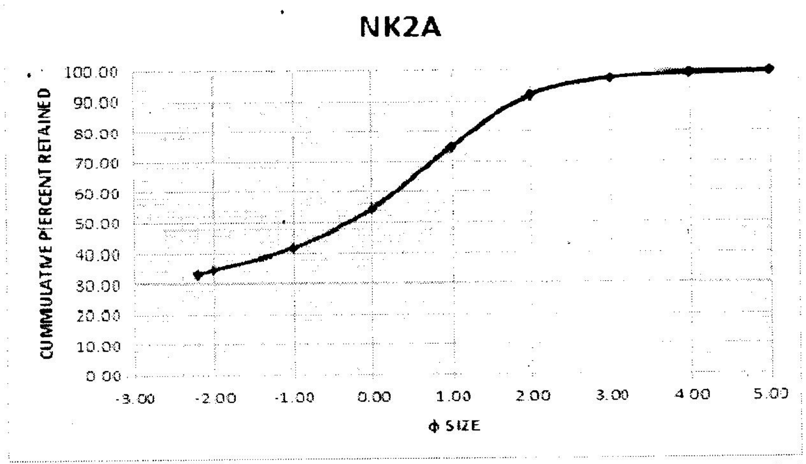


Figure 4.3.7 particle size analysis curve for sample NK 2A

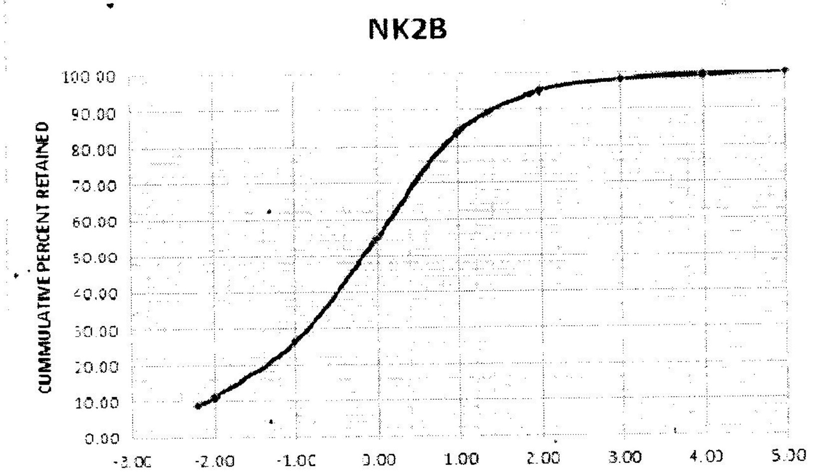


Figure 4.3.8 particle size analysis curve for sample NK 2B

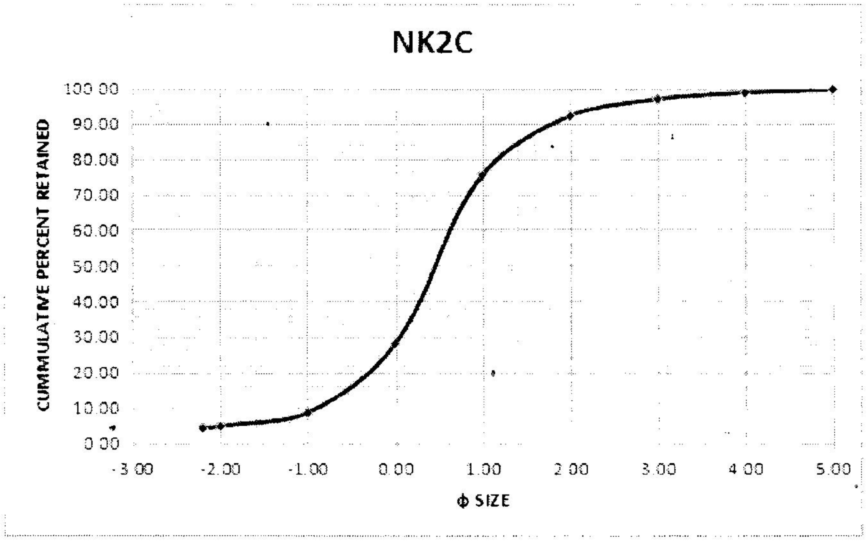


Figure 4.3.9 particle size analysis curve for sample NK 2C

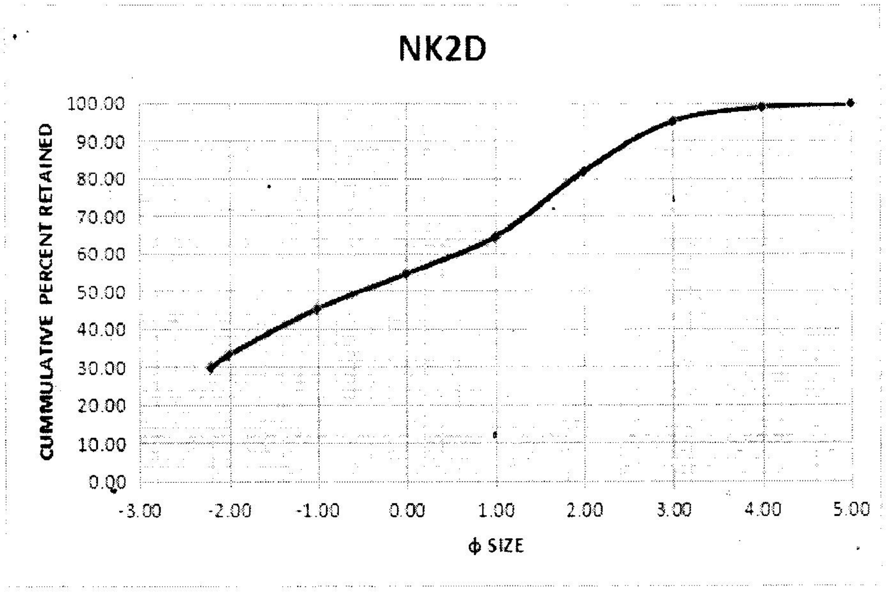


Figure 4.3.10 particle size analysis curve for sample NK 2D

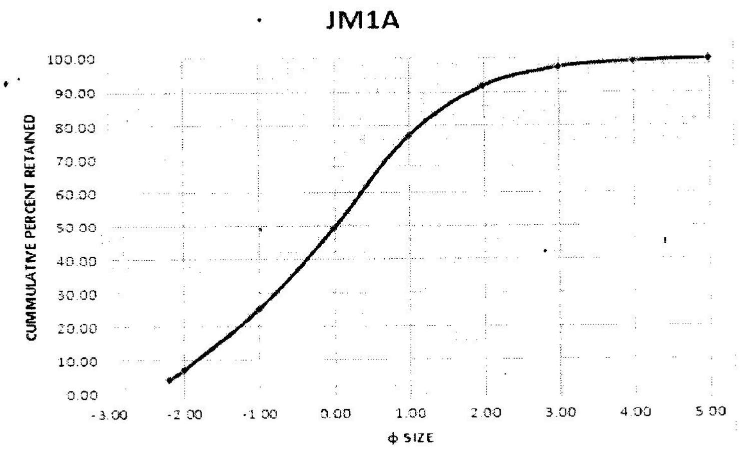


Figure 4.3.11 particle size analysis curve for sample JM1A

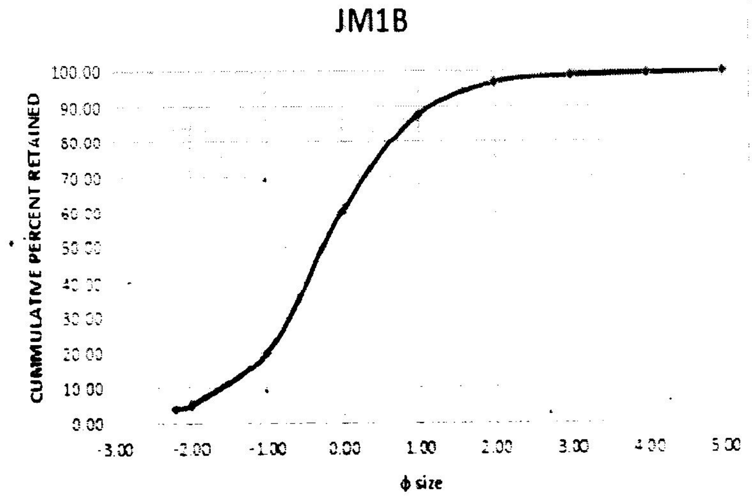


Figure 4.3.12 particle size analysis curve for sample JM 1B

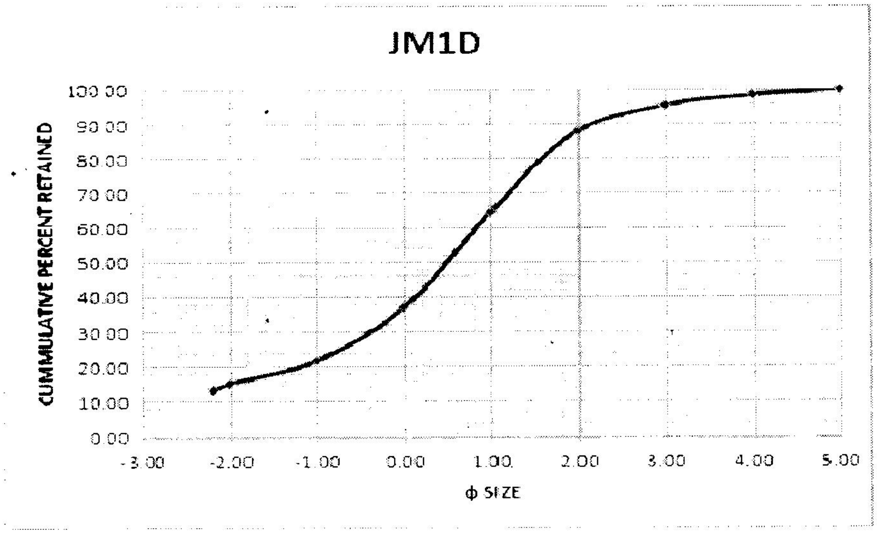


Figure 4.3.13 particle size analysis curve for sample JM 1D

4.3.2 Grain Size Data and Interpretation

The results of the grain size analysis of the sandstones were used to compute the textural parameters such as mean, standard deviation (sorting), skewness and kurtosis (Table 4.6). The mean size of the samples range from -0.1 to 0.60 with average of 0.4 and thus suggesting they are predominantly medium to coarse grained.

Standard deviation (sorting) and skewness values range from 0.1 to 0.9 (average of 0.6) and -0.1 to 1.50 (average of 0.6), respectively, indicating that the sandstones are mainly poorly sorted and positive – symmetrically skewed.

Kurtosis values also suggest they are mesokurtic to platykurtic. The poor sorting and positive skewness suggest fluvial environments for the sandstones. Several authors have used poor sorting and positive skewness as indicators of low energy environment characterized by current inconsistency and typical of fluvial system (Selley, 1985; Tucker, 1988; Amajor & Ngerebara, 1990). To further constrain the paleo-environments according to Friedman (1967, 1979) and Moila & Weiser (1968), bivariate plots of the grain size paramaters (skewness versus standard deviation and mean versus standard deviation) were plotted and the plots suggest predominant fluvial origin

4.3.3 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 4.3.14). The plots based on Friedman (1979), showed that 100% of the samples plotted falls within the river field environment for samples from Lokoja Sandstone. The plots based on Moiola and Weiser (1968) showed that 99.9% of the studied samples plotted within river field environment for the whole samples from Lokoja Sandstone and Patti Formation (Fig 4.3.14).Using the distinction of Friedman (1961), 98% of samples plotted are within fluvial environment for the samples from Lokoja Sandstone. Standard Deviation versus Mean Size The plot of standard deviation versus mean size based on the Friedman (1979) shows that 80% of sample from Lokoja Sandstone falls within river sand field.

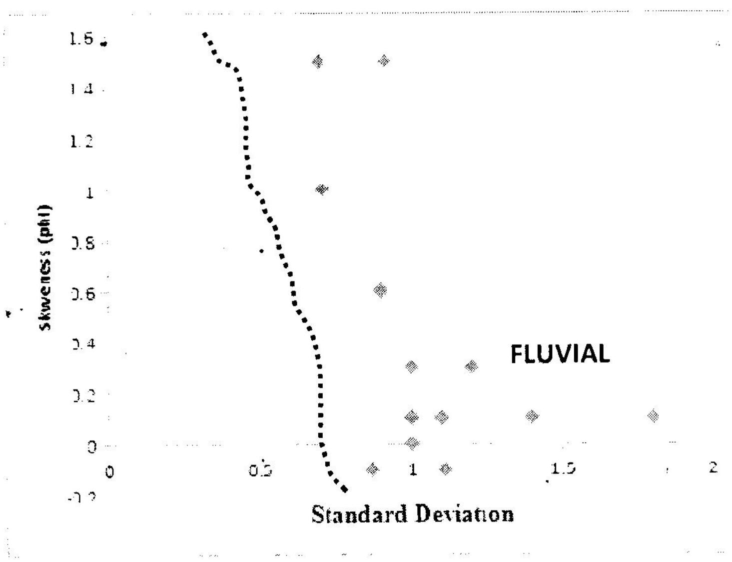


Figure 4.3.14: Bivariate plot of standard deviation vs skewness for the whole samples from Lokoja Sandstone (Adapted from Friedman,1979)

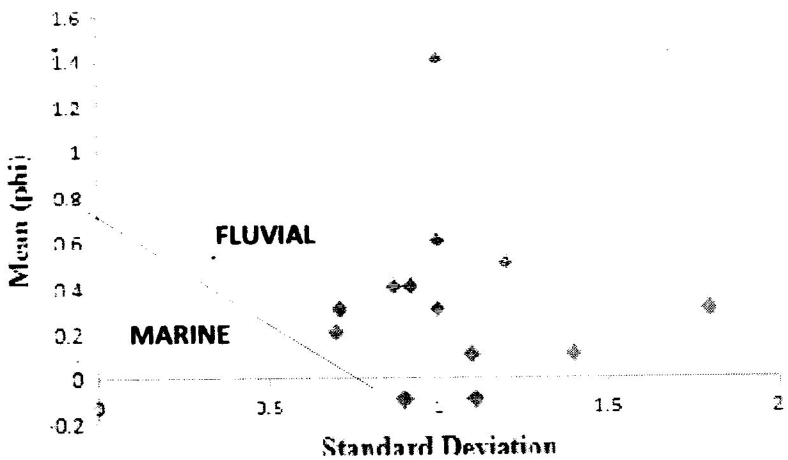


Figure 4.3.15: Bivariate plot of standard deviation vs mean for the whole samples from Lokoja Sandstone (Adapted from Moiola and Weiser, 1968).

4.4 PEBBLES MORPHOLOGY

A total of one hundred and sixty(160) pebbles were collected from two (2) locations which are Natako1 and Natako 2. The pebbles were washed and dried. Broken pebbles were removed. Pebble morphometric measurement using vernier caliper after Krumbeins(1941) method was used. The long (L), intermediate(I) and short (S) axes of the pebbles were measured. Pebble indices such as flatness ratio(FR), flatness index (FI), elongation ratio (ER) maximum projection sphericity index(MPSI) and oblate prolate index (OPI) with the visual estimation of pebbles roundness using roundness chart of Powers(1953). Morphometric studies of pebbles showed variations in environment of deposition from fluvial to marine settings for the Lokoja sandstone. The scatter plots of maximum projection sphericity index (MPS.I) versus oblate – prolate index (O.P.I.) indicate river origin for the pebbles. The roundness versus elongation ratio (E.R) shows the same fluvial source. The mean roundness value (0.3) reflects angular to subrounded pebbles and short transportation history.

Table 4.6: pebbles morphological analysis interpretation

Pebble morphometric parameters	characteristics	Define limits from previous studies	Interpretation of
Flatness Index(FI)	Consist of over 90% above fluvial limit	Beach <45%, fluvial >45%	fluvial
Elongation ratio	Over 95% has values between 0.6- 0.9	fluvial	fluvial
Maximum projection sphericity index (MPSI)	The pebbles analyses about 97% were 0.66	Beach <0.66, fluvial >0.66	Predominatly fluvial
Oblate prolate (OP)	The OPI shows significant of fluvial deposit with minimal beach	Beach <-1.5, fluvial >-1.15	Fluvial dominated
Roundness	60% has values below 0.3 and 40% has values above 0.45	Fluvial <0.35 littoral >0.45	Mainly fluvial/littoral with few beach pebbles

TABLE 4.7 PEBBLE MORPHOMETRY TABLES FOR NKIB AND NK2B RESPECTIVELY

NKIB PEBBLES

S/ N	L	I	S	S/L	S/L*100	I/L	L-I/L-S	SPHERICITY	OP INDEX	ROUNDNESS
1	4.1	3.0	2.5	0.6	61.0	0.7	0.7	0.8	3.1	0.3
2	1.7	1.4	0.7	0.4	41.2	0.8	0.3	0.6	-4.9	0.4
3	3.9	2.2	1.4	0.4	35.9	0.6	0.7	0.6	5.0	0.4
4	2.5	1.6	1.4	0.6	56.0	0.6	0.8	0.8	5.7	0.3
5	3.6	1.7	1.6	0.4	44.4	0.5	1.0	0.7	10.1	0.2
6	2.9	1.8	1.2	0.4	41.4	0.6	0.6	0.7	3.6	0.2
7	2.9	2.5	1.7	0.6	58.6	0.9	0.3	0.7	-2.8	0.3
8	3.5	2.5	1.3	0.4	37.1	0.7	0.5	0.6	-1.2	0.4
9	2.0	1.3	0.8	0.4	40.0	0.7	0.6	0.6	2.1	0.2
10	3.5	2.9	1.8	0.5	51.4	0.8	0.4	0.7	-2.9	0.2
11	1.8	1.0	0.6	0.3	33.3	0.6	0.7	0.6	5.0	0.2
12	2.4	1.9	1.2	0.5	50.0	0.8	0.4	0.7	-1.7	0.3
13	3.0	2.1	1.2	0.4	40.0	0.7	0.5	0.6	0.0	0.3
14	2.1	1.4	1.0	0.5	47.6	0.7	0.6	0.7	2.9	0.3
15	3.3	2.8	2.2	0.7	66.7	0.8	0.5	0.8	-0.7	0.4
16	2.6	1.5	1.1	0.4	42.3	0.6	0.7	0.7	5.5	0.2
17	2.4	1.7	1.3	0.5	54.2	0.7	0.6	0.7	2.5	0.3
18	2.9	2.2	1.7	0.6	58.6	0.8	0.6	0.8	1.4	0.3
19	2.0	1.8	1.0	0.5	50.0	0.9	0.2	0.7	-6.0	0.2
20	2.7	1.2	0.9	0.3	33.3	0.4	0.8	0.6	10.0	0.2
21	2.1	1.5	1.2	0.6	57.1	0.7	0.7	0.8	2.9	0.3
22	2.7	1.5	1.3	0.5	48.1	0.6	0.9	0.7	7.4	0.2
23	3.2	1.7	1.1	0.3	34.4	0.5	0.7	0.6	6.2	0.2
24	5.7	3.6	2.0	0.4	35.1	0.6	0.6	0.6	1.9	0.2
25	5.0	4.3	3.0	0.6	60.0	0.9	0.4	0.7	-2.5	0.3
26	5.3	3.5	2.4	0.5	45.3	0.7	0.6	0.7	2.7	0.3
27	2.3	1.5	0.7	0.3	30.4	0.7	0.5	0.5	0.0	0.2
28	2.3	1.6	1.1	0.5	47.8	0.7	0.6	0.7	1.7	0.2
29	3.1	2.2	1.0	0.3	32.3	0.7	0.4	0.5	-2.2	0.2
30	2.4	2.0	1.0	0.4	41.7	0.8	0.3	0.6	-5.1	0.2
31	3.3	2.4	2.0	0.6	60.6	0.7	0.7	0.8	3.2	0.4
32	3.4	3.0	2.0	0.6	58.8	0.9	0.3	0.7	-3.6	0.3

33	2.9	2.5	1.4	0.5	48.3	0.9	0.3	0.6	-4.8	0.3
34	3.2	2.1	1.4	0.4	43.8	0.7	0.6	0.7	2.5	0.4
35	3.5	2.6	1.2	0.3	34.3	0.7	0.4	0.5	-3.2	0.3
36	4.7	2.5	2.2	0.5	46.8	0.5	0.9	0.7	8.1	0.2
37	2.0	1.4	1.2	0.6	60.0	0.7	0.8	0.8	4.2	0.2
38	5.4	4.5	3.7	0.7	68.5	0.8	0.5	0.8	0.4	0.7
39	2.3	1.6	1.3	0.6	56.5	0.7	0.7	0.8	3.5	0.3
40	3.5	2.7	2.0	0.6	57.1	0.8	0.5	0.8	0.6	0.3
41	2.5	2.1	1.6	0.6	64.0	0.8	0.4	0.8	-0.9	0.3
42	2.0	1.5	1.0	0.5	50.0	0.8	0.5	0.7	0.0	0.2
43	1.7	1.2	1.0	0.6	58.8	0.7	0.7	0.8	3.6	0.3
44	1.8	1.2	0.7	0.4	38.9	0.7	0.5	0.6	1.2	0.2
45	2.4	1.8	1.4	0.6	58.3	0.8	0.6	0.8	1.7	0.3
46	4.0	2.7	2.3	0.6	57.5	0.7	0.8	0.8	4.6	0.3
47	3.2	2.3	1.5	0.5	46.9	0.7	0.5	0.7	0.6	0.3
48	2.6	1.3	1.2	0.5	46.2	0.5	0.9	0.8	9.3	0.2
49	2.0	1.3	0.9	0.5	45.0	0.7	0.6	0.7	3.0	0.2
50	2.2	1.6	1.4	0.6	63.6	0.7	0.8	0.8	3.9	0.3
51	2.9	2.0	1.6	0.6	55.2	0.7	0.7	0.8	3.5	0.4
52	1.7	1.3	0.7	0.4	41.2	0.8	0.4	0.6	-2.4	0.2
53	1.9	1.6	0.9	0.5	47.4	0.8	0.3	0.6	-4.2	0.3
54	2.9	1.4	1.0	0.3	34.5	0.5	0.8	0.6	8.4	0.3
55	2.8	2.2	1.4	0.5	50.0	0.8	0.4	0.7	-1.4	0.3
56	4.5	1.8	1.0	0.2	22.2	0.4	0.8	0.5	12.2	0.2
57	3.2	2.6	1.9	0.6	59.4	0.8	0.5	0.8	-0.6	0.3
58	2.7	2.0	1.5	0.6	55.6	0.7	0.6	0.7	1.5	0.3
59	2.0	1.5	0.9	0.5	45.0	0.8	0.5	0.6	-1.0	0.3
60	3.4	2.2	1.2	0.4	35.3	0.6	0.5	0.6	1.3	0.2
61	2.3	1.5	1.3	0.6	56.5	0.7	0.8	0.8	5.3	0.2
62	2.5	2.1	1.0	0.4	40.0	0.8	0.3	0.6	-5.8	0.3
63	1.7	1.4	0.7	0.4	41.2	0.8	0.3	0.6	-4.9	0.3
64	1.7	1.3	1.0	0.6	58.8	0.8	0.6	0.8	1.2	0.2
65	1.9	1.5	1.3	0.7	68.4	0.8	0.7	0.8	2.4	0.2
66	1.8	1.7	1.4	0.8	77.8	0.9	0.3	0.9	-3.2	0.2
67	1.7	1.1	0.8	0.5	47.1	0.6	0.7	0.7	3.5	0.2
68	1.5	1.1	0.9	0.6	60.0	0.7	0.7	0.8	2.8	0.2
AV	2.8	1.9	1.3	0.4	49.3	0.7	0.5	0.6	1.5	0.3
ST D	0.9	0.7	0.5	0.1	11.0	0.11	0.18	0.18	4.09	0.8

NK2B
PEBBLES

S/N	L	I	S	S/L	S/L*100	I/L	L-I/L-S	SPHERICITY	OP INDEX	ROUNDNESS
1	6.7	5.5	3.9	0.6	58.2	0.9	0.2	0.7	0.0	0.5
2	4.0	3.0	2.3	0.6	57.5	0.8	0.6	0.8	1.5	0.4
3	3.8	3.4	2.2	0.6	57.9	0.9	0.3	0.7	-4.3	0.3
4	4.2	2.5	2.0	0.5	47.6	0.6	0.8	0.7	5.7	0.3
5	3.3	1.6	1.5	0.5	45.5	0.5	0.9	0.8	9.8	0.2
6	4.7	2.3	1.8	0.4	38.3	0.5	0.8	0.7	8.6	0.2
7	4.7	3.4	2.2	0.5	47.3	0.7	0.5	0.7	0.2	0.4
8	2.4	2.1	1.6	0.7	66.7	0.9	0.4	0.8	-1.9	0.1
9	5.9	3.7	1.5	0.3	25.4	0.6	0.5	0.5	0.0	0.5
10	4.2	2.6	2.1	0.5	50.0	0.6	0.8	0.7	5.2	0.2
11	3.2	2.1	1.5	0.5	46.9	0.7	0.6	0.7	3.1	0.2
12	3.9	3.3	2.3	0.6	59.0	0.8	0.4	0.7	-2.1	0.3
13	2.8	1.6	1.3	0.5	46.4	0.6	0.8	0.7	6.5	0.3
14	4.0	2.9	1.6	0.4	40.0	0.7	0.5	0.6	-1.0	0.5
15	2.9	2.2	1.2	0.4	41.4	0.8	0.4	0.6	-2.1	0.4
16	3.4	1.7	1.5	0.4	44.1	0.5	0.9	0.7	8.9	0.3
17	5.3	1.7	1.7	0.3	32.1	0.3	1.0	0.7	15.6	0.2
18	4.3	2.8	1.8	0.4	41.9	0.7	0.6	0.6	2.4	0.5
19	3.8	2.8	2.2	0.6	57.9	0.7	0.6	0.8	2.2	0.5
20	3.6	2.2	1.7	0.5	47.2	0.6	0.7	0.7	5.0	0.4
21	3.3	2.7	1.3	0.4	39.4	0.8	0.3	0.6	-5.1	0.5
22	2.5	2.1	1.5	0.6	60.0	0.8	0.4	0.8	-1.7	0.4
23	3.7	3.1	2.2	0.6	59.5	0.8	0.4	0.8	-1.7	0.5
24	2.4	1.7	1.3	0.5	54.2	0.7	0.6	0.7	2.5	0.4
25	3.2	2.6	1.7	0.5	53.1	0.8	0.4	0.7	-1.9	0.5
26	3.3	3.0	1.5	0.5	45.5	0.9	0.2	0.6	-7.3	0.5
27	3.9	1.7	1.5	0.4	38.5	0.4	0.9	0.7	11.4	0.2
28	4.5	2.3	1.4	0.3	31.1	0.5	0.7	0.6	6.7	0.2
29	2.9	2.3	1.4	0.5	48.3	0.8	0.4	0.7	-2.1	0.2
30	3.7	2.7	2.0	0.5	54.1	0.7	0.6	0.7	1.6	0.1
31	2.2	1.8	1.5	0.7	67.3	0.8	0.6	0.8	1.7	0.5
32	2.7	2.3	1.4	0.5	51.9	0.9	0.3	0.7	-3.7	0.4
33	2.1	1.7	0.6	0.3	28.6	0.8	0.3	0.5	-8.2	0.1
34	2.1	1.7	1.5	0.7	71.4	0.8	0.7	0.9	2.3	0.4
35	2.7	1.7	1.1	0.4	40.7	0.6	0.6	0.6	3.1	0.4
36	2.9	2.0	1.5	0.5	51.7	0.7	0.6	0.7	2.8	0.4
37	5.2	4.0	2.6	0.5	50.0	0.8	0.5	0.7	-0.8	0.5
38	2.7	2.4	1.7	0.6	63.0	0.9	0.3	0.8	-3.2	0.3
39	3.1	2.6	2.0	0.6	64.5	0.8	0.5	0.8	-0.7	0.3
40	2.6	1.5	1.2	0.5	46.2	0.6	0.8	0.7	6.2	0.2
41	3.5	3.0	1.5	0.4	42.9	0.9	0.3	0.6	-5.8	0.5
42	2.7	2.1	1.3	0.5	48.1	0.8	0.4	0.7	-1.5	0.5
43	3.6	2.8	2.1	0.6	58.3	0.8	0.5	0.8	0.6	0.5
44	2.5	2.2	1.4	0.6	56.0	0.9	0.3	0.7	-4.1	0.4

45	4.3	3.1	1.5	0.3	34.9	0.7	0.4	0.6	-2.0	0.4
46	2.5	1.7	1.3	0.5	52.0	0.7	0.7	0.7	4.0	0.2
47	3.9	2.9	2.4	0.6	61.5	0.7	0.7	0.8	2.8	0.5
48	2.2	1.5	1.0	0.5	45.5	0.7	0.6	0.7	1.8	0.5
49	3.0	2.8	1.7	0.6	56.7	0.9	0.2	0.7	-6.1	0.5
50	2.1	1.5	0.7	0.3	33.3	0.7	0.4	0.5	-2.1	0.4
51	2.7	1.9	1.4	0.5	51.9	0.7	0.6	0.7	2.2	0.4
52	3.0	2.0	0.9	0.3	30.0	0.7	0.5	0.5	-0.8	0.2
53	3.7	2.9	1.0	0.3	27.0	0.8	0.3	0.5	-7.5	0.3
54	3.1	2.0	1.0	0.3	32.1	0.6	0.5	0.5	0.9	0.2
55	2.5	1.7	1.5	0.6	60.0	0.7	0.8	0.8	5.0	0.4
56	2.3	1.6	1.1	0.5	47.8	0.7	0.6	0.7	1.7	0.2
57	2.6	2.0	1.5	0.6	57.7	0.8	0.5	0.8	0.8	0.2
58	3.0	1.8	1.2	0.4	40.0	0.6	0.7	0.6	4.9	0.4
59	2.7	2.2	1.2	0.4	44.4	0.8	0.3	0.6	-3.8	0.4
60	2.4	1.7	1.4	0.6	58.3	0.7	0.7	0.8	3.9	0.4
61	2.7	2.3	1.1	0.4	41.5	0.8	0.3	0.6	-5.8	0.1
62	3.3	1.8	1.3	0.4	39.4	0.5	0.8	0.7	6.3	0.2
63	3.0	2.0	1.9	0.6	63.3	0.7	0.9	0.8	6.5	0.2
64	2.2	1.2	1.1	0.5	50.0	0.5	0.9	0.8	8.2	0.3
65	2.4	1.2	0.7	0.3	29.2	0.5	0.7	0.6	7.1	0.4
66	3.0	1.5	1.2	0.4	40.0	0.5	0.8	0.7	8.3	0.2
67	2.7	1.7	1.3	0.5	48.1	0.6	0.7	0.7	4.5	0.4
68	2.1	1.7	1.4	0.7	66.7	0.8	0.6	0.8	1.1	0.1
69	3.2	2.0	1.2	0.4	37.5	0.6	0.6	0.6	2.7	0.2
70	2.5	1.8	0.8	0.3	32.0	0.7	0.4	0.5	-2.8	0.1
71	2.5	2.0	1.4	0.6	56.0	0.8	0.5	0.7	-0.8	0.3
72	2.3	1.5	1.0	0.4	43.5	0.7	0.6	0.7	2.7	0.3
73	2.9	1.6	1.1	0.4	37.9	0.6	0.7	0.6	5.9	0.2
74	2.6	2.1	1.0	0.4	38.5	0.8	0.3	0.6	-4.9	0.3
75	2.6	1.2	1.0	0.4	38.5	0.5	0.9	0.7	9.8	0.2
76	1.9	1.5	1.3	0.7	70.3	0.8	0.6	0.8	1.9	0.1
77	2.2	1.1	1.2	0.5	54.5	0.5	1.1	0.8	11.0	0.2
78	2.6	1.6	1.0	0.4	38.5	0.6	0.6	0.6	3.3	0.2
79	2.1	1.5	1.2	0.6	57.1	0.7	0.7	0.8	2.9	0.2
80	2.5	1.3	0.9	0.4	36.0	0.5	0.8	0.6	6.9	0.2
81	2.8	1.4	1.0	0.4	35.7	0.5	0.8	0.6	7.8	0.2
82	2.2	1.4	1.1	0.5	50.0	0.6	0.7	0.7	4.5	0.3
83	2.1	1.5	1.1	0.5	52.4	0.7	0.6	0.7	1.9	0.2
84	2.1	1.7	1.1	0.5	52.4	0.8	0.4	0.7	-1.9	0.2
85	2.5	1.7	0.9	0.4	36.0	0.7	0.5	0.6	0.0	0.3
86	1.7	1.2	0.8	0.5	47.1	0.7	0.6	0.7	1.2	0.4
87	1.8	1.6	1.1	0.6	61.1	0.9	0.3	0.7	-3.5	0.5
88	2.2	1.4	1.2	0.5	54.5	0.6	0.8	0.8	5.5	0.4
89	1.6	1.4	1.2	0.8	75.0	0.9	0.5	0.9	0.0	0.5
90	2.3	1.2	1.2	0.5	52.2	0.5	1.0	0.8	9.6	0.3
91	2.5	1.7	1.4	0.6	56.0	0.7	0.7	0.8	4.1	0.4
92	2.0	1.3	1.0	0.5	50.0	0.7	0.7	0.7	4.0	0.2
93	2.2	1.5	1.0	0.5	45.5	0.7	0.6	0.7	1.8	0.2

94	2.2	1.6	1.1	0.5	51.2	0.7	0.5	0.7	0.5	0.2
95	1.6	1.1	0.9	0.6	56.3	0.7	0.7	0.8	3.8	0.1
96	2.6	1.2	0.7	0.3	26.9	0.5	0.7	0.5	8.8	0.2
97	1.7	1.2	1.1	0.6	64.7	0.7	0.8	0.8	5.2	0.2
98	1.9	1.5	1.0	0.5	52.6	0.8	0.4	0.7	-1.1	0.1
99	2.1	1.4	0.9	0.4	42.9	0.7	0.6	0.7	1.9	0.2
100	2.1	1.2	1.0	0.5	47.6	0.6	0.8	0.7	6.7	0.2
AV	2.9	2.0	1.4	0.5	48.4	0.7	0.6	0.7	2.0	0.3
STD	0.9	0.7	0.5	0.1	10.9	0.1	0.2	0.1	4.6	0.1

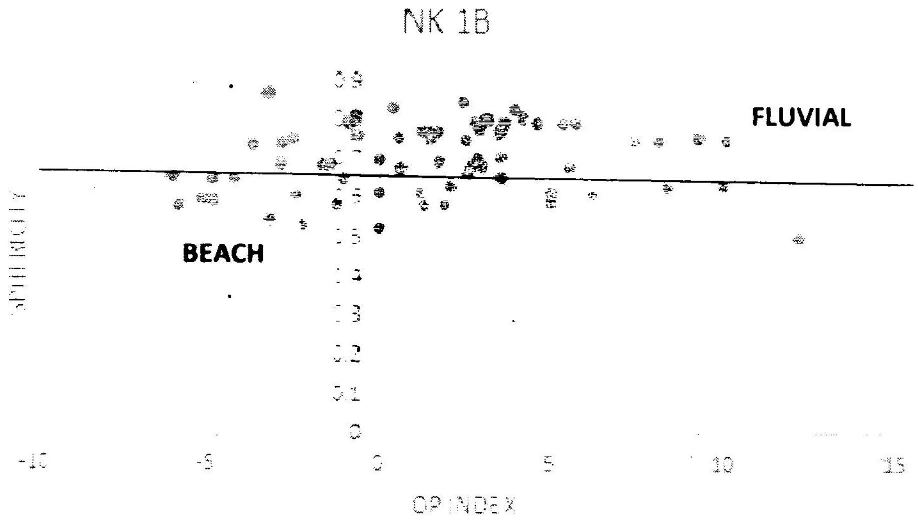


Fig 4.4.1 sphericity against oblate prolate index for NK1B

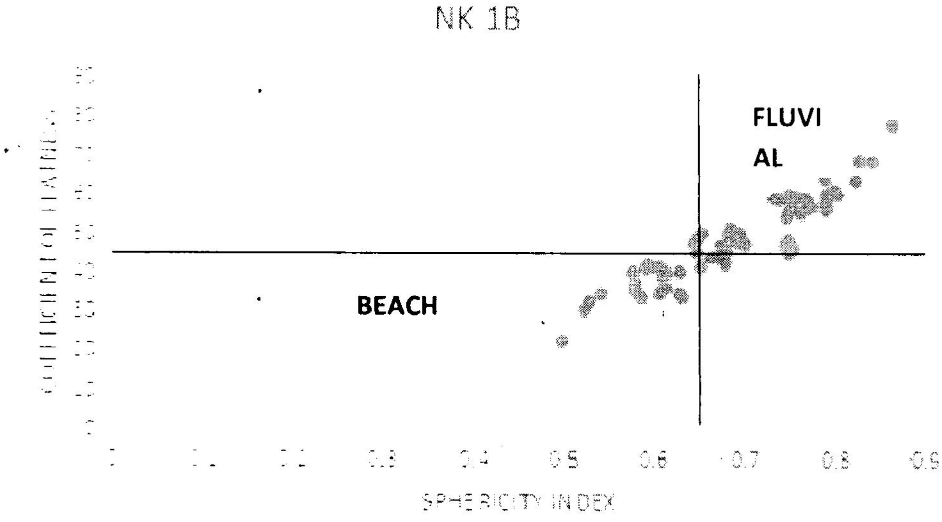


FIG 4.4.2 : Cofficient of flatness against sphericity index for NKIB

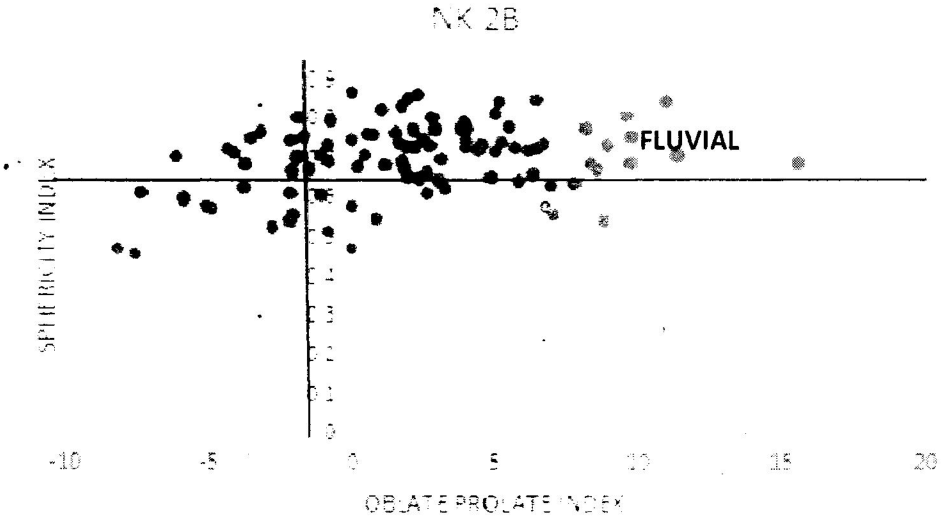


FIG 4.4:3: Sphericity index against oblate prolate index for NK2B

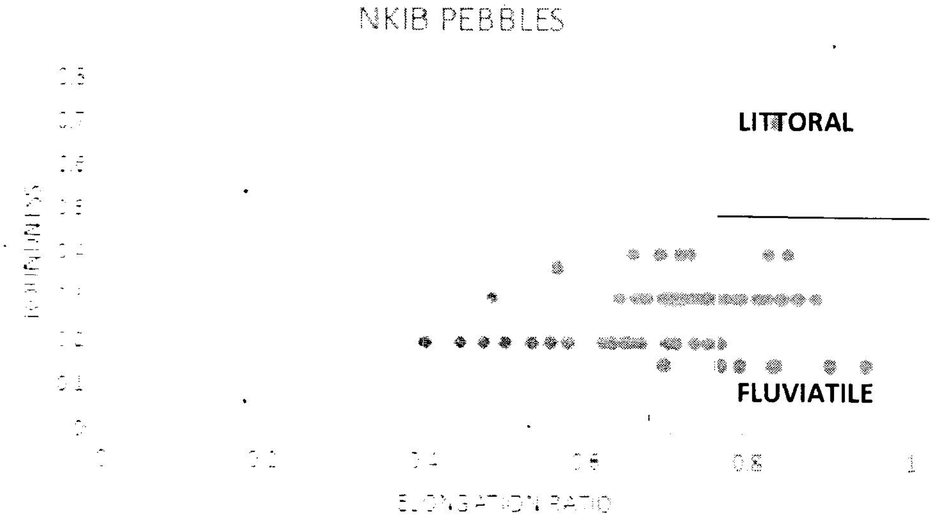


Fig 4.4.4: Roundness against Elongatio ratio for NK1B

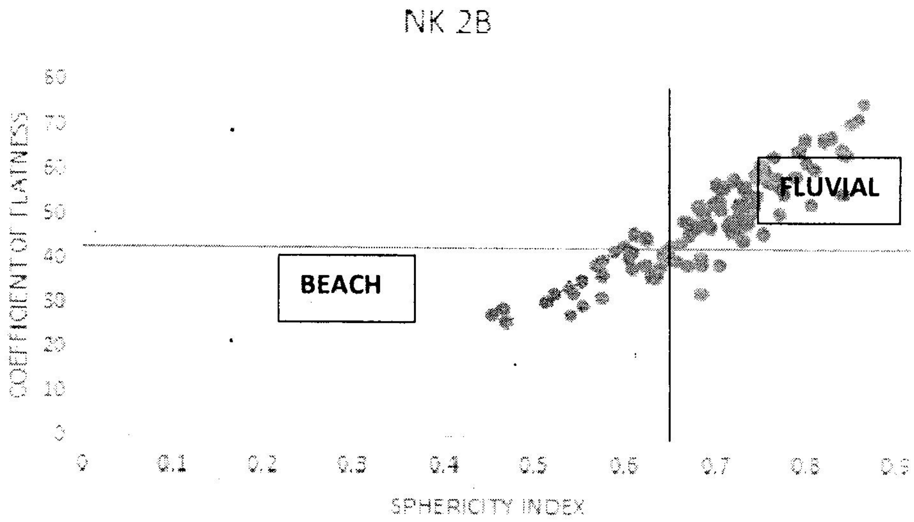


Fig 4.4.5: Co-efficient of flatness against Sphericity Index NK2B

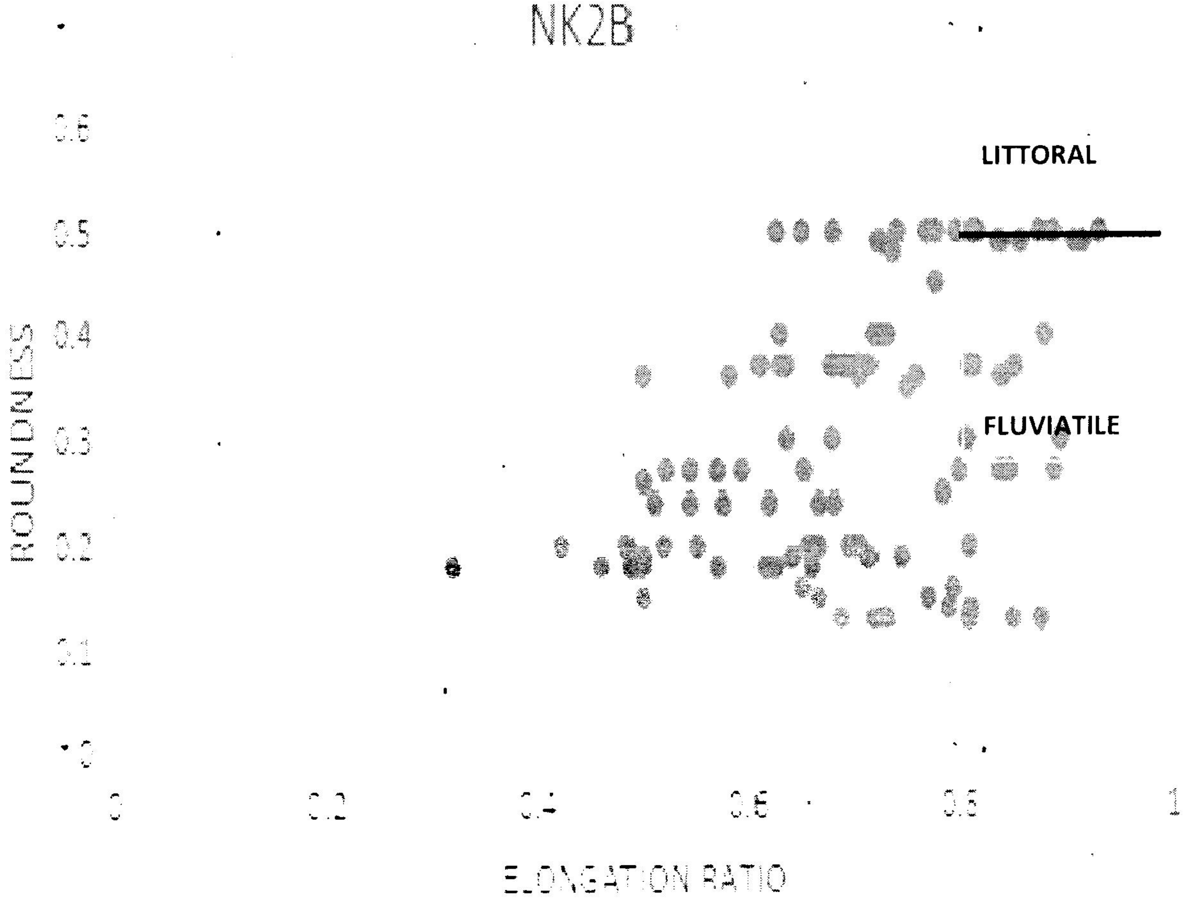


Fig 4.4.6: Roundness against Elongation ratio NK2B

4.5 Petrographic Study

The petrography of the sandstone revealed that 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. Monocrystalline quartz is dominant while polycrystalline quartz occurs in some of the samples studied.

4.5.1 Mineral composition and provenance

Quartz comprises an average of 70% of the framework of the sandstone. The next most abundant mineral is feldspars which shows an average of 23%. Table (4.9). The feldspar crystals are generally quite distinct from quartz grains as they exhibit low relief, and are cloudy (Plate I-IV). The feldspar is mainly microcline with little plagioclase. Microcline shows cross-hatched twinning under cross polarized light while plagioclase feldspar show albite twinning with narrow twin laminae under cross polarized light.

The photomicrograph of the samples obtained from petrographic analysis of rocks in the study area are shown in pictures:

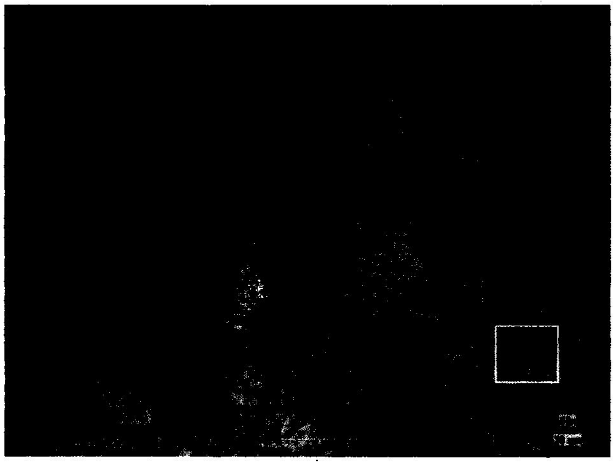


Plate I: Natako1C under XPL (Mg x50) Co-ordinate: (N07 51’ 49”, E006 45’ 14”). (M-microcline, Q-quartz, B-biotite)

Plate I: Natako1C under PPL (Mg x50) Co-ordinate: (N07 51’ 49”, E006 45’ 14”). (Q-quartz, B-biotite)

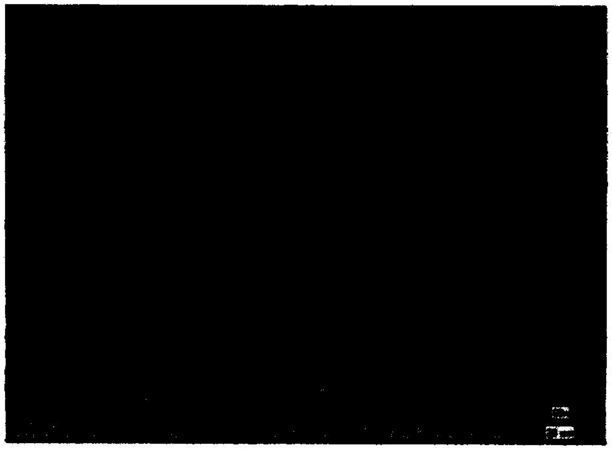


Plate II: Natako 2E under XPL (Mg x50) Co-ordinate: (N07 51’ 49”, E006 45’ 14”). (P-Plagioclase feldspar, Q-quartz)

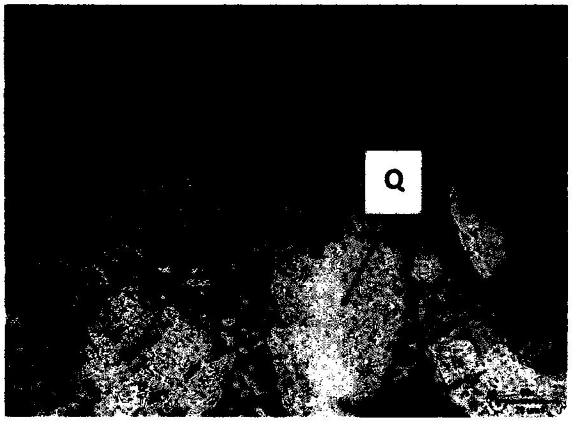


Plate II: Natako 2E under XPL (Mg x50) Co-ordinate: (N07 51’ 49”, E006 45’ 14”). (P-Plagioclase feldspar, Q-quartz)

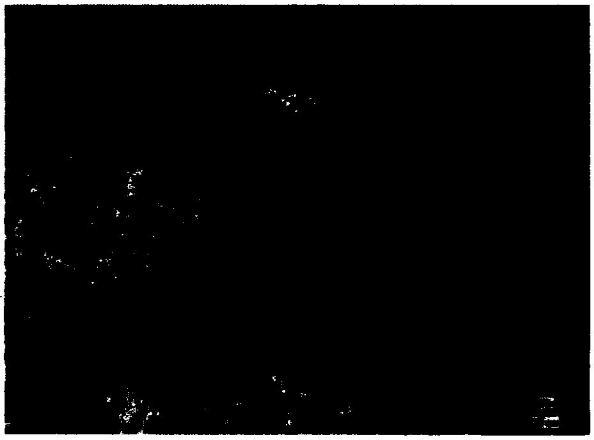


Plate III: Natako 2A under XPL (Mg x50) Co-ordinate: (N07 51' 49", E006 45' 14"). (Feldspar, Q-quartz, B-biotite)

Plate III: Natako 2A under XPL (Mg x50) Co-ordinate: (N07 51' 49", E006 45' 14"). (Feldspar)

Plate IIV: Nataco 1d under XPL (Mg x50) Co-ordinate: (N07 51' 49", E006 45' 14"). (M-microcline, Q-quartz,)

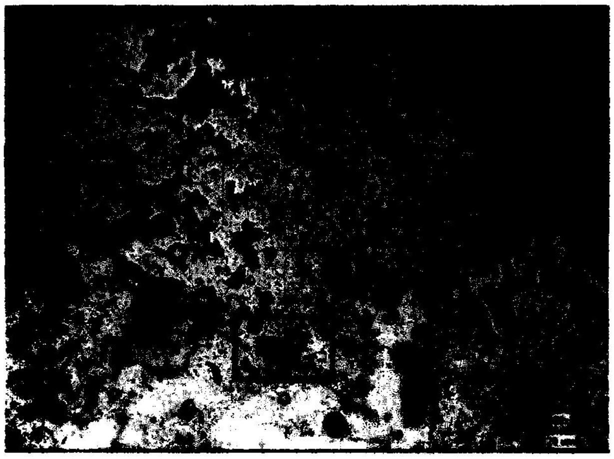


Plate IIV: Nataco 1d under PPL (Mg x50) Co-ordinate: (N07 51' 49", E006 45' 14"). (M-microcline)

Table 4.9: Results of Petrographic Analysis of Representative Sandstones from the Study Area Showing visual Estimated Mineralogical Composition in Percentages (Nwajide and Hoque, 1985; Igwe et al., 2013)

Sample Number	**Quartz (%)**	**Microcline Feldspar (%)**	**L.F (%)(lithic fragment)**	**MMI =Q/(F+L)**
NK1A	70	24	6	2.33
NK1C	59	36	5	1.49
NK1D	68	24	8	2.13
NKIG	71	20	9	2.44
NK2A	69	25	6	2.23
NK2E	70	23	7	2.33
JM1A	68	21	11	2.13
JM1B	72	20	8	2.57
AVERAGE	68	24	8	2.20

4.4.2 Maturity

MMI = **Mineralogical** maturity index.

The mineralogical maturity index is calculated thus;

$$\text{MMI} = \frac{\text{Proportion of Qtz}}{\text{Proportion of Fsp} + \text{Proportion of R.F}}$$

Since MMI value is less than 3.0 but greater than 1.0 as shown in table 4.9; hence the studied samples are said to be mineralogically immature sediments (Nwajide and Hoque, 1985; Igwe et al., 2013).

Table 4.10: Maturity scale of Sandstone: Limiting % of Q and (F + RF) MI and maturity stage (Nwajide and Hoque, 1985; Igwe et al., 2013).

Q =≥ 95% (F + RF) = 50%	MI = ≥ 19 supper mature
Q =95-90% (F + RF) = 5-10%	MI = 19 - 9.0 sub mature
Q = 90-75% (F + RF) =10-25%	MI =9.0-3.0 sub mature
Q =75-5O% (F + RF) = 25-50%	MI =3.0-1.O immature
Q = < 50% (F + RF) > 50%	MI ≤ 1 Extremely immature

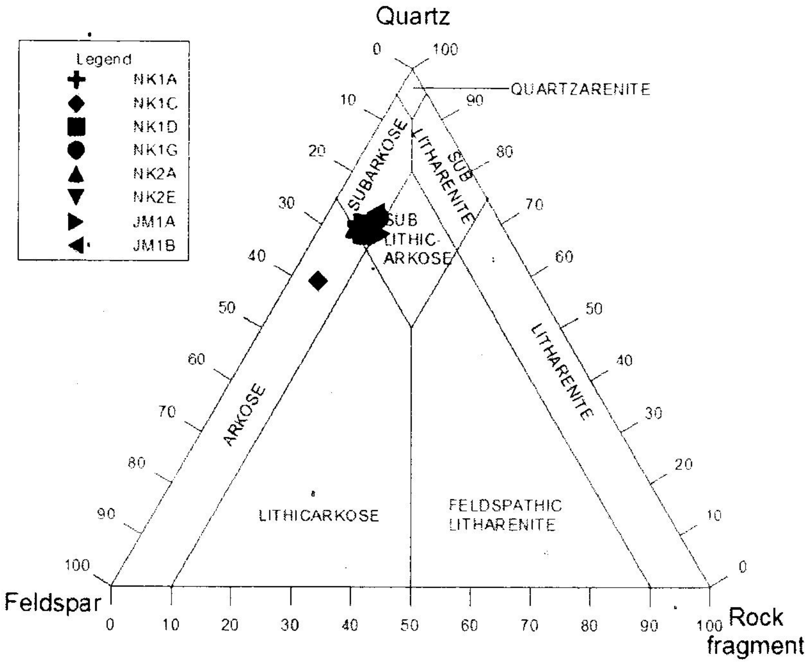


Figure 4.5; QFL Ternary Plot of Sandstone from all the Locations in the Study Area (After Folks, 1974), indicating that the sandstones are sub arkose.

4.6 Heavy Mineral Analysis

The dominant accessory heavy minerals are composed mainly of opaque minerals magnetite and hematite. The non-opaque minerals include rutile, zircon, and chlorite are also present. Two main mineral groups: the opaque and non opaque were observed in the sandstone samples analysed. From the modal analysis of detrital grains of heavy minerals carried out on each slide, the opaque minerals (magnetite and hematite) account for high percent in total amount. The non-opaque minerals include zircon, rutile, tourmaline, muscovite, monazite, diopside and garnet. Zircon and rutile are present in significant amount as dominant non opaque, ultrastable minerals. The above association reflects 'a source area dominated by igneous and metamorphic origin, Tourmaline occurs only in few samples. The low abundance of tourmaline may indicate immaturity. Zircon is recognized in thin section by its high relief, colourless appearance, prismatic habit as well as its very high interference colours. Rutile occurs as small reddish- brown prismatic to a cicular crystals with very high relief. Tourmaline is identified by its high relief, pleochroic nature and absence of cleavage with good prismatic habit. It is usually black but sometimes green and shows reddish colour on rotation.

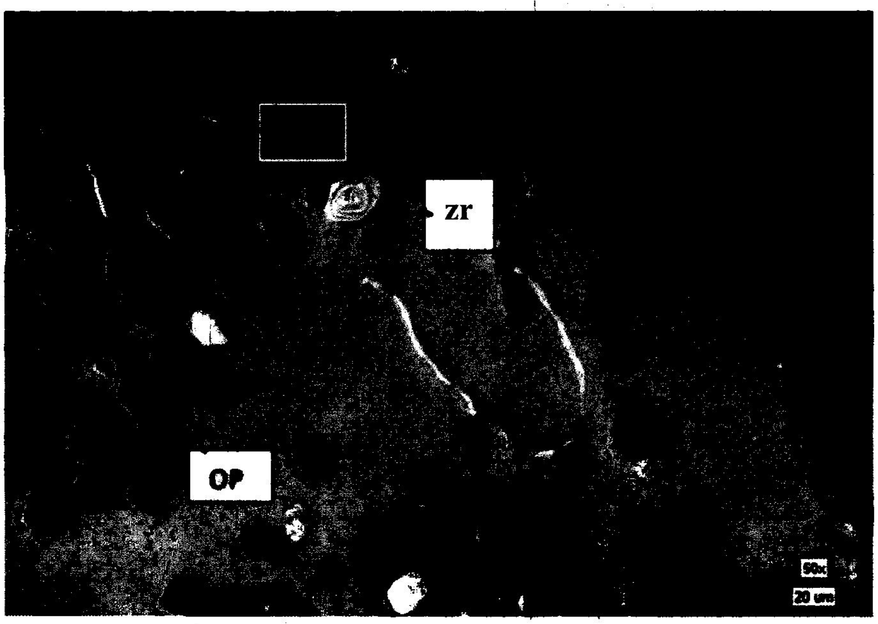


Plate V : Photomicrograph of Heavy mineral of Lokoja sandstone Natako 1B (N07^0 51' 49", E006^0 45' 14"). (rutile, zircon)

Plate VI : Photomicrograph of Heavy mineral of Lokoja sandstone Natako 1A (N07^0 51' 49", E006^0 45' 14"). (zircon, opaque minerals)

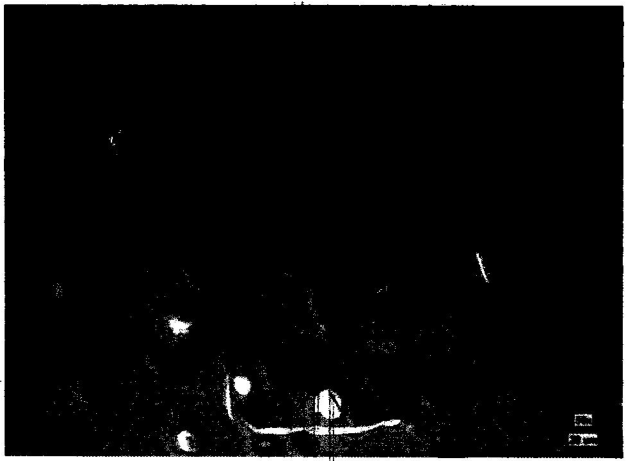
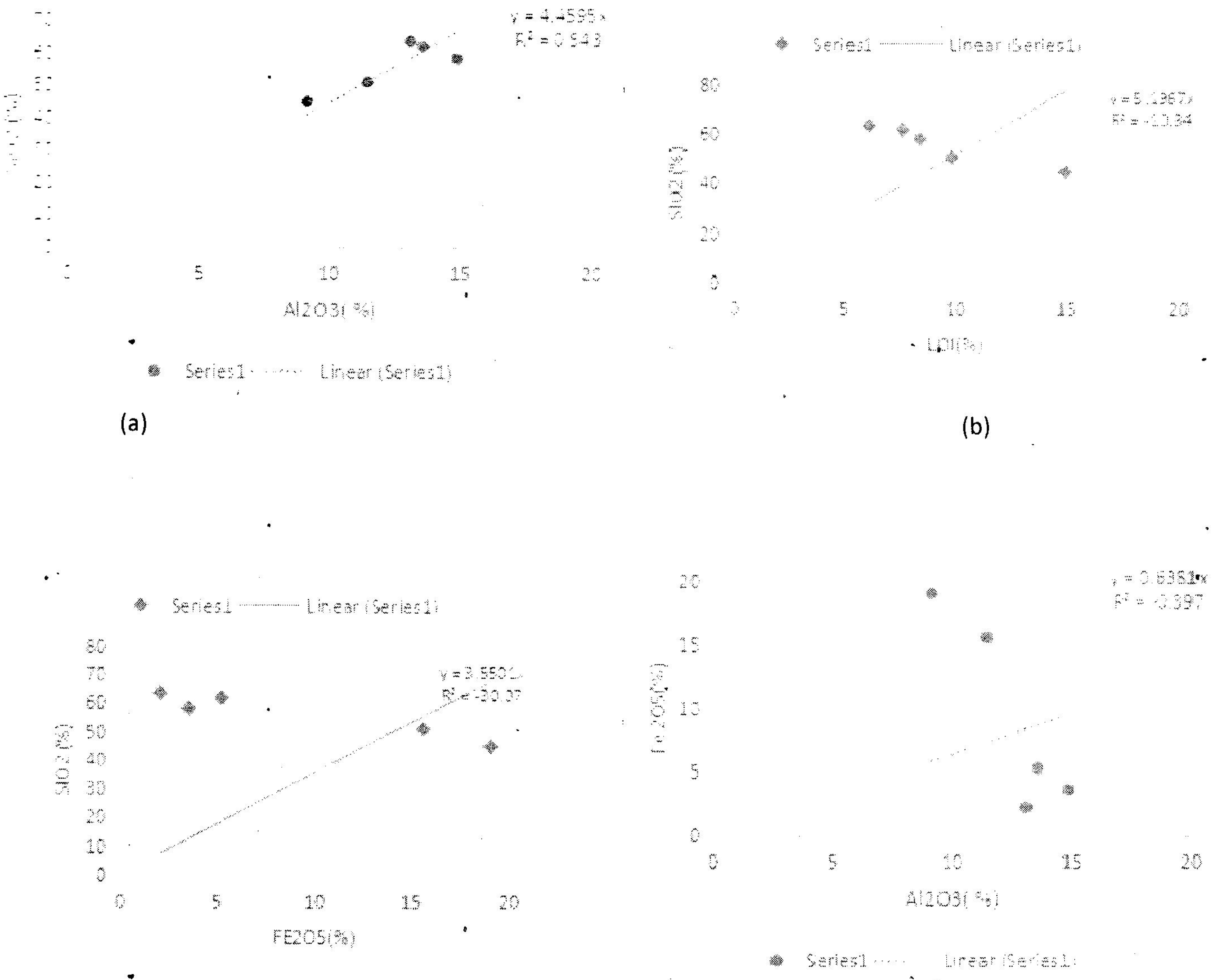


Plate VII : Photomicrograph of Heavy mineral of Lokoja sandstone Jimeta 1A (N08^0 2' 49", E006^0 45' 57"). (Rutile, Zircon, opaque minerals)

4.7 Geochemical Data: The results of the major oxides are shown in Table 4.9.. Generally, there are lower values of TiO ; CaO, NaO, PbO and MnO. The K_2O content of the Lokoja sandstone indicates slightly enriched K-feldspar or illite (Akpokodje et al., 1991; Okunlola and Idowu, Titanium is mainly concentrated in phyllosilicates (Condie et al., 1992) and is relatively immobile compared to other elements during various sedimentary processes and may strongly represent the source rocks (McLennan et al., 1993). The sandstone of Natako and Jimeta Formation shows lower TiO_2 values, which .suggests more felsic material in the source rocks.The low concentrations of Fe_2O_5 +TiO_2 +MgO (av 63.93% for Natako and Jimeta sandstone); imply that the sediments are chemically inert and non-corrosive. For the associated claystone, such concentration may offer good quality kaolin (Ojo et al. 2011).Cross plots of % SiO_2 versus Fe_2O_3(Fig. 4.6a); SiO_2 versus Al_2O_3 (Fig. 4.6b) and SiO_2 versus LOI (Fig. 4.6c) all indicate negative correlation. These demonstrate influence of weathering processes through enrichment of silica and depletion of Fe and Mg as well as the decrease in LOI with increasing weathering and maturity of these sediments. The negative correlation between $SiO_2$and Al_2O_5 is also an indication of the fact that most of the silica is present as quartz grains (Tijani et al., 2010). However, the positive correlation between Fe_2O_3 and Al_2O_3 (Fig. 4.5d) is an indication of a common source. Positive correlations with Al_2O_3 are shown by most of the major elements. It can be concluded, therefore, that the enrichment of other major elements in the Lokoja is related to the enrichment of ferromagnesian minerals and feldspars probably due to short transportation of the source material Textural studies on the Lokoja Formation indicate a fluvial setting for the associated sandstones and pebbles. The sandstones are medium to coarse grained, poorly sorted and mainly sub arkose. Heavy mineral assemblages are mainly; zircon, rutile, tourmaline and staurolite, with ZTR index ranging from 62 to 78%, indicating immature to slightly matured sandstone with a source in adjoining basement complex. The ternary plots of the framework elements of the sandstone indicate passive margin, continental block provenance and deposited in humid paleoclimatic environment. Whole rock elemental analysis of the investigated samples revealed that SiO_2 content of the Lokoja sandstone are on the average 56%. The provenance is majorly Felsic igneous provenance.

Table 4.11 Geochemical Analysis result

Oxide composition	NK1D	NK2A	JM1A	NK2D	NKIB
SiO_2	44.87	63.51	50.90	61.90	58.07
TiO_2	1.59	0.83	2.06	1.18	1.20
Al_2O_3	9.14	13.10	11.45	13.56	14.86
Fe_2O_5	19.08	2.11	15.61	5.24	3.56
CaO	4.27	4.32	3.65	4.16	5.29
MgO	2.5	2.61	1.98	2.08	2.30
Na_2O	1.83	3.44	2.04	2.10	3.17
K_2O	0.67	2.87	1.46	1.20	2.19
MnO	0.011	0.054	0.001	0.001	0.001
V_2O_5	0.048	0.01	0.079	0.053	0.047
Cr_2O_3	0.067	0.057	0.039	0.11	0.059
CuO	0.096	0.063	0.084	0.064	0.093
NiO	ND	ND	ND	0.007	0.16
As_2O_3	ND	0.007	ND	0.005	0.10
$Zr0_2$	0.35	0.093	0.40	0.12	0.094
BaO	0.08	0.33	ND	0.07	0.01
PbO	ND	0.062	ND	0.24	0.27
ZnO	0.03	ND	0.031	0.01	0.11
SrO	0.30	0.330	0.30	0.23	0.01
Rb_2O	0.068	0.087	0.088	0.044	ND
Ga_2O_3	ND	0.01	0.02	0.02	ND
L.O.I	14.90	6.10	9.80	7.60	8.40
total	99.9	99.9	99.9	99.9	99.9



(a)

(b)

(c)

(d)

Fig 4.6: cross plots of major oxides: (a) SiO_2 against Fe_2O_3. (b) SiO_2 against Al_2O_3. © SiO_2 against LOI. (d) Fe_2O_5 against Al_2O_5

	NK1D	NK2A	JM1A	NK2D	NK1B
Discrimnant 1	23.63	12.808	19.541	15.315	15.149
Discrimnant 2	-9.558	-11.098	-8.8523	-5.922	-9.0285

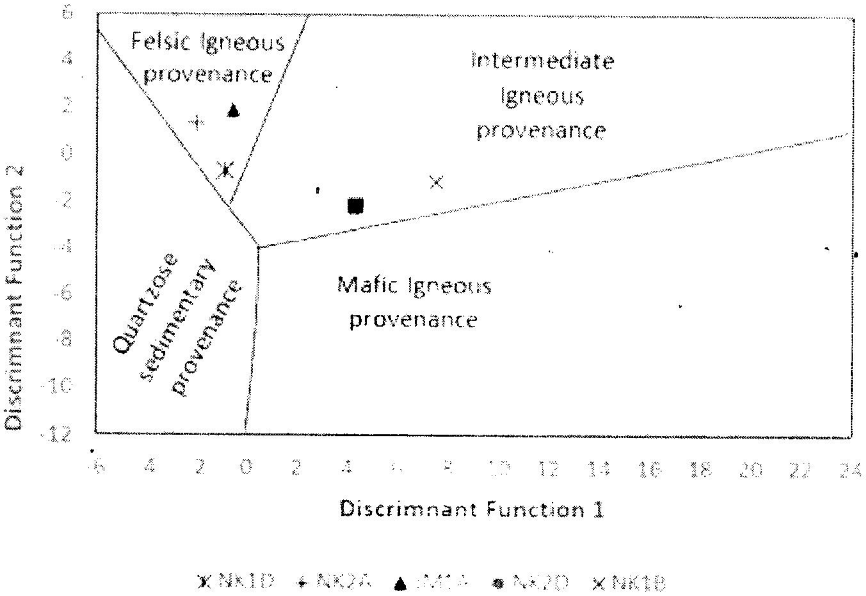


Fig 4.7 Discriminant function diagram for sedimentary provenance of the sediments in Lokoja Formation using the major elements. The discriminant function are calculated as follows

Discriminant 1: = (-1.773 * TiO_2) + (0.607 * Al_2O_3) + (0.760 * Fe_2O_3) + (1.500 * MgO) + (0.616 *CaO) + (0.509 * Na_20) + (-1.224 * K_20) + (-0.090)

Discriminant 2: = (0.444 * TiO_2) + (0.070 +Al_2O_3) + (-0.250 * Fe_2O_3) + (-1.142 *MgO) + (0.438 * CaO) + (1.475 * Na_20) + (-1.475 *K_20) + (-6.861)

4.8 Discussion of Results

The result of the grain size analyses show that the Lokoja sandstones are generally poorly sorted, medium to coarse grain in texture indicating both less winnowing and abrasion. Consequently, the grains probably retained original configuration and texture. This is an indication of rapid deposition and short distance of transportation reflecting a fluvial setting (Friedman 1979). The result of simple skewness measure and sorting measure reflects a positively skewed and poorly sorted grains indicatives river sands (Friedman, 1979). Kurtosis plots indicate a range from platykurtic to leptokurtic.

The detrital mode of the sandstone is composed of an average of 70% with a range from 59% to 74% quartz. The feldspar grains range from 16 to 36% with an average of 23% while the average for lithic fragment is 8% with a range of 1 to 11% (Table 4.4). The mineralogical maturity of the sandstone was evaluated using the formulae proposed by Pettijohn (1975) which is based on the Q/(F+L) ratio (Table 4.10). The maturity indices indicated that the sandstone is immature, due to its high feldspar content. In order to classify the sandstone, detrital mode of Quartz (Q), Feldspar (F) and Lithic fragment (L) was plotted on Folk's (1974) QFR Ternary diagram (Fig. 4.4). This scheme classifies the sandstone as Sub Arkose.

The heavy mineral suites are indicative of igneous and metamorphic sources, perhaps, the southwest and north central Basement Complex terrains. The calculated mineral maturity index (MMI) and ZTR indices suggest mineralogically immature to sub mature sediments.

CHAPTER FIVE

CONCLUSIONS

Findings from this study revealed the occurrence of basal conglomerates, massive to pebbly sandstones, sandysilt and claystone units with overlying laterite and ironstone capping which shows a fining upward sequence indicating a fluvial environment for the Lokoja Sandstones. Results of grain size analysis show that, the sandstones range from medium to coarse grain, poorly sorted suggesting less winnowing, abrasion, hence the grains retain the original configuration and texture. This suggests a fluvial setting for the Lokoja Sandstones. The pebble morphometric analyses indicate a fluvial depositional environment for the Lokoja Sandstone. The scatter plots of Roundness versus Elongation ratio delineate angular to sub-rounded pebbles. The low roundness value [0.3] is an indication of fluvial environment and short transportation history. The heavy mineral suites indicate that the sediments were derived from the basement rocks probably from the southwestern and the north central domains.

The textural assessment of Lokoja Sandstone revealed poorly sorted sub-arkose immature sandstone with the quartz showing both monocrystalline and polycrystalline crystal forms with more of the undulatory forms which depict its derivation mainly from metamorphic origin. Abundance of feldspathic grains is a reflection of its closeness to the provenance which is perhaps located in the north central basement domain on account of the paleocurrent azimuth trend towards the southeast.

Thin section study shows that the Lokoja Sandstones are mineralogical immature and classified as sub arkose. The framework composition suggests short transportation.

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APPENDICES

Plate I: Photomicrograph of Lokoja sandstone Natako 1C under PPL and XPL (Mg x50)

Plate II: Photomicrograph of Lokoja sandstone Natako 2E under PPL and XPL (Mg x50)

Plate III: Photomicrograph of Lokoja sandstone Natako 2A under PPL and XPL (Mg x50)

Plate IV: Photomicrograph of Lokoja sandstone Natako 1D under PPL and XPL (Mg x50)

Plate V:-Photomicrograph of Heavy mineral of Lokoja sandstone Natako 1B

Plate VI : Photomicrograph of Heavy mineral of Lokoja sandstone Natako 1A

Plate VIII : Photomicrograph of Heavy mineral of Lokoja sandstone Jimeta 1A