TEXTURAL AND GEOCHEMICAL INVESTIGATION OF MOUNT PATTI SEDIMENTS, LOKOJA, SOUTHERN BIDA BASIN.

by

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A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF GEOLOGY, FACULTY OF SCIENCE, FEDERAL UNIVERSITY OYE-EKITI

IN

Partial Fulfilment of the Requirements for the Award of Bachelor of Science (B.Sc.) Degree in Geology

February, 2019.

Certification

This is to certify that this research project on theTEXTURAL AND GEOCHEMICAL INVESTIGATION OF MOUNT PATTI SEDIMENTS, LOKOJA, SOUTHERN BIDA BASIN carried out by DARAMOLA EMMANUEL OLUWASEUN with matriculation number GLY/14/2254 under the supervision of PROF. O. J. OJO has been approved as meeting on of the requirements 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.

Project Supervisor   Date........................ 19/02/2019

Head of Department   Date................................

External Examiner Prof S.A. Opeloye   Date........................... 25/02/19.

Dedication

I dedicate this work to God Almighty who has been the source of my strength throughout this program and the course of this project. I also dedicate this work to my Mother; Mrs. Elizabeth Daramola who has encouraged me all the way and gave all it takes to finish that which I have started. To all my siblings and friends.

Acknowledgements

Overall appreciation goes to Almighty God who has provided all that was needed to complete this project.

My deepest gratitude goes to my supervisor, Prof. O. J. Ojo, whose contribution and constructive criticism has pushed me to expend the kind of efforts I have extended to make this work as original as it can be. Thanks to him I have experienced true research and my knowledge on the subject matter has been broadened.

My utmost regards goes to my Mother who painstakingly gave me her financial support to ensure the perfection of this work. I also appreciate my siblings and my supportive friends, who stayed with me to make this work a successful one.

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Abstract

The Southern Bida Basin is a part of the Middle Niger Basin (also known as the Bida Basin). The bida basin is NW-SE intracratonic basin which extends from Kontagora (in the North) to south of Lokoja (in the south). The sequence exposed at the study area, Mount Patti, belongs to the Lokoja sub-basin, southern bida basin. The conglomerate, sandstones and claystone of the Lokoja and Patti Formation as well as the Ironstone facies of the Agbaja formation are exposed at the study area. Sampling was done to cover the three formations of the southern Bida Basin. The study aimed at using geochemical approach to deduce Maturity of the sandstone and conglomerate of the Lokoja and Patti Formation, Class of sandstone, Provenance of the sediments, Paleoweathering and resource potential of the ironstone facies of the Agbaja Formation. The depositional environment and textural characteristics of the sandstone facies was also determined using Grain Size Analysis. A total of 8 fresh outcrop samples were obtained from the study area. The samples were subjected to detailed lithologic description by visual examination. Geochemical analysis was done using X-ray fluorescence (XRF) to determine major oxides. Weathering indices of chemical index of alteration has a range of 60.05-99.88% which indicate moderate to intense chemical weathering in the source area. Log (SiO_2/Al_2O_3) vs Log (Fe_2O_3/K_2O) diagram for sandstone classification indicate that the sandstones are rich in iron. Result of the XRF analysis in the sandstone facies and conglomerate of Lokoja Formation, Patti Sandstone and Claystones shows high Iron (Fe_2O_3) content ranging from 2.6% to 37.51% and Aluminum (Al_2O_3) and silica (SiO_2) contents are also fairly high ranging from 3.99% - 17.04% and 34.70% - 85.61% respectively. The Calcium (CaO) and Magnesium (MgO) content ranges from 0.14%-0.61 and 0.011%-0.18% respectively. The TiO_2 values ranges from 0.51%-3.72% and MnO exist in negligible amount (<0.001%).

The grain size analysis of the sandstone facies indicated that they are fine to very coarse grained, poorly sorted, strongly coarse to fine skewed and very platykurtic to platykurtic which implies textural maturity of the sediments of Patti sandstone. The sandstones are deposited in fluvial environment. The geochemical variation and discriminant bivariate plots revealed the matured, litharenite to sublitharenite sediments deposited in a continental environment were derived from intermediate igneous provenance and quartzose sedimentary provenance and have been moderately to highly weathered.

Geochemical investigation of Mount Patti Oolitic and Pisolitic iron ore was carried out in order to provide comprehensive geochemical data and and resource potential of the ironstone facie in the studied area. The investigation involved major elements and grade determination. Result of the XRF analysis shows high Iron (Fe_2O_3) content ranging from 79.97% to 82.13%. Aluminum (Al_2O_3) and silica (SiO_2) contents are also fairly high ranging from 5.40% - 3.48% and 0.72% - 0.66% respectively. In addition, the ores contain other impurities such as CaO, MgO, TiO_2 and MnO which exist in considerable negligible amounts.

CHAPTER ONE

INTRODUCTION

Lokoja is the capital of Kogi State. It is located at the intersecting point of longitude $7^0 49$'N and latitude 6^0 44'E (Okpoko, 1993). The town lies on the western bank of the River Niger at an altitude of 45 – 125 metres (Alabi, 2009). Lokoja is also approximately 162 kilometres from Abuja the Federal Capital Territory (FCT) of Nigeria. In other words, the town is strategically located as it is a gateway to the Northern and Southern parts of the country (Alabi, 2009). The study area lies on the slope of a hill known as Mount Patti which is above 400 metres above sea level (Figure 1.1). The three formations of the southern Bida Basin are exposed at Mount Patti as a result of upliftment proceeding deposition. This work reveals the textural and geochemical characteristics of the outcropping sediments in parts of the Southern Bida Basin exposed at Mount Patti. The major oxide variation reveals the maturity, Paleoweathering condition of the provenance and the resource potential of the Agbaja ironstone facies.

1.1 Aim and objectives of the study

The aim of the whole work is to determine the sedimentological and geochemical characteristics of the Lokoja, Patti and Agbaja formation at the Mount Patti. The objectives includes

i. To ascertain the textural characteristics of the sandstones in the study area
ii. To determine the provenance and Paleoweathering condition of the sediment of the study using geochemical data
iii. To examine the resource potential of the ironstone facies exposed at Mount Patti

1.2 Physiography

The terrain of the region comprises dissected undulating plains on one hand, and lofty hill masses and mesas on the other. The plains have developed on the hummock of Basement Complex, due t o the removal of the overburden Cretaceous sediments by erosion, while the hill masses and mesa s have formed from the sedimentary Formation, because of their resistant lateritic/ironstone cappi ng. Lokoja, which lies on a plain element bordering the Niger River, is sandwiched between the N iger River and one of the main high plateau ridges, the Mount Patti. The ridge, which is star-shap ed, reach an altitude of 400 m, and together with the Niger River, had streamlined the Lokoja tow n to a linear pattern.

1.3 Climate

Lokoja, in Kogi State experiences two types of seasons namely; the rainy and the dry seasons. The wet or rainy season lasts from May to September each year, with the highest period or months of rainfall being between August and September. The annual average rainfall ranges from 1000mm to 1500mm, while the mean annual humidity is about 70% (Kogi state Tourist Guide, n.d). On the other hand, the dry season usually sets in from October to April. Lokoja experiences an average sunshine hour of 6.7 per day. Thus, Lokoja generally experiences hot weather condition and this could prevail all through the year. However, it is important to note that during the dry months of November, December, January and February, the temperature experienced in Lokoja could be as high as 33^0c to 36^0c (EJPAU, 2007).

1.4 Vegetation

The vegetation of the area falls within the Guinea Savannah zone. There are tall grasses, shrubs and trees with very big roots and trunks in the study area. These grasses and trees are greenish and blossom during the wet seasons, but wither during the dry seasons, thereby leaving the land relatively open. Some of the trees found in the area are Shea butter- *Vitellaria paradoxa*, oil bean- *Spakia* coined, locust bean–*Parkia Biglobosa* etc (www.onlinenigeria.com). From field work observation the dominant tree on the Mount Patti hill is the Boabab tree. Given the existence of geologic features like sedimentary rocks and aluminum along the river beds, farming activities are carried out extensively and this helps in agricultural productivity (www.kogistatenigeria.org, 2009).

1.5 Soils in the Study Area

From field work observations, the soil within the study area is mostly loamy having composition of silt, sand and clay. The study area is very close to the Nigerian Basement complex, if not part of it. From field observations, the soil type in the area seems to have been formed from the weathering of the basement complex rocks. And as such, would support agriculture to a high extent as a result of the minerals incorporated in the soil from the original rocks they weathered from.

1.6 Occupation of the Inhabitants of the Study Area

Agriculture is a surviving occupation in Lokoja since the 19th century, the agricultural practice in volves grazing of livestock and cultivation of food crops (Nigeria.gov.ng). The Ironstone (major ore of Iron) in the southern Bida Basin has made mining a minor occupation in the past few year. The Iron stone is being mined for the production of Aluminum and Steel.

1.7 Previous Study

Nton and Adamolekun (2016) reported that Textural studies on the Lokoja and Patti Formations indicate a fluvial setting for the associated sandstones and pebbles. The sandstones are medium to coarse grained, poorly sorted and mainly arkose for the basal Lokoja Formation and subarkose for successive sequence and that of the Patti Formation. 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 content of the Lokoja sandstone are on the average 60% while that of Patti Formation is 75%; thus indicating more mature sediment of the Patti sandstone facies. The composition, provenance, weathering, tectonic setting and redox proxy of the Campanian sandstone of Lokoja-Basange Formation, Middle Niger (Lokoja sub-basin) southern Nigeria has been assessed using integrated mineralogical, geochemical and pore water chemistry approach (Akinyemi *et al.,* 2014). The medium to coarse grained clastic units exposed along Auchi-Igarra Road consists of sandstone intercalated with kaolinitic clay materials at the basal part. The sandstone bodies are moderate to poorly sorted suggesting deposition in a low energy setting, possibly in a shelf or floodplain. (Akinyemi *et al.,* 2014) The colour variations of the sandstone bodies are indication of differences in the cementing materials. Two specific geochemical intervals were established based on the mineralogical composition. The first interval revealed quartz and kaolinite as major crystalline minerals with traces of hematite. The second geochemical interval showed quartz and kaolinite as the major crystalline minerals with minor quantities of grossite and halloysite. The geochemical datasets revealed mature lithic arenites including sub-greywacke and protoquartzites clastic sediments. The inverse correlation between Eh and EC, TDS and Mg (at 0.05 significant levels) in the studied sandstone samples suggest well oxygenated environment of deposition. The high CIA, PIA, and CIW indices obtained revealed high detrital input dominated by strong chemical weathering. This ultimately led to the formation of clay minerals by hydration and leaching of all major cations, such as Ca^{2+}, K^{+}, and Na^{+}, present in feldspar minerals (Akinyemi *et al.,* 2014). The average MIA values in both profile A and B are indicative of intense to extreme weathering of mineralogical component of the detrital materials from the source areas. The studied Campanian sandstones of Lokoja-Basange Formation are plotted in the field of the active and passive continental margin settings (Akinyemi *et al.,* 2014). The mean ratio of Ti/Zr also suggests active and passive continental margin settings. Moreover, the higher ratios of La/Y and La/Th and corresponding lower ratios of La/Co and Th/Co indicate felsic source rock. Furthermore, the lower ratios of Ba/Sr, Cr/Zr, Ti/Zr and higher ratio of Zr/Y probably suggest felsic source rock. The low Cu/Zn ratios of studied sandstone samples suggest deposition under oxidizing conditions (Akinyemi *et al.,* 2014).

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 (Madukwe et al., 2014). 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 (Madukwe et al., 2014). 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. The source area is recognised by semi arid to arid conditions resulted moderate to strong weathering affecting due to CIA and MIA values (Madukwe et al., 2014). (Imrana and Haruna 2017) Koton Karfe oolitic iron ore has an average grade of 47.43% and high percentages of gangue (silica and Alumina), impurities and deleterious elements of phosphorous and sulphur above permissible limit for commercial exploitation (Imrana and Haruna 2017). Therefore the Koton Karfe iron ore occurrence is of low grade. The petrographic studies revealed that the Koton Karfe iron ore contain goethite as the major iron ore mineral with some appreciable amount of hematite and little quartz as the gangue mineral (Imrana and Haruna 2017).

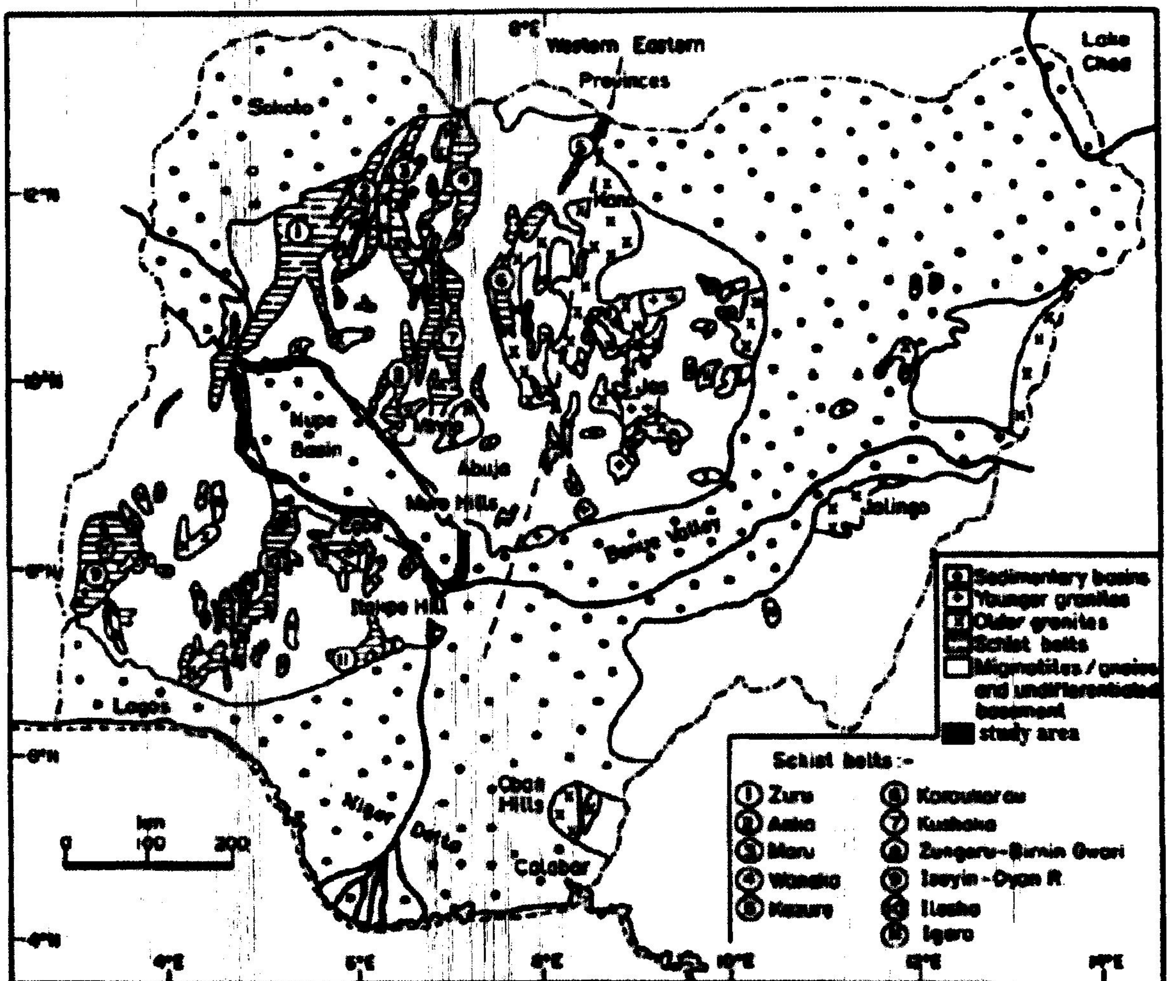

Figure 1.1: Geologic map of Nigeria showing the lithopetrological units and the study area (modified from Obaje 2009)

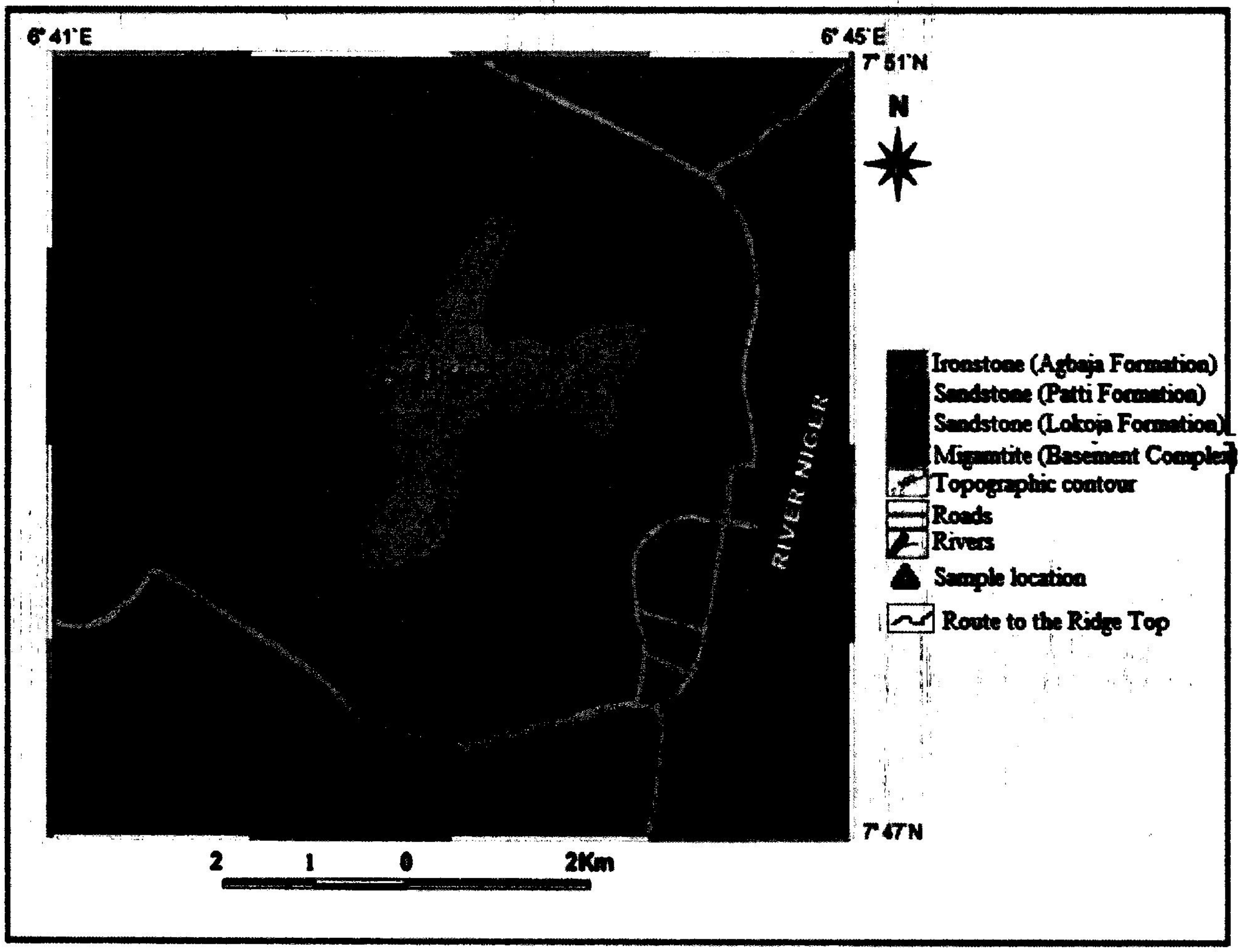

Figure 1.2: Geologic map of the study area modified from Federal Surveys of Nigeria, 1963, Sheets 141 Lokoja NW, NE

CHAPTER TWO

LITERATURE REVIEW

2.1 Tectonic Setting

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

a. The Niger River with its flood plain and distributaries,

b. A belt of mesas and buttes, and

c. The plains.

The Niger River runs ESE in the southern marginal area of the basin. Its flood plains are broad and marked in most areas by a series of elongated ponds running parallel to the river. The belt of discontinuous mesas runs from an area about 16 km east of Mokwa to Lokoja and SW Dekina covering about 10% of the basin. The top lies between 260 and 500 meters around the Niger/Benue confluence areas. Flat lying to gently rolling plains covers about 70% of the basin. The plains lie between 60 and 180 meters above sea level in the Lokoja area. Sediment thickness in the Middle Niger Basin is estimated to be between 3000 and 3500 meters (Whiteman, 1982; Braide, 1992). The basin occupies a gently down warped trough. The epeirogenesis responsible for the basin genesis seems closely connected with the Santonian tectonic crustal movements which mainly affected the Benue Basin and SE Nigeria. The buried Basement complex probably has a high relief (Jones, 1955) and the sedimentary formations have been shown to be about 2000 metres thick by gravity survey (Ojo and Ajakaiye, 1976), constituted of posttectonic molasse facies and thin marine strata, which are all unfolded. Borehole logs, Landsat images interpretation, and Geophysical data across the basin suggest that it is bounded by a NW-SE trending system of linear faults (Kogbe *et al.*, 1983). Gravity studies also confirm central positive anomalies flanked by negative anomalies (Ojo, 1984; Ojo and Ajakaiye, 1989). This pattern is consistent with rift structures as observed in the adjacent Benue Trough/Basin. A detailed study of the facies indicates rapid basin-wide changes from various alluvial fan facies through flood-basin and deltaic facies to lacustrine facies (Braide, 1992). Consequently, a simple sag and rift origin earlier suggested may not account for the basin's evolution. According to Braide (1992) paleogeographic reconstruction suggests lacustrine environments were widespread and elongate.

Lacustrine environments occurred at the basin's axis and close to the margins. This suggests that the depocenter must have migrated during the basin's depositional history and subsided rapidly to accommodate the 3.5 km thick sedimentary fill. The basin's strata are Late Cretaceous (Campanian –Maastrichtian) in age and were named the Nupe Sandstone by Russ (1930). However, the Sandstone is referred to by Adeleye and Dessauvagie (1972) as a Group (instead of a formation). Adeleye (op. cit.) sub-divided the Group into four formations: Bida Sandstone (oldest), Sakpe Ironstone, Enagi Siltstone and Batati Ironstone (youngest). A lateral facies variation occurs in the basin. Around Lokoja, the sequence was usually referred to as the Lokoja Sandstone (Jan du Chene *et al.*, 1978; Idowu and Enu, 1992). However, the Sandstone is only partly equivalent to the Nupe Sandstone (Dessauvagie, 1975) and is overlain by Patti Formation (Jones, 1958). The Bida area and Lokoja area are considered separately as the stratigraphy are different. The Lokoja, Patti and Agbaja Formations occur as the three formational units in the southern Middle Niger basin.

The Lokoja Formation consists of pebbly clayey grit and sandstone, coarse-grained cross bedded sandstone, and few thin oolitic iron stones. A basal conglomerate of well-rounded quartz pebbles in a matrix of white clay is rarely exposed. Its thickness depends on the relief of the underlying Basement Complex floor and varies between 100 and 300 metres (Dessauvagie, 1975) The Patti Formation is a sequence of fine to medium-grained, grey and white sandstones, carbonaceous siltstone, clay stone, shale and oolitic and Concretional ironstone. Thin coal seams may be present and white gritty clays are common. The maximum exposed thickness is 70 m (Jones, 1958), while the oolitic ironstones ranges from 7- 16 m thick. A Maastrichtian (and possibly Senonian) age was thus assigned to it based mainly on correlation with other formations e.g. the Nupe Sandstone and Enugu Shale of Campano Maastrichtian age. Jan du Chene (1979) have recorded a palynomorph assemblage and a foraminifera fauna respectively from the Lokoja area. The micro fauna is considered to be a marsh assemblage. The palynomorphs are made up mainly of pollen and spores, the assemblage of which is indicative of a Maastrichtian age (Adediran and Jan du Chene, op. cit.). Dessauvagie (1975) indicates that Patti formation yielded fossil plants (from the carbonaceous beds) and dates the formation as Campanian to Maastrichtian. More recently, Ojo (2009) reported a rich and well preserved palynomorph assemblage from the black shale outcrop samples of the Patti Formation collected between Kotonkarfi and Abaji and between Lokoja and Agbaja. The outcrop is constituted by marine dinocyst and the more copious continental sporomorphs. Ojo (2009) reasoned that the assemblage is a confirmation evidence for the Late Cretaceous Tethys – South Atlantic connection through the Nupe Basin. The Agbaja Formation consists of oolitic ironstone and occurs as the topmost stratigraphic sequence in the Agbaja Plateau, on mesas around the southern part of the basin and the Lokoja area.

2.2 Stratigraphy

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 (Jones, 1955, 1958; Adeleye, 1973, 1974; Braide 1992 and Ladipo et al. 1994). 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).

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 (Obaje, 2009). The fine grained sandstones, siltstones and clays represent flood plain overbank deposits. However, Petters (1986) reported on the occurrence of some diversiy arenaceous foraminifera (Fig. 7.3) 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

Outcrops of the Patti Formation occur between Koton-Karfi Abaji and Ahoko. 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 stratified with occasional soft sedimentary structures (e.g. slumps),.and other structures such as wave ripples, convolute laminations, load structures (Obaje, 2009). Interbedded claystones are generally massive and kaolinitic, whereas the interbedded grey shales are frequently carbonaceous (Obaje, 2009). The subsidiary sandstone units of the Patti Formation are more texturally and mineralogically mature compared with the Lokoja sandstones. The predominance of argillaceous rocks, especially siltstones, shales and claystones in the Patti Formation requires suspension and settling of finer sediments in a quiet low energy environment probably in a restricted body of water (Braide, 1992). The abundance of woody and plant materials comprising mostly land-derived organic matter, suggests prevailing fresh water conditions. However, biostratigraphic and paleoecologic studies by Petters (1986) have revealed the occurrence of arenaceous foraminifera in the shales of the Patti Formation with an assemblage of Ammobaculites, Milliamina, Trochamina and Textularia which are essentially cosmopolitan marsh species similar to those reported in the Lower Maastrichtian marginal marine Mamu Formation (the lateral equivalent) in the adjacent Anambra Basin (Gebhardt, 1998). Shales of the Mamu Formation on the south. side of the Anambra Basin are commonly interbedded with chamositic carbonates and overlain by bioturbated siltstones, sandstones and coal units in coarsening upward cycles towards the north side of the basin (Akande et al., 1992). This sequence is overlain by herringbone crossbedded mature sandstones of the Ajali Formation (MiddleMaastrichtian) in the northern fringes of the basin hence providing strong evidence for shallow marine, deltaic to intertidal depositional environments for the Maastrichtian sediments of the Anambra Basin (Obaje, 2009). The Patti Formation therefore appears to have been deposited in marginal shallow marine to brackish water condition identical to the depositional environments of similar lithologic units of the Mamu and Ajali Formations in the Anambra Basin (Ladipo, 1988; Adeniran, 1991; Nwajide and Reijers, 1996).

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 (Obaje, 2009). 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 Sandstone 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).

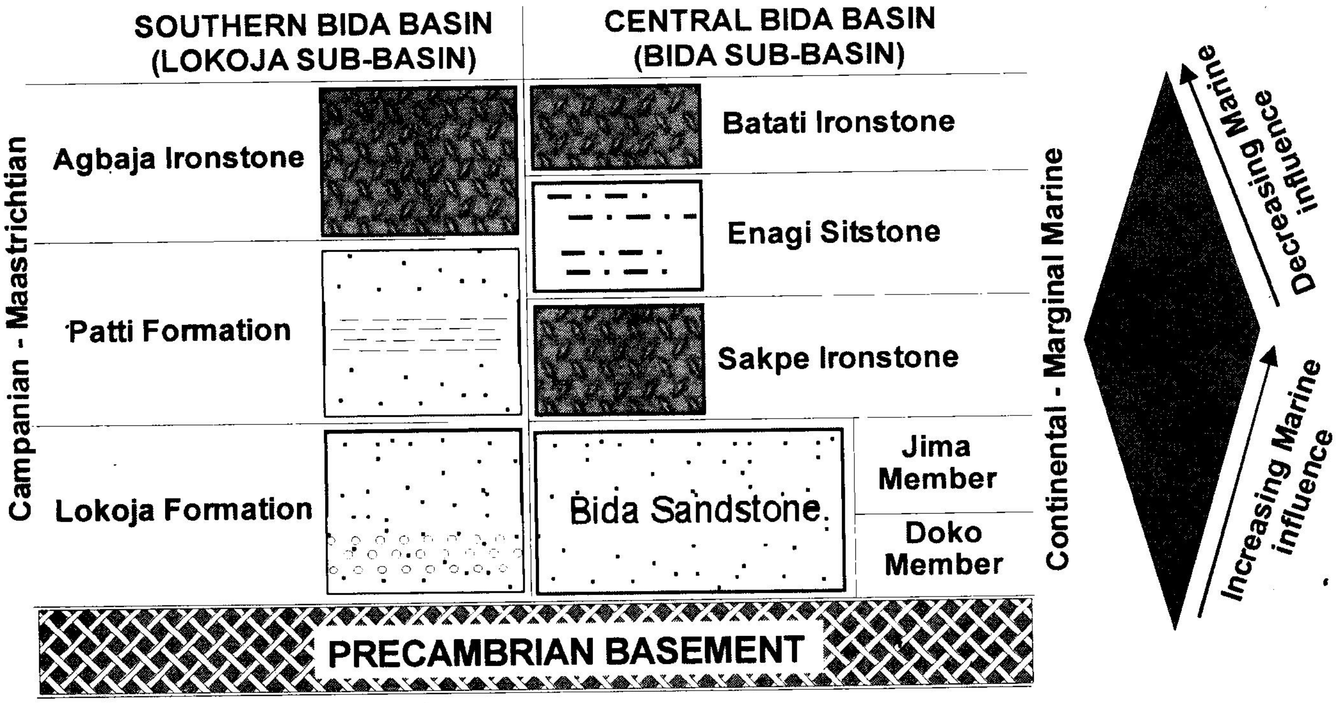

Figure 2.1 Stratigraphic successions in the Mid-Niger Basin (Modified from Obaje, 2009)

CHAPTER THREE
MATERIALS AND METHODS

3.1 Materials for Sampling and Data collection

The following materials were used on the field for collecting samples and acquirement some data such as the elevation and the Longitude and Latitude of each location.

Global Positioning System (GPS): The GPS was used to get the actual Longitude and Latitude; and elevation at each location.

Geological Hammer and chisel: This hand-held tool was was used to collect fresh samples of rocks on the field.

Compass Clinometer: The Clinometer was used to determine the strike and Dip on the field.

Sample bags: Used in keeping samples after they have been collected to prevent it from being contaminated and shattering.

Masking tapes: used for labelling samples on the field after they have been kept in the sample bags.

Camera: Used for taking pictures of structures and outcrops on the field.

Measuring Tape: Used for measuring the thickness of the strata.

Plate I

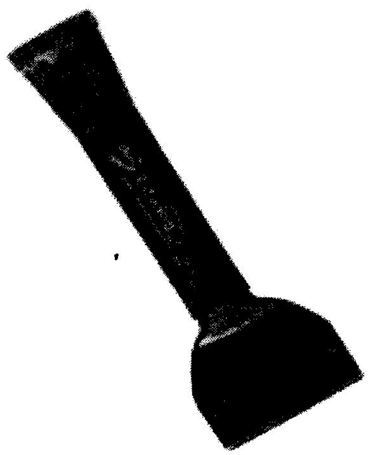

Plate II

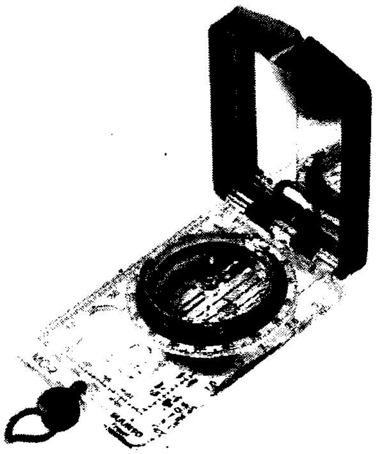

Plate III

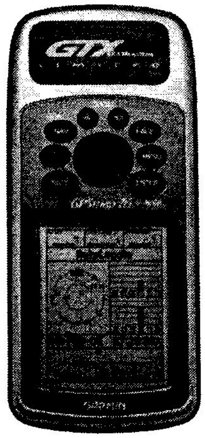

Plate IV

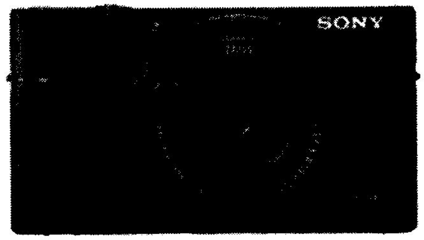

Plate V

3.2 Method of Data collection

Data, such as elevation, longitude and latitude of each location were collected using the GPS (Global Positioning System). The strike and dip of the underlying basement rock was measured using the compass clinometer and images of outcrops and the structures on them were taken using the camera. The Outcrops at each locations were logged bed by bed and described using mineralogical, structural and textural characteristics.

3.3 Field work and Sample Collection

The southern middle Niger Basin characteristically lacks exploratory well or well preserved borehole sample, thus leaving us with the option of outcrop samples. Based on lateral and vertical facies changes, and bed thickness, a lithologically description and a systematic sampling of outcropping sediments was carried out to obtain samples for further analysis. A total number of eight (8) samples were selected for this study. Four (4) samples from the Lokoja Formation, two (2) samples from the Patti Formation and two (2) samples from Agbaja Formation.

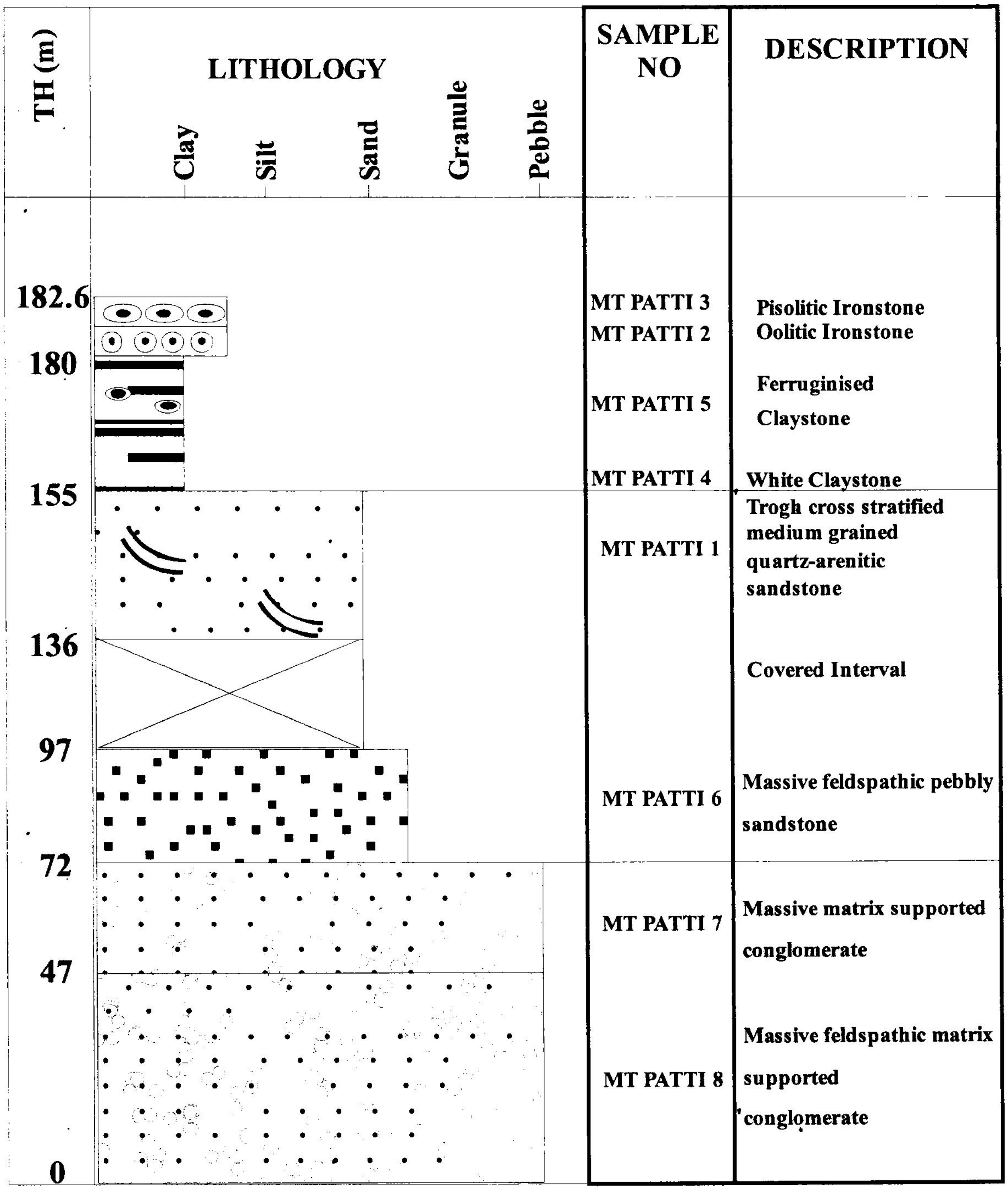

Figure 3.1. The lithologic section of the Mount Patti, Lokoja.

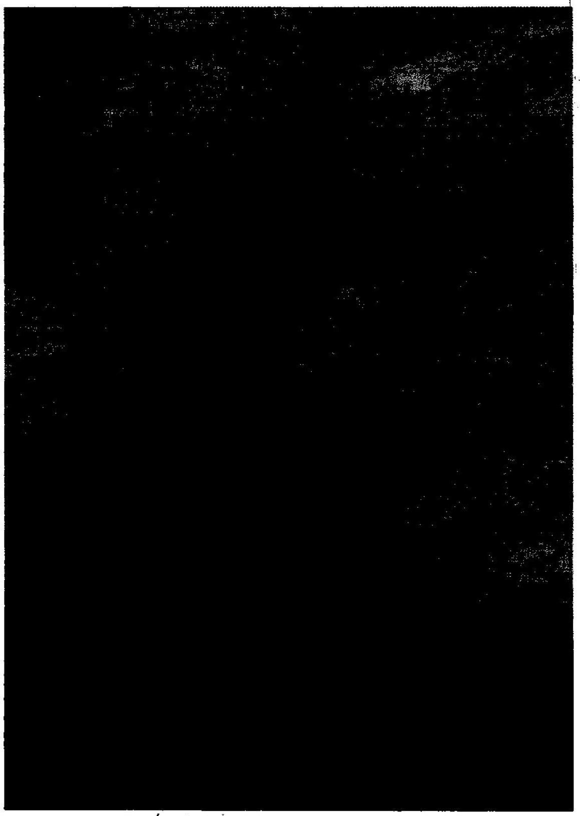

Figure 3.2a: The cross stratified Sandstone of the Patti Formation exposed at Mount Patti

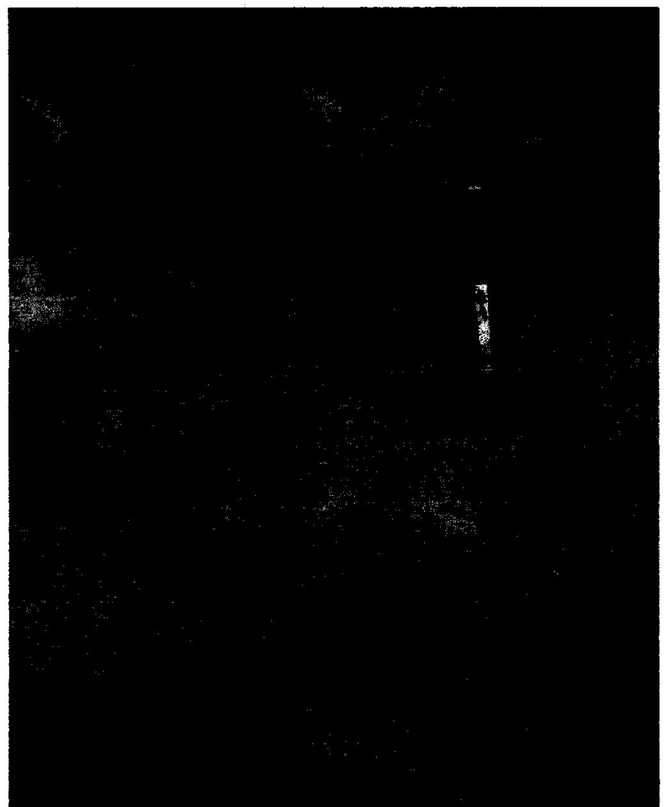

Figure 3.2b: Claystone of the Patti Formation exposed at Mount Patti

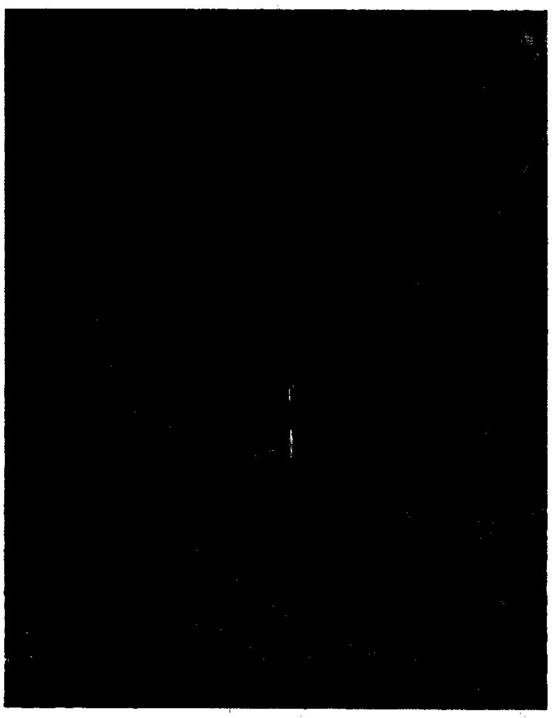

Figure 3.2c: The Conglomerate of the Lokoja formation exposed at Mount Patti

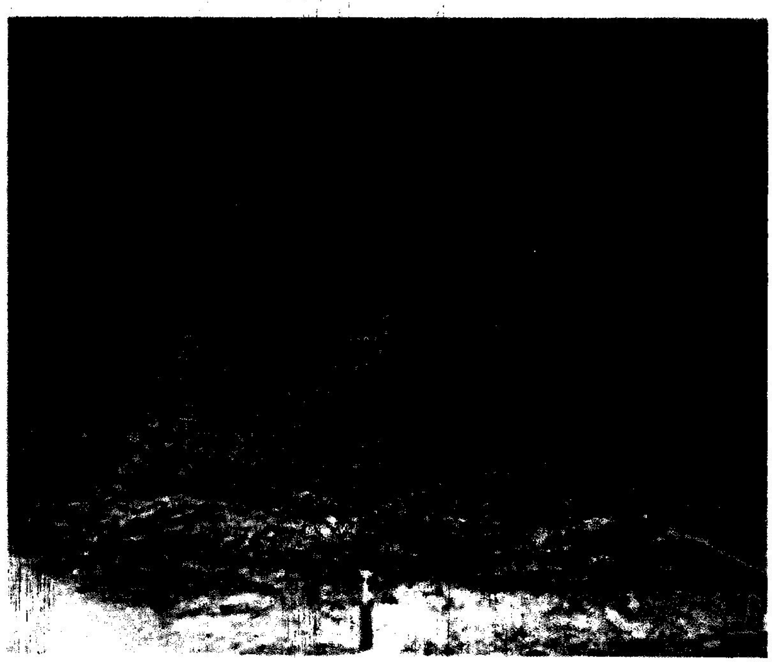

Figure 3.2d: The Ironstone facies of the Agbaja formation exposed at Mount Patti

3.4 Processing and analyses of the Samples

3.4.1 Grain Size Analysis (Mechanical sieving)

Two selected sandstone samples from the Lokoja Formation were air dried, hand crushed, thoroughly mixed and 100g of each sample weighed and sieved in an automated sieve shaker for 10mins to obtain quantitative data set for further statistical analysis including the Graphic Mean (Mz); Inclusive Graphic Standard Deviation (σ1), Inclusive Graphic Skewness (SK) and Graphic Kurtosis (KG).

3.4.1 Geochemical analysis using XRF (X-ray Fluorescence)

The analysis of major and trace elements in geological materials by XRF is made possible by the behavior of atoms when they interact with X-radiation. An XRF spectrometer works because if a sample is illuminated by an intense X-ray beam, known as the incident beam, some of the energy is scattered, but some are also absorbed within the sample in a manner that depends on its chemistry (serc.carleton.edu/research _education). When this primary X-ray beam illuminate the sample, it is said to be excited. The excited sample in turn emits X-rays along a spectrum of wavelengths characteristic of the types of atoms present in the sample. How does this happen? The atoms in the sample absorb X-ray energy by ionizing, ejecting electrons from the lower (usually K and L) energy levels. The ejected electrons are replaced by electrons from an outer, higher energy orbital. When this happens, energy is released due to the decreased binding energy of the inner electron orbital compared with an outer one. This energy release is in the form of emission of characteristic X-rays indicating the type of atom present. For XRF chemical analyses of rocks, samples were collected from difference crushed steps to reduce it to an average grain size of a few millimeters to a centimeter and then ground into a fine powder. Care must be taken particularly at this step to be aware of the composition of the crushing implements, which will inevitably contaminate the sample to some extent. The powdered sample was then used for the XRF chemical analyses.

3.4.2 Grain Size Analysis

Equipment:

1. 6 sets of sieves =5, 6, 10, 16, 30, 40, 100, 200, 230, pan (9 sieves and the pan)
2. Electronic Balances to measure mass of samples

Materials:

1. 2 Sandstone samples
2. Small sheet of paper for recording values
3. 2 containers to place sieved samples in; these can be weighing trays or beakers

Sieve Analysis Laboratory Procedure

1. Two split samples (Mt Patti 1 and Mt Patti 6) of approximately 100 gram was taken for the sieve analysis. These samples were hand crushed, dried and mixed. All large chunks of vegetation and bugs were picked and removed from the samples.
2. The sieves were weighed on the electronic balance and the mass of each sieves were recorded in Table 5 and 6 with respect to their number.
3. The sieves are stacked such that the screen with the smallest mesh is at the base and the largest is at the top. The sieves were arranged according to their number (from the smallest to the largest). The US Standard Sieve Mesh # was used, opening in millimeters (micrometers), and Phi Scale; see table 1. The pan was placed at the very base of the stack. Sample was poured onto the top screen and was properly covered.
4. With a high amplitude of vibration, the sieves shakes continuously for 10 minutes.
5. Gently prying off the top cover of the screen set. In the same manner, the first screen was removed from the stack; being very careful not to launch any grains off across the lab. The screen was turned over and its contents dump on the paper laid on the table (which is larger than the area of the sieve). The sand was transferred to the weighing pan and weighed on the electronic balance. The weight of the sample was recorded on the sheet of paper in grams.
6. Repeat (5) for each screen and the pan.
7. The cumulative weight percentage was plotted against the phi size to calculate the Graphic Mean (Mz), Inclusive Graphic Standard Deviation ($\sigma 1$), Inclusive Graphic Skewness (SK) and Graphic Kurtosis (KG).

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Table 1: Formula used for Grain size analysis statistical calculations

Statistical values	Formula Used	Source
Graphic Mean	$M = \frac{\phi16 + \phi50 + \phi84}{3}$	Folk and Ward (1957)
Inclusive Graphic Standard Deviation	$D = \frac{\phi84 - \phi16}{4} + \frac{\phi95 + \phi5}{6.6}$	Folk and Ward (1957)
Graphic Skewness	$S = \frac{\phi84 + \phi16 - 2(\phi50)}{2(\phi84 - \phi16)} + \frac{\phi95 + \phi5 - 2(\phi50)}{2(\phi95 - \phi5)}$	Folk and Ward (1957)
Kurtosis	$K = \frac{\phi95 - \phi5}{2.44(\phi75 - \phi25)}$	Folk and Ward (1957)

Table 2: Standard deviation values after Folk and Ward (1957)

very well sorted	under 0.35 phi
well sorted	0.35 to 0.50 phi
moderately well sorted	0.50 to 0.71 phi
moderately sorted	0.71 to 1.0 phi
poorly sorted	1.0 to 2.0 phi
very poorly sorted	2.0 to 4.0 phi
extremely poorly sorted	over 4.0 phi

Table 3: Skewness values after Folk and Ward (1957)

strongly fine- skewed	+1.00 to +0.30
fine- skewed	+0.30 to +0.10
near symmetrical	+0.10 to 0.10
coarse-skewed	0.10 to 0.30
strongly coarse-skewed	0.30 to 1.00

Table 4: Kurtosis values after Folk and Ward (1957)

very platykurtic	< 0.67
platykurtic	0.67 to 0.90
mesokurtic	0.90 to 1.11
leptokurtic	1.11 to 1.50
very leptokurtic	1.50 to 3.00
extremely leptokurtic	> 3.00

CHAPTER FOUR

Results and Discussions

4.1 Grain size Analysis and Textural Analyses

The detail the cumulative curves of the studied sandstone samples are presented in figures 4.6-4.16 where grain size parameters were derived. The values of calculated statistical values are presented as follows; the graphic mean using Wentworth (1922) scale shows that the sandstones range from fine grained sand (2.04) to very coarse sand (-0.77) indicating evidence of farther transportation from the source.

The standard deviation is a measure of sorting or variation in sizes to gives an indication of the energy of transportation and textural maturity of the sediments. The values of the graphic standard deviation for the samples analyzed described according to the sorting scale after Folk and Ward (1957) shows that the sandstone samples ranges from moderately well sorted (0.58) to moderately sorted (0.92) which indicates texturally mature sediments.

The skewness is a measure of the symmetry of a distribution curve. An evaluation of the inclusive graphic skewness values for the analyzed samples was done according to the skewness scale derived from Folk and Ward (1957) and the results show ranges from the strongly coarse skewed (-0.42) to fine skewed (0.16). This also confirms the textural maturity as indicated by the sorting values.

Kurtósis measures the peakness after Tucker (1982) and Fork and Ward (1957). The kurtosis result obtained from the studied samples ranges from Mesokurtic (0.91) to very Leptokurtic (1.70) with an average of 1.40, Leptokurtic. While for the Lokoja Formation, it ranges from very platykurtic (0.64) to platykurtic (0.84).

Table 5: Grain size analysis data for Mount Patti 1 (Patti Formation)

MOUNT PATTI 1								
No of sieve	Sieve Size (d) in mm	ϕ phi size	weight of empty sieve (g)	weight of sieve with sample	weight of sample	Individual weight %	Cumulative weight of sample	cumulative weight percentage
5.00	4.00	-2.00	467.80	467.90	0.10	0.10	0.10	5.00
6.00	3.35	-1.74	466.30	466.40	0.10	0.20	0.20	6.00
10.00	2.00	-1.00	458.80	459.40	0.60	0.80	0.80	10.00
16.00	1.18	-0.24	393.20	395.70	2.50	3.30	3.30	16.00
30.00	0.60	0.74	365.30	379.10	13.80	17.10	17.10	30.00
40.00	0.43	1.23	354.40	370.10	15.70	32.80	32.80	40.00
100.00	0.15	2.74	323.80	371.60	47.80	80.60	80.60	100.00
200.00	0.08	3.74	303.70	317.70	14.00	94.60	94.60	200.00
230.00	0.06	3.99	406.60	408.50	1.90	96.50	96.50	230.00
pan			355.40	358.90	3.50	100.00	100.00	pan
					100.00			

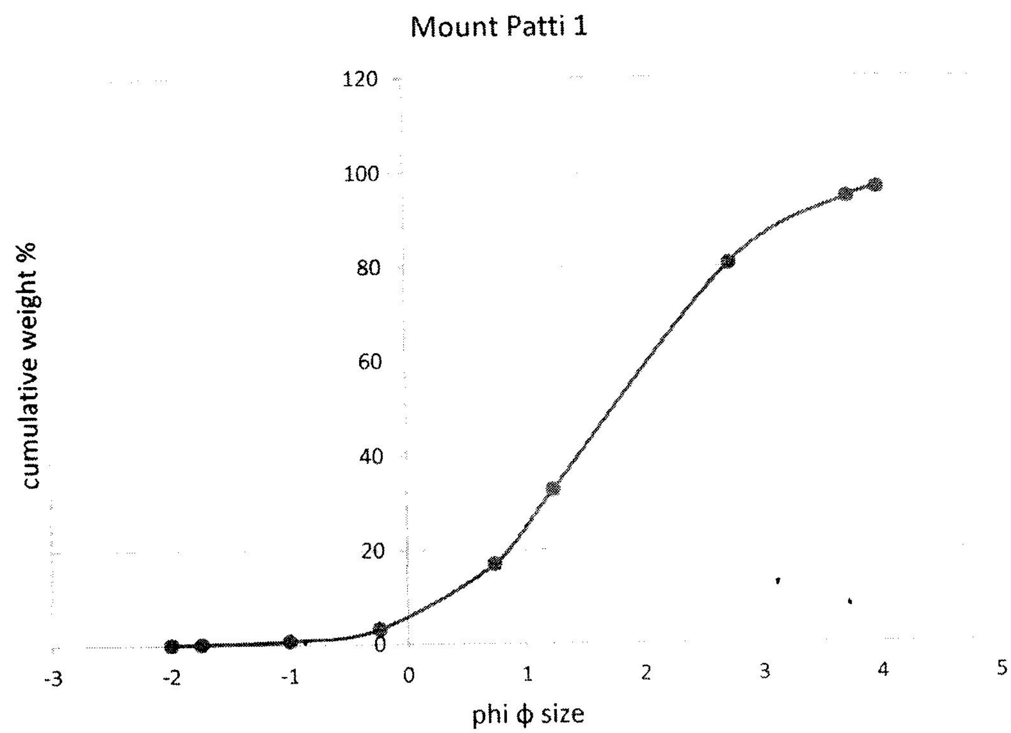

Figure 4.1: Grain size analysis curve for Mount Patti 1 (Patti Formation)

Table 6: Grain size analysis data for mount Patti 6 (Lokoja Formation)

MOUNT PATTI 6								
No of sieve	Sieve Size (d) in mm	ϕ phi size	weight of empty sieve (g)	weight of sieve with sample (g)	weight of sample (g)	Individual weight percent %	Cumulative weight of sample (g)	Cumulative weight percentage (%)
5.00	4.00	-2.00	467.80	498.00	30.20	30.23	30.20	30.23
6.00	3.35	-1.74	466.30	474.80	8.50	8.51	38.70	38.74
10.00	2.00	-1.00	458.80	468.40	9.60	9.61	48.30	48.35
16.00	1.18	-0.24	393.20	402.90	9.70	9.71	58.00	58.06
30.00	0.60	0.74	365.30	385.70	20.40	20.42	78.40	78.48
40.00	0.43	1.23	354.40	361.70	7.30	7.31	85.70	85.79
100.00	0.15	2.74	323.80	333.30	9.50	9.51	95.20	95.30
200.00	0.08	3.74	303.70	306.90	3.20	3.20	98.40	98.50
230.00	0.06	3.99	406.60	406.90	0.30	0.30	98.70	98.80
pan			355.40	356.60	1.20	1.20	99.90	100.00
					99.90	100.00		

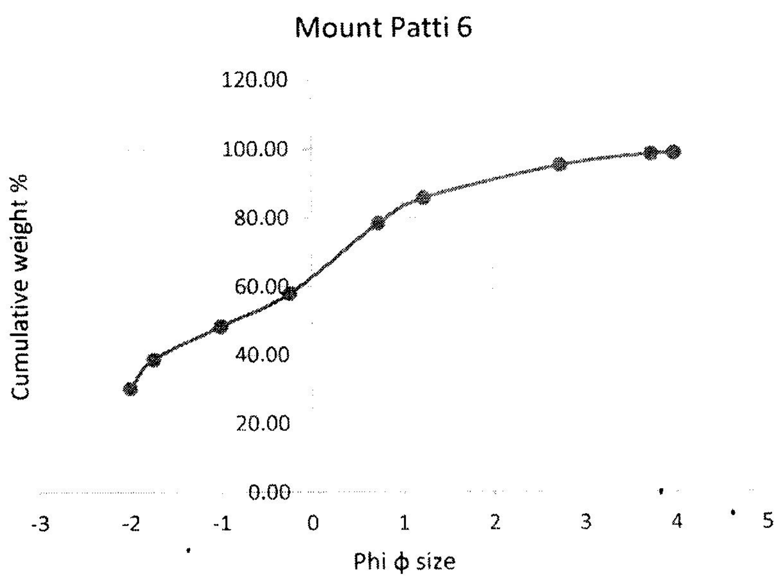

Figure 4.2: Grain size analysis curve for Mount Patti 6 (Lokoja Formation)

Table 7. Interpretations of the Grain Size Data

Sample	Mount Patti 1 (Patti Formation)	Interpretations	Mount Patti 6 (Lokoja Formation)	Interpretations
Mean Grain Size	2.04	Fine grained sand	-0.77	very coarse grained
Standard Deviation	1.15	poorly sorted	1.78	poorly sorted
Skewness	-0.42	strongly coarse skewed	0.16	fine skewed
Kurtosis	0.64	very platykurtic	0.84	platykurtic

4.4 Paleodepositional Environment using Grain Size Analysis

On the basis of environment and processes of deposition which defines the sedimentologic and characteristics of the sediments deposited, fluvial facies is the basic sedimentary facies defined in the outcropping sandstone of the Mount Patti area. Field observation and sedimentological analysis revealed that the sediments are characterized by rapid vertical change in facies, moving from moderately sorted, very coarse to pebbly grained, texturally and mineralogically immature sandstone to an overlying moderately well-sorted, fine grained, texturally and mineralogically mature sandstone (Figures 4.1 and 4.2). Some sedimentary structures such as cross beddings are also some evidence for basic properties of fluvial sediments.

A confirmation of the above conclusion on depoenvironment was achieved by scattered plot of mean versus standard deviation after Moiola and Weiser (1968) and Skewness vs Standard Deviation after Friedman (1967). The standard plot of mean versus standard deviation and Plots of Skewness vs Standard Deviation shows that the sandstone of the Patti Formation and Lokoja Formation were deposited in the Fluvial setting.

All the above reveal and confirm that the outcropping sediments of the Lokoja Formation mapped at Mount Patti are fluvial facies.

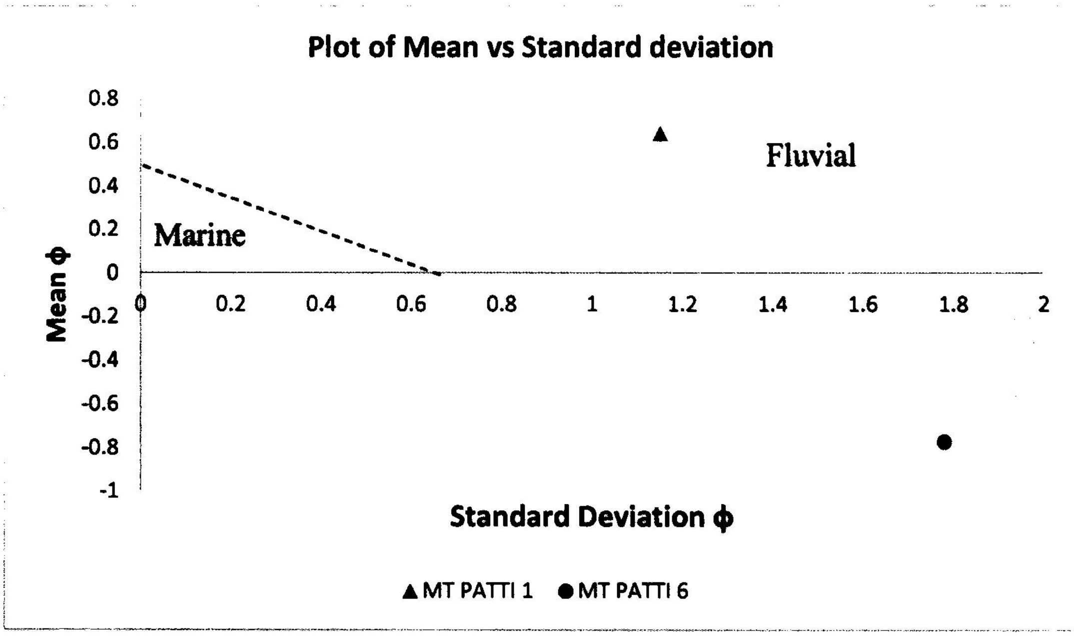

Figure 4.3: Plot of mean versus Standard Deviation for the Lokoja Sandstones exposed in the Mount Patti Area (boundary modified after Moiola and Wieser, 1968)

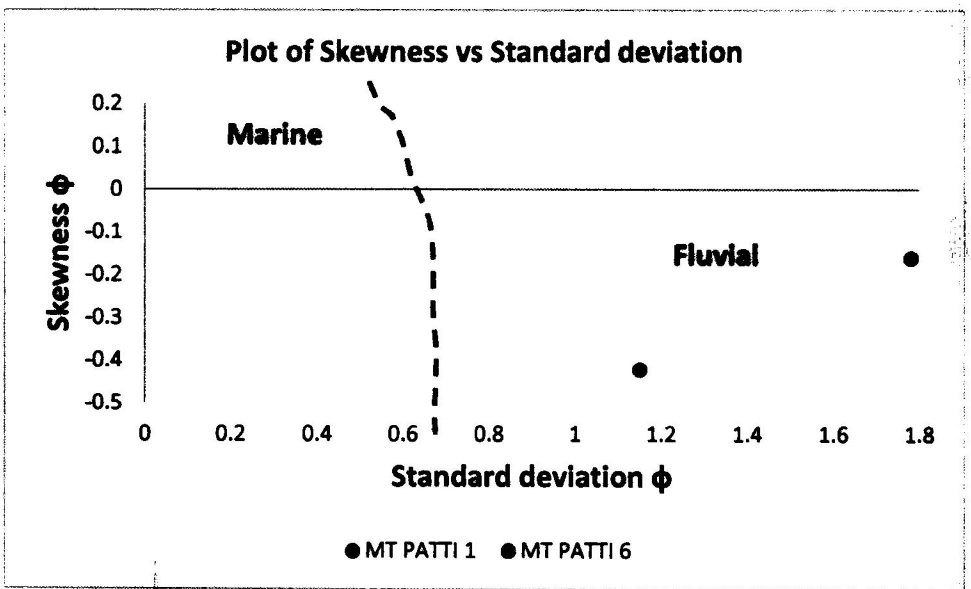

Figure 4.4: Skewness vs Standard Deviation plots for the Lokoja exposed in the Mount Patti area (boundary modified after Friedman, 1967)

4.3 Geochemical Characteristics

4.3.1 Major Oxides Variation

SiO_2/Al_2O_3 is a commonly used index of sedimentary maturation. Values increase during weathering, transport and recycling due to increase in modal framework quartz at the expense of less resistant minerals such as feldspar, amphiboles and lithic fragments. Values of SiO_2/Al_2O_3 less than 8 in sandstones provide evidence for sedimentary maturation. Some modem sediments have values over 30, whereas sandstones seldom exceed 8 (Roser et al 1996). MT PATTI 1 is much matured compared with underlying sediments (Table 11). This could be as a result of weathering which may have caused the supergene enrichment of the overlying claystone. The decrease in the less resistant minerals leads to concentration of quartz content in the sediments. The decrease in the amount of feldspar content increases the mineralogical maturity of the sediments.

The K_2O/Al_2O_3 ratio of siliciclastic rocks can be used as an indicator of the original composition of ancient sediments (Cox et al., 1995). The K_2O/Al_2O_3 ratios for clay minerals and feldspars are different (0.0 to 0.3, 0.3 to 0.9, respectively; Cox et al., 1995). The K_2O/Al_2O_3 ratio in siltstones indicates the presence of clay minerals in these rock types. The value of K_2O/Al_2O_3 ($4.07*10^{-4}$) in the Claystone (MT PATTI 4) indicates low or no k-rich plagioclase and abundance of Clay minerals in the claystone.

Na_2O in claystone (<0.001) is lower when compared to the sandstone (0.37 to -1.93) which is lower than that of the most underlying conglomerate (2.15), the reflect the variation in the supply of Na-rich plagioclase to the basin as well as the preferential leaching behavior of Sodium when compared with potassium during sub aerial weathering.

TiO_2 enrichment in weathering profiles suggests that Ti is immobile under most naturally occurring surface conditions. Aluminum is also considered to be a conservative element in diagenetic environments (Boles 1984). Al_2O_3/TiO_2 ratios of most clastic sedimentary rocks are essentially used to infer the source rock compositions, because the Al_2O_3/TiO_2 ratio increases from 3-8 for mafic igneous rocks, 8-21 for intermediate, and 21-70 for felsic igneous rocks.

Table 8. XRF result for the Major Oxides composition of the Mount Patti section

OXIDE COMPOSITION (%)	MT PATTI 1	MT PATTI 2	MT PATTI 3	MT PATTI 4	MT PATTI 5	MT. PATTI 6	MT PATTI 7	MT PATTI 8
SiO_2	85.61	0.72	0.66	52.39	34.7	61.44	67.59	68.05
TiO_2	1.06	<0.001	0.971	3.72	2.59	1.09	1.06	0.51
Al_2O_3	3.99	5.4	3.48	24.6	7.44	8.32	17.04	13.38
Fe_2O_3	3.64	79.97	82.16	4.52	37.51	15.26	2.63	2.67
CaO	0.21	0.01	0.02	0.03	0.06	0.14	0.42	0.61
MgO	0.1	<0.001	<0.001	0.011	0.013	0.11	0.18	0.019
Na_2O	0.37	0.04	0.05	<0.001	0.04	1.93	1.24	2.15
K_2O	0.54	0.011	0.012	<0.001	0.01	1.29	1.95	6.14
MnO	<0.001	<0.001	<0.001	0.045	<0.001	<0.001	<0.001	<0.001
V_2O_5	0.053	<0.001	<0.001	0.046	0.02	0.052	0.068	0.052
Cr_2O_3	0.06	0.039	0.049	0.08	0.067	0.087	0.052	0.043
CuO	0.048	0.041	0.066	0.055	0.09	0.071	0.059	0.044
As_2O_3	0.009	ND	ND	0.007	ND	ND	ND	0.007
ZrO_2	0.372	ND	0.16	0.662	0.768	0.1	0.1	0.042
BaO	0.19	ND	0.64	0.57	0.68	0.2	ND	0.25
PbO	0.04	ND	ND	0.068	0.29	ND	0.069	0.02
ZnO	ND	0.084	ND	0.02	0.038	ND	0.02	ND
SrO	ND	ND	ND	0.09	ND	0.056	0.082	0.12
Rb_2O	ND	ND	ND	ND	0.037	0.041	0.032	0.066
Ga_2O_3	ND	ND	ND	ND	ND	ND	ND	0.023
Cl	ND	0.979	0.936	1.18	0.746	1.11	ND	ND
LOI	3.7	12.7	10.8	11.9	14.9	8.7	7.4	5.8

Table 9. Discriminant function values for the Conglomerates, Sandstones and Claystone In the outcrop exposed at Mount Patti area.

Discriminant Functions	MT PATTI 1	MT PATTI 4	MT PATTI 6	MT PATTI 7	MT PATTI 8
F1	-6.275	2.685	4.971	-0.397	-5.917
F2	-7.266	-4.614	-1.806	-6.828	-11.705

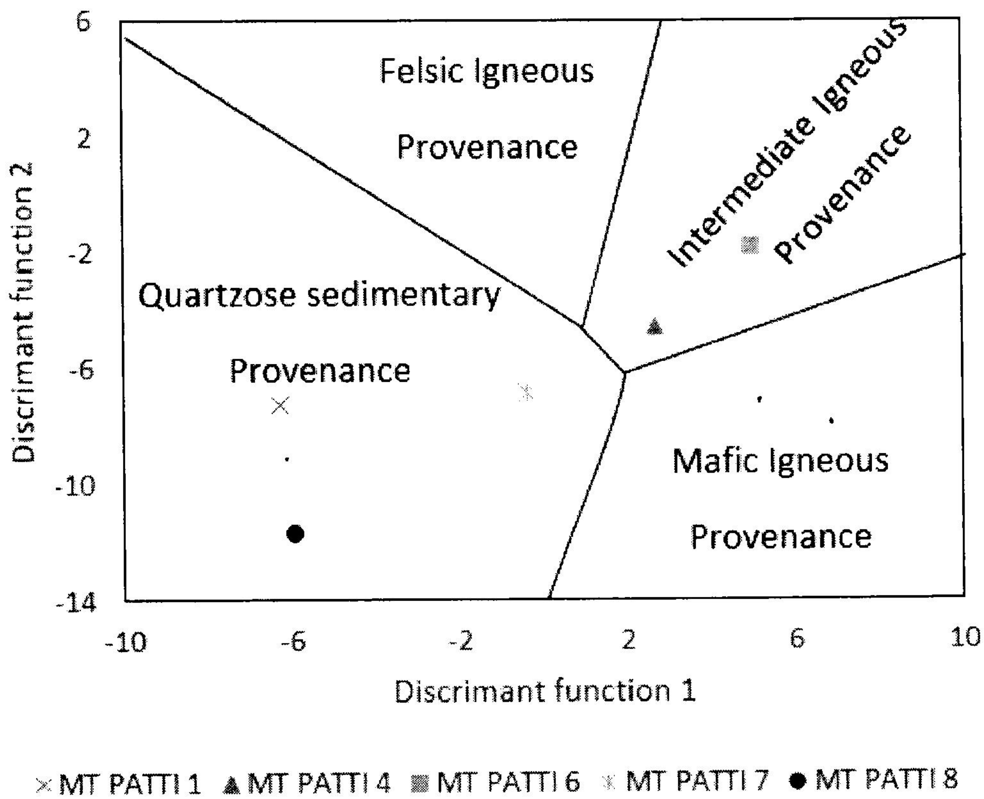

Figure 4.5: Discriminant function diagram for sedimentary provenance of the sediments in the MT PATTI section using major elements (Roser and Korsch, 1988).

NB: The discriminant functions are: Discriminant Function 1 = $(-1.773*TiO_2)$ + $(0.607*Al_2O_3)$+$(0.760*Fe_2O_3)$ + $(1.500*MgO)$ + $(0.616*CaO)$ + $(0.509*Na_2O)$ + $(-1.224*K_2O)$ + (-0.090); **Discriminant** Function 2 = $(0.445*TiO_2)$ + $(0.070*Al_2O_3)$ + $(-0.250*Fe_2O_3)$ + $(-1.142*MgO)$ + $(0.438*CaO)$ + $(1.475*Na_2O)$ + $(-1.475*K_2O)$ + (-6.861)

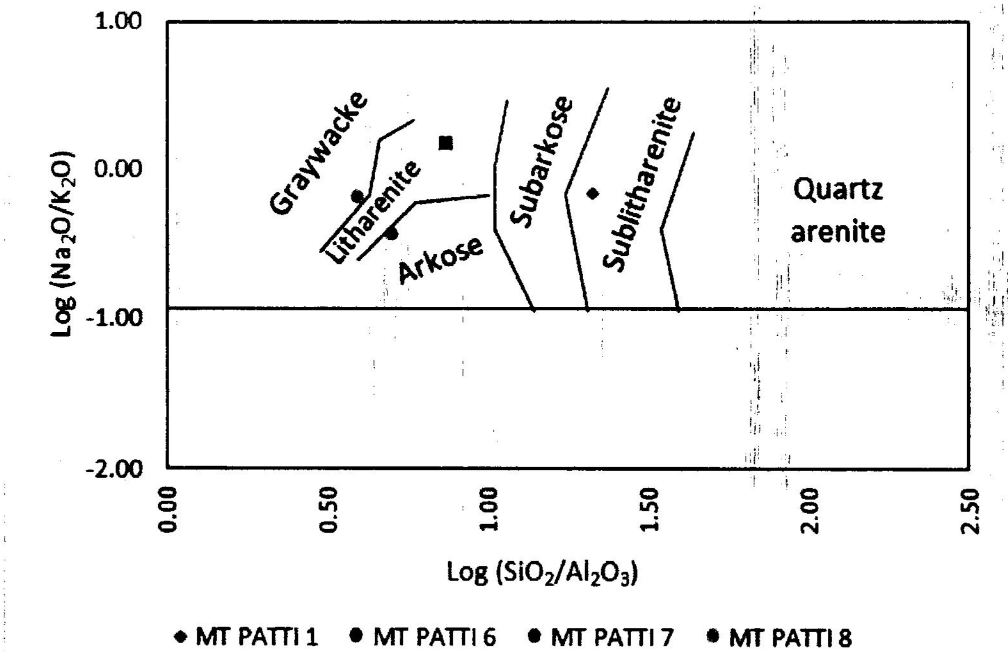

Figure 4.6: Log (SiO_2/Al_2O_3) vs Log (Na_2O/K_2O) diagram for sandstone classification (after Pettijohn et al 1972)

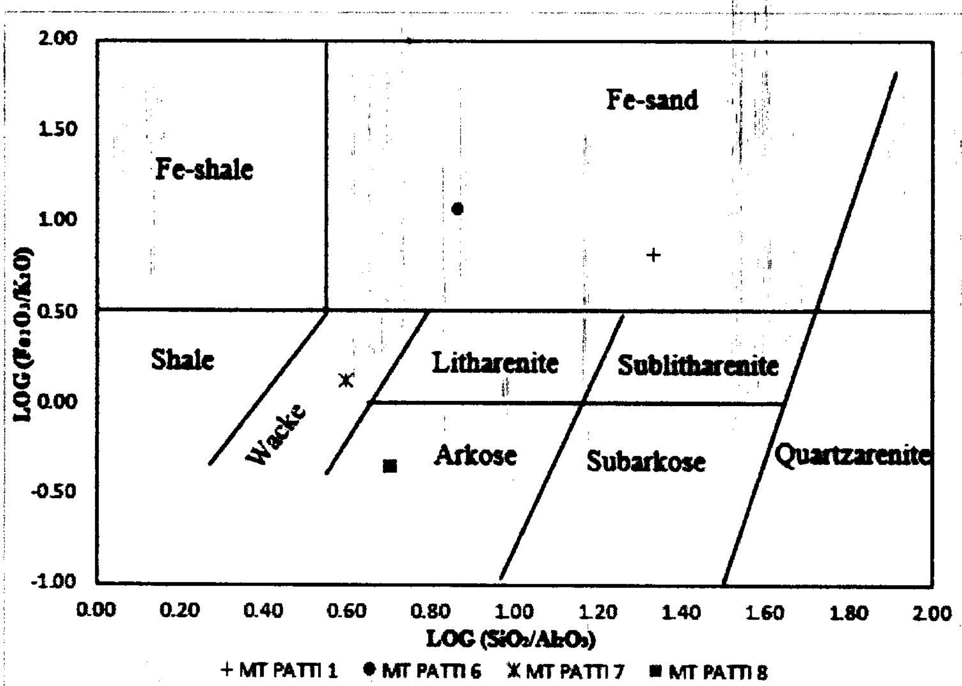

Figure 4.7: Log (SiO_2/Al_2O_3) vs Log (Fe_2O_3/K_2O) diagram for sandstone classification (after Herron 1988)

Table 10. The Al_2O_3/TiO_2 values in the samples, indicating the source rocks for the sediments. ((Roser et al 1996)

SAMPLES	LITHOLOGY	Al_2O_3/TiO_2	PROVENANCE
MT PATTI 1	Sandstone	3.76	Mafic Igneous Rocks
MT PATTI 4	Claystone	6.61	Mafic Igneous Rocks
MT PATTI 6	Sandstone	7.63	Mafic Igneous Rocks
MT PATTI 7	Conglomerate	16.08	Intermediate Igneous Rocks
MT PATTI 8	Conglomerate	26.24	Felsic Igneous Rocks

Table 11. The SiO_2/Al_2O_3 values in the samples, indicating sediments maturation.

SAMPLES	LITHOLOGY	SiO_2/Al_2O_3	MATURATION INTERPRETATION
MT PATTI 1	Sandstone	21.47	Well Mature
MT PATTI 6	Sandstone	7.38	Moderately Mature
MT PATTI 7	Conglomerate	3.97	Not Mature
MT PATTI 8	Conglomerate	5.09	Not Mature

4.4 Paleoweathering

Alteration of minerals due to chemical weathering mainly depends on the intensity and the duration of weathering (Johnson et al 1994). High rates of mechanical erosion are necessary to form clastic sediments generally (Garrels and Mackenzie 1971) and it is appropriate to view the bulk clastic sediments as being derived from highly weathered sources. Thus, in considering the overall effects of weathering on the clastic rocks composition, it is probably more appropriate to examine the early stage and, to a less extent, the intermediate stage of weathering (Taylor and McLennan 1985). Consequently, the dominant process during weathering of the upper crust is the degradation of feldspars and simultaneously forming clay minerals. During weathering, calcium, sodium and potassium largely are removed from feldspars (Nesbitt et al 1980). The amount of these chemical elements surviving in the soil profiles and in the sediments derived from them is a sensitive index of the intensity of weathering (Nesbitt et al 1997). A good measure of the degree of chemical weathering can be obtained by calculating of the Chemical Index of Alteration (CIA; Nesbitt and Young 1982) using the formula;

$$CIA = \frac{Al_2O_3}{(Al_2O_3 + CaO^* + Na_2O + K_2O)]} \times 100$$

High values (i.e., 76 - 100) indicate intensive chemical weathering in the source areas whereas low values (i.e., 50 or less) indicate unweathered source area. In this study, the CIA values presented in table 12 shows that claystones suggests that all the studied samples ranges from 60.05 to 99.88, thus suggests moderate to intense weathering.

Table 12. The CIA values of the samples, indicating the degree of chemical weathering of the source area.

SAMPLES	LITHOLOGY	CHEMICAL INDEX OF ALTERATION (CIA)	INTERPRETATION
MT PATTI 1	Sandstone	78.08	Moderate chemical weathering
MT PATTI 4	Claystone	99.88	Intensive chemical weathering
MT PATTI 5	Ferruginized Claystone	98.54	Intensive chemical weathering
MT PATTI 6	Sandstone	71.23	Moderate chemical weathering
MT PATTI 7	Conglomerate	82.52	Intensive chemical weathering
MT PATTI 8	Conglomerate	60.05	Low chemical weathering

4.5 Resource Potential

The quality of raw iron ores and its viability for commercial exploitation is mainly determined by its chemical composition and when compared with other exploited and exported iron ores in the world. Table 13 shows the results of the total chemical analysis of Mount Patti Ironstones in weight percentages. The most important elements and components of consideration in iron ores are the content of Fe, gangue ($SiO_2$and Al_2O_3) and contaminants such as phosphorous and sulfur. The ores may also contain other impurities such as MnO, MgO, TiO_2 and CaO, which may exist in considerably negligible amounts.

Guider (1981) suggest that Alumina, sulphur, and phosphorous represent contaminations in the steel making process and they are specific targets during iron ore beneficiation. For commercial viability, iron ores should preferably have high Fe contents and low impurity element contents, in order to make the exploitation profitable and the investment successful. In the world practice, no minimum standards have been set for iron, silica, alumina, calcium, and magnesium percentages in commercial iron ores, although Dobbins and Burnet (1982) made certain generalizations for classification and evaluation of quality and grade, the raw iron ores can be divided into three basic classes depending on the total Fe content:

(i) High-grade iron ores with a total Fe content above 65%,

(ii) Medium-or average-grade ores with varied Fe contents in the range of 62–64%, and

(iii) Low-grade ores with Fe contents below 58%.

The generalized contents of the most important elements in raw iron ores used in assessing iron ore quality are given in Table 14.

Table 13. Results of the total chemical analysis of Mount Patti Ironstones

OXIDE COMPOSITION (%)	MT PATTI 2	MT PATTI 3
SiO_2	0.72	0.66
TiO_2	<0.001	0.971
Al_2O_3	5.4	3.48
Fe_2O_3	79.97	82.16
CaO	0.01	0.02
MgO	<0.001	<0.001
Na_2O	0.04	0.05
K_2O	0.011	0.012
MnO	<0.001	<0.001
V_2O_5	<0.001	<0.001
Cr_2O_3	0.039	0.049
CuO	0.041	0.066
As_2O_3	ND	ND
ZrO_2	ND	0.16
BaO	ND	0.64
PbO	ND	ND
ZnO	0.084	ND
SrO	ND	ND
Rb_2O	ND	ND
Ga_2O_3	ND	ND
Cl	0.979	0.936
LOI	12.7	10.8

To determine the grade of an iron ore, the iron oxide (Fe_2O_3) has to be converted to elemental state of iron (Fe total), to achieve this, value of the oxide content is multiplied by its conversion factor. From the XRF result in table 13, the Fe_2O_3 content ranges from 79.97 to 82.16% with an average of 81.07%. The conversion is calculated below;

Fe wt=55.847g

O wt =15.999g

Molecular weight of Fe_2O_3 =2(55.847) + 3 (15.999)

=159.69g/mol

For the iron (Fe total) proportion = Fe_2/ Fe_2O_3

=2(55.847l/159.69

111.694/159.69

=0.6994

Therefore, the average of Fe_2O_3 (81.07%) when multiply by the conversion factor is the average percentage grade of Fe

i.e grade of Fe= 81.07×0.6994

= 47.43% **(Grade)**

From this calculation, this only implies that the lronstones of the Mount Patti area is of low grade using the generalized percentages of element of major interest (Dobbins and Burnet 1982) in assessing the iron ore quality. The SiO_2 content between 0.66% to 0.72% in Mount Patti is not greater than the generalized percentage of < 6 % (Dobbins and Burnet 1982). The SiO_2 content suggests that the iron ore at the Mount Patti can be used as a good raw material for steel production but bad for cast iron production. The major effect of silicon is to promote the formation of grey iron. Grey iron is less brittle and easier to finish than white iron. It is preferred for casting purposes for this reason. Turner (1900) reported that silicon also reduces shrinkage and the formation of blowholes, and thus increases its quality for making cast iron. Aluminium oxide increases the viscosity of the slag (Rosenqvist, 1983). High aluminium will also make it more difficult to tap off the liquid slag during production. Aluminium in Mount Patti iron ore is high in concentration which ranges between 3.48% to 5.40%. The Al_2O_3 in the pisolitic ironstone (MT PATTI 3 = 3.48%) is within the range of the permissible level of 3-4% set for direct iron production without prior beneficiation while the Al_2O_3 in the oolitic ironstone (MT PATTI 2 = 5.40%) is a bit higher but can be used for iron production prior beneficiation.

Table 14. Generalized percentages of elements of major interest in assessing the ore quality after Dobbins and Burnet (1982)

Components	Total Fe			SiO_2	Al_2O_3	Phosphorus	Sulphur
Content (mass %)	Low (L)	Medium (M)	High (H)	<6	3-4	0.05-0.07	0.1
	<58	62-64	>65				

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and Conclusions

The standard plot of mean versus standard deviation and Skewness vs Standard Deviation confirmed that the sandstones of Patti Formation and Lokoja Formations exposed at Mount Patti were deposited in the Fluvial setting.

Plot of Log (SiO_2/Al_2O_3) vs Log (Na_2O/K_2O) diagram for sandstone classification (after Pettijohn et al 1972) reveals that the conglomerates of the Lokoja Formation are Wacke and Arkose and the sandstones of the Lokoja Formation falls in the Litharenite field while the sandstone of the Patti Formation falls in the Sublitharenite field. Scattered Plot of Log (SiO_2/Al_2O_3) vs Log (Fe_2O_3/K_2O) diagram for sandstone classification (after Herron 1988) also reveals that the sandstone are rich in Iron which could be as a result of iron enrichment through leaching of the overlying Agbaja Ironstone facies.

The SiO_2/Al_2O_3 values in the samples indicates sediment maturation. This value rises as the intensity of weathering increases. The sandstone and conglomerates of the Lokoja Formation is mineralogically immature as a result of the abundant composition of less resistant minerals. The high value of SiO_2/Al_2O_3 in sandstone of the Patti Formation reveals that it is much more matured as a result of low composition of less resistant minerals.

The discriminant plot of sediment maturity ((Roser and Korsch 1988) shows that the sediments of the sandstone and claystone of the Patti Formation were derived from a Quartzose sedimentary Provenance and intermediate igneous provenance respectively. This plot also reveals that the sandstone and conglomerates of the Lokoja Formation were derived from Quartzose sedimentary provenance and intermediate igneous provenance.

The geochemical data were employed to interpret the resource potential of the Ironstone Facies of the Agbaja Formation. Using the generalized percentages of element of major interest (Dobbins and Burnet 1982) in assessing the iron ore quality, the grade of Iron in the Pisolitic and Oolitic Ironstones of the Agbaja Formation in the Mount Patti area is 47.43%, which implies that they are of low grade. The SiO_2 content between 0.66% to 0.72% of the Ironstone in the Mount Patti area is not greater than the generalized percentage of < 6 % (Dobbins and Burnet 1982). Therefore, the grade of ore in the ironstone samples implies that they can be used as a good raw material for steel production but bad for cast iron production.

5.2 Recommendations

It is recommended that more detailed geochemical studies should be carried out in the study area to determine the grade of iron ore in the ironstones of the Mount Patti area. The Claystones should be analysed to determine the amount of chemical impurities which may make it unsuitable for the desired industrial use.

References

Adeleye D.R. (1973). Origin of ironstones: an example from the Mid-Niger Basin, Nigeria. J Sediment Petrol no. 43, pp.709–727.

Adeleye D.R. (1974). Sedimentology of the fluvial Bida Sandstones (Cretaceous), Nigeria. Sediment Geol no. 12, pp. 1–24.

Adeleye, D.R. (1972). Sedimentology of the fluvial Bida Sandstones (Cretaceous) Nigeria. Sedimentary Geology vol. 12, pp. 1-24.

Adeleye, D.R., and Dessauvagie, T. F. G. (1972). Stratigraphy of the Niger embayment near Bida, Nigeria. In: T.F. G. Dessauvagie and A.J. Whiteman (eds) African geology, University of Ibadan Press, pp. 181-186.

Adeniran B.V. (1991). Maastrichtian tidal flat sequences from the northern Anambra Basin, Southern Nigeria. NAPE Bull., no. 6 pp.56–66.

Akande S.O., Hoffknecht A., Erdtmann B.D. (1992). Rank and petrographic composition of selected Upper Cretaceous and Tertiary coals of Southern Nigeria. Int J Coal Geol., no. 20, pp. 209–224.

Akande S.O., Ojo O.J., Erdtmann B.D., Hetenyi M. (2005). Paleoenvironments, organic petrology and Rock-Eval studies on source rock facies of the Lower Maastrichtian Patti Formation, Southern Bida Basin, Nigeria. J Afr Earth Sci no. 41, pp. 394–406.

Akinyemi, S. A., Adebayo, O. F., Ojo, A.O., Fadipe, O. A., Gitari, W. M. (2014). Geochemistry and mineralogy of the Campanian Sandstone of Lokoja-Basange Formation, Middle Niger Basin (Lokoja sub-basin), Nigeria: Implications for provenance, weathering, tectonic setting and paleo-redox condition. Journal of Natural Sciences Research www.iiste.org ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online) vol. 4, no. 16

Alabi, M.O. (2009). "Revitalizing Urban Public Open Spaces, Through Vegetative Enclaves in Lokoja, Nigeria", Journal of Geography and Regional Planning vol. 2, no. 3.

Braide, S.P. (1992). Geological development, origin and energy mineral resources potential of the Lokoja Formation in the Southern Bida Basin. Journal of Mining and Geology vol. 28, pp. 33-44.

Cox, R., Lowe, D.R. and Cullers, R.L. (1995). The influence of sediment recycling and basement composition on evolution of mudrock chemistry in the southwestern United States Geochim. Cosmochim. Acta, vol. 59, pp. 2919-2940.

Dessauvagie, T. F. G. (1975). Explanatory note to the geological map of Nigeria, scale 1: 1,000,000. Jour. Min. and Geol. (Nig. Min. Geol. And Met. Soc.), vol. 9, no. 12, pp. 328.

Dobbins M. S. and Burnet G. (1982). "Production of an iron ore concentrate from the iron-rich fraction of power plant fly ash,"Resources and Conservation, vol. 9, pp. 231–242,

EJPAU, (2007). Evaluation of Drought from Rainfall Data for Lokoja- A Confluence of two Major Rivers.

Folk, R. L. and Ward, W. C. (1957). Brazo River bar: A study in the significance of grain size parameters. Journal of Sedimentary Petrology, vol. 27, pp. 3 – 26

Friedman G.M. (1967). Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands, J. Sediment. Petrol., no: 37, pp. 327–354.

Garrels, R.M. &Mckenzie, F.T. (1971). Evolution of Sedimentary Rocks. W.W. Worton and Co. Inc. New York, pp. 394

Gebhardt H. (1998). Benthic foraminifera from the Maastrichtian Lower Mamu Formation near Leru (Southern Nigeria): paleoecology and paleogeographic significance. J Foraminiferal Res., no. 28, pp. 76–89.

Guider J. W. (1981). "Iron ore beneficiation—key to modern steelmaking," Mining Engineering, vol. 33, no. 4, pp. 410–413,

Herron, M.M., (1988). Geochemical Classification of Terrigenous Sands and Shales from core to log data. Journal of sedimentary Petrology, vol. 58, pp. 820 - 829.

http://www.nigeria.gov.ng/index.php/2016-04-06-08-39-54/north-central/kogi https://en.climate-data.org/africa/nigeria/zamfara/kogi-389954/

https://serc.carleton.edu/research_education/geochemsheets/techniques/XRF.html

Idowu, J.O. and Enu, E.I. (1992). Petroleum geochemistry of some Late Cretaceous Shales frome the Lokoja Sandstone of Middle Niger Basin, Nigeria. Journal of African Earth Sciences, vol.14, pp. 443-455.

Imrana A., Haruna I.V. (2017). Geology, Mineralogy And Geochemistry 0f Koton-Karfe Oolitic Iron Ore Deposit, Bida Basin. Kogi State, Nigeria. international journal of scientific & technology research vol. 6

Jan du Chene, R., and Salami, M.B. (1978). Comptes Rendus des Seances, vol. 13, no. 1, pp. 5-9.

Jan Du Chene, R., Klasz I DE, Archibong E.E. (1979). Biostratigraphic study of the borehole Ojo-1, SW Nigeria, with special emphasis on the Cretaceous Microfloral. Revue de Micropaleontology, vol. 21, pp. 123-139.

Johnson, C. E., Litaor, M. I., Billett, M. F., and Bricker, O. P. (1994). Chemical weathering in small catchments: Climatic and anthropogenic influences, in Moldan, B., and Cerny, J., eds., Small catchments: A tool for environmental studies: London, England, John Wiley, pp. 323–341.

Jones, H.A. (1955). The oolitic ironstone of Agbaja Plateau, Kabba Province. Record of the Geological survey of Nigeria, pp. 20 – 43.

Jones, H.A. (1958). The oolitic ironstone of Agbaja Plateau, Kabba Province. Record of the Geological survey of Nigeria, pp. 20 – 43.

Kogbe, C. A., Ajakaiye, D. E., and Matheis, G. (1983). Confirmation of rift structure along the Middle- Niger Valley, Nigeria. Journal of African Earth Sciences, vol.1, pp. 127-131.

Kogi State Tourist Guide (no date).

Ladipo K.O. (1988). Paleogeography, sedimentation and tectonics of the Upper Cretaceous Anambra basin, South-Eastern Nigeria. J Afr Earth Sci. no. 7, pp. 865–871.

Ladipo K.O., Akande S.O., Mucke A., (1994). Genesis of ironstones from the Mid-Niger sedimentary basin: evidence from sedimentological, ore microscopic and geochemical studies. J Mining Geol no. 30, pp.161–168.

Madukwe, H. Y., Akinyemi, S. A., Adebayo, O. F., Ojo, A. O., Aturamu, A. O. , Afolagboye, L. O., (2014). Geochemical and Petrographic Studies of Lokoja Sandstone: Implications on Source Area Weathering, Provenance, and Tectonic Setting. international journal of scientific & technology research vol. 3

Moiola, R.J., and Wieser D. (1968). Textural parameters; an evaluation, jour. Sed. Petro., vol.38 pp. 45-53

Nesbitt, H.W., and Young, G.M. (1982). Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. Nature, vol. 299, pp. 715–717

Nesbitt, H.W., G. Markovics and R.C. Price, (1980). Chemical processes affecting alkalis and alkali earths during continental weathering. Geochim. Cosmochim. Acta, vol. 44, pp. 1659-1666.

Nesbitt, H.W., Young, G.M., McLennan, S.M. and Keays, R.R. (1996). Effect of chemical weathering and sorting on the petrogenesis of siliciclastic sediments, with implications for provenance studies. J. Geol., vol. 104, pp. 525–542.

Nton M. E. and Adamolekun O. J. (2016). Sedimentological and Geochemical characteristics of outcrop Sediments of Southern Bida Basin, central Nigeria: implications for provenance, paleoenvironment and tectonic history Ife Journal of Science vol. 18, no. 2

Nwajide C.S., Reijers T.J.A., (1996) Sequence architecture in outcrops: examples from the Anambra Basin, Nigeria. NAPE Bull., no. 11, pp. 23–33.

Obaje, N.G. (2009). Geology and Mineral Resources of Nigeria. Springer, Berlin, Germany, ISBN-13: 9783540926849, pp. 93

Ojo, O.J. (2009). Occurrence of some Maastrichtian Dinoflagellate Cysts from the Upper Cretaceous sediments in southeastern Bida basin, Nigeria: implication for age and Paleoenvironments: journal of applied science vol. 2, no. 3

Ojo, S.B. (1984). Middle Niger Basin revisited: magnetic constraints on gravity interpretations. Abstract, 20th Conference of the Nigeria Mining and Geosciences Society, Nsukka, pp. 52–53.

Ojo, S.B, and Ajakaiye D.E. (1989). Preliminary interpretation of gravity measurements in the Mid-Niger Basin area, Nigeria. In: Kogbe, C.A. (Ed.), Geology of Nigeria. 2nd edition,Elizabethan Publishers, Lagos, pp. 347– 358.

Ojo, S.B. and Ajakaiye, D.E. (1976). Preliminary interpretation of gravity measurements in the Middle Niger Basin area, Nigeria. In C.A. Kogbe (editor) Geology of Nigeria pp. 295 – 307.

Okpoko, P.U (1993). "The people of Lokoja" in Audah B.W, Okpoko, A.I and Folorunsho C.A (eds) Some Nigerian People. Special Book Issue, West African Journal of Archaeology. (WAJA).

Olaniyan O., Olobaniyi S.B. (1996). Facies analysis of the Bida Sandstone formation around Kajita, Nupe Basin, Nigeria. J Afr Earth Sci no. 23, pp. 253–256.

Petters S. W. (1986). Foraminiferal biofacies in the Nigerian rift and continental margin deltas. In: Oti MN, Postma G (eds) Geology of deltas. AA Balkema, Rotterdam, pp. 219–235.

Pettijohn, F.J., Potter, P.E., and Siever, R. (1972). Sand and Sandstone.New York, Springer-Verlag, pp. 618.

Rosenqvist, Terkel (1983). Principles of Extractive Metallurgy, McGraw -Hill Book Company

Roser, B.P., and Korsch, R.J. (1988). Provenance signatures of sandstone–mudstone suites determined using discriminant function analysis of major-element data. Chemical Geology, vol. 67, pp. 119–139.

Roser, B.P., Cooper, R.A. Nathan, S. and Tulloch, A .J. (1996). Reconnaissance sandstone geochemistry, provenance, and tectonic setting of the lower Paleozoic terraines of the West Coast and Nelson, New Zealand. New Zealand. J. Geol. Geophys., vol. 39, pp. 1-16.

Taylor, S. R., and McLennan, S. M. (1985). The Continental Crust: its Composition and Evolution: An Examination of the Geological Record Preserved in Sedimentary Rocks: Oxford, U.K., Blackwell, pp. 328

Tucker, M. E. (1982). The Field Description of Sedimentary Rocks. Geological Society of London handbook series, vol. 2, pp. 112.

Turner, T. (1900). The Metallurgy of Iron (2nd ed.), Charles Griffin & Company, Limited

W. Russ, (1930). The Minna-Birnin Gwari belt, Report of Geological Survey of Nigeria.

Wentworth, C. K. (1922). A Scale of Grade and Class Terms for Clastic Sediments. The Journal of Geology, vol. 30, no. 5, pp. 377-392.

Whiteman, A.J. (1982). Nigeria. Its Petroleum Geology, Resources and Potential. Graham and Trotman, London, pp. 399.