PETROGRAPHIC/GEOCHEMICAL INVESTIGATIONS OF THE SANDSTONE MEMBER OF PATTI FORMATION, SOUTHERN BIDA BASIN

BY

OYEWOLE RASAQ BABATUNDE

GLY/14/2263

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 the research project on the petrographic investigation of the sandstone member of Patti formation, southern Bida Basin was actually carried out by Oyewole Rasaq Babatunde with matriculation number GLY/14/2263 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.

Signature............................ Date 20/2/2019.............................

Project Supervisor

Signature...................................... Date................................

Prof. O.J.Ojo

Head of Department

Signature Prof. S.A. Opeloye.......................... Date 25/02/19...............................

(Name of External Examiner)

External Examiner

DEDICATION

I dedicate this work to God Almighty my creator, my strong pillar, my source of strength, wisdom, knowledge and understanding. And I also dedicate this work to my parent Mr and Mrs Oyewole, my supervisor Mrs Ndukwe, the head of department in person of Prof O.J. Ojo and my 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, Mrs Ndukwe, whose contribution and constructive criticism enabled me to be more diligent and my knowledge on the subject matter has been broadened.

I also appreciate my siblings and my supportive friends who stayed with me to make this work a successful one.

TABLE OF CONTENTS PAGES

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

ABSTRACT

The study area is located in the Bida Basin in North-Central Nigeria. The study area is Southern Bida Basin which lies between the latitude 7°45′27.56″ and 7°51′0.4″ N of the equator and longitude 6°41′64″ and 6°45′36.58″E. The objectives of the study are to determine the paleoenvironment of deposition of the sediments in the study areas and also to determine the provenance of the sediments. Seven (7) sandstone samples of Patti Formation of Koton Karfi and Ozi Formations were collected for textural, petrographic and heavy minerals analysis with a view to determining the provenance of the sedimentary rocks. The texture of Patti Sandstones reveals well sorted, sub-arkose immature sandstone with the quartz showing both monocrystalline with more of the undulatory forms which depict its derivation mainly from metamorphic origin. The major oxides of the sandstone at Koto are; (0.49%-81.5%) SiO_2 ; (0.52%-2.51%) TiO_2; (4.03%-15.53%) Al_2O_3; and (2.91%-77.38%) Fe_2O_3. Other oxide such as CaO, MgO, Na_2O, K_2O, MnO, V_2O_5, Cr_2O_3, CuO,ZrO_2, BaO, PbO, ZnO, SrO, Rb_2O, Ga_2O_3, and SO_3 are <1% each. The elemental oxides of the sandstone at Ozi are; (80.23%-84.91%) SiO_2 ; (0.76%-1.22%) TiO_2; (6.27%-6.34%) Al_2O_3; and (2.87%-3.21%) Fe_2O_3. Other oxide such as (0.06%-2.33%) CaO, (0.69%-1.41%) K_2O, MgO, Na_2O, MnO, V_2O_5, Cr_2O_3, CuO,ZrO_2, BaO, PbO, ZnO, SrO, Rb_2O, Ga_2O_3, and SO_3 are <1% each. The discriminant diagram is indicating the source rock for each sediments of Patti formation Sample KT1C is from Mafic Igneous Rocks while Samples KT1A, Z1B and Z1C from Quartzose Sedimentary provenance. The Iron content of sample KT1D is high and this is as a result of the leaching of the ironstone overlying the formation. The Ternary diagram plotted for sandstone in Patti formation shows that the sandstones of Patti Formation are essentially Arkose to lithic Sub-arkose. From our heavy mineral analysis we know that the results indicated the dominance of opaque minerals over the non-opaque minerals.

CHAPTER ONE

INTRODUCTION

1.1 GENERAL STATEMENT

Geology is an aspect of science that is concerned with the study of the earth and its composition. The earth is not a static body but is constantly subjected to changes, both on it's surface and beneath its surface. A rock is an aggregate of minerals. The rock records events in the long history of the earth, all rocks make their contribution to the record. In some sense, geology is Earth history.

Geological mapping is a systematic and general study of the natural and artificial exposure of rocks with the aim of determining their composition. origin, age and forms of bedding and application of their occurrence on the topographic map. Geological mapping also involves plotting the location and attitude of the various rock units, faults and fold on a base map.

The surface area of Nigeria is 923.668 km^2 and is covered in nearly equal proportions by crystalline rocks (metamorphic and igneous rocks) and sedimentary rocks

The study area is located in the Bida Basin in North-Central Nigeria. It is a NW-SE trending intracratonic sedimentary basin extending from Kontagora in Niger State of Nigeria to areas slightly beyond Lokoja in the south (Fig 1.1).

1.2 AIM AND OBJECTIVES OF THE STUDY

The aim of the study is to improve on the existing knowledge of the study area by carrying out detailed geological investigation to determine paleoenvironment of deposition and the succession in the area. The following are the objectives of the study:

- To deduce the facie and facies association in the study areas.
- To investigate the paleoenvironments of deposition of the sediments in the study areas.
- To establish the mineralogical composition or the lithology units setting in which the sediments were formed.
- To provide an information on the source (provenance) and maturity of the sediments.

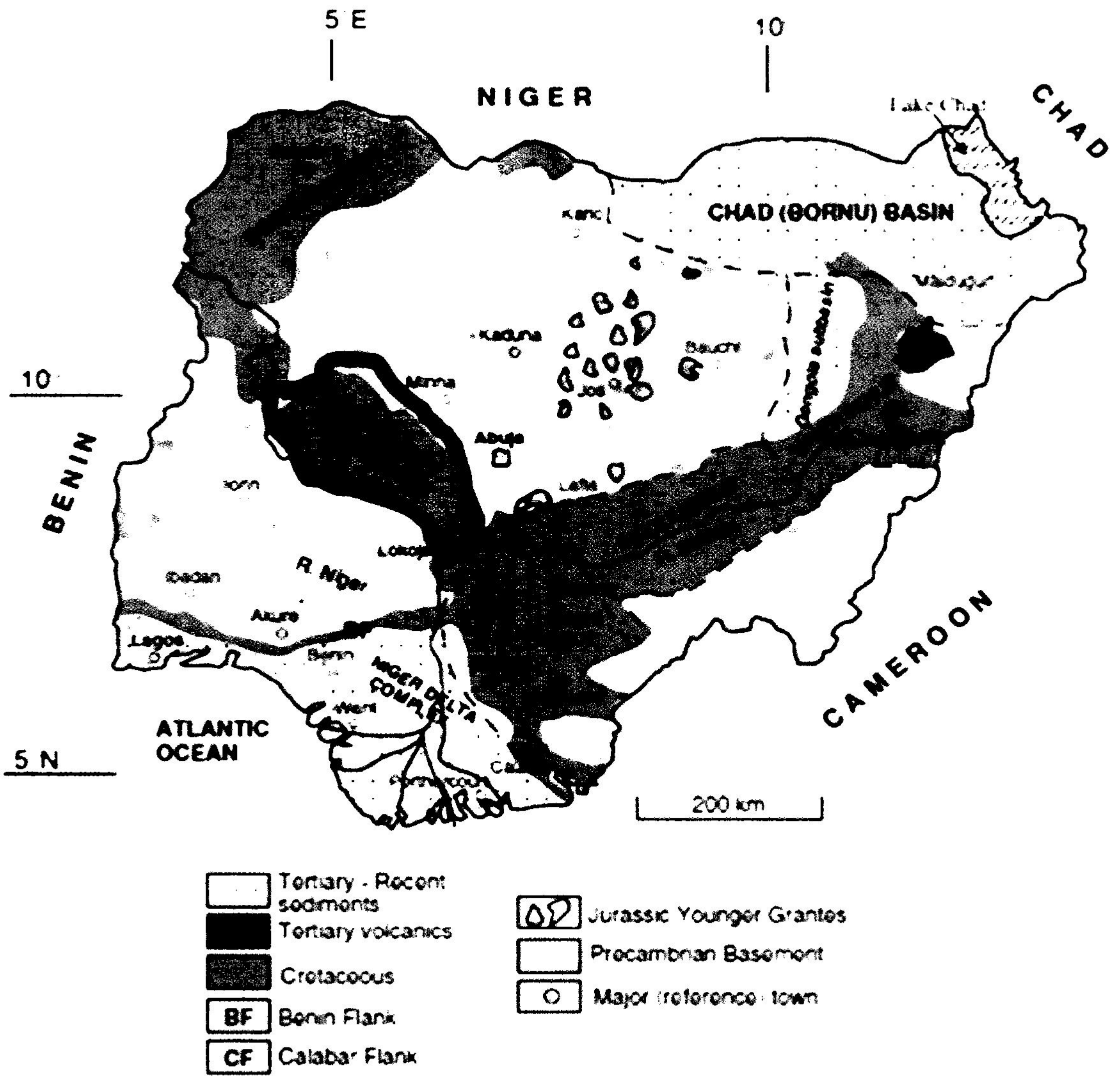


Figure 1.1: Geological Map of Nigeria showing the location of the Bida Basin (After Obaje et al. 2009).

1.3 THE AREA OF STUDY (LOCATION, EXTENT AND ACCESSIBILITY)

Lokoja is the administrative headquarters of Kogi State in Nigeria. It is about 165km southwest of Abuja as the crow flies, and 390km Northeast of Lagos by same measure. It is well connected through state and federal highway. It is located close to confluence of the River Niger and Benue; the area is sandwiched between a water body and a hill i.e River Niger and Mount Patti respectively which had streamlined the settlement to a linear and has a modifying effect on the climate.

The study area is Southern Bida Basin which lies between the latitude 7°45′27.56″ and 7°51′0.4″ N of the equator and longitude 6°41′64″ and 6°45′36.58″ E (Fig.1.2) of the Greenwich Meridian.

Residential districts are of varying density, and the city has various suburbs. The study area covers Southern Bida Sub-Basin and the areas where studies were carried out includes Koton Karfi and Ozi (Fig 1.2).

Most of the outcrops were accessed through footpaths, main roads and traversing through bushes, rivers and farmlands with the aid of a compass clinometer and Global Positioning System (GPS).

1.4 DRAINAGE

Lokoja is drained by River Niger and Benue rivers and their tributaries as shown (Fig.1.2). The confluence of the Niger and Benue rivers which could be viewed from the top of Mount Patti is located within the study area. It has been deeply dissected by erosion into tabular hills separated by river valleys. The flood plains of the Niger and Benue river valleys in Lokoja have the hydromorphic soils which contain a mixture of coarse alluvial and colluvial deposits. The alluvial soils along the valleys of the rivers are sandy, while the adjoining laterite soils are deeply weathered and grey or reddish in colour, sticky and permeable. The soils are generally characterized by a sandy surface horizon overlying a weakly structured clay accumulation.

1.5 RELIEF

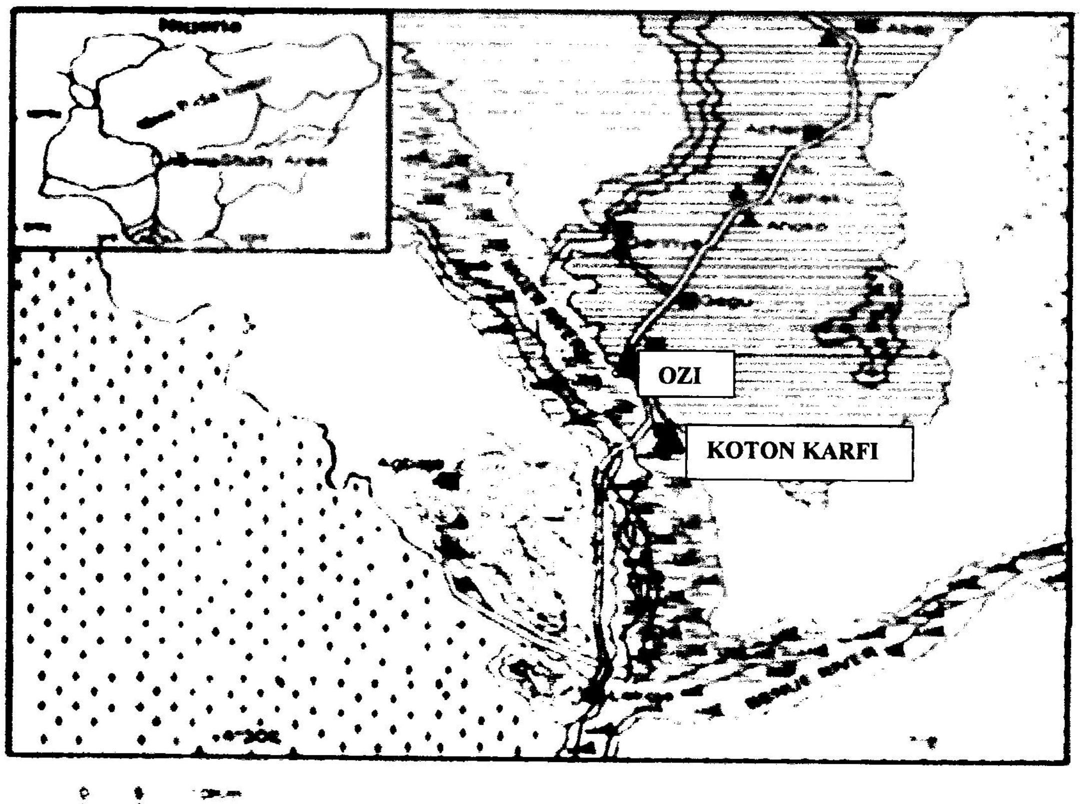
The land rises from about 300m along the Niger-Benue confluence, to the heights of between 300 and 600 metres above the sea level in the uplands. The general relief is undulating and characterized by high hills.

1.6 CLIMATE

The climate of Lokoja and its environs falls into koppen-Aw, this means it is the warm continental type (Olatunde and Ukoeje, 2016). Rainfall onset is around March/April while cessations is around October/November, with a short break in August. The average annual temperature rarely falls below 30.7^{0}C with February and March being the hottest month (Ifatimehin, Ishaya and Ujoh, 2010).

1.7 VEGETATION

The main vegetation type in the study area is Guinea savanna or parkland savanna with tall grasses and some trees which are green in the rainy season with fresh,leaves and tall grasses. The different types of vegetation are not in their natural luxuriant state owing to the careless human use of the forest and the resultant derived deciduous and savanna vegetation.



LEGEND
Alluvium Recent and Swamp Forest
Maastrichtian Agbaja Ironstone Formation
Maastrichtian Patti Formation
Campanian-Maastrichtian Lokoja Formation
Pre-Cambrian - Lower Paleozoic Basement Complex
Studied Outcrop Locations

Figure 1.2: Map of the study area (Modified after Ojo, 2009).

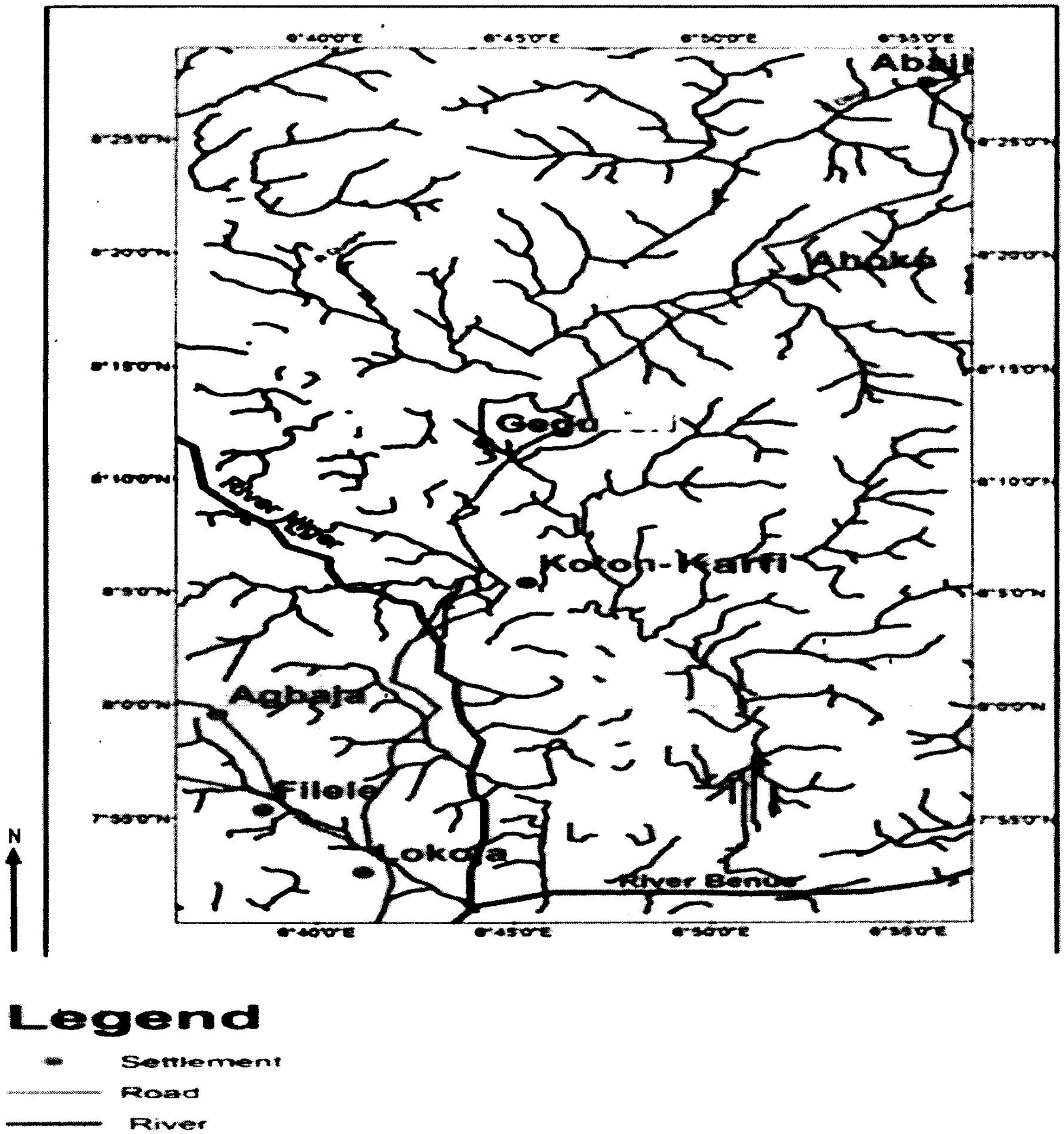


Figure 1.3: Drainage map of the study area (After Abua et al. 2005)

1.8 SOILS IN THE STUDY AREA

The soil in the study area is mostly loamy having composition of clay, sand and silt. Mount patty which is one of the hilly area in the surrounding is composed of igneous and metamorphic rocks belonging to the basement complex. Out of this majority is composed of mica-schist gneisses and Meta sediments.

Weathering of these materials from the plateau gives them a thin soil cover that is being washed down by erosion to give medium aggregates particularly desired by the building/ construction industries.

1.9 OCCUPATION OF INHABITANTS OF THE STUDY AREA

Agriculture serves as the main occupation of the people. However, the status of the Lokoja as an administrative headquarters brought some institutions into the area, which put many people in the public institutions like the Kogi State Polytechnic, Specialist Hospital and other governmental offices. Another occupation they establish on is Trading, there is also production of steel in Lokoja.

1.10 PREVIOUS WORK

Some of the previous work done on the study area include the researches carried out by Obaje (2009) and Ojo (2009) which are of great and absolute importance.

The main study area was the Lokoja Formation and Agbaja Formation where samples were collected to determine textural, geochemical, petrographic and heavy minerals analysis with a view to determining the provenance of the sedimentary rock. The methods employed in the research were field work and laboratory analyses where the field work involved description, logging, measurement and sample collection of various lithologic units. Petrographic analysis showed that sandstones from Lokoja and Agbaja Formations are composed of mostly quartz and feldspar. Most of the quartz grains are polycrystalline with undulose extinction and few are monocrystalline. The texture of Lokoja Sandstones reveals 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. The conglomerate and sandstone facies are mostly restricted to the Lokoja area. The ironstone mainly found at Agbaja was identified in Oolitic form. The iron rich sediments were noted to have been derived from the rocks of the northern basements, which had been transported to the environment of deposition, as azimuth of primary structure indicate southwardly direction. The research therefore reveals provenance through petrography and heavy mineral analysis from the samples collected on the field by the researchers.

A different study was also carried out by Madukwe et al; (2004) which is a bit similar to the previouse study stated above as it was carried out on the same area. This particular study deals with Geochemical, Petrographic and Granulometric study (grain size analysis) on the Lokoja Sandstone which marks a different from the previously stated workdone. 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.

CHAPTER TWO

REGIONAL GEOLOGY/TECTONIC SETTINGS

2.1 GEOLOGY OF NIGERIA

The geology of Nigeria is divided into three, which are the Basement Complex, the Sedimentary Basins and the Younger Granites. The Basement Complex comprises of Migmatite Gneiss, the schist belts, the older granites and the undeformed acid and basic dykes whereas the Sedimentary Basins comprises of the Anambra Basin, Borno Basin, Benue Trough, Sokoto Basin, Niger Delta Basin, Bida Basin and Dahomey Basin.

Nigeria is located between latitudes 4°N and 14°N of the equator and between longitudes 3°E and 15°E of the Greenwich Meridian with a total land area of approximately 923,768 square kilometres, Nigeria is the fourth largest country in West Africa. The greatest distance from east to west is approximately 13,000km while from north to south is about 11,000km.

The Precambrian rocks of Nigeria, collectively known as the Basement Complex, occupy nearly half the total area of the country while the other half is covered by the Cretaceous and younger sedimentary rocks (Figure. 2.1).

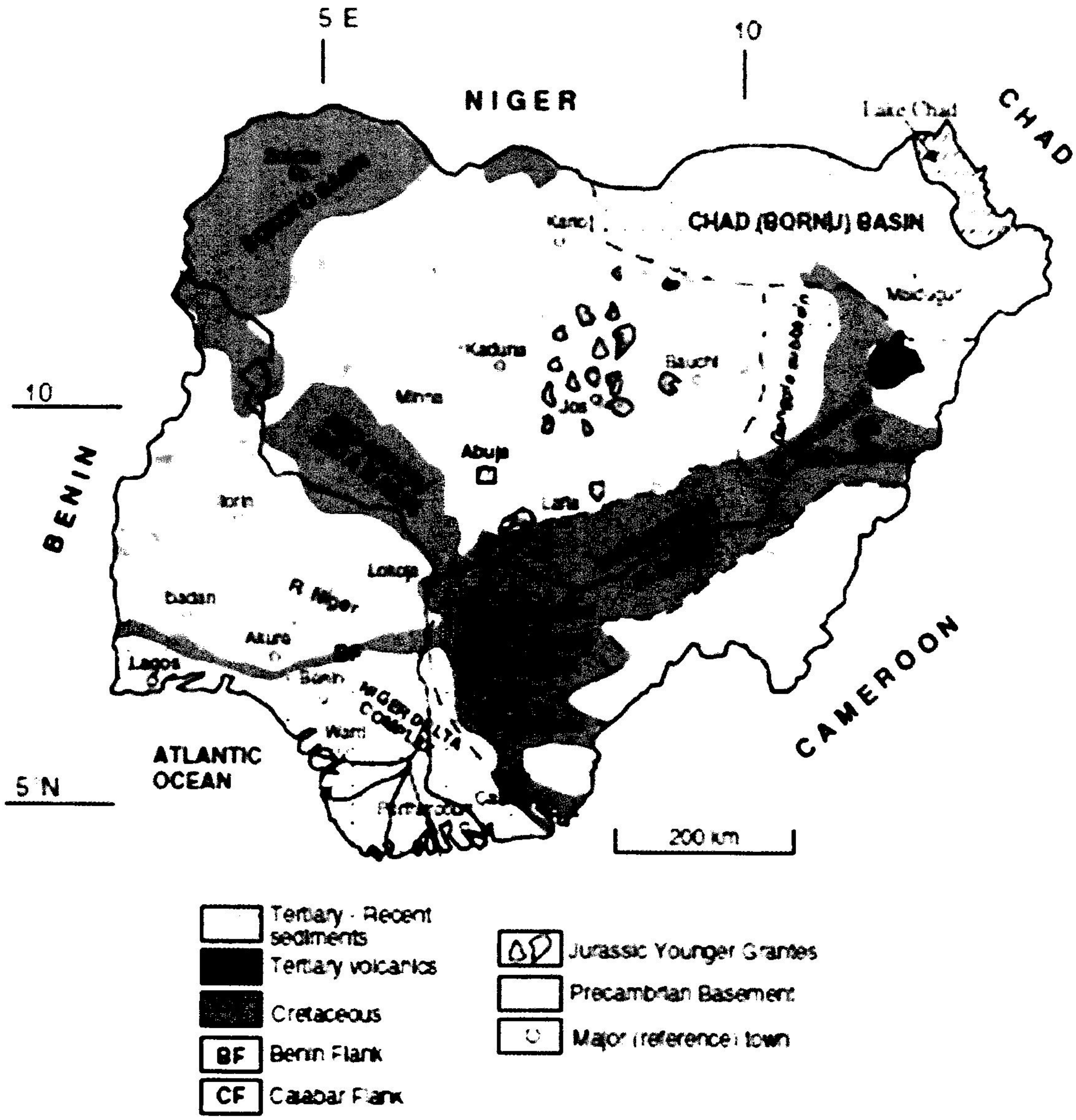


Figure 2.1: Geological sketch map of Nigeria showing the major geological components; Basement,Younger Granites, and Sedimentary Basins (After Obaje, 2009).

2.1.1 BASEMENT COMPLEX

As one of the three major litho-petrological components that make up the geology of Nigeria. the Nigerian Basement Complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons and south of the Tuareg Shield (Black 1980). It is intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is unconformably overlain by Cretaceous and younger sediments. The Nigerian basement was affected by the 600 Ma Pan-African orogeny and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin (Burke and Dewey, 1972; Dada, 2006). The basement rocks are believed to be the results of at least four major orogenic cycles of deformation. metamorphism and remobilization corresponding to the Liberian (2,700 Ma), the Eburnean (2,000 Ma). the Kibaran (1,100Ma) and the Pan-African cycles (600 Ma) (Abaa. 1983).

The crystalline rocks in Nigeria outcrop in 3 main areas:

1. The largest in the north central Nigeria has a roughly circular plan.
2. A triangular area in the south west which runs westwards into the neighboring Benin Republic
3. A rectangular area broken up into 3 parts by sedimentary rocks on the eastern border with Cameroon.

Within the Basement Complex of Nigeria, four major petro lithological units are distinguishable, (Obaje, 2009) namely:

I. The migmatite — Gneiss Complex (MGC).

2. The Schist Belt (Metasedimentary and Metavolcanic rocks).

3. The Older Granites (Pan African granitoids).

4. Undeformed Acid and Basic Dykes.

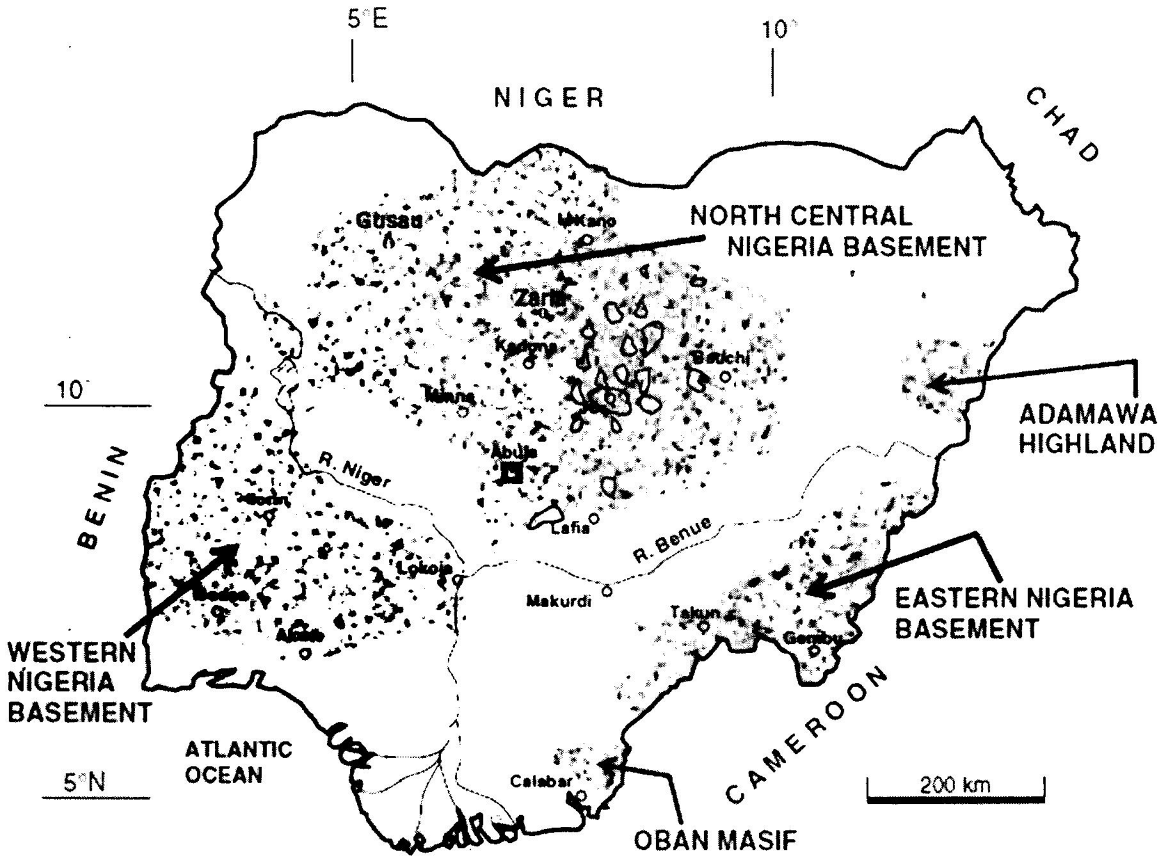


Fig. 2.2: Basement Geology of Nigeria (After Obaje,2009).

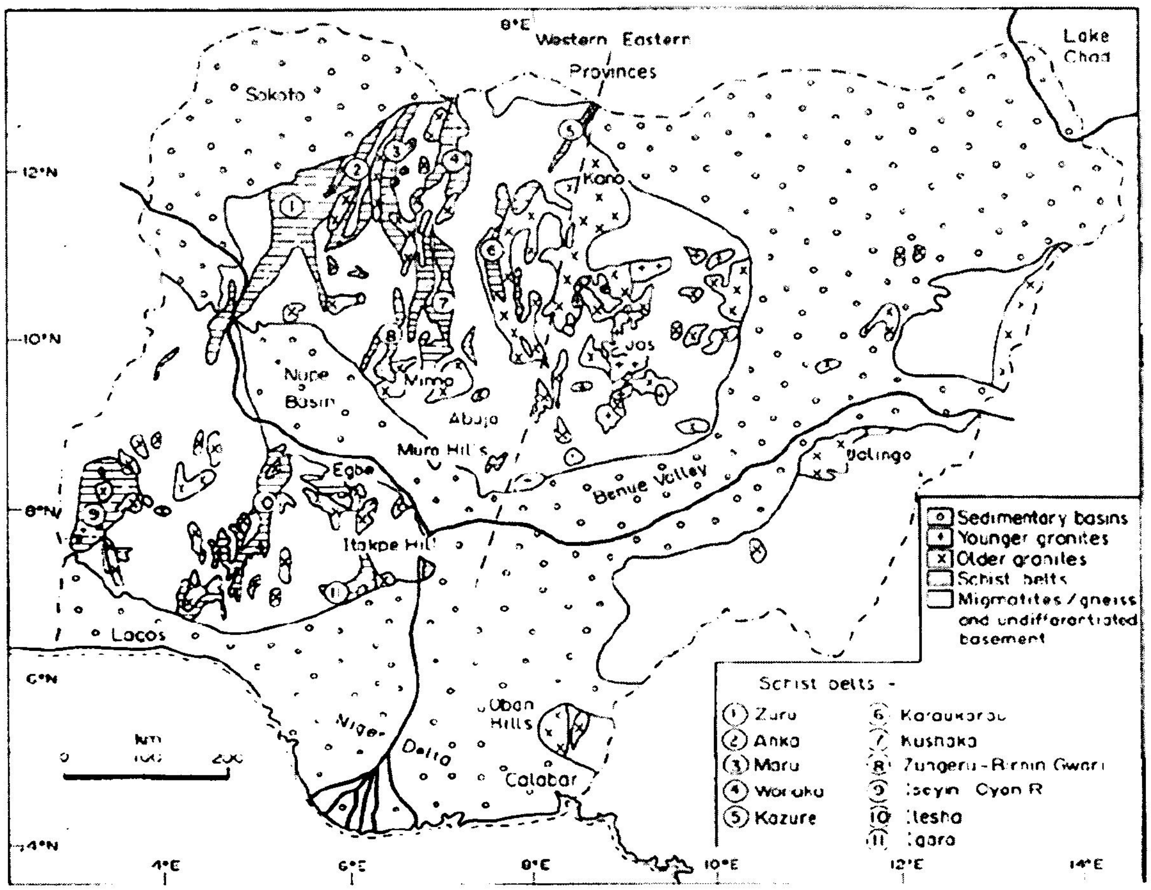


Fig. 2.3: Schist belt localities within the context of the Geology of Nigeria (After Woakes et al.,1987)

2.1.1.1 MIGMATITE-GNEISS COMPLEX

The Migmatite — Gneiss Complex is generally considered as the Basement Complex 'sensu stricto" (Rahaman, 1988; Dada, 2006) and it is the most widespread of the component units in the Nigerian basement. It has a heterogeneous assemblage comprising migmatites, orthogneisses, paragneisses, and a series of basic and ultrabasic metamorphosed rocks. The Migmatite Gneiss Complex is the oldest basement rock, and it typically exhibit coarse grained (plutonic) texture of the light coloured part comprising more or less igneous rocks like pegmatites, aplites and granites (Obaje 2009). The Migmatitie-Gneiss Complex makes up about 60% of the surface area of the Nigerian basement (Rahaman and Ocan, 1978). Many areas in northern, western and eastern Nigeria are covered by rocks of the Migmatite — Gneiss Complex. These eastern Nigeria are covered by rocks of the Migmatite — Gneiss Complex. These areas include, but not limited to: Abuja, Keffi, Akwanga, Bauchi, Kaduna, Kano, Funtua, Okenne, lghe. Ajaokuta (in northern Nigeria); Ibadan, Ile-Ife, Akure, Ikerre, (in western Nigeria) and Obudu and the Oban Massif areas in eastern Nigeria (Tubosun, 1983).

2.1.1.2 SCHISTBELTS

The Schist Belts also referred to as metasedimentary and metavolcanic rocks comprise low grade, metasediment-dominated belts occupying N-S trending synformal troughs. They are infolded into the older Migmatite-Gneiss Complex. The lithological variations of the schist belts include coarse to fine grained elastics, pelitic schists, phyllites, banded iron formation, carbonate rocks (marbles/dolomitic marbles) and mafic metavolcanics (amphibolites) Obaje, (2009). Rahaman (1976) and Grant (1978) for example suggest that there were several basins of deposition whereas Grant (1978) for example suggest that there were several basins of deposition whereas Oyawoye (1972) and McCurry (1976) consider the schists belts as relicts of a single supracrustal cover. Olade and Elueze (1981) consider the schist belts to be fault-controlled rift-like structures. Grant (1978), Holt (1982) and Turner (1983), based on structural and lithological associations, suggest that there are different ages of sediments. However, Ajibade et al, (1979) disagree with this conclusion and show that both series contained identical deformational histories. The structural relationships between the schist belts and the basement were considered by Truswell and Cope (1963) to be conformable metamorphic fronts and it was Ajibade et at

(1979) who first mapped a structural break. The geochronology of the schist belts remains problematical although the ages of the intrusive cross-cutting Older Granites provide a lower limit of ca 750Ma Obaje (2009) . A Rb/Sr age of 1,040 ± 25 Ma for the Maru Belt phyllites has been accepted as a metamorphic age by Ogezi (1977).

2.1.1.3 THE OLDER GRANITES

The term "Older Granite" was introduced by Falconer (1911) to distinguish the deeps Seated, often concordant or semi-concordant granites of the Basement Complex from the high- level, highly discordant tin-bearing granites of Northern Nigeria. The Older Granites are believed to be, pre, syn and post-tectonic rocks which cut both the migmatite-gneiss-quartzite complex and the schist belts. They range widely in age (750 -450 Ma) and composition Obaje (2009). They represent a varied and long lasting (750-450 Ma) magmatic cycle associated with the Pan-African orogeny. The rocks of this suite range in composition from tonalites and diorites through granodiorites to true granites and syenites. Charnockites form an important rock group emplaced during this period. They are generally high level intrusions and anataxis has played an important role (Rahaman, 1981). The Older Granites suite is notable for its general lack of associated mineralization although the thermal effects may play a role in the remobilization or mineralizing fluids (Obaje, 2009).

The Older Granites are the most obvious manifestation of the Pan-African orogeny and represent significant additions of materials (up to 70% in some places) to the crust (Rahaman, 1988). Attempt to classify the Older Granites with respect to timing during an orogenic event are valid over only short distances. Contact features between members of the Older Granites suite suggest the coexistence of several magmas. Dada (2006) was of the opinion that the term 'Pan African Granitoids" be used for the Older Granites not only on the merit of age which was not available at the time they were named Older Granites, but because it covers several important petrologic groups formed at the same time. The granitoids which outcrop with the schist belts in northwestern and southwestern Nigeria include biotite granites, biotite muscovite granites, syenites, chanockites serpentinites and anorthosites (Obaje 2009). Rahaman (1988) discarded the earlier classification of members of the Older Granites suite on the basis of their texture, mineraological composition and the relative timing of their emplacement. In its place, members of the Older Granite suite were classified as follows, based mainly on the textural characteristics:

1. Migmatitic granite;
2. Granite gneiss;
3. Early pegmatites and fine-grained granite;
4. Homogeneous to coarse porphyritic granite;
5. Slightly deformed pegmatite aplites and vein quartz; and
6. Undeformed pegmatites, two-mica granites and vein quartz.

2.1.1.4 UNDEFORMED ACID AND BASIC DYKES

The undeformed acid and basic dykes are late to post-tectonic Pan African, they crosscut the Migmatite-Gneiss Complex, the Schist belts and the Older Granite. They include felsic dykes that are associated with Pan-African granitoids on the terrain such as the muscovite, tourmaline and beryl-bearing pegmatites. micro-granites. aplites and syenite dykes (Dada. 2006); and Basic dykes (the youngest units) that are generally regarded as the less common basaltic, doleritic and lamprophyric dykes. The age of the felsite dykes has been put between 580 and 535 Ma from Rb-Sr studies on hole rocks (Dada. 2006). While the basic dykes have a much lower suggested age of ca. 500 Ma (Grant. 1970). The structural and geochronological importances of this suite of rocks, which have been put to immense chronological use elsewhere (Dada. 2006) are often overlooked in Nigeria. When they cross-cut basement, they could be used to infer relative age of metamorphic structures and rock suites and could also suggest the existence of older basement windows in the Nigerian schist belts, apart from the immense guide they provide in sampling for isotope geochemistry, analysis and interpretation (Dada, 2006).

2.1.2 THE YOUNGER GRANITE

The Mesozoic Younger Granite ring complexes of Nigeria form part of a wider province of alkaline anorogenic magmatism. They occur in a zone 200 km wide and 1,600 km long extending from northern Niger to south central Nigeria. Rb/Sr whole rock dating indicates that the oldest complex of Adrar Bous in the north of Niger is Ordovician in age, with progressively younger ages southwards. The most southerly ring complex of Afu is Late Jurassic in age (Bowden et al., 1976). Aeromagnetic anomalies suggest that a series of buried NE–SW lineaments of incipient rifts controlled the disposition of the individual complexes (Ajakaiye,1983). The Younger Granites have been studied in most detail in Nigeria, partly for their intrinsic interest, providing comparative data for study of similar formations elsewhere in the world, but mainly because in the early 1900s they were recognized as the source of rich alluvial cassiterite deposits that had long been known to exist on and around the Jos Plateau Detailed filed mapping of the ring complexes has demonstrated a consistent succession of magmatic activity from volcanism to plutonism associated with the emplacement of mainly granite melts at high levels in the crust. The most striking petrographic feature of the whole province is the overwhelmingly acid nature of the rocks and the similarity of the rock types found in all areas. Over 95% of the rocks can be classified as rhyolites, quartz-syenites or granites, with basic rocks forming the remaining 5%. Many of the rocks have strongly *alkaline* to *peralkaline* compositions, other are *aluminous* to *peraluminous*.

2.1.3 SEDIMENTARY BASINS

Formation of the Sedimentary Basins in Nigeria is related to the geo-dynamic processes of the dispersal of the Gondwanaland (Burke and Dewey, 1972). The basins, which are either directly linked to the spreading edge of the continent or indirectly to the tension generated by the divergent tectonics., are believed to be vestiges of the fragmentations which led to the separation of the African and south-American plates as well as the formation of the south Atlantic. The opening of the Atlantic in the early Mesozoic era triggered the crustal fragmentation of West-Central African craton into a rift system (Burke and Dewey, 1972). The basins are all rift related and consist of sediment fill which differently are between Cretaceous to Tertiary. The Geologic basins of Nigeria are: (Fig 2.1)

1. The Benin Basin/Dahomey Basin

2. The Bida/Mid Niger Basin

3. The Sokoto/SE lullemeden basin

4. Borno/ SW Chad Basin

5. The Benue Trough (Gongola sub-basin, Yola arm)

6. The Niger Delta

7. Anambra Basin

2.2 ORIGIN OF BIDA BASIN

The Bida Basin can be divided into Northern and Southern (or Lokoja) Sub-Basins. The stratigraphic succession of the Bida Basin, collectively referred to as the Nupe Group by Adeleye, (1974) comprises a NW-SE trending belt of Upper Cretaceous sedimentary rocks, deposited as a result of subsidence during Cretaceous opening of the South Atlantic Ocean. Sinistral offset along the NE-SW axis of the Benue Trough appears to have been translated to north-south and NW-SE trending shear zones to form the Bida Basin at high angle to the Benue Trough (Benkhelil, 1989).

This detailed study of the facies indicates rapid basin-wide changes from various alluvial fan facies through flood-basin and deltaic fades to lacustrine fades. Paleogeographic reconstruction suggests lacustrine environments were widespread and elongate. Lacustrine environments occurred at the basin's axis and close to the margins. This suggests the depocenter must have migrated during the basin's depositional history and subsided rapidly to accommodate the 3.5km-thick sedimentary fill.

Although distinguishing pull-apart basins from rift basins, based solely on sedimentologic grounds, may be difficult, the temporal migration of the depocenter, as well as the basin architecture of upward-coarsening cyclicity, show a strong tectonic and structural overprint that suggests a tectonic framework for the Southern Bida basin similar to the origin of a pull apart basin.

2.3 GEOLOGICAL SETTING OF THE BIDA BASIN

Bida Basin is a NW-SE trending intracratonic basin extending from Kotangora (northern Nigeria) to Lokoja in the central part of Nigeria (Fig.2.1). It forms a shallow linear depression with sedimentary thickness that varies from 2 km to 3.5 km and occupies a gently downwarped trough (Ojo and Ajakaiye, 1989) and (Udensi and Osazuwa, 2004). The origin of the basin is closely related to Santonian tectonic crustal movements, which affected the Benue Basin and SE Nigeria. A post-Santonian shallow cratonic sag and pull-apart origin was proposed by (Whiteman, 1982). Geophysical studies have shown that Bida Basin is bounded by a NW-SE trending system of linear faults and central positive anomalies flanked by negative anomalies (Ojo, and Ajakaiye, 1989). This structural pattern is consistent with rift related structures as observed in the adjacent Benue Trough. The stratigraphy of the Bida Basin was previously referred to as Lokoja Series (Falconer, 1911). This was followed by the work of (Russ, 1930) who referred to these sedimentary successions as Nupe Group. (Jones, 1958) divided the sedimentary successions into northern Bida and southern Bida Basins.

The southern Bida Basin comprises of three formations which are Campanian to Maastrichtian in age: Lokoja Formation, Patti Formation and Agbaja Ironstone (Akande et al; 2005) and (Ojo and Akande, 2009). These formations have their lateral equivalents in the northern Bida Basin which are Bida Sandstone, Sakpe Ironstone, Enagi Siltstone and Batati Ironstone respectively. In the southern Bida Basin, the Lokoja Formation unconformably overlies the Precambrian crystalline basement complex rocks, the Patti Formation and the Agbaja Formation overlies the Lokoja formation (Fig.2.2). The Formation comprises false bedded conglomerates, cross bedded pebbly and coarse grained sandstones, siltstones and claystones. These different lithologic units were interpreted as products of braided fluvial depositional environments, flood plain and overbank deposits (Ojo and Akande 2009). The Lokoja Formation is overlain by Patti Formation, which consists of sandstones, siltstones, claystones and shales with interbeds of ironstones. This Formation was interpreted as products of quiet water deposition in shallow marine environment. Marginal marine environment has also been suggested for the Formation based on the occurrence of arenaceous species of foraminifera (Ammobaculites, Milliamina, Trochamina and Textularia) recovered from the shales (Akande et al; 2005). The Agbaja Formation consists of sandstones and claystone interbeds with oolitic and concretionary massive ironstone beds. The ironstone forms the cap in most topographic highs in the area and consisting of brown, yellow to white geothitic and kaolinitic oolites in a yellow limonitic silty matrix. (Ladipo et al; 1994) interpreted the sandstones and claystones lithofacies as products of abandoned channels and overbank deposits influenced by marine reworking to form the massive and concretionary oolitic ironstones. Evidences of marine transgression have also been documented in the Agbaja Ironstone (Braide et al; 1992) and (Olaniyan and Olobaniyi, 1996).

The hydrocarbon resource evaluation of the Bida Basin has been carried out in line with the standard evaluation of the composite petroleum system of a basin that begins usually with the determination of source rock availability if any, followed by reservoir availability and quality, migration of any generated hydrocarbons, trapping mechanisms and sealing integrity.

The Bida Basin has potential source rocks composed of carbonaceous shales, intercalated with sandstones and clay. Interpretation of geochemical data by Obaje et al. (2004) indicates that organic matter in these source rocks is in the early-mature stage of gas generation and may have reached peak stages in the deeper portions of the basin. Further geochemical investigations (Obaje, 2009) suggest that kerogen in the Patti Formation is dominated by Type III material (vitrinites) with some Type II (liptinites) and Type IV (inertinites). Vitrinite reflectance and fluorescent properties of investigated macerals suggest immature to marginally mature kerogens with Ro values varying mostly from 0.42 to 0.63%. T0C values range from 0.17 to as high as 3.8% (mean = 2.3%). Rock Eval data for the shale support the microscopic evidence for the prevalence of landderived humic kerogen derived from terrestrial organic matter. The results indicate that the shales are gas prone with minor oil generation potential.

2.3.1 NORTHERN BIDA BASIN

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

2.3.1.1 THE BIDA SANDSTONE

The Bida Sandstone is divisible into two members, namely the Doko Member and the Jima Member. The Doko Member is the basal unit and consists mainly of very poorly sorted pebbly arkoses, sub-arkoses and quartzose sandstones. These are thought to have been deposited in a braided alluvial fan setting. The Jima Member is dominated by cross-stratified quartzose sandstones, siltstones and claystones. Trace fossils comprising mainly Ophiomorpha burrows have been observed. These were also observed in the overlying Sakpe Ironstone, suggesting a possible shallow marine subtildal to intertidal influence during sedimentation. The Jima Sandstone Member is thus considered as the more distal equivalent of the upper part of the Lokoja Sandstone, where similar features also occur.

2.3.1.2 THE SAKPE FORMATION

The Sakpe Ironstone comprises mainly oolitic and pisolitic ironstones with sandy claystones localy, at the base, followed by dominantly oolitic ironstone which exhibits rapid facies changes across the basin, at the top.

2.3.1.3 THE ENAGI SILTSTONE

The Enagi Siltstone consists mainly of siltstones and correlate with the Patti Formation in the Lokoja Sub Basin. Other subsidiary lithologies include sandstone-siltstone admixture with some claystones. Fossil leaf impressions and rootlets have been found within the formation. The

formation ranges in thickness of between 30m and 60m. Mineral assemblage consists mainly of quartz, feldspars and clay minerals.

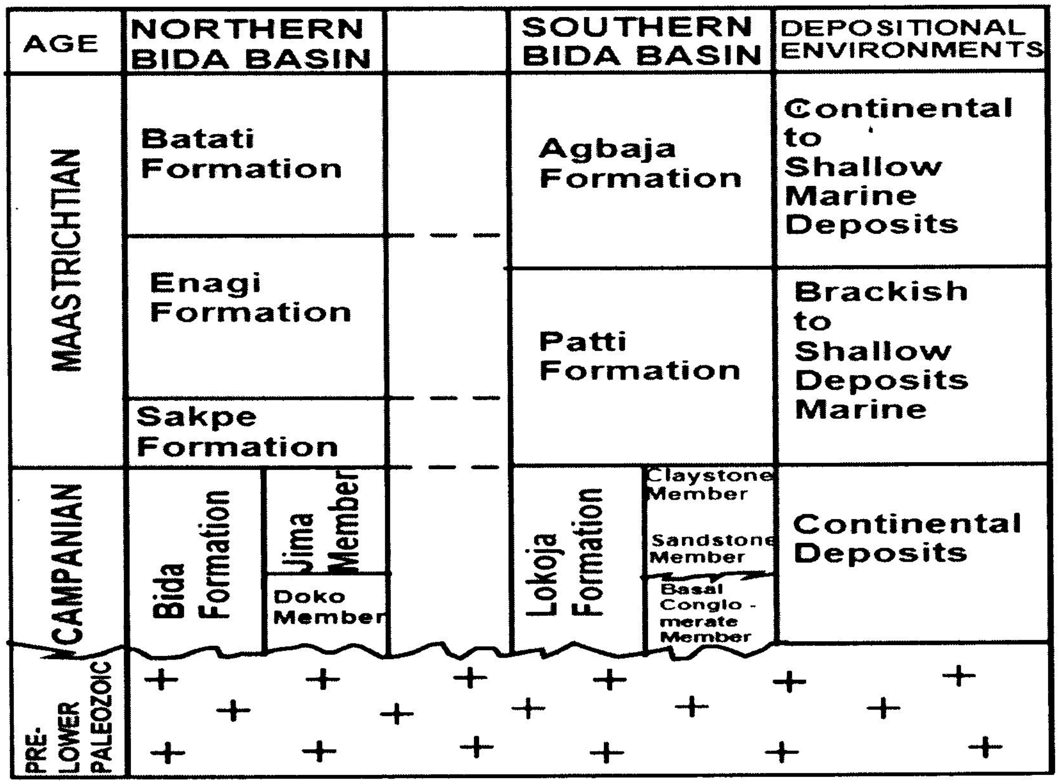


Figure 2.4: Stratigraphy of the NW-SE trending Bida Basin. Stratigraphic relationship and depositional environments in the northwestern and southeastern parts are highlighted (Modified from Ojo and Akande, 2009)

2.3.1.4 THE BATATI FORMATION

This formation constitutes the uppermost units in the sedimentary sequence of the Bida Basin. The Batati Formation consists of argillaceous, oolitic and geothitic ironstones with ferruginous claystone and siltstone intercalations and shaley beds occurring in minor proportions, some of which have yielded nearshore shallow marine to fresh water fauna (Adeleye, 1974).

2.3.2 SOUTHERN BIDA BASIN

Three formations are recognized in the southern Bida Basin (Fig.2.4) all of which are Campanian to Maastrichtian in age (Adeleye, 1971; Adeleye and Dessauvagie, 1972; Agyingi, 1991). The formations are the basal Lokoja Sandstone, Patti Formation and the uppermost Agbaja Ironstone.

2.3.2.1 THE LOKOJA FORMATION

Lithologic units in this formation range from conglomerates, coarse to fine grained sandstones, siltstone and claystones in the Lokoja area. Sub-angular to sub-rounded 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 outcrops. 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 diversified arenaceous foraminfers from clayey intervals of the Lokoja Formation more common in the overlying Patti Formation where shallow marine depositional conditions are known to have been more prevalent 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 been more prevalent.

2.3.2.2 THE PATTI FORMATION

Outcrops of the Patti Formation occur extensively on the Agbaja Plateau, Ahoko and Abaji on the Lokoja-Abuja expressway. 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 deformational sedimentary structures (e. g. slumps), and other structures as wave ripples. convolute laminations and load structures. Trace fossils (especially Thallasinoides) are frequently preserved. Interbedded claystones are generally massive and kaolinitic, whereas the interbedded grey shales are frequently carbonaceous. The subsidiary sandstone units of the Patti Formation are more texturally and mineralogically mature compared with the Lokoja Formation sandstones. The predominance of argillaceous rocks, especially siltstones, shales and claystones in the Patti Formation requires suspension and settling of finer sediments in a quite 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 southern side of the Anambra Basin are commonly interbedded with chamositic carbonates and overlain by bioturbated siltstones, sandstones and coal units in coarsening upward cycles toward the northern side of the basin (Akande et al., 2006). This sequence is overlain by herringbone-cross-bedded mature sandstones of the Ajalli Formation (Middle Maastrichtian) in the northern fringes of the basin hence providing strong evidence for shallow marine, deltaic to intertidal depositional environments for the Maastrichtian sediment of the Anambra Basin. 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 Ajalli Formations in the Anambra Basin (Ladipo, 1988; Nwajide and Reijers, 1996). The more marine influences in the adjacent Anambra Basin is probably related to the nearness of that basin to the Cretaceous Atlantic Ocean prior to the growth of the Niger Delta.

2.3.2.3 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. The Agbaja Formation is best exposed on the Agbaja Plateau where it overlies successively the Lokoja and Patti Formations. The Agbaja Formation consists of sandstone beds in this region. The sandstones and claystones are interpreted as abandoned channel sand overbank deposits influenced by marine reworking to form the massive concretionary and oolitic ironstones that had been mapped in some details (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 Olabaniyi, 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

MATERIALS AND METHODS

3.1 MATERIALS

MEASURING TAPE: Is a round narrow band of woven fabric; which is used for linear measurement, each measuring tape is about 50m long.

HAMMERS: A handheld tool consisting of a solid, heavy metal which is used in driving electrodes into ground. The handle is usually light and it is made of wood/plastic. The metal head weigh about 2kg.

COMPASS CLINOMETER: This is an instrument that indicates directions, typical by means of freely-turning needle pointing to magnetic north. It is also used to determine the dip strike of a rock or outcrop before traversing i.e. the general rock trend.

GPS (GLOBAL POSITIONING SYSTEM): this is used to pinpoint the longitudinal and latitudinal co-ordinates of the study area as well as the elevation.

The other materials used are sample bags and masking tape.

3.2 METHODS

The methods employed in this study were field mapping and laboratory analyses. The field work involved outcrop description, logging of the outcrop, measurement of beds thickness and sample collection. Bedding characteristics in term of texture and lithology were studied in the field. Laboratory investigations of samples included grain size analysis, petrography and heavy mineral analysis. Sandstone samples were collected from Lokoja and environs. Each sample was divided into 3 parts: One part for grain size analysis, another for petrographic studies and the third part for heavy mineral analysis.

3.3 FIELD MAPPING AND SAMPLE COLLECTION

A geological traverse covering outcrops around Koto and Ozi, where the Formations were encountered. Most of the outcrops were road cuts which represent the different lithofacies of the formation.

3.3.1 LOGGING

Exposed stratigraphic sections at Koto and Ozi were logged accordingly and beds were identified based on sediment grain sizes and textures, colour and sedimentary structures. The logging was carried out with the aid of a measuring tape extended from buttom to top of each beds and recorded at intervals keeping into cognisance the forward extension of each beds so as to obtain the accurate thickness.

3.3.2 SAMPLING

A geological hammer used in chipping, breaking and taking rock samples is the basic tool in sample materials. A chisel is employed to support the hammer to create fractures in the rock for easy breakage. A Global Positioning System (GPS) was used in taking accurate reading of the longitude and latitude and the geographic positions of outcrops on the field. A field notebook was used to record various sample locations and representation of geological information on the field and representation of the lithologic section of each sample locations were drawn . A digital camera was used in taking pictures of these rocks in-situ and interesting features to serve as back up memory in addition to the field notebook. Based on the in situ observations, textural and compositional studies of the outcrop, tentative names were given to rock samples taken from the outcrop. Attempts were also made to determine the geologic history, to explain the sequence of events as it affect rocks in the area. Finally, samples were taken with the aid of sledge hammer, a sample bag is then used to carry properly labeled samples, which were taken for petrographic preparation and other analysis.

3.4 PROCESSING AND ANALYSES OF THE SAMPLES

The laboratory study involved petrography, grain size analysis, and heavy mineral analysis, geochemistry and polished section. The prepared thin sections were examined under the petrological microscope to identify mineral assemblages. The optical properties of minerals such as colour, cleavage, relief etc, under plane polarized light (PPL) and birefrigence, extinction under cross polarized light (XPL) also studied. Detailed description of the mineral composition and textural characteristics were interpreted.

3.4.1 GRAIN SIZE ANALYSIS

The Standard grain size analysis test determines the relative proportions of different grain sizes as they are distributed among certain size ranges. Grain size distribution is one of the most important characteristics of sediment. Characterizing the physical properties of sediment is important in determining its suitability for various uses as well as studying sedimentary environments and geologic history.

The physical properties of sediment can be described by several parameters. Grain size is the most important of these and is the main way in which sediments are classified. Other commonly used properties of sediments are sorting and shape(roundness and sphericity).

Apparatus Required for grain size analysis are;

i. Stack of Sieves including pan and cover

ii. Weighing Balance

iii. Rubber pestle and Mortar (for crushing the soil if lumped or conglomerated)

iv. Mechanical sieve shaker

The Test procedure are;

i. Take a representative oven dried sample of soil that weighs about 500g. (this is normally used for soil samples, the greatest particle size which is 4.75mm).

ii. If soil particles are lumped or conglomerated, crush the lump and not the particles using the pestle and mortar.

iii. Determine the mass of the sample accurately. W_t (g).

iv. Prepare a stack of sieves. Sieves having larger openings (i.e lower numbers) are placed above the ones having smaller opening sizes (i.e higher numbers).

v. Make sure the sieves are clean, if any soil particles are stuck in the openings try to poke them out using brush.

vi. Weigh all sieves and the pan separately

vii. Pour the soil from step 3 into the stack sieves from the top and place the cover, put the stack in the sieve shaker and fix the clamps, adjust the time on 10 to 15 minutes and get the shaker going.

viii. Stop the sieve shaker and measure the mass of each sieve + retained soil.

ix. The data derived are then recorded in a table.

3.4.2 TECHNIQUE FOR SEPERATION OF HEAVY MINERALS

Separation of heavy-mineral particles by gravity is accomplished using a so-called heavy liquid and two superposed separatory funnels. The technique is reliable and particularly useful where large amounts of sediment must be processed. It suffers, however, from the disadvantage that complete separations normally require from one to three hours. A typical arrangement of apparatus for gravity separation of heavy minerals is shown in. In order to serve as a suitable medium for gravity separation of heavy-mineral particles, a heavy liquid, in addition to having a high specific 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. Unfortunately, heavy liquids having the last two properties are not coin. It must be kept in mind at all times that the liquid that is been used is highly toxic and that the fumes are toxic as well. All procedures must be carried out under a well-ventilated hood you will use tetrabromoethane ($C_2H_2Br_4$), which has a specific gravity at 20°c of 2.96; bromoform ($CHBr_3$) is also commonly used as a heavy liquid. although for this exercise you will perform only on. separation, it is necessary to be aware that using different liquids or mixtures of liquids of proper densities one can separate heavies into smaller and smaller classes of differing specific gravity.

Test Proceedure;

1. If necessary, sieve sample in order to obtain material in 1 to 4 (1/2—1/16 mzn) range.

2. Weigh sample - about 25g is sufficient and record sample weight.

3. Pour tetrabromoethane into upper (separatory) funnel (see figure 3.1). The funnel should be about 1/2 full.

4. Pour sample into tetrabromoethane and stir thoroughly in order to wet all particles and dispers, air bubbles.

5. Allow particles to settle; stir periodically so that particles will not adhere to funnel wall. Cover funnel with watch glass to reduce heavy-liquid evaporation loss.

6. When heavy minerals have settled to bottom of separatory funnel, open pinch-cock and allow heavy-mineral particles to drop onto filter paper in lower funnel. Close pinch-cock so that minerals floating in remaining heavy liquid will remain in the separatory funnel.

7. After heavy liquid has drained from filter paper into used heavy-liquid bottle below, remove papr and place upside down in porcelain dish or large watch glass containing acet one. If necessary, use plastic squeeze bottle containing acetone to wash into the dish any particles which adhere to the filter paper; decant excess acetone into fluid waste container.

8. Dry heavy-mineral fraction, and label and retain fraction for compositional determination and provenance analysis.

9. Using the same apparatus set-up as before, drain the remaini ng heavy liquid through filter paper in the lower funnel and into the used heavy-liquid bottle below. Th. light minerals will collect on the filter paper. It may b• necessary to use a squeeze bottle containing acetone to wash p articles that adhere to the side of the separatory funnel. If this is necessary, it **is** important during the washing process to replace the bottle used for collection f undil uted used heavy liquid with one used for collection of fluid waste (i.e., a mixture of acetone and heavy Iiquid).

10. Using the same procedure as that outlined in Steps 7 through 9, collect, dry, record weight and retain the light— mineral fraction for compositional determination.

➢ DETERMINATION OF HEAVY MINERAL COMPOSITION

1. Under the binocular microscope, the composition of the heavy-mineral fraction that is saved from the seperation can be studied.

2. Estimation of particle-type percentages and recording of data.

3. Using the fractions derived in the seperation, particle-type percentage are estimated and data recorded.

4. Diagram your estimates of the percentages of various particle.

3.4.3 TECHNIQUES FOR PREPARATION OF THIN SECTION

In the laboratory, a total of four rock samples were selected and cut into slices with a micro-cutting machine. Field studies require integration of content, knowledge, observation and interpretation, analysis. experiment and theory and all their representations. All need to come together to form a coherent internally consistent interpretation. Thin sections were prepared for six of the collected samples during the exercise in order to carry out the petrographic study. 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 immense heat at a temperature of about 80° to 90°C after which a small quantity of aradite is added to the heated sample. Prior to mounting on a glass slide with aradite, 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 while the minerals optical properties such as cleavage colour, relief etc. were studied under a Plane polarized Light (PPL) and Cross Polarized light (XPL) of the petrological microscope. The results attained from these analyses were subjected to interpretation to delineate the texture, mineralogical, and modal composition of the rock types being analyzed.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 LITHOLOGIC DESCRIPTION OF THE STUDY AREA

The beds being deposited in the study area range from conglomerates, coarse to fine grained sandstones, siltstone and claystones in the Lokoja area. Both grain supported and matrix supported conglomerates form recognizable beds at the base of distinct cycles at outcrops. Sub-angular to sub-rounded cobbles, pebbles and granule sized quartz grains in the units are frequently distributed in a clay matrix. The sandstone units are frequently cross-stratified, poorly sorted and composed mainly of feldspar and quartz and are thus texturally and mineralogically immature as indicated in the lithologic sections and field photographs that would be presented after each studied area varying lithology description.

4.1.1 LITHOLOGIC DESCRIPTION OF OUTCROP AT KOTON KARFI

With the use of a Global Positioning System (GPS), It was discovered that the outcrop is located at latitude 08° 00 ' 44.2" N and longitude 006° 47' 06" E with an elevation of 55m. The outcrop has four beds of different lithologic unit starting from the base with very fine massive sandstone which is 2.5m thick overlain it is the massive clayey medium grained sandstone which is 2.6m thick, overlaying the massive clayey medium grained sandstone is the coarse to pebbly sandstone which is 2.8m thick and overlaying them all is an oolitic ironstone which is 4m thick. The total thickness of the outcrop in this location is 11.9m (Fig. 4.1 and 4.2).

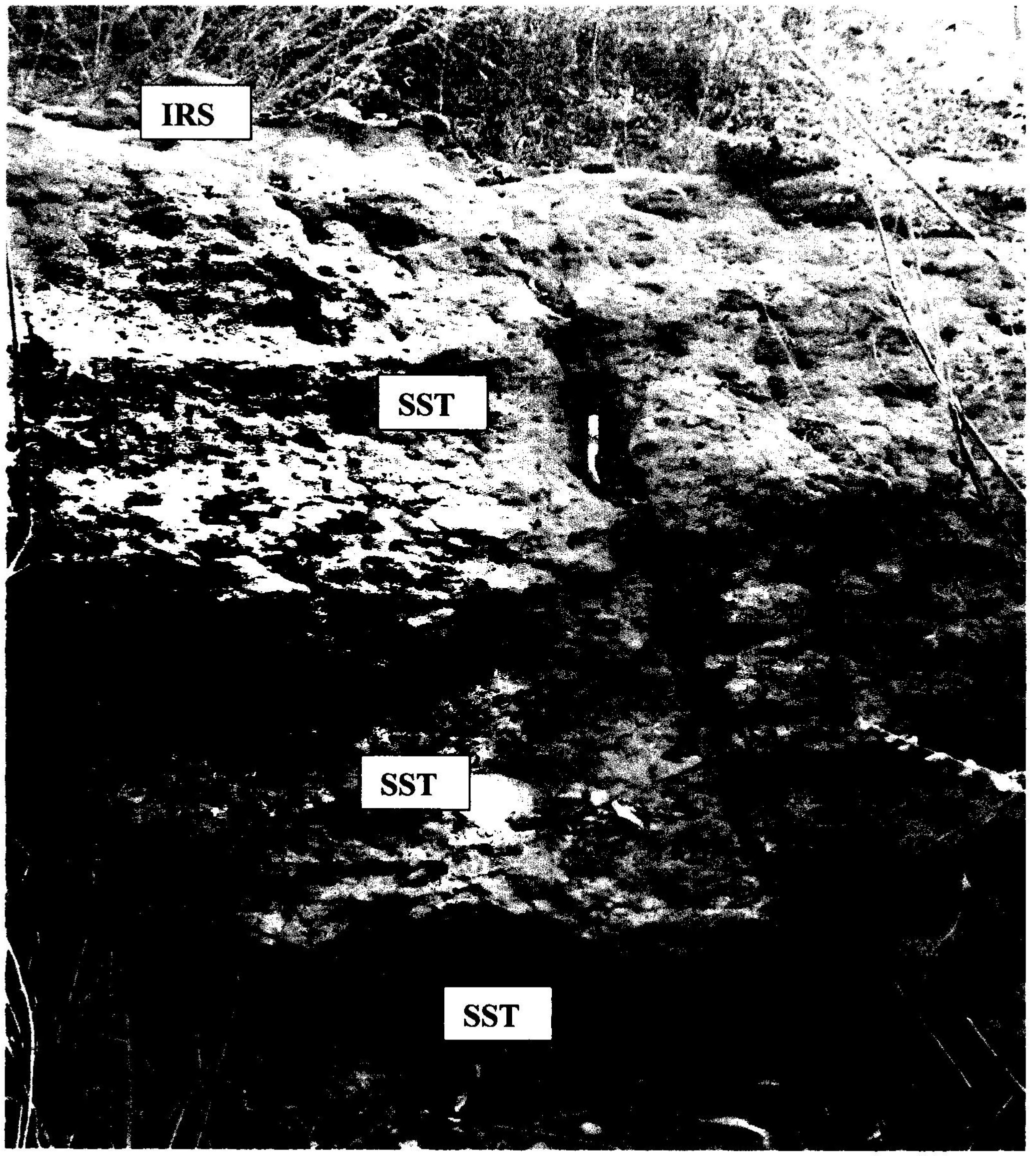


Fig. 4.1: Field photograph of Koton Karfi (lat. 08° 00 ' 44.2" N, long. 006° 47' 06" E) showing Sandstone (SST) and Ironstone (IRS)

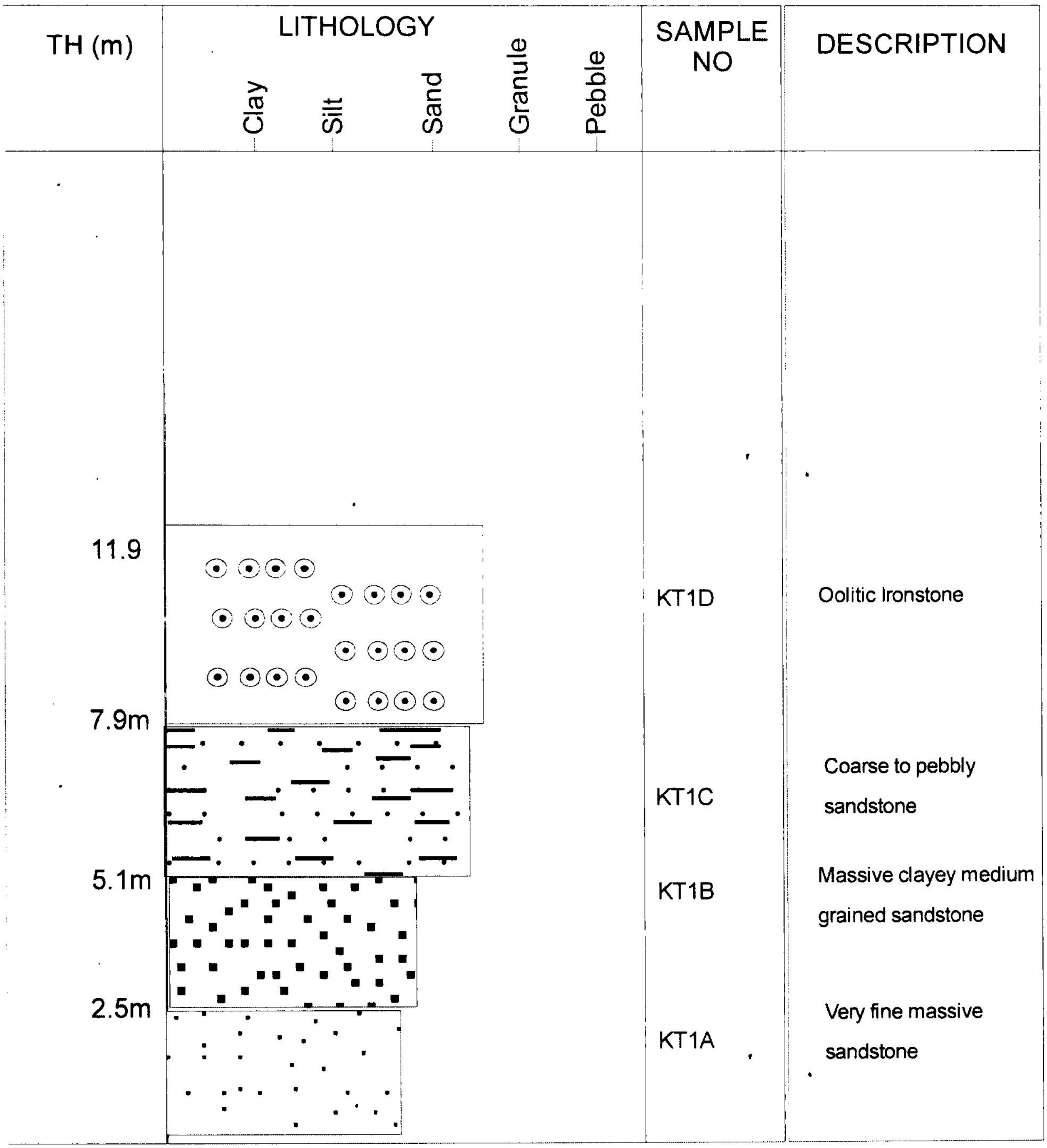


Fig. 4.2: Lithologic section of the outcrop at Kotn Karfi showing various lithologic unit.

4.1.2 LITHOLOGIC DESCRIPTION OF OUTCROP AT OZI

The outcrop is located at latitude 08° 08' 52.3" N and longitude 006° 46' 49.5" E with an elevation of 63m. The outcrop has four beds of different lithologic unit. Starting from the base, the first bed is massive fine-medium grained sandstone with ironstone intercalation, it is 0.7m thick; the second bed is trough cross stratified coarse-pebbly grained sandstone and it is 1.55m thick, the third bed is coarse to pebbly sandstone and it is 1.6m thick and overlying the three beds is an oolitic ironstone which is 5m thick (Fig. 4.3 and 4.4).

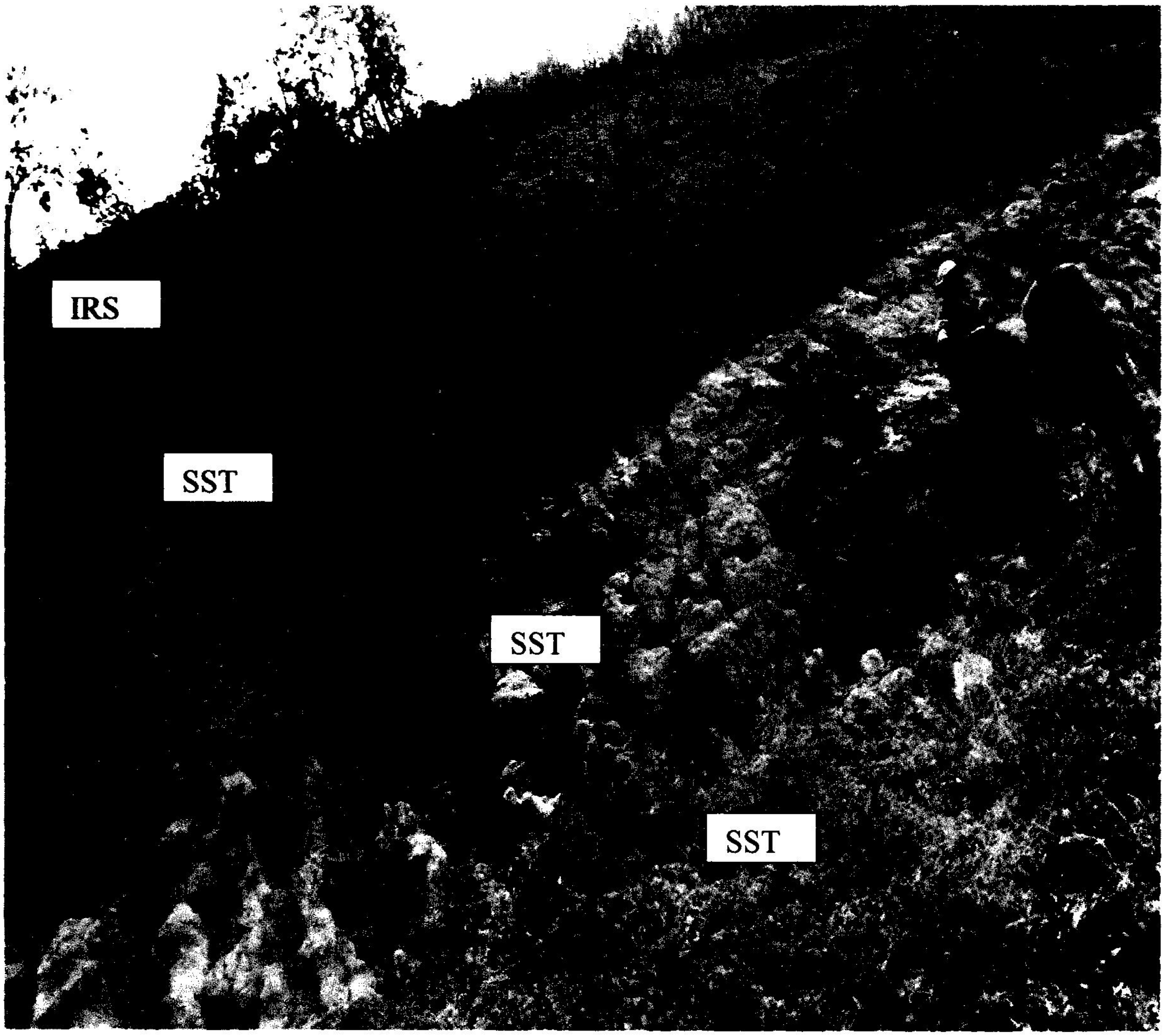


Fig. 4.3: Field photograph of sandstone exposure at Ozi (lat. 08° 08 ' 52.3" N, long. 006° 46' 49.5" E) showing Sandstone (SST) and Ironstone (IRS)

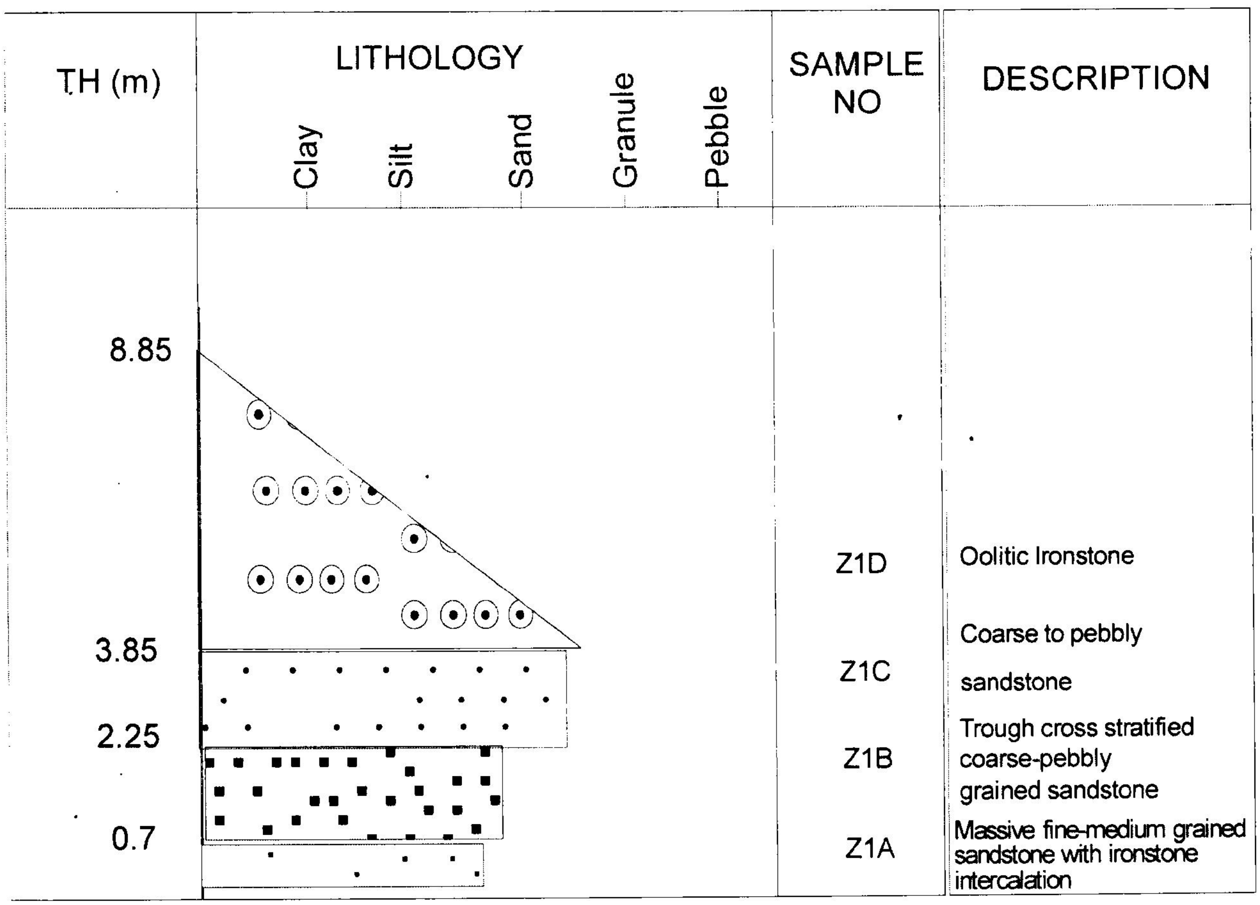


Figure 4.4: Lithologic section of the outcrop at Ozi showing various lithologic unit.

4.2 GRAIN SIZE ANALYSIS

Grain size analysis was carried out at Geology laboratory of Federal University Oye-Ekiti. Three (3) different samples were analysed, two samples from Ozi and one from Koto. The aim of this analysis is to determine the depositional environment of the samples. The graph of Cummulative weight percent against phi size is used to determine the values for Ø5, Ø16, Ø25, Ø50, Ø75, Ø84 and Ø95. These values are then substituted into the equations below to determine the graphic mean, inclusive graphic standard deviation (sorting), inclusive graphic skewness (skewness) and kurtosis of the sand sample. The table below shows the formulas for the graphic mean, sorting, skewness and kurtosis. (Table 4.1)

4.2.1 GRAIN SIZE ANALYSIS DATA

The data derived from the grain size analysis proceedure were recqrded in a table and graphs were plotted as cummulative % weight retained against phi (ϕ). The datas generated include mean, graphic mean, standard deviation, inclusive graphic skewness and kurtosis.

Table 4.1; showing the formulas needed for determining the values for interpreting the data acquired

	FORMULA USED	SOURCE
Graphic Mean	$M = \frac{\phi16 + \phi50 + \phi84}{3}$	Folk and Ward (1957)
Inclusive Graphic Standard Deviation	$D = \frac{\phi84 - \emptyset16}{4} + \frac{\phi95 - \emptyset5}{6.6}$	
Graphic Skewness	$S = \frac{\phi84 + \phi16 - 2(\phi50)}{2(\phi84 - \phi16)} + \frac{\phi95 + \phi5 - 2(\phi50)}{2(\phi95 - \phi5)}$	
Kurtosis	$K = \frac{\phi95 - \phi5}{2.44(\phi75 - \phi25)}$	

4.2.1.1 PROCESSING AND ANALYSES OF THE SAMPLES

Table 4.2: Grain size analysis data for KT1B

KT1B								
No of sieve	Sieve Size (d) in mm	ф 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	4	-2	467.8	469.4	1.6	1.80	1.8	1.8
6	3.35	-1.74416	466.3	466.7	0.4	0.45	2.25	2.25
10	2	-1	458.8	464.8	6	6.75	9.00	9.00
16	1.18	-0.23879	393.2	405.1	1.19	1.34	10.34	10.34
30	0.6	0.736966	365.3	390.5	25.2	28.35	38.69	38.69
40	0.425	1.234465	354.4	370.2	15.8	17.77	56.46	56.46
100	0.15	2.736966	323.8	349.7	25.9	29.14	85.60	85.60
200	0.075	3.736966	303.7	313.2	9.5	10.69	96.29	96.29
230	0.063	3.988504	406.6	407.5	0.9	1.01	97.30	97.30
pan			355.4	357.88	2.4	2.70	100.00	100.00
Total					88.89	100.00		

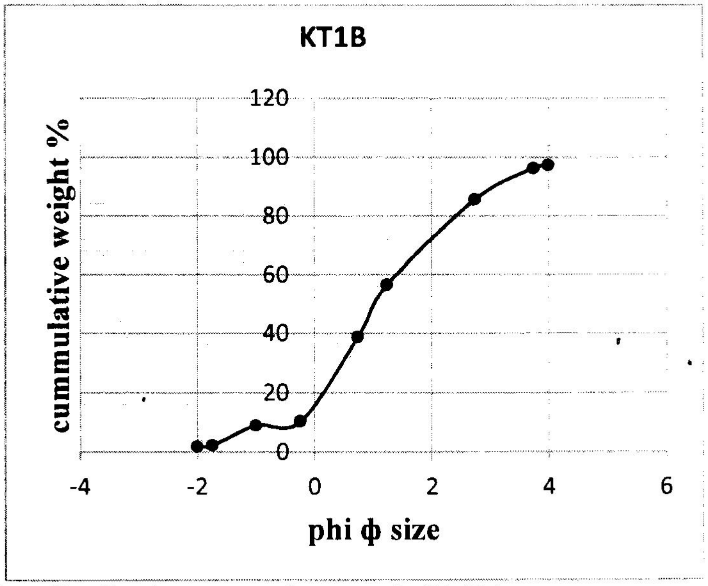


Figure 4.5: Particle size distribution curve for sample KT1B

Graphic Mean (M) - This is the average size category of the sample.

$$M = \frac{\phi16 + \phi50 + \phi84}{3}$$

$$M = \frac{0.1 + 0.95 + 2.6}{3}$$

= **1.2167 phi**

Inclusive Graphic Standard Deviation (D) or Sorting – This is a measure of sorting or variation is sizes.

$$D = \frac{\phi84 - \phi16}{4} + \frac{\phi95 - \phi5}{6.6}$$

$$D = \frac{2.6 - 0.1}{4} + \frac{3.7 - 1.35}{6.6}$$

= 0.9812 **phi**

Graphic Skewness (S) – this shows if it is bell shaped or shifted to side.

$$S = \frac{\phi84 + \phi16 - 2(\phi50)}{2(\phi84 - \phi16)} + \frac{\phi95 + \phi5 - 2(\phi50)}{2(\phi95 - \phi15)}$$

$$S = \frac{2.6 + 0.1 - 2(0.95)}{2(2.6 - 0.1)} + \frac{3.7 + (-1.35) - 2(0.95)}{2(3.7 + 1.35)}$$

S= 0.2046 phi

Kurtosis (K) – shows if the distribution is bell shaped, very flat or very peaked.

$$K = \frac{\phi95 - \phi5}{2.44(\phi75 - \phi25)}$$

$$K = \frac{3.7 + 1.35}{2.44(2.05 - 0.35)}$$

K = 1.217 phi

Table 4.3: Grain size analysis data for Z1A

Z1A								
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	4	-2	467.8	467.9	0.1	0.11	0.11	0.11
6	3.35	-1.7	466.3	466.3	0	0.00	0.11	0.11
10	2	-1	458.8	459.2	0.4	0.45	0.56	0.56
16	1.18	-0.2	393.2	395.2	2	2.27	2.83	2.83
30	0.6	1	365.3	380.3	15	17.03	19.86	19.86
40	0.425	1.2	354.4	361.2	6.8	7.72	27.58	27.58
100	0.15	2.7	323.8	365.7	41.9	47.56	75.14	75.14
200	0.075	3.7	303.7	321.6	17.9	20.32	95.46	95.46
230	0.063	4.0	406.6	407.4	0.8	0.91	96.36	96.36
pan			355.4	358.6	3.2	3.63	100.00	100.00
Total					88.1	100.00		

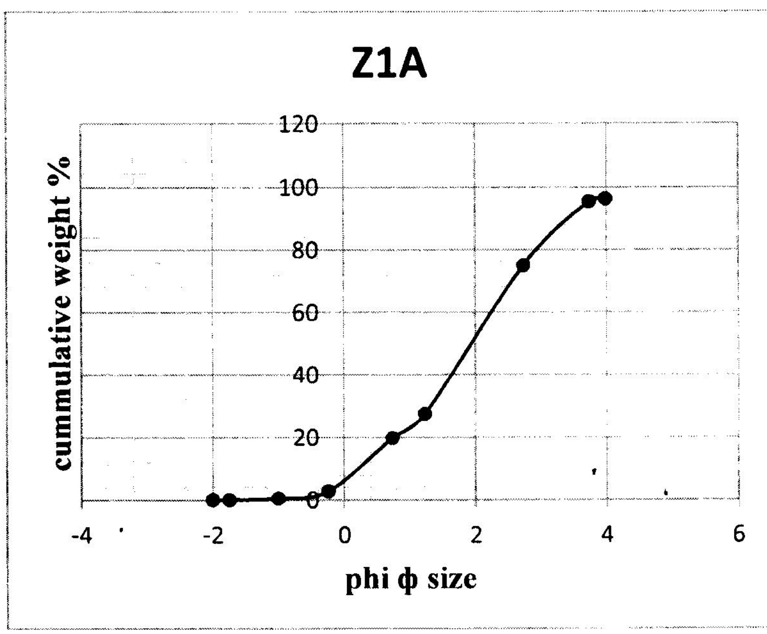


Figure 4.6: Particle size distribution curve for sample Z1A

Graphic Mean (M) - This is the average size category of the sample.

$$M = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

$$M = \frac{0.9 + 1.8 + 3.05}{3}$$

= 1.9167 phi

Inclusive Graphic Standard Deviation (D) or Sorting – This is a measure of sorting or variation is sizes.

$$D = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

$$D = \frac{3.05 - 0.9}{4} + \frac{3.7 - 0}{6.6}$$

= 1.0981 phi

Graphic Skewness (S) – this shows if it is bell shaped or shifted to side.

$$S = \frac{\phi 84 + \phi 16 - 2(\phi 50)}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2(\phi 50)}{2(\phi 95 - \phi 5)}$$

$$S = \frac{3.05 + 0.9 - 2(1.8)}{2(3.05 - 0.9)} + \frac{3.7 + 0 - 2(1.8)}{2(3.7 - 0)}$$

S= 1.0679 phi

Kurtosis (K) – shows if the distribution is bell shaped, very flat or very peaked.

$$K = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

$$K = \frac{3.7 - 0}{2.44(2.7 - 1.18)}$$

K = 0.9976 phi

Table 4.4: Grain size analysis data for Z1B

Z1B								
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	4	-2	467.8	467.9	0.1	0.10	0.1	0.1
6	3.35	-1.7	466.3	466.3	0	0.00	0.10	0.10
10	2	-1	458.8	460.6	1.8	1.81	1.91	1.91
16	1.18	-0.2	393.2	396.3	3.1	3.12	5.03	5.03
30	0.6	1	365.3	385.6	20.3	20.44	25.48	25.48
40	0.425	1.2	354.4	377.5	23.1	23.26	48.74	48.74
100	0.15	2.7	323.8	367.5	43.7	44.01	92.75	92.75
200	0.075	3.7	303.7	308.2	4.5	4.53	97.28	97.28
230	0.063	4.0	406.6	407.5	0.9	0.91	98.19	98.19
pan			355.4	357.2	1.8	1.81	100.00	100.00
Total					99.3	100.00		

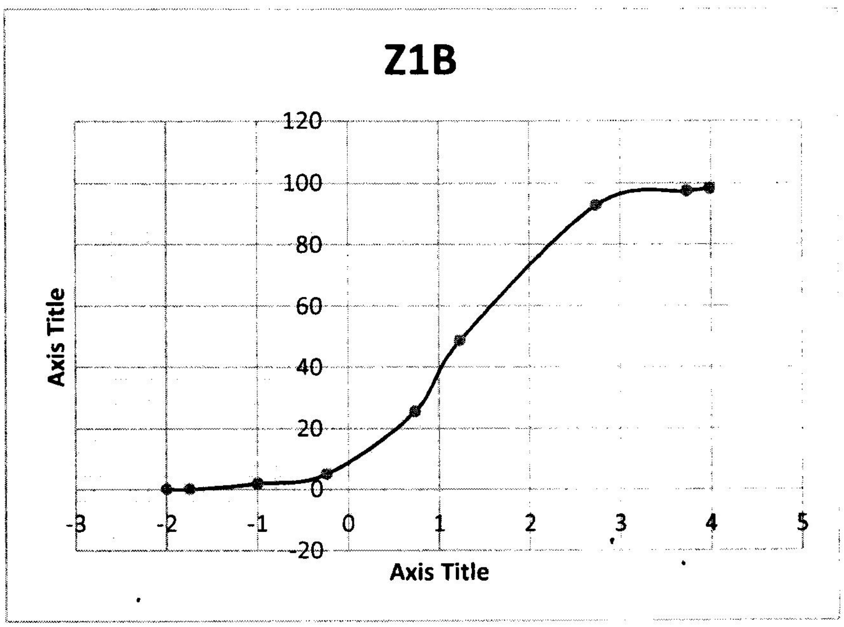


Figure 4.7: Particle size distribution curve for sample Z1B

Graphic Mean (M) - This is the average size category of the sample.

$$M = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

$$M = \frac{0.35 + 1.25 + 2.2}{3}$$

$$= \mathbf{1.2667\ phi}$$

Inclusive Graphic Standard Deviation (D) or Sorting – This is a measure of sorting or variation is sizes.

$$D = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

$$D = \frac{2.2 - 0.35}{4} + \frac{3.2 - (-0.2)}{6.6}$$

$$= \mathbf{0.9777\ phi}$$

Graphic Skewness (S) – this shows if it is bell shaped or shifted to side.

$$S = \frac{\phi 84 + \phi 16 - 2(\phi 50)}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2(\phi 50)}{2(\phi 95 - \phi 5)}$$

$$S = \frac{2.2 + 0.35 - 2(1.25)}{2(2.2 - 0.35)} + \frac{3.2 - 0.2 - 2(1.25)}{2(3.2 + 0.2)}$$

S= 1.4384 phi

Kurtosis (K) – shows if the distribution is bell shaped, very flat or very peaked.

$$K = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

$$K = \frac{3.2 - (-0.2)}{2.44(1.9 - 0.69)}$$

K = 1.152 phi

Table 4.5: Data interpreted for calculated values

SAMPLE ID	GRAPHIC MEAN	INCLUSIVE GRAPHIC STANDARD DEVIATION / SORTING	INCLUSIVE GRAPHIC SKEWNESS	KURTOSIS
Z1A	Medium Grained (1.9167)	Poorly sorted (1.0981)	Strongly fine skewed (1.0679)	Mesokurtic (0.9976)
Z1B	Medium Grained (1.2667)	Moderately sorted (0.9777)	Strongly fine skewed (1.4384)	Leptokurtic (1.152)
KT1B	Medium Grained (1.2167)	Moderately sorted (0.9812)	Coarse skewed (0.2046)	Leptokurtic (1.217)

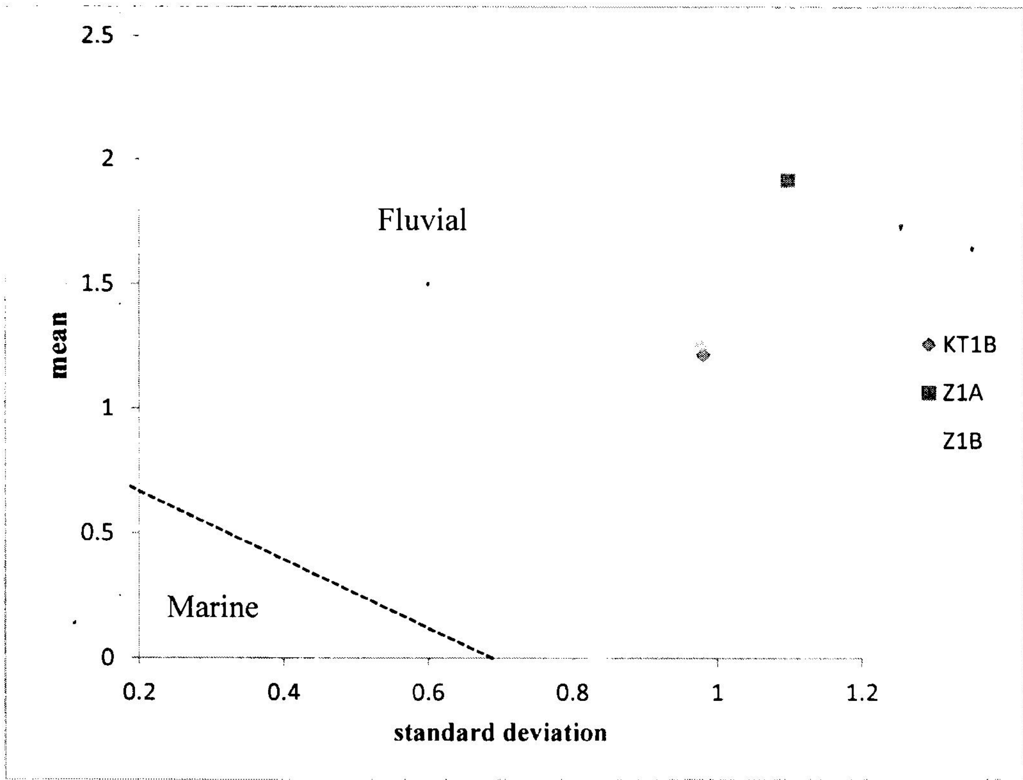


Figure 4.8: Scattered plot of mean against standard deviation to determine the environment of deposition. (boundary modified after Moiola and Wieser, 1968 1968)

4.2.1.2 Paleodepositional Environment using Grain Size Analysis

As for the environment of deposition which defines the characteristics of the sediments being deposited, fluvial environment is the basic sedimentary environment defined in the outcropping sandstone of the Koto and Ozi area. This conclusion on the depositional environment was achieved by the boundary modified after Moiola and Wieser, 1968 (Fig 4.8) from the scattered pot of mean against standard deviation. The boundary reveal and confirm that the sediments gotten from Koto and Ozi are fluvial facies. Field observation and sedimentological analysis has also revealed that the sediments are characterized by rapid vertical change in facies, moderately well sorted and are medium grained.

4.3 GEOCHEMISTRY

4.3.1 MAJOR ELEMENTS GEOCHEMISTRY

The results of the major oxides are shown in Table 4.5. The elemental oxides of the Koto sandstone are; 0.49%-81.5% SiO_2 ; 0.52%-2.51% TiO_2; 4.03%-15.53% Al_2O_3; and 2.91%-77.38% Fe_2O_3. Other oxide such as CaO, MgO, Na_2O, K_2O, MnO, V_2O_5, Cr_2O_3, CuO,ZrO_2, BaO, PbO, ZnO, SrO, Rb_2O, Ga_2O_3, and SO_3 are <1% each. The elemental oxides of the Ozi sandstone are; 80.23%-84.91% SiO_2 ; 0.76%-1.22% TiO_2;6.27%-6.34% Al_2O_3; and 2.87%-3.21% Fe_2O_3. Other oxide such as 0.06%-2.33%CaO, 0.69%-1.41% K_2O, MgO, Na_2O, MnO, V_2O_5, Cr_2O_3, CuO,ZrO_2, BaO, PbO, ZnO, SrO, Rb_2O, Ga_2O_3, and SO_3 are <1% each.

The average compostion of Ozi sandstone are; SiO_2 (82.57%); Al_2O_3 (6.31%); Fe_2O_3 (3.04%) making up > 90% while the koto sandstone average compostion are; SiO_2 (42.03%); Fe_2O_3 (35.48%); Al_2O_3 (8.63%); with other oxides < 2%.

The TiO_2 value is relatively low (< 2%) in Koto sandstone having the highest value averaging 1.84%. This value is lower in Ozi sandstone with an average of 0.99%. Generally, there are lower values of CaO, Na_2O, MnO and V_2O_5.

The comparatively higher values of K_2O and Na_2O in the Ozi sandstone as against that of Koto sandstone indicate relatively compositionally matured Koto sandstone.

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 low concentrations of Fe_2O_3 +TiO_2 +MgO (average 4.32% for Ozi sandstone) imply that the sediments are chemically inert and non-corrosive.

Cross plots of % SiO_2 versus Fe_2O_3 (Fig. 10a); SiO_2 versus Al_2O_3 (Fig. 10b) SiO_2 versus LOI (Fig. 210c) and Fe_2O_3 versus Al_2O_3 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 the sediment.

Table 4.6: Major Oxides concentrations for Koto and Ozi Sandstone.

Sample No.	KT1A	KT1C	KT1D	ZIB	ZIC	AVERAGE	
Formation	Koto	Koto	Koto	Ozi	Ozi	Koto	Ozi
Rock type /Oxides(%)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
$Si0_2$	81.511	44.1	0.49	80.23	84.91	42.03	82.57
TiO_2	2.48	2.51	0.516	1.22	0.759	1.84	0.99
Al_2O_3	7.33	14.53	4.03	6.34	6.27	8.63	6.31
Fe_2O_5	2.91	26.14	77.38	2.87	3.21	35.48	3.04
CaO	0.06	0.038	0.15	2.33	0.06	0.08	1.20
MgO	0.02	0.02	0.1	0.55	0.02	0.05	0.29
Na_2O	0.17	0.13	0.04	0.39	0.41	0.11	0.40
K_2O	0.38	0.41	0.09	1.41	0.69	0.29	1.05
MnO	0.03	0.007	0.29	0.073	0.01	0.11	0.04
V_2O_5	0.063	0.048	0.064	0.062	0.027	0.06	0.04
Cr_2O_3	0.051	0.046	0.028	0.047	0.041	0.04	0.04
CuO	0.06	0.073	0.043	0.061	0.046	0.06	0.05
ZrO_2	0.58	0.877	0.03	0.12	0.097	0.50	0.11
BaO	ND	0.2	ND	0.02	0.09	ND	0.06
PbO	0.092	0.19	ND	0.062	0.046	ND	0.05
ZnO	0.033	0.02	0.064	ND	ND	0.04	ND
SrO	ND	ND	0.3	ND	ND	ND	ND
Rb_2O	ND	0.033	ND	ND	ND	ND	ND
Ga_2O_3	0.03	0.02	ND	0.01	ND	ND	ND
SO_3	ND	<0.001	ND	ND	ND	ND	ND
Br	ND	0.007	ND	ND	ND	ND	ND
Ta_2O_5	ND	ND	0.083	ND	ND	ND	ND
L.O.I	4.2	10.6	16.3	4.2	3.3	10.37	3.75
As_2O_3	ND	ND	ND	0.005	0.014	ND	0.01
Total	100	99.999	99.998	100	100	99.68	99.996
SiO_2/Al_2O_3	11.12	3.04	0.12	12.65	13.54	4.87	13.10
Al_2O_3/TiO_2	2.96	5.79	7.81	5.20	8.26	4.69	6.37

4.3.2 GEOCHEMISTRY PROVENANCE

	KT1A	KT1C	Z1B	Z1C
Discriminant function 1	-7.20	14.70	-6.14	-4.82
Discriminant function 2	-5.77	-11.66	-7.64	-7.26

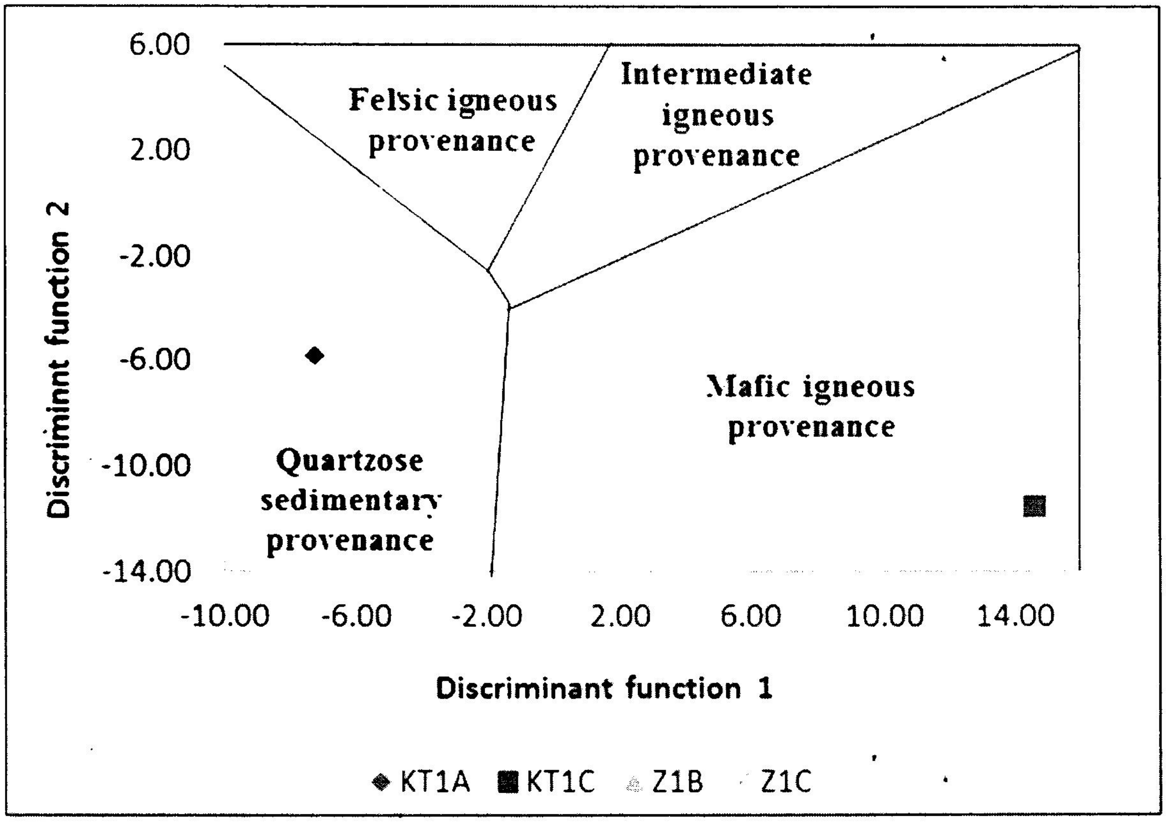
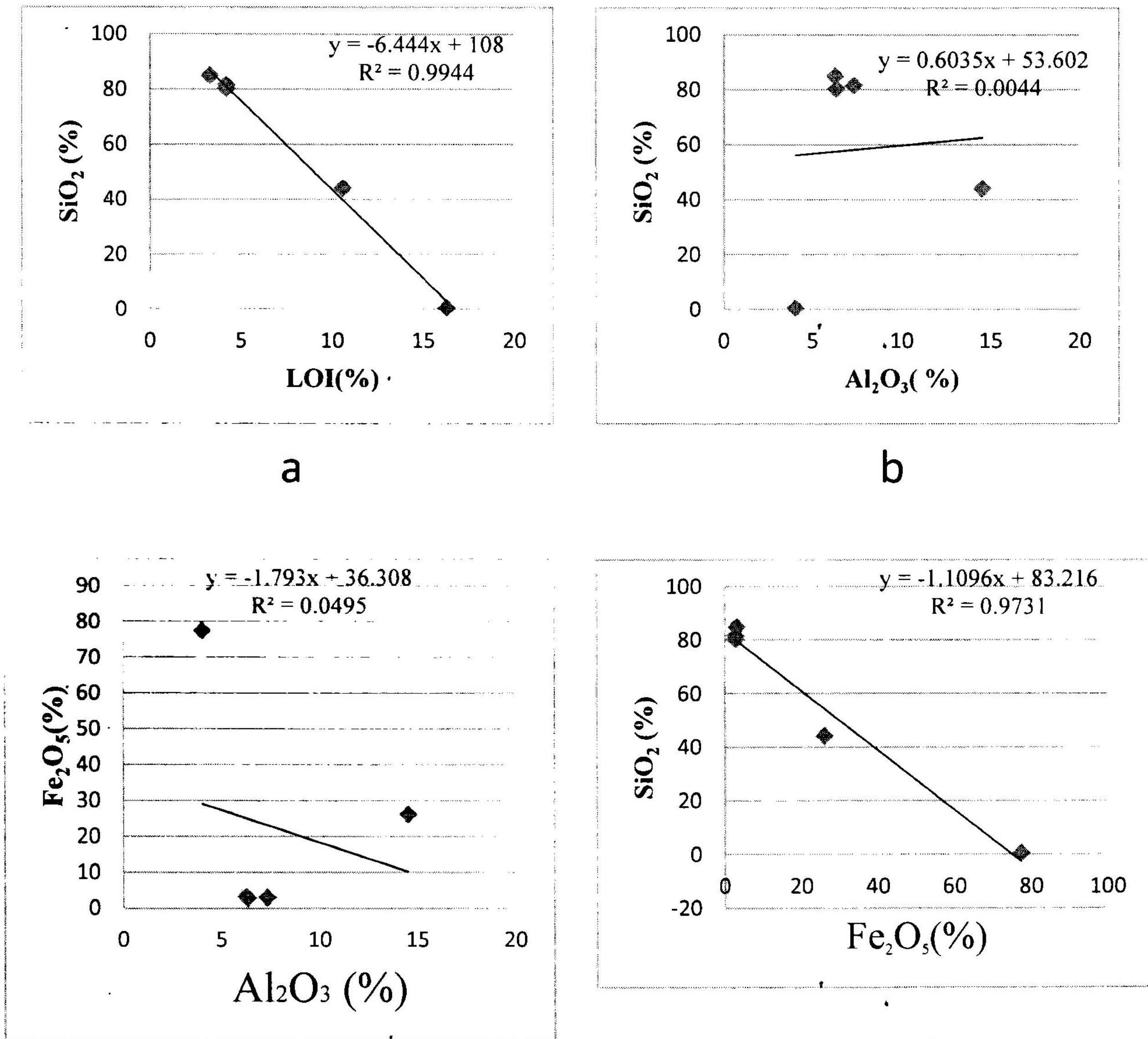


Figure 4.9: Discriminant function diagram for sedimentary provenance of the sediments in Patti formation using major elements (Roser and Korsch, 1988). The discriminant fuction are :- Discriminant Function 1= (-1.773 x TiO_2) + (0.607 x Al_2O_3) + (0.760 x Fe_2O_3) + (-1.500 x MgO) + (0.616 x CaO) + (0.509 x Na_2O) + (-1.224 x K_2O) + (-9.090); Discriminant Function 2 = (0.445 x TiO_2) + (0.070 x Al_2O_3) + (-0.250 x Fe_2O_3) + (-1.142 x MgO) + (0.438 x CaO) + (1.475 x Na_2O) + (-1.426 x K_2O) + (-6.861)

The figure above is indicating the source rock for each sediments of Patti formation, sample KT1C is from Mafic Igneous Rocks while Sample named KT1A, Z1B and Z1C are from Quartzose Sedimentary provenance. The Iron content of sample KT1D is high and this is as a result of the leaching of the ironstone overlying the formation.



c d

Figure 4.10: Cross Plots of Major Oxides: (a). SiO_2 against LOI . (b). SiO_2 against Al_2O_3 (c). Fe_2O_3 against Al_2O_3 (d). SiO_2 against Fe_2O_5.

4.4 PETROGRAPHY

In order to examine the microtextural and mineralogical features in the thin section of a rock with higher resolution than that of the naked eye, a microscope is used. A microscope has two systems of lenses. The first lens system (objective) produces a magnified image of the object. This real image is viewed by the second lens system (ocular or eyepiece) that also provides further magnification.

4 samples from the study area were selected for thin section petrographic examination, in order to determine their lithology and likely provenance areas. The sandstone have undergone alteration and grain coatings, comprise a range of detrital sandstones, volcaniclastic sandstones, altered igneous grains and sparse metasedimentary rock types. The thin section slides of this samples with their qualitative and quantitative data are presented below.

4.4.1 MINERAL COMPOSITION AND PROVENANCE

Petrography analysis shows the sandstones from Koto and Ozi Formations are composed of mostly quartz and feldspar. The petrography of the thin section photomicrograph reveals Quartz, Feldspar, Clay matrix and cement of varying compositions in empty spaces between the varying minerals. The quartz crystals shows straight extinction and generally colourless and clear as opposed to feldspars which are cloudy and greyish in color. Feldspar composition are mostly minute because they are less resistance to weathering and appears to have been mostly dissolved while monocrystalline quartz is dominant in all samples (Plate 4.1-4.8) Quartz comprises an average of 55.6% of the framework of the conglomeratic sandstone which are mostly angular to sub-angular texturally. The next most abundant mineral is feldspars about average of 22.5%. The feldspar crystals are generally quite distinct from quartz grains as they exhibit low relief, straight, cloudy and angular to sub angular texturally denoting short distance of transportation (Plate 4.1-4.8). The quartz is mostly angular to sub-angular with straight and embayed boundaries. Most of the grains are equant while others are elongate.

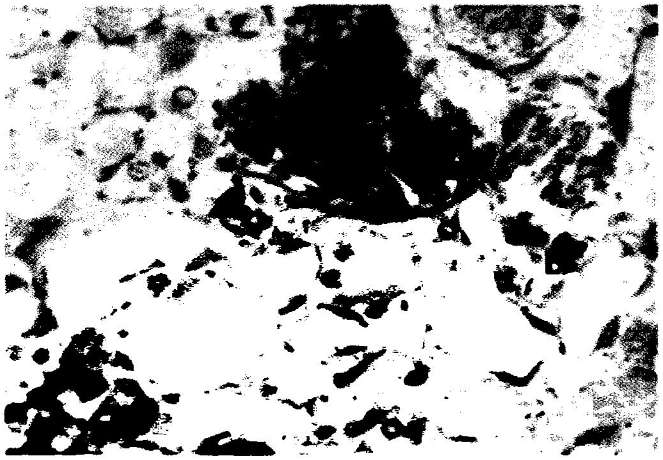


Plate 4.1: Photomicrograph of Patti sandstone KT1A under PPL (Mg X50) (MQ – Microcline \Quartz, MF – Microcline Feldspar, B - Biotite) (Lat. 08° 00 ' 44.2" N, Long. 006° 47' 06" E)

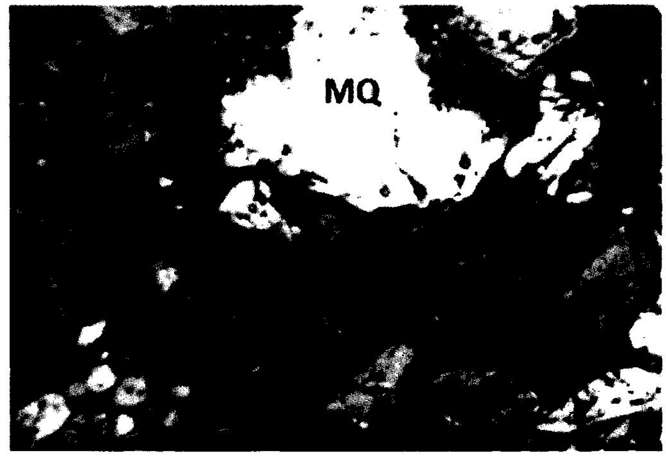


Plate 4.2: Photomicrograph of Patti sandstone KT1A under XPL (Mg X50) (MQ – Microcline Quartz, MF – Microcline Feldspar, B - Biotite) (Lat. 08° 00 ' 44.2" N, Long. 006° 47' 06" E)

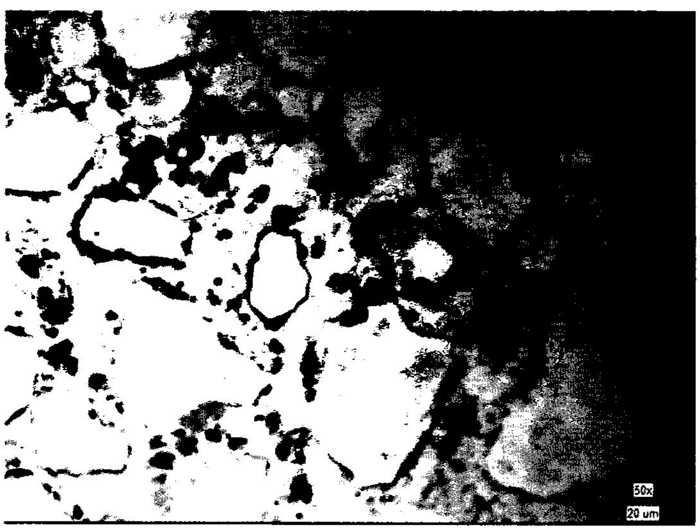


Plate 4.3: Photomicrograph of Patti sandstone KT1C under PPL (Mg X50) (MQ – Microcline Quartz, MF – Microcline Feldspar, B - Biotite)

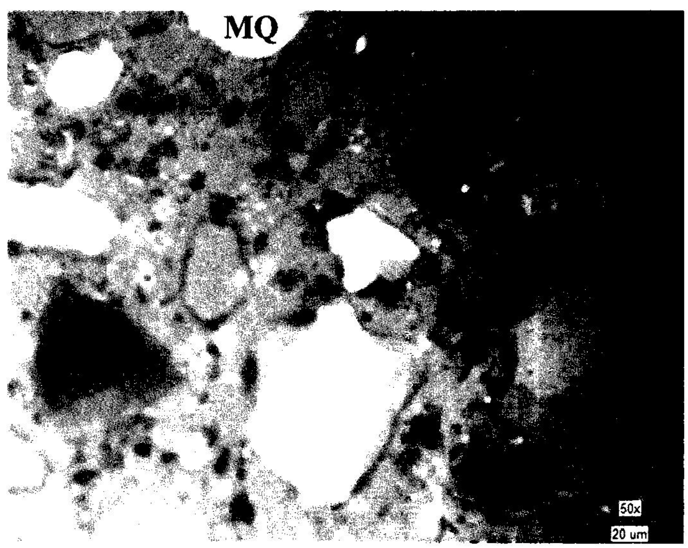


Plate 4.4: Photomicrograph of Patti sandstone KT1C under XPL (Mg X50) (MQ – Microcline Quartz, MF – Microcline Feldspar, B - Biotite)

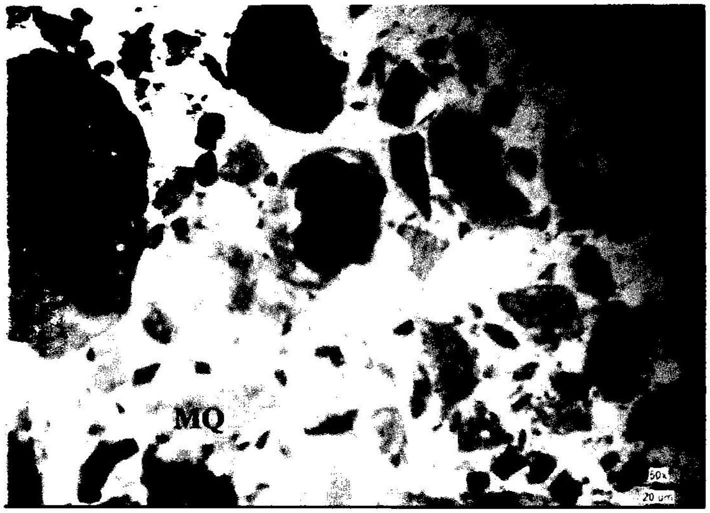


Plate 4.5: Photomicrograph of Patti sandstone KT1D under PPL (Mg X50) (MQ – Microcline Quartz, MF – Microcline Feldspar, B - Biotite)

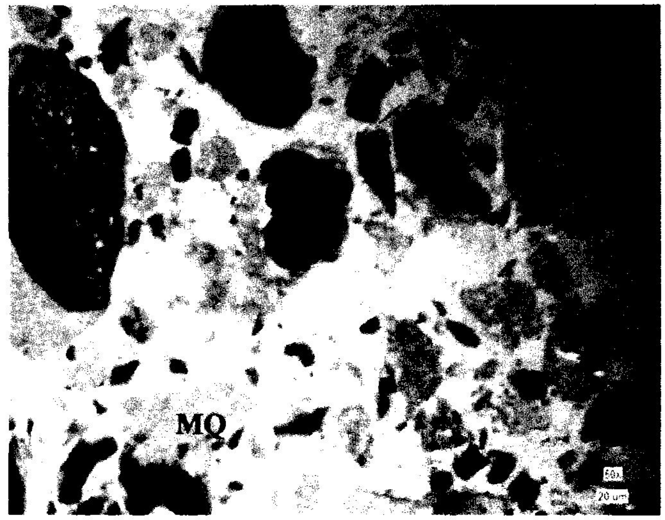


Plate 4.6: Photomicrograph of Patti sandstone KT1D under XPL (Mg X50) (MQ – Microcline Quartz, MF – Microcline Feldspar, B - Biotite)

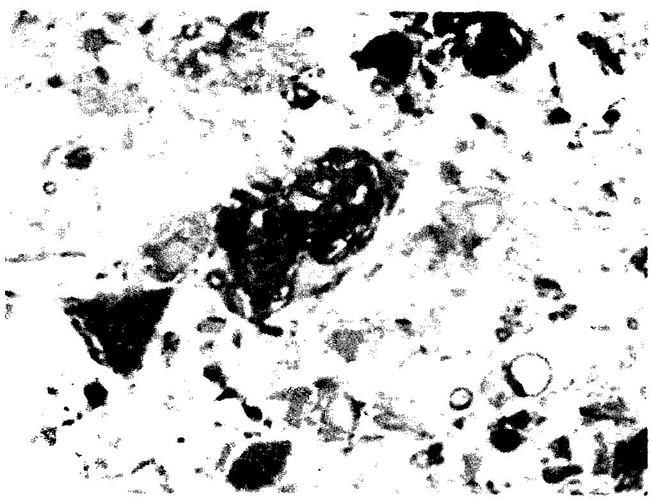


Plate 4.7: Photomicrograph of Patti sandstone Z1B under PPL (Mg X40) (MQ – Microcline Quartz, MF –Microcline Feldspar, B - Biotite)

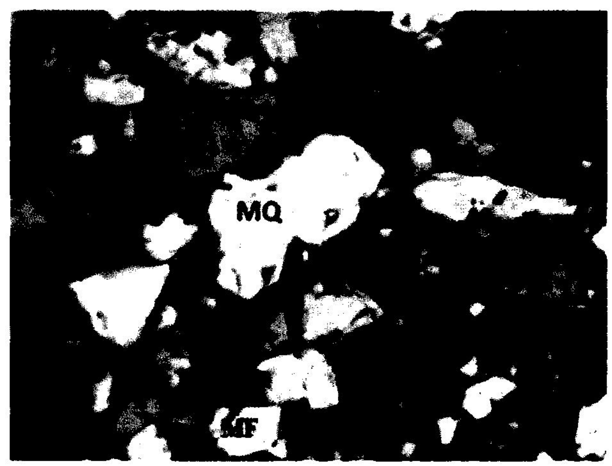


Plate 4.8: Photomicrograph of Patti sandstone Z1B under XPL (Mg X50) (MQ – Microcline Quartz, MF – Microcline Feldspar, B - Biotite)

Table 4.7: Modal Analysis of Sandstone obtained from petrographic study

SAMPLE ID	QUARTZ (%)	FELDSPAR (%)	ROCK FRAGMENT (%)	MINERALOGICAL MATURITY INDEX(Q/(F+R))
KT1A	65	20	5	2.6
KT1C	50	25	8	1.52
KT1D	52	20	5	2.08
Z1B	65	20	11	2.09
AVERAGE	58	21.25	7.25	1.77

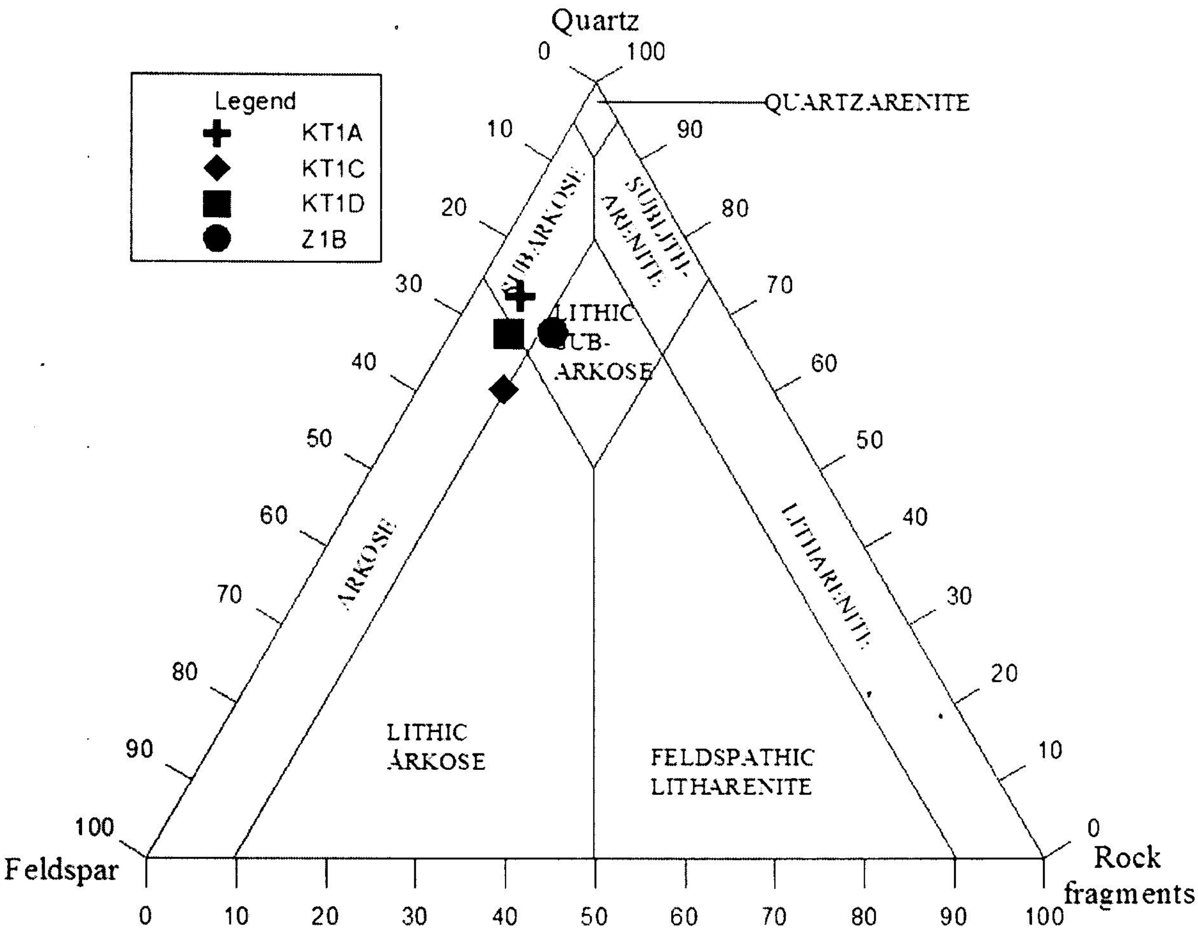


Figure 4.11: Tenary diagram of Sandstone in Patti Formation, the diagram shows that sample ID KT1A, KT1C AND KT1B are Arkose while Z1B is Lithic Sub-Arkose. (modified after Folk, 1974).

4.5 HEAVY MINERAL ANALYSIS

Heavy mineral analysis was carried out on four samples from the Koton Karfi and Ozi. The samples were viewed under the microscope for further analysis (Plate 4.9-4.14). From the heavy mineral photomicrograph, it was observed the dominant accessory heavy minerals are composed mainly of opaque minerals magnetite and hematite. Two main mineral groups: the opaque and non-opaque were observed in the sandstone samples of Koto and Ozi as indicated in the photomicrograph above.

There are variation of garnet from colourless to yellow coloration, The non-opaque minerals include zircon, rutile, tourmaline, staurolite, chloritoid, and garnet. Zircon and rutile are present in significant amount as dominant non opaque, ultrastable minerals. 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 a

ppearance, prismatic habit as well as its very high interference colours. Rutile occurs as small reddish- brown prismatic to acicular 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. Ultrastable minerals such as zircon, rutile and tourmaline are resistant to mechanical integration and chemical decomposition compared to the metastable and the unstable types. They are also polyvarietal and thus excellent indicators of provenance. Euhedral zircon is an indicator of volcanism.

Plate 4.9: Photomicrograph (Mg X30) of heavy mineral Of KT1B showing Zircon (Z), Opaque Minerals (Op), Staurolite (Sr), Tourmaline (Tr), Garnet (G) and Hornblende under PPL (Lat. 08° 00 ' 44.2" N, Long. 006° 47' 06" E)

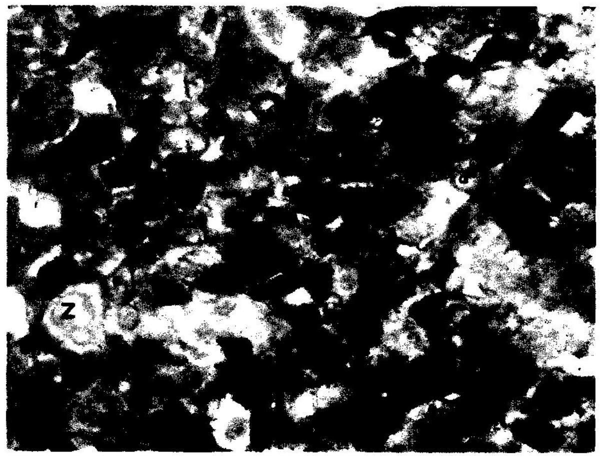


Plate 4.10: Photomicrograph (Mg X30) of heavy mineral Of KT1B showing Zircon (Z), Opaque Minerals (Op), Rutile(R), Staurolite (Sr), Tourmaline (Tr), Garnet (G) and Hornblende under XPL (Lat. 08° 00 ' 44.2" N, Long. 006° 47' 06" E)

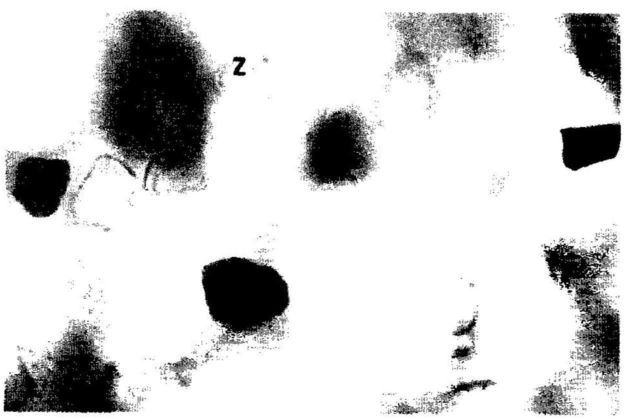


Plate 4.11: Photomicrograph (Mg X40) of heavy mineral Of Z1B showing Zircon (Z), Chloritoid (Ch), Opaque Minerals (Op), and Hornblende under PPL (Lat. 08° 08' 52.3" N, Long. 006° 46' 49.5" E)

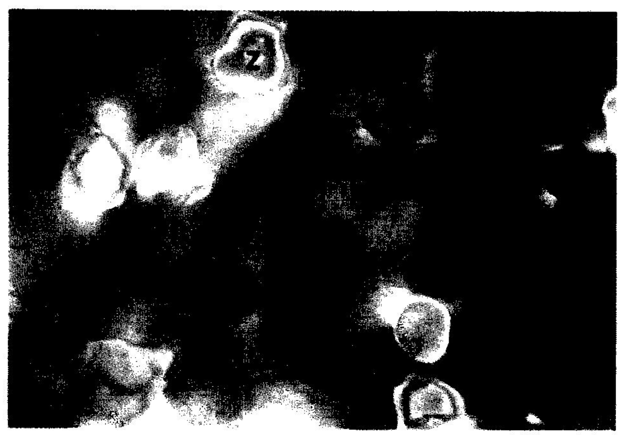


Plate 4.12: Photomicrograph (Mg X40) of heavy mineral Of Z1B showing Zircon (Z), Chloritoid (Ch), Opaque Minerals (Op), and Hornblende under XPL (Lat. 08° 08' 52.3" N, Long. 006° 46' 49.5" E)

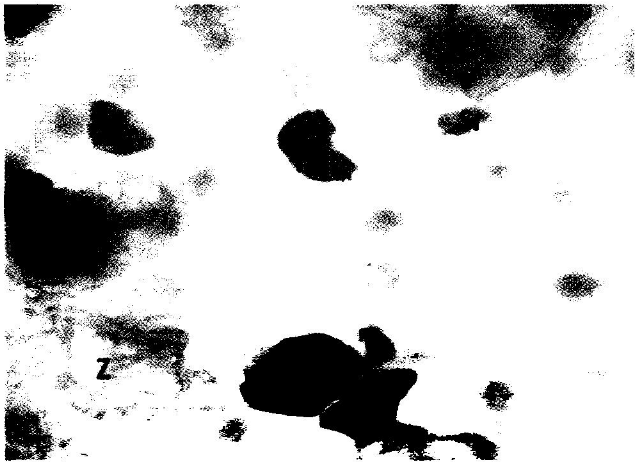


Plate 4.13: Photomicrograph (Mg X40) of heavy mineral Of Z1C showing Zircon (Z), Tourmaline(Tr), Staurolite (Sr), Opaque Minerals (Op), and Hornblende under PPL (Lat. 08° 08' 52.3" N, Long. 006° 46' 49.5" E)

Plate 4.14: Photomicrograph (Mg X40) of heavy mineral Of Z1C showing Zircon (Z), Tourmaline(Tr), Staurolite (Sr), Opaque Minerals (Op), and Hornblende under XPL (Lat. 08° 08' 52.3" N, Long. 006° 46' 49.5" E)

Table 4.8: Percentage Composition of the Non-opaque and Opaque Heavy Mineral Suites from the analysis above

Sample ID	Zircon (%)	Tourmaline (%)	Rutile (%)	Chloritoid (%)	Staurolite (%)	Hornblende (%)	Opaque (%)
KT1B	33	19	4	-	4	5	45
Z1B	36	10	3	5	-	2	30
Z1C	34	14	-	-	5	4	44

CHAPTER FIVE

CONCLUSIONS

5.1 Conclusions

Textural studies on the Patti Formation indicate a fluvial setting for the investigated sandstone. Grain size analysis shows that the sandstones of Patti Formation are medium grained, moderately to well sorted and mainly arkose for Koton Karfi sandstone and Lithic Sub-arkose for Ozi sandstone and that the sediments are deposited in a Fluvial environment.

Petrographic analysis of the sandstone shows that the sandstone has higher percentage of Quartz, lesser amount of Feldspar and lower proportion of rock fragments. The Ternary diagram plotted for sandstone in Patti Formation shows that the sandstones of Patti Formation are essentially Arkose to lithic Sub-arkose.

Elemental analysis of the samples investigated revealed that SiO_2 content of the Patti sandstones exposed at Ozi has an average of 82.57% while those exposed at Koton Karfi is 42.03%; thus indicating more mature sediment of sandstone exposed at Ozi. The discriminant diagram is indicating the source rock for each sediments of Patti formation, sample KT1C is from Mafic Igneous Rocks while Sample named KT1A, Z1B and Z1C are from Quartzose Sedimentary provenance. The Iron content of sample KT1D is high and this is as a result of the leaching of the ironstone overlying the formation. From our heavy mineral analysis we know that the results indicated the dominance of opaque minerals over the non-opaque minerals.

REFERENCES

Abaa S.I., (1983) The structure and petrography of alkaline rocks of the Mada Younger Granite Complex, Nigeria. J Afr Earth Sci 3:107–113

Abua, M.A., Iremoko, C. O. and E. I. Igelle, (2005). Assessment of Soil Properties Under Shifting cultivation System of Farming in Lokoja, Kogi State, Nigeria. Greener Journal of Agricultural Sciences, 6(10):294-303 sa

Adeleye D.R, (1974) Sedimentology of the fluvial Bida Sandstones (Cretaceous), Nigeria. Sediment Geol 12:1–24

Adeleye D.R., Dessauvagie TFJ (1972) Stratigraphy of the Mid-Niger Emabyment near Bida, Nigeria. In: Dessauvagie TJF, Whiteman AJ (eds) Proceedings of the Conference on African Geology, Ibadan University Press, Ibadan, pp 181–186

Ajakaiye D.E., (1983) Deep structures of alkaline ring complexes from geophysical data. In: Abstract, international conference on alkaline ring complexes in Africa. Zaria, Nigeria

Ajibade A.C., Fitches W.R., Wright J.B., (1979) The Zungeru mylonites, Nigeria: recognition of a major unit. Rev de Geol Geog Phys 21:359–363

Akande SO, 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 41:394–406

Benkhelil J (1989) The origin and evolution of the Cretaceous Benue Trough, Nigeria. J Afr Earth Sci 8:251–282

Black R (1980) Precambrian of West Africa. Episodes 4:3–8

Bowden P, van Breemen O, Hutchison J, Turner D.C., (1976) Palaeozoic and Mesozoic age trends for some ring complexes in Niger and Nigeria. Nature 259:297–299

Braide S.P., (1992a) Geologic development, origin and energy mineral resource potential of the Lokoja formation in the Southern Bida Basin. J Mining Geol 28:33–44

Braide S.P., (1992b) Syntectonic fluvial sedimentation in the central Bida Basin. J Mining Geol 28:55–64

Braide S.P., (1992c) Alluvial fan depositional model in the northern Bida Basin. J Mining Geol 28:65–73

Burke K.C., Dewey J.F., (1972) Orogeny in Africa. In: Dessauvagie TFJ, Whiteman AJ (eds), Africa geology. University of Ibadan Press, Ibadan, pp 583–608

Dada S.S., (2006) Proterozoic evolution of Nigeria. In: Oshi O (ed) The basement complex of Nigeria and its mineral resources (A Tribute to Prof. M. A. O. Rahaman). Akin Jinad & Co. Ibadan, pp 29–44

Falconer J,D., (1911) The geology and geography of Northern Nigeria. Macmillan, London, 135pp

Folk, R.l.., 1974, Petrology of Sedimentary Rocks; Hemphill, Austin Texas, pp. 182

Gebhardt H., (1998) Benthic foraminifera from the Maastrichtian Lower Mamu Formation near Leru (Southern Nigeria): paleoecology and paleogeographic significance. J Foraminiferal Res 28:76–89

Grant N.K., (1970) Geochronology of Precambrian basement rocks from Ibadan, South-Western Nigeria. Earth Planet Sci Lett 10:19–38

Grant N.K., (1978) Structural distinction between a metasedimentary cover and an underlying basement in the 600 my old Pan-African domain of Northwestern Nigeria. Geol Soc Am Bull 89:50–58

Holt R.W., (1982) The Geotectonic Evolution of the Anka Belt in the Precambrian Basement Complex of N.W. Nigeria. Unpublished Ph.D. Thesis, The Open University

Ifatimehin, O. 0; Ishaya, S and Fanan U, (2010) "An Analysis of Temperature Variation Using Remote Sensing Approach in Lokoja Area, Nigeria" Journal of Production Agriculture and Technology (PAT), Nassarawa State University Keffi PAT December 6 (2): 35-44

Jones M.P., (1953) Preliminary investigation of the occurrence of Columbite in the Afu Hills

Ladipo K.O., (1988) Paleogeography, sedimentation and tectonics of the Upper Cretaceous Anambra basin, South-Eastern Nigeria. J Afr Earth Sci 7:865–871 .

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 30:161–168

Madukwee, H.Y., Akinyemi, S. A., Adebayo, O. F., Ojo, A. O., Aturamu, A.O and Afologboye, L. O. (2004); Geochemical and Petrographic studies of Lokoja Sandstone: Implication on Sources area weathering, provenance and tectonic setting. International Journal of Scientific and Technology Research, Vol. 3Issue 12, pp 21-25

McCurry P., (1976) The geology of the Precambrian to Lower Palaeozoic Rocks of Northern Nigeria – A Review. In: Kogbe CA (ed) Geology of Nigeria. Elizabethan Publishers, Lagos, pp 15–39

Nwajide C.S., Reijers T.J.A., (1996) Sequence architecture in outcrops: examples from the Anambra Basin, Nigeria. NAPE Bull 11:23–33

Obaje N.G, Wehner H, Scheeder G, Abubakar M.B., Jauro A (2004)., Hydrocarbon prospectivity of Nigeria's inland basins: from the viewpoint of organic geochemistry and organic petrology. AAPG Bull 87:325–353

Obaje, N.G., 2009.Geology and Mineral Resources of Nigeria Springer – Verlag, Berlin Heidelberg, 217p.

Ogezi A.E.O., (1977) Geochemistry and Geochronology of Basement Rocks from Northwestern Nigeria. Unpublished Ph.D. Thesis, University of Leeds

Ojo O.J., and Akande, S.O., (2009) Sedimentology and Depositional Environments of the Maastrichtian Patti Formation, Southeastern Bida Basin, Nigeria. Cretaceous Research, 30, 1415-1425

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

Olade M. A and Elueze A.. (1981) Petrographic studies of metabasic rocks and meta-ultramafites in relation to mineralization in Nigerian schist belts. J Mining Geol 18:31–36

Olaniyan O, Olobaniyi S.B., (1996) Facies analysis of the Bida Sandstone formation around Kajita, Nupe Basin, Nigeria. J Afr Earth Sci 23:253–256

[illegible]de, A. F. and Ukoje, J.E. (2016) "Perception of Causes, Effects and Use of Local Adaptive Measures for Mitigating Thermal Discomfort in Lokoja, Kogi State, Nigeria" Journal of Contemporary Urbanology Vol. 3 No 1. PP 57-68, Department of Urban and Regional Planning, Benue State University.

[illegible] M.O. (1972) The basement complex of Nigeria. In: Dessauvagie TFJ, Whiteman AJ (eds) African geology. Ibadan University Press, pp 66–102

[illegible] K.E. (1986) Guidelines for evaluating petroleum source rocks using programmed pyrolysis. AAPG Bull 70:318–329

[illegible] M.A. (1976) Review of the basement geology of South-Western Nigeria. In: Kogbe CA (ed) Geology of Nigeria, 2nd edn, Elizabethan Publishers, Lagos, pp 41–58

[illegible] M.A. (1981) Recent advances in the study of the basement complex of Nigeria. Abstract. 1st Symposium on the Precambrian Geology of Nigeria

[illegible] M.A. (1988) Recent advances in the study of the basement complex of Nigeria. In: Geological Survey of Nigeria (ed) Precambrian Geol Nigeria, pp 11–43

[illegible] MA., Ocan O (1978) On relationships in the Precambrian Migmatite-gneisses of Nigeria. Niger J Min Geol 15:23–32

[illegible] M.N., Nton, M.E. and Kitagawa, R. 2010. Textural and geochemical characteristics of the Ajali Sandstone, Anambra Basin, SE Nigeria: Implication for its provenance. Comptes Rendus Geoscience, 342, 136 – 150p

Truswell J.F., Cope R.N., (1963) The geology of parts of Niger and Zaria Provinces, Northern Nigeria. Geol Suvey Nigeria Bull 29:1–104

Tubosun I.A. (1983) Geochronologie U/Pb du Socle Precambrian du Nigeria. Unpublished 3 eme Cycle Thesis, Univ. des Sciences et Techniques du Languedoc. Montpellier

Turner D.C. (1983) Upper Proterozoic schist belts in the Nigerian sector of the Pan-African Province of West Africa. Precambrian Res 21:55–79

Udensi E.E. Osazuwa I.B., (2004) Spectral determination of depths to magnetic rocks under the Nupe Basin, Nigeria. NAPE Bull 17:22–27

Woakes M, Rahaman M.A., Ajibade A.C., (1987) Some metallogenetic features of the Nigerian basement J Afr Earth Sci 6:54–64

Younger Granite Complex. Geological Survey of Nigeria, Unpublished Report, No. 1114