GEOLOGY AND PROVENANCE OF CLAY DEPOSITS IN PARTS OF CENTRAL BIDA BASIN, NIGERIA

By

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA; IN PARTIAL FULFILMENT OF THE AWARD OF A DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN GEOLOGY

DEPARTMENT OF GEOLOGY,
FACULTY OF SCIENCE, AHMADU BELLO UNIVERSITY, ZARIA.

APRIL, 2017

DECLARATION

I declare that the work in this dissertation entitled "GEOLOGY AND PROVENANCE OF CLAY DEPOSITS IN PARTS OF CENTRAL BIDA BASIN, NIGERIA" has been carried out by me in the Department of Geology. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other Institution.

Alabi, Adekola Amos ...……. ……..

Signature Date

CERTIFICATION

This dissertation entitled "GEOLOGY AND PROVENANCE OF CLAY DEPOSITS IN PARTS OF CENTRAL BIDA BASIN, NIGERIA" by Adekola Amos ALABI meets the regulations governing the award of the degree of Doctor of philosophy (Ph.D) Geology of the Ahmadu Bello University, and is approved for contribution to knowledge and literary presentation.

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DEDICATION

This fruitful dissertation is dedicated to my wife Lydia Tani Alabi (Nee Yisa), my awesome great kids, Deborah Adebimpe and Miriam Opeyemi and to my parents Mr and Mrs Alabi, thanks for your prayer, support, love and understanding.

ACKNOWLEDGMENT

Every research work requires the toil, time and devotion of extraordinary people. Words are not adequate to express my gratefulness to those who God assigned to be my support in this tremendous research. Though I fear making the mistake of leaving someone out, I do want to acknowledge with great thanks giving to the following people who made this entire work possible:

Professor I. Garba (Vice Chancellor A.B.U Zaria), Professor U.A. Danbatta and Dr. T. Najime (Acting Head of Department Geology A.B.U Zaria) my mentors and dynamic supervisors whose supervision and criticism kept me motivated and focus.

Professors S. A. Alagbe, P. O. Ogunleye and H. Hamza, Drs. M. L. Garba, A. A. Ibrahim (Kazaure), I. Hamidu, E. O. Obiosio, A. E. Ikpokonte, I. Y. Abubakar, S. S. Magaji and A. B. Jolly, Mr. R. Abubakar, Mr. S. M. Elatikpo, Mr Stephen Gazama and Mall Kabiru (All of the Department Geology A.B.U Zaria) whose treasured contributions, conversation and friendship inspired my focus.

Professor E. O. Okosun, Late Professor I. M. Ogunbajo, Drs. I. N. Idris, C. Unuevho, N. M. Waziri, M.O. Jimoh, T. A. Ako, B.Y. Alkali (Geology Department, Federal University of Technology Minna), Engr. Jedna Samuel (NDISL Benin), Olatomiwa Olaniyi (NPDC Benin) Uncle Tunde Adedokun (LAUTECH Ogbomoso), Deacon M. O. Fabumi, Deacon Aremu Jesse, Mr S.F. Kolawole (Kogi State University Ayanbga), Mr Dele Ojuola (Nile Drill Company), Mr Raheem Mudashir Olayiwola (NESREA, Abuja) and Mallam Abba Mohammed Jibril (Center for Geodynamics, Toro Bauchi) whose continuous stream of encouraging words never end.

My brothers and sisters: Adebayo Alabi, Oluwasegun Alabi, Oluwaremilekun Popoola, Oluwasoji Alabi and Folasadeade Alabi, whose unwavering confidence in my life and study is appreciated greatly.

Finally, to the Nupe and Fulani communities in the Bida area, thank you all for been a pathfinder and field guide during the fieldwork.

ABSTRACT

Systematic geological, mineralogical and geochemical investigations of clay deposits in central Bida basin and part of its adjacent northwestern basement complex area were carried out. Ten representative rock samples from the basement area and thirty clay samples from the central Bida basin were analyzed using Inductively Coupled Plasma mass spectrometer (ICP – MS) and X-Ray Fluorescence (XRF) to determine major oxides, trace and rare earth elements composition, X-ray Diffraction (XRD) to determine mineralogical composition, while petrography analysis was used to study mineralogical compositions and the minerals optical features of the basement rocks using transmitted petrographic microscope. A topographic base map covering the study area was generated from mosaic topographic map of Minna, Mokwa, Lafiagi and Baro on a scale of 1:250,000. Part of the basement rocks mapped is composed of migmatitic-gneiss, mica schist, phyllite and Older Granite. Metasedimentary rocks mapped in the study area include; muscovite schist, biotite schist, amphibole schist and quartz schist. In the field, contact between mica schist, amphibole schist and Zungeru mylonite gnies is sharp, while in some area gradational contacts were observed between the mica schist and phyllite. The Older Granite occur as ridges and inselberg, andas minor intrution in the mica shist and migmatitic gneiss. The mapped basement rocks are part of Ushama Schist Formation, Kushaka Schist Formation and Birnin Gwari Schist Formation. Modal and petrographic analyses suggest that the rocks are enriched in felsic minerals. Major oxides, trace and rare earth elements composition also reveal that the basement rocks were formed from upper continental crust while the positive Ce anormaly observe in schist and phyllite suggest clay rich sediments protholith for these rocks. The clays deposits in the central Bida basin are white and fine grained from center of the basin to dirty white towards the

margin, red tint colour observed in the clay is inherited from overburden ironstone/laterite through percolating water. Vertical thickness of the clay ranges between 4 and 8 meters.Thus suggesting non-uniformity in the supply of clay minerals to the basin. Kaolinite is the dominant clay mineral in the study clay deposits (66.2 – 22.1%) with concentration increasing from the basin margin to the center. The increase in kaolinite composition compared to quartz composition is suggestive of the high velocity of transporting energy of clay materials from the source area to the basin. Plots of Na_2O/Al_2O_3 against K_2O/Al_2O_3 for basement rocks suggest that the phyllite, quartz schist, mica schist, and amphibole schist were of sedimentary origin while migmatitic gneiss and mylonite gniess are of igneous origin. Also, provenance discrimination plots of Th/Co versus La/ Sc, Sc versus Th, Cr versus V, Fe_2O_3 versus MgO and K_2O/Al_2O_3 versus log MgO/Al_2O_3 suggest that the studied clays werefrom felsic continental material. The cross plot ratio of V/Cr, La/Th and authgenic uranium ratios value of 1.5 ppm for studied clays suggest fluvial environment of deposition (flood plain, alluvial fan and braided channel) in the Bida basin which were further weathered/altered in-situ in the basin prior to the last phase of marine incursion that deposited the Enagi siltstone Formation during the upper Maastrichtian. Major oxides elements compositions of the clays suggest that clays in Sake and Shegba can be utilized for the production of refractory bricks, pottery production and ceramics while clays in Batati, Kpaki, Lemu, Kutigi, Gubaji, Nami, and Nakama require beneficiation for upgrade to meet specific industrial application. Elemental compositions of the studied clay deposits, suggest that the clays do not meet recommended dietary allowance for medical applications.

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CHAPTER ONE:GENERAL INTRODUCTION

1.1 Preamble

The Bida basin is a northwest - southeast trending,gently down-warped trough that is perpendicular to the main axis of the Benue Trough. It extends from Kontagora in the north to Dekina in the south and covers an area of about 700 km^2.Its maximum width isabout 160Km (Ojo and Ajakaiye, 1989). The Bida basin is one of the younger sedimentary basins of Africa (Campanian – Maastrichitian), and is bounded to the north and south by the Precambrian basement rocks (Figure 1.1).

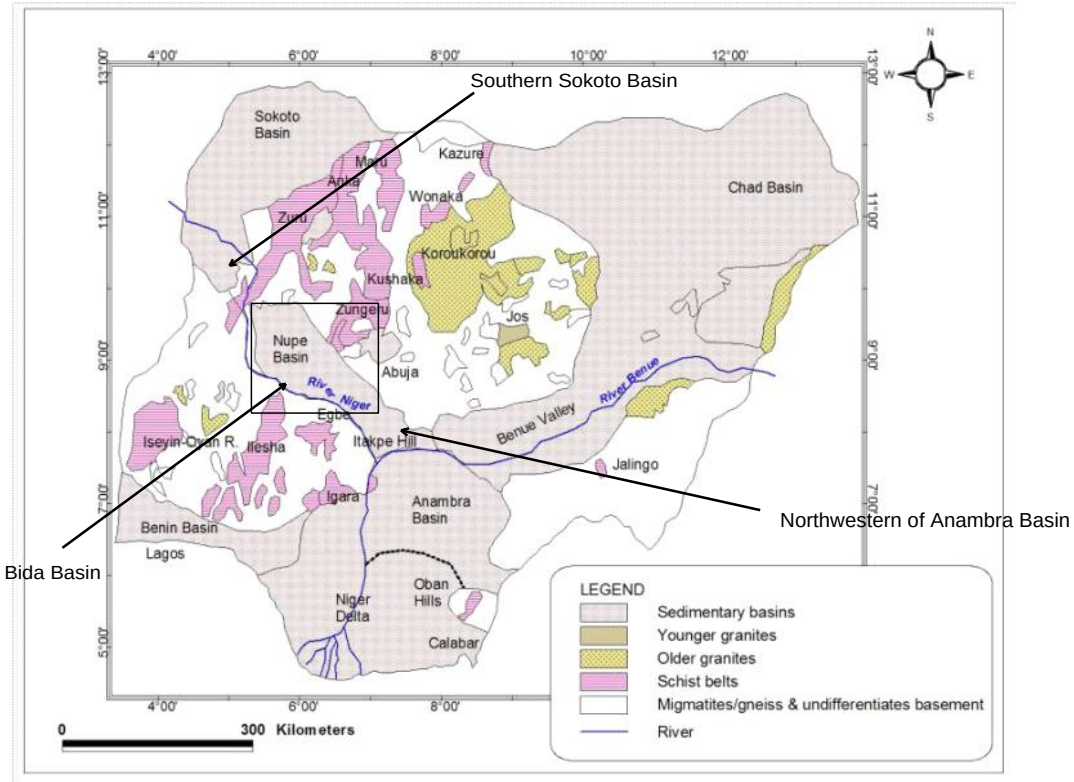


Figure 1.1: Geological map of Nigeria showing the location of Bida basin and adjoining basins (modified after Bassey, 2012)

The basin is described as a “down warped basin” because the epeirogenesis responsible for the basin genesis is closely connected with the crustal movement of the Santonian orogeny of Southeastern Nigeria and the nearby Benue valley (Adeleye, 1973). Landsat images and seismic data revealed a northwest – southeast trending faults system(Kogbe*et al.,* 1981). Its origin is related to the tectonic activities in the south eastern Nigeria. Brade (1992b) viewed the evolution of Bida basin from the southern part, as tectonic extension playing a major role which is consistent with the characteristics of strike-slip basin enumerateby Nilsen and Sylvester (1995).The first major marine incursion was suspected to have taken place during the early part of the uppermost Maastrichtian phase from the south via the Anambra basin, at the uppermost Maastrichtian period.The peak of the marine transgression was reached during which very extensive sandstones and thick kaolinite beds of the Patti Formation in the southern Bida basin was deposited (Akande *et al.,* 2005).

Stratigraphically, Bida basin is divided into the southern and northern part. The southern sectorconsists mainly ofLokoja Sandstone, Patti Formation and Agbaja Ironstone while the north sector is composes ofBida Sandstone, Sakpe Ironstone, Enagi Siltstone and Batati Ironstone (Adeleye, 1973, Obaje, 2009). Braide (1992a) divided the Bida basin in to southern, central and northern part geographically with the aim of establishing the syntectonic fluvial sedimentation of the central part of the basin (Figure 1.2). The northern part is considered to extend from Kontagora to Kudu/Wushishi areas to the southeast; the central sector extends from Lemu to Katcha/Baro area while the southern sector extends from Gulu/Baro area and makes contact with the Benue Trough. Economic resources associated with the basin are ironstone, clay and laterite.

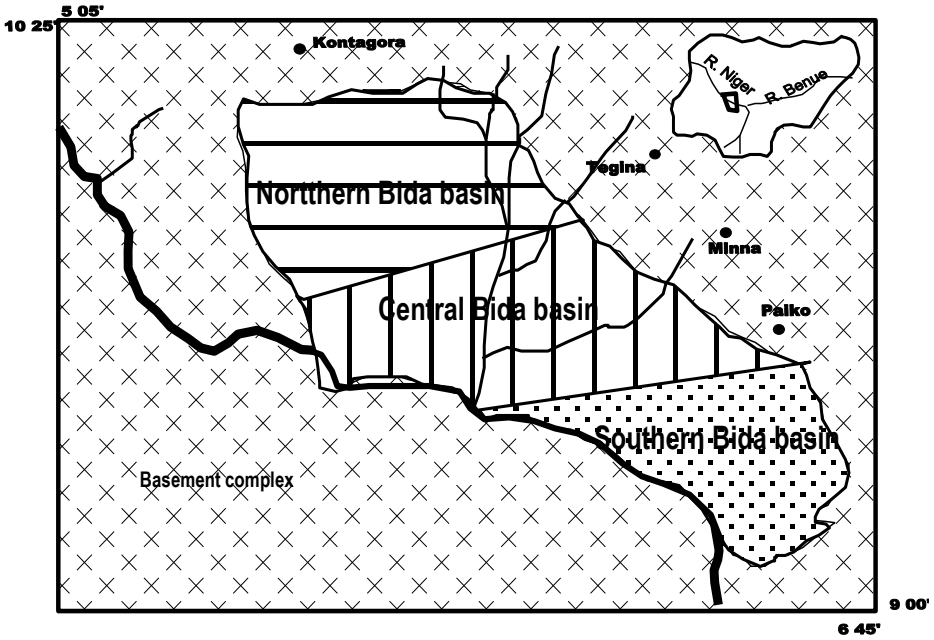


Figure 1.2: Geographical subdivision of Bida Basin into Northern, Central and southern parts (Modified after Braide, 1992a)

1.2 Location and Accessibility of Study Area

The study area is bounded by latitudes 8^{o} 55' and 9^{o}55'N and longitudes $5^{o}30^{'}$ and $6^{o}45^{'}$ E, covering an area of 110 kilometers X 138.5 kilometers (15,235 square kilometers) and constituted the central part of the Bida basin and part of the northwestern basement rocks (Figure 1.3).

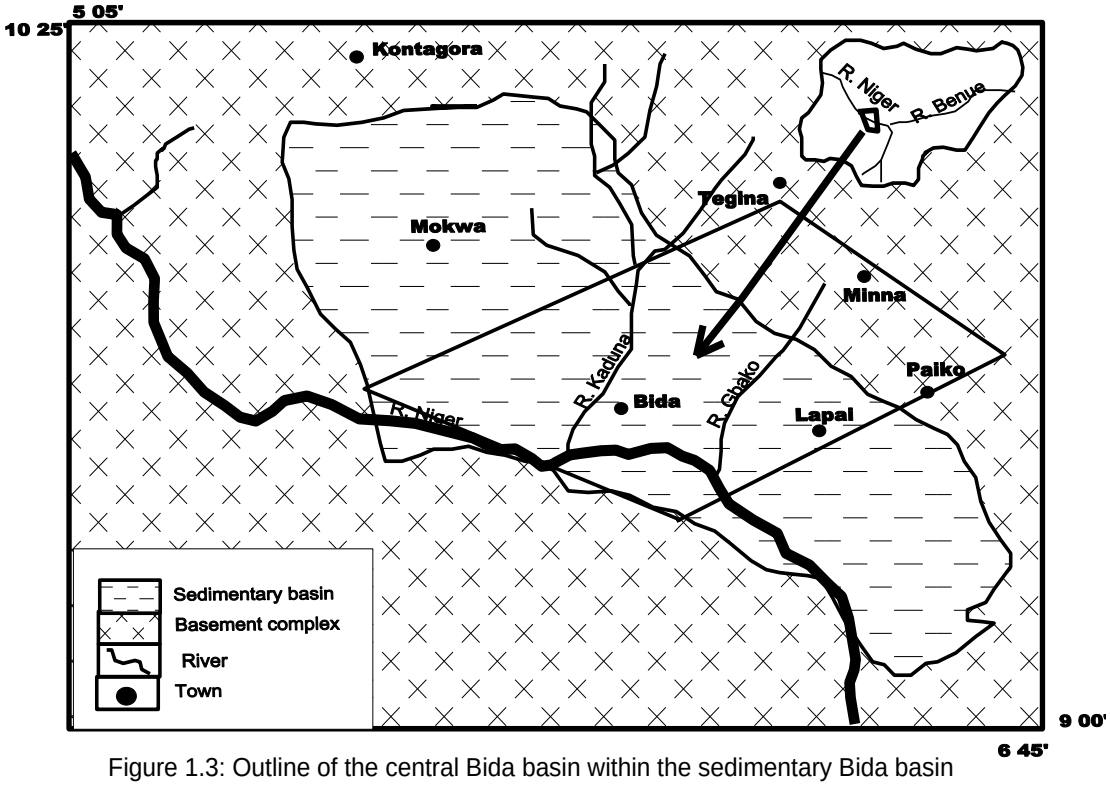


Figure 1.3: Outline of the central Bida basin within the sedimentary Bida basin (Modified after Adeleye, 1989).

Major settlements in the area are Kpaki, Kutigi, Batati, Bida, Agaie, Lapai, Lemu, Paiko, Minna and Zungeru (Figure 1.4).

Almost all the areas are connected with accessible road through the major towns and villages. Lapai, Agaie, Bida, Kutigi, Mokwa are accessible along Abuja – Ilorin federal road. The Wushishi and Lemu area is accessible through Zungeru – Bida federal road which links Minna. Other areas are accessible through feeder roads.

1.3 Relief and Drainage

Adeleye, (1989) recognized three physiographical units in the Bida basin, this unite consists of (i) The Belt of mesas, (ii) Plains, and (iii) The River Niger and its flood plains and tributaries.

The belt of mesas is discontinuous and runs from an area of about 16 kilometers east of Mokwa, through an area south of Bida to Baro, Lokoja and southwest Dekina. The mesas occupy about 10 % of the basin. The top of mesas are capped with sandstones or ironstones/ferruginised massive laterite and lies between 150 – 300 meters above sea level in the Lemu/Bida (study area); 260 meters around Niger/Benue confluence area. The mesas have been irregularly dissected by the River Niger and its tributaries.

Intermit breaks of slope are sometimes present along the mesas walls. They are indication of the occurrences of relatively resistant beds.About 70% of the basin is covered by flat-lying to gently rolling plains. The monotony of the landscape is sometimes broken by mesas which are conical or flat – topped. Many of such hills are common along Mokwa – Bida and Bida – Zungeru roads. Around Lokogoma in the north, the plainrises between 120 – 360 meters above sea level; 120 – 240 meters around Kpaki; 150 – 135 meters around Bida, and about 60 – 180 meters in the Agaie area to the south.

The River Niger runs northwest - southwest in the southern marginal areas of the Bida basin and forms the southern boundary of the study area. Its flood plain is broad and locally up to 20 kilometers wide. The flood plain is marked in most areas by a series of elongated ponds running parallel to the river channel. The most important tributaries are the River Kaduna, River Gbako and River Mariga which meander through the northern Nigeria Basement Complex, and display dendritic drainage pattern (Figure 1.4).

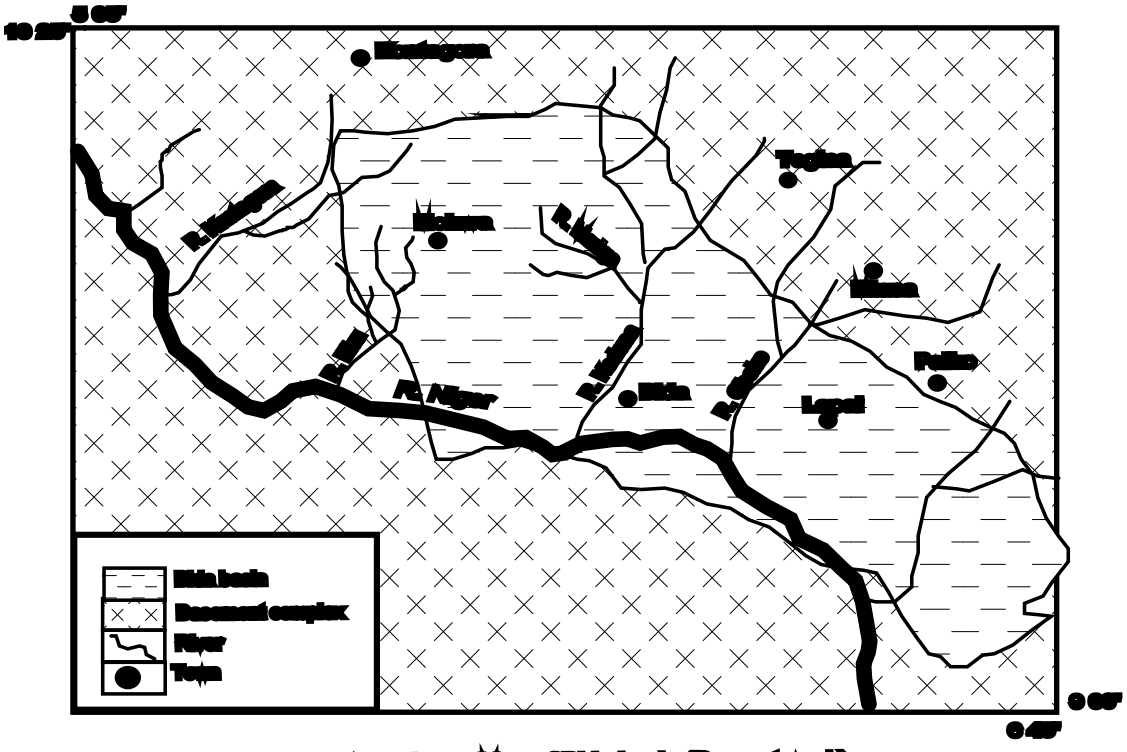


Figure 1.4: Drainage Map of Bida basin (Present work)

1.4 Climate and Vegetation

The study area lies within the Guinea climate region of Nigeria climate regions marked by dry season (November – March) and wet/raining season (April - October) with highest amount of rainrecorded in the month of July. Annual rainfall is between 1,000 and 1,250 millimeters,mean annual temperature is between 18^{o}C and 36^{o}C and relative humidity is about 80% in the morning but may drop to 70% during the dry season (Reuben, 1978). Two air masses dominate the climate of the study area: the maritime air mass (moisture laden) influence by south - west trade wind and the tropical continental air mass (Harmattan). The tropical continental air mass (Harmattan) is responsible for low relative humidity, high day temperature of about 36^{o}C, dry and dusty, while the maritime air mass (moisture laden) is responsible for the rainfall and low temperature.

The vegetation is of typical Guinea Savanna belt of the West Africa rich in grasses of average height of 2 to 3 meters and also fire-resistance trees which reach up to 18 meters in height. The trees and grasses are interspersed and become gradually small and less luxuriant in appearance. Acacia's trees of between 3 to 6 meters high are found on the plains, they have thick leaves and thorns. There are isolated natural forest at the foot of Fazhi mesa and Kodan village. Flood plains are characterized by tall grasses and scanty palm trees of average height of 7 meters. The common trees are baobab, kapko, acacia, shear- butter and locust-beans plant.

1.5 Statement of Research Problem

Ojo (2012) reported a thin bed of brown kaolnitic clay of average thickness of 0.3 meters intercalated with siltstone and fine sand in the sedimentary sections at Share, Gbugbu and Wariku in the northern Bida basin. Ojo and Akande (2012) documented a 2.0 meters thick clay bed interbedded with cross stratified sandstone in Shonga and Agbona ridge section in the northern Bida basin which has attracted artisanal miners for pott making and local medicinal use in the area.

Kaolinitic clay has been reported to occur within the sandstone beds of the Bida Sandstone in the northwestern part of the Bida basin (Oluyide *et al.,* 1998). Also, Akande *et al.,* (2005) documented the occurrence of clay within the sandstone, shale and oolitic ironstone of the Patti Formation in the southern Bida basin. Braide (1992c) recovered agglutinated foraminifera from black shale at the central Bida basin and suggested marine depositional conditions. Adeleye(1989) suggested shallow marine to freshwater for the origin of Sakpe ironstone formation from evidence of biota and texture of the ironstone. He also studied regional dips of

the campanian – Maestrichian beds and their overall vertical grain-size distribution and suggested that the original grains were derived from the southwestern Nigeria Basement Complex. Idris-Nda (2010) studied the aquifer system of the Bida basin and concluded that the sedimentary fill of the basin are weathered product of northeast adjoining basement. In addition, the Steel Raw Material Exploration Agency of Nigeria (1989) has reported large occurrences of clay in some locations in the northern part of the Bida basin.

Ajibade *et al*., (1989) recognized four petro-lithological units adjacent to the Bida basin, this include; the Migmatite – Gneiss Complex, the Schist Belt, the Older Granite and undeformed Acid and Basic Dykes. The schist belts are composed predominantly of pelitic to semi pelitic rocks, while the Older Granite ranges in composition from tonalite and diorite through granodiorite to granite and intruded both the migmatite – gneiss and the schist belt.

Unfortunately, in all these studies detailed geological investigation of the clay occurrence, provenance and industrial application/medicinal application study and the impact of the adjoining basement complex have not been undertaking and the geological maps of the clay occurrences and the adjoining basement rocks have not been produced.

1.6 Justification of the Study

In this study, clay deposits in the central Bida basin will be evaluated and characterized basedonmineralogicaland chemical compositions so as to unravel the protholit, environment of deposition and industrial/human benefits of the clay deposits. Also, the geology of part ofthe adjacent Basement Complex rocks will be investigatedto give insight of therock type, mineralogy and elemental compositions, and proposed its influence to the Bida basin.

Updated geological map of the central Bida basinon the scaleand its adjoining Basement Complex on the scale of 1:200,000will be produced, whilethe provenance, environment of deposition would be established and industrial/human benefit of the clay will be proposed.

1.7 Aim and Objectives

The aim of this research is to present mineralogical data and geochemical characteristics, and to deduce the provenance, sedimentation, environment of deposition and economic potential of the clay deposits in central Bida basin.

The objectives are to:-

1. Map and locate the clay deposits in the central Bida basin, produce a geological mapcovering the central Bida basin and the part of the adjoining basement complex.
2. Study the mineral and element concentration variations of the clay deposits, deduce signatures of provenance,deposition environment and compare these signatures to the stratigraphy and sedimentation of northern Bida basin
3. Assess the elemental composition of the clay and determine industrial/medicinal application.

1.8 Previous Works

Ako (2014) mapped the Zungeru amphibole on a scale of 1:25,000 and recognized; massive and weakly foliated varieties. He concluded that the amphibole is of sedimentary origin. Elatikpo *et al*., (2013) studied the petrogenesis of gneiss within the Malumfashi schist beltand concluded that the gneiss were derived from igneous rock formed at relatively shallow depth while banded and augen gneiss were derived by moderated degree of partial melting of the lower crustal materials.Alabi (2011),mapped the basement rocks that bounded the northeastern part of the Bida

basin (Paiko Sheet 185NW) on scale 1: 25,000 and classified the rocks in the area into porphyritic biotite granite, tonalite and granodiorite.

Ajibade *et al*., (2008) mapped Minna area on a scale of 1:100,000 and described the Older Granite as irregular, composite body forming contact with most metamorphic rocks units and truncated the Birnin Gwari, Kushaka Schist and the Zungeru Mylonite. The Older Granite are composed of coarse - medium grained tonalites which are weakly foliated, while the tonalites are injected into the rocks of Kushaka Formation to form migmatites with tonalite as the leucosome.

In other areas in Minna, granite and granodiorites intruded the tonalities in lit-part-lit fashion to form migmatite of another type of which the tonalites occur as the paleosome. Some of the granitoids are very coarse to coarse-grained granite and granodiorite and are distinctly the youngest of the major groups as they criss-cross the tonalite, granite and granodiorites. Other minor rocks mapped within the Minna batholiths include gabbro, diorite, microgranite and hornblendite (Ajibade *et al*., 2008).

Oluyide*et al.*, (1998) mapped part of Ilorin Sheet 50 on a scale of 1:100,000 and described the Older Granites in the southwestern of the study area as ranging from porphyritic granite through medium to fine grained granite, syenite, granodiorite and granitic gneiss. Granodiorite, quartz-diorite, diorite and syenite, have been recorded in the northern part along River Kaduna while dykes and veins of aplite, pegmatite, quartz-tourmaline and microgranite are commonly associated with these rocks (Truswell and Cope, 1963).

McCurry (1973), mapped the schist belts in the northwestern Nigeria (Kushaka schist, Birnin Gwari schist and Ushama Schist Formations), that constitute the adjoining basement rocks to the

study area and reported micaceous schist, phylite, amphibole, quartzite, muscovite quartzite, and ferruginous quartziteof which the ferruginous quartzite is composed of thin bands of iron oxide, mostly magnetite with a little heamatite alternating with less iron-rich quartzite. Quartzites in Zungeru area are feldspathic and fissile in charater. There are however good exposures of amphibolite schist in the gorge of the River Kaduna at Zungeru.

Goro *et al*., (2014) studied the characteristics of a massive sandstone interval in northern Bida basin which form part of the present study area, and came up with four lithofacies displaying varying degrees of mottled colour. These are: (i) sand conglomerate facies, (ii) medium to coarse grained sandstone facies, (iii) siltstone facies and,(iv) fine to medium grained sandstone facies. Claystone and shale occurrence as been reported by Okunlola and Olubunmi (2012) at the base of an outcrop section at Ahoko and Abaji of Patti Formation (southern Bida Basin) occurring below siltstone and sandstone inter-bedded with bioturbated ironstone, mineralogical the claystone and the shale are composed of kaolinite and illite with non-clay minerals of microcline, quartz, zircon, pyrite and hematite. Idris-Nda (2010) studied the aquifer system of the Bida basin and concluded that the sedimentary fill of the basin is a weathered product of adjoining basement materials deposited as an alternating sand and clay, with the percentage of sand increasing to the north of a lacustrine deposition environment. Braide, 1992 concluded that the sedimentary deposits in Bida basin are characterised by high to low energy depositional environment in a meandering braided river system, of which thick deposits occurred where meandering is large and reported shallow depth of carbonaceous peat deposits at Kudu, Makera, and Bokani areas. Also, Braide (1992a) studied the alluvial fan depositional in the northern Bida basin and repoted

syn-depositional tectonic subsidence control responsible for upward coarsening sequence recognized in the alluvial fans.

Adeleye (1971) and Adeleye and Dessauvagie (1972), identified the presence of clay deposits in the middle Niger Basin associated with the Nupe Sandstone (Bida Sandstone). They studied the stratigraphic succession in the area and reported the direct overlying of the basement complex by a coarse conglomerate and clay-sandstone admixture.According to Adeleye (1973), the conglomerates were themselves overlained by sandstones, subsidiary claystones and siltstones. All the clay occurrences investigated fall within the Cretaceous - Maastrichtian Middle Niger Basin (Bida basin).

Adeleye (1973) reported three main types of clay in Bida basin which include; (i) earthy brown to red lateritic clays; (ii) gray ball clay and (iii) white-silty clays. The lateritic clay occurs beneath thin to thick covers of laterite within sections on the mesas. Red stains of laterite are noticeable on these clays which grade into white – sandy kaolin within the peneplains. The gray ball – clays within the Bida basin occur on alluvial plains of rivers, which are derived from the feldspar rich basement rocks.

Table 1.1: Summary of the geology of the Basement Complex adjacent to the Bida basin (Ajibade*et al*., 2008)

	Rock Type	Lithologies	Age
	Bida sandstone	Sandstone with conglomerate and claystone	Cretaceous
		Noncornformity	
Intrusion	Older Granite	Microgranite and pegmatite Very coarse to coarse- grante biotite, muscovite granite, foliated in parts Medium grained granite and granodiorite, foliated in parts. Medium- to coase-grained tonalite (weakly to strongly foliated). Pan- African injection migmatite	Pan- African
	Charnockitic rocks	Gabbro, diorite	
The Schist Belts	Birnin Gwari Schist Formation	Phyllites, mica schist, metagreywacke, pebbly schist, meta-dacite and meta – rhyolite	?Pan- African
	Ushama Schist Formation	Phyllites, mica schist, quartz mica schist, amphibolites	?Pan- African
	Kushaka Schist Formation	Phyllites, mica schist, quartz mica schist, amphibolite, ferruginous quartzite, marble	?Pan- African
	Oro Schist Formation	Phyllites, mica schist, amphibolite, ferruginous	?Pan- African
Gneissic Complex	Zungeru Mylonites	Sheared gnesiss, mylonitic straurolite schist, quartz mylonites Mylonite gneiss, mylonite schist, blastomylonite, phillonite and amphibolites	Pre- Pan- African affected by Pan-African tectonism ?Pan- African
	Early Migmatite Complex	Banded gneiss, agmatite, anatetic migmatite, biotite gniess	

CHAPTER TWO: LITERATURE REVIEW

2.1 Regional Geology

Geodynamic model for the evolution of the Basement Complex has been erected through geological and geophysical evidence from the western province and cratonic margin (Grant, 1969; Caby *et al*., 1981; Black *et al.*, 1979). The tectonic setting is viewed as a collision type orogeny with eastward dipping subduction zone. The subduction zone in the southern sector of the belt (Ghana – Togo – Benin) is shallow dipping, extending under the Dahomeyan shield that resulted to the steep thermal gradient to the east of Nigeria (Burke and Dewey, 1972 and Trompetee 1979). The collision at the cratonic margin led to the reactivation of the Dahomeyan basement including Nigeria. The Dahomeyan was thickened to form a Titbetan type crust. The formation of granitic magma is as a result of partial melting in the lower part of the thickened crust.

The suture at Sassandral, along the eastern margin of the West Africa Craton and the nature of the Pan-African orogeny has been used to relate the evolution of schist belt to the subduction processes in the craton margin. Vaniman (1976), Holt (1982) and Turner (1983) considered the schist belt to have been deposited in a back-arc basin developed after the onset of subduction at the cratonic margin, while Anka schist belt is comparable to those of island arc. Mc Curry and Wright, (1977) and Turner, (1983) believed that the schist belts represent additional micro-continent separating preexisting micro-continent. The volcanic rocks in some area of the basement have chemical characteristics that show possible ocean floor derivation.

The crustal thinning in the western Nigeria province is related to the initial crustal extension and continental rifting at the craton margin about 1000 Ma ago, which led to the formation of graben

like structures in a broad zone in Nigeria and the deposition of predominantly clastic sediments with minor volcanic rocks. Closure of the ocean at the craton margin about 600 Ma ago, and crustal thickening to the east led to the deformation of the upper mantle and lower crust and the emplacement of the Older Granite in Nigeria. Regional uplift around Anka led to the post-tectonic deposition of coarse clastic sediments associated rhyolitic and dacitic volcanic rocks which have been dated at 500 Ma (Ajibade *et al.,* 1987).

Nigeria lies to the south of the central and eastern Hoggar-Aïr domains (Figure 2.1) both regions are polycyclic and are of similar distance from the cratonic margin. They are characterized by large volumes of Pan-African granitoids. The central Hoggar and the western province of the Nigeria basement both contain north – south trending schist belts that are parallel to the cratonic margin, but those of the central Hoggar are of higher grade. The occurrence of extensive shear and mylonite zones in the Tuareg shield that divided the whole shield into structural provinces is a major structure that differentiate Nigeria basement from Tuareg shield. Although such structures in Nigeria basement has been recognized in the north – south trending mylonite and fault zone in Zungeru (Ajibade *et al*., 1979).

The low grade schist belts of the central Hoggar which are assumed to be of late Proterozoic age are interpreted as intracratonic trough bounded and controlled by the shear zone (Black, 1980). In Nigeria there is no direct evidence to support fault bounded troughs to schist belt, but the Ile-Ife Fault Zone is assumed to have controlled the deposition of the eastern unit of the Ilesha schist belts.

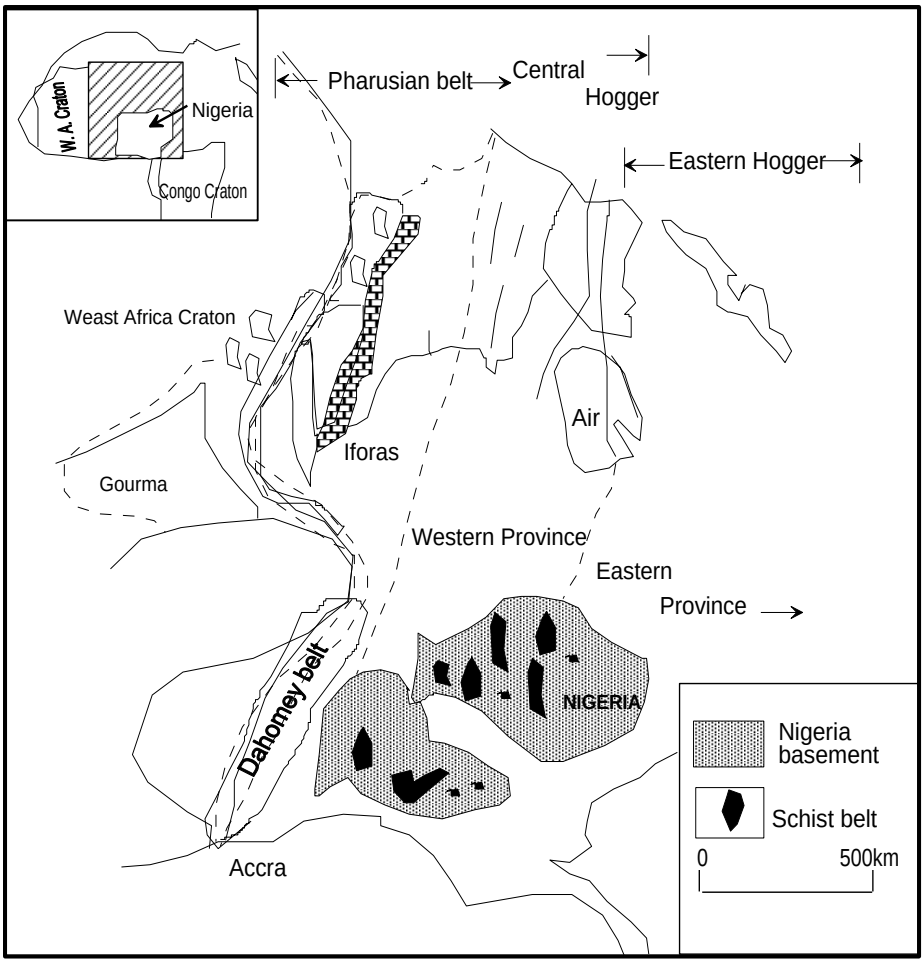


Figure 2.1: Tectonic evolution map of Nigeria basement complex within West African craton (modified after Caby *et al.*, 1981)

2.2 Impact of Orogenic events in Nigeria Basement Complex

The major orogenic events that result in the reactivation of the Central and Eastern Hoggar are responsible for the Nigeria Basement Complex major orogenic events of Eburnean, Kibaran and Pan-African. These orogenic events have left impacts relating to emplacement of various rock type and structures on the Nigeria Basement Complex.

2.2.1 Eburnean Orogeny

The Eburnean orogeny (2,000 ± 200 Ma) is considered to be the last event that affected the West African craton (Wright, 1985). This event in not well documented in the Nigeria Basement Complex. However, the Ibadan granite gniess in the southwestern Nigeria which has yielded an age of 2200 Ma, is the only reliable evidence for this event.

Grant (1970) obtained the age of 2282 ±73 Ma for pink granite which is emplaced into banded gneiss and quartzite in Ibadan area through Rb/Sr whole rock analysis, while Oversby (1975) obtained Archaean age of 2750 Ma for the banded gneisses that were cross cut by dolerite dykes in Ojo quarry in Ibadan area. Ogezi (1977) obtained Rb – Sr data on migmatites and gneiss from various part of northwestern Nigeria. He obtained variation ages between 3,100 and 2,400 Ma reference line on the Kaduna and Mallam Tanko migmatite, as well as ages between 3,100 and 600 Ma reference line on the Malumfashi migmatite respectively. The Eburnean event was accompanied by wide spread activities and green schist facies metamorphism, there is no evidence for the occurrence of Eburnean sediments in Nigeria. However, the only reliable evidence for this event comes from Ibadan granite gneiss which has yielded an age of 2200 Ma (Ekweme, 1990c).

2.2.2 Kibaran Orogeny

The evidence for a possible Kibaran event in the northwestern Nigeria Basement Complex was reported by Grant *et al.*,(1972) who provided two single-sample whole-rock ages of $1275^{\pm}75$ and 1120 ± 70 Ma for banded gneiss from Kusheriki region, he also obtained Rb-Sr single-sample whole-rock age of 1351± 75 Ma on a migmatite sample west of Kaduna and age of 1159 ±75 Ma on another migmatite sample west of Kaduna area.

Ogezi 1977 and Holt *et al.,* interpret the age of the northwestern Nigeria schist belts based on the Kibaran isotope age obtained from phyllite of Maru Belt. Grant *et al.,* 1972, document Kibaran isotope overprinting of basement gneiss in the north western Nigeria. Although all the radiometric ages obtained reflects Kibaran event in Nigeria, the concept of Kibaran event in Nigeria is of the most controversial of all orogenic events in Nigeria. This is because no granitic intrusion of this age is fund in Nigeria basement.

2.2.3 Pan-Africa Orogeny

Most of theOlder Granite suite of northern and northcentral Nigeria has been dated as Pan-African. Burke and Dewey, (1972), Grant, (1978), and Turner, (1983) viewed tthe Pan-African event as related to plate tectonic activities that involved the collision of the Birrimian plate (comprising the present day West African craton) and Dahomean plate. The Pan-African event involved crutal thinning and ensimatic mechanism that result to ocean opening. Subduction and continental collision–type orogeneses in respond to the closure of the Buem Ocean at the east-dipping plane (Burke and Dewey, 1972; Black *et al*., 1979). According to Burke and Dewey (1972), the early stage of the Pan-African event started with the open and closure of the Buen Ocean in Late Proterozoic time.

The closure is along an east-dipping plane, and this reactivated Dahomea, while Birrimea remained stable. This led to the development of a complete orogenic cycle during the Pan-African (Grant, 1970; 1971), on the other hand interpreted the Pan-African as thermo-tectonic event in part of Nigeria and adjacent countries. K-Ar and Rb-Sr, data obtained on fine grained micas and whole-rock from the Older Granite suite of which the ages lies within the range of 450-550 Ma, and believed to mark the final stages of Pan-African event.

The age of 794 ± 73 Ma was obtained from Zaria granite through whole-rock Rb-Sr 3-errochron date corresponding to 794 ± 73 Ma and with a low initial ratio of 0.7044, but relatively high error (+ 0.0053), Ogezi (1977). He considered the errorchron age as the age of intrusion of granite. McCury, 1973 considered the Zaria granite as the oldest dated member of Pan-African granite cycle in Nigeria. The Manchi Granodiorite yield eleven point Rb-Sr, isochron age of 679 ±65 Ma, with an initial ratio of 0.7074±0.0008 which defines the age of intrusion of granodioritic magma probably generated by partial fusion of older crutal component Ogezi (1977). The Pan-African is also recognized in the gneiss and migmatites of Malumfashi area, where eight gneiss samples were used to define an imprecise whole rock errorchron age of 610 Ma, with an ratio of 0,707 ±0.0021(Ogezi, 1977). He interpreted this age as the metamorphic age of the gneiss and migmatites, during which there was an open system in the Rb – Sr physcio-chemica environment of pre-existing basement rocks.

Rb-Sr isochron age of 692± 161 Ma and U-Pb Zircon age of 605± 10 Ma was obtained on the Panyam granite (Van Breemen *et al.,* 1977). He also obtained 663 ± 164 Ma from Bauchi charnockitic rocks and concluded that the peak period of Older Granite emplacement in the north-central Nigeria took place about 610 Ma ago. K-Ar age of 780 ± 40 Ma was obtained by Snelling, 1964 from hornblende granite which occur about 6.5 kilometers away from Kano. Also, Tougarinov *et al.*, (1968), reported U-Pb age of 680 ±? Ma of K-feldspar from Rukuba Older Granite. Jacobson *et al.,* (1963) study Kusheriki area to the southwest of Kazure Schist belt and reported Rb-Sr single whole rock age of 549 ± 14 Ma for porphyritic granite.

Ajibade (1980) obtained an errorchron age of 505 ± 12 Ma on biotite of the Minna Granodiorite. Ogezi (1977) has also obtained a Rb-Sr age of 565 ± 46 Ma on the gneiss granite from saibodji,

Gusau. All these are consistent with previous correlation among the Older Granite complex in northwestern Nigeria.

Van Breemen *et al, (*1977) and Ajibade *et al,* (1987), reported that most Rb-Sr isotopic measurements on the Older Granite from northwestern Nigeria give $^{87}Sr/^{86}Sr$ ratio of 0.7065 to 0.7125, these ratio are above the upper mantle value of 0.701 (600 Ma ago). This suggested heavy contamination (by older crustal rocks) of magma originally generated by partial fusion of upper mantle rocks. It was also thought of alternatively the Pan-African granite melts were generated by partial melting of crustal rocks (high initial ratio). The Older Granite of the Kazaure schist yielded a Rb – Sr age of 592 ± 14 Ma (Danbatta, 1999).

2.3 Geology of Nigeria Basement Complex

The Nigerian Basement Complexcovers about half the surface area of Nigeria while the remaining 50 % are of sedimentary rocks and formed a part of the Pan-African mobile belt that lies between the West African and Congo Cratons and south of the Tuareg Shield (Black, 1980). It is intruded by the Mesozoic alkaline ring complex 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). The first three cycles were characterized by intense deformation and isoclinals folding accompanied by

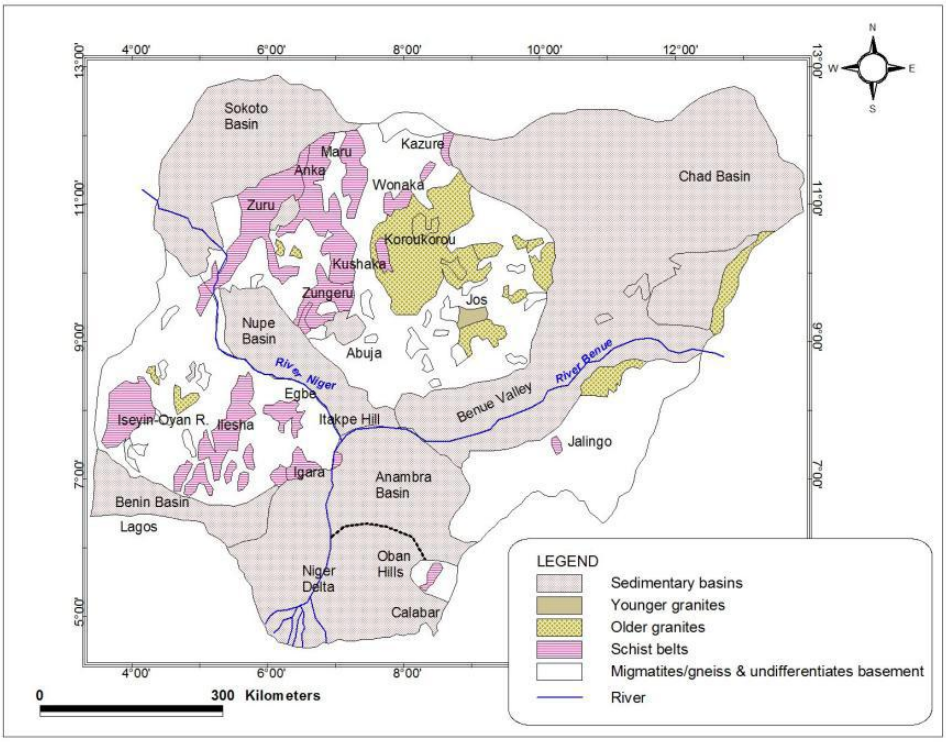
regional metamorphism, which was further followed by extensive migmatization. The Pan-African deformation was accompanied by a regional metamorphism, migmatization and extensive granitization and gneissification which produced syntectonic granites and homogeneous gneisses (Abaa, 1983). Late tectonic emplacement of granites and granodiorites and associated contact metamorphism accompanied the end stages of this last deformation. The end of the orogencywithin the basement complex of Nigeria was marked by faulting and fracturing (Gandu,*et al*., 1986; Olayinka, 1992). Ajibade *et. al.*, (1989), four major petro-lithological units are distinguishable within the basement complexof Nigeria (Figure 2.2). These include:

(i) The Migmatite – Gneiss Complex (MGC)

(ii) The Schist Belt (Metasedimentary and Metavolcanic Rocks)

(iii) The Older Granites (Pan African Granitoids)

(iv) Undeformed Acid and Basic Dykes



Figiure 2.2: Geological map of Nigeria showing the Precambrian basement, Jurasic Younger Granite and Cretaceous sedimentary basins (after Bassey, 2012)

2.3.1 Migmatite – Gneiss complex

The migmatite – gneiss complex is generally considered as the basement complex sensu strict (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, orthogneises, paragneisses, and a series of basic and ultrabasic metamorphosed rocks. Petrographic evidence indicates that the Pan-African reworking led to re-crystallization of many of the constituent minerals of the migmatite – gneiss complex by partial melting with majority of the rock types displaying medium to upper amphibolites facies metamorphism. The migmatite – gneiss complex has ages ranging from Pan-African to Eburnean. The migmatite-gneiss complex also termed by some workers as the "migmatite-gneiss-quartzite complex" makes up about 60% of the surface area of the Nigerian basement (Rahaman and Ocan, 1978). These rocks record three

major geological events (Rahaman and Lancelot, 1984);the earliest, at 2,500 Ma, involved initiation of crust forming processes (e.g. the banded Ibadan gray gneiss of mantle origin) and of crustal growth by sedimentation and orogeny; next came the Eburnean, 2,000 ± 200 Ma, marked by the Ibadan type granitic gneiss; this was followed by ages in the range from 750 to 500 Ma which represent the imprint of the Pan-African event which not only structurally overprinted and re-set many geochronological clocks in the older rocks, but also gave rise to granite gneisses, migmatites and other similar lithological units.

The gneiss had variable lithology which include; mylonite, augen-gneiss and sheared gneiss (McCurry, 1973, Ekwueme and Onyeagocha, 1982). Feldspathic quartzites of ancient metasediments are associated as relicts with these lithologies. There are different types of migmatised (banded gneiss) and unmigmatised gneiss, which form the host into the intrusion granitoids were emplaced. Ajibade *et al.*, (1987), revealed two generation of migmatitic-gneiss of widely different ages within the northwestern basement complex of Nigeria: (i) those formed by anatexis in ultra high metamorphic terrains (Early Migmatite); (ii) those formed by magmatic injection around some large mesozonal granite plutons, referred to as injection migmatite (Pan-African Migmatite). Around Minna, field relationship shows the emplacement of the batholith result in the extensive migmatisation of the Kushaka Schist Formation. The early migmatite type are differentiated in the field from the Pan-African Migmatite by complex fold structures with several generation and types of leucosomes which include granitic, aplitic and pegmatitic materials, the Pan-African Migmatite show simple structures which include alternating schistose and tonalitic, granitic or pegmatitic layers.

2.3.2 The Schist Belts

The Schist Belts comprise low grade metasedimentary and metavolcanic rocks belts trending N – S which are best developed in the western half of Nigeria. These belts are considered to be Upper Proterozoic in age and consist of supracrustal rocks which have been infolded into the migmatite-gneiss-quartzite complex. The schist belts occurred as series of synformal troughs and strike, intercalated with relicts of migmatites and gneisses or intruded granites which separated and lie within them. Each of the schist belts is separated from adjacent belt by migmatite, gniesses and granites.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 (1979) who first mapped a structural break.

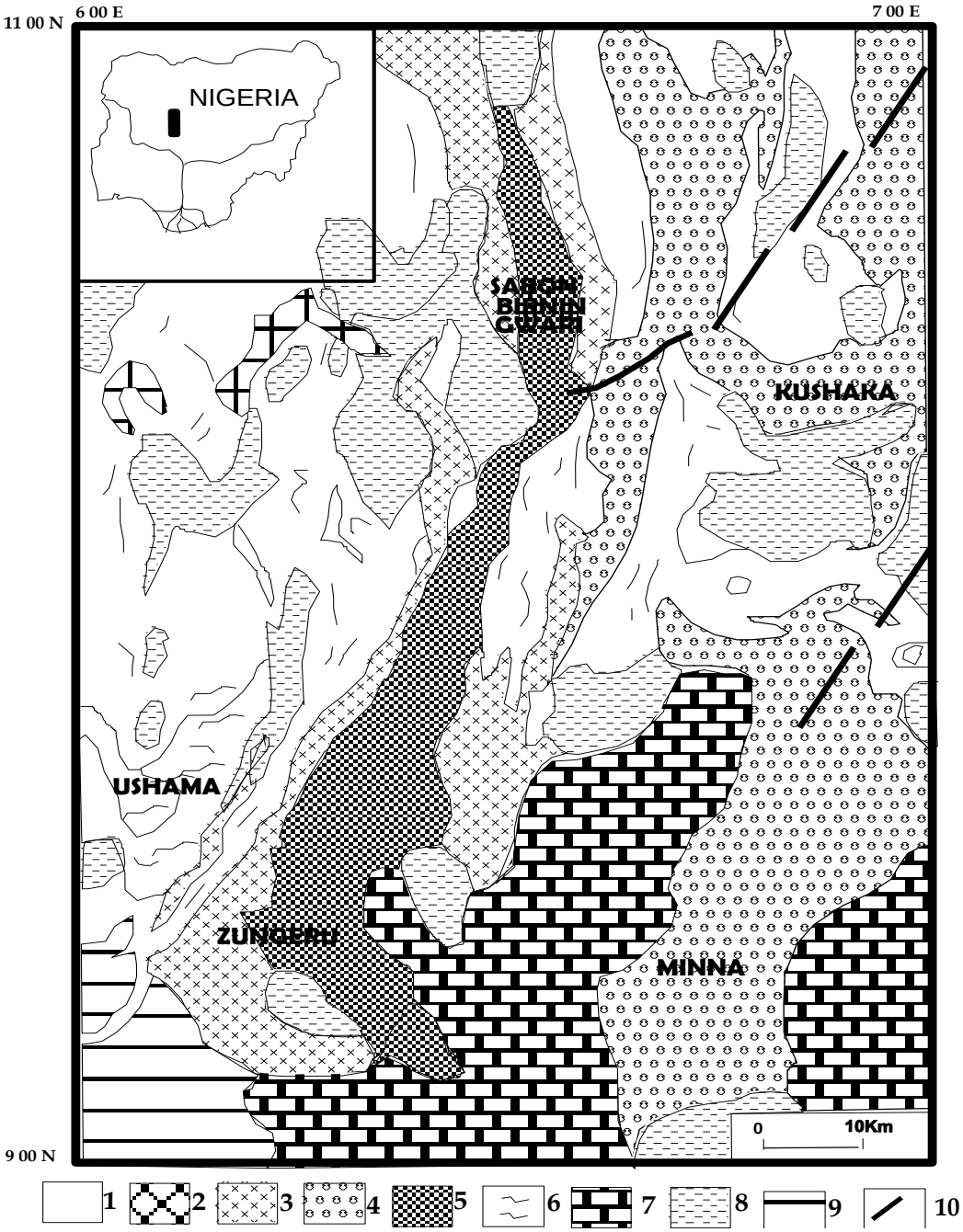
All the schist belts are composed predominantly of metamorphosed pelitic to semi pelitic rocks and each belt differ in the concentration of these rock units such as conglomerates, greywackes, quartzites, calcareous rocks and volcanic rocks. The schist belts rocks are predominantly micaceous schist, phylites, amphibolites, quartzites, and also included is acid and intermediate volcanic and plutonic rocks interbedded with the metasedimentary rocks. The amphibolites in the schist belts are suggested to be of tholeiitic in nature and of ocean floor and island arc affinity (McCurry and Wright, 1977).

The geochronology of the schist belts remains problematical although the ages of intrusive cross-cutting Older Granites provide a lower limit of ca 750 Ma. A Rb/Sr age of 1,040 ± 25 Ma for the Maru belt phyllites has been accepted as a metamorphic age by Ogezi (1977). The schist belt rocks are generally considered to be Upper Proterozoic.

Truswell and Cope (1963) recognized eight schist belts in the northwestern part of Nigeria and gave each belt formational name of Anka, Maru, Malunfashi, Wonaka, Zuru, Kushaka, Birnin Gwari and Ushama formations, of which Kushaka, Birnin Gwari and Ushama formations occurred adjacent to the northeast of Bida basin (Figure 2.3).

2.3.2.1 Birnin Gwari Formation

Birnin Gwari Formation extend from Minna area northward into the Kusheriki area and trend in northeast – southwest direction, forming a flat laying and sometimes rise over 100 meters above the surrounding country rocks. The formation is composed of metamorphosed clastic sedimentary rocks, mainly phyllites and mica schist with which metagrwackes, pebbly schist is interlayered. The phyllites are finely laminated which is defined by alternation of quartz-rich and sericite/chlorite-rich layers that vary in width from 0.5 millimeters to 5 millimeters. In thin section the phyllite is composed of quartz, feldspar, muscovite, sericite, and chlorite, iron oxides are present in variable amounts while calcite and epidote are present as disseminated granules. Graphite occurred in the silvery gray phylite. Feldspar is generally untwined as replaced by alteration products of the feldspar type can hardly be determined, but is belived to be albite. Some flakes of brown biotite occurred in some samples (Ajibade, 2008).Mica schist is the common rock type to the south of the belt. The rock is gray, fine- to medium grained and composed of quartz, plagioclase, biotite and muscovite.



1. Migmatite gneiss (pre-Pan-African) 2. Kyanite and sillimanite bearing quatwite.
3. Zungeru Mylonite 4. Kushaka Formation 5. Birnin Gwari Formation
6. Ushama Schist Formation 7. Foliated tonalite 8. Late Pan-Africa granite
9. Cretaceous to Recent Sediments 10. Major Fracture

Figure 2.3: Geological map of the Kusheriki/Minna-Zungeru area (Modified after Ajibade *et al*., 1980).

Garnet and tourmaline are the accessory minerals. The metagraywackes are present as interlayered with the phylites and volcanic rocks. In thin section the metagraywackes matrix is composed of quartz, plagioclase, biotite and muscovite. The pebbly schist was mapped in the Kusheriki area as a wide belt of 6 – 8 kilometers by Truswell and Cope (1963). The pebbly schist extended from Zungeru to Minna region forming a thin belt of 1 – 10 meters wide, the pebbles are strongly deformed into ellipsoidal shape with axes lying in the foliation, or rotated and aligned to form a pebble lineation as observed near Beji railway crossing.

The metavolcanic rocks occurred as layer of varying thickness and are closely related with the metasedimentary rocks in the entire formation. These rocks are fine-grained, dark grey or creamy white, weathered brownish-red and commonly containing megacrysts of quartz and feldspar, some are medium grained and gneissose in outcrops. The contacts between the metavolcanic and metasedimentary are sharp. The apophyses protruding of the metasediments rock suggested their emplacement as sill.

2.3.2.2 Kushaka Schist Formation

The Kushaka Schist Formation is well exposed in the northeastern part of Minna region, intruded by the large volume of granitic rocks which fragmented the belt into small bodies and separated by granite and granodiorites. The migmatization of Kushaka Schist Formation is as a result of emplacement of the granitic rocks. The Kushaka schist Formation formed a sharp contact with the tonalites which often difficult to separate the two rocks. The schist is deeply weathered and displayed a near vertical schistose and folds. The tonalite often occurred as valley adjacent to the schist ridges. The rock types in the formation include metapelites, marble and amphibolite. The metapelites are greenish – grey in fresh sample but weathered to brownish red, and composed of

quartz, feldspar, muscovite, chlorite, biotite and garnet of which muscovite and chlorite are dominate. Marble occurred in Kwakuti as low ridge and low hill they are fine to coarse grained crystalline rocks and are white to creamy in fresh sample, black marble varieties occurred locally. Amphibolite bodies occurred with intercalation of metaphylites forming sheet-like bodies and intrusive pugs or relics of large flows. The amphibolites are fine-grained and banded but a time massive and coarse grained, they consist of hornblende and plagioclase, biotite, epidote and quartze.

2.3.2.3 Ushama Schist Formation

The Ushama schist Formation occurred at the southwestern part of Kushaka Formation and formed the smallest of all schist formations of northwestern Nigeria. In many areas the schist is poorly exposed and few outcrops are extremely weathered. The Ushama schist Formation consist of mica schist, quartz schist, and quartzite with some amphibolites layers. The pelitic rocks are composed of quartz, muscovite, biotite and plagioclase. Occurrence of staurolite in the rocks is an indication of amphibolites facies metamorphic grade. the quartz schist are composed of quartz, which is medium grained and polygonal in texture, plagioclase and biotite occurred as interstitial flakes with strong preferred orientation.

2.3.3 The Pan-African Granitoid (Older Granites)

The term Pan-Africa Granitiod (Older Granite) was introduced by Felconer (1911) to distinguish the deep-seated, often concordant or semi-concordant granites of the basement complex from the high – level, highly discordant tin-bearing granites of Northern Nigerian. 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. They represent a varied and long lasting (750 – 450 Ma) magnatic cycle associated with the Pan – African orogeny. The rocks of this suite range in composition from tonalities 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 anatexis 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 of mineralizing fluids.

The Older Granites are the most obvious manifestation of the Pan-African orogeny and represents 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 suite suggest the coexistence of several magmas. Compositionally, the granites plot in the field of calc-alkaline rocks on the AFM diagram and although they contain significant amount of alkalis, are also often slightly corundum normative. 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 within the schist belts in northwestern and southwestern Nigeria include biotites, biotite muscovite granites, syenites, charnockitic rocks, serpentinites and anorthosites. Rahaman (1988) discarded the earlier classification of members of the Older Granites suite on the basis of their texture, mineralogical 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:

Migmatitic granite; Gneissic granite;Early pegmatites and fine-grained granite;Homogeneous to coarse porphyritic granite; slightly deformed pegmatite aplites and vein quarz; and undeformed pegmatites, two-mica granites and vien quartz.

In northern Nigeria, the abundance of Pan-African granites appears to increase eastward. In the west of Zaria these occur as isolated intrusions (McCurry, 1973). McCurry (1973) working mainly west of Zaria divided the granites into main groups according to their field relationships. The first "syntectonic" group comprised elongate batholithic sheets that are partly concordant, and foliated. The second group "late tectonic" are made up of poorly foliated discordant bodies, rich in mafic xenoliths and having a lower proportion of potash feldspar. The late granites are considered to be the products of widespread remobilization and reactivation of older basement rocks during the Pan-African orogeny.

The Older Granites occur intricately associated with the migmatite-gneiss complex and the schist formations into which they generally intruded. Older Granite rocks therefore occur in most places where rocks of the migmatite – gneiss complex or of the schist belt occur. However, Older Granites are particularly noteworthy in and around Minna, Wusasa (Zaria), Abuja, Bauchi, and Akwanga, areas. In Minna, area the Older Granite account for 40% of the rock types and ranges is porphyritic granite or granodiorite with megacrysts of potash feldspar which ussully form prominent topographic feature as inselbergs and whalebacks. It is often foliated and has variable contact with the relationship with the country rocks.The Older Granite in Minna area

rnges from tonalite, biotite granite and granodiorite, biotite muscovite granite and very coarse and coarsely porphyritic granite and granodiorite (Ajibade 2008).

2.4The Evolution of the NigeriaSchist Belts

The evolution of the Nigeria schist belts has been classified by various works to have been formed through three major processes. Danbatta (1999) suggested ensialic process for the Kazaure schist belt. McCurry (1971) suggested the evolution of the schist through ensialic process. Ajibade and Wright (1989)favoured the evolution of the schist belt through ensimatic processes. Holt (1982) suggested ensialic and ensimatic processes for the evolution of the schist belts. Also, Ogezi (1977) and Bafor (1982) suggested the formation of rift zones where sufficient extension led to the production of a small oceanic basin.

2.4.1 Evolution of Nigeria Schist belt through Ensialic processes

The Nigeria schist belts are attributed largely to a polycyclic re-working of older crust during the Liberian (2700 ± 200 Ma), Eburnian (2000 ± 200 Ma) and Kibaran (1100 ± 200 Ma) orogenies.The schist belts are considered to have evolved mainly by ensialis processes similar to those proposed to explain the Damaran component of the Pan-African belt system (Martin and Meybeck, 1979).The schist belts were thought to be once a wide spread suppercrustal cover rocks deposited in a single basin on the migmatite–gneiss basement and intruded by Older Granite (Russ, 1957; Oyawoye, 1964; Ajibade, 1971; 1976; Grant, 1968; 1978).

Vaniman (1976) proposed the existence of a major Nigeria sedimentary trough to be responsible for the formation of the schist belts, of which the trough is a back-arc basin developed during the Pan-African collision of Dahomea with the Birrimea basements. Also, in the southwestern

Nigeria Olade and Elueze (1979) proposed a marginal basin model to explain the evolution of the Pan-Africa schist belts. Holt (1982), concluded that the schist belts were deposited in a retro-arc basin related to the subduction processes along the margin of the West Africa craton, this he observed the chemical characteristics of island arc and continental environments. Chukwu-Ike (1978) recognized major faults that are related to the schist belts in northwestern Nigeria and concluded that the schist is belts are fault bounded ensialic troughs.

2.4.2 Evolution of Nigeria Schist belt through Ensimatic processes

Turner (1983) and Utke (1987) suggested that the schist belts represent additional micro-continent separated from pre-existing continent. Bafor, (1982) and Shibayan, (1990) used geochemical evidence to suggest that schist belts to have evolved as small oceans. This was presumed to account for the possible existence of a palaeosuture in the northwestern Nigeria basement (Ajibade *et al*., 1979). These workers have suggested that Nigeria basement may represent a mosaic of island arcs, inter arc sedimentary basin and continental fragments.

2.4.3 Evolution of Nigeria Schist belt through Ensialic and Ensimatic processes

A model model for the evolution of some of the northwest Nigeria schist belts have been proposed by Wright (1979) and suggested the closure of small oceans between a series of micro-continents. He concluded that the closure of Maikwonga-Sabo mafic/ultramafic rocks are reminants of a Kibaran (1100 Ma) palaeosuture involving collision between micro-continents.

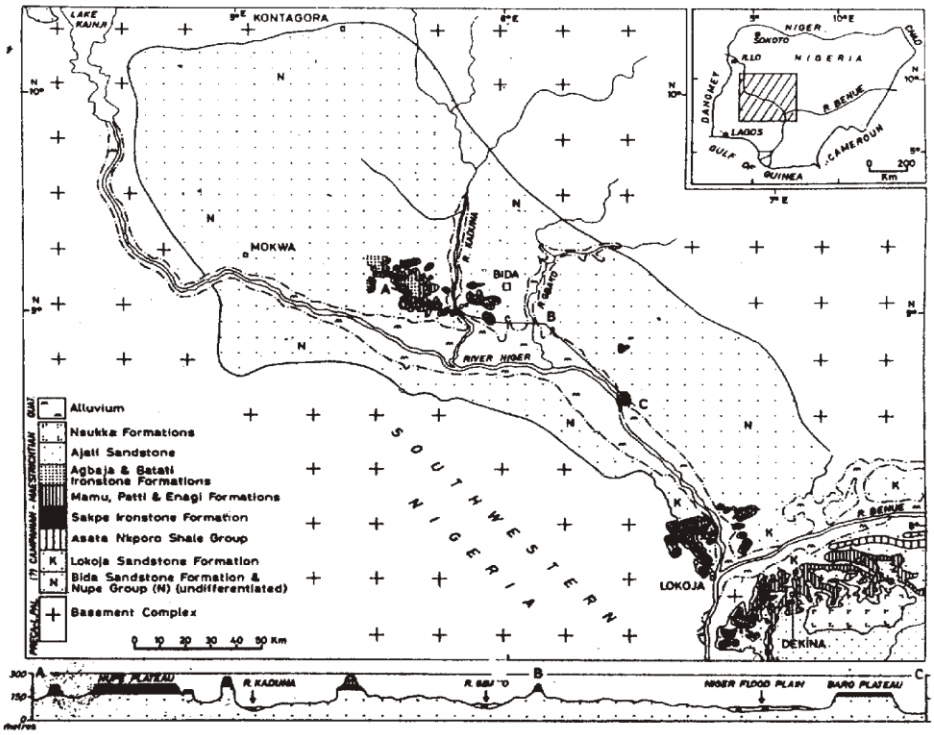
Mafic and Ultramafic rock units that are associated and preserved in the Sabo fault zone have ensimatic affinities (Ajibade *et al*., 1977; Danbatta, 1991), this suggested that any schist belts without this features are considered ensialic basin. Danbatta (1999) proposed the evolution of

Kazaure schist belt throughensialic processes on the migmatite-gniess basement with the protholiths forming the metasediments depositedin a predominantly shelf or deltaic environment that alow deposition of coarse clastic sediments. Furthermore he used a model that considered evolution of the schist belts in the context of Pan-Africa and Eburnean events.

Olade and Elueze (1979), Ogezi (1977) and Ajibade *et al*., (1980) have favored dominantly ensialic processes in the evolution of the schist belts while Ajayi (1980), Rahaman (1981) and Egbuniwe (1982) have stressed that some include oceanic materials with tholelitic affinities.

2.5 Bida Basin

The Bida basin is bounded to the north and south by the Precambrian basement rocks. The largest portion of the basin occurred at the southern half of Niger State, which formed the central portion of the basin that constitutes the study area (Figure 2.4).



Figur 2.4: Geological Map of Bida Basin Northwestern Nigeria (Adeleye, 1989).

2.5.1 Structural Evolution of Bida basin

The Bida basin is a gently down-warped trough trending northwest southeast perpendicular to the main axis of the Benue Trough, and extends from Kontagora in Niger State to Dekina in Kogi State. It covers an area of about 700 square kilometers, the maximum width of the basin in the middle Nigeria is 160 kilometers (Ojo and Ajakaiye, 1989).

Several authors have expressed different view on the genesis of Bida Basin. King (1956) and Kennedy (1964) described the Bida Basin as rift bounded tensional structure produced by faulting associated with the Benue Trough system and the drifting apart of the Africa and Brazilian Plates (Figure 2.5). They noted the possibility that the bounding rift faults of this asymmetrical rift structure may have been obliterated by subsequent erosion. The existence of faults along the margin, have conclusively proven from gravity studies across the basin. However, landsat imagery interpretations as well as other geophysical data across the Bida basin suggested that the basin is bounded by a system of linear NW - SE fault (Kogbe, 1981) which supported a rift model. Gravity data (Ojo and Ajakaiye, 1989) also confirm a central positive anomaly flanked by negative anomalies of rift structures. Whiteman (1982) suggested that the Bida basin was formed from simple cratonic sag, whilst Braide (1992) advance a wrench fault tectonic model for the basin. Kogbe *et al.*, (1981), related the origin of the basin to the isostatic subsidence that have been induced by tectonic activity associated with the Younger Granite emplacement in the Jurassic and to a lesser extent Benue Trough, which resulted in the outflow of material from the lower part of the Niger lineament.Geophysical data (Adeniyi, 1985; 1986) suggested that up to 3.5 kimometers of sediments may have accumulated in the deepest part of the Bida basin.

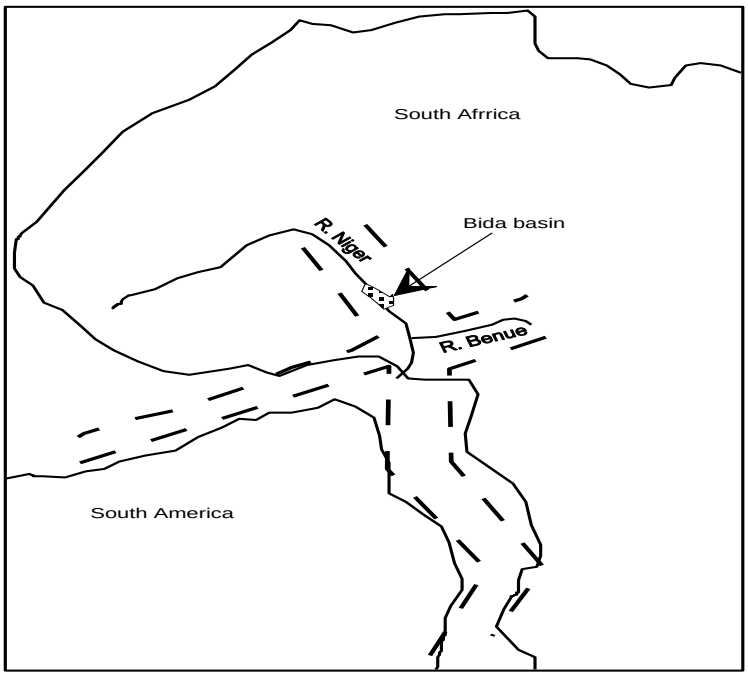


Figure 2.5: Tectonic evolution map of the Bida basin resulting from the extension of the Atlantic rift into the African plate as Cretaceous rift valleys (Modified after Kings's, 1950)

2.5.2 Stratigraphy and sedimentation of Bida basin

The buried Precambrian basement complex is directly overlain by rounded to sub-rounded coarse conglomerates, clay-sand-pebble admixtures and cross- stratified sandstones locally with scattered pebbles, cobbles and boulders. The stratigraphy and sedimentation of the Upper Cretaceous (Campanian – Maastrichtian) succession of the Bida basin have been study and documented by Adeleye and Dessauvagie (1972).The sedimentation of northen Bida basin has been proposed by several workers. Among these workers are Braide (1992b), Adeleye and Dessauvagie (1972), Murat (1972) and Whiteman (1982).In the central part of the basin around Bida, four mapable stratigraphic units are recognizable in the area comprising the Bida Sandstone Formation (including the Doko and Jima members), Sakpe Ironstone, Enagi Siltstone and Batati Ironstone Formations that were correlated withthree stratigraphic units in the southern

Bida basin comprising of the Lokoja Formation, Patti Formation and Agbaja ironstone (Figure. 2.6).

2.5.2.1 Bida sandstone Formation

The Bida sandstone Formation consists of two members, the upper Jima sandstone member with a total thickness of 90 meters and overlies the lower Doko sandstone member with a thickness of 182 meters. The Doko sandstone member consists of arkoses, feldsparthic sandstone and quartz sandstone. Smaller amounts of lithic – feldsparthic sandstone, subgreywackes, sandy siltstone and intra – formational breccias occurs (Adeleye, 1973). Along the Zungeru-Bida road, close to Zungeru, near the northern margin of the basin, coarse grained sandstone and basal conglomerates crop out overlying schist. The conglomerates are quartzitic and range in size from pebbles (2-8centimeters across) to gravel. The pebbles have clay ironstone cement. The basal conglomerate may be part of the Doko member.

Jima sandstone member – The Jima member consists of quartzose sandstone, brownish, massive beds cross-stratified with subsidiary greywacke, siltstone, claystone and breccias. Rapid facies change typifies the member. Leaf impressions are the only trace fossil which have been found and occur mainly in the argillaceous rocks. The age of the Bida Sandstone Formation has been proposed by Adeleye and Dessauvagie (1972) to be late Cretaceous (Campanian-Maastrichtian).

Sedimentological evidence indicates deposition in a braided stream environment for the Doko sandstone member, while Jima member is deposited under lower stream energy than that which prevailed during the deposition of the Doko member, (Whiteman, 1982). The presence of leaves

and ferruginous channel margin deposits is taken to indicate deposition under tropical to subtropical conditions (Adeleye, 1973).

2.5.2.2 Sakpe ironstone Formation

The Sakpe Ironstone Formation is sub-divided into the Baro and Wuya ironstone members (Adeleye, 1973). The Wuya ironstone member consists of oolitic and pisolitic ironstone with small amount of locally developed claystones. The member has a thickness of about 5meters at the type locality.

The Baro ironstone member consists of oolitic ironstone and ferruginous sandstone which are locally pyritic and concretionary. Rapid facies change characterizes the unit and gradation exists between ferruginous and quartzose facies (Adeleye, 1973). The member caps the entire Baro plateau and the thickness varies, attaining a maximum of 3meters. The Baro and Wuya members are considered to be lateral equivalents (Whiteman, 1982).

Fossils found in the Wuya member were Turritella, faunus and a bivalve indent, while the Baro member yielded fossil wood and basal burrows which were identified as Skolithus (Goldring in Adeleye, 1973). The occurrence of faunus is taken by Adeleye (1973) to indicate a Maastrichtian age for the Sakpe ironstone Formation, but Turritella is known to range in Nigeria down into rocks as old as Cenomanian (Reyment, 1965). Adeleye (1973) holds the view that the Sakpe Ironstone Formation was deposited under marine condition in a sea which was not connected with southern Nigeria but with Tethys via a northerly connection situated in the Sokoto area of the Iullemmeden Basin. Whiteman (1982) however holds the view that a more substantial case can be made for a connection with the south in which he believes that the late Campanian sea in which the Nkporo and Araromi marine shale were laid down transgressed into the Bida basin and

that the Sakpe and Batati ironstone formations were probably laid down during this transgression. Whiteman (1982) holds the view that the most that can be said about the age of the Sakpe-Enagi and Batati units is that they are late Cretaceous. This he deduced from the few fossils that were found in the formation and their limited variety.

2.5.2.3 Enagi siltstone Formation

This formation was proposed by Adeleye (1973) to consist of siltstone with subordinate amounts of sandstones, siltstone-sandstone admixtures and claystone. The Formation occurs just below the tops of the major mesas such as the Doko and Nupe plateau. It has a thickness of between 30 – 60 meters. The age is classed as Maastrichtian because of its stratigraphic position between the Sakpe ironstone and Batati ironstone (Adeleye 1973).

Adeleye (1973) suggest a fluviatile environment of deposition which was as a result of the withdrawal of the Tethys north wards. The grain size, lithology, structures and flora, according to him indicate deposition under flood plain condition. He considers the Enagi siltstone Formation to be the lateral equivalent of the Lokoja carbonaceous and shaly sandstone or Patti Formation. However Whiteman (1982) and Murat (1972) believe that the late Campanian deposits were laid down in the Bida basin which was a side basin adjacent to the Anambra Basin. This formation ranges in thickness between 9 meters and 60 meters, and is well exposed below mesas at Enagi and Doko area. Adeleye (1972) suggested continental origin of this formation.

2.5.2.4 Batati ironstone Formation

The Batati Ironstone Formation is subdivided into the Edozhigi ironstone member and the Kutigi ironstone member. Where the two members occur together the Edozhigi member rests uncomformably on the Kutigi member (Adeleye, 1973).

The Edozhigi member consists of goethitic and oolitic ironstone, whereas the Kutigi member consists of mixed goethitic and kaolinitic oolites. The Kutigi member has a maximum thickness of 3 meters, while the Edozhigi member has a maximum thickness of 15 meters. Adeleye (1973) has listed the following fossils from the Batati ironstone formation. *Ostrea, lopha, venericardia, cardidea, faunus beyenburgi, faunus miskalensis, turritella,* and burrows *of Alpheus sp.* This assemblage according to Adeleye (1973) indicates an age not older than Maastrichtian, although these trace fossils are said to range into the Eocene (Whiteman 1982). The assemblage is also taken to indicate a second marine transgression into the central Nupe basin, Adeleye (1973). Murat (1972) and Whiteman (1982) however hold the view that Sakpe and Batati assemblage are Campanian in age; that they were laid down during the late Campanian marine transgression. The authors also believe that the assemblage could also indicate a late Cretaceous age.

Braide (1992) recognized six (6) broad lithofacies from which he interpreted the sedimentary paleoenvironment. The six facies and their reconstructed paleoenvironments are:

(i) Fanglomerate facies interpreted as part of an alluvial fan channel environment.

(ii) A cross-stratified sandstone facies interpreted as a fluvial channel environment

(iii) A siltstone facies interpreted as a flood plain environment.

(iv) A facies of epsilon cross-stratification inferred to represent point bar deposition.

(v) A variegated siltstone facies interpreted as the remnant of extensive pond deposits.

(vi) A facies of organic accumulation interpreted to reflect concentrated vegetal debris.

He concluded that the consanguineous association of the facies demonstrated an ancient meandering fluvial environment developed from alluvial fans and braided fluvial channels in poorly drained flood plains, and sedimentation was in response to syntectonism.

Braide (1992) subdivided the alluvial fans into three lithofacies: proximal, mid-fan, and distal fan facies. The proximal fan facies have poorly sorted massive base-of-slope breccias, conglomerates and pebbly sandstone. The mid-fan facies consists of pebbly sandstone and clast-supported pebble and cobble conglomerate, while the distal fan facies consist of fine sandstone with horizontal planar lamination and ripple cross lamination, Braide 1992 also distinguished flood basin and lacustrine facies in the northern sector of the basin. A coarsening-upward sequence may indicate a possible control on sediment by tectonic activity (Braide 1992).

Okosun *et. al*.(2007) recognized five main interpretative facies within the Bida sandstone outcrops based on the environment of deposition; (i) Alluvial fan (ii) Lacustrine (iii) Fluvial channel (iv) Flood plain and (v) Mire. The Alluvial fan facies comprise of conglomerates, breccias and sandstone; lacustrine facies comprise of siltstones, sandy and silty mudstones; flood plain facies consist of fine grained sandstone, siltstone and mudstone; fluvial channel consists basically of sandstones which are coarse, medium and fine grained; the mire facies comprises brown to black peat and lignite beds interbedded with siltstone and mudstones.

Adeleye (1972) recovered fossils from the ironstone and suggested marine excursion by Tethy Sea responble for marine condition for the oolites. Murat (1972) and Whiteman (1982) suggested the ironston from Sakpe and Batati are of Maastichian.

2.5.2.5 Lokoja Formation

The Lokoja Formation formed part of the basal unit that overlying the basement complex unconformably and is a lateral equivalent of the Bida Sandstone. It is composed of sub-angular to rounded quartz pebbles in a clay matrix.Lithologic units in this formation range from Conglomerates, fine to very coarse-grained Sandstone, siltstones and Claystone. Predominant Sandstone Facies vary from milky to purple in colour and massive to cross-stratified. Generally, they are poorly sorted and composed mainly of quartz and feldspar, thus texturally and mineralogically immature (Ojo, 1992). This formation has been interpreted as continental (alluvial fan) deposite(Braide, 1992)

2.5.2.6 Patti Formation

The Patti Formation is about 70 – 100 meters thick and is well exposed along Abaji Kotonkarfi road cut, overlain the Lokoja Formation. This formation consists of sandstone, Siltstone, Claystone and Shale and is predominantly fine-grained lateral extension of Enagi Siltstone and part of sakpe Ironstone in the central Bida basin. The Sandstone unit of this Formation is more mineralogical and textural mature compared to the Lokoja Formation (Ojo and Akande, 2003).

2.5.2.7Agbaja Ironstone

This the topmost and lateral equivalent of the Batati Formation in the Central Bida basin, overlaying the Patti Formation and formed the lateritic capping for the Campanian –Maastrichian deposits. Three sub-facies of Oolitic, Concretional and Massive Ironstones has been described. Marine influence wave action which re-worked kaolin mud into concentric Oolites often with nuclei of Pyrite or Siderite that have been replaced by iron oxides has been reported by Ladipo *et al*. (1994).

Sedimentation in the Bida basin possibly started in the middle to late Maastrichian time with alluvia fan system and braided alluvial channels which flanked the north – west to south – east faulted- bounded margins of the Basin. The first major marine transgression took place by the early part of the uppermost Maastrichian phase from the south via Anambra Basin. With continued transgression estuarine to shallow marine condition prevailed, accompanied by part of reworking of the Sandstones. At the period of uppermost Maastrichian, the peak of transgression was reached during which very extensive Sandstones and thick Kaolinite beds of the Patti Formation were deposited. The end of Maastrichian phase marked the period of rapid regression (Adeleye, 1989) and formation of the Upper (Batati and Agbaja) Ironstone members.

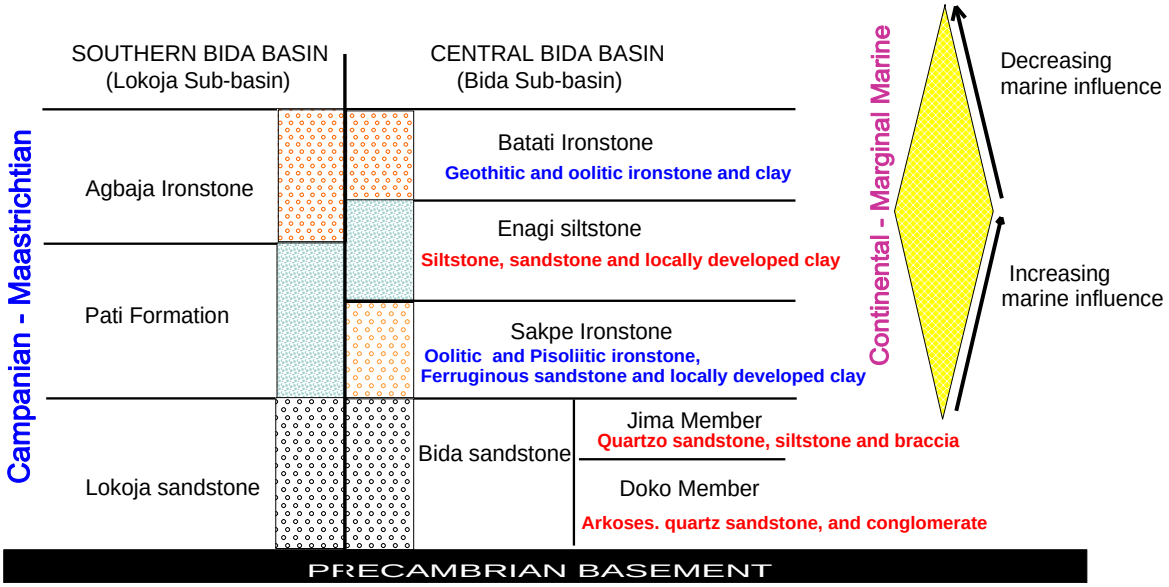


Figure 2.6: Stratigraphy of Bida Basin (Modified after Adeleye*et.al.*,1972 and Obaje, 2009)

CHARPTER THREE: MATERIALS AND METHODS

3.1 Fieldwork

A topographic base map on a scale of 1:200,000 (covering central Bida basin and the adjoining basement complex) was generated for the study area from mosaic topographic maps of Minna, Mokwa, Lafiagi, and Baro on scale 1:250,000. The study area which is about 15,207.5 square kilometers (110 x 138.25 kilometers) was systematically mapped by traverse method. Specific traverse were taken along roads and footpaths, as well as river and stream courses.The field work started in December 2010 and additional visits were made to the area between November, 2011, March, 2012, October, 2013 and January 2014. A Garmin e-Trex Geographical Positioning System (GPS) was used for locating the coordinates of location of the clay occurrences while compass clinometer was used measuring the bearing of clay deposits.

Indicator test and appraisal of the clay occurrences were carried out in the field by gradually adding water to powdered and homogeneously mixed clay soil sample in a plastic beaker. The sample gradually assumes lumps and eventually attained plastic stage at which it was rolled out in long, unbroken thread upon a flat surface of wood. This is to confirm that the material under investigation is clay. Texture characteristics colour and area extent of clay exposures were recorded in field notebook. These tests were employed in quantification of clay in the study area. Also systematic geological mapping of the adjacent basement rocks was carried out between October 2013 and January 2014. During the fieldwork, emphasis was placed on outcrops, rock type and their lithological relationship, and surface structure. Photograph of clay occurrence and basement outcrop were taken using Sony digital camera of 1.5 mega pixels, and each location of clay occurrence and basement outcrop units were recorded on the base map.

3.1.1 Methodology for sampling

Clay samples were obtained from well exposed clay lithologic unit on mesa, while pitting was adopted in grid pattern where there waspoor exposure of clays on plain. Sampling was done at different vertical intervals using a hammer and plastic shovel. Thirty clay samples were collected in the field, stored in cloth sample bags and well label and transported to the laboratory fore analysis. Samples of basement rocks adjoining the central Bida basin were obtained in the field using geological hammer. These rocks were studied in hand specimen for their mineralogical composition, texture, structure, colour and their relationship with other rocks. Twenty fresh representative basement rock samples were collected for identification and laboratory analysis.

3.2 Laboratory Analysis

The analytical methods employed are Inductively Coupled Plasma mass spectrometry (ICP – MS), and X-Ray Fluorescence (XRF) to determine major, trace and rare earth elements.

X-ray Diffraction (XRD)analysis was undertaken in order to determine the mineralogical composition of the clays and basement rocks,while thin section petrographic analysis was also carried out to determine optical character of minerals and textural composition of the basement rocks.

3.2.1 X-ray Diffraction (XRD) Analysis

Ten samples of basement rock and clay were analysed using X-ray Diffraction (XRD) which is based on constructive interference of monochromatic X-rays and a crystalline sample. These X-rays are generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward the sample.

The interaction of the incident rays with the sample produces constructive interference (and a diffracted ray) when conditions satisfy Bragg's Law ($n\lambda=2d \sin \theta$). This law relates the wavelength of electromagnetic radiation to the diffraction angle and the lattice spacing in a crystalline sample. These diffracted X-rays are then detected, processed and counted. By scanning the sample through a range of 2θangles, all possible diffraction directions of the lattice should be attained due to the random orientation of the powdered material. Conversion of the diffraction peaks to d-spacing allows identification of the mineral because each mineral has a set of unique d-spacing. Typically, this is achieved by comparison of d-spacing with standard reference patterns.

The samples collected from the field were pulverized to -75μm, mounted on a glass slide and bombarded with X-rays using the new Empyrean PANalytical machine of D4674 (2011) model, powered by 45KV generator, and tube current of 40KV. The X-rays are diffracted by planes of atoms in the crystal structure and patterns were produced, the diffraction patterns were recorded at scan range of 1-75 degree with a K-alpha 1 and K-alpha 2 radiations. The analysis was carried out in the geochemical laboratory of theActivation Laboratories limited (Actlabs) Ontario, Canada.

3.2.2 X-Ray Fluorescence (XRF Analysis)

Fifteen basement rock samples were analysed for major and trace elements by X-Ray Fluorescence technique this is made possible by the behavior of atoms that constituted mineral phases of the geomaterial, when they interact with radiation. When materials are excited with high-energy, short wavelength radiation (X-rays), they can become ionized. If the energy of the radiation is sufficient to dislodge a tightly-held inner electron, the atom becomes unstable and an

outer electron replaces the missing inner electron. When this happens, energy is released due to the decreased binding energy of the inner electron orbital compared with an outer one. The emitted radiation is of lower energy than the primary incident X-rays and is termed fluorescent radiation. Because the energy of the emitted photon is characteristic of a transition between specific electron orbital in a particular element, the resulting fluorescent X-rays can be used to detect the abundances of elements that are present in the sample.

One gram of pulverized rock samples were mixed with four grams of the flux lithium tetraborate acid and introduced in to the crucible. A bead was produced after heating to about 200^{o}C. The bead was introduced into the sample cup and was carefully placed on the sample charger of EnergyDispersive X-ray Flourescence (EDXRF) machine.

3.2.3 Inductively Coupled Plasma Mass Spectrometer (ICP – MS) analysis

Geochemical characterization of thirty clay samples for major, minor and trace element geochemistry using an ICP mass spectrometer (Perkin-Elmer, Elan 6000) and inductively coupled plasma spectrograph on powdered, pressed pellets prepared from 3 – 5 grams samples. It was digested by weighing 0.2 gram aliquot in a graphite crucible mixed with 1.5 gram $LiBo/LiB_2O_7$flux. The crucibles were placed in an oven and heated at 980^{o} C for 30 minutes. The cooled bead was dissolved in 5% HNO_3 (ACS grade nitric acid diluted in demineralised water). Calibration standards and reagent blanks were added to sample sequentially.

3.2.4 Petrographic Analysis

Fresh sample of basement rocks were observed in hand specimen and classified in the field based on colour, texture, structure and visible mineralogical composition. Thin sections of rock samples from the basement area were prepared in the Geological Laboratory of the Federal University of Technology Minna, Nigeria.

3.2.5 Data Analysis and Interpretation

XRD analysis diffractogram patterns of the clays were perfomed by marching the diffractogram patterns produced with database produce by XPert high score plus which comprises of Joint Committee on Powder Diffraction Standard(JCPDS), and Inorganic Crystal Structure Database (ICSD). The followings were also indentified, Name/Formula, crystallographic systems of the clay minerals found. The data analysis and interpretation was carried out in the geochemical laboratory of theActivation Laboratories limited (Actlabs) Ontario, Canada.

The EnergyDispersive X-ray Flourescence of the analysis were used to determine elemental composition (major and trace elements) of rock samples by comparing absorbance of rock samples and those of artificial standard.

An Inductively Coupled Plasma(ICP) emission spectrograph (Specro Ciros Vision 735) was used for determining major oxides and some trace elements. Loss on ignition (LOI) was determined by measuring the weight loss after heating 1 gram at 95^{o}C for 90 minutes. The precision of REE data were normalized relative to the chondrite values. This was carried out in the geochemical laboratory of the Activation Laboratories limited (Actlabs) Ontario, Canada.

Rock thin sections were studied with the aid of A *Nikon Labophot-Pol* petrographical microscope, and the mineralogical composition of each rock were identified and named on the basis of their optical propertiesunder planepolarized light (relief, pleochroism, cleavage and habit) and cross polarized light (twining,alteration and zoning). Photomicrograph of rock thin sections were taken based on the observed optical properties under plane polarizedlight and cross polarizedlight.

CHAPTER FOUR: RESULTS

4.1 Lithology and Field Relationship

4.1.1 Basement rocks

The basement rocks in the study area (central Bida basin) comprise of migmatitic-gneiss,schist, amphibolites, phyllite and Older Granite. The migmatitic gneiss exposures account for about 5%, schist and phyllite about 40% and Older Granites 55% (Figure 4.1). The migmatitic-gneiss, schist, amphibolites and phyllite trend generally in the NNE – SSW direction, with gentle dip of average 58^0 E.

4.1.1.1 Migmatitic gneiss

Migmatitic gneissoccurs as low lying ridge intruded by pegmatite veins particularly with thicknesses ranging between 10 meters and 22.5 meters.The rock is well exposed along stream channels in Birnin Maza and Minna areas. Generally, the migmatitc gniess display lit-par-lit injection of light grey coloured rock.

The migmatitic gneiss is mostly found in the southeast of the study area, its contact with the granite was observed at Birnin Maza area and were they form sharp contacts.

4.1.1.2 Mica schist, Phyllite and Amphiboleschist

Metasedimentary rocks consist of muscovite schist, biotite schist, amphibole schist and quartz schist. Around Zungeru, the muscovite and biotite schist is in association with the phyllite and quartz schist. The phyllite is exposed around the Zungeru Hyrolo-electric dam site is highly weathered. It is also exposed along Pandogari – Alawa road and Tegina – Makira road. Amphibole and quartz schist are well exposed along the River Kaduna in Zungeru and along River Chanchaga channel in Garatu (Minna- Kateregi road) forming a narrow ridge (Plate I).

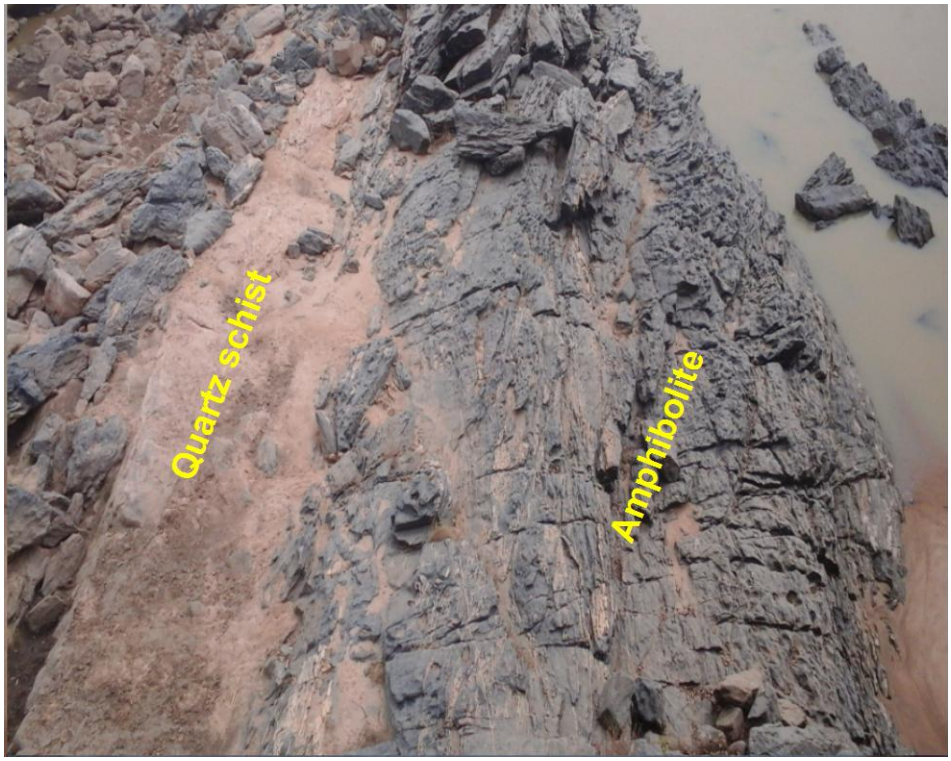


Plate I: Ridge of amphibolite and quartz schist at section along River Kaduna in Zungeru (9^{o} 40'N - 6^{o} 13' 09″E)

The muscovite schist is, highly weathered and poorly exposed at the northwest of Zungeru and well exposed at the northeast of Zungeru.

The biotite schist is well exposed in the study area; it forms gradational contact with the muscovite schist and sharp contact with amphibole schist and the Zungeru mylonite that is considered to be part of Kushaka schist Formation.

The schist is in association with quartzite in some location around Zungeru,showing interlocking texture andgenerally white in colour while the ferruginised varieties show red bands.

4.1.1.4 Pan-African Granitiod (Older Granites)

The Pan-African Granitiod(Older Granite) intruded into the migmatite-gniess and metasedimentary/metavolcanic, it occurred as ridges and inselberg in Minna, Paiko, Birnin Maza and Zungeru areas.They reached average height of 230 meters above mean sea level, and about 30 meters above surrounding country rocks and constitute the major lithology in the study area. The Older Granites have various colours, texture and mineralogical composition with metasedimentary rocks preserved as xenolith in some locations.

The Older Granite in the study area includes: biotite granite, muscovite granite and granodiorite. The Older Granite lithology varies from medium-grained, porphyritic to coarse grained texture.



Plate II: Granite around Paiko Village displaying cross joints (9^{o} 19'N - 6^{o} 37E)

Aplite occur as veins in granite and in some cases in schist with irregular width (5 – 15 centimeters) and can be traced for several meters and more feldspathic in composition. Pegmatite occurred as veins in granite, and schists and migmatite and trends generally in the NE -

SWdirection along foliation planes in schists. Quartz veins are of varying dimensions occuring in all lithological units but are most common in granite occupying fractures and joints.

4.1.2 Geological structures

Geological structures mapped within the basement complex include; joints, faults, folds and veins. Joints ranges from simple joints to complex joints as observed on granitic rock around Paiko (Plate II) and are either open joints (average aperture of 3 centimeters) or healed joints (filled with other minerals).The joint reading obtained in the field (Table 4.1), show principal joint directions within the basement complex have NE – SW and NW – SE directions (Figure 4.1). TheNE – SW direction coincides with the strike of the rocks. The conjugate north-northeast and south-southwest, and north-northwest and south-southeast can be classified as oblique joints, as they cut the strike of the rocks at an acute angle.

Table 4.1: Joints direction values from Basement complex rocks

Joint Direction	F1	Joint Direction	F2	F1+F2	$\frac{F1+F2}{TOTAL}$ X 100
0 – 30	13	181 – 210	11	18	29.21
31 – 60	7	211 – 240	5	10	13.48
61 – 90	3	241 – 270	3	17	6.74
91 – 120	6	271 – 300	6	16	13.48
121 – 150	11	301 – 330	11	22	24.72
151 – 180	6	331 – 360	5	20	12.36
TOTAL		89			100

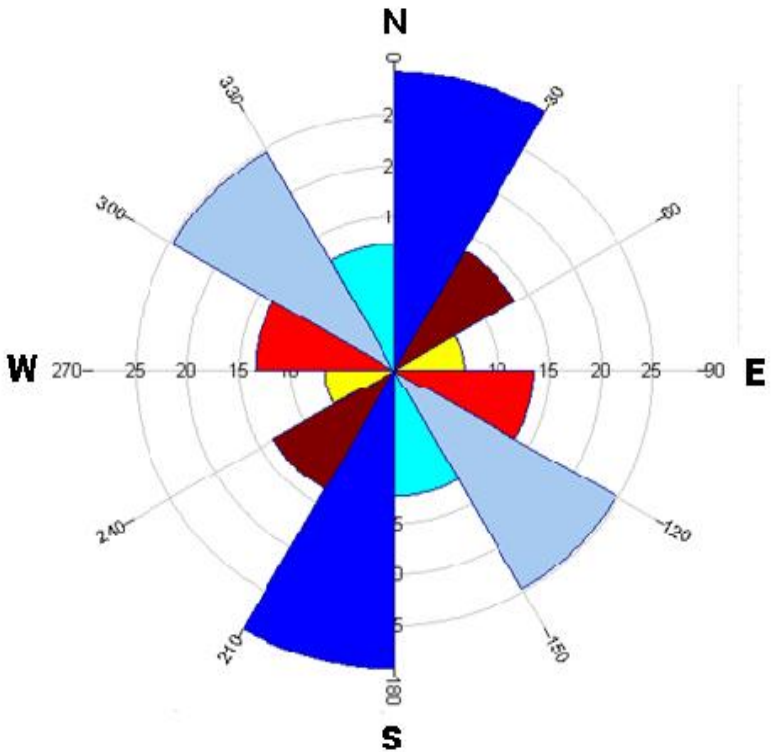


Figure 4.1: Regional trend of joints within the Basement Complex

The mylonitic rocks exposures in Zungeru area representnt a major fault zone that suggested regional intensive shearing of gneiss, schist and quartzitic rocks. Minor faults commonly trend in NE – SW direction (average 60^{o}, 210^{o}). Fault with sinistral displacement is common on granitic-gniess rock, while dextral movement in a NW – SE direction is common on granitic rocks (Plate III).



Plate III: Dextral fault on granitic outcrop in northeast of Minna area (9^{o} 38' 12″N - 6^{o} 34' 06″E)

Symmetric fold are common on the migmatite – gneiss, while the simple folds were found on schist (Plate IV). The schistose rocks that were found to have folds are those around the migmatites.



Plate IV: Asymmetric fold on migmatite-gneiss in Birnin Maza area (9^{o} 40'21″N - 6^{o} 14' 05″E)

Rock and mineral veins ranging from aplite (dyke), quatzo-feldspathic rock, quartz and feldsparof width ranging from 45centimeters to 5 centimeters are common on all rock types mapped in the area. A pegmatite hosting tourmaline was mapped within the schist around Tagwai dam in Minna area.

4.2 Petrography

4.2.1 Migmatitic gneiss

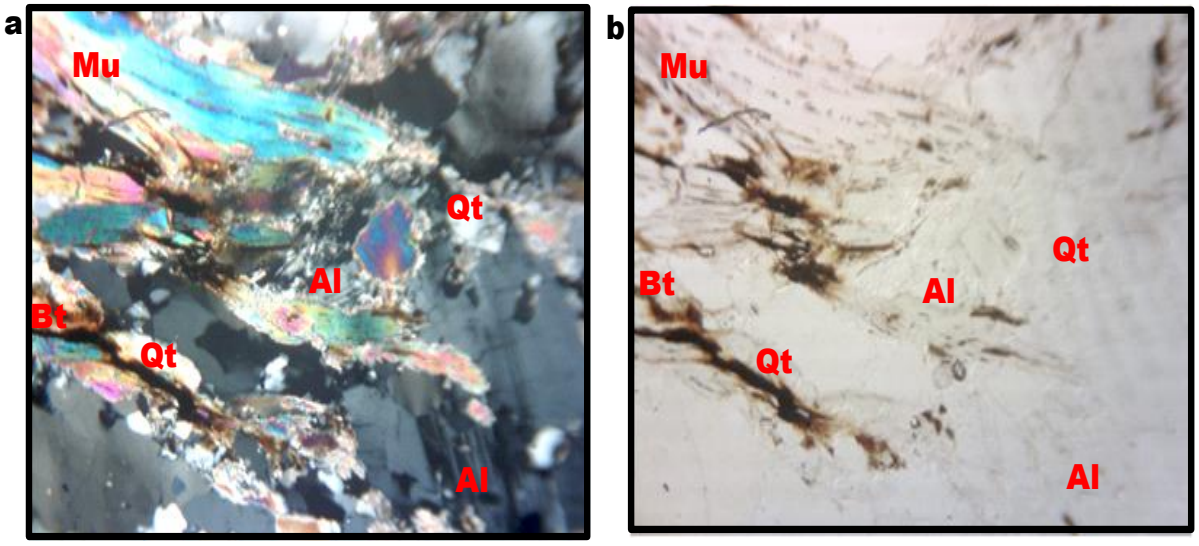
The migmatitic gniess is medium to coarse grained texture, with well developed bandsof coarseto medium grained light minerals (leucosomes) and fine to medium grained dark minerals (melanosomes)that differentiated it from other metamorphic rocks (Plate V).



Plate V: Migmatitic gneiss around Birnin Maza/Lapai area (9^{o} 40'13″N - 6^{o} 24' 15″E)

In thin sections, minerals observed in gneiss includes; biotite, quartz, muscovite, and plagioclase.

The biotite show deep brown to second order brown interference colours with no twining and subhedral habit forming lamellae usually with brown pleochroism in plane polarized light (Plate VIb). In cross polarized light,albiteshowsgrey to colourless colour with albite twining, surrounded by an outer quartz and biotite mineral. Muscovite is colourless. Quartz is colourless with subhedral habit and low relief (Plate VIa).



Qt=quartz Bt=biotite Al= albiteMu=muscovite

Plate VIa: Photomicrograph of migmatitic gneiss in cross polarized light. (10X)
Plate VIb: Photomicrograph of migmatitic gneiss in plane polarized light. (10X)

4.2.2 Metasediments/metavolcanic rocks

Mentasediments and metavolcanic rocks in the study area includebiotite schist, muscovite schist, amphibole schist, quartz schist and phyllite, and amphibolites represent the metavolcanics.Biotite schist and muscovite schist are the most abundant rocks in the study area; it ranges from fine to

medium grained in texture and brown to grey in colour, displaying crenulation cleavage in some areas (Plate VII). Muscovite schist isinterlayered with a thin belt (average 15 centimeters) of amphlbolite in Kundu area (Plate VIIb).Biotite schist is intermediate in colour and fine - medium grained, the strong alignment of the phyllosilicate minerals defines the schistosity of these rocks.

In thin section, the biotite schist is composed of albite, biotite and quartz under cross and plane polarized light (Plate VIIIa and VIIIb). Albite shows faint blue to grey colour with typical lamellar twining also alteration of plagioclase is noticed. Microcline is of first order white with cross-hatched twining and colourless with a trace of cleavage. Biotite displayed stretched structure and altered to chlorite (deep brown colour).

In thin section, the muscovite schist is composed of muscovite, quartz, Albite, biotite andchlorite(Plate IX). Muscovite is pale brown showing slightly pleachroism colour in plane polarized light. Albite iscolourless in plane polarized lightwith low relief, gray in cross polarized light with laminar twinning and faintly cloudy altered to clay mineral. Quartz is white with low relief in plane polarized light. Biotite is brown altered to chlorite.

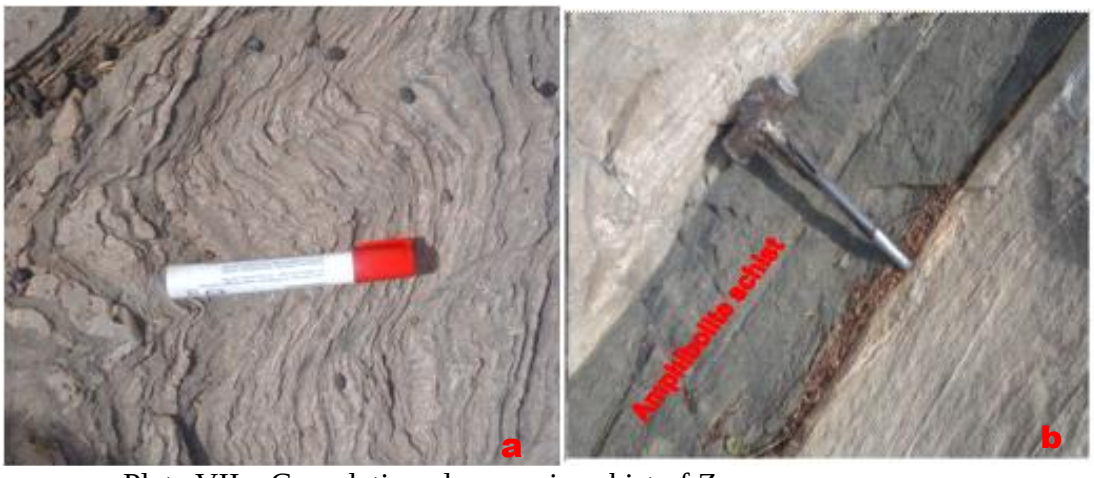
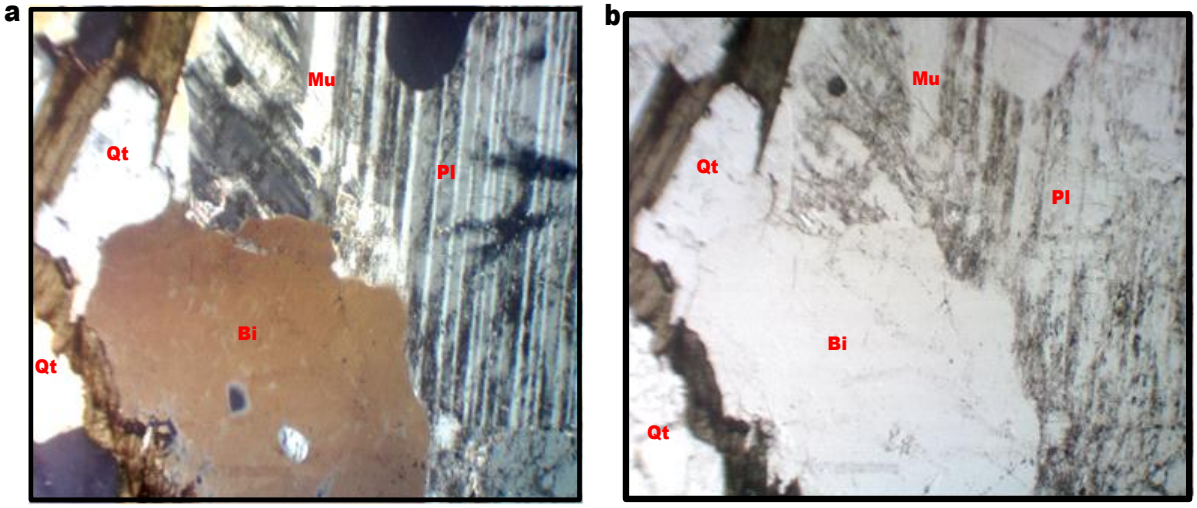


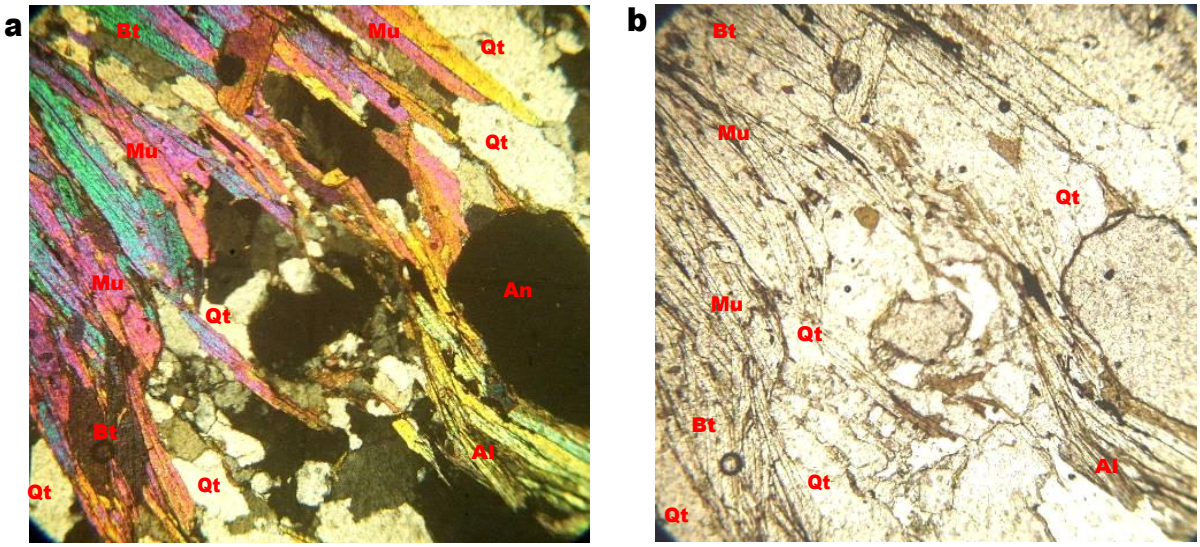
Plate VIIa: Crenulation cleavage in schist of Zungeru area

Plate VIIb: Intruded amphibolite schist trending in Kundu area



Qt=quartz Bt=biotite Pl= plagioclase Mu= muscovite

Plate VIIIa: Photomicrograph of Biotite schist in cross polarized light (10X)
Plate VIIIb: Photomicrograph of Biotite schist in plane polarized light (10X)

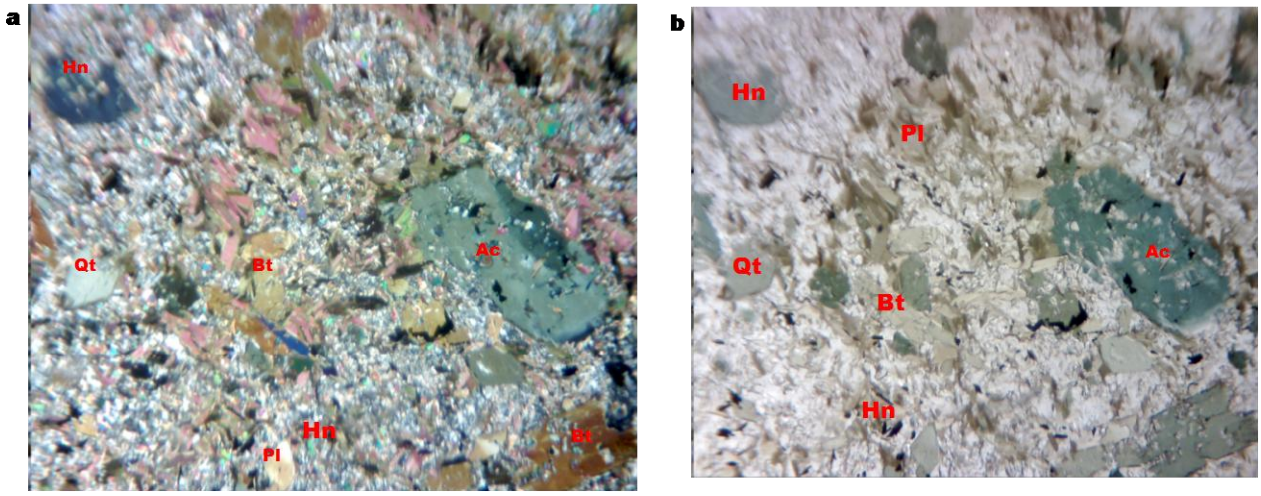


Qt=quartz Mu=muscovite Bt= biotiteAl= albite An= anatase

Plate IXa: Photomicrograph of Muscovite schist in cross polarized light (10X)
Plate IXb: Photomicrograph of Muscovite schist in plane polarized light (10X)

Amphibole schist is associated with mylonite and quartz schist along thechannel of River Kaduna in Zungeru area, with average width of about 5 meters. The rock is fine graine, dark in colour and of two textural varieties; the massive and the schistose amphibole. In some locations the amphibole is interlayered with muscovite schist. Quartz schist is light colour, fine grained and faintly foliated. The quartz schist and amphibolite formed alternate bands along River Kaduna channel in Zungeru (Plate I).

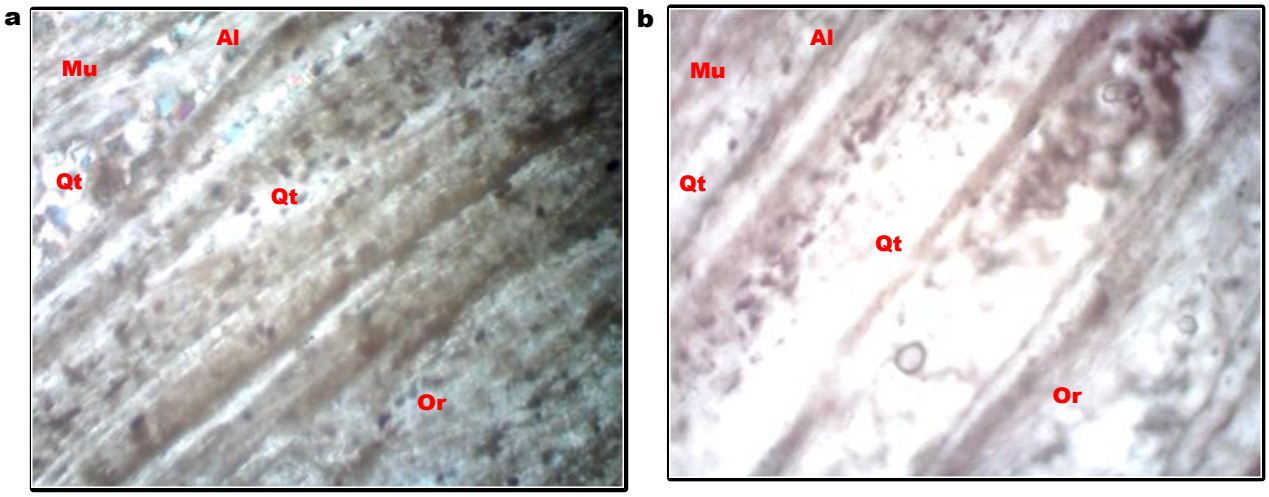
In thin section, the amphibolit is composed of hornblende, plagioclase, biotite, quartz and actinolite. Hornblende is greenish brown colour with simple twining, subhedral habit and positive relief. Plagioclase is yellow coloured and cloudy altered with low positive relief, Epidote is deep blue coloured and occurred as large grain in ground mass of fine minerals. Plagioclase is colourless, subhedral, negative relief and shows granoblastic texture (Plate X).



Bt= biotiteHn= hornblende Qt=quartz Ac= actinolitePl= plagioclase

Plate Xa: Photomicrograph of amphibole schist in cross polarized (10X)
Plate Xb: Photomicrograph of amphibole schist in plane polarized (10X)

Phyllite is silvery grey to green in colour, fine grained, finely laminated and slippery in hand specimen. Thin section observation of phyllite show mineralogical composition of quartz, orthoclase, muscovite and albite. In plane polarized light, albite is grey showing faint albite twining. Quartz shows subhedral habit, first order white,and low relief. Muscovite is milky white with moderate relief(Plate XIb).In crossed polarized light orthoclase is colourless with low relief. Muscovite is colourless showing faint cleavage with anherdral habit. Albite is colouless.The rock show preferred alternation of quartz and feldsparminerals in thin section (Plate XIb).



Qt=quartz Al= albite Or= orthoclaseMu= muscovite

Plate XIa: Photomicrograph of phyllite in cross polarized (10X)
Plate XIb: Photomicrograph of phyllite in plane polarized (10X)

4.2.3 Mylonitic rocks

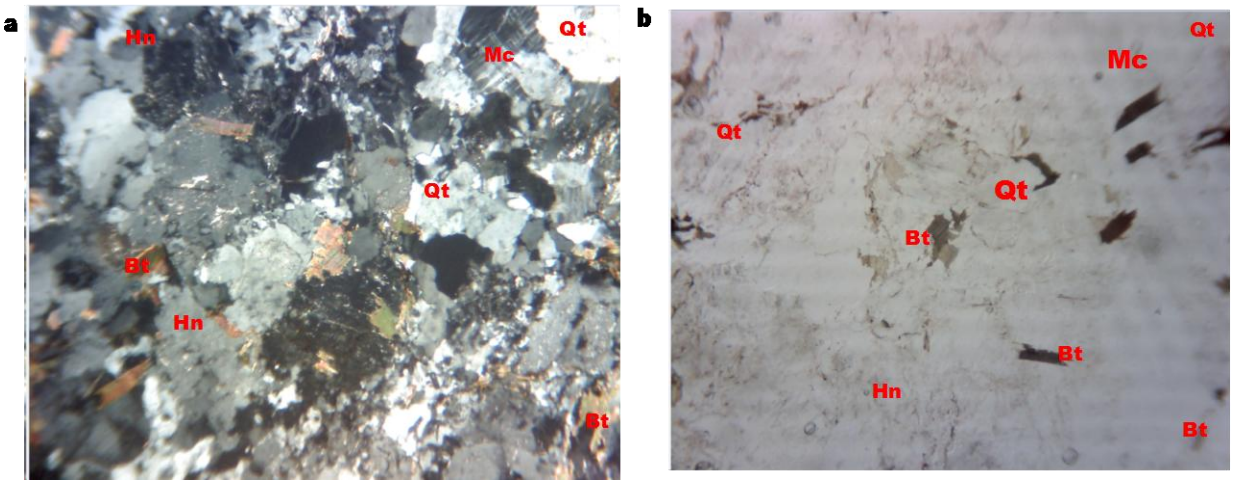
Mylonitic rocks comprises of quartz mica mylonite scist, muscovite schist mylonite and gneiss mylonite. Quartz mylonite is light in colour composing of quartz and feldspar. Muscovite schist mylonite showing flakes of muscovite with well developed foliation plane. Themylonite gneiss

retained it weakly band of light and dark colour. The whole mylonitic rock unit display fine grained texture and cataclasticstructure (Plate XII).

In thin section the mylonitic gneissshows relicts of biotite, quartz, plagioclase, and hornblende minerals. Plagioclase and quartz crystal are in the fine groundmass of microcline, and hornblende. In plane polarized light, biotite has high relief and cleavage in one direction with subhedral character. Hornblende shows pleochroism of light green to pale green in plane polarized light(Plate XIIb). In cross polar, hornblend shows cleavage in two directions with equigranular texture (Plate XIIb).



Plate XII: Exposure of Zungeru mylonitic rock on Zungeru–Tegina Road cut (9^{o} 43'12″ N - 6^{o} 09'16″ E)



Bt= biotiteHn= hornblende Qt=quartz Mc= microcline

Plate XIIIa: Photomicrograph of gneiss mylonite in cross polarized light (10X)
Plate XIIIb: Photomicrograph of gneiss mylonite in plane polarized light (10X)

4.2.4 Older Granites

Three varieties of the Older Granite mapped iin the study area include; (i) muscovite granite, (ii) biotite granite, and (iii) granodiorite.

The medium grain muscovite granite and biotite granites are well exposed in the study area, the muscovite schist around Maikunkele area hasxenoliths ofgranite. In hand specimen the muscovite and biotite granite are composed of quartz, micas and feldspar and ranges from medium to coarse grain texture. Granite exposure display layeredstructure in Beji area, and extend to about 500 meters (Plate XIV).



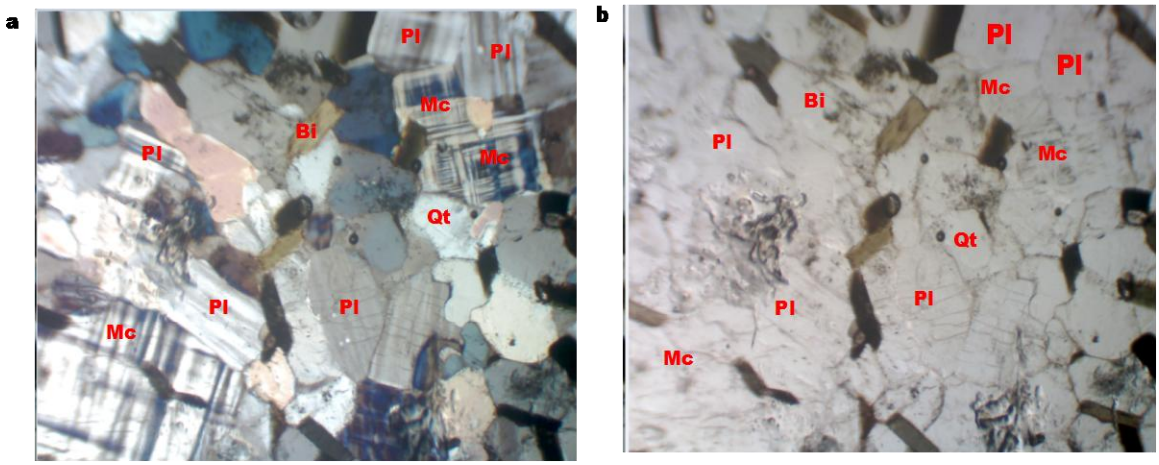
Plate XIV: Coarsed grained granitic rock along Minna – Zungeru roa displaying layered structure (9^{o} 38' 23″N - 6^{o} 15'15″ E)

The coarse feldspar rich granite occurred at Alawa area, Minna areas and along River Mariga. Porphyritic granite has fine to medium ground mass.The phenocryst is pinkish colour feldspar (Plate XV).

Thin section observation of coarse grained granite show that it is composed of biotite, microcline, plagioclase and quartz. In plane polarized light, plagioclase is colourless to gray, low relief with laminar twinning and cloudy, this mineral is subhedral in character. Microcline is colourless to gray in colour with cross-hatched twinning and positive relief in plane polarized light (Plate XVIb).Under cross polarized light biotite is brown coloured with moderate relief and cleavage in one direction (Plate XVIa)..



Plate XV: Porphyritic Biotite Granite outcrop in Paiko village area (9^{o} 19'10″ N - 6^{o} 68'02″ E)



Bt= biotite Mc= microcline Qt=quartz Pl= plagioclase

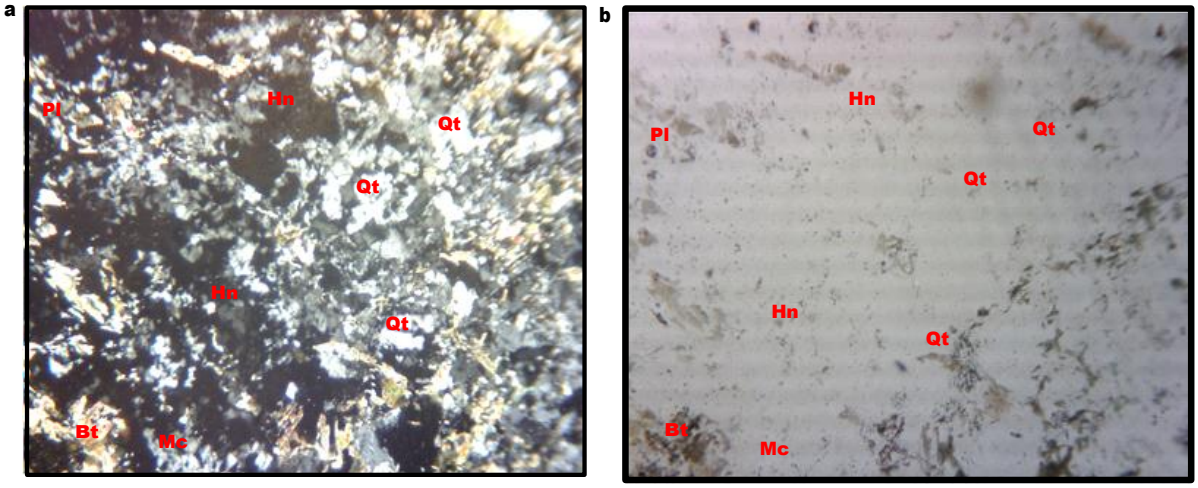
Plate XVIa: Photomicrograph of coarse granite in cross polarized (10X)
Plate XVIb: Photomicrograph of coarse granite in plane polarized (10X)

In thin section granodiorite is composed of plagioclase, hornblende, biotite, microcline and quartz. The plagioclase is colourless, low relief and faint lamellar twining. Hornblende is deep

green coloured and subhedral. Biotite is brown coloured, moderate relief and with cleavage in one direction. Quartz is white to clourless and subhedral crystal (Plate VIII).



Plate XVII: Granodiorite showing xenoliths of leucocratic granite (9^{o} 08'N - 6^{o} 29'E)



Bt= biotiteHn= hornblende Qt=quartz Pl= plagioclase Mc=microcline

Plate XVIIIa: Photomicrograph of granodiorite in cross polarized light (10X)
Plate XVIIIb: Photomicrograph of granodiorite in plane polarized light (10X)

4.2.5Mineralogy of the Basement Rocks

X-ray diffraction analysis result of the basement rocks show percentage mineralogical composition of the migmatitic gneiss and mylonite gneiss iscompose of quartz ranging from28% to 32.5%, actinolite (green fibrous amphibole) 14.8% to 20.6%, albite 27.9% to 38.5%, Biotite 18.5% and cordirite 18.8% in mylonite gneiss.

Biotite schist is composed of 33.1% quartz, 23.9% microcline, 23.4%albite, and 19.2% biotite, while the muscovite schists are composed of quartz ranging from 30.1% to 33.6% Muscovite 18.8% to 26.3% and albite 20.3% to 40.3%. Furthermore,amphibole schist is composed of 25.5% quartz,42.4% actinolite and 33.3% albite.

Granite contains 38.3% quartz, 10.6% biotite, 10.6% muscovite and 20.8% albite. Granodiorite is composed of 38.3% quartz, 27.8% actinolite, 7.8% chalcopyrite and 33.3% albite.

Table 4.2:% Modal composition of Basement Complex rocks

Location	1	2	3	4	5	6	7	8	9	Total
Migmatitic gniess	28	18.5	n.d	n.d	14.8	n.d	n.d	38.5	n.d	99.8
Biotite schist	33.1	19.2	n.d	23.9	n.d	n.d	n.d	23.4	n.d	99.9
Muscovite schist	32.1	n.d	18.8	28.5	n.d	n.d	n.d	20.6	n.d	100
Muscovite schist	33.6	n.d	26.3	n.d	n.d	n.d	n.d	40.3	n.d	100.2
Muscovite schist	30.1	n.d	22.2	n.d	n.d	n.d	n.d	20.3	n.d	99.8
Ampbibolite schist	25	10.3	n.d	n.d	42	n.d	n.d	22.7	n.d	100
Phyllite	24.9	n.d	10.5	23.4	nd	23.1	n.d	n.d	n.d	104
Mylonite gniess	32.5	n.d	n.d	n.d	20.6	n.d	n.d	27.9	18.8	99.8
Phorphyritic granite	38.3	10.6	19.5	10.6	nd	n.d	n.d	20.8	n.d	99.8
Granodiorite	38.3	10.2	n.d	n.d	27.2	n.d	11	13.1	n.d	99.8

1= Quartz 2= Biotite 3= Muscovite 4= Microcline 5= Actinolite 6= Plagioclase
7=Chalcopyrite8=Albite 9=Cordierite nd=not detected

4.3 Sedimentary Rocks

In the study area, eight clay deposts were on isolated hills in Nami, Gubaji, Lemu, Nakama, Batati, Kutigi, and Sapke, while Shegba and Kpaki clay depositswere on floodplain and lowland

area respectively. The clay varies between white and dirty white in colour with occasional reddishprobably due to stain arising from leaching of iron.

The clays are gritty to feel, sticky to figers. The succession in the messas is oftencapped by oolitic ironstone /ferruginised sandstone (Plate XIX).



Plate XIX. Oolitic ironstone in Kutigi area (8^{o} 13' 04″N - 5^{o} 3' 13″E)

4.3.1Clay occurrence in Batati area

4.3.1.1 Batati Section (09°10'05″N - 05°45'05″E)

Along Batati – Danban road, there isexposuredclay bedof about 5 meters thick on an apprioximately 22 meters high hill. The Lithologic section of the deposit isconsisting of massive medium grained sandstone, clay, ferruginized clay and capped by geothitic ironstone (Figure 4.2). The hill is about 9 kilometers to Dabban village off Bida – Batati road.

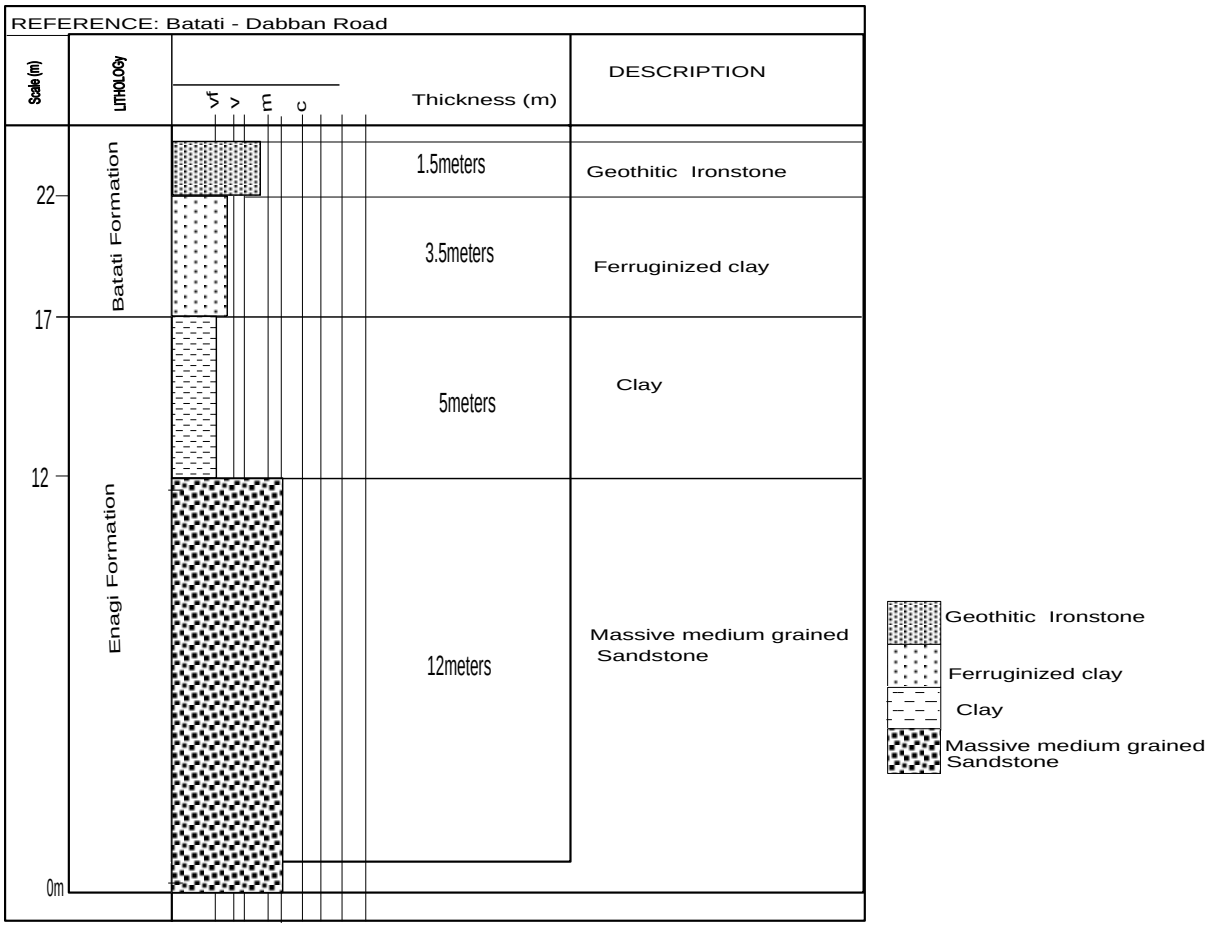


Figure 4.2: Lithologic section at Batati with the clay bed stack between lateritand sandstone(09°10' 05″N - 05°45' 02″E*)*

4.3.1.2 Shegba Section (09°15' 09″N - 05°54' 09″E)

Shegba village is about 20 kilomters north of Batati village, is between Bida and Kutigi on the Bida - Mokwa federal road. Clay occurrence in Shegba is within the alluvial plain of River Kaduna. The clay is grey in colour with some mica flakes and sticky to fingers. Field measurements from dug pits revealed 5 meters thick clay,the clay is presently use for pottery work by the native of Shegba (Figure 4.3). To west of this location is a hill of about 15 meters high consisting of sandstone, lateritic soil and capped by ironstone.

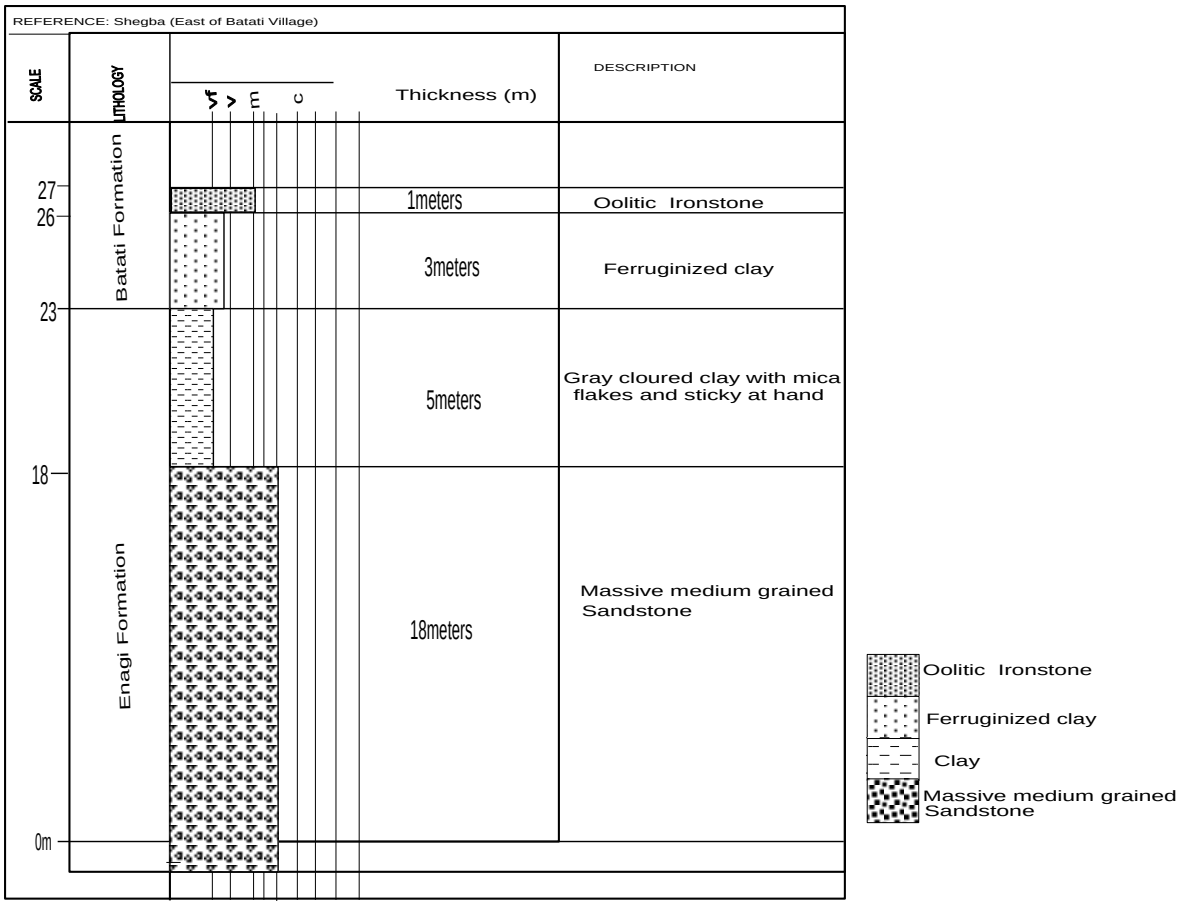


Figure 4.3: Lithologic section at Shegba with the clay bed stack between laterite and sandstone (09°15' 09″N - 05°54' 09″E)

4.3.1.3 Kutigi Sections (09°13'15"N - 05°35' 07" E and 09° 15' 22"N - 05°36' 24"E)

Kutigi town host two hills containing clay, the first occurrence is located on a hill east of Kutigi village. The basal unit of this hill is ferruginous sandstone overlain by lateritic clay. At the top of this unit is exposed clay bed of about7 meters thick, overlain by laterite and capped by thin layer of oolitic ironstone (Figure 4.4a).

The second clay occurrence is to the west of Kutigi town. It consists of clay bed of about6.0 meters capped by laterite and sandstone (Figure 4.4b). The occurrence consists ofmassive medium grained sandstone, laterite with sandstone, clay, ferruginized clay and Oolitic ironstone. Both occurrences are white in colour with red stains of iron minerals, and are about one kilometer apart.

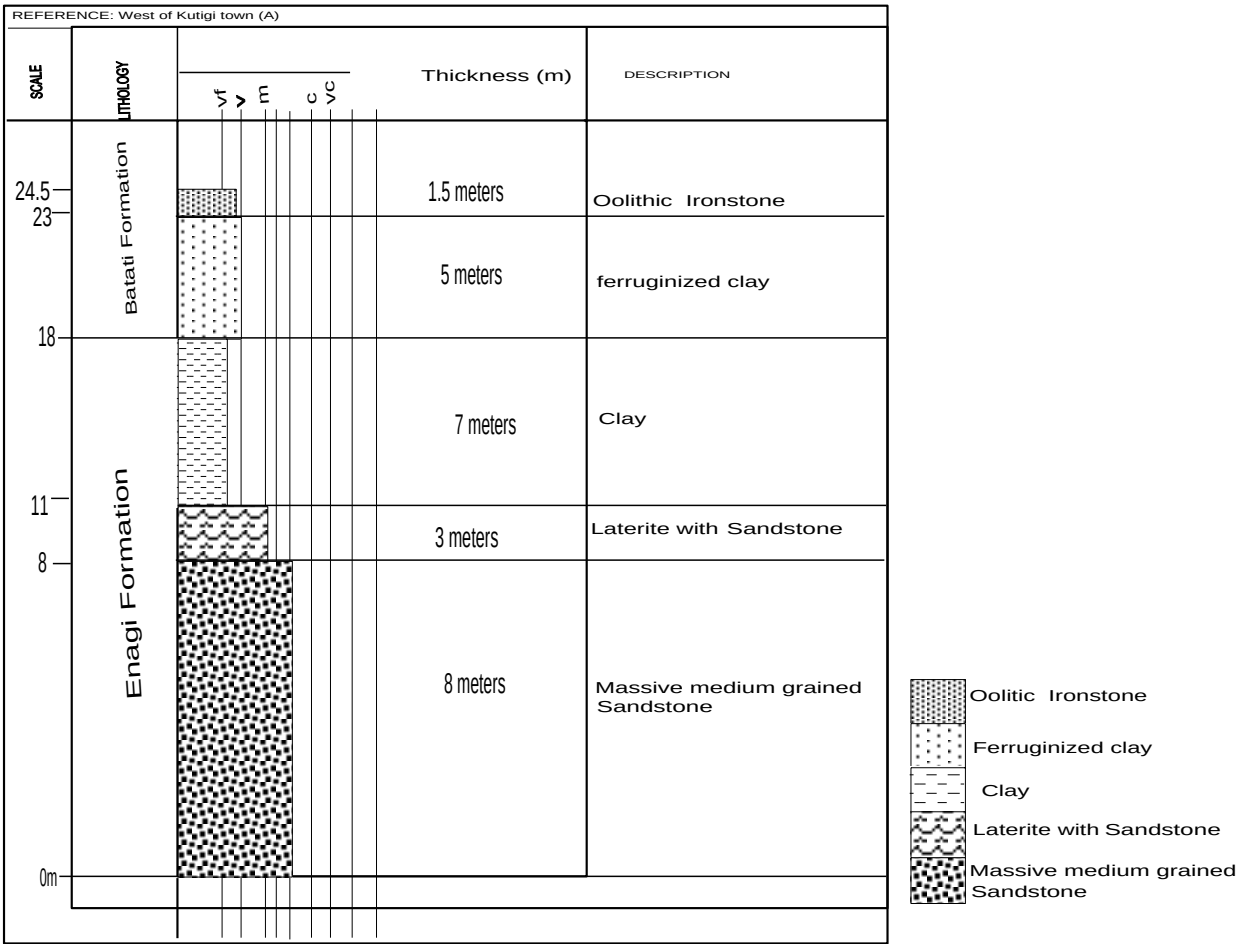


Figure 4.4a: Lithologic sections at Kutigi "A" with the clay bed stack between laterite and sandstone beds (09°13'15″N - 05°35' 07″ E

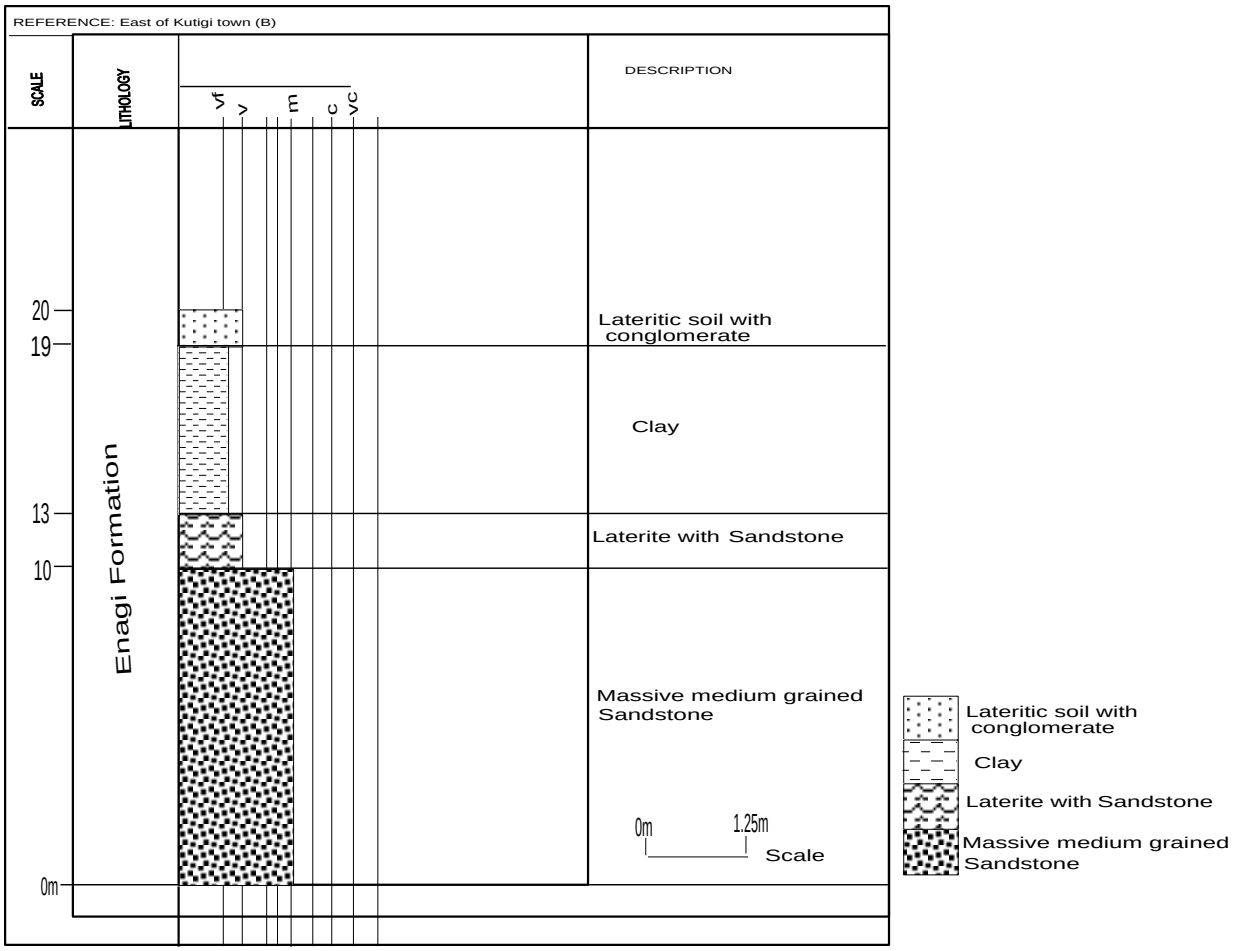


Figure 4.4b: Lithologic sections at Kutigi "B" a with the clay bed stack between laterite and sandstone beds (09° 15' 22″N - 05° 36' 24″E))

4.3.2 Clay occurrence in Enagi area

4.3.2.1 Kpaki Sections (09°20' 09"N - 05°32' 16"E and 09°22' 12"N - 05°32' 22"E)

Two clay deposits occur in Kpaki village.The first clay deposit 'A' is along Kpaki - Kodan road, about one kilometer away from Kapki village. The exposed clay bed is 8 metersthick(Figure 4.5a).

The second clay deposit 'B' is about 2 meters away and to east of the first deposit.The clay measured about 4 meters thick. The Lithologic section of the deposit is consisting ofmassive

medium grained sandstone, clay, ferruginized clay and capped by thin bed of ferruginized sandstone (Figure 4.5b).

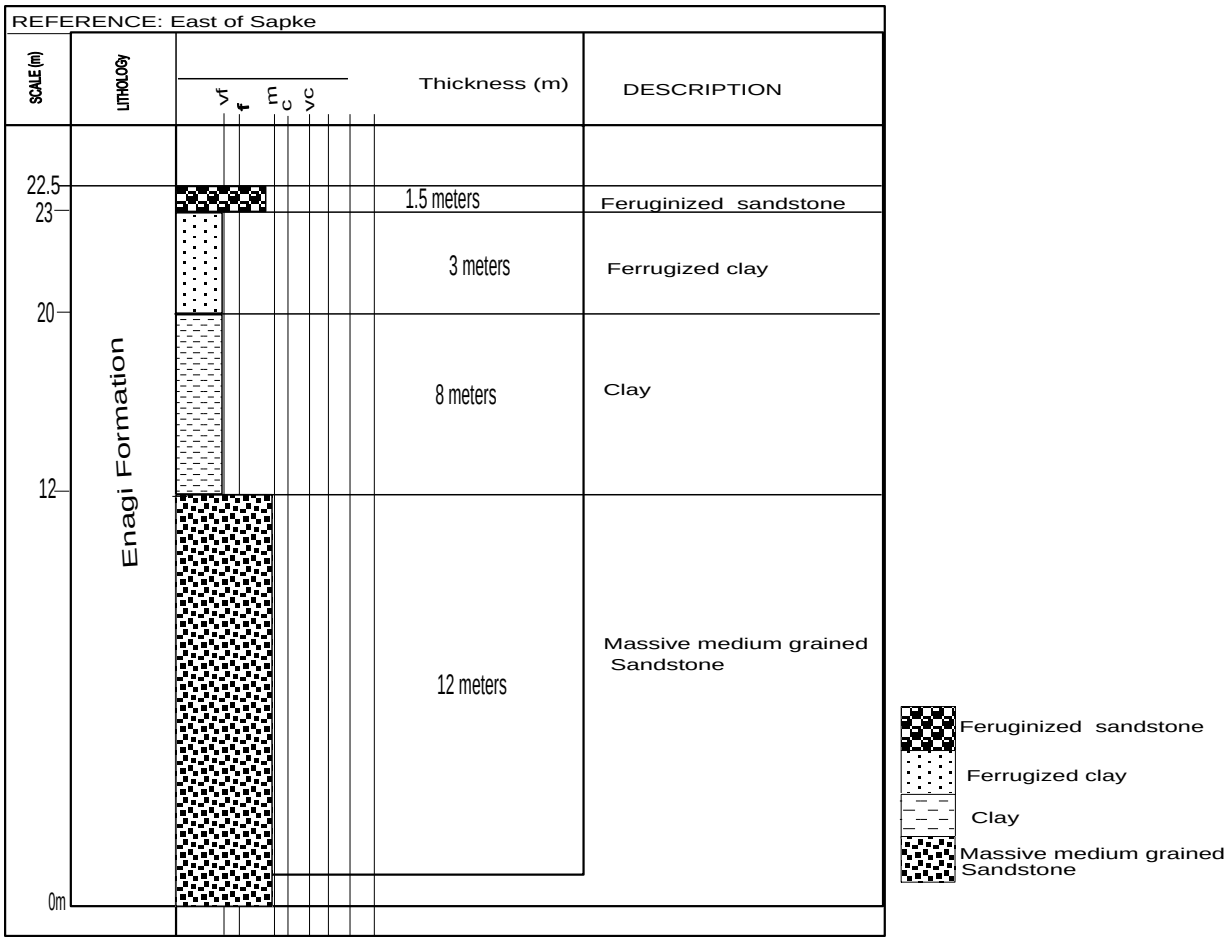


Figure 4.5a: Lithologic sections at Kpaki "A" with the clay bed stack between lateritic clay and sandstone (09°20' 09″N - 05°32' 16″E)

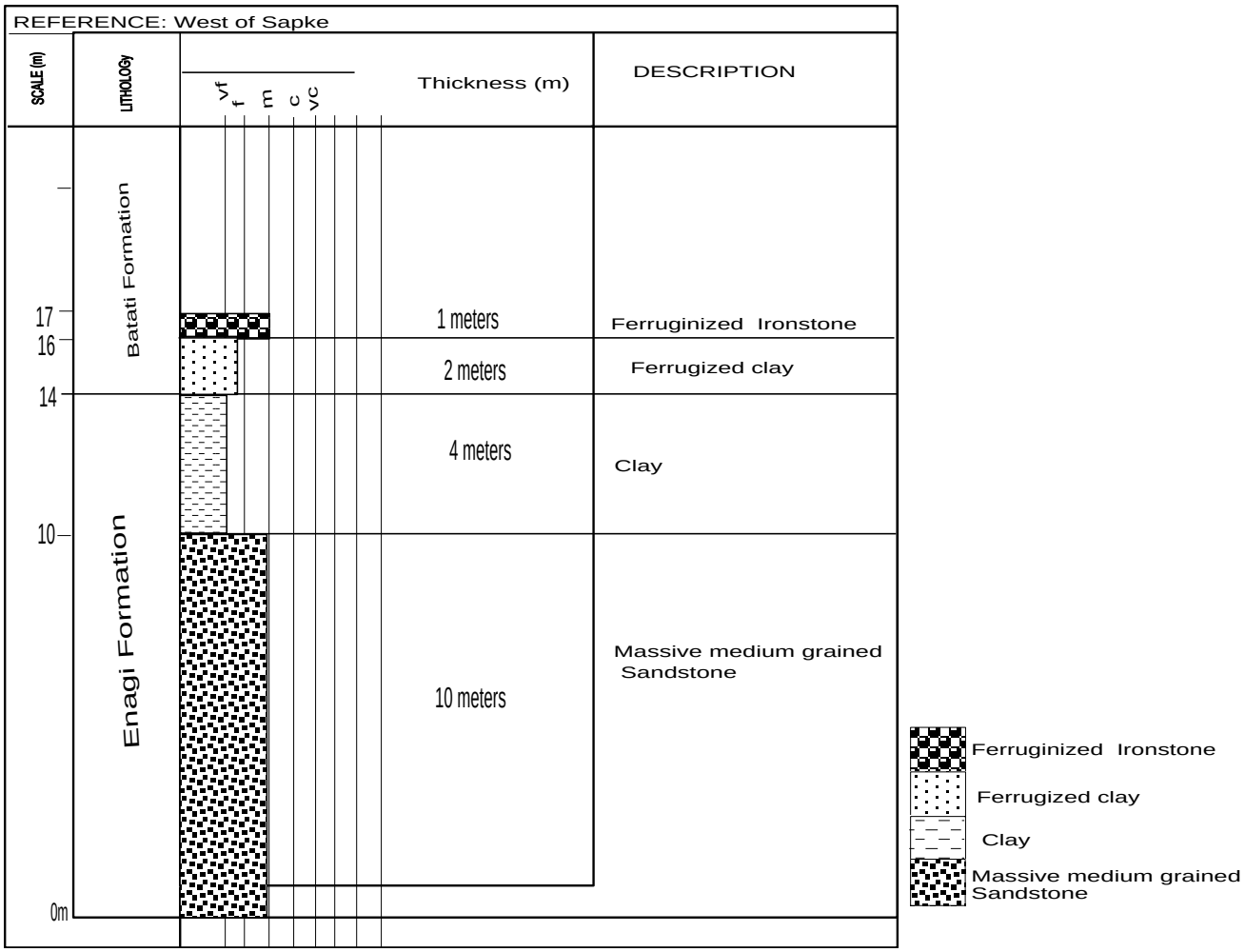


Figure 4.5b: Lithologic sections at Kpaki "B" with the clay bed stack between lateritic clay and sandstone (09°22' 12″N - 05°32' 22″E)

4.3.3 Clay occurrence in Sakpe area

4.3.3.1 Sakpe Section (09°05' 12" N - 05°33' 21" E)

At Sapke, clay occurred in two locations, the first location is to the east of Sapke. Aclay bed is poorly exposed between lithologic sections of massive medium grained sandstone, clay, ferruginized clay and capped by thin bed of ferruginized sandstone.

The second location is to west of Sapke and about 2 kilometers away from the first location. A small clay bed is well exposed on a mesa with lihtoligic section of massive mediumgrained sandstone, laterite and caped by about 1.5 meters siltstone. The clay is of average thickness of 5 meters and area extent of about one square kilometer (Figure 4.6).

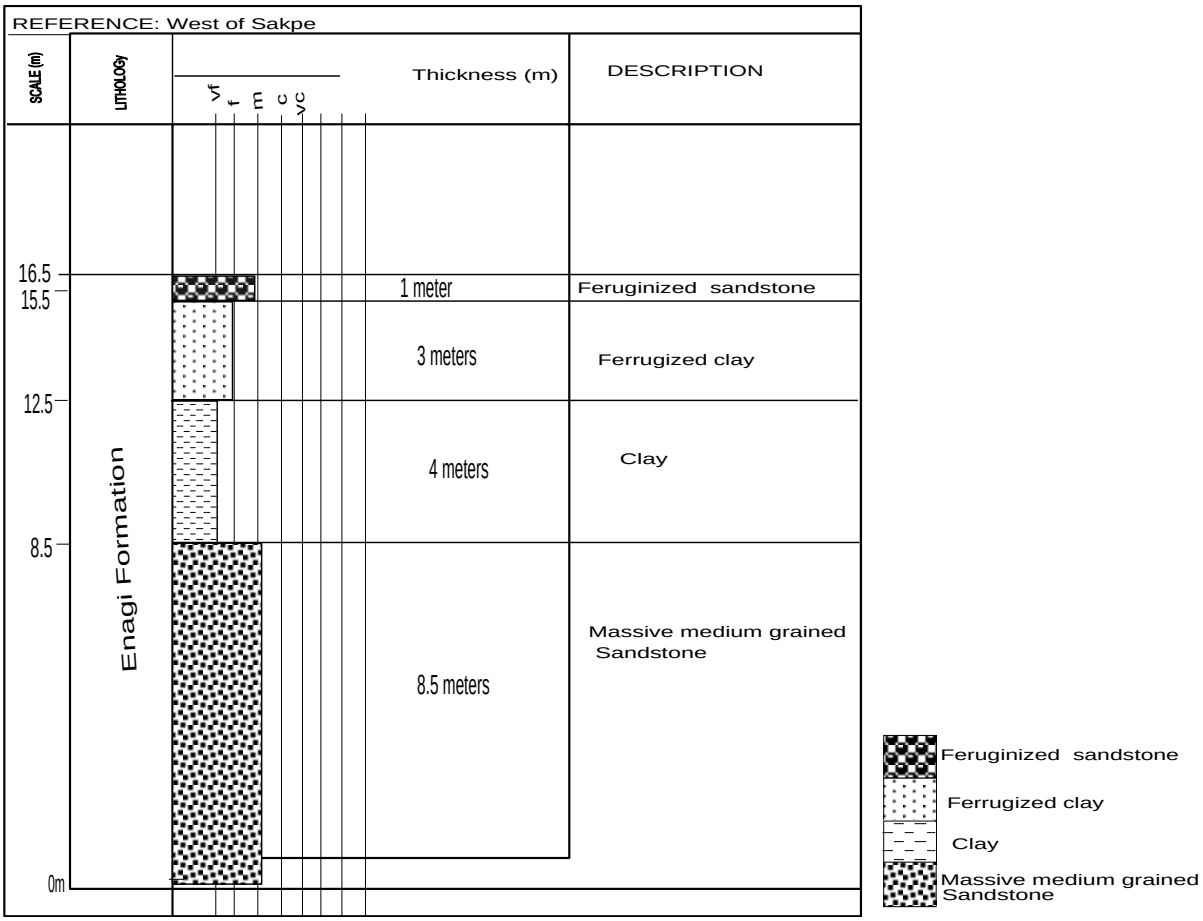


Figure 4.6: Lithologic section at Sakpe with the clay bed stack between laterite and sandstone (09°05' 12″ N - 05°33' 21″ E)

4.3.4 Clay occurrence in Bida area

4.2.4.1 Nami Section (08°40' 13" N - 06°30' 15" E)

Nami hill is about 2 kilometers away from Nami village and 21 meters in height.It extended in northeast southwest direction. This section consists of ferruginised sandstone, clay, silty clay and silt. The clay is dirty white of average exposure thickness of 4 meters (Figure 4.7).

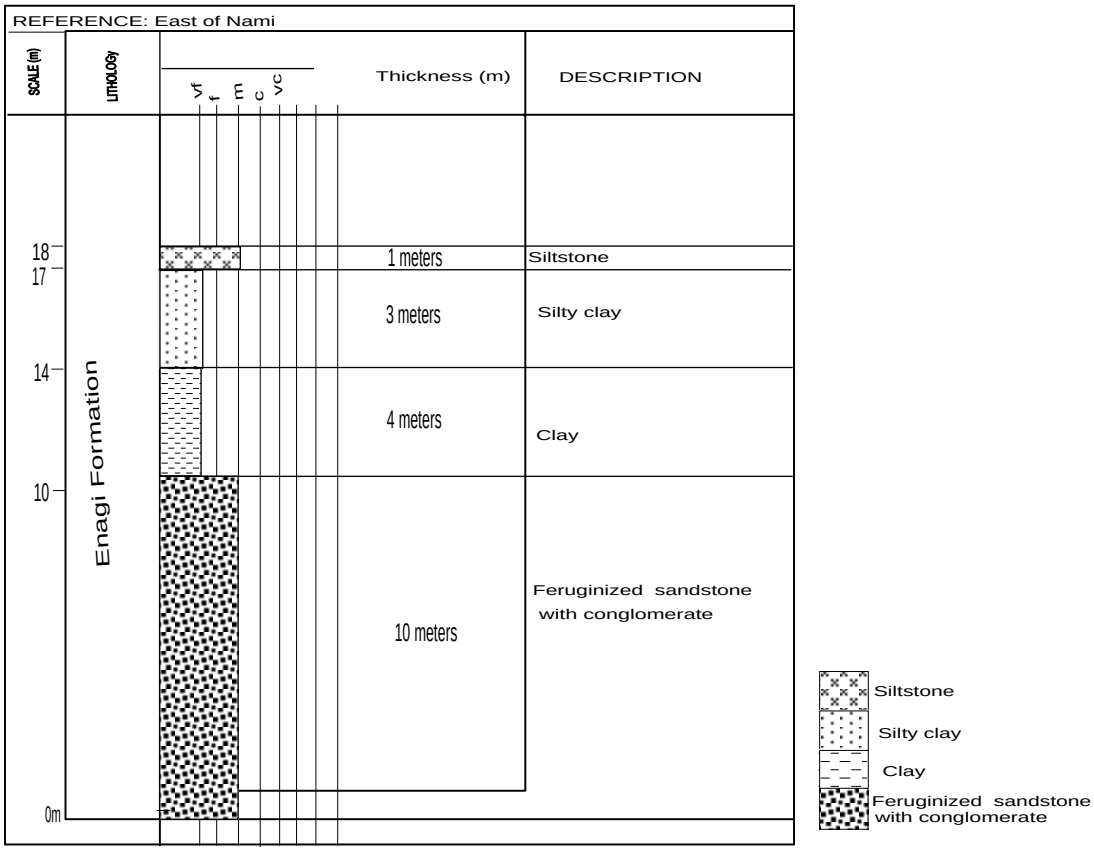


Figure 4.7: Lithologic section at Nami with the clay bed stack between laterite and sandstone (08°40' 13″ N - 06°30' 15″ E)

4.3.4.2 Gubaji Section (08°56' 24" N - 06°10' 19" E)

At Gubaji, a hill about 30 m high near Gubaji village contained a white clay bed at the top of a thick bed of lateritic soil. The lithogic sectionsconsist of massive coarsed grained sandstone, ferruginized sandstone, clay, ferruginized clay and capped by ferruginized (Figure 4.8). Field

measurements from exposed clay body give 5 meters. The hill extended to about one kilometers striking in a NE – SW direction.

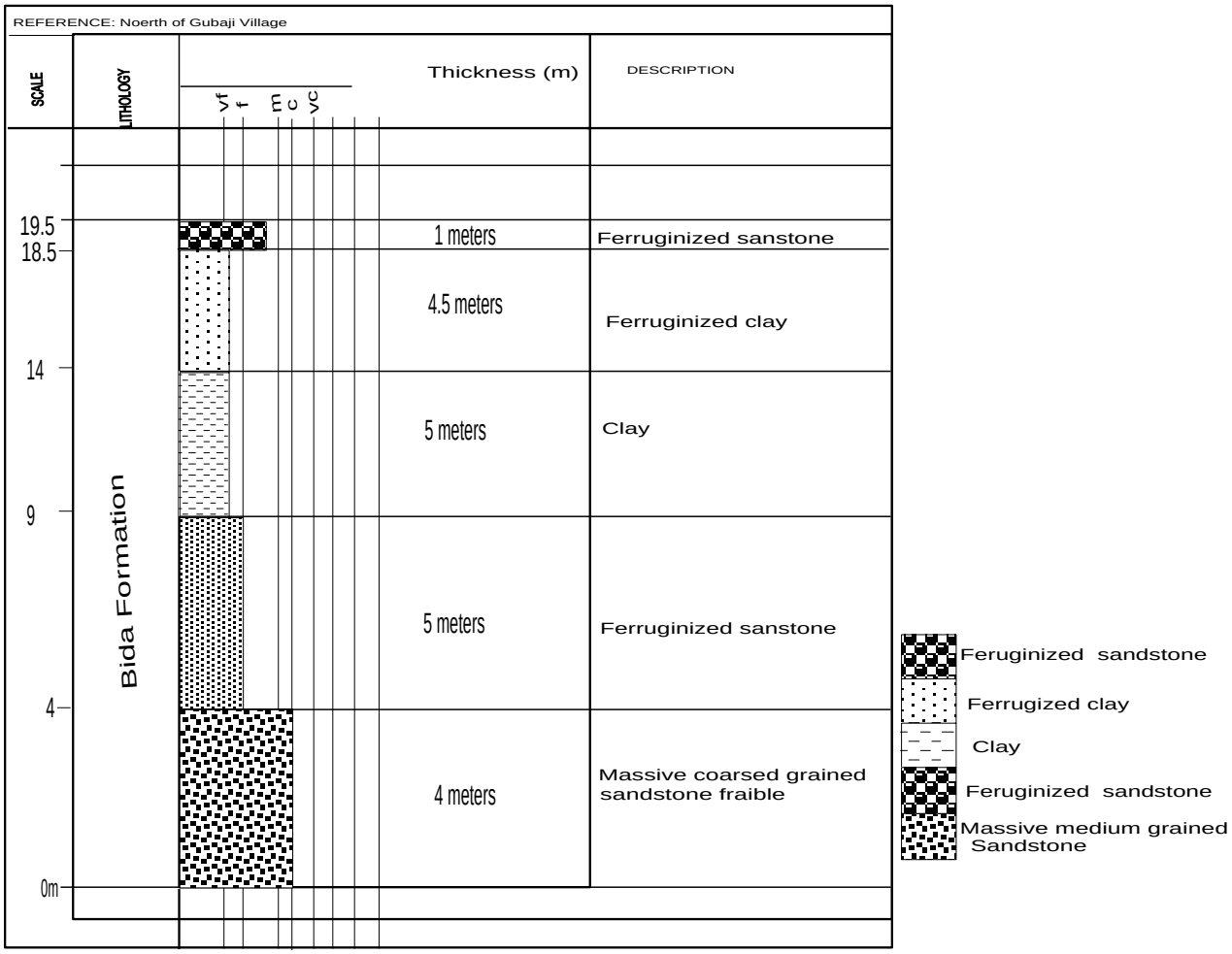


Figure 4.8: Lithologic section at Gubaji with the clay bed stack between lateriticbeds (08°56' 24″ N - 06°10' 19″ E***)***

4.3.4.3 Lemu Section (09°22'17 "N - 06°03'21" E)

Lemu clay occurrence is on a hill east of Lemu town, the hill is underline by coarse grained sandstone, the sandstone is friable and contain matrix of breccias. At the top of the sandstone is

an exposed clay bed of about 4.5 meters, sandy towards the top, followed by lateritic clay and capped by leterite (Figure 4.9).

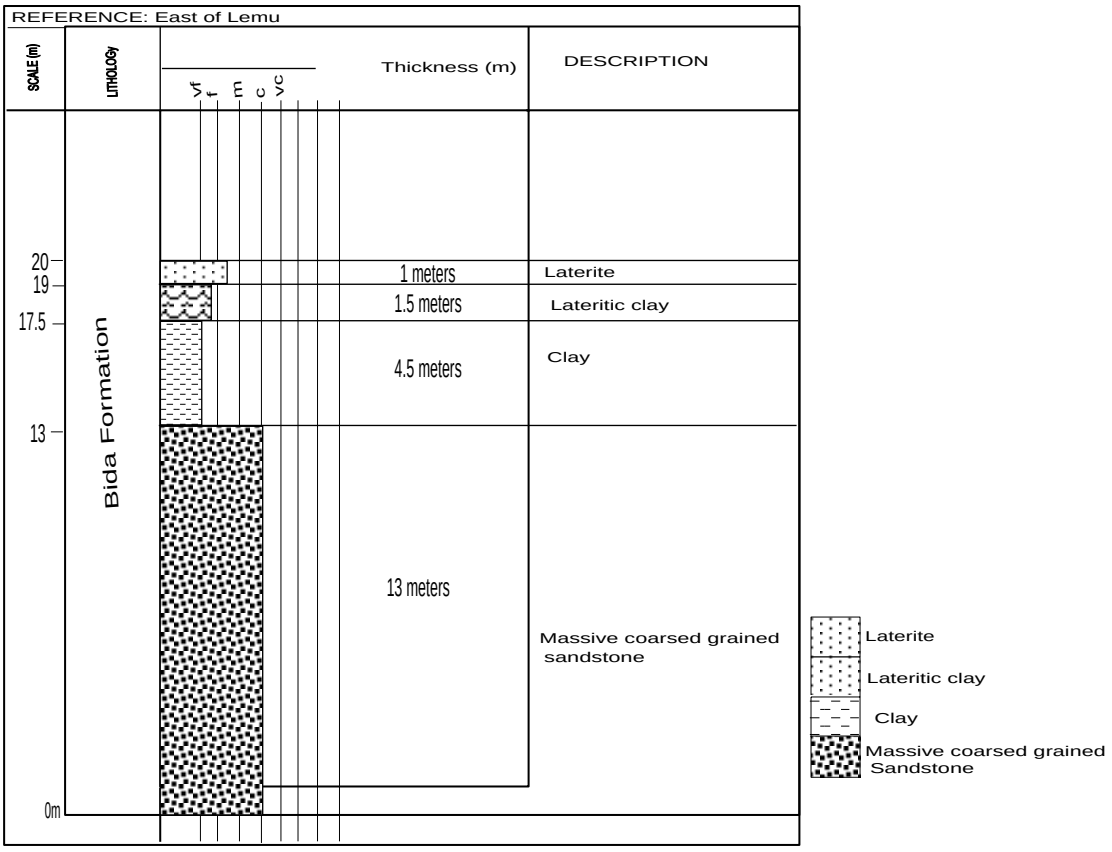


Figure: 4.9: Lithologic section at Lemu with the clay bed stack between lateritic clay and sandstone (09°22'17 ″N - 06°03'21″ E)

4.3.4.4 Nakama Section (09°10' 14" N - 06°04'19" E)

Nakama clay occurrence is to the northeast of Bida town and to the southwest of Lemu clay occurrence. The clay is exposed on a hill of about 25 meters high and350 meters long, on Bida – Lemu road cut. The lithologic sections consist of massive medium grained sandstone, lateritic clay, clay and capped by fine grained sandstone. The clay is white in colour with purple tint(Figure 4.10).

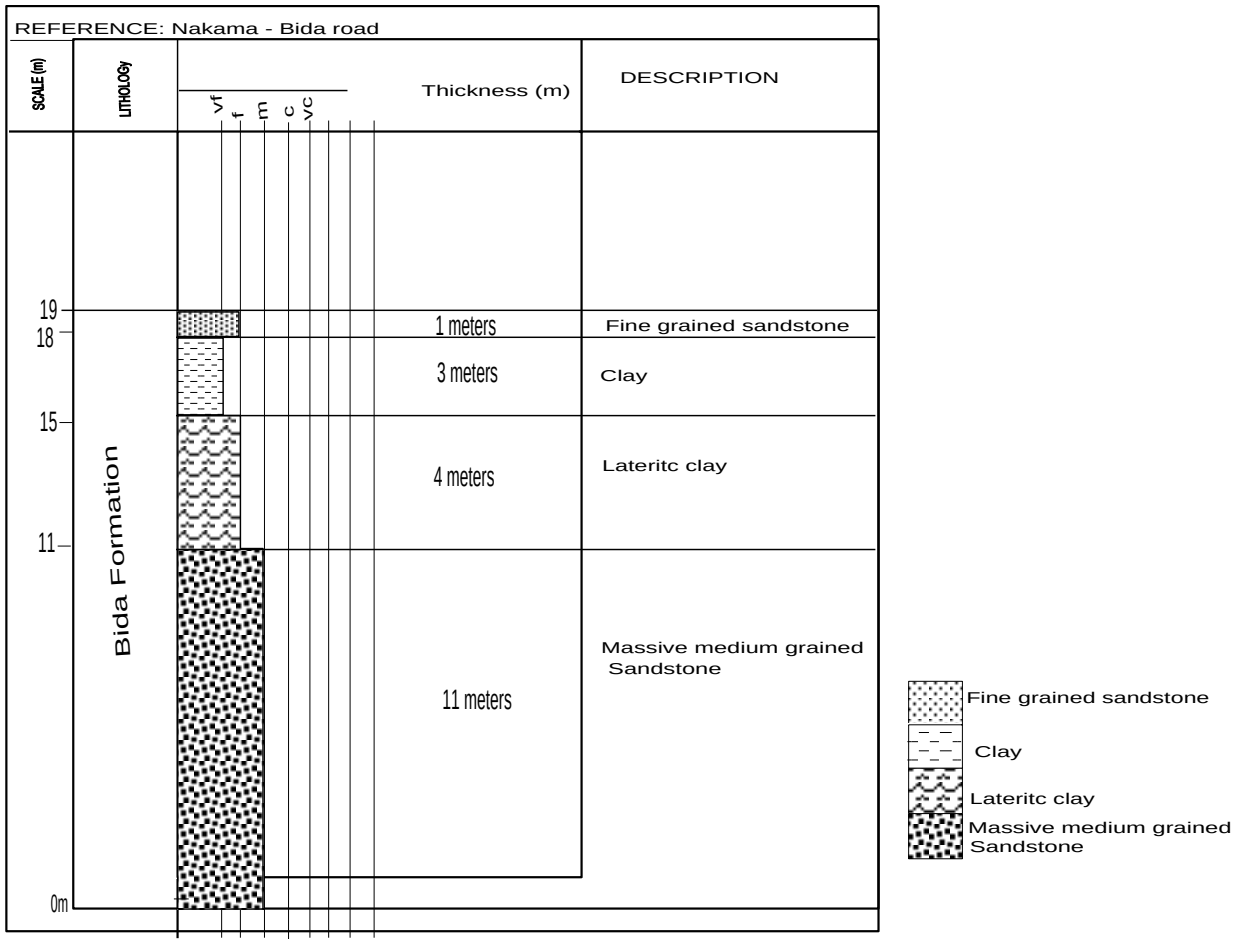


Figure 4.10: Lithologic section at Nakama with the clay bed stack between sandstone and lateritic clay beds (09°10' 14″ N - 06°04'19″ E)

4.4Geochemical compostions

Geochemical composition of the basement rocks and clay are presented in Appendix I, II, III and IV

4.4.1Chemicalcomposition of basement rocks

The major oxide composition of basement rocks is presented in Table 4.3a and 4.3b. The roocks generally have high SiO_2contents, with highest values recorded in gneiss, quartz schist, and mica schist. The SiO_2value ranges from 49.12% to 82.46%, with the lowest value recorded in phyllite and amphibolite. Alumina (Al_2O_3) values range between 11.09% and 17.20%, Fe_2O_3 values range between 0.46% and 14.63%, CaO values ranges between 0.03% and 10.18%, MgO values range between 0.01% and 10.90%, K_2O values range between 0.14% and 6.55%, TiO_2values range from 0.08% to 1.87%. All other oxides Na_2O, MnO, P_2O_5, and Cr_2O_3 have values <5% in all samples. The average SiO_2 (72%) in the gneiss and the granitiod is higher than that of other rock types except for quartz schist (82%). TiO_2 (0.2)and Fe_2O_3 (1.4)averages are lower compared to all other rock types, reflecting felsic character of migmatitic – gneiss and granitoid (except granodiorite).

Generally, there is remarkable enrichment of Rb content in the range of 885.5 to 748.3 ppm compare to the mean average crustal value of 90 ppm except for granodiorite and amphibolites that slightly lower in the range of between 41.8 to 87.1 ppm. There is noticeable depletion ofHigh Field Strength Elements (HFSE) like Hf, Thu, U and Nb. There also depletion of transition elementlikes V and Co while Ni is relatively enriched. Ratio of SiO_2/Al_2O_3 for granitic rocks ranges between 4.70 to 5.28, phyllite 2.56, muscovite schist 3.9, biotite schist 4.2,

migmatitic gneiss and mylonite gneiss between 5.09 to 5.4, amphibolites 4.01 and quartz mica shist 5.56(Table4.4a and b).

Table 4.3a: Percentage major oxide distribution in basement complex rocks

	Granitic rocks						
Oxide (wt %)	Medium grained Granite(# 3) Minimum	Maximum	Average	PorphyriticGranite (# 1)	Granodiorite (# 1)	Phylite (# 1)	Quartz schist (# 1)
SiO_2	73.2	74.01	73.89	71.79	52.93	43.94	82.46
Al_2O_3	13.45	14.50	13.98	15.26	11.09	17.20	14.82
Fe_2O_3	0.46	1.45	0.96	0.82	14.52	11.63	2.03
CaO	0.66	0.75	0.17	1.27	9.03	3.18	0.54
MgO	0.01	0.09	0.05	0.13	10.51	8.90	1.10
Na_2O	3.00	2.79	2.99	3.94	0.34	0.07	1.06
K_2O	6.55	6.44	6.50	5.43	0.14	6.41	1.84
MnO	0.01	0.66	0.04	0.02	0.14	0.22	0.02
TiO_2	0.02	0.08	0.05	0.07	0.68	1.34	0.81
P_2O_5	0.02	0.03	0.03	0.02	0.12	0.04	0.01
Cr_2O_3	0.05	0.05	0.05	0.07	0.06	0.13	0.001
LOI	0.44	0.97	0.71	0.50	6.38	6.09	0.92
SiO_2/Al_2O_3	5.28			4.70	4.77	2.56	5.56

Table 4.3b: Percentage major oxide distribution in basement complex rocks

	Gniess				Schist				
Oxide (wt %)	Migmatitic Gniess (# 2) Minimum	Maximum	Average	Mylonite Gniess (# 1)	Muscovite schist(# 3) Minimum	Maximum	Average	Biotite Schist (# 1)	Aphibolite (# 1)
SiO_2	73.72	74.09	73.91	73.07	57.68	69.94	62.52	59.89	49.12
Al_2O_3	14.50	14.52	14.51	13.56	14.60	17.09	16.27	14.13	12.20
Fe_2O_3	0.46	0.87	0.67	0.76	3.51	8.71	6.81	8.23	14.63
CaO	0.66	1.36	1.01	1.45	0.03	1.58	0.62	0.17	10.18
MgO	0.01	0.11	0.06	0.26	0.94	3.15	1.87	3.95	10.90
Na_2O	3.00	4.183.59		4.65	0.04	3.52	1.25	0.01	2.34
K_2O	3.75	6.555.15		3.56	2.14	4.76	3.45	2.89	6.16
MnO	0.01	0.01	0.01	0.07	0.06	0.38	0.18	0.12	0.13
TiO_2	0.02	0.09	0.06	0.08	0.49	0.98	0.77	1.01	1.87
P_2O_5	0.01	0.020.02		0.07	0.04	0.14	0.08	0.04	0.14
Cr_2O_3	0.05	0.05	0.05	0.07	0.04	0.06	0.05	0.05	0.01
LOI	0.41	0.54	0.48	0.67	0.48	6.38	4.28	6.99	6.09
SiO_2/Al_2O_3	5.09			5.4	3.8			4.2	4.01

(# 1) Number of sample

Table 4.4a: Trace element distribution in basement complex rocks

	Granitic rocks						
	Medium grained Granite (# 3)			Porphyritic Granite	Granodiorite	Phylite	Quartz schist
(ppm)	Minimum	Maximum	Average	(# 1)	(# 1)	(# 1)	(# 1)
Ba	0.04	0.12	0.08	0.15	0.07	0.10	0.06
Be	3.0	1.0	2.0	1.0	1.0	3.0	4.0
Co	2.9	2.6	2.75	3.6	1.6	1.3	3.4
Cs	1.9	4.0	2.95	2.1	22.7	34.7	3.5
Hf	3.0	1.1	2.05	0.3	5.7	3.0	3.4
Nb	17.3	0.5	8.9	1.5	12.3	13.5	5.4
Rb	202.5	136.7	169.6	103.1	57.1	743.8	191.0
Sn	2.0	1.0	1.5	1.0	3.0	6.0	2.0
Sr	67.1	337.4	202.3	440.7	10.4	19.3	97.3
Ta	0.3	1.0	0.2	1.0	0.8	0.4	0.4
Th	26.5	11.2	18.9	8.5	10.8	5.5	7.3
U	10.4	1.0	5.7	0.7	4.9	6.0	0.9
Zr	91.0	31.9	61.5	12.3	830.1	115.6	96.8
Y	77.4	1.9	39.7	3.1	74.5	17.0	6.1
Ni	1104.5	102.7	103.6	105	107.3	293.2	103.8
Ti	0.6	0.6	0.6	0.3	0.6	2.3	1.8
V	8.0	121	64.5	35	155	28.0	141

Table 4.4b: Trace element distribution in basement complex rocks

	Gniess				Schist				
	Migmatitic Gniess (# 2)			Mylonite	Muscovite schist (# 3)			Biotite	Amphibolite
(ppm)	Minimum	Maximum	Average	Gniess (# 1)	Minimum	Maximum	Average	Schist (# 1)	(# 1)
Ba	0.08	0.12	0.1	0.08	0.07	0.11	0.13	0.06	0.11
Be	1.0	2.0	1.5	2.0	1.0	6.0	3.0	2.0	3.0
Co	2.6	3.3	2.95	3.3	8.3	118.5	55.9	23.4	54.4
Cs	4.0	4.4	2.2	4.4	12.5	22.7	18.3	110.4	34.7
Hf	1.1	1.8	1.45	1.8	5.7	5.8	5.75	4.8	3.0
Nb	0.5	2.8	1.65	2.8	11.1	14.5	12.6	12.5	13.5
Rb	88.5	136.7	112.6	88.5	197.1	217.5	211.6	142.3	41.8
Sn	1.0	2.0	1.5	2.0	3.0	4.0	3.5	3.0	6.0
Sr	188.2	337.4	262.8	188.2	110.4	233.0	94.8	19.0	19.3
Ta	1.0	0.6	0.8	0.6	0.7	2.1	1.2	1.2	0.4
Th	11.2	1.9	6.55	11.9	10.8	27.8	16.7	7.8	5.5
U	0.8	1.0	0.9	0.8	2.8	12.6	6.76	4.1	6.0
Zr	31.9	65.9	48.9	65.9	207.2	244.8	277.4	215.9	65.6
Y	1.9	3.7	2.8	3.7	119.0	74.5	41.7	43.1	17.0
Ni	0.6	0.7	0.65	85.6	78.1	107.3	94.9	136.2	293.2
Ti	8.0	121	64.5	0.6	1.0	1.8	1.4	0.7	1.9
V	8.0	<8	<8	0.5	141	214	173	33	0.8

(# 1) Number of sample

Table 4.5a: Rare element distribution in basement complex rocks

REE	Granitic rocks						
	Medium grained Granite (# 3)			Porphyritic Granite	Granodiorite	Phylite	Quartz
(ppm)	Minimum	Maximum	Average	(# 1)	(# 1)	(# 1)	schist (# 1)
La	13.5	33.7	30.4	23.5	54.4	36.2	26.5
Ce	8.3	27.8	22.2	41.2	64.3	110.5	33.8
Pr	1.02	2.73	1.87	4.21	19.21	8.28	6.05
Nd	3.5	9.6	6.55	15.3	88.1	32.9	3.51
Sm	0.69	1.65	1.17	2.08	18.61	5.36	0.79
Eu	0.70	0.51	0.61	0.75	4.25	1.23	2.57
Gd	0.68	1.14	0.91	1.51	15.95	4.57	0.35
Tb	0.12	0.14	0.13	0.17	2.29	0.52	1.54
Dy	0.58	0.75	0.67	0.79	13.30	2.83	0.24
Ho	0.08	0.11	0.09	0.11	2.63	0.54\	0.60
Er	0.23	0.34	0.28	0.17	7.15	1.69	0.07
Tm	0.04	0.05	0.04	0.03	11.08	0.24	0.46
Yb	0.29	0.43	0.36	0.16	7.24	1.54	0.08
Lu	0.03	0.06	0.04	0.01	1.05	0.27	
ΣLREE	62.19			86.29	244.6	193.2	18.74
ΣHREE	3.13			3.7	54.94	13.43	3.46
LREE/ HREE	19.87			23.32	4.452	14.38	54.16
ΣREE	65.32			89.99	299.5	224.9	22.2

Table 4.5b: Rare earth element distribution in basement complex rocks

	Gniess				Schist				
(ppm)	Migmatitic Gniess (# 2)			Mylonite Gniess (# 1)	Muscovite schist (# 3)			Biotite Schist (# 1)	Amphibolite (# 1)
	Minimum	Maximum	Average		Minimum	Maximum	Average		
La	5.0	13.5	9.25	5.0	41.2	54.2	48.8	27.9	36.2
Ce	8.3	27.8	18.1	8.2	64.3	188.3	166	54.0	110.5
Pr	1.02	2.73	1.9	1.05	9.49	19.21	12.9	7.63	8.28
Nd	3.5	9.6	6.55	3.7	36.2	88.1	54.5	34.3	32.9
Sm	0.69	1.65	1.17	0.79	5.96	18.61	10.3	7.13	5.36
Eu	0.51	0.70	0.60	0.75	1.06	4.25	2.21	2.45	1.23
Gd	0.68	1.41	0.91	0.64	4.87	15.95	9.08	7.40	4.57
Tb	0.12	0.14	0.13	0.14	0.62	2.29	1.27	1.04	0.52
Dy	0.58	0.75	0.66	0.78	5.61	13.30	8.17	6.05	2.83
Ho	0.08	0.11	0.09	0.14	0.61	2.63	1.5	1.40	0.54
Er	0.23	0.34	0.28	0.43	1.76	7.15	4.16	3.77	1.69
Tm	0.04	0.05	0.04	0.05	0.27	1.08	0.64	0.54	0.24
Yb	0.29	0.43	0.36	0.45	1.49	7.24	4.12	3.28	1.54
L	0.03	0.06	0.04	0.08	0.22	11.05	0.61	0.53	0.27
ΣLREE	36.97			18.74		292.5		130.9	193.2
ΣHREE	31.1			3.46		31.76		26.46	13.43
LREE/ HREE	1.19			54.16		92.09		4.95	14.38
ΣREE	68.07			22.2		324.3		157.36	206.6

(# 1) Number of samples

The basement rocks are generally enriched in Light Rare Earth Element (LREE) depleted in Heavy Rare Earth Element (HREE) (Table 4.5a and b and Figure 4.16). The sum of Rare Earth Element (REE) for granite and migmatitic gneiss ranges between 65.32 and 89.99 ppm, Mylonite gneiss and quartz schist 22 ppm, mica schist and amphibolites between 157.3 and 324.3 and granodiorite 299.5 ppm.

The plot of SiO_2 versus $Na_2O + K_2O$ show the chemical classification of the granitic basement rocks to be of granite, granodiorite, and monzodiorite (Figure 4.11).

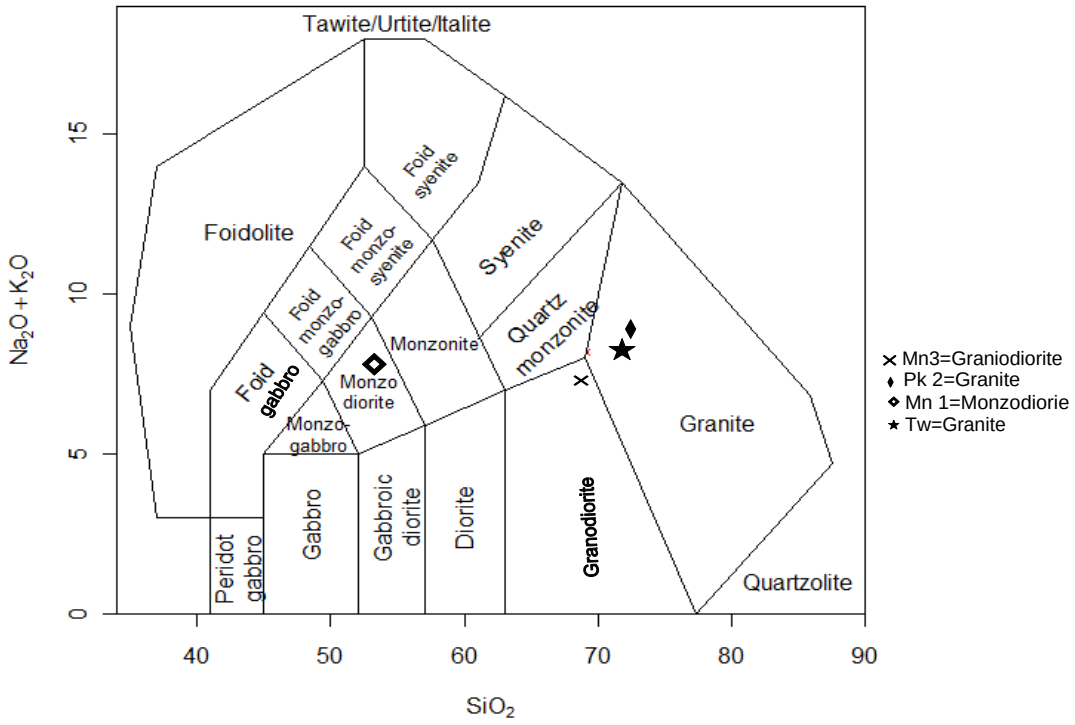


Figure 4.11: Alkali-Silica diagram of the granitiods from the study area (after Cox *et al*., 1979).

On the molar plot A/NK vs A/CNK discriminating diagram, phyllite, muscovite schist, biotite schist and quartz schist plotted within the peraluminous field, and amphibole schist, migmatitic gneiss and mylonite gniess plotted in theperalkaline field. Furthermore granodiorite is within the metaluminous field (Figure 4.12).

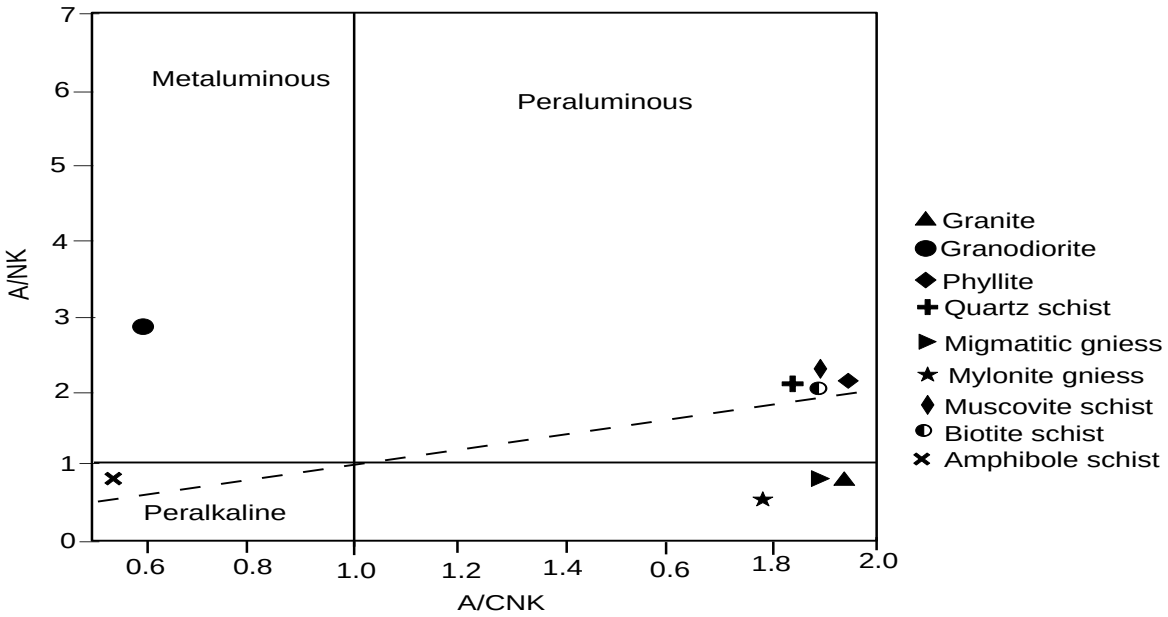
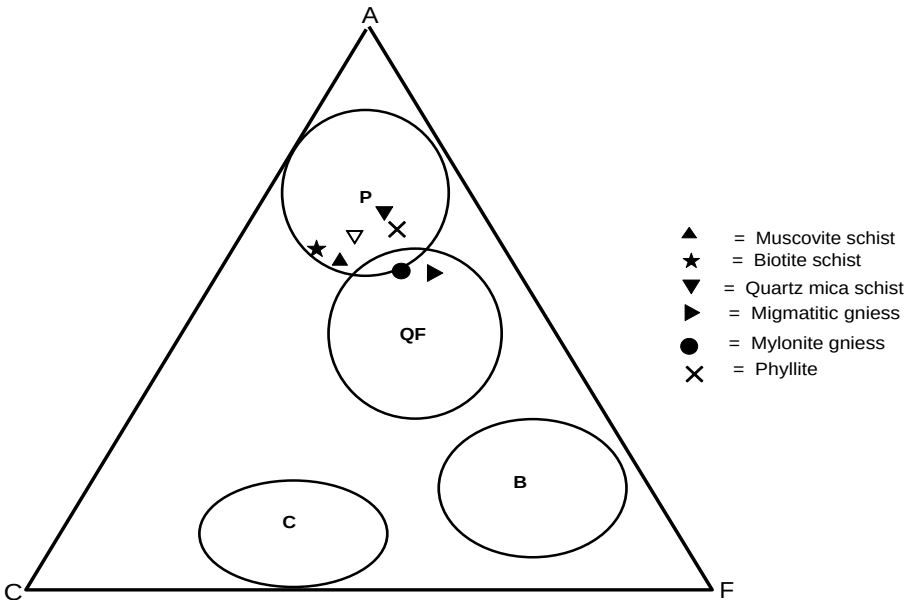


Figure 4.12: A/NK vs A/CNK discriminatingdiagram of basement rocks of the studied area (after Shand, 1943).

Eskola (1915) proposed ACF diagram for the study of metamorphic rocks. The metamorphicrocks in the study area plot in the field of pelitic and quartzo-feldspathic rocks (Figure 4.13)



P = Pellitic rock QF = Quartzofeldspartic rock B = Basic rocks C = Carbonate rocks

Figure 4.13: ACF Plotof metasedimentary and metaigneous rocks from the study area (after Eskola, 1915).

On the diagram for discrimination of metasedimentary and metaigneous rocks (after Layreloup *et al*., 1977), the metamorphic rocks in the study area plot way from igneous field (Figure 4.14). Also, the plot of the composition of metasedimentary versus metaigneous discrimination after De LaRoche (1974), plots of the metamorphic rocks in the study area scattered way from igneous rock suite (Figure 4.15), suggestingmetasedimentary rocks rather than metaigneous rocks.

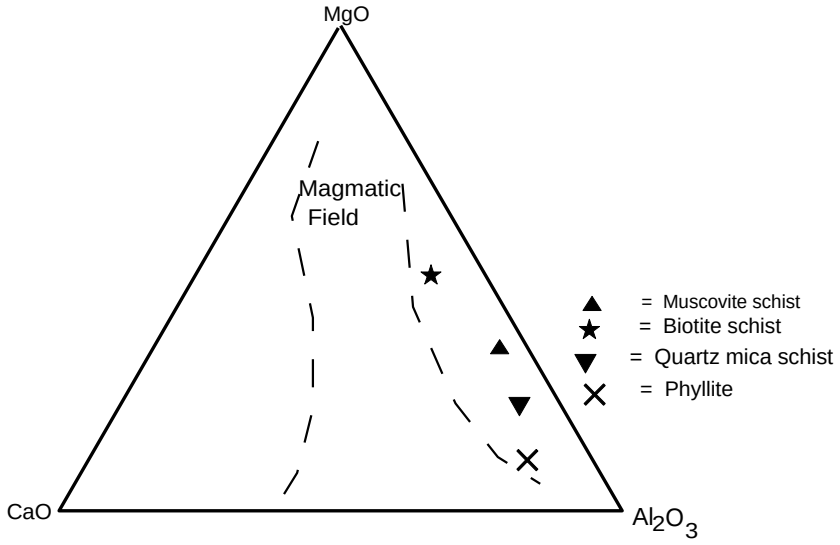


Figure 4.14: MgO – CaO - Al_2O_3diagram for the discrimination of metasedimentary and metaigneous rocks from the study area(after Leyreloup *et al*., 1977).

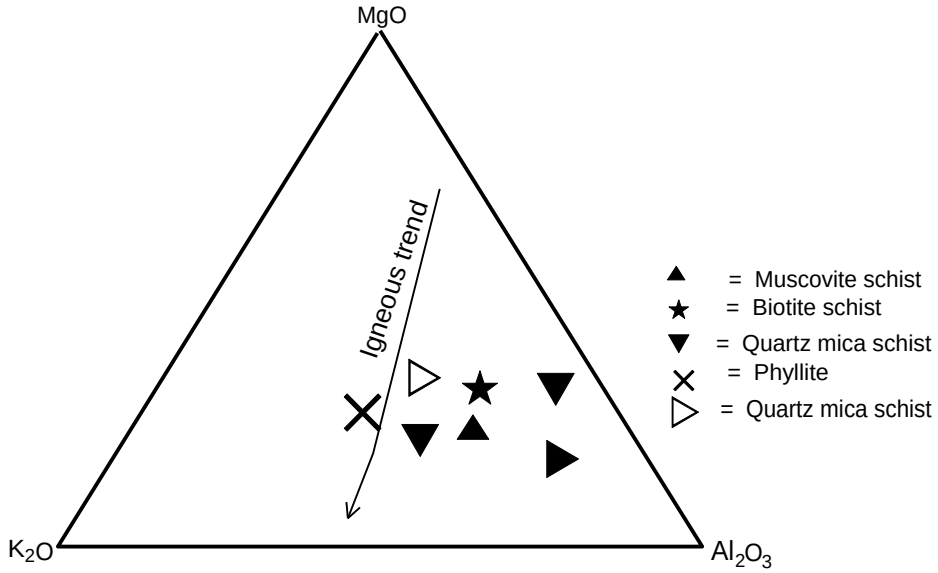


Figure 4.15: MgO – K_2O - Al_2O_3diagram for the distinction of metasedimentary and metaigneous rocks from the study area (after De LaRoche, 1974).

The chondorite normalized REE pattern for basement rocks generally show typical light REE (LREE) enrichment, moderattely negative Eu anomalies and heavy-REE moderately depleted (Figure 4.16).

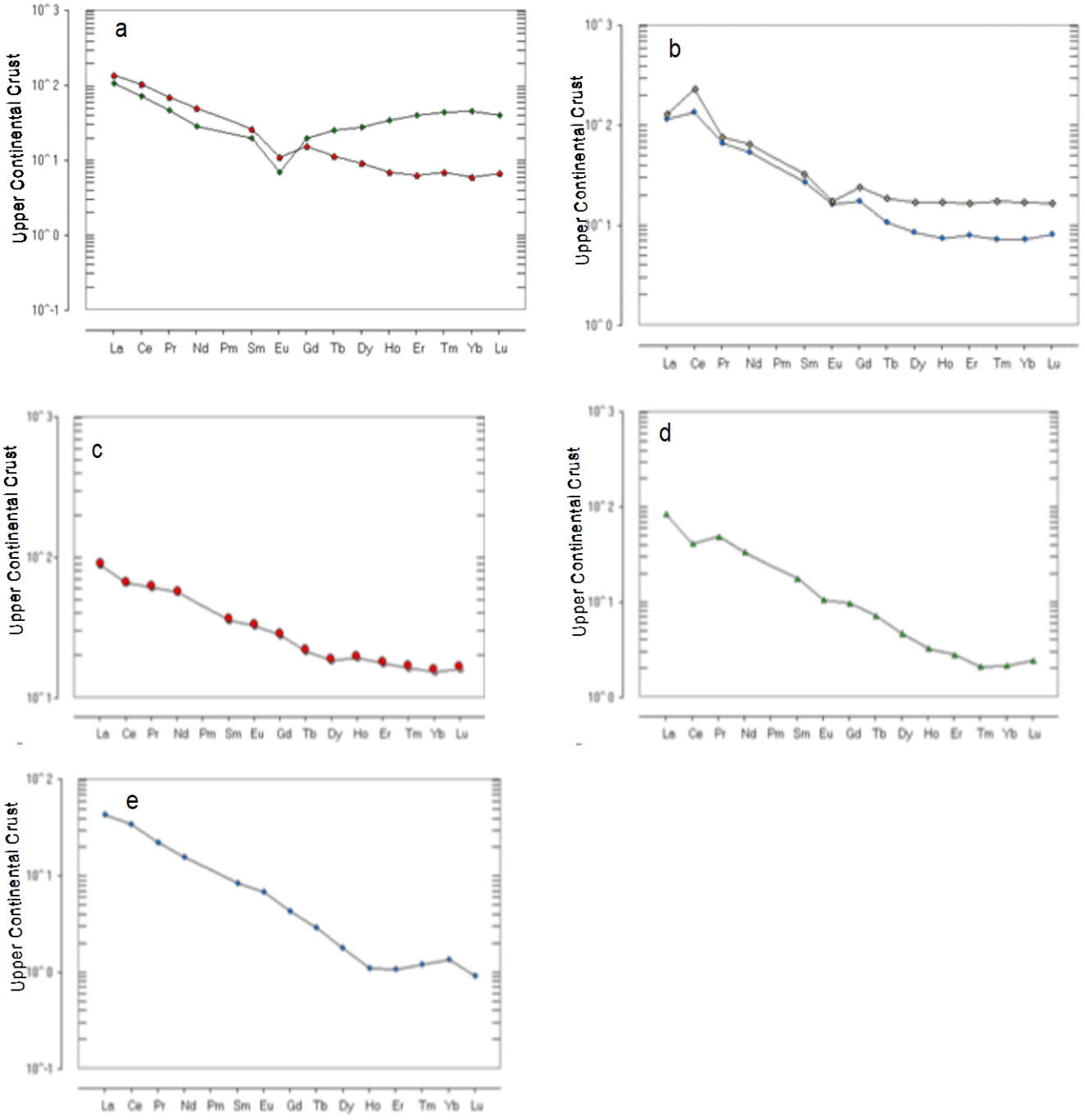


Figure 4.16: Chonderite normalized REE patterns for basement rocks (after Taylor and McLenna, 1985); (a) Migmatitic gneiss and Mylonite gniesschondrite normalized REE patterns (b) Phyllite and mica schist chonderite normalized REE pattern (c) Granite chonderite normalized REE pattern (d) Amphibole schist chonderite normalizedREE patterns (e) Granodiorite chonderite normalizeREEpattern

4.4.2 Mineralogical composition of clay deposits

Result of the X-Ray Diffraction (XRD) analysis is presented in Table 4.6. The mineralogical assemblage of all the clays have been indicated against their major diagnostic peaks. The predominant clay mineral in the samples from the study area is Kaolinite, while the non-clay minerals are quartz, muscovite and anatase.

Table 4.6: Mineralogical Composition ofthe Clay from Central Bida Basin

Location	Quartz	Kaolinite	Muscovite/Illite	Microcline	Anatase	Total %
Nami	42.4	55.0	1.9	n.d	0.7	100
Gubaji	61.5	33.4	4.6	n.d	0.4	99.9
Lemu	75.3	22.1	2.2	n.d	0.4	100
Nakama	65.1	28.1	6.3	n.d	0.5	100
Shegba	35.8	52.4	5.1	6.2	0.6	100.1
Batati	50.7	42.6	6.0	n.d	0.8	100.1
Kutigi 1	50.8	40.5	7.9	n.d	0.8	100
Kutigi 2	39.7	47.3	11.9	n.d	1.0	99.9
Sakpe	27.8	66.2	4.7	n.d	1.3	100
Kpaki	56.0	37.4	5.7	n.d	0.9	100

The mineralogiy of clay occurrence is composed of quartz which range from 27.8wt% to 75.3wt%, muscovite/illite from 1.9% to 7.9 5.7%, and microcline 6.2%, anatase (a titanium oxide mineral found in intermediate to mafic rocks) from 1.3% to trace.

Generally, kaolinite account for 55% of the clay occurrence at Shegba, Sakpe, Kutigi, Nami, Batati and Kpaki while quartz account for 40%, muscovite/illite and anatase account for 5%. Nakama, Gubaji and Lemu occurrences have mineral composition of kaolinite 30%, quartz 65% and muscovite/illite and anatase 5% (Figure 4.17).

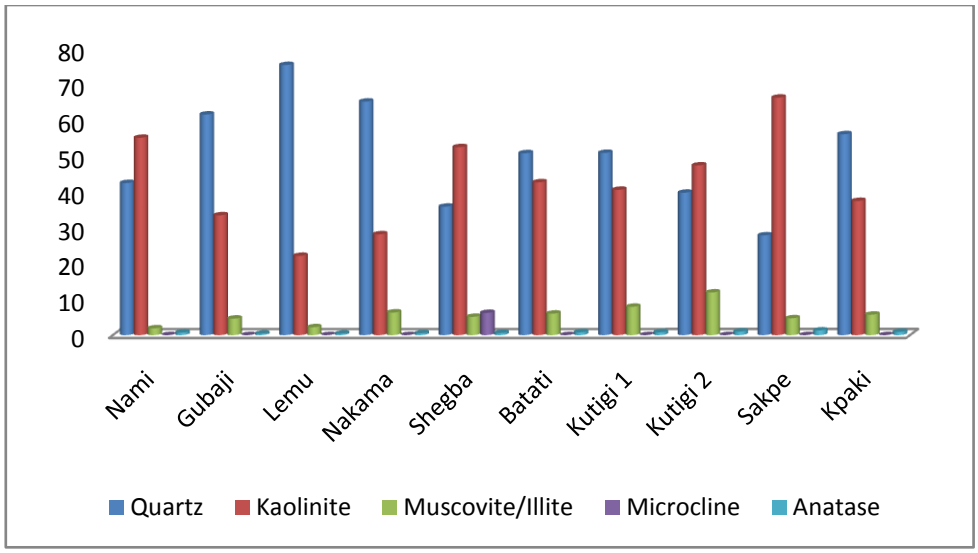


Figure 4.17: Bar chart of average percentage mineralogical composition of the studied clay

4.4.3 Chemical composition of clay deposits

The geochemical analysis result of thirty clay samples from the study area show high value of SiO_2 rangingingfrom 54.91% to 87.37 %, moderately high Al_2O_3 ranging from 7.4 % to 29.67 %, and a low value of Fe_2O_3 ranging from 1.13 % to 7.11wt %. Also, the samples are low in CaO, Na_2O and K_2O exceptthe clay from Shegba which is slightly higher in K_2O. Lost of Ignition (LOI), range from 3.56% to 11.95 in all the studied clays (Table 4.7)

Table4.7: Percentage major oxides distribution of clays in the study area

(%)	SiO_2%	Al_2O_3%	Fe_2O_3%	MnO%	MgO%	CaO%	Na_2O%	K_2O%	TiO_2%	P_2O_5%	LOI%	Total
Location												
Nami 1	67.84	19.23	1.85	0.008	0.04	0.03	0.03	0.14	1.039	0.05	8.30	98.56
Nami 2	69.58	18.12	1.70	0.007	0.04	0.03	0.04	0.14	1.054	0.05	8.26	99.05
Nami 3	68.34	18.74	1.79	0.007	0.04	0.03	0.03	0.14	1.052	0.03	8.32	98.53
Gubaji 1	77.53	12.93	0.78	0.012	0.06	0.03	0.03	0.34	2.160	0.05	4.86	98.79
Gubaji 2	81.13	11.52	0.72	0.012	0.09	0.04	0.07	0.43	1.926	0.05	4.28	100.3
Gubaji 3	79.73	11.01	0.67	0.012	0.05	0.03	0.03	0.29	2.020	0.02	4.42	98.29
Lemu 1	85.16	7.63	1.13	0.010	0.10	0.12	0.04	0.14	0.863	0.02	3.56	98.78
Lemu 2	85.16	7.46	1.05	0.007	0.04	0.04	0.04	0.13	0.860	0.02	3.56	98.36
Lemu 3	87.37	7.55	1.06	0.007	0.04	0.04	0.04	0.13	0.879	0.01	3.65	100.8
Nakama 1	63.52	23.39	1.09	0.008	0.12	0.09	0.06	0.71	1.699	0.06	8.41	99.15
Nakama 2	70.11	19.65	1.17	0.010	0.10	0.09	0.09	0.75	1.548	0.04	7.43	101.0
Nakama 3	69.66	19.79	1.14	0.009	0.09	0.09	0.09	0.75	1.511	0.04	7.42	100.6
Shegba 1	57.98	18.70	7.11	0.079	0.66	0.30	0.23	1.74	0.967	0.03	11.95	99.74
Shegba 2	59.80	18.33	6.98	0.057	0.64	0.30	0.22	1.76	0.962	0.03	11.48	100.6
Shegba 3	58.84	18.93	7.04	0.080	0.66	0.30	0.23	1.76	1.004	0.03	11.84	100.7
Batati 1	66.88	21.70	1.12	0.009	0.09	0.08	0.09	0.72	1.610	0.06	8.44	100.8
Batati 2	64.28	22.32	1.14	0.009	0.10	0.08	0.08	0.69	1.673	0.07	8.40	98.84
Batati 3	70.43	19.23	1.19	0.009	0.09	0.09	0.08	0.77	1.525	0.05	7.37	100.8
Kutigi A1	67.29	19.92	1.14	0.009	0.10	0.09	0.09	0.75	1.553	0.06	7.33	98.34
Kutigi A2	67.63	20.27	1.18	0.009	0.12	0.09	0.10	0.76	1.616	0.04	7.39	99.21
Kutigi A3	69.19	19.68	1.13	0.009	0.09	0.09	0.11	0.79	1.538	0.05	7.38	100.1
Kutigi B1	63.02	23.06	1.12	0.009	0.09	0.08	0.11	0.76	1.715	0.06	8.54	98.56
Kutigi B2	66.73	21.96	1.12	0.009	0.09	0.08	0.08	0.72	1.663	0.06	8.43	100.9
Kutigi B3	64.92	21.81	1.09	0.008	0.10	0.08	0.09	0.70	1.629	0.04	8.41	98.90
Sakpe 1	54.91	29.15	0.97	0.007	0.05	0.07	0.05	0.30	1.764	0.05	11.37	98.68
Sakpe 2	55.83	29.36	0.96	0.007	0.05	0.07	0.06	0.31	1.874	0.05	11.31	99.88
Sakpe 3	55.71	29.67	0.92	0.006	0.05	0.07	0.05	0.31	1.793	0.05	11.36	99.99
Kpaki A1	72.42	17.13	0.94	0.010	0.08	0.03	0.10	0.53	1.822	0.04	6.40	99.51
Kpaki B1	73.06	15.91	1.36	0.011	0.10	0.05	0.09	0.58	1.833	0.03	5.77	98.80
Kpaki B2	74.86	15.60	1.32	0.011	0.09	0.06	0.10	0.58	1.830	0.04	5.72	100.2
PASS	62.80	18.90	7.22	0.11	2.20	1.30	1.20	3.70	1.00	0.16	6.00	-
UCC	66.00	15.20	5.00	0.08	2.20	4.20	3.90	3.40	0.50	-	-	-

Trace elements concentration of the clays (Table 4.8), are similar contents. The clays are enriched in Th, V, Sr, Co and depleted in Cr, Rb, Zr and Ba relative to Post Archean Australian Shale average (PAAS). Also, trace elements have similar trace elements composition to Upper Continental Crust (UCC).

Table 4.8: Trace elements distribution of clay in the study area

(ppm)	Sc	Be	V	Ba	Sr	Y	Zr	Cr	Co	Ga	Rb	Nb	Sn	Cs	Th	U
Location																
Nami 1	11	1	74	103	61	33	874	90	1	25	8	16	3	0.7	27.5	7.0
Nami 2	11	1	73	101	54	30	878	100	1	24	9	17	4	0.7	26.3	6.7
Nami 3	11	1	71	99	56	32	883	140	2	24	9	17	3	0.7	25.5	6.7
Gubaji 1	11	2	77	140	21	87	1967	110	3	20	11	45	16	0.6	28.3	11.5
Gubaji 2	11	2	72	117	18	89	1704	80	2	17	10	34	6	<0.5	29.0	11.0
Gubaji 3	11	2	70	118	16	88	2000	90	2	18	10	39	8	<0.5	27.6	10.7
Lemu 1	6	1	46	301	26	37	875	60	1	10	8	19	3	0.8	19.8	3.8
Lemu 2	6	1	44	105	16	39	839	50	1	10	8	14	3	0.8	18.7	3.9
Lemu 3	6	1	43	106	16	37	864	130	1	10	9	14	3	0.8	19.3	3.8
Nakama 1	15	2	87	230	36	41	919	110	6	31	25	28	5	0.9	34.5	6.0
Nakama 2	13	2	79	220	31	36	1023	90	5	27	25	27	5	0.8	31.6	5.5
Nakama 3	12	2	79	215	31	37	1046	90	5	27	25	24	5	0.7	30.7	5.5
Shegba 1	15	3	116	479	71	36	459	90	16	26	107	22	3	6.2	17.6	5.7
Shegba 2	15	3	111	451	75	37	485	120	14	26	108	23	3	6.1	18.6	5.8
Shegba 3	15	3	116	499	72	36	464	90	17	27	111	23	3	6.4	18.3	5.9
Batati 1	14	2	87	220	36	44	1163	100	6	29	24	33	6	0.9	35.5	6.3
Batati 2	14	2	82	213	33	45	1107	110	6	30	24	31	6	0.9	33.7	6.2
Batati 3	12	2	81	236	34	39	1170	130	5	27	25	31	5	0.8	33.3	5.9
Kutigi A1	12	2	77	214	31	39	1043	90	5	27	25	25	5	0.8	30.7	5.5
Kutigi A2	12	2	78	214	32	39	1044	130	5	28	25	26	5	0.8	31.8	5.6
Kutigi A3	12	2	81	216	34	38	1173	80	5	27	26	31	5	0.8	33.7	6.0
Kutigi B1	14	2	88	222	37	43	965	100	6	30	25	31	5	0.9	35.8	6.3
Kutigi B2	14	2	87	218	36	42	1087	150	6	30	24	31	5	0.9	36.7	6.6
Kutigi B3	14	2	83	216	33	39	1014	110	6	30	24	29	6	0.9	33.3	6.1
Sakpe 1	18	3	86	107	40	58	992	130	10	40	13	36	5	0.5	38.0	7.8
Sakpe 2	18	3	82	114	37	54	1017	150	10	39	13	35	6	0.6	33.1	6.9
Sakpe 3	18	3	85	107	39	55	993	130	9	38	12	36	5	0.5	36.3	7.2
Kpaki A1	13	1	73	179	25	46	1011	90	4	25	17	32	5	1.1	18.2	6.2
Kpaki B1	10	1	81	186	26	63	1247	110	4	22	17	23	4	0.9	19.0	6.1
Kpaki B2	10	2	79	185	26	62	1346	80	4	22	18	23	4	0.8	18.8	6.1
PASS	16	1	150	650	99	27	210	110	23	32	160	19	7	15	0.77	3.1
UCC	11	3	60	550	98	22	190	35	10	28	112	25	8	10	10.7	2.8

The rare earth elements concentrations of the clays are similar. Chonderite- normalized patterns are typical for the Post Archean Australian Shale (PAAAS) average with enrichment of LREEs (Figure 4.18). All samples show week negative Eu anomalies ranging from 1.10 – 2.15 ppm.

In general, chondrite-normalized REE patterns of the clays display high light REE/heavy REE ratio between 2.34 and 19.511 (Table 4.9), flat HREE and week negative Eu anomaly. High light REE/heavy REE ratio and negative Eu anomaly suggest felsic source rocks, while

low light REE/heavy REE ratio and lack of Eu anomaly, mafic source rocks (Cullters and Graf, 1983). The clays in the study area have high light REE/heavy REE ratio and week negative Eu anomaly thus confirming that the source rocks are of felsic composition.

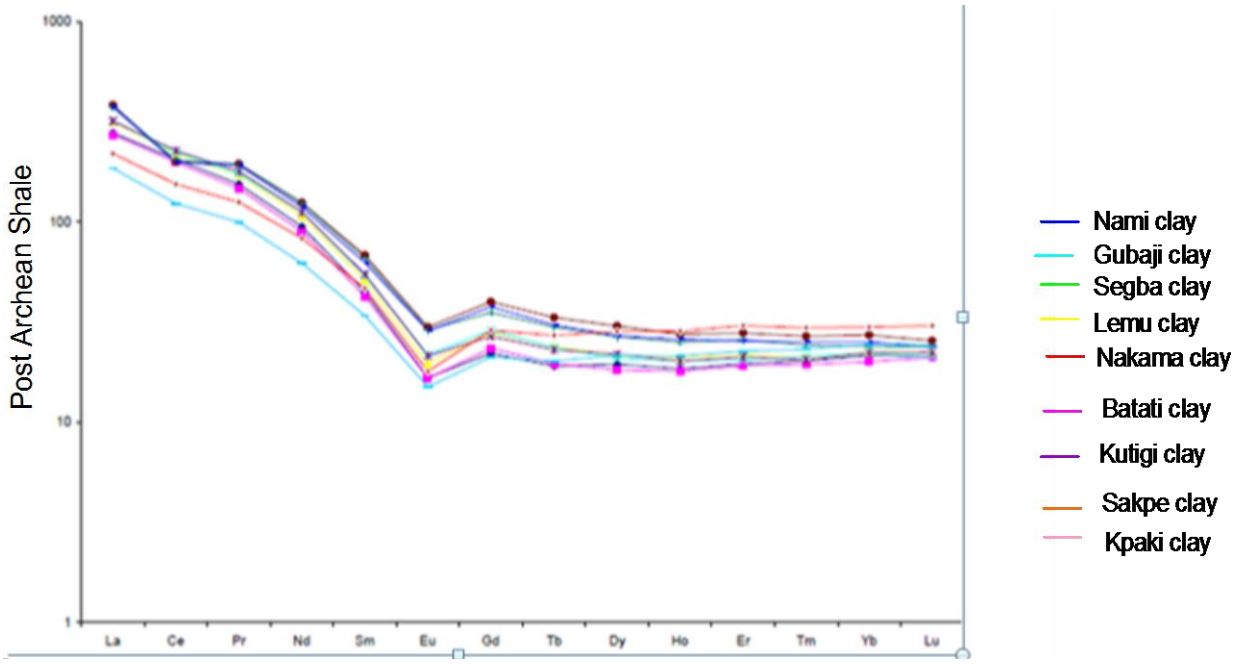


Figure 4.18: Chondrite normalized rare earth elements diagram (after Taylor and McLenna, 1985) of the clays from the study area.

Table 4.9 Rare elements distribution of clays in the study area

(ppm)	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	LREE	HREE	LREE/HREE	ΣREE
Location																		
Nami 1	114	208	21.9	73.6	11.5	1.79	8.0	1.2	6.7	1.2	3.4	0.52	3.5	0.55	429	26.86	15.97	455.86
Nami 2	117	215	22.6	76.1	12.0	1.77	7.8	1.1	6.1	1.1	3.5	0.50	3.2	0.50	442.7	22.69	19.51	468.27
Nami 3	117	214	22.7	75.3	12.3	1.80	7.9	1.1	6.3	1.2	3.6	0.53	3.4	0.52	441.3	26.35	16.75	467.65
Gubaji 1	63.7	121	14.4	52.9	11.1	1.55	10.5	2.0	13.4	2.9	9.4	1.48	10.1	1.52	263.1	52.85	4.98	315.95
Gubaji 2	60.9	117	14.0	51.6	10.7	1.32	10.2	2.0	13.2	3.0	9.4	1.51	10.2	1.55	254.2	52.38	4.85	308.09
Gubaji 3	62.5	122	14.4	54.1	10.9	1.36	10.1	1.9	13.2	2.9	9.7	1.53	10.3	1.60	263.9	52.59	5.02	316.49
Lemu 1	60.8	118	13.1	48.1	8.5	1.51	6.5	1.0	6.0	1.2	3.8	0.56	3.7	0.55	248.5	24.82	10.01	273.32
Lemu 2	53.8	108	12.2	44.6	8.3	1.34	6.6	1.0	6.3	1.3	4.0	0.59	3.9	0.60	226.9	25.63	8.85	252.53
Lemu 3	55.9	111	12.5	46.0	8.7	1.42	6.7	1.1	6.5	1.3	4.0	0.58	3.8	0.61	234.1	35.96	6.51	270.06
Nakama 1	106	192	20.8	69.4	10.5	1.57	6.8	1.1	6.5	1.3	4.2	0.63	4.1	0.66	398.7	26.86	14.84	425.56
Nakama 2	86.0	165	17.1	56.3	8.4	1.16	5.5	0.9	5.7	1.2	3.8	0.61	3.9	0.63	332.8	34.26	9.71	367.06
Nakama 3	84.3	160	16.4	53.7	8.0	1.19	5.4	0.9	5.9	1.2	4.0	0.64	4.2	0.64	322.4	14.21	22.69	336.61
Shegba 1	62.4	131	12.9	46.7	9.0	1.62	6.9	1.1	6.6	1.3	3.8	0.58	3.5	0.54	262	22.94	11.42	284.94
Shegba 2	62.6	115	13.0	48.4	9.2	1.75	7.4	1.1	6.7	1.3	4.0	0.59	3.9	0.57	248.2	27.31	9.09	275.51
Shegba 3	62.7	133	13.1	48.3	9.0	1.77	7.2	1.1	6.4	1.3	3.7	0.56	3.6	0.57	266.1	26.2	10.16	292.3
Batati 1	100	183	19.3	65.7	9.8	1.46	7.5	1.2	7.2	1.5	4.7	0.71	4.7	0.72	377.8	29.69	12.72	407.49
Batati 2	102	187	20.5	58.3	10.6	1.56	7.3	1.2	7.5	1.5	4.8	0.73	4.8	0.75	378.4	30.114	12.57	408.54
Batati 3	85.7	163	17.1	54.8	8.5	1.21	5.8	0.9	6.1	1.2	4.1	0.63	4.3	0.66	329.1	24.9	13.2	354
Kutigi A1	84.9	161	16.6	55.1	8.4	1.24	5.6	0.9	6.0	1.3	4.1	0.64	4.2	0.68	325.1	24.66	13.18	350.66
Kutigi A2	87.5	167	17.2	56.4	8.6	1.21	5.7	0.9	6.3	1.3	4.2	0.65	4.5	0.69	326.7	24.81	13.17	361.51
Kutigi A3	85.7	161	16.4	53.3	8.2	1.19	6.1	1.0	5.9	1.3	4.1	0.62	4.2	0.68	324.6	25.09	12.94	349.69
Kutigi B1	99.4	177	19.2	63.9	9.8	1.41	7.3	1.2	7.0	1.5	4.6	0.68	4.7	0.72	369.3	29.11	12.69	398.41
Kutigi B2	101	181	19.5	67.0	10.3	1.57	7.4	1.2	6.7	1.4	4.4	0.68	4.6	0.69	378.8	28.64	13.23	407.44
Kutigi B3	100	184	20.0	66.8	10.5	1.55	6.9	1.1	7.1	1.4	4.5	0.65	4.6	0.72	381.3	28.50	13.38	409.82
Sakpe 1	120	162	21.8	74.4	13.1	2.15	10.3	1.6	9.8	1.9	5.9	0.86	5.7	0.82	391.3	39.03	10.01	430.33
Sakpe 2	119	165	21.6	73.7	12.6	2.09	9.1	1.5	8.7	1.8	5.5	0.77	5.0	0.76	391.9	35.22	11.13	427.12
Sakpe 3	118	161	21.5	70.8	12.0	2.07	9.8	1.5	8.8	1.8	5.4	0.81	5.2	0.77	383.3	36.16	10.60	419.46
Kpaki A1	58.2	100	11.1	37.1	6.5	1.09	5.5	1.0	7.0	1.5	4.8	0.74	5.1	0.78	212.9	90.61	2.34	303.41
Kpaki B1	69.0	125	14.0	49.5	8.9	1.29	7.5	1.3	9.2	2.0	6.5	0.95	6.2	0.98	266.4	35.92	7.42	302.32
Kpaki B2	64.6	124	13.9	48.8	8.7	1.28	7.5	1.4	9.2	2.0	6.4	0.97	6.4	0.98	260	36.13	7.20	296.13
Average	85.4	143	17.0	76.3	12.6	1.86	8.55	1.4	9.6	1.9	5.9	0.89	5.76	0.98	324.4	32.5	11.20	357.9
PAAS	38.0	80.0	8.90	32.0	5.60	1.10	4.70	0.7	4.40	1.0	2.9	0.40	2.80	0.43	164.5	16.97	9.69	181.00
UCC	30.0	64.0	7.10	26.0	4.50	0.88	3.80	0.6	3.50	0.8	2.3	0.33	2.20	0.32	131.6	13.57	9.70	146.17

CHARPTER FIVE: DISCUSSION

5.1 Basement Complex Rocks

5.1.1 Field and petrographic charateristics

Based on field observation, constituent minerals and textural features the rocks from the study area are; migmatitic gneiss, mylonite gneiss, mica schist, phyllite, amphibolite, qartz mica schist, medium grained granite, granodiorite and porphyritic granite. These rocks are part of the metamorphic and igneous rocks bordering the northern part of the Bida basin.

Ajibade *et al*.(2008) distinguished two types of migmatitic gneiss in Minna area; the early migmatite and late migmatite. The early migmatitic gneiss is believe to have formed during the early period of high-grade metamorphism history of the basement prior to the deposition of the rocks of the schist belts and is associated with complex fold structures. The late migmatites (Pan-African) are believed to have been formed by magmatic injection related to emplacement of the Older Granites with simple fold structures. In the study area, the migmatitic gneiss and mylolite gneiss have simple and micro folds suggesting that these rocks belong to the late migmatite Pan-African event.

The mylonite gneiss is closely associated with the amphibole schist and quartz mica schist.The rockis fine grained. In thin section the constituent minerals are finely grained and stretched.This conform with the explanation of Garg (2003), that cataclastic structures are characterized by the development of extremely fine mass under the influence of severe crushing and shearing effects of dynamic metamorphism.

Mylonite gneiss retained its alternating dark and light minerals, and occured promenant in Zungeru area with no clear contact with other rocks porbably due to poor exposure of the contact with other rocks,the migmatitic gneiss is composed of quartz, biotite, hornblend, chlorite and muscovite while the mylonite gneiss is composed of quartz, biotite, hornblend and microcline.

The mica schist in the study area includes: (i) biotite schist (ii) muscovite schist. These schists commonly contain megacrysts of quartz, feldspar and granitic rocks. Suggesting the intrusion of granitic rocks in to the mica schist.The biotite schist is medium grained composed of quartz, biotite, plagioclase and muscovite. Muscovite schist is composed of quartz, muscovite, albite, biotite and anatase a mineral commonly found as small grain in mafic and intermediate metamorphic rocks.

Amphibole has sharp contact with the quartz schist as observed along River Kaduna in Zungeru and River Chanacha in Gada Eregi area. Similarly, Russ (1957) mapped transitional contact along River Namanye in Zungeru area and suggested based on chemical study that the amphibolite was probably derived from calcareous sediments. Field contact relationship and fine texture of amphibolite schist and quartz mica schist suggest that these rocks are of similar provenance and they have undergone similar deformational history. Chemical plot of Na_2O/Al_2O_3 versus K_2O/ Al_2O_3(Garrels and Mackenzie1971) (Figure 5.1) and TiO_2 versus SiO_2 (Tarney, 1977) (Figure 5.2) suggest sedimentary protholit of amphibole. Amphibolite is composed of biotite, hornblende, quartz, plagioclase suggesting and epidote, a common mineral in the low-grade regional metamorphic (greenschist facies) terrane. The combine textural characterict and presence of epidote reveal low grade metamorphism and deformation character of the amphibole.

Phylliteis finely laminated which can be interpreted as foliation planes. The rockis poorly exposed towards the Bida basin and is considered aspart of Ushama schist belt.The rock display alternation of quartz, plagioclase feldspar. In thin section the phyllite is composed of quartz, albite and chlorite,the feldspar minerals are cloudy as result of alteration of the rock.

The granitic rock observed in the field range from medium grained to porphyritic granite and granodiorite. The medium grained granite is weakly foliated and occurs as intrusionin the granodiorite. The granitic rocks occurred as high level intrusion ridge and batholiths in the study area. In thin section the granitic rocks are composed of quartz, microcline, biotite, plagioclase, hornblend and chlorite.

Field observations and petrographic studies reveal that the Basement Complex rocks in the study are part of Usham Formation, Kushaka Formation and partly Birnin Gwari Formation of northwestern Nigeria

5.1.2 Mineralogy of basement complex rocks

Mineralogicalcomposition of the basement rocks revealed suggested the rocks to be muscovite schist, biotite schist, gneiss, granite, and amphibole schist.High concentration of alkali feldspar cornfirm the feldsparthic character of the schist and grantic rocks, while the presence of actinolite,a mineral group of amphibole is common in amphibolite, mylonite gneiss and granodiorite cornfirming the mafic character of these rocks. The presence of cordierite in mylonitegneiss of zungeru area, a silicate mineral commonly found in low to medium grade metamorphic rocks, suport the gneiss mylonite of Zungeru area to have been the product of low to medium grade dynamic metamorphism.

5.1.3 Chemical analysis of basement complex rocks

The relatively higher total alkalis average (45%) and K_2O/Na_2O ratio (1.59) in the mica schist than phyllite is indication of abundance K-feldspar (microcline and orthoclase) and is consistent with the petrographic study.

Lower concentration of Fe_2O_3, MnO, MgO, CaO and P_2O_5 in migmatitic gneiss, mica schist, phyllite and granite rocks reflect felsic character of these rocks. The MgO/Fe_2O_3+ MgO ratio in mafic rocks usually is >1, while that of felsic is<1. The ratio of MgO/Fe_2O_3+ MgO in mica schist and phyllite is 0.31 and 0.46, suggesting felsic character of these rocks. The plot of SiO_2 versus $Na_2O + K_2O$ shows the chemical classification of the granitic basement rocks are granite, granodiorite, and monzodiorite(Figure 4.12).

Quartz schist is richer in SiO_2 (82%), low in concentration of K_2O (1.84 %) and K_2O/Na_2O ratio (1.7) compare to phyllite and muscovite schist with average K_2O of 4.4 % and K_2O/Na_2O ratio of 56.7, thus reflecting low concentration of feldspar in the quartz schist and enriched feildspar in phyllite, muscovite schist. Moderate concentration of SiO_2 (49.12%), Al_2O_3 (12.20%), Fe_2O_3(14.67%), MgO (10.90%) and CaO (10.18) observe in amphibole of Zungeru area may suggest it marine affinity. Also, high CaO (10.18%) content is an indication of Ca-rich pyroxene, Ca-feldspar and actinolite.

On theA/NK versus A/CNK, muscovite schis, biotite schist, phyllite and quartz schist plot within the peraluminousfield, suggesting alumina oversaturation and felsic character of these rocks. Granodiorite plot whithin the field of metaluminous, suggesting the rock is biotite and hornblended riched and mafic charater. While granite, mylonite gneiss, migmatitic gneiss and

amphibole are in the peralkaline field,suggesting these rocks are sodium, amphibole riched and mafic character (Figure 4.13).

On the discriminant plot of sedimentary and igneous protolith ofDeLaRoche (1974), plots of the metamorphic rocks in the study area does not show any characteristic of igneous trend but rather scattered relative to igneous trend.This suggests sedimentary origin of these rocks (Figure 4.14). Furthermore, on the Mg – CaO - Al_2O_3discriminantionplot after Leyreloup (1977), the mica schists and phyllite in the study area plot outside magmatic field support the sedimentary origin of these rocks (Figure 4.14).

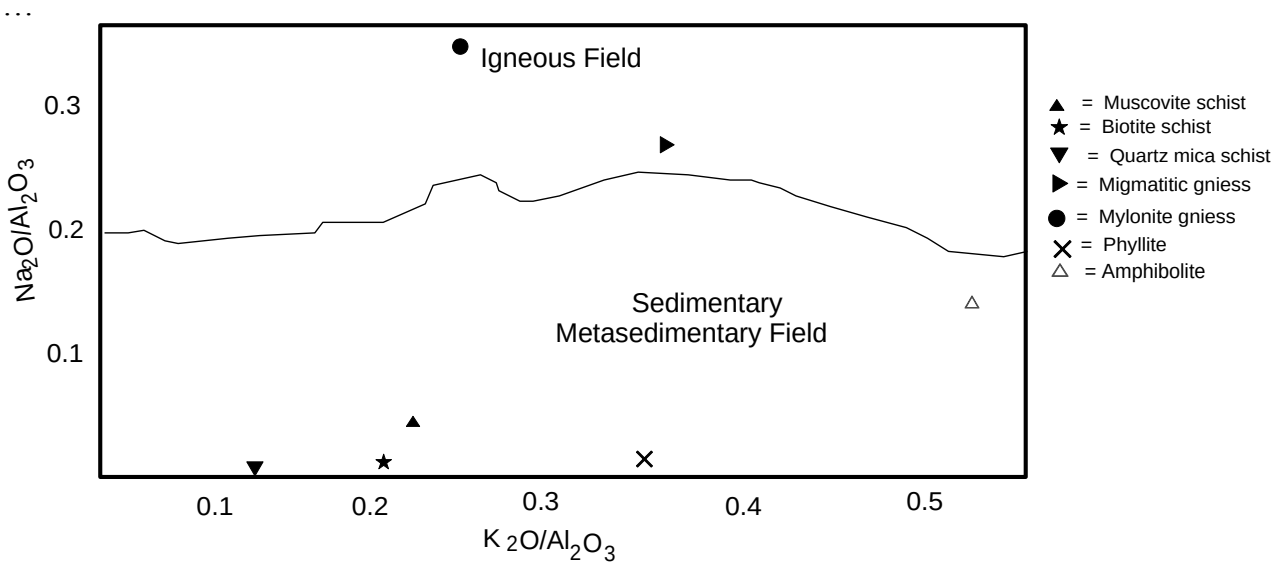


Figure 5.1: Na_2O/Al_2O_3 versus K_2O/ Al_2O_3 plot for basement rocks in the study area (after Garrels and Mackenzie1971)

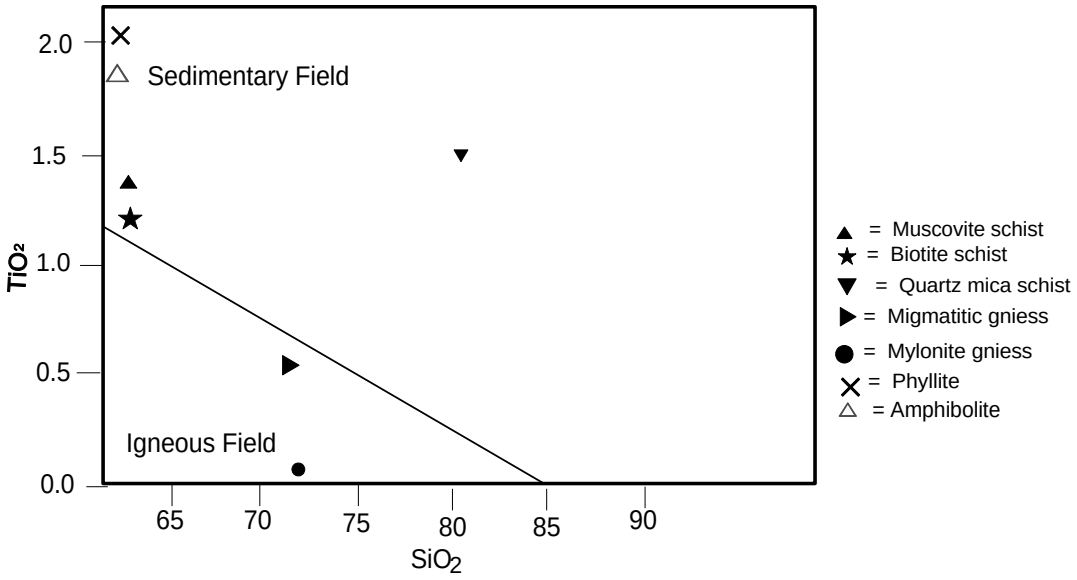


Figure 5.2: TiO_2 versus SiO_2 discrimination plot for basement rocks in the study area (After Tarney, 1977)

Plots of Na_2O/Al_2O_3 versus K_2O/ Al_2O_3 and TiO_2 versus SiO_2 of phyllite, quartz schist, muscovite schists, amphibolite and biotite schist are within the sedimentary field while migmatitic gneiss and mylonite gniess falls in the igneous field respectively (Figure 5.1 and 5.2), suggesting the rocks in the study area to be of igneous and sedimentary origin. Russ (1957) identified sedimentary composition of the quartz-feldsparthic mylonite in the study area. Truswell and Cope (1963) suggested that the mylonite gneiss is of granitic protoloith, while Ajibade (1971) identified the mylonite to be of sedimentary protolith. In this study muscovite schist, biotite schist, phyllite, quartz mica schist and amphibolites are of sedimentary protolith while migmatitic gneiss and mylonite gneiss are of igneous protolith.

The abundance of trace elements such as Ni, V, Rb, Sr, Ba, Zr, Y, Nb and rare earth elements (La – Lu) are commonly used in deducing the origin of felsic rocks.These trace elements are enriched in granite, migmatitic gniess, mica schist which sugest felsic character of these rocks

while granodiorite and amphibolites are depleted.These elements suggest their mafic protolith. Furthermore, Zr and Rb are known to be more concentrated in acidic rocks their concentration (115.6- 830.1 ppm) in phyllite, mica schist and quartz mica schist implies felsic charater.

The rocks from the study area show similar rare earth elements distribution patterns, with enrichment in LREE (La – Sm) indicating high degree of REE fractionation.Negative Eu anomalies are suggestive of feldspar fractionation, since plagioclaseis the only rock forming minerals that is relatively enriched in Eu. This is believed to be the plagioclase feldspar.Murray *et al.,* (1990, 1991a) have shown that the Ce anomaly depends on sediment depositional environment. Thus, increasing positive values indicate more oxic environment of deposition, whereas decreasing values indicate more reducing or anoxic environment of deposition. Pelagic sediments usually show negative Ce anomaly while Fe oxide-rich sediments such as red clay, shows a positive Ce anomaly. Strong positive Ce anomaly observed in phylllite and muscovite schist suggested oxic condition and clay rich sediments of the protholits prior to metamorphism.

5.2 Occurrence of Clay in the Central Bida Basin

5.2.1 Clay occurrences and field relationship

Ten clay occurrences were recorded in the study area through geological mapping.Vertical sections log show variation in lithology/composition of the discret geological units associated with the clay occurrence. The clays are white and fine grained from center of the basin to dirty white and become grity toward the border with Basement Complex, which suggest chemical modification along path way from the source area. Red tint colour observed in the clay is inherited from overburden ironstone/laterite through perculating water. Vertical thickness of the

clay varies from 4 to 8 meters.This suggests that the fluvial environment of deposition of the clay ranges from flood plain, through braided stream, meandering stream.

Maurice (2001), reveal the formation of illite to incomplete chemical alteration of K-feldspar along pathway from source area.The presence of illite in the clays suggest incomplete chemical alteration of K-feldspar to kaolinite or due to diagenesis of kaolinite within the basin, while muscovite may suggestresistance to weathering within the basin.

5.2.2 Mineralogy of the clay occurrences

The clay occurrence is dominated by kaolinite clay mineral (average 42.5%) with little concentration of illite.This confirm that the study clay to be kaolin.

The origin of clay minerals in sedimemtary basins are product of weathering of mica, albite and muscovite/k-feldspar in source area, aided by the mechanism of physical sorting and chemical modification during transportation and deposition(Maurice 2001). In the area with high temperature and high precipitation, weathering will be intense and fast, whereas in arid region weathering will proceed at a much slower rate due to lower precipitation.

In the central Bida basin, supply of mica, albite and k-feldspar from the adjoining basement rocks, low topography and humid tropical climate favoured the formation of kaolinite. This is supported by the presence of feldspars and rock fragment of schist, gneiss and pegmatite in the Bida Formation around Share and Pategi in the northern Bida basin (Ojo and Akande 2003).

Illite is an intermediate weathering product which can be formed from either feldspar or muscovite. The depletion of potassium ion in the mica is a diffusion controlled mechanism and K^+ release rate from biotite is approximately two orders of magnitude faster than from muscovite

(Leonard and Weed, 1970). Formation of kaolin pre-date illite, at shallow depth illite can precipitate directly from kaolin (De Almeida Martins, 1999). The illitization of kaolin is a sequence of thermodynamic destabilizationat about 120^{o} to 140^{o} C and shallow depth.K^{+}/H^{+}activity at the near surface is induced by K^{+}-rich fluidsbuffering of initially acidic pore fluids by dissolution of K-feldspar,the leachedK^{+} is incorporated into the kaolinite mineral structure to form mixed layer of kaolinite and illite minerals (Figure 5.3).

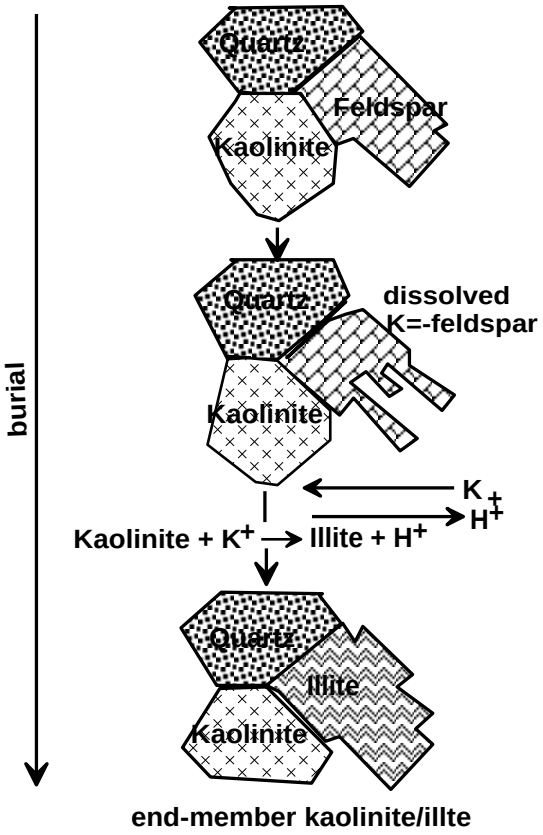


Figure 5.3: Idealized schemes of the illitization process (modify after Berger et al., 1997)

The clays in the studied area are mixed clay mineral of kaolinite and illite. Kaolinite is the dominant clay mineral ranging from 66.2%to 22.1%while illite range from 1.9% to 11.9%.This variationssuggestedfluvial environment of deposition, shallow depththat influence the illitization process in the basin. Also, incomplete in-situ chemical alteration of muscovite mica (least resistant to chemical weathering) may be responsible for the formation of illite.

Quartz is the dominant non-clay resistancemineral in all the clay samples. Its variation suggests it resistance to weathering. Clays at the basin margin have considerably high composition of quartz compare to clays at the basin center, signifying the paleo-current directionfrom basement to the basin center.

The presence of anatase which is always found in felsic granite, metamorphic rocks and in placer deposit sugest the source of material of the central Bida basin to be from the felsic rocks of the Basement Complex. The presence of microcline observed in Shegba clay deposite which is along the flood plain of River Kaduna (local name River Wuya) does not only suggest felsic source, but also indicate incomplete distruction along transportation parth way and chemical alteration of microcline during the processes of clay formation.

Mineral variation indices of the studied clay show increase in kaolinite content from the basin /basement complexmargin (NW) towardsthe centre of the basin (SE), and inverse variation of quartz content to kaolinite . This suggests mineral maturity of the clay towards the basin center andit also reflectsreduction in transport energy of sediments supply from the source area (basement complex) where clay materials are carried in suspension and deposited in the basin.

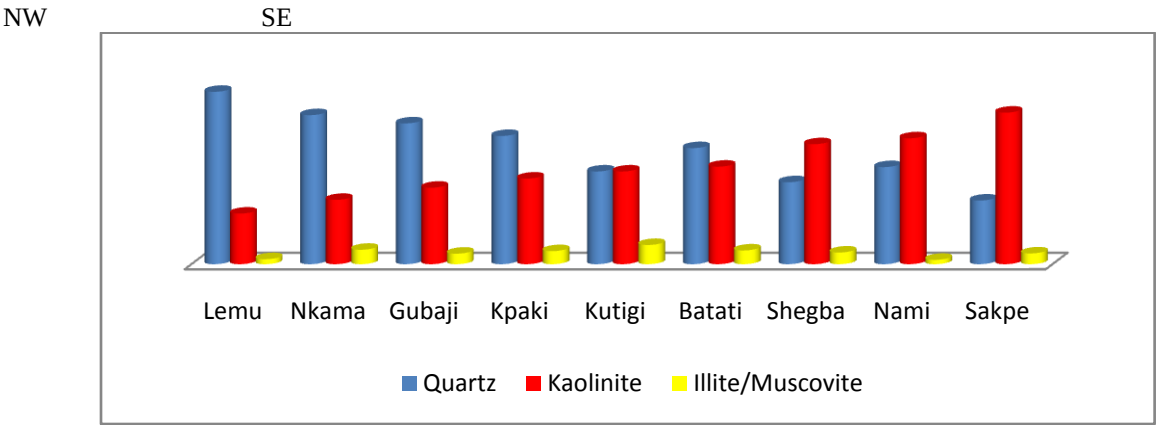


Figure 5.4Plot of clay mineral variations in the central Bida basin clays

5.2.3Geochemistry of clay occurrence

The low content of Na_2O, K_2O and CaO suggest intensive weathering and destruction of feldspar during transportation.Thus, the slightly higher of K_2O in Shegba clay show the contribution of illite mineral and incomplete destruction of microcline. TiO_2 is relatively immobile during weathering compared to other elements and is mainly concentrated in phyllosilicates (Condie *et al.,* 1992).It concentration in sedimentary rocks is strongly controlled by the amount of alkali-feldspar and mica in the source rock (Mc Lennan *et al.,* 1993). Although P_2O_5 is low, it may be explained by the accessory minerals like monazite in silicic source rock. Loss of ignition (LOI) that range from 3.56% to 11.95 in all the studied clays is due to hydration stage of the clays which is responsible for the release of structural water and CO_2 respectively.

Nagetive covariation plots of SiO_2 with Al_2O_3in the study claysuggest residue of SiO_2 and Al_2O_3as a result chemical weathering of felsic source rock (Figure 5.5a and b). Positive covariation plot of SiO_2 versus TiO_2suggest mixed source materials. However, Na and K contents are usually controlled by feldspar and thus negative covariation of SiO_2 with K_2O and Na_2O implies the destruction of plagioclase feldspar and depletion K_2O and Na_2O as a result of

chemical alterationof the source rocks (Figure 5.5c and d). Also, negative covariationof Fe_2O_3, CaO, MnO and MgOwith SiO_2 suggestthe source rock to be of felsic character (Figure 5.5e and h). Furthermore, negative covariation of $SiO_2$with CaO surport felsic character source material of the clays.

Chemical variation index show a gradual increase of Zr/Cr and Zr/Rb ratios toward the basin from the basin margin, suggesting enrichment of Zr in clay due to its immobility and felsic source further more, Cr/V ratios are similar in the studied clays, suggesting the clays to be of similar source material and have suffered similar weathering intensity (Figure 5.6).

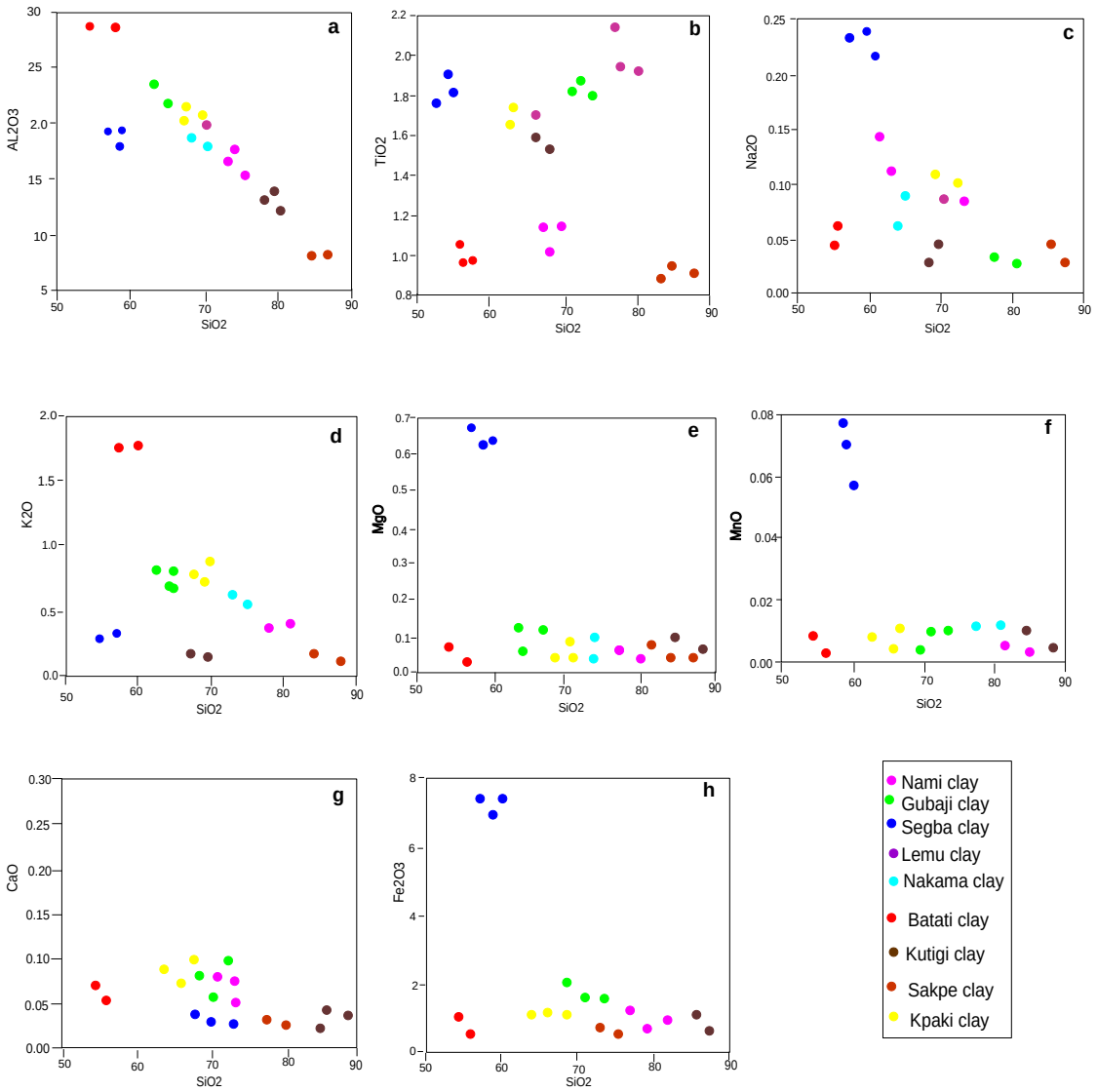


Figure 5.5: Covariation plots of SiO_2 versus major elements of clays from study area

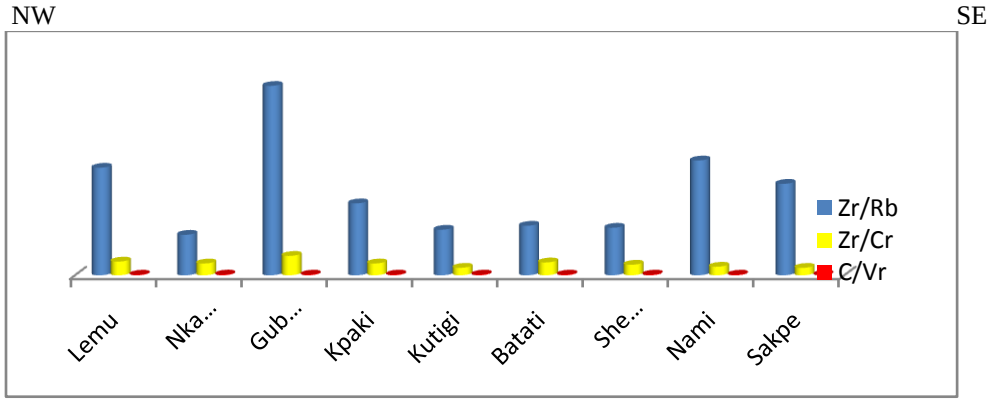


Figure 5.6: Plot of clay element ratio variations in the central Bida basin clays

5.2.4 Sedimenthology and paleo-environment of clay deposition central Bida basin

Field evidence revealed that most of the clay deposits are capped by thin layer of oolitic ironstone and locally developed ferruginised sandstone, suggesting stratigraphic position of the study clay to be part of Bida Sandstone Formation and Enagi Siltstone Formation respectively. Sequence to previous workers observations and suggestions, the sediments supply of the Bida basin (Bida sandstone Formation and Sakpe Iron Formation)during the Campanian age are favored by continental sediment supply and marine sedimentsupply. The Enagi Siltstone Formationis fovored by continental sediments supply during theMaastichian age, while Batati Ironstone Formation is by marine sediment supply. It can be concluded from stratigraphic succession proposed by Adeleye (1972), that the basin has experienced two phases of marine withdrawal (during the lower Campanian and upper Maastrichian ages) subsequent to two phases of marine incursions (during the upper Campanian and lower Maastrichian ages).

Trace elements composition and ratios of the study clay deposits suggest continental originof the clay materials that were deposits in the alluvial environment (flood plain, alluvial fan and braided channel) in the Bida basin and wereweathered/altered chemically in-situ in the basin prior to the last phase of marine incursion that deposited theEnagi siltstone formation during the upper Maastrichian age.

Oxygen interaction with sediment during sedimentation can be use to interpret environment of sediment deposition.Oxic sediments reflect strong level of oxygen and sediment interraction at the time of deposition near surface or continental environment regime (0 meter - %50 meters depth) which include; flood plain, ox-bow lake, alluvial fan and braided channel), whereas subanxoic (50 meters to 100 meters depth) and anoxic (>100 meters depth) reflect sub-marine

and marine environments of low and absent of atmospheric oxygen interaction with the sediments at the time of deposition. Also, anoxic environment favoured marine fossil and organic minerals accumulation (Jones and Mining, 1994).

Abundance and ratio of redox sensitive trace elements are frequently utilized to asses the paleo-environment (oxic/redox) condition of modern and ancient sediments. The ratio of uranium to thorium as been used as a redox indicator (Jones and Mining, 1994), ratios of uranium to thorium below 1.25ppm suggest oxic conditions of sediment deposition while above 1.25ppm suggest anoxic conditions of sediment deposition. The study clays exhibit U/Th ratios ranging between 0.17ppm and 0.41ppm (average 0.35ppm), suggesting oxic environment of deposition. Authigenic uranium content also is used as an indicator of marine environment condition (Wignal and Myers, 1988), authigenic uranium is evaluated using the fomular:

$$U_{(\text{authigenic uranium})} = U_{(\text{total uranium})} - Th/3.$$

Authigenic uranium values below 5 indicate oxic deposition environment, whereas value below 5 is anoxic deposition environment. The study clays authigenic values ranges between -5.3ppm and 1.5ppm, suggesting the clays were deposited in an oxic environment. The source of this uranium may be attributed to the leaching of uranium from accessory mineral in the clay source rocks.

Vanadium and chromium ratio has been used as index of paleo-environment condition studies (Jones and Mining, 1994). Chromium is mainly associated with detrital sediments and usually subtitute for aluminium in the clay structure (Bjorlykke, 1974) while vanadium is associated with organic matter and are found in anoxic environments (Shaw *et al*., 1990). V/Cr ratios values above 2 suggest anoxic condition, while values below 2 suggest oxic environment of deposition

(Jones and Manning, 1994). In the study clays V/Cr ratioranges between1.0ppm and 1.5ppm (average 1.1) suggesting oxic depositional environment of the clays.

Interpretation of oxic condition using thresholds established by Jones and Manning (1994) suggested V/Cr of >4.25 for suboxic/oxic condition, 2-4.5 for dysoxic condition and <2 for oxic condition, also La/Th by Wignal and Myersn (1988) suggested La/Th of <5 for oxic condition and >5for anoxic condition. The study clay suggests oxic condition at the time of the clay deposition in the basin (Figure 5.7), which is in aggrement with the trace elements ratio values in this study.

Sediments of the Bida basin has been studied extensively in terms of depositional environments and stratigraphy, but with differing approach and interpretation of environmental conditions present at the time of sediment accumulation (Adeleye 1972; Braide 1992;Murat 1972;). In this study, the trace element ratios and thresholds values of the clay deposits in the central Bida basin suggest oxic environment (non-marine) of deposition of the clays.

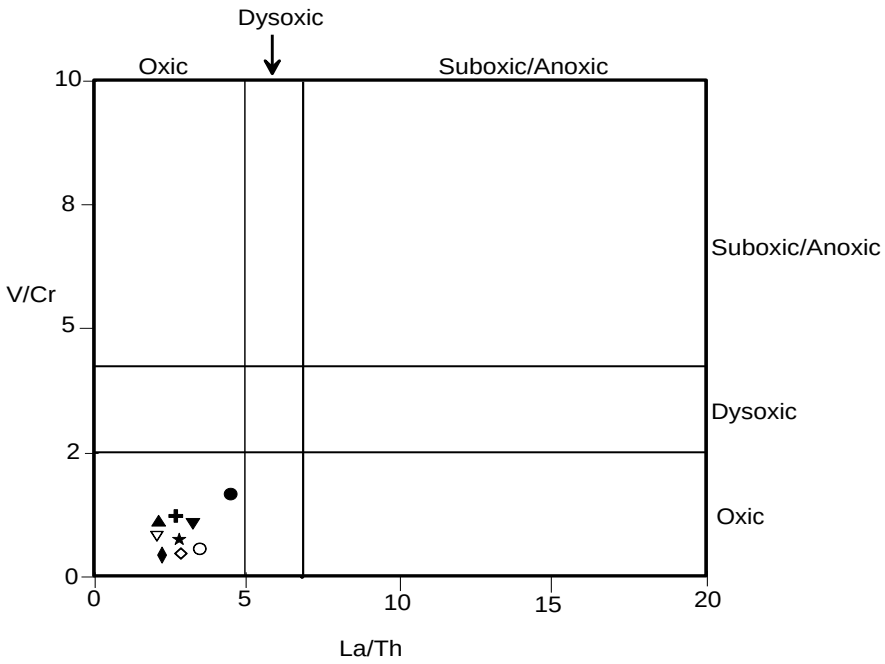


Figure 5.7: Crossplot of V/Cr Versus La/Th ratio of study clays used as paleo-oxic proxies. Ranges from Jones and Mining, (1994) and Wignal and Myers, (1988)

5.3Tectonism, Weathering and Provenance

5.3.1 Basement complex

Field observation and petrographic studies of the basement rocks in the study area reveal linearity in the amphibolite, mica schistm phyllite and mylonite gneiss rocks of Zungeru area which trend of NE – SW direction,this may suggest the formation of these rocks in pre-existing deep seated fracture and mark major shear zone (mylonite) in the study area (Figure 5.8).

All the joints observed in the field are refered to three genetic types, namely longitudinal joint, cross joint and oblique joints (Figure 4.2).The longitudinal joints runs in SW –NE direction and are parallel to the foliation planes while the oblique joints run in SE – NW direction and bisected the foliation plane, the cross joints are rare and commonly found in the granite aroud Paiko (Plate II). These joints are product of shearing, compresional and tensional forces that

accompanied the formation and emplacement of metamorphic and granitic rocks during the Pan-Africa orogeny.

Phyllite and mylonite in thin section is indication of low grade metamorphism and severe crushing and shearing while the presence of large crystal of epidote in thin section of the amphibole sugest low-grade metamorphism of the amphibole schist in the the study area.

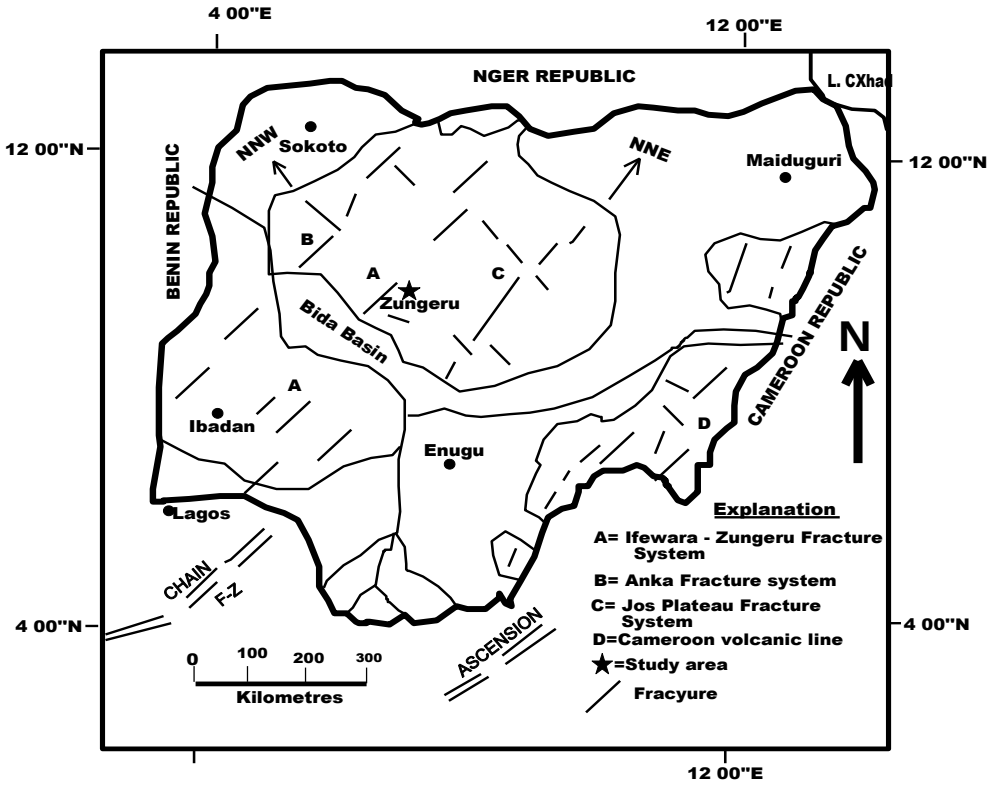
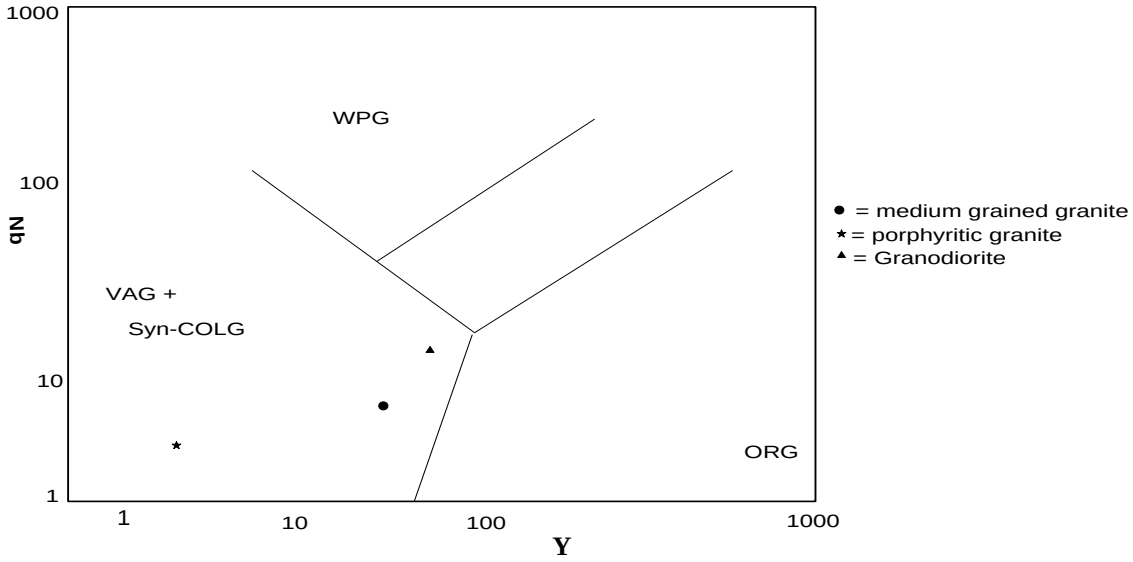


Figure 5.8: Major fracture and lineament trends in the Nigeria Basement complex (Adapted from Wright 1977 and Oluyide, 1988)

The Older Granite of Nigeria evolved by continental – continental collision type orogeny that led to subduction and reactivation of the basement (Burke and Dewey, 1972). Partial melting inthe lower crust and the upper mantle, result in the mineralogy variation of granitic rocks as a result of magma mixing.This variation do not represent separate intrusion. It is likely that the earliestrocks appear to be basic and intermediate intrusive rocks but where later modifified by

granitisation that result in the intrusion of a diverse granites and granodiorite mapped in the studied area. In this study granitic rocks fall within syn-collision granite field (Figure 5.9), suggesting the granitic rocks in the study area evolvedat the time of continental – continental collision during the Pan-Africa orogeny.



Syn-COLG = Syn-collision granite VAG = Volcanic arc granite
WPG = Within plate magin ORG = Ocean ridge granite

Figure 5.9: Nb – Y discrimination diagram (after Peace *at el.* 1984) with plots of rocks from study area

Ruxton (1968) proposed weathering index known as Ruxton Ratio that is best suited for determinations of weathering intensity of igneous and metamorphic rocks from humid regions using SiO_2/Al_2O_3 ratio, Ruxton Ratio value of <3.9 for intensively weathered rocks, 4 - 4.5 for moderately weathered rocks and >4.5 for least weathered rocks. In this study, phyllite and muscovite schist have Ruxton Ratio value of between 3.3 and 3.9 suggesting intensive weathering of these rocks, moderate weathering for amphibolites schist and biotite schist (4.01

and 4.2), and resistant weathering for granitic rocks and gniesses (5.09 and 5.28) (Figure 5.10 and, Table 4.3b and 4b). These rocks formed intergal part of Ushama and Gwari Formations that constituted basement rocks in the study area. Field observation reveals poor exposure of these rocks between Tegina and Gobarawa toward the basin, and along Pandogari – Alawa road. The joints along foliation constitute conduits for ground water movement that facilitate the weathering these rocks.

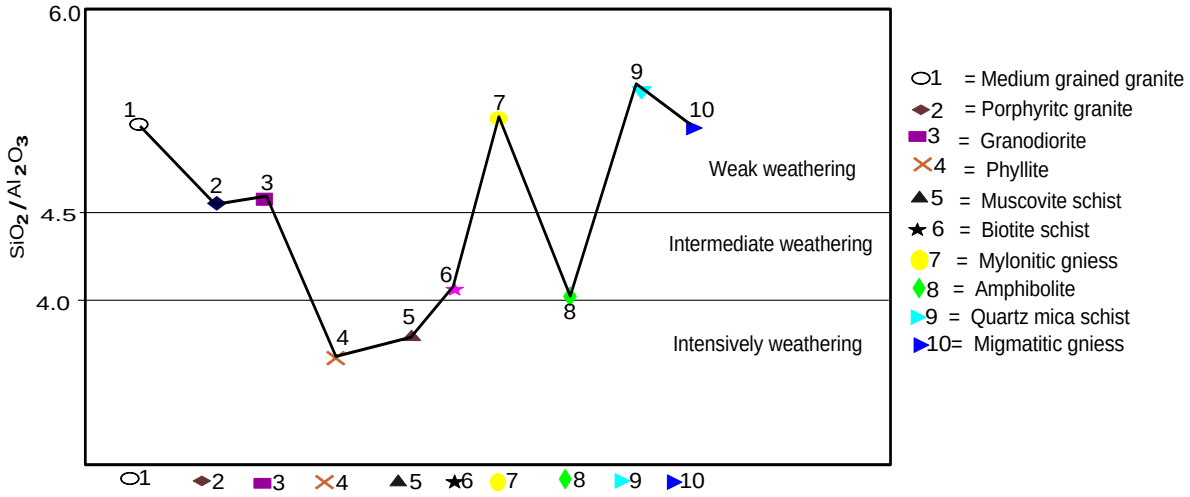
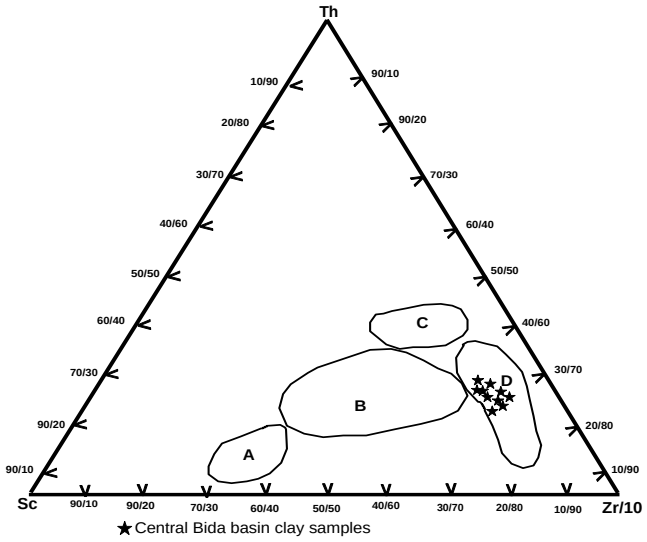


Figure 5.10: Plots of weathering intensity for basement rocks in the study area

5.3.2 Clay Minerals

Provenance of sedimentary clays depends largely upon tectonic setting, mineralogical composition, weathering index and mobility of various elements during weathering and transportation of sediments from the source rock. Comparing chemical compositions of sedimentary rock with those of known tectonic settings make it possible to establish tectonic setting of any sedimentary rocks. Bhatia and Crook, (1986), proposed a ternary discrimination tectonic setting diagram plot of Th – Sc – Zr/10. Plotting of the clay under investigation shows that all samples fall in the field of Passive Margin (Figure 5.11). The bivariant plot of TiO_2versus

Fe_2O_3 (Bhatia and Crook 1986) supported the Passive Margin provenance of the study clays (Figure 5.12). These plots suggest the study area is part of extensive passive margin region of West African Craton that was affected by Pan-African orogeny about 600 Ma ago.



Oceanic island B- Continental Island-arc C- Active continental margin
D- Passive margine

Figure 5.11: Tectonic setting discrimination diagram (after Bhatia and Crook, 1986) with plots of study clays

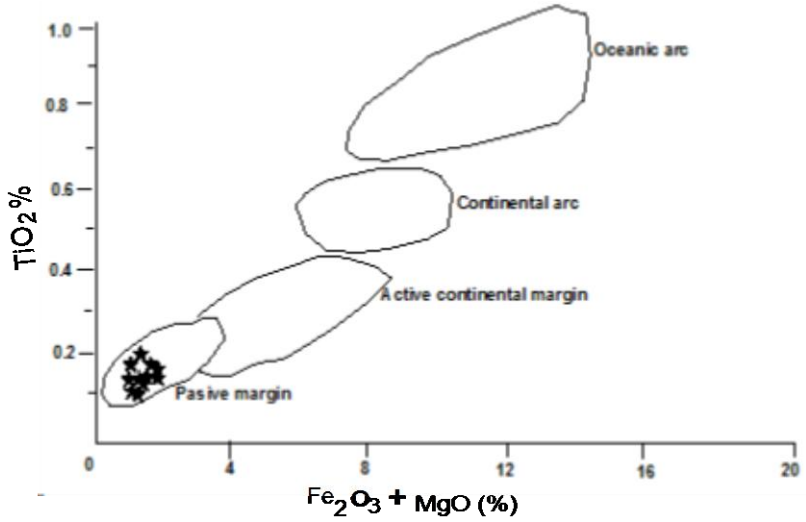


Figure 5.12: Bivariate plot of TiO_2 versus Fe_2O_3 + MgO diagram (after Bhatia M. R 1983) with plots of study clays

Trace elements has been used to categorized the provenance of clay minerals as either mafic or felsic source.Trace elements such as Cr, V, Ni, CO, Th and La in addition to Ti and Al have been suggested (El Kammar et al, 1992 and Mc Lennan and Taylor, 1991). Also, due to low mobility of rare earth elements (REEs) and high field strength elements (HFSEincluding Y, Ti, Nb, Zr, Ta, Th, Sc, Hf and Co during weathering, transportation and diagenesis, they have been mostly used for provenance studies. The application of ratio value of mobile and immobile elements are useful in the differentiation of felsic and mafic source materials.

Trace elements ratio such as La/Sc, Th/Co, Th/Sc and Th/Cr are used to differentiate felsic and mafic source rocks and may permit boundaries on the average provenance chemical composition (Wronkiewiez and Condie, 1993; Cox *et al*., 1995; Cullers, 1994).

Clay samples from the study area are quite enriched in Y, Zr, Nb, Th and U.These elements are enriched in felsic rocks rather than mafic rocks, which suggest the clays in the study area to be of felsic provenance. The moderately concentration of Co, Rb, Sr and Ba in the clays, which are always associated with clay minerals is inherited from the sources rocks.The Th/Sc, Th/Co, Th/Cr, Cr/Th, and La/Sc ratiosof clays from the study area compared with those of sediments derived from felsic and mafic rocks (fine fraction) as well Post Archean Australian Shale (PAAS) values and Upper Continental Crust (UCC) (Table 4). The comparisons reveal the study clay ratios are within the range of felsic source rock. Also, the ratios of La/Sc and Th/Sc are fairly constant in sedimentary rocks (2.4 and 0.9) respectively (Taylor and Mc Lennan, 1985). Also, La/Sc and Th/Sc ratios suggested sedimentary nature of the study clay (Table 5.1).

Table 5.1: Element average ratio of study clays comparewith mafic rock, felsic rock, PASS and UCC

Location	Th/Sc	Th/Co	Th/Cr	Cr/Th	La/ScU/ThU-Th/3La/Th V/ $CrAl_2O_3/TiO_2$
Batati	2.6	6.0	0.3	3.36	7.210.25-2.064.581.518.50
Kutigi	2.6	6.1	0.4	3.1	7.140.41 -1.5 2.231.25.98
Sakpe	2.0	3.7	0.3	3.5	6.550.20-2.63.42 1.2 8.84
Kpaki	1.6	4.6	1.1	2.22	5.310.17-4.93.02 1.113.7
Nami	2.4	12.3	0.21.5		10.5 0.31-0.22.570.919.3
Gabaji	2.5	11.1	0.4	1.26	5.60.18-5.22.751.313.4
Lemu	3.6	19.3	0.2	4.67	9.310.18-5.2 2.751.212.8
Nakama	2.4	6.1	0.3	3.19	7.010.18-5.33.221.413.4
Shegba	1.2	1.2	0.2	5.11	4.210.33 -4.93.41 1.216.5
Felsic	>1.0	>1.4	>0.1	< 15	>2.5 - - - - -
Mafic	<0.22	<1.4	<0.04	>25	<0.9 - - - - -
PAAS	0.9	0.63	0.3	7.53	2.44.70- 2.60 0.7 -
UCC	0.79	0.63	0.13	7.76	2.21 3.79 - 3.201.3 -

The plot of La – Th – Sc compositional ternary diagram after Cullers 1994 (Figure 5.13) which is used to discriminate felsic and basic provenances, show the cluster of data for the clay in the study area along Th-La and close to La than Th edge and in the region of typical gneiss source. This indicate felsic source of the study clay.

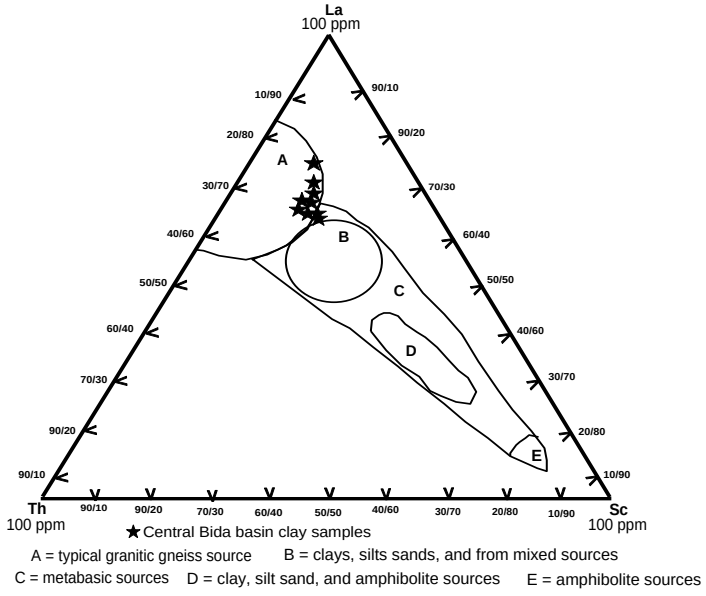


Figure 5.13: The plot of La – Th – Sc f (after Cullers 1994a) with plots of study clays

Furthermore the plot of Th/Co versus La/ Sc ratio (Cullers, 2000) shows the cluster of clays at the felsic rock end, suggesting a felsic source rocks (Figure 5.14). On the scatter diagram of Sc – Th plot after Roser and Korsch 1986 (Figure 5.15), all of the clays plot in the field of continental signature (typical of Upper crust material) indicating felsic continental source.

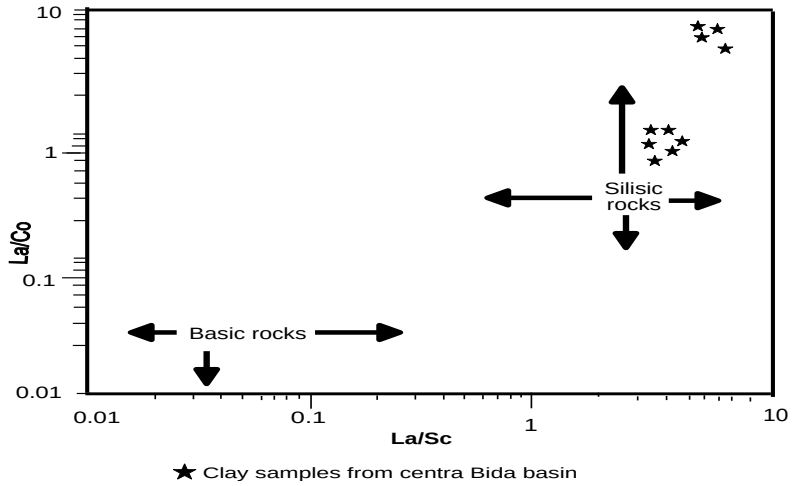


Figure 5.14: Th/Co versus La/ Sc diagram (after Cullers, 2002)with plots of study clays

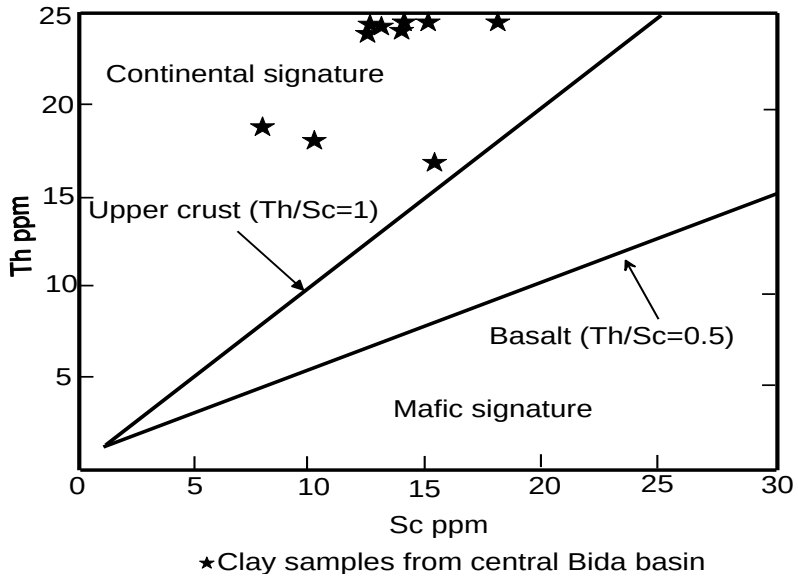


Figure 5.15: Sc – Th plot (after Roser and Korsch, 1986) with plots of study clays

Roser and Korsch (1988) used major elements discriminant function to discriminate intermediate, felsic, mafic and quartzose source provenance. Most of the studied clay samples fall within the field of felsic igneous provenances.Confirming felsic character of studied clays in the study area (Figure 5.16).

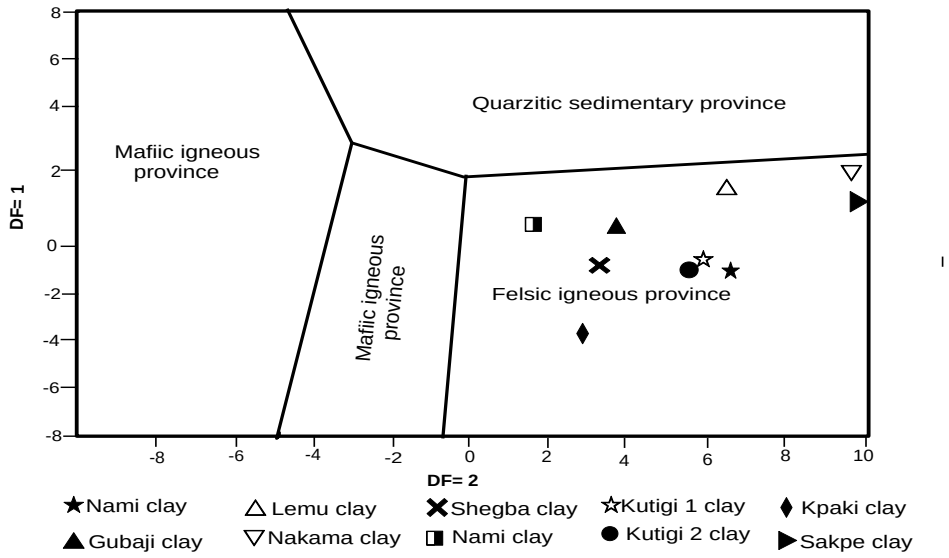


Figure 5.16: Provenance discriminant function plot (after Roser and Korsch, 1988) with plots of study clays

The ratio of Cr/V play important role in differentiating felsic source from mafic source, the ratio of Cr/V less than 8 (typical of UCC and PAAS) signify felsic source while ratio above this figure signify mafic source (McLennan*et al*., 1993). The plot of Cr versus V supported the felsic source of the clays in the study area (Figure 5.17).

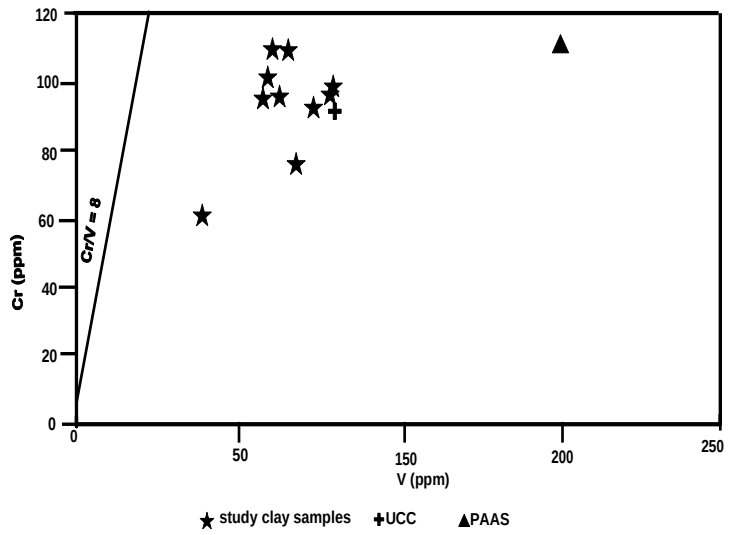


Figure 5.17: Source discrimination plots of Cr versus V diagram(after McLennan *et al*., 1993)with plots of study clays

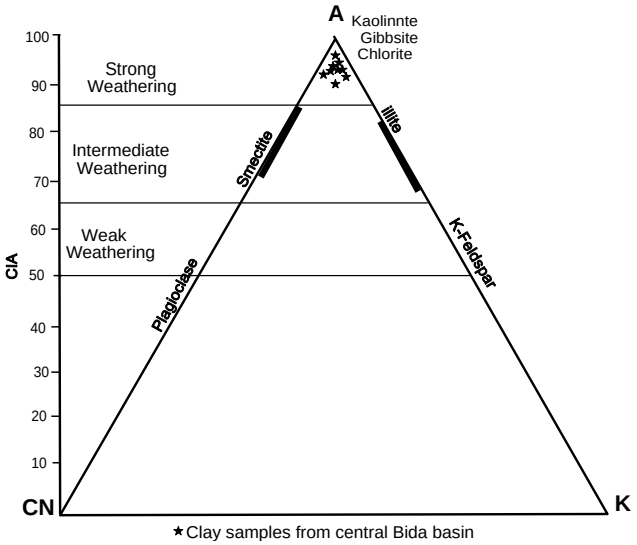
The removal of Ca, Na and K by solution during weathering process due to their high mobility resul in the abundance of these elements with respect to less easily removed elements can be used to estimate the extent of chemical weathering in the source rocks, whereas Al is the least mobile element in feldspar during weathering.

The central Bida basin clays show ΣREE content ranging between 252.53 and 468.27 with average of 357.9 which is slightly above UCC and PAAS (146.17 and 181.00) suggesting continental source rocks. ΣREE content of the study clays as observed, suggest similar source of material.

Rare earth elements (REE) pattern has been used reliably as indicator of sediment provenance, and are highly resistant to fractionation during weathering and diagenesis and preserved in terrigenous sediments. The study clays show distinct enrichment in LREE, with negative Eu anomalies. Moreover, the enrichment of incompatible elements (LREE) over compatible

elements (HREE), suggests felsic provenance and a relatively severe weathering condition (McLennan et al., 1993).

Nebsitt and Young (1982) used the ternary diagrams of chemical index of alteration CIA= Al_2O_3 / (Al_2O_3 + CaO + Na_2O + K_2O) * 100) to deduced weathering trend and intensity. CIA value of 50% - 65% reflect weak weathering, 65% - 85% intermediate weathering while 85% - !00% strong weathering. The CIA values of the clay samples range between 99% and 89%, average 95.5% and plot near Kaolinite (Figure 5.18), indicating strong intensive weathering of the source rock. Th/U ratio is of interest in determination of weathering intensity of sediment rocks. The Th/U ratio in most upper continental crust rocks is typical between 3.5 and 4.0 (McLennan *et al*., 1993), thus Th/U ratio value higher than 4.0 indicate intense weathering in sources area. The Th/U ratio average of the central Bida basin is 4.63 suggesting the clay samples are of intensive weathering of it source rocks.



A = Al_2O_3 C = CaO K = K_2O

Figure 5.18: A-CN-K diagram (after Nebsitt and Young, 1982)with plots of study clays

The differences in the source rock, the intensity of chemical weathering, sorting of minerals during transportation and deposition in the sedimentary basin and post-deposition alteration can be resolved using the relation between Nb and Zr (Fralick and Kronberg, 1997; and Fralick, 2003). Applying geochemical plot of Nb vs Zr, it revealed that all the claysin the study are from similar source rocks (Figure 5.19).

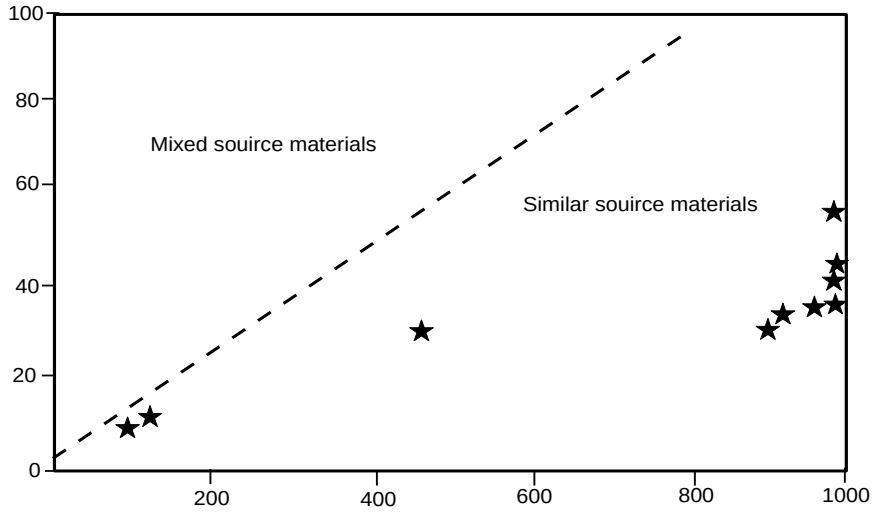


Figure 5.19: Plots of Nb and Zr discriminate (after Fralick and Kronberg, 1997, Fralick, 2003)with plots of study clays

Basement rocks adjacent to Bida basin are composed of alkali feldspar. These rocks were chemically weathered, and the rock minerals transported to the basin. The alkali feldspar minerals and other clastic materials deposited in the basin are favored by the prevailing tropical climate, early diagenetic process and in-situ intensive leaching of silica and potassium by meteoric water the favored the formation of kaolinite and illite.

In this study, two dissolution stages are inferred:

(i) early stage (surface weathering) ofK-feldspar alteration to kaolnite in respond to meteoric influx, resulting to the leaching of K^+;

(ii) late stage of K-feldspar alteration in responds to change in temperature, leaching of $K^+$by water and incorporate of K^+ in the aluminosilicate structureresulting in the precipitation ofillite.

$2KAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2K^+$ ……...(i)
K-Feldspar Kaolinite

$KAlSi_3O_8 + Al_2Si_2O_5(OH)4 \rightarrow KAl_3Si_3O_{10}(OH)_2 + 2SiO_2(aq) + H_2O$……... (ii)
K-feldspar Kaolinite Illite Quartz

Also,mafic grain dissolution liberate Fe^{2+} and Mg^{2+} and precipitate them around quartz grain and form feruginized sandstone while the leaching of soluble ions leaves the moreinsoluble ions, predominantly iron and aluminium and precipitation of iron aluminium hydroxide as laterite.

Marine clays generally contain suite of clay minerals of illite, kaolinite, chlorite, and mix-layer clays, whereas non-marine clays are rich in Kaolinite and small amount of illite. Generally, non-marine clay minerals are differentiated from marine clay minerals by their low concentration of MgO, high concentration of SiO_2 and Fe_2O_3 while marine clay minerals has high concentration of MgO, low concentration of SiO_2 and Fe_2O_3. Binary plots of Fe_2O_3 versus MgO and K_2O/Al_2O_3 versus log MgO/Al_2O_3 after Ratcliffe et al., (2007) suggest the clays to be of non-marine source (Figure 5.20 and 5.21). Also, ternary plot of of Fe_2O_3, MgO and SiO_2/Al_2O_3 after Ratcliffe et al., (2007) support the non-marine source of the kaolins (Figure 5.22).

Adeleye (1971), suggested marine to fresh water origin of the ironstones in the southern part of Bida basin by evidence of biota and texture. Braide, (1992) studied sedimentology, characteristic depositional motifs, sedimentary structure and depositional mode of the central Bida basin and

reported non-marine character. This study show non-marine origin of the kaolins in central Bida basin.

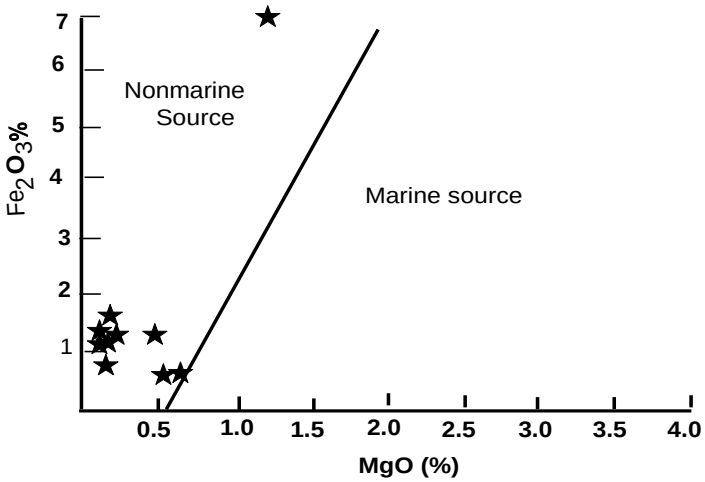


Figure 5.20: Binary diagram of depositional environment differentiation (after Ratcliffe *et al.*, 2007) with plots of study clays

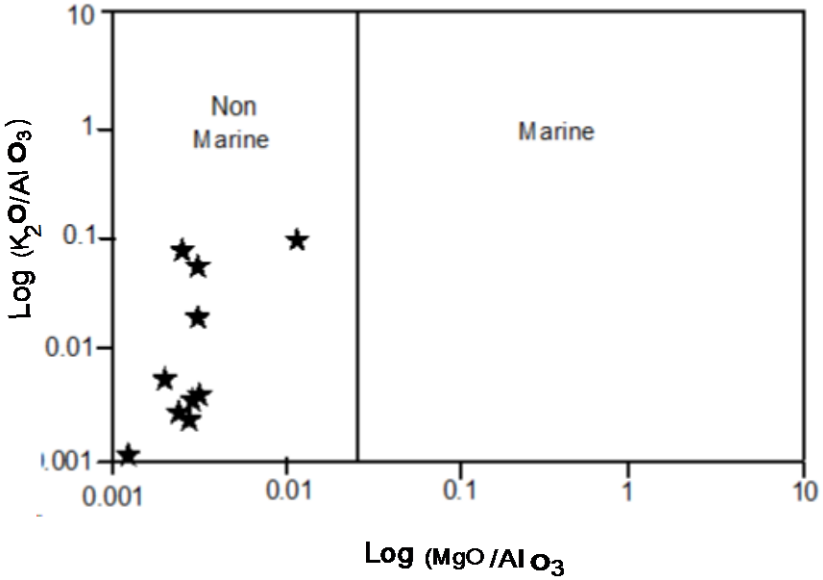


Figure 5.21: Plot of depositional environment differentiation (after Roadset, 1978) with plots of study clays

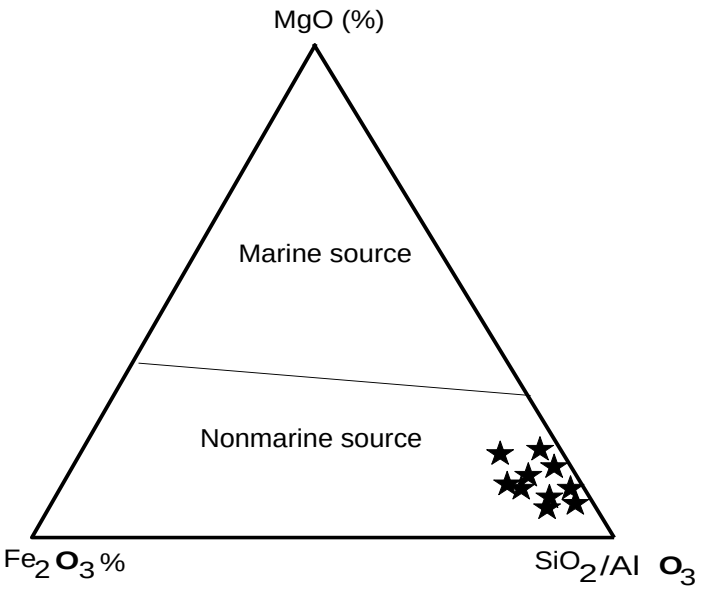


Figure 5.22: Ternary diagram of depositional differentiation (after Ratcliffe *et al.*, 2007) with plots of study clays

5.4 Industrial Applications and Human benefits of central Bida clay deposits

5.4.1 Industrial applications

Clay material with kaolinite mineral compositon of >40% is considered to be of industrial important Bridley (1966). This implies that the clay occurrences in Nami, Shegba, Kutigi, Batati and Sakpe of which their kaolinite content ranges from 42% to 66.2% can be considered for industrial application.

Chemical composition of kaolin couplewith physical properties (grain size, linear firing shrinkage, and color) plays important role in the industrial applications of clay.Major oxides (SiO_2, Al_2O_3, Na_2O, K_2O, Fe_2O_3, TiO_2 and CaO) play asignificant role in the industrial application of kaolin, SiO_2act as glossy binding for clay particles which gives strength to finished pottery body. It also acts as an agent of dispersion and chemical inert and resistance to frosting.$Al_2O_3$is important ingredient of glazing agent, improve strength, toughness, brightness

and durability of ceramic body and also cement the crystalline phase of other ingredient and high resistance to abrasion. Na_2O and K_2O are fluxing agents in ceramic and as functional filler in paint, plastic, rubber and adhesives, it also reduce the melting temperature of quartz and help to control viscosity of glass.

Free or low Fe_2O_3content in clay make it suitable for molding or making of pottery, it low concentration also act as agent of durabity in tile and sanitarywares. It gives red colouration to finished poterry product. TiO_2provide white pigment, whiteness and opacity for paints, coating in plastic and paper while CaO act as cementing agents/adhesive material in ceramic and cement industries.

In ceramic applications: Kaolin was originally used in the manufacture of whiteware ceramics; the amount of kaolin used for this purpose is now greatly exceeded by that used in the paper industry. The major markets for kaolins in the whiteware ceramic industry are tableware, vitreous-china sanitaryware, wall tiles, electrical porcelain and glazes.

Paint applications: Water based decorative paints: gloss; semi-gloss and silk; exterior matt - smooth and textured; interior matt; primers.

Rubber applications: Kaolin is incorporated into both natural and synthetic rubber compounds and is the rubber industry's most widely used non-black filler with reinforcing properties.White cement applications: In the production of white cement, iron is a deleterious component which can be avoided by using kaolin with very low iron content.Glass fibre applications: The preferred raw material for introducing alumina to glass compositions for glass fibre manufacture is kaolin. Also in plastics applications, kaolin has many uses as filler in plastics.

Agricultural industries: The caking or setting of granular fertilisers (prills), is a serious problem since the caked mass must be broken down into its individual particles before it can once again become a free-flowing product. Kaolin, some of which is amine-coated, acts a non-stick coating to fertiliser prill. As colour is of no significance, cheaper grades can be used.

In pharceutical industry kaolin is used as a protentant for temporary relief of anorectal itching, diapers, adsorbent to bind toxic and control diarrhea, treatment of enteritic, cholera and dysentery, dustind powder and exipient, drying adent to dry oozing and weeping poisons (RDA, 1989).Other industries where kaolin as find use includestextiles, inks, dyes, adhesives, crayons and pencils, toothpastes and cosmetic applications.

The chemical composition of the study clays compared with industrial specifications (Figure 5.2a and 5.2b), Sakpe clay depositcan be utilize as raw material for the production of Refractory bricks (Parker, 1967), Pottery production (Arua and Onyeoku, 1978) and Ceramics (Singer and Sonja, 1971).

Batati, Kutigi and Sakpe clays may require beneficiation to upgrade Al_2O_3 level to meet raw material for the production of Refractory bricks, Pottery production and Ceramics. Shegba clay has find use for pot making by the native of the area (Appendx 1i), considerable level of Fe_2O_3in shegba clay will impact coloration effect on finished product. In Kutigi and sakpe the clay has been used locally for house painting.The study clay caintain considerable high content of quartz that can cause damage to the skin (due to it abbressiveness) and thus render it unfit for talcum powder production.

5.4.2 Human benefits

Kaolin consumption is common among pregnant women, lactacting women and children in the developing nations for extra minerals and stimulation of siliva flow. In India eating of kaolin (geophogia) with potatoes is thought to be effective in the elimination of food betterness and prevent stomach pain and vomiting, while high concentration of Na and P could relieve a mineral shortage in the remen.

Twenty one inorganic elements made up of five mojor minerals (Ca, Na, K, Mg, and P) in several hundred milligrams/dayand fifteen trace elements in few milligrams/day are required and considered as being essential to human life.

Manganese an essential element that is stored in the human kidney and liver, it mentain reproductive of blood cells and functioning of Central Naervous system and require for various biochemical and enzymatic process and help in elimilating fatique, the Recommended Dietry Allowances (RDA) value for manganese is 2 mg/day. In the study clay manganese concentration ranges between 0.02 and 0.06, low compare to Recommended Dietry Allowances (RDA) value.

Zinc is nutritional important elements (Paulet al., 2007). Zinc is good for the multiplication of skin cell, bone metabolism, and functioning of taste and eyesight (Thunus and Lejuene, 2004). Low concentration of zinc in human is known for recurrentinfection, lack of immunity, growth retardiation, skin change and poor appetite. Pregnant and lacting women require 11 to 12 mg/day (RDA, 2001), estimated safe and adequate daily intake of zinc is between 10 and 20 gm/day (Tugel et al., 2005). Excessive and prolong intake of large dosea can result in fatique and dizziness (Hess et al., 2012).

Iron (Fe) insufficient concentration in the body can cause anemia and excessive menstrual flow in wemen (Mokoba, 2008), whereas excess of Iron could cause chronic overload of iron in the body and may result in heart failure. Cobalt (Co) is required in the sytnthesis of vitamin B_{12}, excess of cobalt in human system can caose cobalt poisoning and death (RDA, 2001). Recomemded intake of 15 to 1mg is required for cobalt, whereas in the study clay cobalt value range between 0.0001 and 0.0006 mg suggesting lower values compare to recommended values. Chromium is important for improving blod sugar regulation for people with diabetes, improve depression and weight loss, however, excess and prolong intake cancause skin irritation, headaches, dizziness, nausea, mood change and impaired thinking. Chromium in the study clay is considerably high compire to the required in human body system (0.001 and 0.034).

Alluminium is required low quantity for the regulartion of human body temperature, regular blood and promote hardness of bone, large amount intake of alluminium can cause anemia, asteomalacia (brittle or soft bones), glucose intolerance and cardic arrest in human whereas low concentratin of alluminium in the blood circulation can cause heart failure and deformation of bones, reauired quantity in human blood is between 0.003 and 0.006 mg (RDA, 2001). The vstudy clay value is considerable high in the study clay. Titanium constitu ninth most abundant metal in the earth crust, it high concentration can cause adverse effects by producing oxidative stress, cell damage and slow immue response, recomende intake of between 0.0005 to 0.0008 (RDA, 2001). They study clay value range between 0.097 and 1.211 sugeest high values as against recommended values.

Magnessium is required for energy production, structural development of bone and alsorequire for the synthesis of DNA, RNA and antioxidant. In the secretion of enzymes magnesium is required in high level (Ghefat *et al.,* 2010). Magnesium concentration in the study clay range between 0.024 and 0.543 mg compare with Recommended Dietry Allowances (RDA) of 420 mg. Sodium value for Recommended Dietry Allowances (RDA)is 1500mg, it is essential in in co-regulating of high temperature in the body with potassium (Micheal, 2008). Sodium concentration in the study clay is lower and range between 0.371 and 0.226) mg.Comparison of the study clay with element composition of raw clay recommended for dietary allowance in pregnant and lactating women show a signifigant low content of element of Ca, Cr, Cu, Fe, K, Na, and Mg, whereas Co show a significant high concentration. This sugest the study do not meet dietary allowances for pregenant and lactating women. Although geophagic is not a common practice by the native of the study area.

Table 5.2b: Chemical comparison of the study clay with raw kaolin industrial specifications

Oxide %	Reference Samples						Nami	Gubaju	Lemu	Nakama
	A	B	C	D	E	F				
SiO2	51.70	67.50	44.90	45.90-48.5	38.67	59.81	67.8	77.53	85.15	63.52
Al_2O_3	25.44	26.50	32.35	33.5-36.1	9.45	29.76	19.2	12.93	7.63	23.39
Fe_2O_3	0.5-1.20	0.5-1.20	0.43	0.30-0.60	2.70	3.02	1.85	0.78	1.13	1.09
MgO	0.2-0.70	0.1-0.19	Tr	-	8.5	1.45	0.03	0.03	0.12	0.09
CaO	0.1-0.20	0.18-0.30	Tr	0.0-0.50	15.84	1.32	0.007	0.06	0.10	0.12
Na_2O	0.8-3.50	0.20-1.50	0.14	0.0-1.6	2.76	0.47	0.03	0.03	0.04	0.06
K_2O	-	1.10-3.10	0.28	0.0-1.6	2.76	0.87	0.14	0.34	0.14	0.71
TiO_2	1.0-2.80	0.10-1.0	1.80	0.0-1.70	-	0.92	1.04	2.16	0.86	1.69
P_2O_2	-	-	-	-	-	-	-	-	-	-
MnO	-	-	-	-	-	-	-	-	-	-
LIO	-	12.04-12.50	-	-	3.04	10.56	8.30	4.86	3.56	8.41

(A) = Refractory bricks (Parker, 1967) (B) = Ceramics (Singer and Sonja, 1971) (C)= Ruber (Keller, 1964)
(D) = Paper (Keller, 1964) (E) = Bricks (Murray, 1960) (F) = Pottery (Arua and Onyeoku, 1978)

Table 5.2b: Chemical comparison of the study clay with raw kaolin industrial specifications

Oxide %	Reference Samples						Shegba	Batati	Kutigi	Sakpe	Kapki
	A	B	C	D	E	F					
SiO_2	51.70	67.50	44.90	45.90-48.5	38.67	59.81	57.98	66.88	65.33	54.91	72.42
Al_2O_3	25.44	26.50	32.35	33.5-36.1	9.45	29.76	18.70	21.70	21.66	29.15	17.13
Fe_2O_3	0.5-1.20	0.5-1.20	0.43	0.30-0.60	2.70	3.02	7.11	1.12	1.15	0.97	0.94
MgO	0.2-0.70	0.1-0.19	Tr	-	8.5	1.45	0.30	0.08	0.09	0.05	0.03
CaO	0.1-0.20	0.18-0.30	Tr	0.0-0.50	15.84	1.32	0.66	0.09	0.1	0.05	0.08
Na_2O	0.8-3.50	0.20-1.50	0.14	0.0-1.6	2.76	0.47	0.23	0.09	0.10	0.05	0.10
K_2O	-	1.10-3.10	0.28	0.0-1.6	2.76	0.87	1.74	0.72	0.76	0.30	0.53
TiO_2	1.0-2.80	0.10-1.0	1.80	0.0-1.70	-	0.92	0.97	1.61	1.66	1.76	1.82
P_2O_2	-	-	-	-	-	-	-	-	-	-	-
MnO	-	-	-	-	-	-	-	-	-	-	-
LIO	-	12.04-12.50	-	-	3.04	10.56	11.95	8.44	7.91	11.37	6.40

(A) = Refractory bricks (Parker, 1967) (B) = Ceramics (Singer and Sonja, 1971) (C)= Ruber (Keller, 1964)
(D) = Paper (Keller, 1964) (E) = Bricks (Murray, 1960) (F) = Pottery (Arua and Onyeoku, 1978)

Table 5. 3: Recommended Dietry Allowances (RDA) of some elements for pregnant and lactating Women (RDA, 2001)

Location	Ca	Cr	Cu	Fe	Mn	Zn	K	Na	Co	Mg
Nami	0.028	110	10	1.236	0.005	<30	0.116	0.022	1	0.024
Gubaji	0.042	90	<10	0.532	0.009	<30	0.240	0.022	2	0.038
Lemu	0.028	80	<10	0.742	0.005	<30	0.108	0.029	1	0.0241
Nakama	0.071	90	30	0.781	0.006	<30	0.622	0.066	5	0.0543
Shegba	0.472	120	<10	4.923	0.061	60	1.460	0.170	15	0.398
Batati	0.064	110	<10	0.814	0.006	<30	0.597	0.059	6	0.054
Kutigi	0.071	120	<10	0.783	0.006	<30	0.630	0.081	5	0.060
Sakpe	0.037	130	<10	0.675	0.005	40	0.573	0.371	10	0.030
Kpaki	0.064	90	10	0.923	0.008	<30	0.481	0.074	4	0.543
Pregnant	1000	0.03	1000	27	2	11	4700	1500	0.006	420
Lactation	1000	0.045	1300	9	2.6	12	5100	1500	-	420

Chemical comparison of study clay with clays from other sedimentary basins in Nigeria; Mpu western Niger Delta, Afikpo Calabar, Afam eastern Niger Delta and Ubaja Anambra basin. The comparison show high concentration of SiO_2 average 70.2% and low concentration of Al_2O_3 average 17.5% in the study clay compare to other sedimentary clays of SiO_2 average 54.7% and $Al_2O_3$28.3% (Table 5.3a and 5.3a).

Table 5.3a: Chemical comparison of study clay with clays from other sedimentary basins in Nigeria

Oxide %	Nami	Gubaju	Lemu	Nakama	Shegba	1	2	3	4	5
SiO_2	67.8	77.53	85.15	63.52	57.98	59.45	59.81	42.2	50.41	57.41
Al_2O_3	19.2	12.93	7.63	23.39	18.70	21.70	29.76	26.2	31.62	28.32
Fe_2O_3	1.85	0.78	1.13	1.09	7.11	2.0	3.02	5.10	2.43	3.63
MgO	0.03	0.03	0.12	0.09	0.30	0.36	1.45	0.70	0.17	1.27
CaO	0.007	0.06	0.10	0.12	0.66	0.23	1.32	1.60	0.11	1.21
Na_2O	0.03	0.03	0.04	0.06	0.23	0.34	0.47	2.90	0.02	0.32
K_2O	0.14	0.34	0.14	0.71	1.74	1.74	0.87	0.30	0.29	0.32
TiO_2	1.04	2.16	0.86	1.69	0.97	1.52	0.92	-	2.73	1.83
P_2O_2	-	-	-	-	-	0.03	-	-		-
MnO	-	-	-	-	-	0.04	-	0.03	0.02	0.05
LIO	8.30	4.86	3.56	8.41	8.95	9.68	10.56	-	10.23	10.03

(1) Mpu clay (Obrike *et al*. 2012) (2) Afikpo clay (Arua and Onyeoku, 1978) (3) Afam clay (Jubril *et al.* 1991) (4) Ubaja clay (Onyeobi *et al.* 1912) (5) Ubulu-Uku (Emofurieta *et al.* 1992)

Table 5.3b: Chemical comparison of study clay with clays from other sedimentary basins in Nigeria

Oxide %	Batati	Kutigi	Sakpe	Kapki	1	2	3	4	5
SiO_2	66.88	65.33	54.91	72.42	59.45	59.81	42.2	50.41	57.41
Al_2O_3	21.70	21.66	29.15	17.13	21.70	29.76	26.2	31.62	28.32
Fe_2O_3	1.12	1.15	0.97	0.94	2.0	3.02	5.10	2.43	3.63
MgO	0.08	0.09	0.05	0.03	0.36	1.45	0.70	0.17	1.27
CaO	0.09	0.1	0.05	0.08	0.23	1.32	1.60	0.11	1.21
Na_2O	0.09	0.10	0.05	0.10	0.34	0.47	2.90	0.02	0.32
K_2O	0.72	0.76	0.30	0.53	1.74	0.87	0.30	0.29	0.32
TiO_2	1.61	1.66	1.76	1.82	1.52	0.92	-	2.73	1.83
P_2O_2	-	-	-	-	0.03	-	-	-	-
MnO	-	-	-	-	0.04	-	0.03	0.02	0.05
LIO	8.44	7.91	11.37	6.40	9.68	10.56	-	10.23	10.03

(1) Mpu clay (Obrike *et al*. 2012) (2) Afikpo clay (Arua and Onyeoku, 1978) (3)Afam clay (Jubril *et al.* 1991) (4) Ubaja clay (Onyeobi *et al.* 1912) (5) Ubulu-Uku (Emofurieta *et al.* 1992)

CHARPTER SIX: SUMMARY, CONCLUSIONAND RECOMMENDATIONS

6.1 Summary

The Bida basin has experienced two episodes of marine incursions during the upper Campanian and lower Maastrichian that resulted to the deposition of Sakpe Ironstone and Batati oolitic and geothitic ironstone, and also two episodes of marine withdrawer during the lower Campanian and upper Maastrichian that resulted to the deposition (continental material) of Bida sandstone, Enagi siltstone and the study clay deposits.

Ten clay deposits were mapped in the central Bida basin, which were mostly capped by ironstons and feruginzed sandstone in some locations. The clay is dominant kaolinitic clay, the clays are of similar source and (from the adjoining basement complex. Major elements plots and trace element ratios/plots suggest the clay deposits to be of continental crust origin and were deposited in fluvial environment.

The fieldwork, mineral and chemical compositions of the part of basement complex rocks revealed rocks to be granite, granodiorite, monzo diorite, muscovite schist, biote schist, quartz schist, migmatitic-granite and mylonite gniess with concentration of feldspars average 42% (microcline, plagioclase and albite) in the felsic rocks.

Clay mineral variation indices of clays show increase in kaolinite content from the basin /basement complexmagin (NW) towards the centre of the basin (SE), and inverse variation of quartz content to Kaolinite . This suggest mineral maturity of the clay towrds the basin center and it also reflect reduction in transport energy of sediments supply from the source

area (basement complex) where clay materials are carried in suspension and deposited in the basin.

Futhremore, chemical variation index show a gradual increase of Zr/Cr and Zr/Rb ratios toward the basin from the basin magin, suggesting enrichment of Zr in clay due to its immobility and felsic source rocks. Cr/V ratios are are similar in the study clays, suggesting the clays to be of similar source material and have suffered similar weathering intensity.

Low/high concentration of some elements and element ratios of the clay deposits suggest poor industrial applications and medical benefits of the study clays, except for Sakpe,clay deposits that can be utilize as raw material for the production of Refractory bricks, Pottery and ceramics production. High SiO_2 content (average 65.3%) of all the study clays will render it unfit in the production of talcum powder. The central Bida basin clays compare favourably with clays from Mpu western Niger Delta, Afikpo Calabar, Afam eastern Niger Delta and Ubaja Anambra basin.

6.2 Conclusion

The clay deposits in central Bida basin are predominantly kaolinitic clay, they occurred in plains an on masses capped by oolitic/geothitic ironstone and ferrugized sandstone withraging from 8 to 4 meters. The clayswere suggested to have been formed in fluvial environment (after marine withdrawal) during the influx of weathered sediments that wheretransported from the adjoining Basement Complex rocks, deposited and favored by early diagenesis process and in-situ intensive leaching in the basin during the upper Maastrichian age.

Bulk mineral composition and abundance of major and trace elements in the clay shows evidence of felsic protolith of the souce rocks, intensive weathering and alteration of the feldspars in-situ in the basin that form kaolinite. Illite concentration is atributed to incomplete degration of K-felspar to kaolinite or to diagenesis of kaolinite within the basin. Trace element ratios of the clays show felsic source rocks and non-marine provenance, while the REE patterns show similar source of the clay materials and futher strengthen the predominance felsic sources (upper continental crusts).

Field mapping, mineral and chemical composition of the part of the adjoining Basement Complex rocks to the basin,suggested these rocks are granite, granodiorite, mica schist, quatz schist, migmatitic gneiss, mylonite gneiss and amphibole.

Combine geological fieldwork and field observation has allowed a sketch that depict the physiography of the study area (Figure 6.1).This present study therefore represent contribution to the understanding of the influence of the basement complex on the central Bida basin and provide some evidence for provenance, environment of deposition and industrial applications/human benefits of the clay deposits in the central Bida.

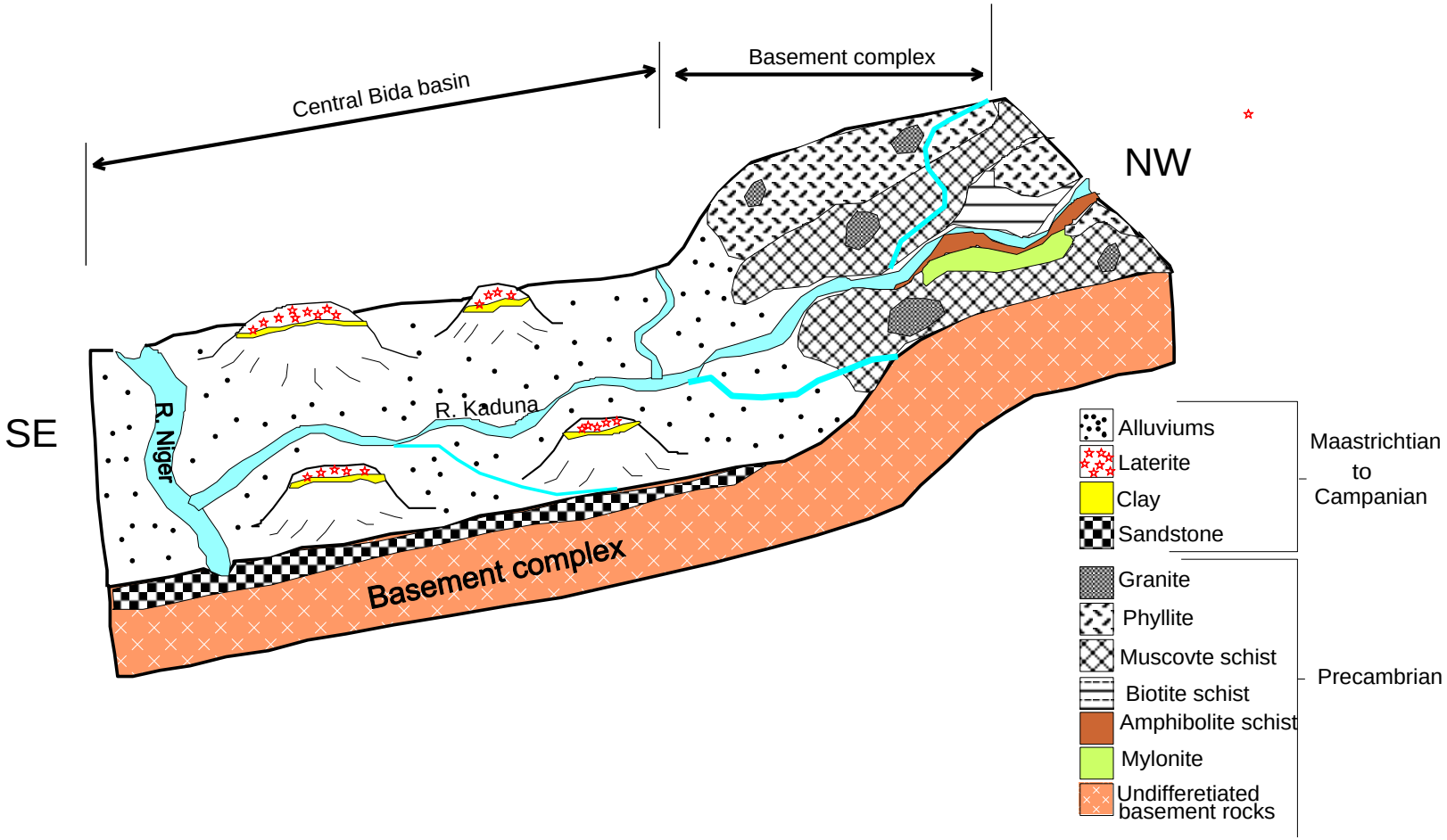


Figure 6.1: Physiography sketch for the study area

6.3 Recommendations

In the light of this study, reserve estimation, beneficiation and physical characteristics of the clays in the central Bida basin is recommended as this will further reveal the economic potentials of these deposits. Also, similar study should be b extent to other part of the basin to provide regional provenance, sedimentation and economic potential clay deposits in the entire basin.

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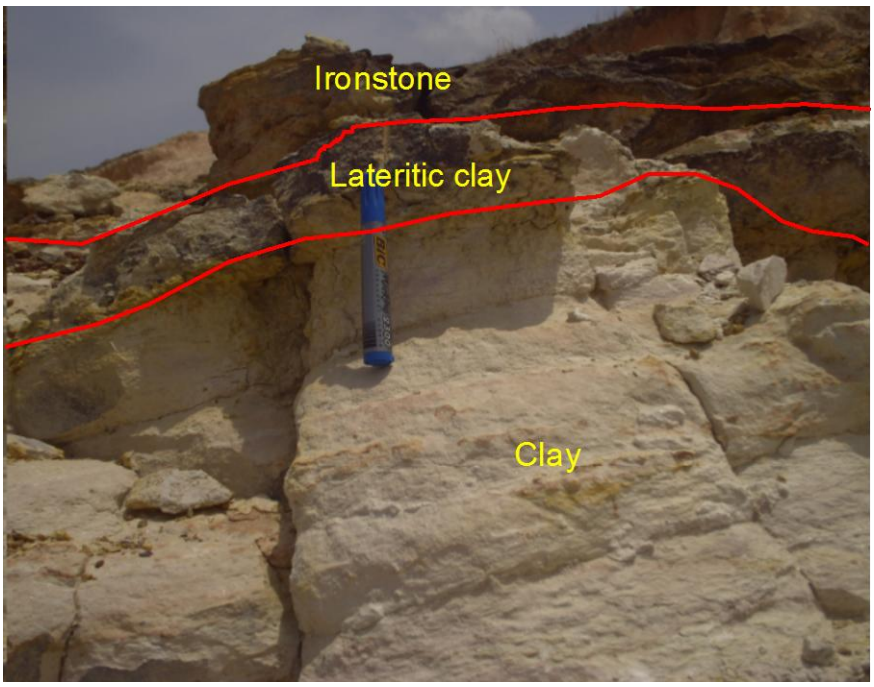
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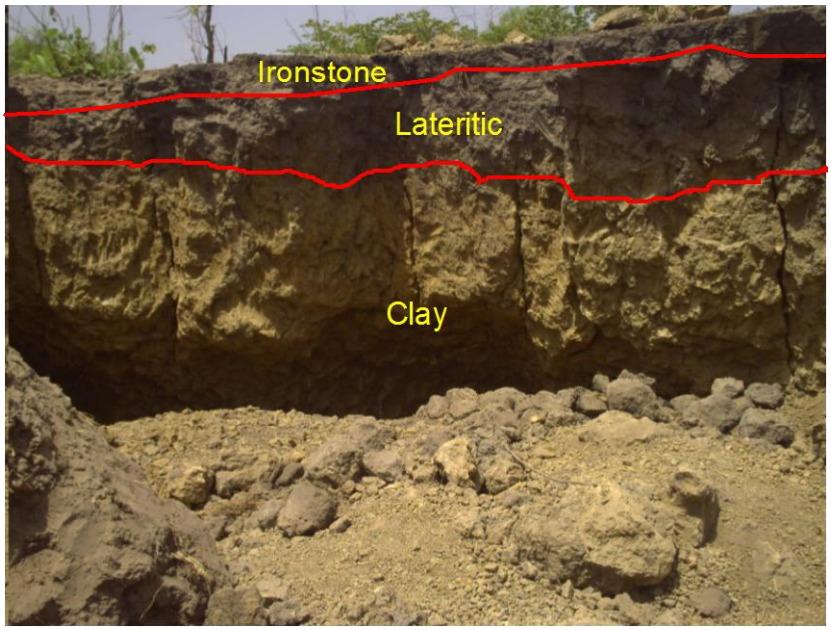
APPENDIX I

Joint Directions taken on basement complex rocks in the study area

Location	Joint Direction (^{0})
1	030, 210, 320, 140, 118, 174, 298, 006.
4	024, 204, 032, 212, 080, 260, 162, 342.
5	128, 308, 138, 144, 324, 164, 318, 352, 280, 100.
6	248, 182, 286, 164, 010, 190, 068, 200, 344, 106.
8	214, 032, 082, 268, 056, 234, 152, 332, 300, 120, 312,128.
12	236,056, 310, 136, 200, 020, 122, 302, 304.
15	140, 320, 280, 100, 290, 110, 028, 110, 290.
16	202, 042.
19	006, 196.
20	200, 020, 012, 022, 212, 192, 313, 133, 034, 214.



Appendix Ia: A Clay bed overlain by lateritic clay and ironstone in Batati (09°10' 09″ N - 05°45' 12 ″E***)***



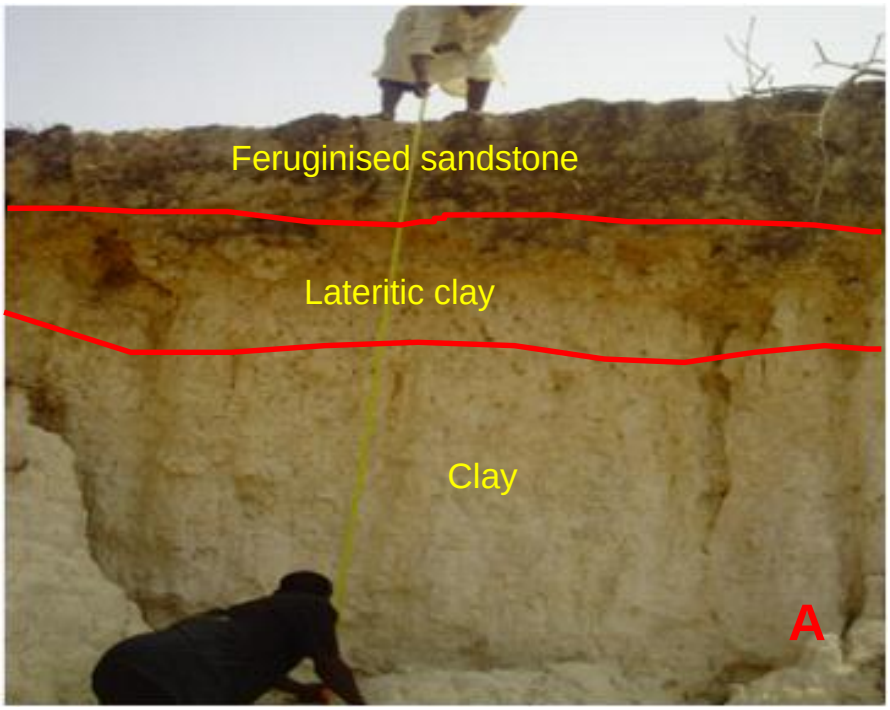
Appendix 1b: A Clay bed overlain by lateritic clay and ironstone in Shegba (09°15' 09″ N - 05°54' 16″ E)



Appendix 1c: A Clay in Kutigi "A" clay occurrence (09°13'15″N - 05°35' 07″ E



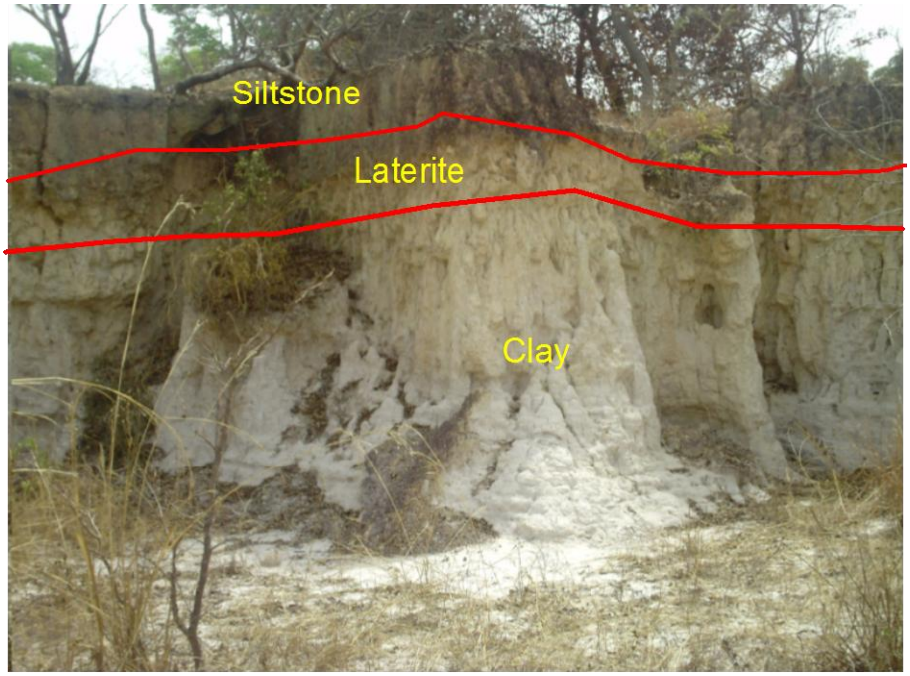
Appendix 1d: A Clay bed in Kutigi "B" clay occurrence and 09° 15' 22″ N - 05°36' 24″ E)



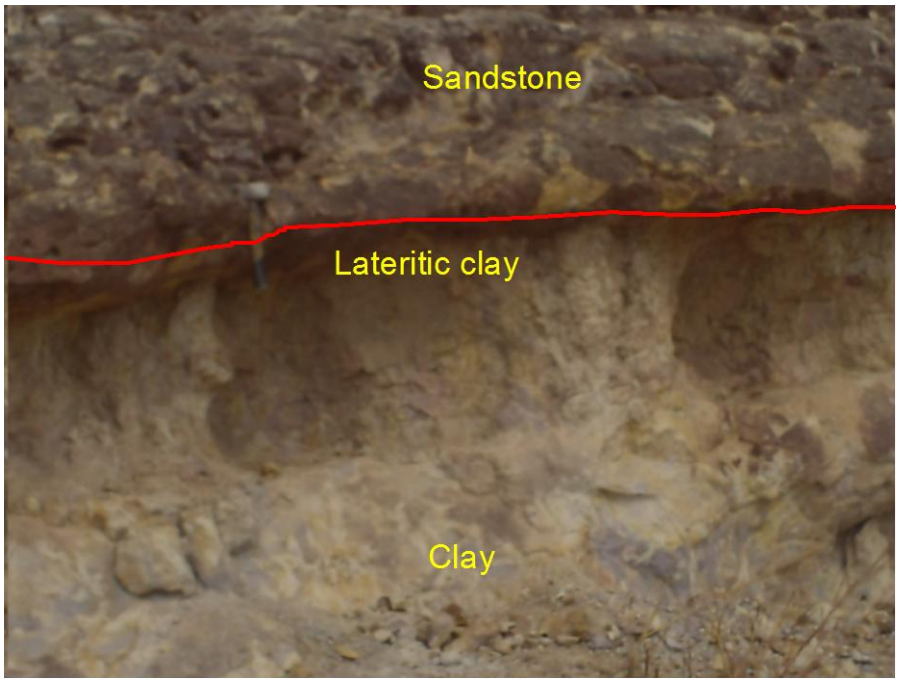
Appendix 1e: A Clay bed overlain by lateritic clay and feruginised sandstone in Kpaki (09°20' 09″N - 05°32' 16″E)



Appendix If: Collection of clay sample from the pit at Shegba (09°15' 09″ N - 05°54' 16″ E)



Appendix 1g: A Clay bed overlain by lateritic and siltstone in Sapke (09°05' 12″ N - 05°33' 21″ E)



Appendix 1h: A Clay bed overlain by lateritic clay and sandstone in Nami (08°40' 13″ N - 06°30' 15″ E)



Appendix 1h: A Clay in Gubagi (08°56' 24″ N - 06°10' 19″ E)



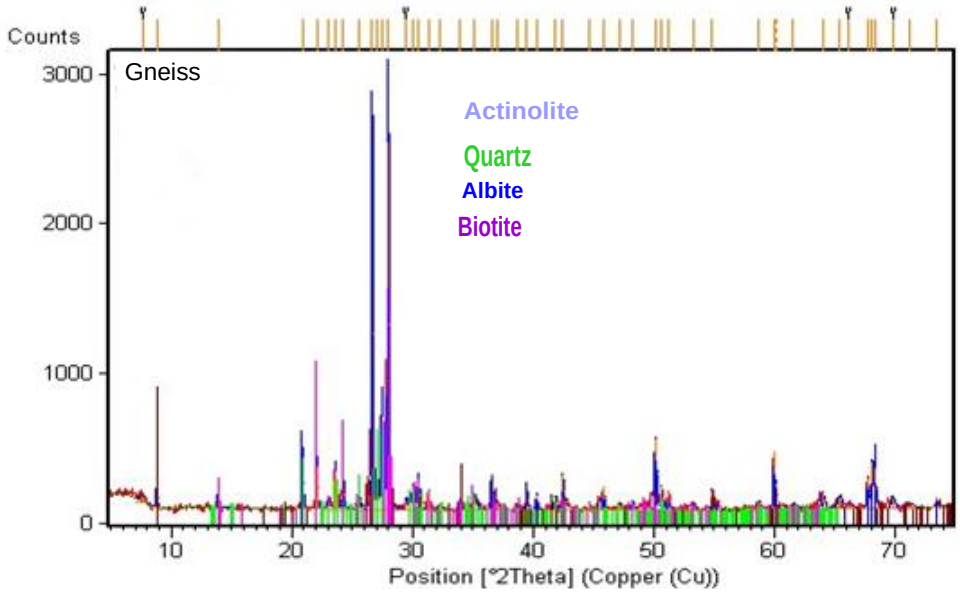
Appendix 1i: Pottery maker using clay occurrence in Shegba



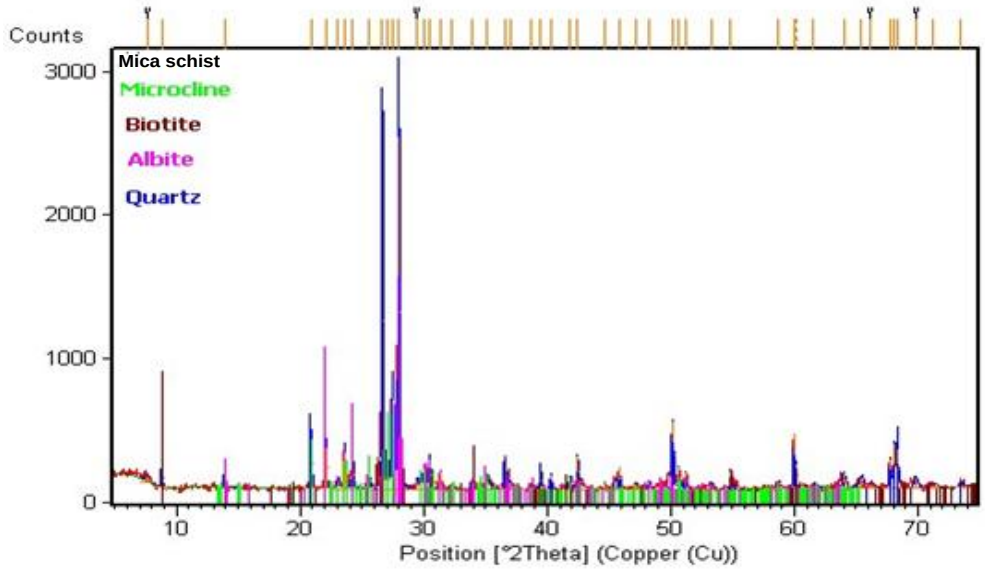
Appendix 1j: Physiography of Bida basin showing a messa in Nakama area (09°10'14″ N - 06°04'19″ E)

APPENDIX II

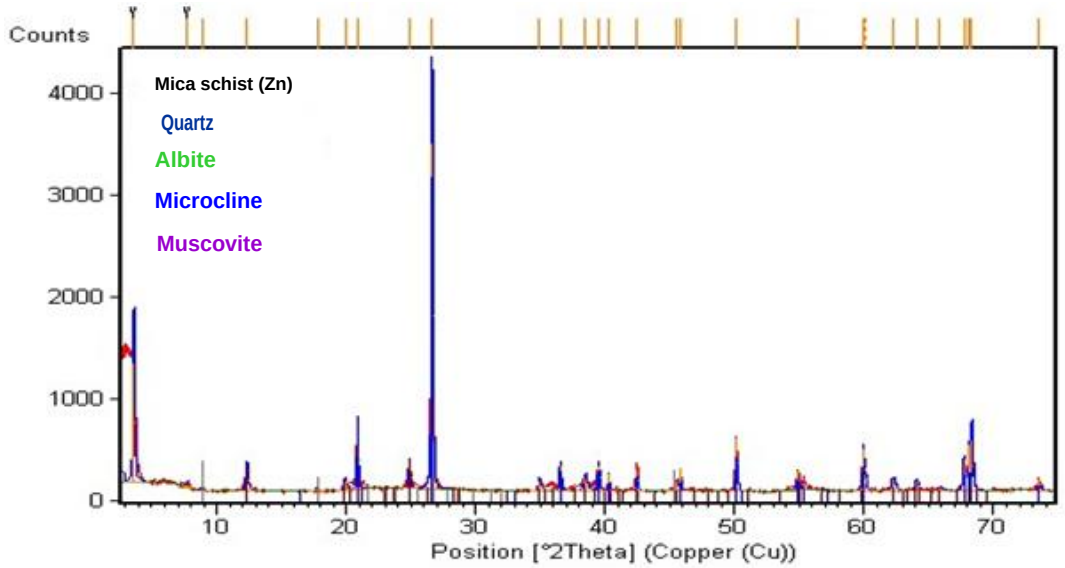
X-ray Diffractogram patern of the basement complex rock samples



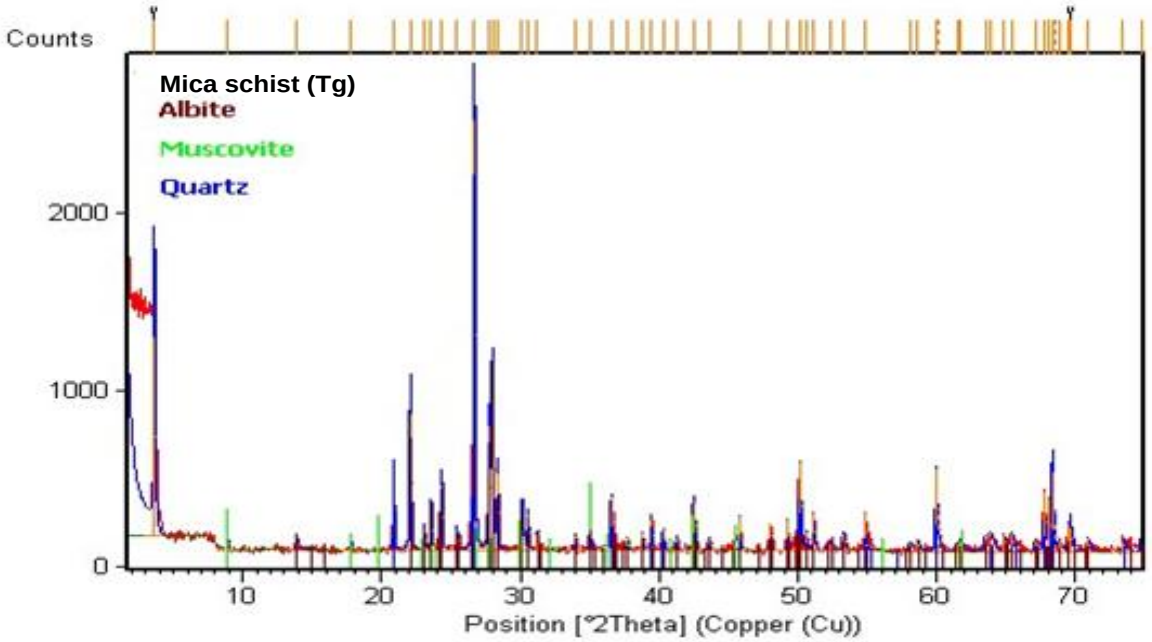
Appendix IIa: X-ray Diffractogram for Gneiss



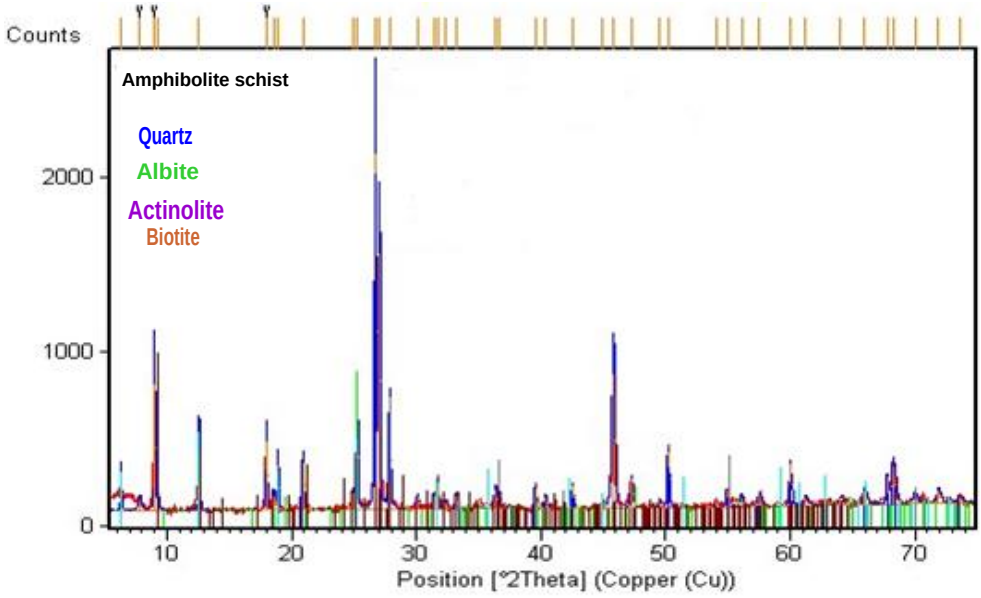
Appendix IIb: X-ray Diffractogram for biotite schist



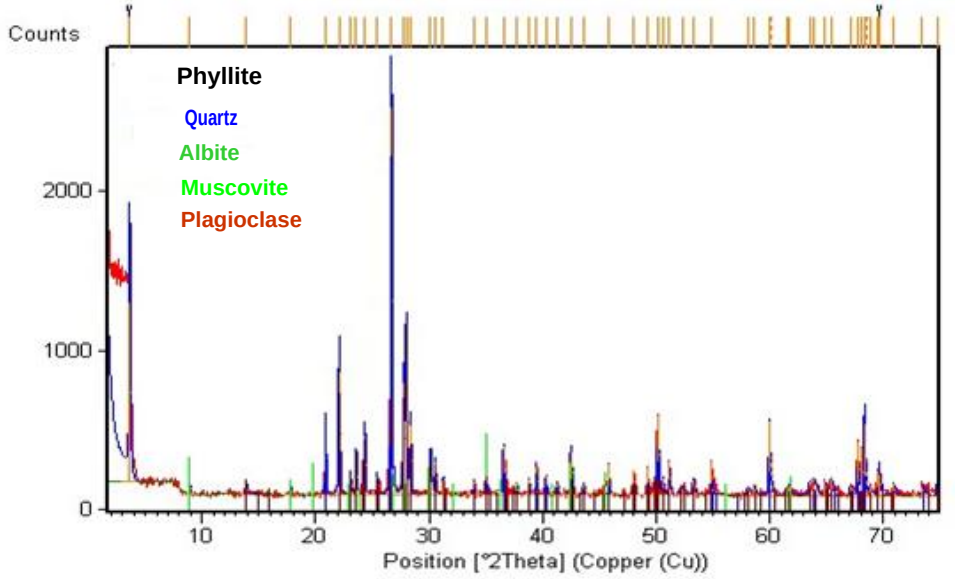
Appendix IIc: X-ray Diffractogram for Muscovte schist (Zn)



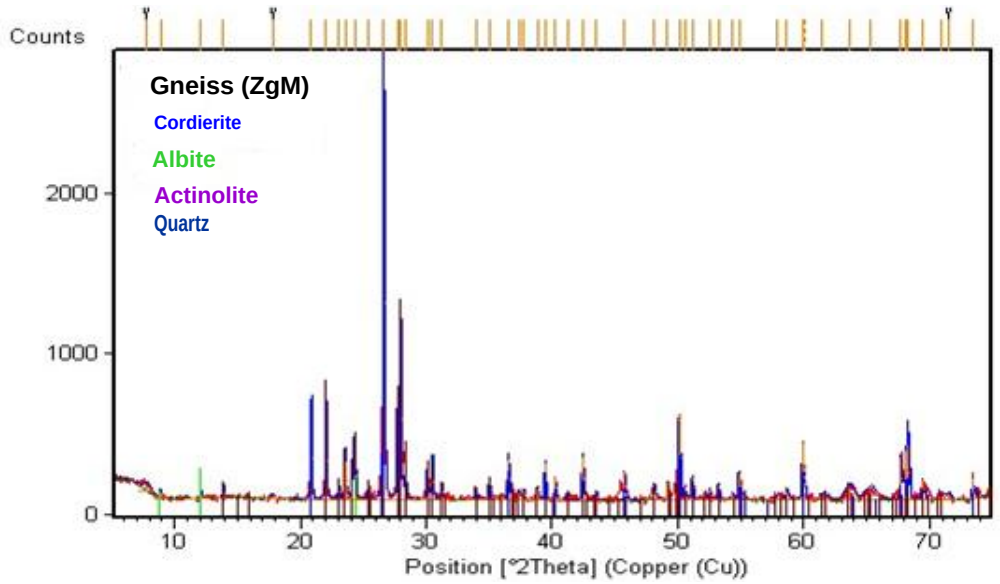
Appendix IId: X-ray Diffractogram for Muscovite schist (Tg)



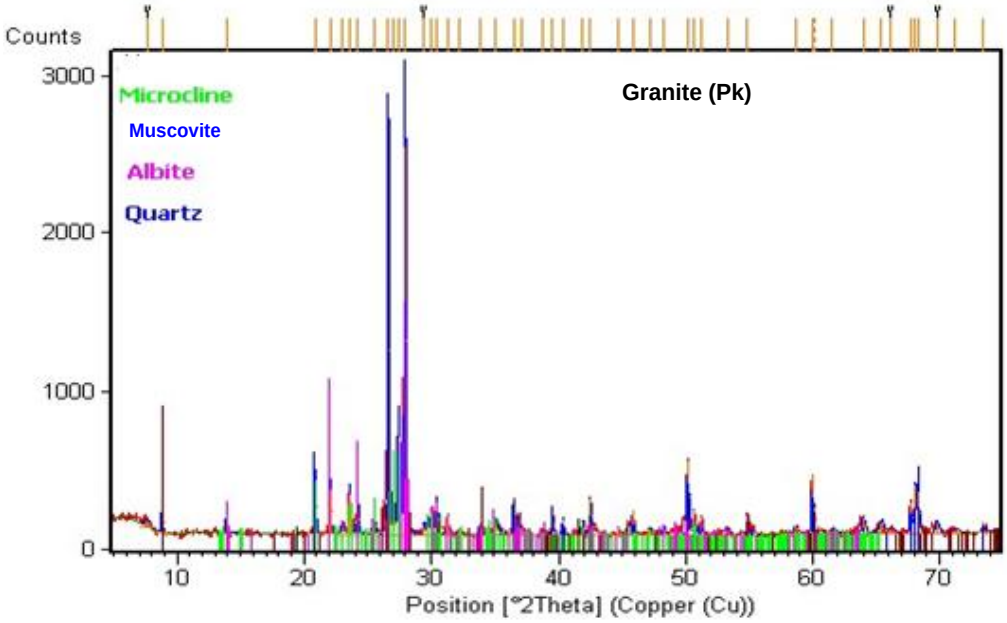
Appendix IIe: X-ray Diffractogram for Amphibolite (Zn3)



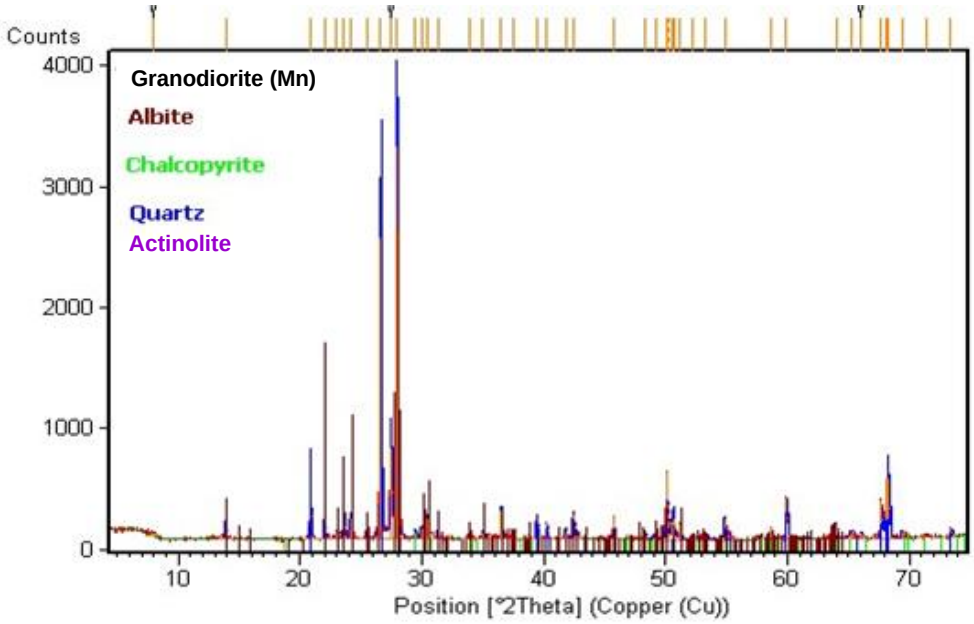
Appendix IIf: X-ray Diffractogram for Phyllite



Appendix IIg: X-ray Diffractogram for Gneiss mylonite (ZgM)



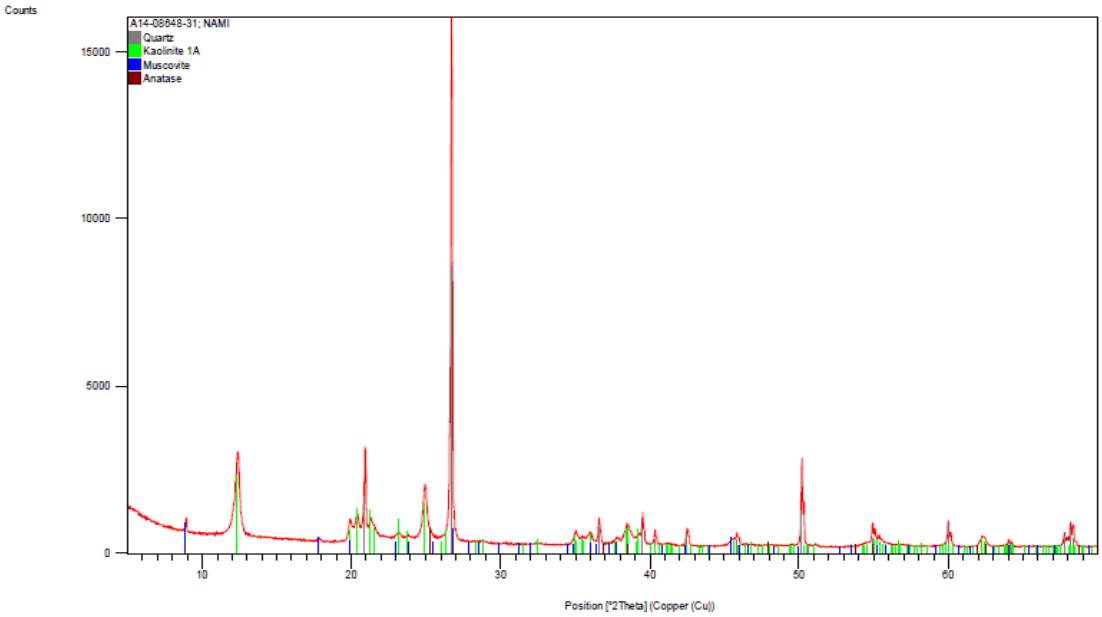
Appendix IIh: X-ray Diffractogram for Granite (Pk)



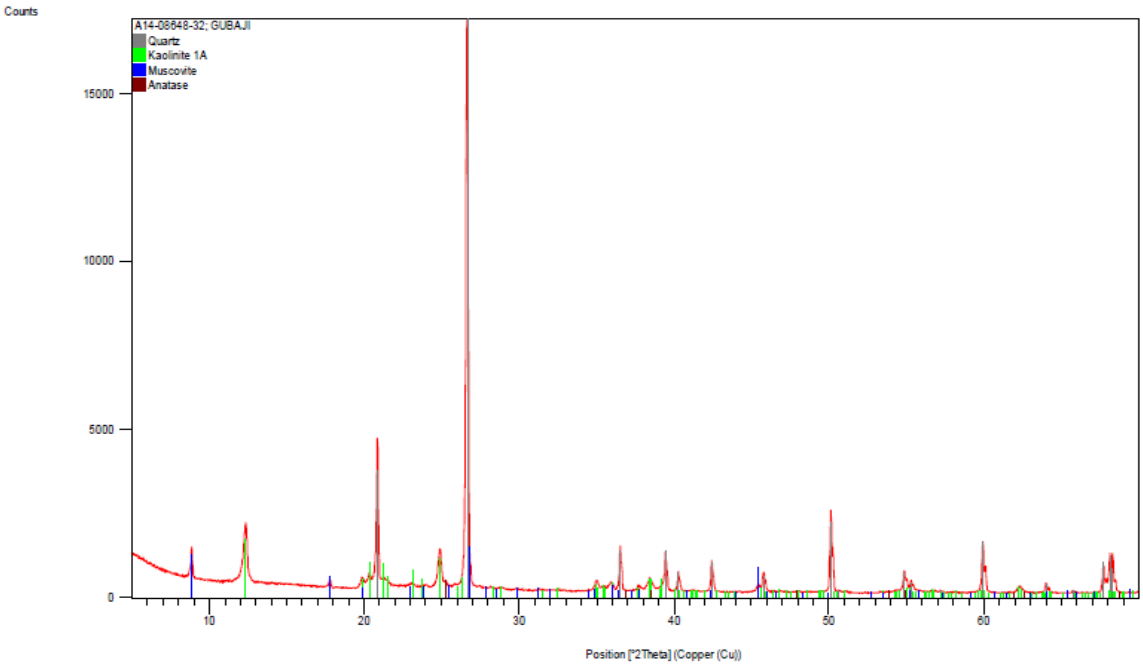
Appendix IIi: X-ray Diffractogram for Granodiorite (Mn1)

APPENDIX III

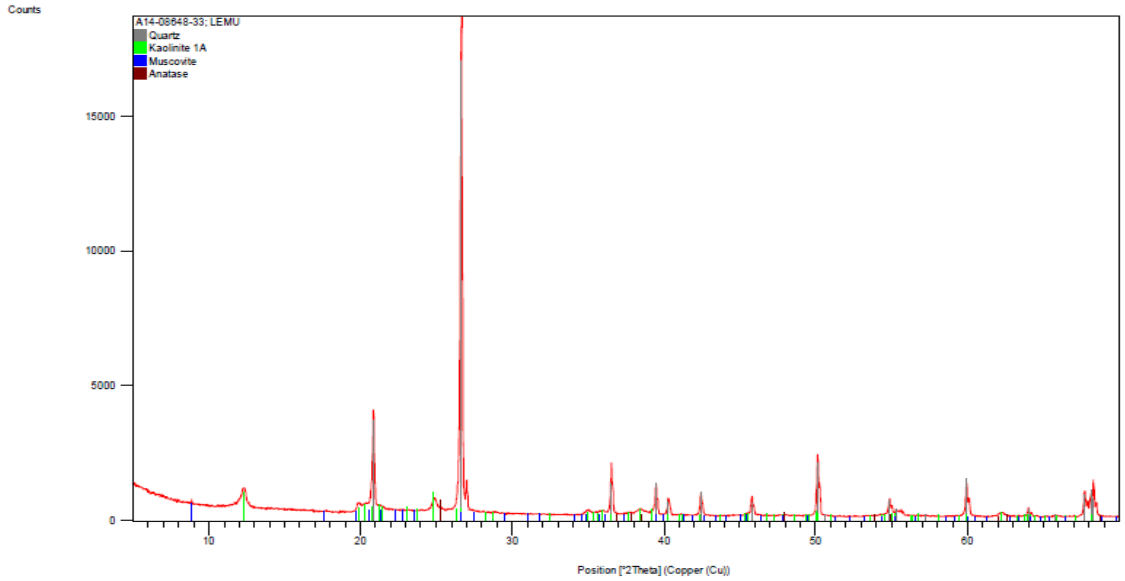
X-ray Diffractogram patern of the central Bida basin clay samples



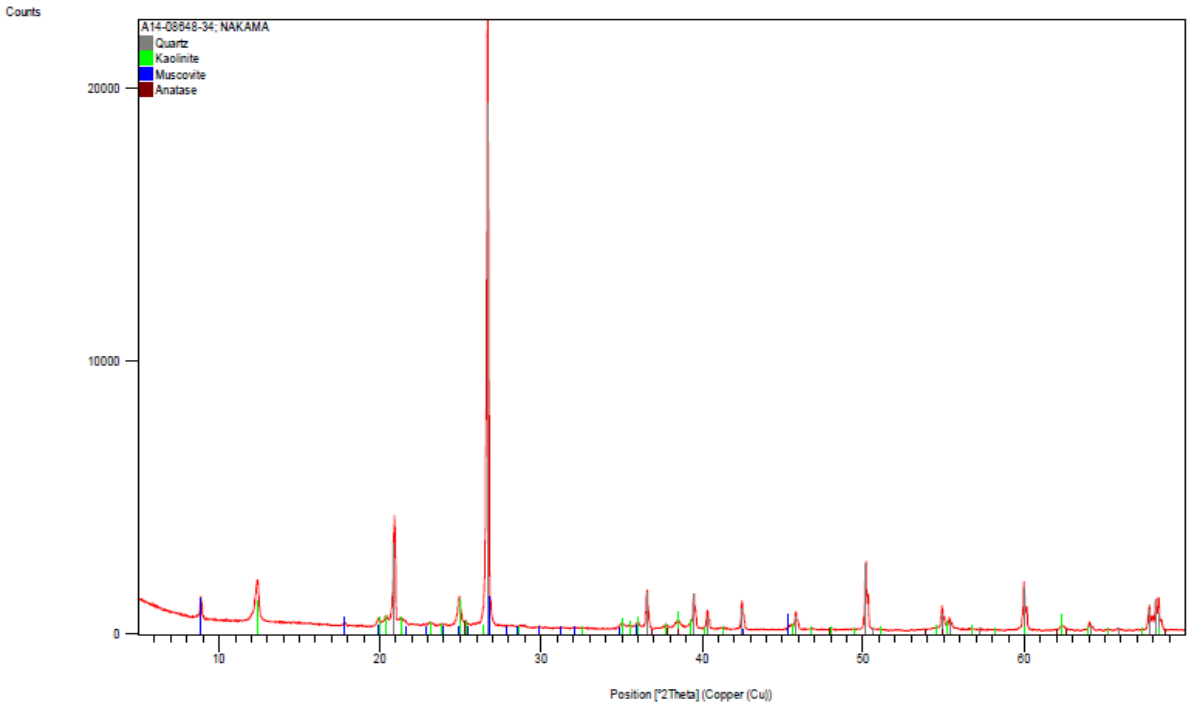
Appendix IIIa: X-ray Diffractogram of the Nami Clay Sample



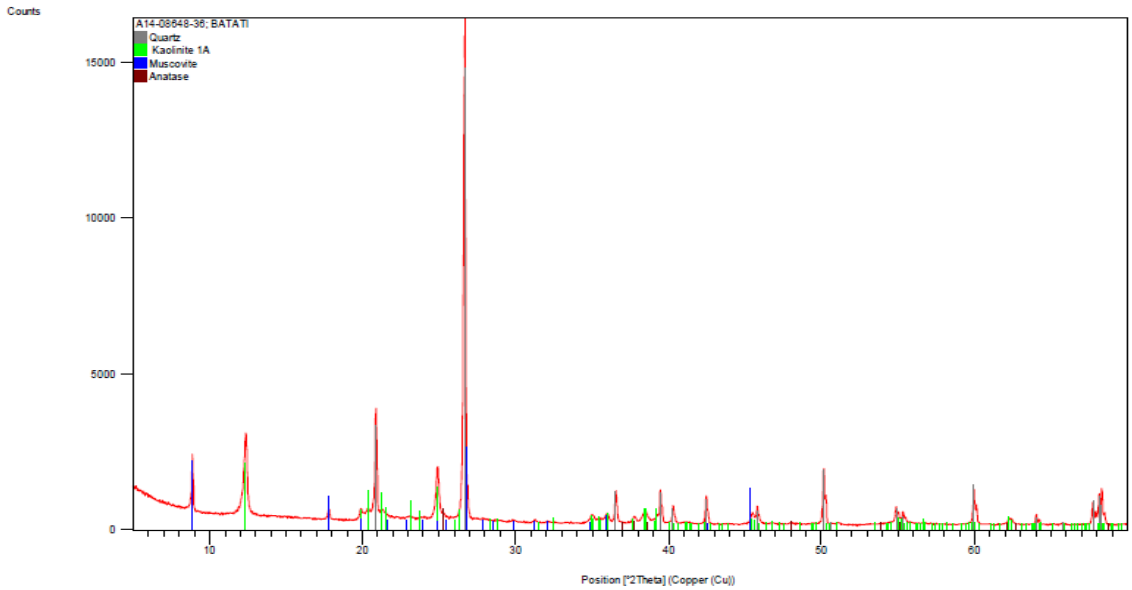
Appendix IIIb: X-ray Diffractogram of the Gubaji Clay Sample



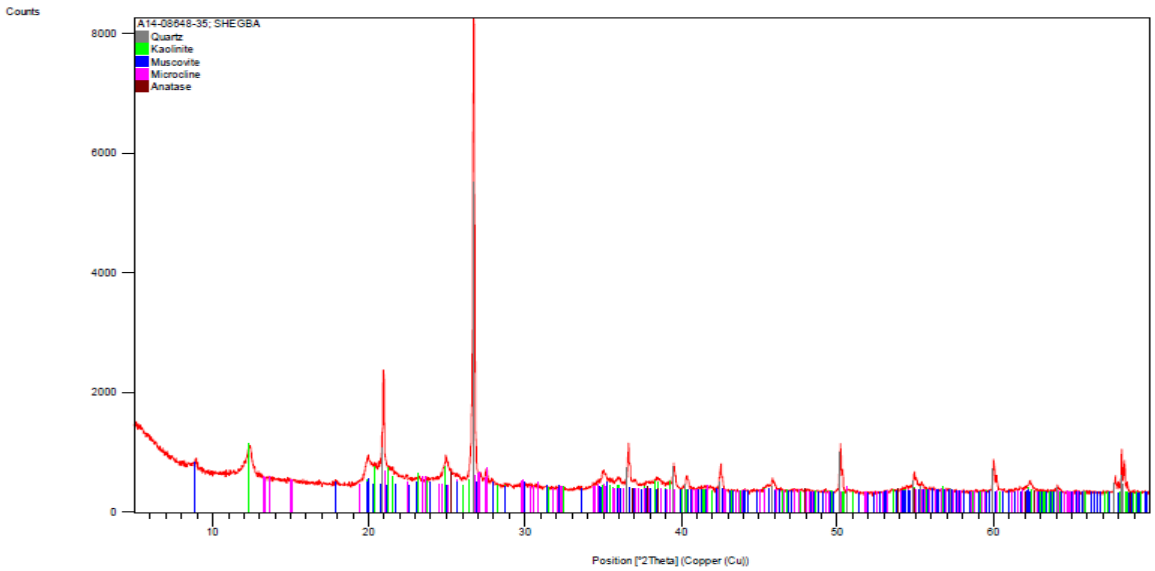
Appendix IIIc: X-ray Diffractogram of the Lemu Clay Sample



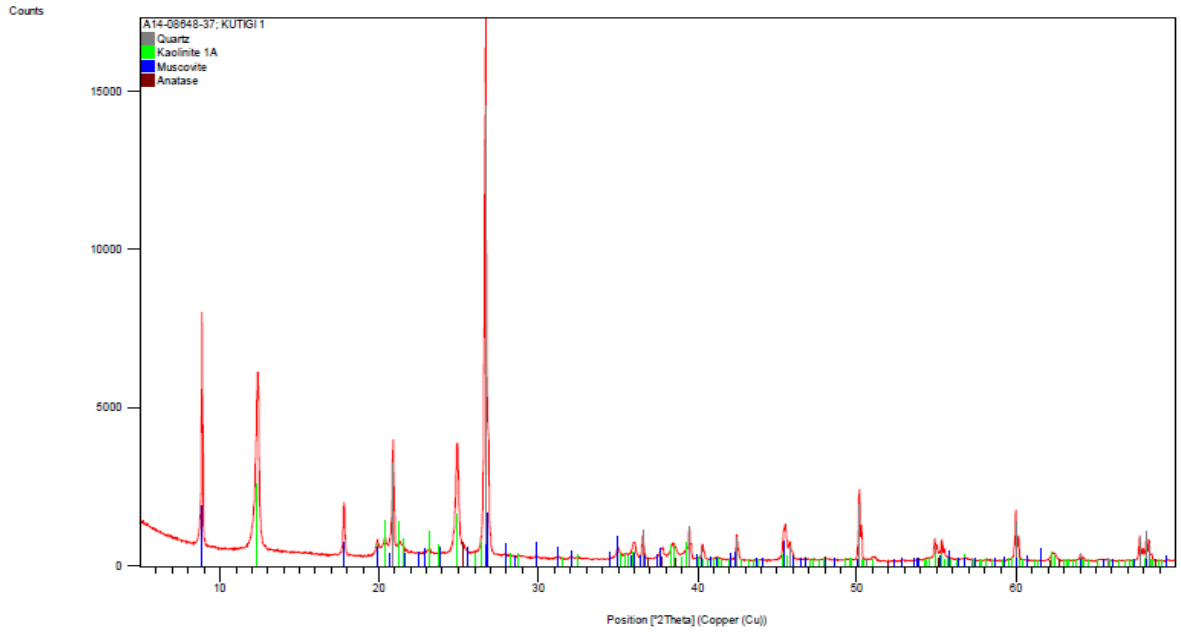
Appendix IIId: X-ray Diffractogram of the Nakama Clay Sample



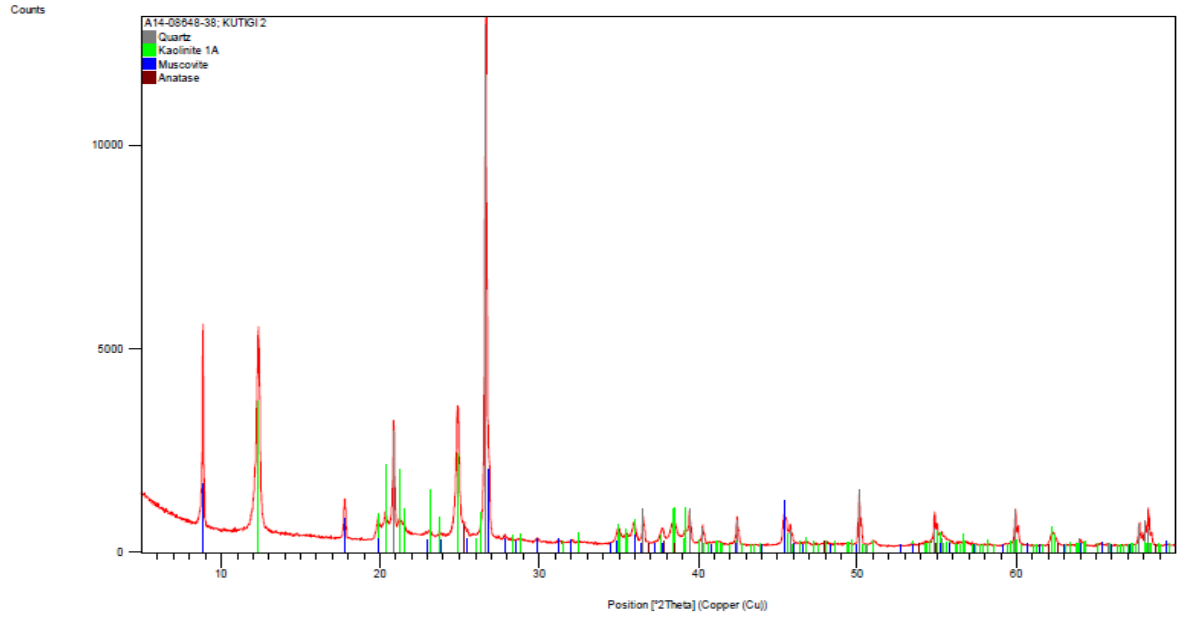
Appendix IIIe: X-Day diffractogram of the Batati Clay Sample



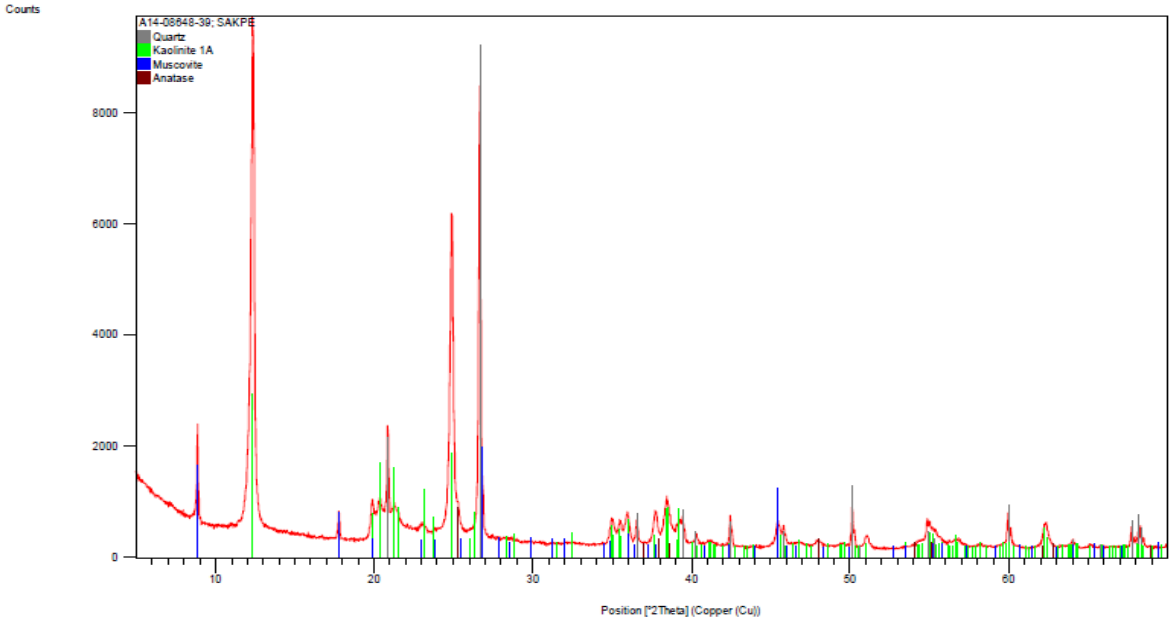
Appendix IIIf: X-ray Diffractogram of the Segba Clay Sample



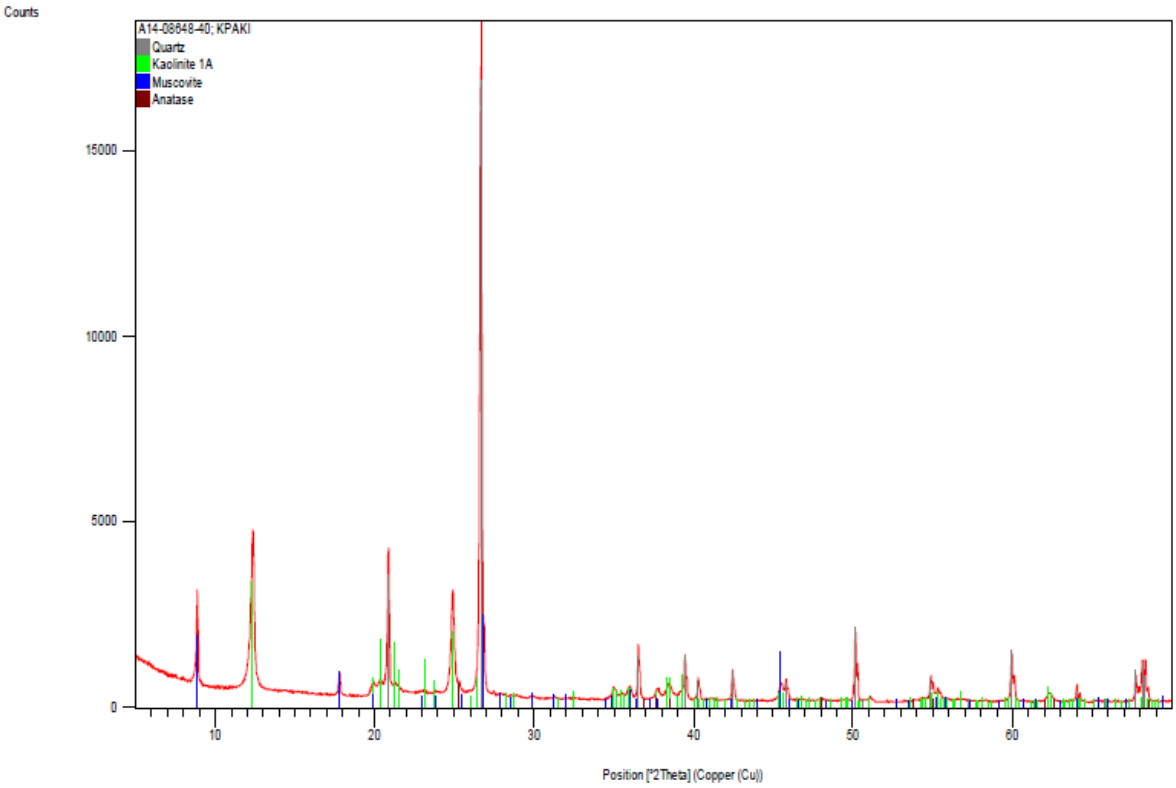
Appendix IIIg: X-ray Diffractogram of the Kutigi 1 Clay Sample



Appendix IIIh: X-ray Diffractogram of the Kutigi 2 Clay Sample



Appendix IIIi: X-ray Diffractogram of the Sakpe Clay Sample



Appendix IIIj: X-ray Diffractogram of the Kpaki Clay Sample

APPENDIX IV
Chemical Analysis

Result of chemical analysi for clay samples from central Bida Basin

Actlabs

Results

Analyte Symbol	SiO2	Al2O3	Fe2O3(T)	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	LOI	Total	Sc	Be	V	Ba	Sr	Y	Zr	Cr	Co	Ni	Cu
Unit Symbol	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01		0.01	1	1	5	3	2	2	4	20	1	20	10
Method Code	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS
NAMI 1	67.84	19.23	1.85	0.008	0.04	0.03	0.03	0.14	1.039	0.05	8.30	98.56	11	1	74	103	61	33	874	90	1	< 20	10
NAMI 2	69.58	18.12	1.72	0.007	0.04	0.03	0.04	0.14	1.054	0.05	8.26	99.05	11	1	73	101	54	30	878	100	1	< 20	10
NAMI 3	68.34	18.74	1.79	0.007	0.04	0.03	0.03	0.14	1.052	0.03	8.32	98.53	11	1	71	99	56	32	883	140	2	< 20	10
GUBAJI 1	77.53	12.93	0.78	0.012	0.06	0.03	0.03	0.34	2.160	0.05	4.86	98.79	11	2	77	140	21	87	1967	110	3	< 20	< 10
GUBAJI 2	81.13	11.52	0.72	0.012	0.09	0.04	0.07	0.43	1.926	0.05	4.28	100.3	11	2	72	117	18	89	1704	80	2	< 20	< 10
GUBAJI 3	79.73	11.01	0.67	0.012	0.05	0.03	0.03	0.29	2.020	0.02	4.42	98.29	11	2	70	118	16	88	2000	90	2	< 20	< 10
LEMU 1	85.16	7.63	1.13	0.010	0.10	0.12	0.04	0.14	0.863	0.02	3.56	98.78	6	1	46	301	26	37	875	60	1	< 20	10
LEMU 2	85.16	7.46	1.05	0.007	0.04	0.04	0.04	0.13	0.860	0.02	3.56	98.36	6	1	44	105	16	39	839	50	1	< 20	< 10
LEMU 3	87.37	7.55	1.06	0.007	0.04	0.04	0.04	0.13	0.879	0.01	3.65	100.8	6	1	43	106	16	37	864	130	1	< 20	< 10
NAKAMA 1	63.52	23.39	1.09	0.008	0.12	0.09	0.06	0.71	1.699	0.06	8.41	99.15	15	2	87	230	36	41	919	110	6	20	10
NAKAMA 2	70.11	19.65	1.17	0.010	0.10	0.09	0.09	0.75	1.548	0.04	7.43	101.0	13	2	79	220	31	36	1023	90	5	< 20	< 10
NAKAMA 3	69.66	19.79	1.14	0.009	0.09	0.09	0.09	0.75	1.511	0.04	7.42	100.6	12	2	79	215	31	37	1046	90	5	< 20	< 10
SHEGBA 1	57.98	18.70	7.11	0.079	0.66	0.30	0.23	1.74	0.967	0.03	11.95	99.74	15	3	116	479	71	36	459	90	16	30	30
SHEGBA 2	59.80	18.33	6.98	0.057	0.64	0.30	0.22	1.76	0.962	0.03	11.48	100.6	15	3	111	451	75	37	485	120	14	30	30
SHEGBA 3	58.84	18.93	7.04	0.080	0.66	0.30	0.23	1.76	1.004	0.03	11.84	100.7	15	3	116	499	72	36	464	90	17	30	30
BATATI 1	66.88	21.70	1.12	0.009	0.09	0.08	0.09	0.72	1.610	0.06	8.44	100.8	14	2	87	220	36	44	1163	100	6	< 20	< 10
BATATI 2	64.28	22.32	1.14	0.009	0.10	0.08	0.08	0.69	1.673	0.07	8.40	98.84	14	2	82	213	33	45	1107	110	6	< 20	< 10
BATATI 3	70.43	19.23	1.19	0.009	0.09	0.09	0.08	0.77	1.525	0.05	7.37	100.8	12	2	81	236	34	39	1170	130	5	< 20	< 10
KUTIGI A1	67.29	19.92	1.14	0.009	0.10	0.09	0.09	0.75	1.553	0.06	7.33	98.34	12	2	77	214	31	39	1043	90	5	< 20	< 10
KUTIGI A2	67.63	20.27	1.18	0.009	0.12	0.09	0.10	0.76	1.616	0.04	7.39	99.21	12	2	78	214	32	39	1044	130	5	< 20	< 10
KUTIGI A3	69.19	19.68	1.13	0.009	0.09	0.09	0.11	0.79	1.538	0.05	7.38	100.1	12	2	81	216	34	38	1173	80	5	< 20	< 10
KUTIGI B1	63.02	23.06	1.12	0.009	0.09	0.08	0.11	0.76	1.715	0.06	8.54	98.56	14	2	88	222	37	43	965	100	6	< 20	< 10
KUTIGI B2	66.73	21.96	1.12	0.009	0.09	0.08	0.08	0.72	1.663	0.06	8.43	100.9	14	2	87	218	36	42	1087	150	6	< 20	< 10
KUTIGI B3	64.95	21.81	1.09	0.008	0.10	0.08	0.09	0.70	1.629	0.04	8.41	98.90	14	2	83	216	33	39	1014	110	6	20	10
SAKPE 1	54.91	29.15	0.97	0.007	0.05	0.07	0.05	0.30	1.764	0.05	11.37	98.68	18	3	86	107	40	58	992	130	10	< 20	< 10
SAKPE 2	55.83	29.36	0.96	0.007	0.05	0.07	0.06	0.31	1.874	0.05	11.31	99.88	18	3	82	114	37	54	1017	150	10	30	10
SAKPE 3	55.71	29.67	0.92	0.006	0.05	0.07	0.05	0.31	1.793	0.05	11.36	99.99	18	3	85	107	39	55	993	130	9	< 20	< 10
KPAKI A1	72.42	17.13	0.94	0.010	0.08	0.03	0.10	0.53	1.822	0.04	6.40	99.51	13	1	73	179	25	46	1011	90	4	< 20	10
KPAKI B1	73.06	15.91	1.36	0.011	0.10	0.05	0.09	0.58	1.833	0.03	5.77	98.80	10	1	81	186	26	63	1247	110	4	20	10
KPAKI B2	74.86	15.60	1.32	0.011	0.09	0.06	0.10	0.58	1.830	0.04	5.72	100.2	10	2	79	185	26	62	1346	80	4	< 20	< 10

Results

Analyte Symbol	Zn	Ga	Ge	As	Rb	Nb	Mo	Ag	In	Sn	Sb	Cs	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	30	1	1	5	2	1	2	0.5	0.2	1	0.5	0.5	0.1	0.1	0.05	0.1	0.1	0.05	0.1	0.1	0.1	0.1	0.1
Method Code	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
NAMI 1	< 30	25	1	< 5	8	16	< 2	3.0	< 0.2	3	< 0.5	0.7	114	208	21.9	73.6	11.5	1.79	8.0	1.2	6.7	1.2	3.4
NAMI 2	< 30	24	1	< 5	9	17	< 2	4.2	< 0.2	4	< 0.5	0.7	117	215	22.6	76.1	12.0	1.77	7.8	1.1	6.1	1.1	3.5
NAMI 3	< 30	24	1	< 5	9	17	< 2	4.6	< 0.2	3	< 0.5	0.7	117	214	22.7	75.3	12.3	1.80	7.9	1.1	6.3	1.2	3.6
GUBAJI 1	< 30	20	< 1	< 5	11	45	< 2		< 0.2	16	< 0.5	0.6	63.7	121	14.4	52.9	11.1	1.55	10.5	2.0	13.4	2.9	9.4
GUBAJI 2	< 30	17	< 1	< 5	10	34	< 2		< 0.2	6	< 0.5	< 0.5	60.9	117	14.0	51.6	10.7	1.32	10.2	2.0	13.2	3.0	9.4
GUBAJI 3	< 30	18	1	< 5	10	39	< 2		< 0.2	8	< 0.5	< 0.5	62.5	122	14.4	54.1	10.9	1.36	10.1	1.9	13.2	2.9	9.7
LEMU 1	< 30	10	1	< 5	8	19	< 2	4.6	< 0.2	3	< 0.5	0.8	60.8	118	13.1	48.1	8.5	1.51	6.5	1.0	6.0	1.2	3.8
LEMU 2	< 30	10	1	< 5	8	14	< 2	4.4	< 0.2	3	< 0.5	0.8	53.8	108	12.2	44.6	8.3	1.34	6.6	1.0	6.3	1.3	4.0
LEMU 3	< 30	10	1	< 5	9	14	< 2	4.4	< 0.2	3	< 0.5	0.8	55.9	111	12.5	46.0	8.7	1.42	6.7	1.1	6.5	1.3	4.0
NAKAMA 1	< 30	31	1	< 5	25	28	< 2	4.5	< 0.2	5	< 0.5	0.9	106	192	20.8	69.4	10.5	1.57	6.8	1.1	6.5	1.3	4.2
NAKAMA 2	< 30	27	1	< 5	25	27	< 2		< 0.2	5	< 0.5	0.8	86.0	165	17.1	56.3	8.4	1.16	5.5	0.9	5.7	1.2	3.8
NAKAMA 3	< 30	27	1	< 5	25	24	< 2		< 0.2	5	< 0.5	0.7	84.3	160	16.4	53.7	8.0	1.19	5.4	0.9	5.9	1.2	4.0
SHEGBA 1	60	26	2	< 5	107	22	< 2	1.4	< 0.2	3	< 0.5	6.2	62.4	131	12.9	46.7	9.0	1.62	6.9	1.1	6.6	1.3	3.8
SHEGBA 2	60	26	2	< 5	108	23	< 2	1.1	< 0.2	3	< 0.5	6.1	62.6	115	13.0	48.4	9.2	1.75	7.4	1.1	6.7	1.3	4.0
SHEGBA 3	60	27	2	< 5	111	23	< 2	1.1	< 0.2	3	< 0.5	6.4	62.7	133	13.1	48.3	9.0	1.77	7.2	1.1	6.4	1.3	3.7
BATATI 1	50	29	1	< 5	24	33	< 2	3.6	< 0.2	6	< 0.5	0.9	100	183	19.3	65.7	9.8	1.46	7.5	1.2	7.2	1.5	4.7
BATATI 2	< 30	30	1	< 5	24	31	< 2		< 0.2	6	< 0.5	0.9	102	187	20.5	68.3	10.6	1.56	7.3	1.2	7.5	1.5	4.8
BATATI 3	< 30	27	< 1	< 5	25	31	< 2		< 0.2	5	< 0.5	0.8	85.7	163	17.1	54.8	8.5	1.21	5.8	0.9	6.1	1.2	4.1
KUTIGI A1	< 30	27	1	< 5	25	25	< 2		< 0.2	5	< 0.5	0.8	84.9	161	16.6	55.1	8.4	1.24	5.6	0.9	6.0	1.3	4.1
KUTIGI A2	< 30	28	1	< 5	25	26	< 2		< 0.2	5	< 0.5	0.8	87.5	167	17.2	56.4	8.6	1.21	5.7	0.9	6.3	1.3	4.2
KUTIGI A3	< 30	27	1	< 5	26	31	< 2		< 0.2	5	0.5	0.8	85.7	161	16.4	53.3	8.2	1.19	6.1	1.0	5.9	1.3	4.1
KUTIGI B1	< 30	30	1	< 5	25	31	< 2	2.8	< 0.2	5	< 0.5	0.9	99.4	177	19.2	63.9	9.8	1.41	7.3	1.2	7.0	1.5	4.6
KUTIGI B2	< 30	30	1	< 5	24	31	< 2		< 0.2	5	< 0.5	0.9	101	181	19.5	67.0	10.3	1.57	7.4	1.2	6.7	1.4	4.4
KUTIGI B3	40	30	1	< 5	24	29	< 2		< 0.2	6	< 0.5	0.9	100	184	20.0	66.8	10.5	1.55	6.9	1.1	7.1	1.4	4.5
SAKPE 1	40	40	2	< 5	13	36	< 2	2.9	< 0.2	5	< 0.5	0.5	120	162	21.8	74.4	13.1	2.15	10.3	1.6	9.8	1.9	5.9
SAKPE 2	40	39	2	< 5	13	35	< 2		< 0.2	6	< 0.5	0.6	119	165	21.6	73.7	12.6	2.09	9.1	1.5	8.7	1.8	5.5
SAKPE 3	40	38	2	< 5	12	36	< 2		< 0.2	5	< 0.5	0.5	118	161	21.5	70.8	12.0	2.07	9.8	1.5	8.8	1.8	5.4
KPAKI A1	< 30	25	1	< 5	17	32	< 2		< 0.2	5	< 0.5	1.1	58.2	100	11.1	37.1	6.5	1.09	5.5	1.0	7.0	1.5	4.8
KPAKI B1	< 30	22	1	< 5	17	23	< 2		< 0.2	4	< 0.5	0.9	69.0	125	14.0	49.5	8.9	1.29	7.5	1.3	9.2	2.0	6.5
KPAKI B2	< 30	22	1	< 5	18	23	< 2		< 0.2	4	< 0.5	0.8	67.6	124	13.9	48.8	8.7	1.28	7.5	1.4	9.2	2.0	6.4

Results

Analyte Symbol	Tm	Yb	Lu	Hf	Ta	W	Tl	Pb	Bi	Th	U
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	0.05	0.1	0.04	0.2	0.1	1	0.1	5	0.4	0.1	0.1
Method Code	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
NAMI 1	0.52	3.5	0.55	22.7	2.0	< 1	< 0.1	39	< 0.4	27.5	7.0
NAMI 2	0.50	3.2	0.50	22.3	1.6	< 1	< 0.1	34	< 0.4	26.3	6.7
NAMI 3	0.53	3.4	0.52	22.6	1.8	< 1	< 0.1	34	< 0.4	25.5	6.7
GUBAJI 1	1.48	10.1	1.52	51.7	4.8	2	< 0.1	26	< 0.4	28.3	11.5
GUBAJI 2	1.51	10.2	1.55	44.3	4.2	2	< 0.1	23	< 0.4	29.0	11.0
GUBAJI 3	1.53	10.3	1.60	58.3	2.8	2	< 0.1	22	< 0.4	27.6	10.7
LEMU 1	0.56	3.7	0.55	22.1	1.9	< 1	< 0.1	16	< 0.4	19.8	3.8
LEMU 2	0.59	3.9	0.60	21.1	2.2	< 1	< 0.1	13	< 0.4	18.7	3.9
LEMU 3	0.58	3.8	0.61	22.2	1.7	< 1	< 0.1	14	< 0.4	19.3	3.8
NAKAMA 1	0.63	4.1	0.66	23.9	2.8	1	0.1	40	< 0.4	34.5	6.0
NAKAMA 2	0.61	3.9	0.63	26.3	2.8	1	< 0.1	33	< 0.4	31.6	5.5
NAKAMA 3	0.64	4.2	0.64	26.5	2.5	1	< 0.1	32	< 0.4	30.7	5.5
SHEGBA 1	0.58	3.5	0.54	11.2	1.9	1	0.4	26	< 0.4	17.6	5.7
SHEGBA 2	0.59	3.9	0.57	12.0	1.8	1	0.5	23	< 0.4	18.6	5.8
SHEGBA 3	0.56	3.6	0.57	11.3	1.9	1	0.5	26	< 0.4	18.3	5.9
BATATI 1	0.71	4.7	0.72	27.6	3.4	2	0.2	38	< 0.4	35.5	6.3
BATATI 2	0.73	4.8	0.75	29.3	2.8	2	< 0.1	36	< 0.4	33.7	6.2
BATATI 3	0.63	4.3	0.66	27.6	2.7	2	< 0.1	32	< 0.4	33.3	5.9
KUTIGI A1	0.64	4.2	0.68	26.7	2.7	1	< 0.1	32	< 0.4	30.7	5.5
KUTIGI A2	0.65	4.5	0.69	27.4	2.6	1	< 0.1	33	< 0.4	31.8	5.6
KUTIGI A3	0.62	4.2	0.68	27.5	2.7	2	< 0.1	35	< 0.4	33.7	6.0
KUTIGI B1	0.68	4.7	0.72	23.2	2.8	2	< 0.1	39	< 0.4	35.8	6.3
KUTIGI B2	0.68	4.6	0.69	25.9	3.1	2	< 0.1	38	< 0.4	36.7	6.6
KUTIGI B3	0.65	4.6	0.72	27.6	2.6	1	< 0.1	37	< 0.4	33.3	6.1
SAKPE 1	0.86	5.7	0.82	25.0	3.3	2	< 0.1	50	< 0.4	38.0	7.8
SAKPE 2	0.77	5.0	0.76	26.9	3.1	1	< 0.1	43	< 0.4	33.1	6.9
SAKPE 3	0.81	5.2	0.77	24.8	3.0	2	< 0.1	48	< 0.4	36.3	7.2
KPAKI A1	0.74	5.1	0.78	23.8	2.8	2	< 0.1	22	< 0.4	18.2	6.2
KPAKI B1	0.95	6.2	0.98	31.0	3.2	< 1	< 0.1	22	< 0.4	19.0	6.1
KPAKI B2	0.97	6.4	0.98	32.9	2.9	< 1	< 0.1	22	< 0.4	18.8	6.1

Result ofChemical Analysis for Basement Complex Rocks

Final Report

Client:	Alabi A. Amos Federal University of Technology Minna
File Created:	5 August, 2013
Job Number:	51350
Number of Samples:	12
Project:	Research
Shipment ID:	
P.O. Number:	
Received:	5 August, 2013

Analyte	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	MnO	TiO2	P2O5	Cr2O3	LOI	SUM
Unit	%	%	%	%	%	%	%	%	%	%	%	%	%
MDL	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.001	-5.11	0.01
Bmz	74.01	13.45	1.45	0.75	0.09	2.79	6.44	0.06	0.08	0.03	0.052	0.44	99.68
Pk 1	74.09	14.52	0.87	1.36	0.11	4.18	3.75	0.01	0.09	<0.01	0.050	0.41	99.54
ZnD	43.94	17.20	11.63	3.18	8.90	0.07	6.41	0.22	1.34	0.04	0.133	6.09	99.27
Pan	62.93	17.09	8.20	0.03	1.51	0.04	2.14	0.10	0.98	0.05	0.064	6.38	99.61
Zn 1	57.68	17.08	8.71	0.24	3.15	0.19	4.76	0.38	0.85	0.04	0.036	5.99	99.24
Tg	65.94	14.60	3.51	1.58	0.94	3.52	4.76	0.06	0.49	0.14	0.052	0.48	99.24
Mn 2	59.89	16.13	8.23	0.17	3.95	0.01	2.89	0.12	1.01	0.04	0.045	6.99	99.54
Mn 1	52.93	11.09	14.52	9.03	10.51	0.34	0.14	0.41	0.68	0.12	0.064	6.38	99.61
Zn 2	82.46	14.82	2.03	0.54	1.10	1.06	1.84	0.02	0.81	0.01	0.001	0.92	99.43
Zn 3	49.12	12.20	14.63	10.18	10.90	0.34	0.16	0.13	0.87	0.14	0.003	6.09	99.27
Mn 3	68.77	14.59	3.71	1.99	1.07	3.66	4.41	0.06	0.51	0.14	0.065	0.66	99.70
Gb	71.78	15.26	0.82	1.27	0.13	3.94	5.43	0.02	0.07	0.02	0.068	0.50	99.47
Pk2	73.72	14.50	0.46	0.66	0.01	3.00	6.55	0.01	0.02	0.02	0.052	0.54	99.68
ZgS	81.43	13.87	2.34	1.05	1.9	1.09	1.78	0.05	0.92	0.05	0.05	0.97	99.98
ZgM	73.07	13.56	0.76	1.45	0.26	4.65	3.56	0,07	0.08	0.07	0.07	0.67	99.67

Be	Co	Cs	Ga	Hf	Nb	Rb	Sn	Sr	Ta	Th	U	V	W
PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM
1	0.2	0.1	0.5	0.1	0.1	0.1	1	0.5	0.1	0.2	0.1	8	0.5
3	2.9	1.9	20.0	3.0	17.3	202.5	2	67.1	0.3	26.5	10.4	8	0.9
2	3.3	4.4	13.1	1.8	2.8	88.5	2	188.2	0.6	1.9	0.8	8	0.7
3	1.3	34.7	30.1	3.0	13.5	743.8	6	19.3	0.4	5.5	6.0	214	1.4
1	18.5	22.7	21.7	5.7	12.3	197.1	3	10.4	0.8	10.8	4.9	141	1.9
6	40.8	19.7	21.4	5.7	11.1	220.2	3	40.1	0.7	11.5	2.8	164	5.2
2	8.3	12.5	19.5	5.8	14.5	217.5	4	223.0	2.1	27.8	12.6	33	0.5
2	23.4	10.4	19.9	4.8	12.5	142.3	3	19.6	1.2	7.8	4.1	155	0.7
1	1.6	22.7	21.7	5.7	12.3	197.1	3	10.4	0.8	10.8	4.9	141	1.9
4	3.4	3.5	16.2	3.4	5.4	191.0	2	97.3	0.4	7.3	0.9	8	0.8
3	54.4	34.7	30.1	3.0	13.5	743.8	6	19.3	0.4	5.5	6.0	214	1.4
1	10.0	11.7	20.5	6.1	14.1	220.1	5	235.8	1.3	25.7	7.8	35	0.9
1	3.6	2.1	13.2	0.3	1.5	103.1	1	440.7	1	8.3	0.7	7	0.5
1	2.6	4.0	12.7	1.1	0.5	136.7	1	337.4	1.0	11.2	1.0	6	0.5
4	3.4	3.5	21.0	3.4	5.4	191.0	2	97.3	0.4	7.3	0.9	<0.5	0.9
2	3.3	4.4	13.1	1.8	2.8	88.5	2	188.2	0.6	1.9	0.8	<0.5	0.7

Zr	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM
0.1	0.1	0.1	0.1	0.02	0.3	0.05	0.02	0.05	0.01	0.05	0.02
91.0	77.4	33.7	59.9	5.90	17.7	3.97	0.52	5.17	1.22	9.04	2.53
65.9	3.7	5.0	8.3	1.02	3.5	0.69	0.70	0.68	0.12	0.75	0.11
115.6	17.0	36.2	110.5	8.28	32.9	5.36	1.23	4.57	0.52	2.83	0.54
230.1	74.5	54.4	64.3	19.21	88.1	18.61	4.25	15.95	2.29	13.30	2.63
244.8	31.7	41.2	188.3	9.49	39.3	6.40	1.32	6.42	0.91	5.61	1.26
207.2	19.0	51.0	95.4	10.01	36.2	5.96	1.06	4.87	0.62	3.29	0.61
215.9	43.1	27.9	54.0	7.63	34.3	7.13	2.45	7.40	1.04	6.05	1.40
230.1	74.5	54.4	64.3	19.21	88.1	18.61	4.25	15.95	2.29	13.30	2.63
96.8	6.1	26.5	33.8	6.05	20.5	3.51	0.79	2.57	0.35	1.54	0.24
115.6	17.0	36.2	110.5	8.28	32.9	5.36	1.23	4.57	0.52	2.83	0.54
227.8	15.4	43.0	85.1	8.65	30.5	5.22	0.82	4.13	0.55	3.01	0.52
12.3	3.1	23.5	41.2	4.21	15.3	2.08	0.75	1.51	0.17	0.79	0.11
31.9	2.9	13.5	27.8	2.73	9.6	1.65	0.51	1.14	0.14	0.58	0.08
96.8	6.1	26.5	33.8	6.05	20.5	3.51	0.79	2.57	0.35	1.54	0.24
65.9	3.7	5.0	8.2	1.05	3.7	0.79	0.75	0.64	0.14	0.78	0.14

Er	Tm	Yb	Lu	Tl	Mo	Ni	Ba
PPM	PPM	PPM	PPM	PPM	PPM	PPM	%
0.03	0.01	0.05	0.01	0.1	0.1	0.1	0.01
8.67	1.47	9.85	1.34	0.6	4.5	104.5	0.04
0.34	0.05	0.43	0.06	0.7	2.3	86.6	0.08
1.69	0.24	1.54	0.27	2.3	0.9	293.2	0.10
7.15	1.08	7.24	1.05	1.8	1.4	107.3	0.07
3.59	0.57	3.64	0.55	1.7	1.1	78.1	0.11
1.76	0.27	1.49	0.22	1.0	4.4	99.3	0.07
3.77	0.54	3.28	0.53	0.7	1.3	136.2	0.06
7.15	1.08	7.24	1.05	0.6	1.4	107.3	0.07
0.60	0.07	0.46	0.08	1.8	3.6	103.8	0.06
1.69	0.24	1.54	0.27	1.9	0.9	293.2	0.10
1.35	0.23	1.28	0.22	0.8	4.9	133.1	0.06
0.17	0.03	0.16	0.01	0.3	3.1	110.1	0.15
0.23	0.04	0.29	0.03	0.6	2.8	102.7	0.12
0.60	0.07	0.46	0.08	1.8	4.5	103.8	0.06
0.43	0.05	0.45	0.08	0.7	2.3	85.6	0.08

APPENDIX V
Mineralogical Analysis

Result ofMineralogical Analysis for Basement Complex Rocks

Location	Quartz	Biotite	Muscovite	Microcline	Actinolite	Plagioclase	Chalcopyrite	Albite	Cordierite	Total
Gniess (Pk1)	28	18.5	n.d	n.d	14.8	n.d	n.d	38.5	n.d	99.8
Mica schist (Mn2)	33.1	19.2	n.d	23.9	n.d	n.d	n.d	23.4	n.d	99.9
Mica schist (Zn1)	32.1	n.d	18.8	28.5	n.d	n.d	n.d	20.6	n.d	100
Mica schist (Tg)	33.6	n.d	26.3	n.d	n.d	n.d	n.d	40.3	n.d	100.2
Mica schist (Pan)	30.1	n.d	22.2	n.d	n.d	n.d	n.d	20.3	n.d	99.8
Ampbibolite schist	25.0	10.2	n.d	n.d	42.0	n.d	n.d	22.7	n.d	99.8
Phyllite (ZnD)	24.9	n.d	10.5	23.4	nd	13.1	n.d	n.d	n.d	104
Gniess mylonite (ZnM)	32.5	n.d	n.d	n.d	20.6	n.d	n.d	27.9	18.8	99.8
Granite (Pk)	38.3	10.6	19.6	10.6	nd	n.d	n.d	20.8	n.d	99.8
Granodiorite (Mn1)	38.3	10.2	n.d	n.d	27.2	n.d	11.0	13.1	n.d	98.3

n.d=not detected

Result of Mineralogical analysi for clay samples from central Bida Basin

Client ID	ActLabs ID	Quartz	Kaolinite	Muscovite/Illite	Microcline	Anatase
NAMI	A14-08648-31	42.4	55.0	1.9	n.d.	0.7
GUBAJI	A14-08648-32	61.5	33.4	4.6	n.d.	0.4
LEMU	A14-08648-33	75.3	22.1	2.2	n.d.	0.4
NAKAMA	A14-08648-34	65.1	28.1	6.3	n.d.	0.5
SHEGBA	A14-08648-35	35.8	52.4	5.1	6.2	0.6
BATATI	A14-08648-36	50.7	42.6	6.0	n.d.	0.8
KUTIGI 1	A14-08648-37	50.8	40.5	7.9	n.d.	0.8
KUTIGI 2	A14-08648-38	39.7	47.3	11.9	n.d.	1.0
SAKPE	A14-08648-39	27.8	66.2	4.7	n.d.	1.3
KPAKI	A14-08648-40	56.0	37.4	5.7	n.d.	0.9