MINERALOGY, GEOCHEMISTRY AND POTENTIAL USES OF CLAY IN PANDOGARI AREA, NORTH-CENTRAL, NIGERIA

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MTech/SPS/2017/7214

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MINNA

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A THESIS SUBMITTED TO THE POSTGRADUTE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY IN GEOLOGY (MINERAL EXPOLORATION)

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ABSTRACT

The basement rock of Pandogari lies within the BirninGwari – Zungeru area in the NW block of the Nigeria Basement Complex that form part of southern sector of the Pan-Africa mobile belt of West Africa. The study area lies between between latitude 10° 21′ 00″ to 10° 25′ 00″ N and longitude 6° 23′ 00″ to 6° 30′ 00″ Eof Tegina Sheet 142NE. This study is aimed at evaluating the mineralogical and chemical characteristics of clay minerals occurrence in Pandogari area and its economic benefits through geological mapping and geochemical study. Thirteen (13) Clay samples and seven (7) rocks were obtained from exposure along roads using hammer and hand trowel. X-Ray Diffraction (XRD), X-Ray Fluorescence (XRF) techniques and petrographic studies were carried out. The X-Ray Diffraction (XRD) analysis results unveiled mineralogical composition of the clay samples to be quartz, muscovite, kaolinite, illite, chlorite and mortimorinolite while X-Ray Fluorescence (XRF) analysis revealed major oxides of SiO_2 (53.10 - 93.60%), MgO (0.02 - 0.10%), Fe_2O_3 (1.24 – 10.02%), CaO (0.05 – 0.81%), Al_2O_3 (2.00 - 20.00%). Geological field work results revealed rocks comprising mica schist and phyllite that were intruded by typical Pan-Africa granitic rocks, poor exposure of mica schist and phyllite shows variation in degree of weathering ranging from intermediate to strong weathering and the depositional environment shows that Pandogari clay belongs to Non-marine source. The schist which are (metasedimentary and metavolcanic rocks) and the Older Granites (Pan African Granitoids), older granite intruded the schist forming batholitic ridges and batholite. The mineralogical composition of quartz, muscovite and abundance of major and trace elements in the clay shows evidence of felsic protolith as the source rocks, intensive weathering and alteration of the feldspars in-situ. Also the low/high concentration of some minerals and elements in the clay samples in the study area suggest it could be used for ceramic and refractory brick, also the clay require beneficiation to meet specific industrial applications. Clay as an industrial mineral will improve the economy of the nation if attention is given to the mineral.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Nigeria as a nation is on increasing demand for mineral resources, the country is so blessed with numerous mineral resources and these resources are for industrial purposes and they are of economic importance, such as constructional materials, electronic materials, metallurgical purposes, agricultural and pharmaceutical.

Both the basement and sedimentary rocks are host of mineral deposit in Nigeria and it is undermined for various political reasons and policies. Basement rocks that host minerals are fractured and healed and some disseminated in them, some sedimentary rocks also host some minerals which can be found in alluvial deposit and also as secondary concentration (halo) form which are to be considered targets for mineral exploration.

Clay as mineral is interconnected silicate sheets with a metal atom; oxygen and hydroxyl grouped in sheets form Two-layered minerals, such as kaolinite. The latter flakes are found interposed between two silicate lamellae, resulting in three layers of minerals, such as vermiculite. During lithification, compacted layers of clay can turn into shale. Under the intense heat and pressure that can form in the layers, shale can turn into slate.

According to Chatterjee (2009), the US Bureau of Mines (USBM) and the US Geological Survey (USGS) has adopted it as a simple and general definition that explains clays as hydrated aluminosilicates of a large number of mineral species, with different proportions of mixed elements.

Clay minerals consist of hydrated aluminous phyllosilicates, which sometimes contain varying quantities of iron, magnesium, alkali metals, alkaline earths and other cations (Schulze, 2005). They are a typical by-product of weathering of materials (including weathering of feldspar and mica) and low-temperature hydrothermal alteration. Clay minerals are generally produced over time by the progressive chemical weathering of (usually siliceous) rocks by low levels of carbonic acid and other dilute solvents. These solvents (usually acids) often move through the weathered rock after leaching through the upper weathering layer (Mourad, 2010).

Clay minerals are typical of certain weathering settings and their study could allow for the reconstruction of the paleo-environments in which they were formed or eventually deposited (Obaje *et al*.,2013).

Clay minerals as explained by Chatterjee (2009) include the following groups:

A. Kaolinite Group [$(OH)8Al_4Si_4O_{10}$] or [$Al_2O_3.2SiO_2.2H_2O$]

1. Kaolinite

Kaolinite is a clay mineral having the chemical composition $Al_2Si_2O_5(OH)_4$. It is a bedded silicate mineral with a single tetrahedral disc bonded by oxygen atoms to a single octahedral aluminium disc (Deer *et al*., 1992). Rocks abundant in kaolinite are known as porcelain or porcelain clay.

The kaolinite framework comprises a tetrahedral layer of silica and an octahedral layer of alumina, bonded with a general layer of oxygen and hydroxyl acids (Figure 1.1). This structural unit is classified as a 1:1 layered clay. The tetrahedral silica layer and the octahedral alumina layer have little, if any, substitution of any other element (Al Ani and Olli, 2008).

Physical attributes and chemical properties that may be important are as follows: kaolin is chemically neutral over a relatively wide pH range (4-9), has low thermal and electrical conductivity, is hydrophobic, readily dispersible in water, has a low temperature and electrical conductivity, is easily dispersed in water, and is easily dispersed in water and can be heat worked or calcined to produce this product which is an excellent filler and expander (Murray, 2007).

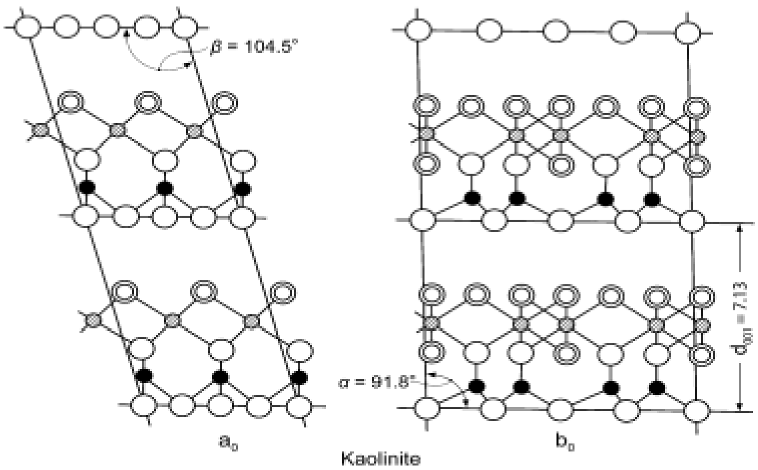

Figure 1.1: Diagrammatic Sketch Structure of Kaolinite(Bates *et al.*,1950)

2. Nacrite

3. Dickite

4. Anauxite

B. The Smectite Group (an early name for the montmorillonite group).

Some smectite groups, which include dioctahedralsmectites, example montmorillonite and nontronite, and trioctahedralsmectites, example soapstone. Most important smectite minerals are sodium montmorillonite, calcium montmorillonite, soapstone (magnesium montmorillonite), notronite (iron montmorillonite), hectorite (lithium montmorillonite) and bedelite.

The nature of the composition is uncertain, one suggestion is [(Al,Mg)8(Si_4O_{10})3$(OH)_2$0.nH_2O] Pusch and Karnland (1996). The very fine particle size, swelling and flake shape give sodium montmorillonite the ability to form almost impenetrable membranes for the passage of water. This renders it well suited as a sealant for filling irrigation canals and landfills and for forming an impervious seal on permeable layers in oil and gas drilling to control fluid loss (Murray, 2007).

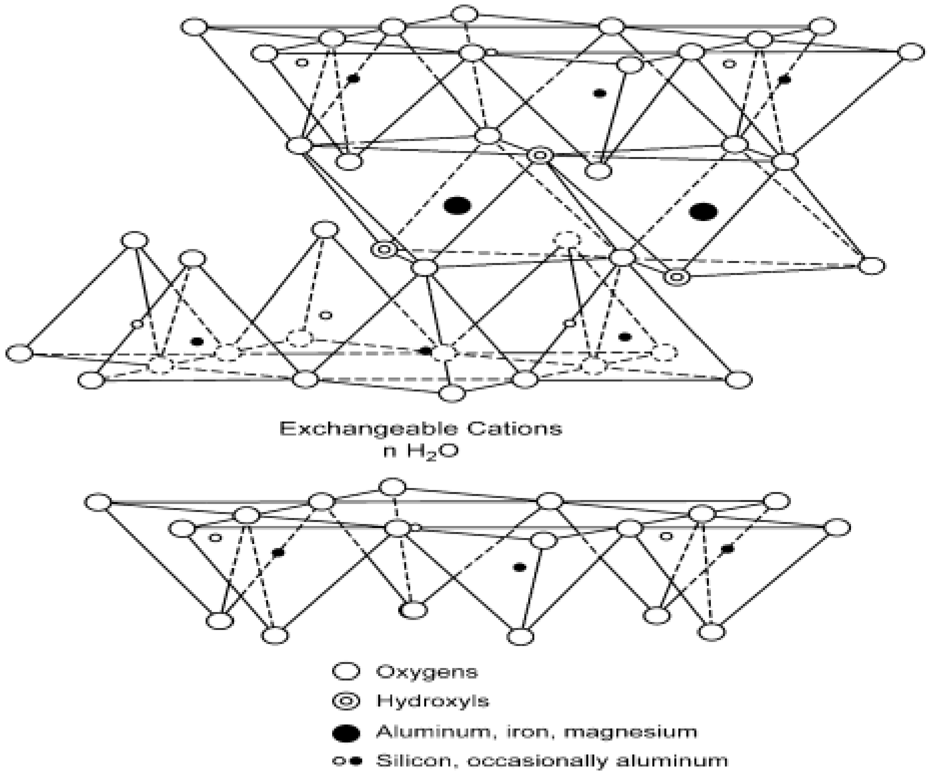

Figure 1.2: Diagrammatic Sketch Structure of Smectite (Guven, 1988)

1. Montmorillonite

2. Beidellite

3. Nontronite

4. Hectorite

C. Illite Group: Contains iron, magnesium and potassium.

The illite group, which encompasses clayey micas. This periodically arranged illit-mectite is called rectorite (Moore & Reynolds, 1997). The physical and chemical properties are highly variable, so these common clays are used for very specific end uses. The physical properties that are generally important are related to their use in the making of building products, such as bricks and tiles. These properties are ductility, green strength, dry strength, shrinkage in dry and baked form, colour in baked form, strength in baked form, different glass content and density in baked form (Murray, 2007).

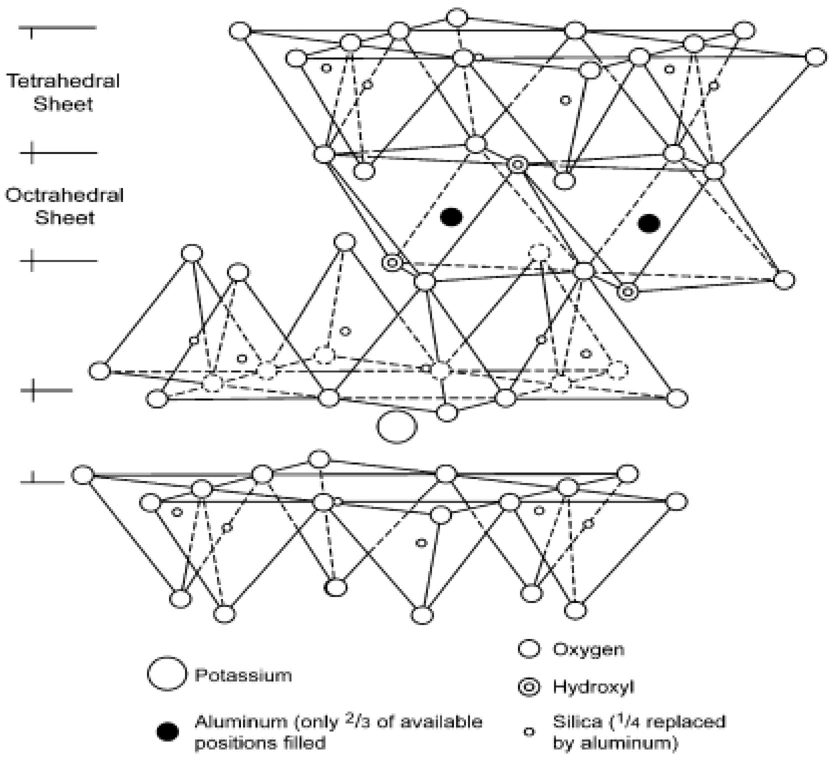

Figure1.3: Diagrammatic Sketch Structure of Illite (Moore & Reynolds, 1997)

D. Halloisite: Contains more water than Kaolinite.

1. Halloisite

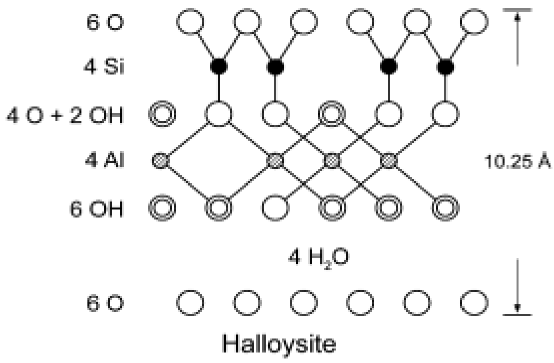

Figure 1.4: Diagrammatic Sketch Structure of Halloisite (Bates *et al*.,1950)

2. Metahalloisite

3. Allophane

4. Endellite

E. Palygorskite: Contains magnesium instead of aluminium.

The small particle size, large surface area (190 m_2/g) and moderate exchange capacity give palygorskite and sepiolite a high capacity to absorb and adsorb a range of liquids, making them very useful in many industrial applications. Another attractive property is that the elongated thin particles provide high viscosity when added to a liquid. This is a physical rather than chemical viscosity, making it very stable as a viscosity and suspension medium in many applications where sodium montmorillonite would flocculate at high salt concentrations or high electrolyte concentrations. Many practices are related to sorption and viscosity (Murray, 2007).

1. Sepiolite

2. Attapulgite

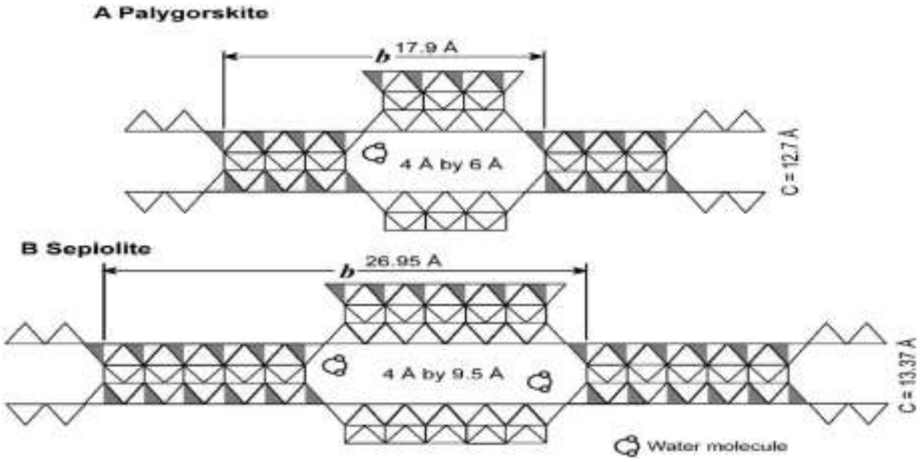

Figure 1.5: Diagrammatic Sketch Structure of (a) Palygorskite and (b) Sepiolite (Guven, 1988)

F. Chlorites: Magnesium-rich clay minerals.

The chlorite group which are magnesium rich which includes a large number of related minerals with important chemical properties differences (Pauling, 1930).

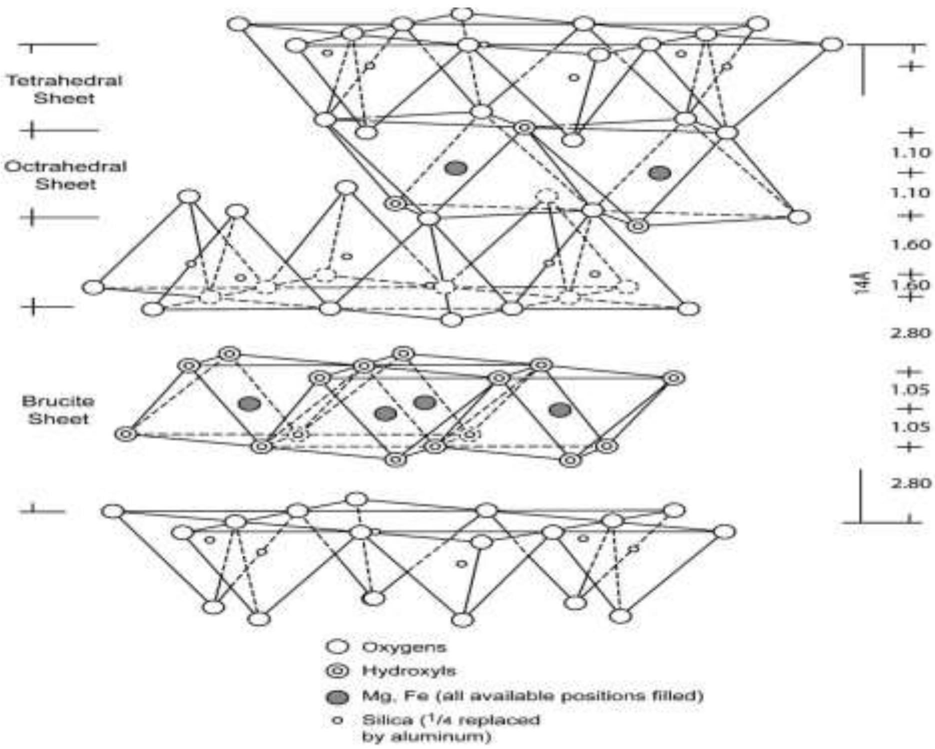

Figure1.6: Diagrammatic Sketch of the Structure of Chlorite (Bailey, 1988)

Bergaya and Langley (2013), explains that clay which people used in early ancient times, it has become a necessity for modern life. It is the material for many types of ceramics, such as porcelain, tiles, tiles and sanitary ware, as well as a basic ingredient in plastics, paints, paper, rubber and cosmetics. It is also non-polluting and can be used as a pollution remover.

The clay is soft, white plastic clay composed mainly of the mineral kaolinite, which is a hydrated aluminium silicate. It is produced by the modification of feldspar and muscovite. Clay deposits are classified as primary or secondary. Primary clays are the result of residual weathering or hydrothermal modification and secondary clays are of sedimentary origin (Al Ani & Olli, 2008).

Clay deposits are usually connected with depositional environments with very low energy, such as large lakes and marine sediments. Clay is one of the most commonly used industrial minerals, with a total world production of over 25 million tons, as a result of secondary deposition processes (Mourad, 2010).China is a major producer of kaolin with 2.1 million tonnes in 2002, accounting for 8.4% of total world production of 24.9 million tonnes (Wilson, 2004). Although used primarily in papermaking, which accounts for about 75% of world production, clay has traditionally found applications in the ceramic, rubber, dye, plastics and pharmaceutical industries (Murray, 2000). The use of clays is multifaceted and extends to various fields such as geology, construction, and environmental remediation, pharmaceutical and cosmetic industries. These uses continue to improve with the addition of clays.

Clay is one of the most used industrial minerals; its total world production exceeds 25 million tons, with China being the major producer of kaolin with 2.1 million tons in

2002. Although it is mainly used in papermaking, which accounts for about 75% of world production.

These applications continue to improve with the synthesis of other materials such as zeolites and nano-composites of clay minerals and polymers using clay as a model (Yaya, 2017). The diverse industrial uses of clay are governed by specific features for each technological usage.

Clay can either be of basement origin as a result of the alteration of feldspar and muscovite also known as primary origin also it could be through the sedimentary origin, that kaolinite were formed elsewhere and were transported and deposited, diagenesis and weathering could also play some role in the formation process.

Clay is a creamy white to dark brown soft clay mineral coloured by iron oxides/hydroxides (and/or rutile/anatase). Its main component is kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), a hydrated aluminosilicate in which a tetrahedral layer of silica is bonded to an octahedral layer of alumina through oxygen atoms (Olaremu, 2015).

1.2 Mode of Formation of Clay

Clays are formed from different environment, some could be from sedimentary environment as a result of weathering process and also basement environment, it could also be from hydrothermal alteration of volcanic activities as shown diagrammatically in figure 1.7

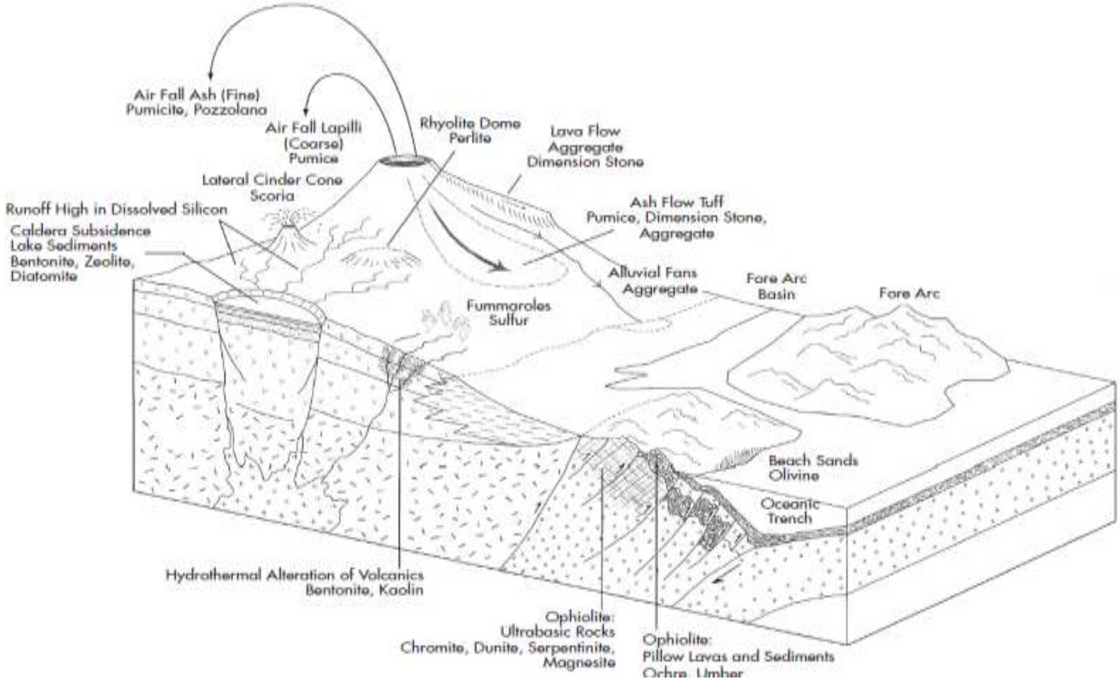

Figure 1.7: Industrial Mineral Deposits Found in Active Continental Margins (Anon 1994)

There are various processes involved in the mode of formation of clay deposits which are described below;

1. **Clay Derived from Chemical Weathering of K-feldspar**

The following chemical equation describes the chemical weathering process of the K-feldspar to clay final product.

$3KAlSi_3O_8 + 2H^+ \rightarrow KAl_3Si_3O_{10}(OH)_2 + 6SiO_2 + 2K^+$

K-feldspar Mica Quartz

$2KAl_3SiO_{10}(OH)_2 + 2H^+ + 3H_2O \rightarrow 3Al_2SiO_5(OH)_4 + 2K^+$

Mica Kaolinite

Kaolinite is a natural product of mica, plagioclase and sodium-potassium feldspar altered under the influence of water, soluble carbon dioxide and organic acids.This

Kaolinite are part of the constituent of clay, and it is when the major constituent is higher that it is called **kaolin clay**

2. Clay Mineral Derived from Weathering of Feldspar

Clay is formed mainly by the disintegration of feldspar (potassium feldspar), granite and aluminosilicates. The type of clay minerals that are formed during the decomposition of rocks containing aluminosilicates is influenced by climate, aluminum/silica ratio and Ilmenite is an intermediate weathering product that can be formed from feldspar or mica. Potassium ion depletion in mica is a diffusion-controlled phenomenon, with K+ release from biotite roughly two magnitudes faster than from dolomite, and clay formation precedes illite, which at shallow depths can directly precipitate from clay (De- Almeida, 1999).

Clay is a marl alteration product due to hydrothermal action. Clay minerals are generally arranged in layers around the source of alteration, with mica and kaolin close to the source of alteration, while chlorite and montmorillonite are farther away. The alteration products of silver tuff are also known to be connected with hot springs and geysers. In addition, clays are formed as weathering processes of aluminosilicates. The characteristics of the clay minerals that occur in a soil depend on the properties of the source material, the climate, the topography, the vegetation and the time at which these variables (Obaje *et al*., 2013).

1.3 Mode of Occurrence of Clay

Clay occurs in chlorite schist, gneisses and dolomites. It is usually originated from Mg-bearing sedimentary rocks or from ultramafic igneous rocks, the former being purer than the latter. In the first case, it is produced by metamorphism under high temperatures and/or pressures caused by geological disturbances, magmatic intrusions, etc. In the second case, it is produced by hydrothermal modification of non-aluminous magnesian silicates (examples are asbestos, amphibole and pyroxene).

Clay may occur as flakes and fibres or lumps. The latter are sometimes called 'massive clay' or 'lava' (a common name for any clay or soapstone) or 'massive hard clay' (a specific name for a variety of hard stone that occurs in large form) or 'French chalk' (a very soft and large kind of clay) Chatterjee (2009). In Nigeria kaolin bearing rocks occur within the schist belts of the basement complex, Okunlola *et al*.(2011).

Notable occurrence can be found in Kagara, North-western Nigeria and Itagunmodi-Igun area within the Ilesha schist belt South-west Nigeria where Clays occur as disconnected lenticular enclaves in massive-textured amphibolites and quartz-biotite schist, Olajide *et al*. (2018).This is consistent with the contention that kaolin claystones in Nigeria are closely associated with mafic and ultramafic rocks, Bolarinwa *et al*. (2015).

Clay is one of the most diverse industrial materials. It is chemically neutral over a fairly wide pH range, changes colour from white to brown and red, and has suitable properties for coatings when used as a pigment or thinner.

The clay is soft, non-abrasive and has low thermal and electrical conductivity. Some applications of clay, such as paper coatings or fillers in paints and plastics, require very stringent specifications, including particle size, colour, brightness and viscosity, while other applications do not require specifications, such as in cement, where chemical composition is paramount. The paper industry consumes the largest amount of clay, which is used both as filler and as a coating material on paper surfaces to increase print enhancement, Omang *et al*. (2019).

Clay can be found in various state of the nation such as Niger, Kogi, Ekiti, Edo, Ondo, Kaduna, Plateau, Adamawa, Delta, Ogun and Oyo State.

Therefore this research tends to determine the potential uses as a function of the mineralogy and the chemistry, in Pandogari area, North-central, Nigeria.

1.4 Statement of the Research Problem

Akintola *et al*. (2017) studied the geochemistry and origin of talc in Kagara in the adjoining studied area and suggested that the talcose rock was derived from an ultramafic protolith which has undergone moderate degree of metamorphism.

Amoka *et al*. (2015) also studied chemical and mineralogical properties of Kagara talc deposit in Nigeria and compared it to many existing commercial talc deposits globally, and suggested that it is suitable for several low to medium grade industrial applications.

Ako (2014) mapped the Zungeru amphibolite on a scale of 1:25,000 adjoining the studied area and recognized; massive and weakly foliated varieties, he concluded that the amphibole is of sedimentary origin.

Alabi (2017) studied the clay occurrence in the adjoining Bida basin and discovered 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 some industrial applications.

Most work carried out in and around the study area focus more on talc, petrology and geochemistry of rocks and clays within Bida basin. This study will therefore focus on the potential uses of the clay occurrences in Pandogari and to contribute to clay mineral inventory in Nigeria.

1.5 Justification of the Study

Clay is one of the foremost industrial minerals products in Nigeria and the world at large because of its industrial usage and its uses in almost every aspect of human lives.

Industrial minerals as needed on daily basis, Nigeria's attention is much on diversification so as not to depend solely on petroleum products, there is need for more research as clay has numerous usage.

Clay can be found in various state of the nation such as Niger, Kogi, Ekiti, Edo, Ondo, Kaduna, Plateau, Adamawa, Delta, Ogun, Oyo state.

The result of this study will add to clay mineral deposit inventory of Nigeria and improve on the Gross Domestic Product (GDP).

Therefore, it is important to undertake this research to understand the development of mineralogy and geochemistry of clay so as to reveal its suitability for various industrial usages and also to contribute to clay mineral inventory in Nigeria.

1.6 Aim and Objectives of the Study

The aim of this research is to unravel the mode of formation, chemistry and mineralogy of clay occurrence around Pandogari area as a function of its suitability for industrial applications.

Objectives

The following objectives are proposed to achieve the aim above;

1. Map and collection of clay and rock samples in areas where they are exposed in the field.
2. Produce the geology map of Pandogari area
3. Prepare and study thin sections of the representative fresh rock samples collected from the study area.
4. Determine the mineralogy of the clay using X-Ray Diffraction spectrometry.
5. Determine the elemental composition of clay using X-Ray florescence.
6. Evaluate the possible industrial applications of clay deposit using mineralogy and chemistry data.

1.7 Scope of the Study

This study intends to evaluate the mineralogy, geochemistry and the potential uses of clay in Pandogari area.

i. The mineralogical, chemical, and physical properties of clay will be determined. These characteristics of clay will be used for the clay mineral composition and potential usage of clay in the study area.

ii. The various properties will be used and compare specific standard or specification for industrial applications.

1.8 The Study Area

The studied area is part of Tegina sheet 164NE, Pandogari is located as part of the Tegina sheet which is within the basement complex of Nigeria. The area consists of meta-sedimentary and meta-igneous rocks that have been subjected to the processes of deformation and metamorphism. These lithologies have been intruded by the Pan-African Granitic rocks (Alabi, 2011).

1.8.1 Climate and Vegetation

The climate of the studied area is typical of the Guinea Savannah. The climate has two seasons, including a Rain season and harmattan season. The total mean annual rainfall in the region is about 1300 mm, distributed in April and October, with the highest rainfall in August and September minimum temperature in December and January is about 24 ºC. The average yearly temperature varies between 32 ºC and 33 ºC. The dry season is characterized by the effects of harmattan, the result of northeast trade winds that blow through the Sahara Desert, often with a red dust that lasts from December to January. In the dry season, most of these areas are degraded to rough ground due to the drying of the soil and the burning of shrubs. The vegetation is a variety of shrubs and tall forest plants along the streams.

Two seasons are prevalent in the study area, namely wet season (April to October) and dry season accompanied by the North-East trade wind which originates from the Sahara desert (Harmattan wind) (November to March). The driest month January witnesses little or no precipitation, whereas September is the wettest month, usually witness precipitation of 280mm (Idris-Nda *et al*., 2017)

Location

The studied area is part of Tegina Sheet 142NE and lies between latitude 10° 21′ 00″ to 10° 25′ 00″ N and longitude 6° 23′ 00″ to 6° 30′ 00″ E.

Pandogari is part of Rafi local government in Niger State, which is characterized with different developmental activities like roads, clinic and other basic amenities. The area mapped is 14.7km by 12.75km which is 187.43km^2.

It is generally accessible from Minna through Zungeru – Tegina, Kagara–Kaduna road; also the area is also accessible from Kaduna through Birnin Gwari– Tegina Road. It is also accessible through Alawa Road. Settlements in the area include Gidan Ajingi, Sabo Gida, Ringa, there are foot path and minor roads that makes the study area accessible.

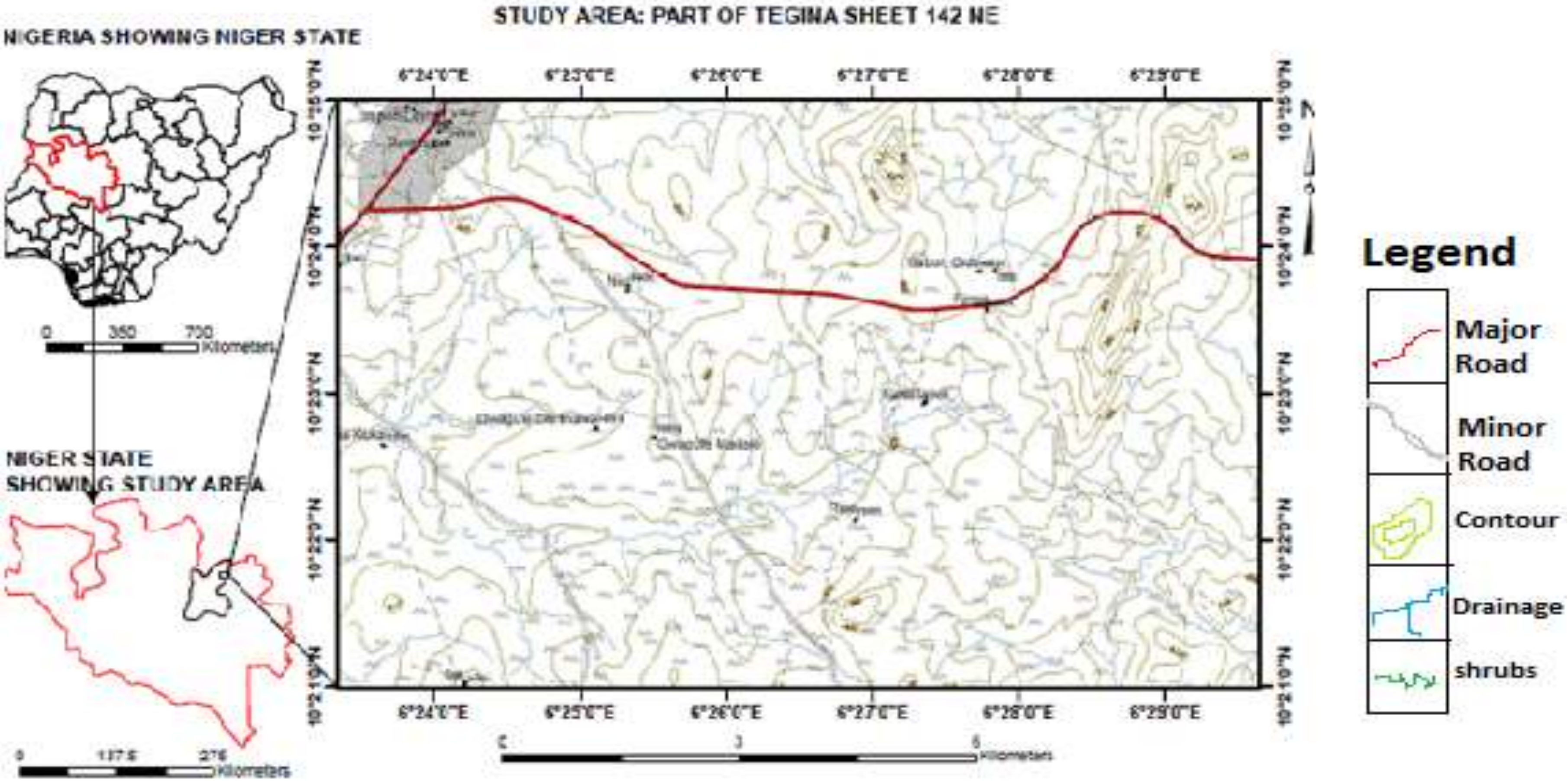

Figure 1.8: Topographical Map of the Studied Area

1.9 Regional Geology and Structural Setting

Alabi (2017) in his work deduced that Volcanic rocks in some areas of the basement rocks of the mapped area are chemically distinctive, suggesting a possible seafloor derivation. Crustal thinning in the Western Province of Nigeria is associated with Crustal expansion and continental margin rupture of the craton about 1000 million years ago, which resulted in the formation of graben-like structures and the deposition of mostly clastic sediments and small volcanic rocks over a wide area of Nigeria. About 600 Ma ago, oceanic closure of the craton margins and Crustal thickening in the east led to crustal distortion of upper mantle and lower crust and formation of old granites in Nigeria.

The basement complex is of Precambrian age and consists of a complex of migmatite gneisses, a gneiss belt, and old granites. The geology of Nigeria consists of three main rock types. They include: sedimentary rocks, young intrusive bodies and basement complexes.

The basement complex of Nigeria consists of three main types of rocks

i. Older granites (Pan-African granites).
ii. Schist belts (meta-sedimentary and metavolcanic rocks).
iii. Metamorphic-gneiss complexes (MGC).

The study area is predominantly N-S trending structures, and the extensive igneous regenerated areas of this basement are attributed to pan-African orogenic events, Van Breeman *et al*. (1977). The work of Ajibade (1980) and Elueze (1981) defined the lithological framework, deformation and metamorphism in the study area. The Kushaka belt is about 50 km wide which extends from the Minna region to Tsohon Birnin Gwari area in north-western Nigeria (Akintola *et al*., 2017).

Most of the economic clay deposits in Nigeria are associated with metamorphic rocks of basement complex schist belt, which the clay deposits of Pandogari belong.

The basement complexes have been studied in the northwest, Gusau and Minna sheets in different parts of the country. In the southwest, it has been studied in the Ibadan 2 plate, Lokoja and Akure plates. The three groups of rocks described above are well exhibited in the western half of the country. The schist belts that occur in the western half are used as a basis for dividing the basement into four main parts.

The basement complex is divided by sedimentary basins in northern and western Nigeria; this is illustrated in Figure 1.9

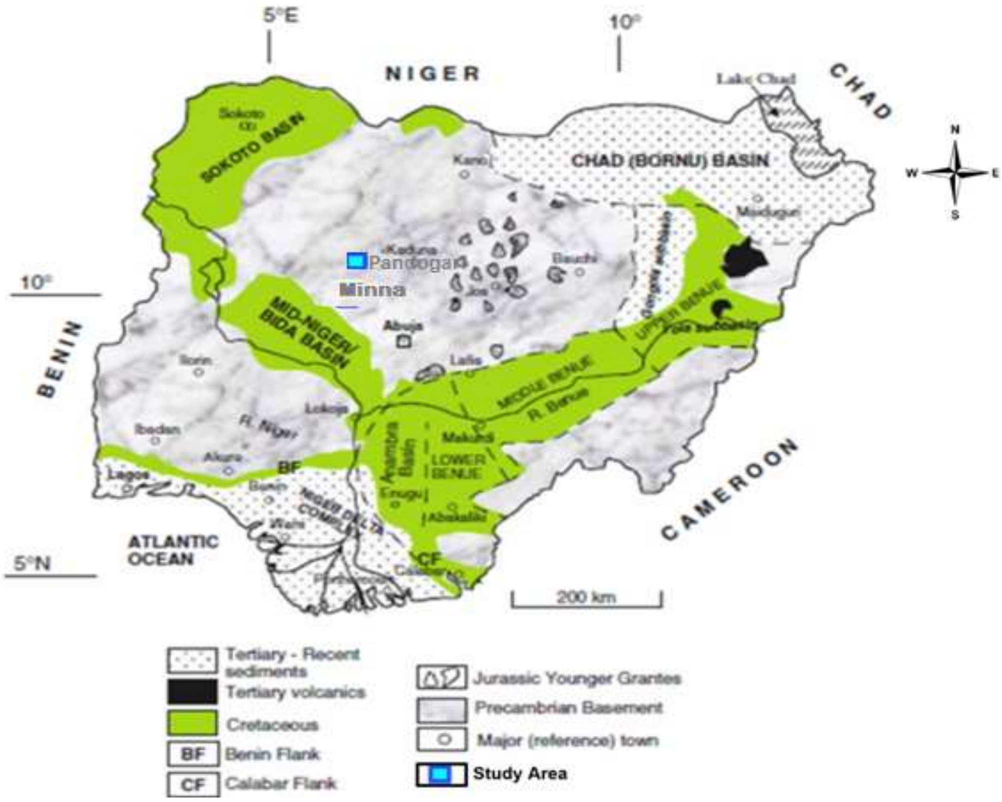

Figure 1.9: Geology Map of Nigeria (Obaje 2009).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Basement Complex of Nigeria

The basement complex is one of the three main petroleum geological components that make up the geology of Nigeria. It is intruded by the Mesozoic ring complex (young granites) of the Jos Plateau and overlain by Cretaceous and younger sediments. The age of the rocks in the basement complex varies from Archean (over 2.5 Ma) to Pan-African (~500-560 Ma). The Nigerian basement rocks are influenced by the 600-year Pan-African orogeny and are located in a region where reactivation occurred following the collision between the passive continental margin of the West African plate and the positive continental margin of the islands (Burke & Dewey, 1972; Dada, 2006).

The basement is thought to be the result of the deformation, metamorphism and remobilisation of at least four major orogenic cycles corresponding to the Liberian (2700m), Kibaran (1100m) and Pan-African (600m) cycles. The first three cycles are characterised by intense deformation and isotopic folding accompanied by regional metamorphism and followed by extensive migration. Pan-African deformation is accompanied by regional metamorphism, migration and extensive granitisation and gneissisation, producing synthetic granites and homogeneous gneisses (Abaa, 1983).

Late tectonic replacement of granites and granodiorites and the associated contact metamorphism accompanied the last phase of recent deformation. The end of the orogeny was characterised by faulting and rifting (Gandu *et al*., 1986). Two main petrological units have been identified within the Nigerian basement complex as related to the studied area.

2.1.1 Pan-African Granite

It consists of granite, amphibolite, syenite, gabbro, gabbro and charnockite and pegmatite. They range from small boulders to large batholiths, forming smooth dome-shaped hills and islands or isolated hills called "inselbergs" intruded into the two aforementioned subgroups. They are of Pan-African age. Some of them, associated with late pegmatites, contain gems, columbite-tantalite, other special metals and cassiterite.

Falconer (1911) used the term "old granites" to differentiate deep, generally harmonic or semi-harmonic granites from the basal complex of the higher, highly disharmonic lead granites of northern Nigeria. The older granites are considered to be pre-tectonic, syntectonic and post-tectonic rocks that dissect both migmatite-gneiss-quartzite complexes and gneiss belts. They have a wide range of ages (750-450 Ma) and compositions. They represent a diverse and long-lived magmatic cycle (750-450 Ma) associated with the Pan-African orogeny. The composition of this group of rocks ranges from tonite and amphibolite, granite-amphibolite to true granite and orthogranite. The Charnockite rocks represent an important group of rocks of this period. They are generally highly intrusive, and axial effects play an important role (Rahaman, 1981). Although thermal effects may have played a role in the remobilisation of mineralising fluids, the Old Granite Group is distinguished by a general absence of associated mineralisation.

Ancient granites are the most obvious manifestation of Pan-African orogenesis and represent a significant addition to the earth's crust (up to 70% in places) (Rahaman, 1988). Attempts to classify ancient granites according to the timing of orogenesis are only valid over short distances. Dada (2006) argues that the term "Pan-African granites" can be applied to ancient granites not only because there was no specific age at the time they were named, but also because it encompasses several major lithological groups that formed at the same time. Granites exposed in the gneiss belts of northwestern and southwestern Nigeria include biotite granite, biotite-dolomite granite, anorthite, charnockite, serpentinite and anorthite.

Rahaman (1988) abandoned the earlier classification of the members of the Old Granite Group based on their texture, mineralogical composition and relative time of formation. Instead, the members of the Old Granite Group are classified mainly on the basis of textural characteristics as follows.

1. Polarised granite.
2. Granitic gneisses.
3. Primitive pegmatites and fine-grained granites.
4. homogeneous to coarse-grained porphyritic granites.
5. Weakly deformed quartz veins and pegmatites; and
6. Undeformed pegmatite-type,quartz-veined granites.

Pan-African granites appear to be increasing eastward into northern Nigeria. They occur as isolated intrusions in western Zaria (McCurry, 1973) divided the granites of western Zaria into two main groups based on their range.

The first group of "composite formations" consists of elongate, partially cohesive and coated lava sheets. The second group of "late tectonic" consists of incoherent bodies with weak foliation, rich in plagioclase-smectite and low in potassium feldspar. The late granites are believed to be the product of extensive reworking and rearrangement of older rocks during the Pan-African orogeny. Late granites are inextricably linked to the migmatitic-gneiss complexes and the gneiss belts in which they are often intruded.

Thus, the oldest granitic rocks are located where most of the migmatitic-gneiss complexes or the rocks of the gneiss belts are found, Woakes *et al*. (1987).

However, the oldest granites are especially visible in the Wusasa (Zaria), Abuja, Bauchi, Akwanga, Ado-Ekiti and Obudu areas. In the Bauchi area and parts of southwestern Nigeria, most of the older granitic rocks are dark green granites with significant amounts of olivine (pyroxene) and pyroxene along with quartz, feldspar and mica. Because of this unusual composition, the older granites in these areas are known as bauchite (in the Bauchi area) and, in southwestern Nigeria, as oyawoyite (after Professor Oyawoye, who first mapped them). For the sake of terminological uniformity, both bauchite and oyawoyite constitute the charnokites of the basal complex.

Ajibade *et al*. (2008) mapped the Minna area at a scale of 1:100,000 and described the Old Granite as an irregular complex that forms contacts with most metamorphic units and cuts the Birnin Gwari, Kushaka Shale and Zungeru mylonite. The Old Granite consists of coarse-medium-grained amphibolite, poorly foliated, and the amphibolite is intruded into the rocks of the Kushaka Formation to form a leucosome-like amphibolite migmatite.

2.1.2 Schist Belts

The shale belts comprise low-grade, meteoritically hosted belts that strike north-south and are best exposed in western Nigeria. These belts were thought to be Upper Proterozoic ultrabasic rocks that have been folded into a migmatite-gneiss-quartzite complex (Obaje, 2009).

Gneiss belts are structurally controlled, elongated, roughly north-northeast to northeast-southwest syncline belts of Precambrian age consisting of metamorphic and metavolcanic rocks near the main deep rock lines with occasional igneous-metamorphic rocks. Mineral resources associated with the shale belt include ironstone, gold, manganese, marble and clay (Obaje, 2009).

Ako (2014) has mapped the amphibolite of Zungeru at a scale of 1:25,000 and has distinguished massive and weakly lobed varieties. It was concluded that the amphibolite is of sedimentary origin.

Muscovite shale consists of quartz, muscovite, dolomite, biotite and anatase, a mineral that usually occurs as small grains in smectites and intermediate metamorphic rocks (Alabi *et al*., 2015).

The Kushaka Formation is well exposed in the northeastern part of the Minna area andis intruded by a large amount of granite, and the granitic belt is divided into small bodies separated by granite and granodiorite. Migrations of the Kushaka Rock Formation are the result of subsidence of granitic rocks (Alabi, 2017). The gneisses in the area are part of the Kushaka rocks and are completely exposed during intense weathering activity.

The characteristics of the clay minerals in a given soil is dependent on the nature of the source material, climate, topography, vegetation, and the time at which these variables occur (Grim, 1968). The most abundant clay mineral found in marine sediments is illite, suggesting that montmorillonite is transformed to illite by slow reaction with K+-rich seawater.

Lithological variations in the shale belt include coarse- and fine-grained clastic rocks, polytypic shale, gabbro, banded iron, carbonate rocks (dacite/dolomite marble) and igneous metamorphic volcanic rocks (amphibolite).

Some of these may comprise fragments of ocean floor debris from later small deposits. For example, Rahaman (1976) and Grant (1978) reviewed several sedimentary basins, while Oyawoye (1972) and McCurry (1976) reviewed the shale belt as remnants of a single upper crustal cover. Olade and Elueze (1979) considered the shale belt as a controlled rift-like structure. In 1978 (1982), Holt (1982) and Turner (1983) proposed different ages of the deposits based on structural and lithological correlations. Nevertheless, Ajibade *et al*. (1979) disagrees with this finding and shows that both series contain the same deformation history.

Truswell and Cope (1963) treated the structural relationship between the shale belt and the basement as a conformal metamorphic front, while Ajibade *et al*. (1979) did map structural faults for the first time.

The shale belts are usually regarded as being of Upper Cenozoic age. The geochemistry of the amphibolite groups within the shale belt has also caused much conflict. Olade and Elueze (1979), Ogezi (1977) and Ajibade (1980) argue that the evolution of the shale belts was dominated by ensailic processes, while Rahaman (1981) and Egbuniwe (1982) stress that some shale belts include marine material with tholeiitic properties. Some metallogenic features of the shale belts are relevant to these questions; the apparent absence of deposits related to subduction may indicate a restricted role in the development of the shale belts for synclinal processes.

Oil shale belt is best developed in western Nigeria, west of 8° East longitude, although small deposits occur sporadically to the east. The oil shale belt is bounded by a north-east direction zone about 300 km. To the west of this zone are the gneisses and migmatites making up Dahomey's Burke and Dewey (1972). Similarly, there are no known gneiss belts to the east over a distance of 700 km to Cameroon, where some gneiss belts thought to be Upper Cenozoic in age are found in the Pan-African granite-saprolite outcrop north of the Congo Craton. These gneiss belts have been mapped and investigated in considerable detail at the various locations: Maru, Anka, Zuru, Kazaure, Kusheriki, Zungeru, Kushaka, Iseyin Oyan, Iwo and Ilesha, (Figure 2.1). The study area is part of the Kushaka Shale Formation, the Birnin-Gwari Shale Formation and the Ushama Shale Formation (Table 2.1).

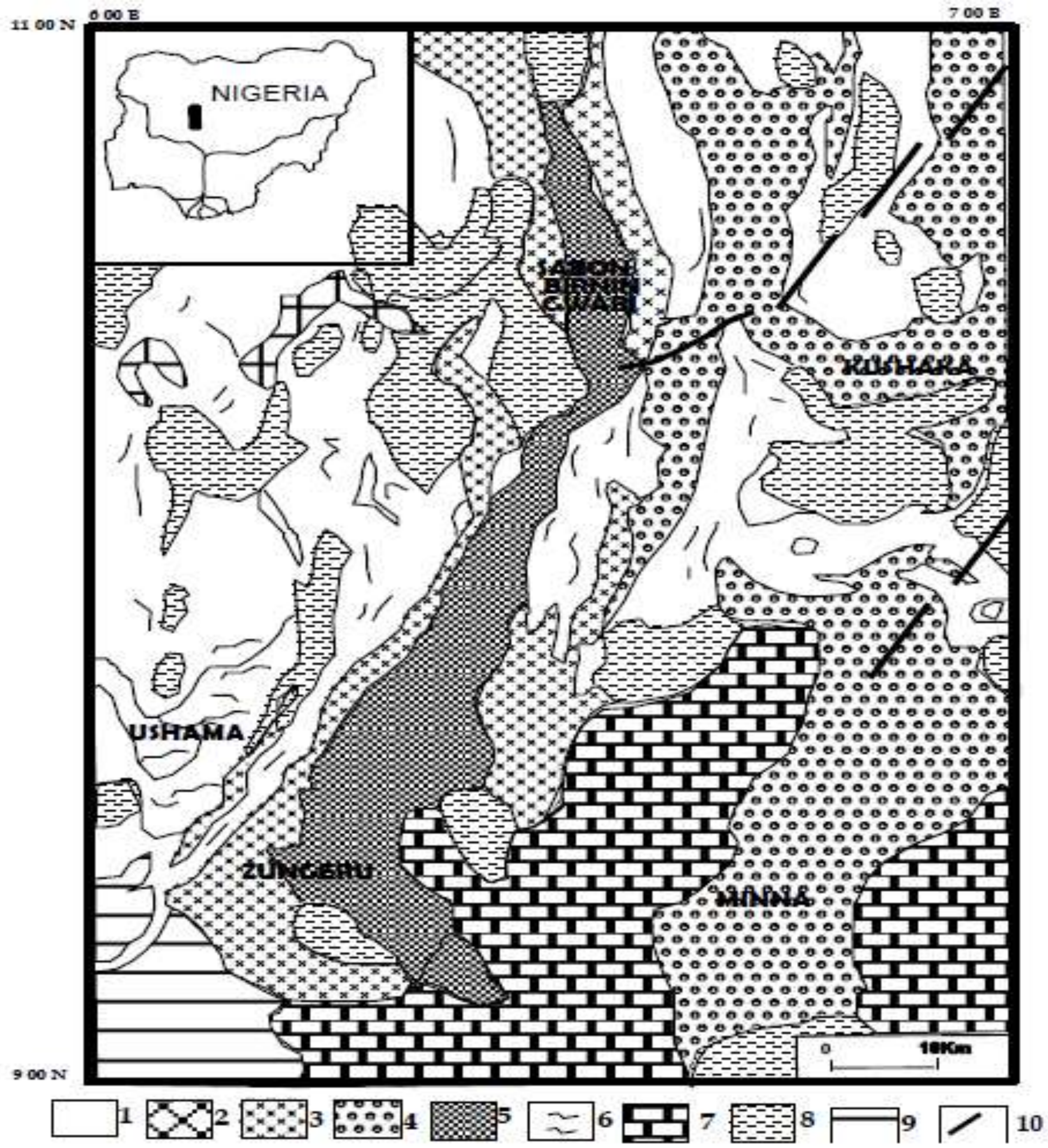

Figure 2.1: Geological Map of the Kusheriki/Minna-Zungeru area (Ajibade *et al*., 1980)

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

The Birnin Gwari Gneiss Formation as well as the underlaying quartz-feldspathic rocks of the Zungeru Granite Formation collectively form a structural unit, the Zungeru-Birnin Gwari Gneiss Belt. The Zungeru granite horizon is revealed on both faces of the gneiss belt. It consists largely of medium to finely graded quartz feldspathic rocks intermingled with amphibolite and some quartzite (Obaje, 2009).

The kushaka strata form several curved gneiss belts divided by gneiss domes and anticlines. They contrast with the Zungeru-BirninGwari belt in relation to lithology, structure and igneous rocks. The main rock type is black micaceous schist with occasional garnet and dolomite. Other rocks are representative of gabbro, metasedimentary sandstones and graphitic schist. Several thick banded iron-bearing units are interbedded with shales. Various amphibolites and amphibolites, amphibolites, chlorites, and talc-bearing schist correlate, at least in part, with travertine-type basalts (Elueze, 1981). The geological maps show various shale belts and basement complexes in Nigeria (Figure 2.2) and Table 2.1 below describes the basement complexes associated with the study area.

Table 2.1 Summary of the Geology of the Basement Complex (Ajibade *et al* .,2008)

	RockType	Lithologies	Age
Intrusion			
	Older Granite		Pan-African
	Charnockitic Rocks	Gabbro, diorite	
The Schist Belts	BirninGwari SchistFormation	Phyllites, mica schist, metagreywacke, pebbly schist, meta-dacite and meta – rhyolite	?Pan-African
	UshamaSchist Formation	Phyllites,micaschist,quartz mica schist, amphibolites	?Pan-African
	KushakaSchist Formation	Phyllites,micaschist,quartzmica schist, amphibolite,ferruginous quartzite, marble	?Pan-African
	Oro Schist Formation	Phyllites, mica schist, amphibolite,	?Pan-African
Gneissic Complex	Zungeru Mylonites	Sheared gnesiss, mylonitic straurolite schist,quartz mylonites	Pre- Pan- African affected by Pan-African tectonism
	Early Migmatite Complex	Mylonitegneiss, mylonite schist, blastomylonite, phillonite and amphibolites	?Pan-African
		Banded gneiss, agmatite, anatetic migmatite,biotite gneiss	

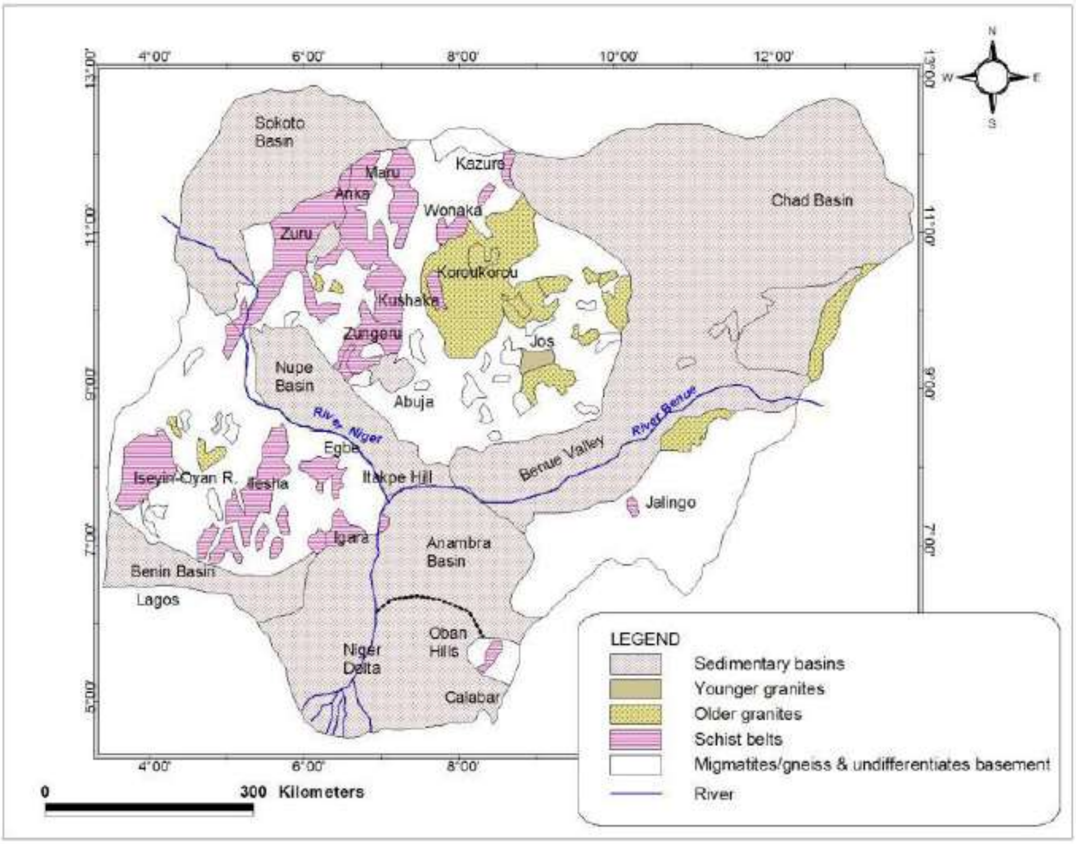

Figure 2.2: Geology Map of Nigeria Showing the Basement Rocks and the Schist Belts (Bassey, 2012).

2.2 Previous Work on Clay

Clay minerals are the product of the progressive chemical weathering of original (mostly silicate) rocks over time in the presence of low levels of Carbonates and other dilute solvents, especially in the hot tropical and subtropical regions of the world. In Addition to the process of weathering, clays are also produced by the hydrothermal transformation of rocks. In relation to the mechanism of deposition, clay is a residue that was formed in situ by leaching (chemical), while others have undergone extensive transport before being deposited (clastic).

According to the area studied, the clays are part of the basalt topography and the weathering activity of the shale is very strong, thus forming the clays in the area.

2.2.1 Types of Clays and Industrial Applications

Clays can be divided into six categories.

1. Clay or China Clay: white clay-like material composed mainly of kaolin, industrial applications: Paper coatings and fillers, refractory materials, fibreglass and insulation materials, rubber, paints, ceramics and chemicals.
2. Ball Clay: clay with minor impurities, industrial applications: Tableware, floor tiles, pottery, sanitary ware.
3. Refractory Clay: Clay with many impurities (lagoon, flint), industrial applications: refractory materials.
4. Bentonite: Clay composed of colloidal minerals, usually montmorillonite, and industrial applications: Drilling mud, foundry sand (Hoffmann, 1959).
5. Fuller's Earth: Non-plastic clay with high magnesium content, similar to bentonite, industrial applications: Absorbent, Fischer *et al*. (1943).
6. Shale: Layered sedimentary rock consisting mainly of clay mineral silt, industrial applications: Raw material for cement and brick production.

2.2.2 Uses and Specifications of Clays

According to the specifications and end use of clays in the earlier work by Obaje *et al*. (2013) which are explained below:

A. Construction industry

Clays and bricks are used raw materials in construction. Bricks are composed of 100% earth materials such as slate, clay and fine-grained laterite. The clay minerals in natural limestone or mixed limestone clays or shales contribute SiO_2, Al_2O_3 and possibly iron, alkali and alkaline clays, depending on the properties of the clay minerals used to produce Portland cement. Kaolinite is most appropriate for the production of portland white cement.

(B) Agricultural Industry

i. Fertilisers

Due to the high potassium content of the clays phlogopite, illite and glauconite, they are used as mineral additives in agriculture to improve soil fertility for crop production. In addition, clays are used as dilutants for chemical fertilizers to achieve optimum relative concentrations of elements.

ii. Pesticides

Clays composed of montmorillonite and kaolin are used as dilutants in pesticide formulations to improve the uniform distribution of toxic active ingredients and retention of pesticides by plants.

iii. Feed Additives

Vermiculite and montmorillonite clays are used as feed additives for poultry, cattle and other livestock.

(c) Textile and Paper Industry

Clays are used for filling, sizing and coating of various textile products. Very fine-grained kaolin clays with a with a particle size of 2-5 microns, it is the best filling material suitable for textiles and paper, Woolman and McGowon (1926).

(D) Pharmaceutical Industry

Clays, in particular kaolin, have been used for centuries in pharmaceutical preparations for intestinal drug adsorption and other therapeutic applications. Clays such as montmorillonite, kaolinite and albite are used in the manufacture of pastes, ointments and body lotions. These clays are used in cosmetic preparations because of their properties such as softness, dispersibility, coagulability, emulsification and adsorption, Goodman and Gilman (1955).

(E) Ceramic Industry

Clay is a very valuable and important raw material for the manufacture of various ceramic products, i.e.

i. Ceramic building materials (bricks, tiles, ceramic pipes, domestic sanitary ware, drainage and sewerage fittings).
ii. Household ceramics (tableware, plates, dishes, vases, dental products such as false teeth, etc.)
iii. Chemical and technical ceramics (chemical-technical instruments/equipment, hospital equipment and acid-resistant tiles and sinks, etc.)
iv. Special laboratory and technical ceramics (aircraft nozzles, crucibles, pestles, pestle, rocket engines and spark plugs).
v. Ceramics in the electrical industry (electrical insulators, motor brushes and battery carbons) Obaje (2008).

(F) Nuclear (Radioactive) Waste Management.

The treatment of effluents and solutions containing highly biotoxic radioactive materials is an important issue for the development of nuclear energy. Clay is used to treat highly radioactive (nuclear) waste by adsorbing ions and then immobilizing them by calcination at temperatures above 10 000˚C, which is sufficient to vitrify the clay and thus leave the radioactive material in an insoluble state (Kerr,1954). In this way, the liquid waste is transformed into a solid form that can be buried without fear of the radioactive material being dissolved and mobilized in groundwater resources.

(G) Petroleum Industry

Bentonite and kaolin are used as catalysts for the thermal cracking of heavy oil fractions into gasoline. Bentonite is also used as drilling mud in the oil and gas industry, Milliken *et al*. (1955). In addition, bentonite and kaolin are used in synthetic rubber to provide ideal reinforcing and curing properties for rubber products. Kaolin is used extensively in the making of reinforced polyester and other reinforced plastics.

(H) Water Clarification

During the clarification of drinking water, colloidal substances are removed by filtration and/or sedimentation processes. Alum is commonly used to flocculate colloidal materials to increase the rate of sedimentation and filtration. In some cases, alum alone is not entirely effective and, according to Nordell (1951), it is preferable to add highly colloidal, easily dispersible clay to the water before adding alum. The alum causes the clay to flocculate, thus collecting and collecting all the colloidal material in the water that would otherwise not settle to the bottom of the water tank. Studies have shown that bentonites are the most suitable for water clarification because they have the necessary dispersion and adsorption properties. Clays can be used in water treatment to reduce and remove undesirable odours and tastes from water and to soften water (Weir, 1938).

(I) Clarification of Wine, Cider, Beer

It is reported that colloidal impurities in wine have a positive charge, so small amounts of negatively charged clay material mixed into the wine, cider or beer for clarification can coagulate and remove them, Olin and Peterson (1937). Bentonite clay is the most suitable for this application.

(I) Production of Colours

Various types of kaolin clays are used in paint production to improve the properties of the brush, body or film surface (gloss or flatness).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Fieldwork and Sample Collection

The field work exercise was carried out in two stages; the first stage was the Reconnaise survey mapping of the study area using conventional geologic mapping methods. The study area was covered by traverse using the base map, also the geographical coordinate were taken using the Global Positioning System (GPS), the extraction of the base map were done from the Tegina sheet 164NE. The second stage involved the map production to a scale of 1:25,000, the strike and dip direction were taken using Compass clinometers, there was the use of the physical properties of the rocks in handspecimen was used to infer the rock type; these properties include colour, texture, structure and mineralogy and were useful in the identification of the major rock units within the study area, construction of the geologic map and the determination the geologic history. Geological logging of the clay occurrence, host rock of clay and collection of clay and rock samples were also carried out using hammer and hand trowel to dig it out also sample bags for laboratory analyses.

The main geologic features that formed the object of interest for this research are the quartz vein intrusion and the weathered alteration zones and the depth of the clay occurrence. In each pit, the geologic features of interest were studied and recorded. Thirteen (13) clay samples were submitted for geochemical analysis samples for both XRD and XRF, thirteen (13) clay samples were selected at random for geochemical analysis and six (6) rock samples for thin section at the Nigerian Geological Agency Laboratory, Kaduna and Federal University of Technology Minna respectively.

3.1.1 Equipment Used for Field Work

The equipment that were used during the field work exercise include the following; compass/clinometre for the collection of structural data such as the strike and dip of rock outcrops and other structural trends, Global Positioning System (GPS) was used to take bearings and accurate positions, geologic hammer to collect samples, sample bags to collect clay samples, hand lens for the identification of mineralogical composition of rock samples, marker for sample labelling, a measuring tape for the measurement of parameters such as the depth, length and breadth of the clay occurrence and measurement of the overburden thickness, thickness of the veins and a digital camera for taking of clay occurrence and important geological structures on the basement rock.

3.2 Laboratory Analysis

3.2.1 Petrography

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

The sample was cut from rock sample with a diamond saw and smoothed visually. This was then placed on a glass slide subsequently smoothed with gradually finer abrasives until the sample was only 30μm in thickness. It is then viewed under an optical microscope that emits light so as to under study the various optical properties like colour, cleavage, twining. Also various minerals present were view both under the plane polarized light and the cross polarized light.

3.2.2 X-Ray Diffraction(XRD) Analysis

Four (4) clay samples were analyzed using X-Ray Diffraction (XRD), which is based on the productive interference of monochromatic X-Rays with a crystal sample. These X-Rays are produced by a cathode Ray tube, filtered to generate monochromatic radiation, which is collimated and concentrated and aimed at the sample. The interaction of the incident Rays with the sample produces constructive interference (and refraction of light) when conditions satisfy Bragg's law ($n\lambda = 2d \sin \theta$). This law relates the wavelength of the electromagnetic emission to the angle of diffraction and the lattice spacing of the crystal sample. These diffracted X-Rays are detected, processed and counted. By scanning the sample over a range of 2θ angles, all possible lattice diffraction directions should be obtained due to the random orientation of the powdered material. Transforming the diffraction peaks into d dimensions allows for mineral identification, as each mineral has a unique set of d dimensions. Typically this is done by comparing the d-distance with a standard reference.

Samples collected from the field were crushed to -75µm, mounted on glass sheets and bombarded with X-Rays using a new Empyrean analysis machine model D4674 (2011), powered by a 45 KV generator with a tube current of 40 KV. X-Rays were diffracted by atomic planes in the crystal structure and produced patterns, which were scanned over a range of 1-75 degrees using K-α1 and K α2 radiation recordings, which were done at the Nigerian Geological Survey Agency (NGSA), Kaduna.

3.2.3 X-Ray Fluorescence Spectrometry (Principle)

The samples to be analyzed by XRF are stirred with primary X-Ray beams. These X-Ray beams (photons) interact with the atoms of the element causing the loss of electrons from the inner shell orbital. This causes the atom to become unstable as it tries to return to a stable electron configuration state. The atom becomes stable by transferring outer-shell orbital electrons to replace the lost inner-shell orbital electrons. This process leads to the release of energy known as fluorescent X-Ray photons that is equivalent to the difference in energy levels between the two (2) orbitals. The emission of this energy is measured during the analysis and it is measured according to its intensity, depending on the concentration of the elements in the sample.

Instrumentation for XRF Spectrometry

The instruments used for XRF analysis are called XRF spectrometers. Two types of spectrometers are commonly used: Wavelength Dispersive Spectrometers (WD-XRF) and Energy Dispersive Spectrometers (ED-XRF).

In these spectrometers, the basic instruments are the X-Ray tube that produces the main beam of X-Rays, the collimator that detects and quantifies the elemental composition of the sample, the diffraction crystal and the counter.

3.2.4 Sample Preparation for XRF Spectrometry

Thirteen(13) samples were analysed by XRF are usually milled into powder and from the powder, samples for major elements analysis can be prepared using the glass beads and trace elements analysis using the pressed pellets.

3.2.5 Powder Pellets for Trace Elements Analysis

To prepare the sample for trace element analysis, 7.5g of powdered sample was weighed into a shaker mill using three (3) pieces of cellulose binder. This mixture was ground to a very fine powder form. The bucket was placed on a steel base and the first disc was inserted with the shiny side facing up. The sample was then introduced into the sample bucket and carefully compressed with a slider, after which a second disc was inserted with the shiny side facing down. A steel ram is inserted and the barrel containing the sample is placed on a press. The air valve is closed and compressed with 20tons of weight, then the air valve is opened and the barrel is removed from the press. The steel ram is removed and the barrel is turned upside down, but this time on an aluminium base. The steel base is removed from the barrel and replaced by a steel ram. The air valve is again closed and the assembly is placed on the press where it is compressed until the plunger falls off. The air valve is opened and the steel slider is removed from the barrel. The opposing discs are carefully separated from the pellets in the middle. The pellets were then properly labelled and submitted to the Nigerian Geological Survey Agency (NGSA) in Kaduna for trace element analysis.

Replicate sampling was used to test the accuracy of the analysis. Duplicates were randomly selected from the collected batch of samples and labelled accordingly before submission to the laboratory.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Field Work

The studied environment is of basement complex that consists of biotite granite and muscovite schist of low to medium grade metamorphism which those at the road cut has been weathered, the schist is trending NE-SW direction and towards the eastern part of the mapped area the schist was less weathered with various joints, folds, quartz veins and biological weathering activities occurrence on the exposed outcrops.

The overburden also is brownish to reddish in colour which may be due to the intensity of the weathering and more so the lateritic content of the soil.

4.2 Structures

4.2.1 Fold

In the schist, the dominant foliation trend is NE-SW, fold were observed on some outcrops both the anticline folds were noted (Plate I). It was not on a large scale but on each outcrop there were representative structural features.

Plate I: Presence of Anticline Folds (N10°23′ 43″, E006° 26′ 41″)

4.2.2 Schistocity

The schist in the area has pronounced schistose structure and this is as result of the grade of metamorphism in the area and these textures and the plane of foliation were noted (plate II)

Plate II: Presence of Schistocity and plane of foliation in Schist (N10°23′ 43″, E006° 26′ 40″)

4.2.3 Fault

Minor or micro fault were observed on quartz vein with a dextral displacement of 5mm was observed in coarse-grained granite.

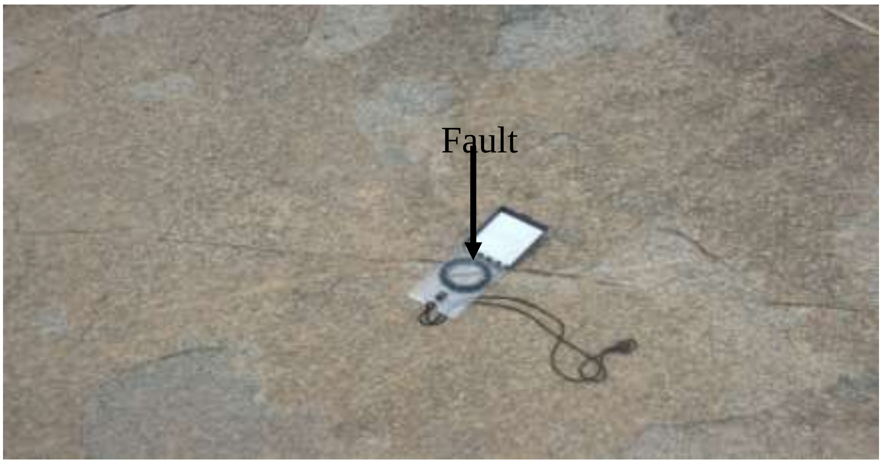

Plate III: Micro-fault in Granite of the Studied Area (Dextral fault) (N10°23′ 38″, E006° 27′ 57″)

4.2.4 Joints

Joints in the granite are mainly Northeast-Southwest and northwest-southeast trending (Plate IV), while joints in the schist are northeast-southwest trending and sparsely jointed. Some rocks in the study area have undergone some degree of physical weathering, resulting in exfoliation. Some of the coarse-grained granite rocks exhibit tight jointing (Plate III).Some of joints are open joints while some are closed joints which have been healed with quartz vein.

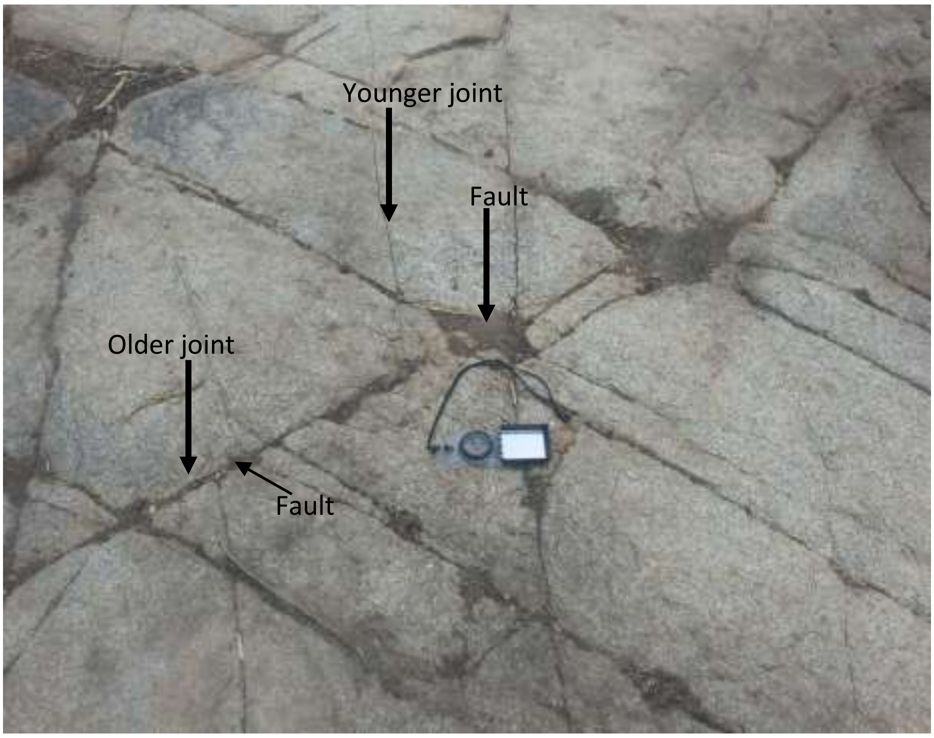

Plate IV: Joints in Granite of the Studied Area (N10°23′ 38″, E006° 27′ 57″)

Table 4.1: Joint values of the studied area

Joint Direction	F1	Joint Direction	F2	F1+F2	F1+F2/Total x100
0-30	13	181-210	2	15	26.31
31-60	19	211-240	2	21	36.84
61-90	11	241-270	1	12	21.05
91-120	1	271-300	0	1	1.75
121-150	2	301-330	5	7	12.28
151-180	0	331-360	1	1	1.75
TOTAL				**57**	**100**

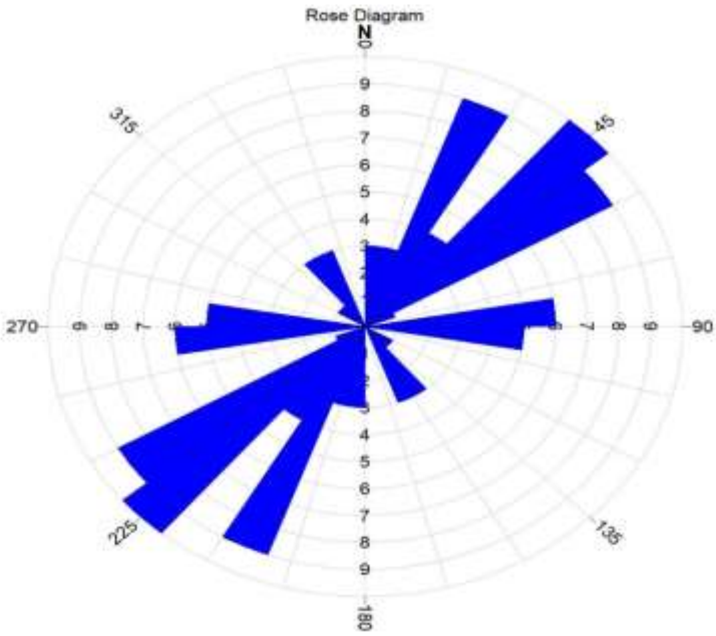

Figure 4.1: Rose Diagram of Joint Directions of the Studied Area

4.3.1 Biotite Granite

The rocks with joints in the area have some sets of joints, with a Northeast-Southwest trending direction (Figure 4.1). Granite bodies show different outcrop elevations, ranging from steep hills to gently low-lying massive rocks, with some granites in the study area having elevations of about 469 m and textures ranging from moderate to coarse.

The granites occur as batholiths with low-lying massive outcrops on ridges. The light granites contain light colour minerals such as Muscovite and Quartz, as observed in hand specimens, and the light granites have medium to coarse grained grain sizes, while the dark granites also have dark colour minerals that are medium to fine grain which is called Aplite (Plate V).

The light colour granite highly fractured and the fracture of different direction with dissected joints, the contact between the light and dark colour is very sharp and the width is from 1m to 0.13m, the granitic area of extent of exposure is about 50m by 50m

Plate V: Presence of an aplite vein (N10°23′ 38″, E006° 27′ 57″)

4.3.2 Petrography of Biotite Granite

Three rock samples were analyzed for thin section so as to correlate it with the XRD results and also to ascertain the origin of the clay, below are the photomicrographs of the granite gotten from the field in Pandogari area.

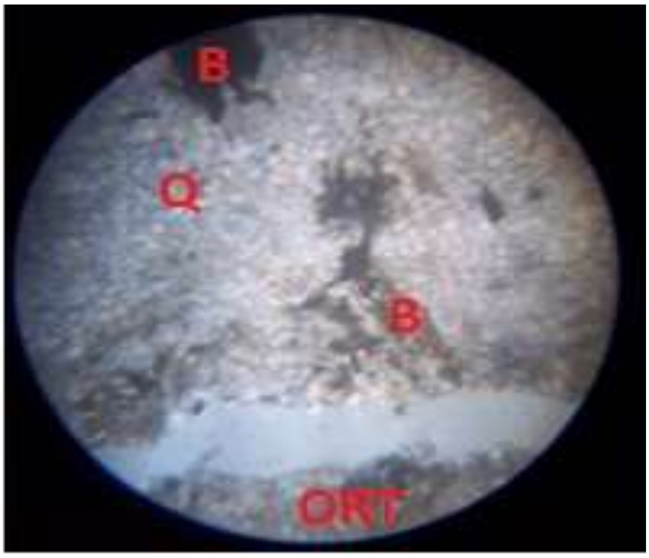

Plate VI A: Photomicrograph of Granite 1 under Cross Polars X72
(B-Biotite,Q-Quartz,ORT-Orthoclase)

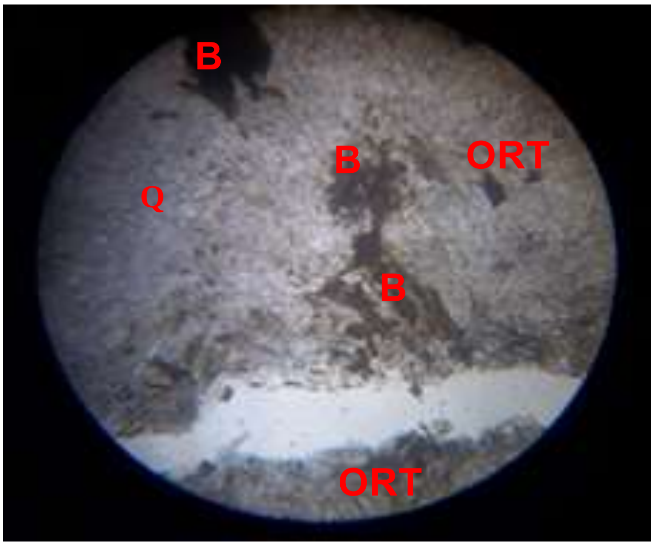

Plate VI B: Photomicrograph of Granite 1 under Plane Polars X72
(B-Biotite,Q-Quartz,ORT-Orthoclase)

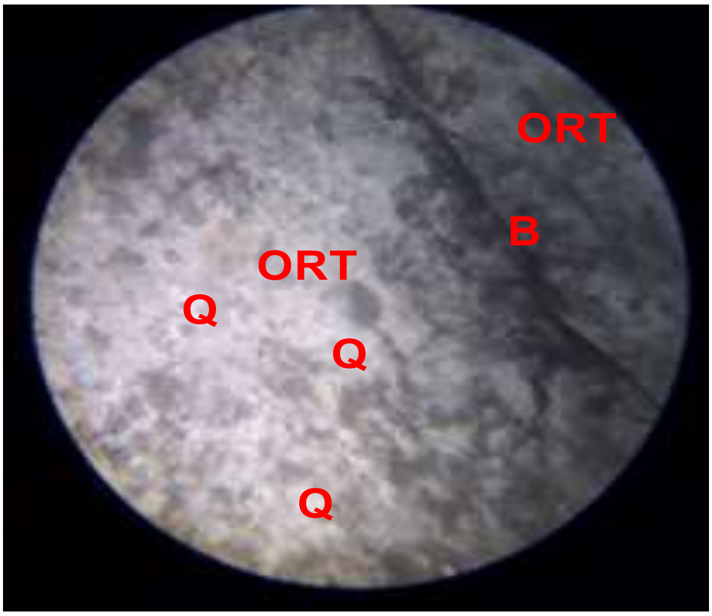

Plate VII A: Photomicrograph of Granite 2 under Cross Polars X72

(B-Biotite,Q-Quartz,ORT-Orthoclase)

Plate VII B: Photomicrograph of Granite 2 under Plane Polars X72

(B-Biotite,Q-Quartz,ORT-Orthoclase)

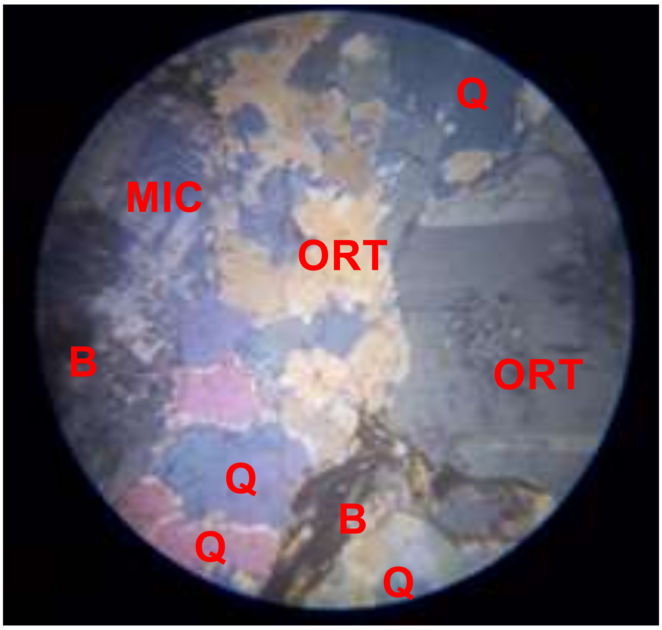

Plate VIII A: Photomicrograph of Granite 3 under Cross Polars X72
(B-Biotite,Q-Quartz,ORT-Orthoclase)

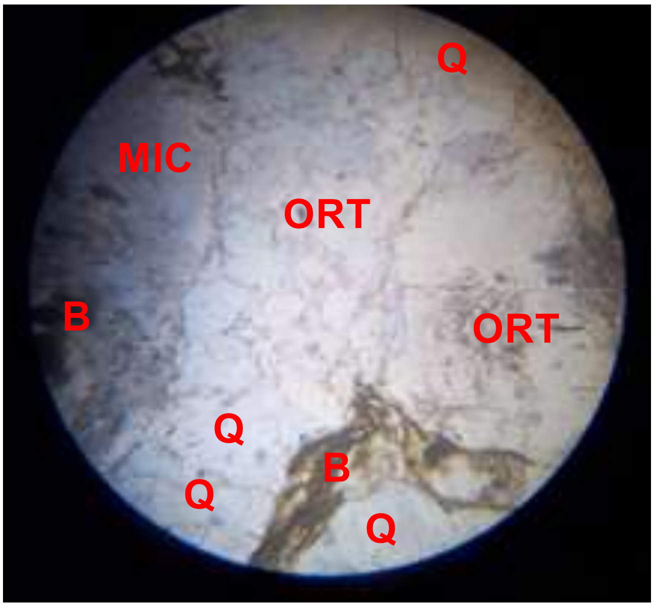

Plate VIII B: Photomicrograph of Granite 3 under Plane Polars X72
(B-Biotite,Q-Quartz,ORT-Orthoclase)

4.3.3 Thin Section Petrography Modal Analysis and Description for Granites

Three (3) granite samples were selected for petrographic analysis so as to reveal the major or dorminant minerals present these were viewed under the petrological microscope and the following properties were observed also the modal analysis were done.

Table 4.2: Detailed Explanation of the Thin Section of Granite 1

Mineral	Colour in PPL	Colour in XPL	Extinction Angle	Diagnostic Feature/Pleochroism	Micro Structure/Crystal Form	Twinning	% in Thin Section	Infered Rock Name
Quartz(Q)(SiO_2)	Colourless	Blueish to milky	Absent	Low pleochroic	Anhedral	Absent	50	Biotite Granite
Plagioclase(ORT)($NaAlSi_3O_8$-$CaAl_2Si_2O_8$)	Colourless	Milky	Absent	Low pleochroic	Anhedral to Euhedral	Absent	20	
Biotite(B)	Dark	Brown to Dark	Absent	Absent	Euhedral	Absent	30	

Table 4.3: Detailed Explanation of the Thin Section of Granite 2

Mineral	Colour in PPL	Colour in XPL	Extinction Angle	Diagnostic Feature/Pleochroism	Micro Structure/Crystal Form	Twinning	% in Thin Section	Infered Rock Name
Quartz(Q)(SiO_2)	Colourless	Blueish to milky	Absent	Low pleochroic	Anhedral	Absent	50	Granite with Microfracture filled Biotite
Plagioclase(ORT)($NaAlSi_3O_8$-$CaAl_2Si_2O_8$)	Colourless	milky	Absent	Low pleochroic	Anhedral	Absent	20	
Biotite(B)	Dark	Brown to Dark	Absent	Absent	Euhedral	Absent	30	

Table 4.4 Detailed Explanation of the Thin Section of Granite 3

Mineral	Colour in PPL	Colour in XPL	Extinction Angle	Diagnostic Feature/Pleochroism	Micro Structure/Crystal Form	Twinning	% in Thin Section	Infered Rock Name
Quartz(Q)(SiO_2)	Colourless	Blueish to milky	Absent	Low pleochroic	Anhedral	Absent	50	Granite
Plagioclase(ORT)($NaAlSi_3O_8$- $CaAl_2Si_2O_8$)	Colourless	Blueish to milky	Absent	Low pleochroic	Anhedral	present	20	
Biotite(B)	Dark	Brown to Dark	Absent	Low pleochroic	Euhedral	Absent	20	
Muscovite(Mic)	Colourless	Pale yellow	0-3	Weak pleochroic	Well form tabular	Twin plane	10	

4.4.1 Muscovite Schist

The schist in the studied area, in hand specimen description are medium to fine grained in textures, they ranges from light to dark gray and greenish in colour. The schist contain muscovite which correspond to part of Ushama schist formation characteristics according to (Ajibade *et al.*,2008), there are folds present, the joints also are of both closed and open joint in the area, pegmatite were also observed in the schist (Plate III), which some are about 7inches.

Plate IX: Pegmatite vein in schist (N10°23′ 43″, E006° 26′ 40″)

4.4.2 Petrography of Muscovite Schist

Three rock samples were analyzed for thin section so as to correlate it with the XRD results and also to ascertain the origin of the clay, below are the photomicrographs of the schist gotten from the field in Pandogari area.

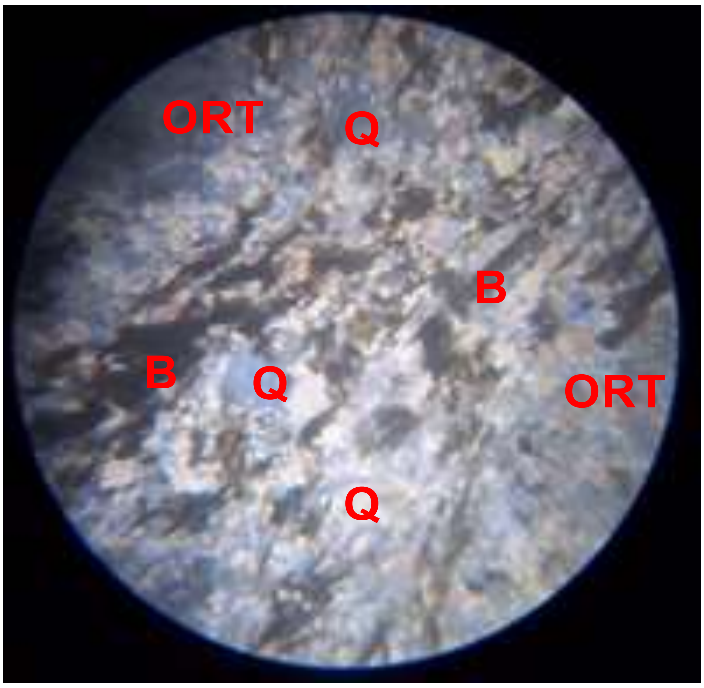

Plate X A: Photomicrograph of Schist 1 under Cross Polars X72

(B-Biotite,Q-Quartz,ORT-Orthoclase)

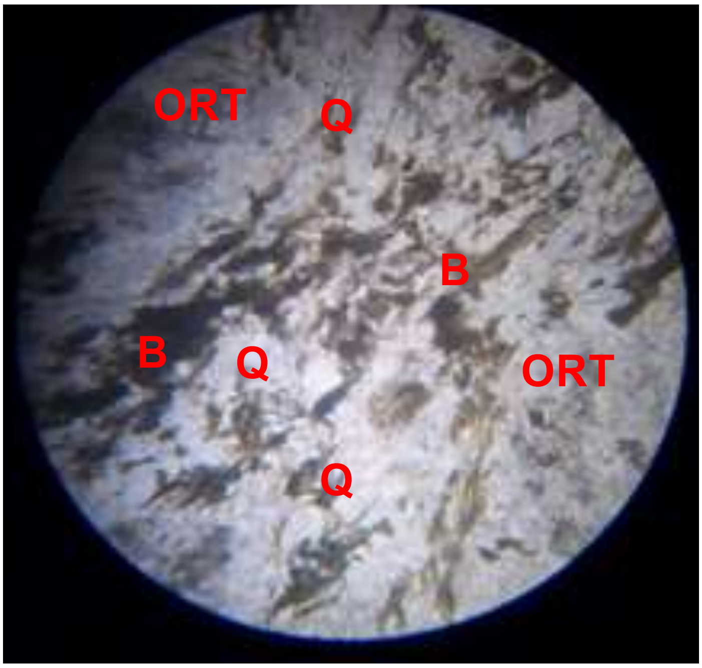

Plate X B: Photomicrograph of Schist 1 under Plane Polars X72

(B-Biotite,Q-Quartz,ORT-Orthoclase)

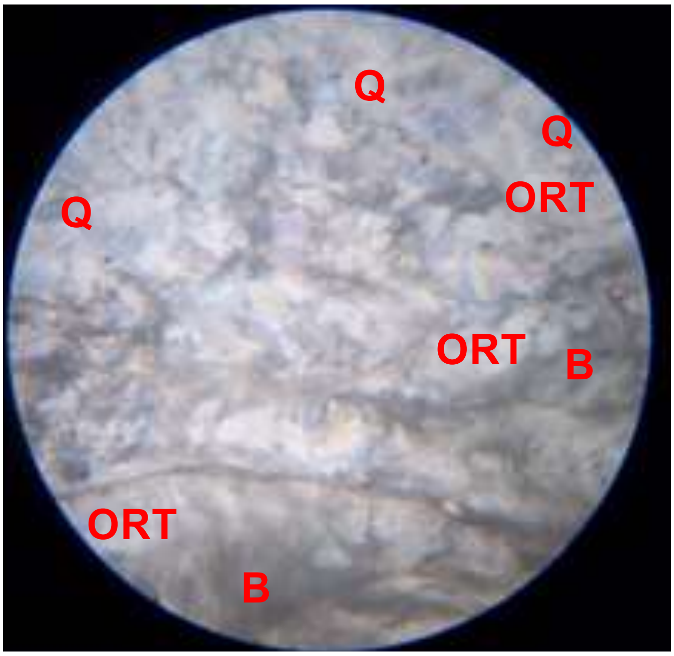

Plate XI A: Photomicrograph of Schist 2 under Cross Polars X72

(B-Biotite,Q-Quartz,ORT-Orthoclase)

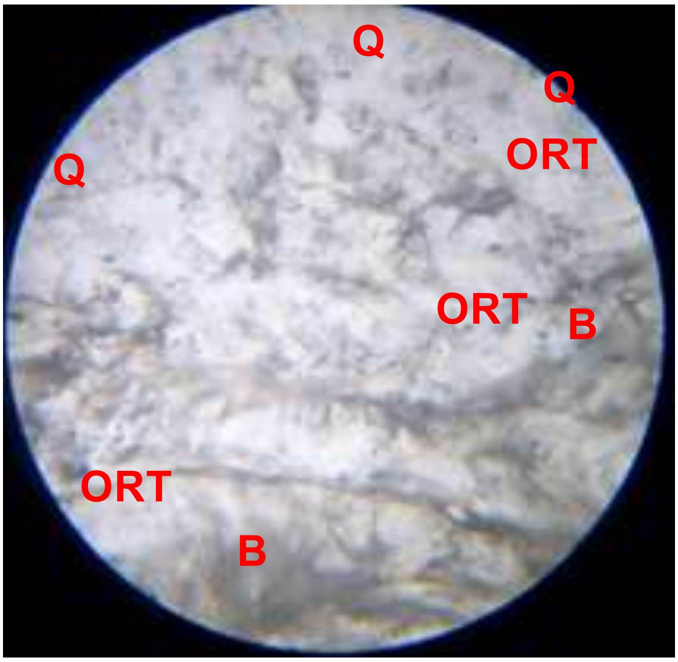

Plate XI B: Photomicrograph of Schist 2 under Plane Polars X72

(B-Biotite,Q-Quartz,ORT-Orthoclase)

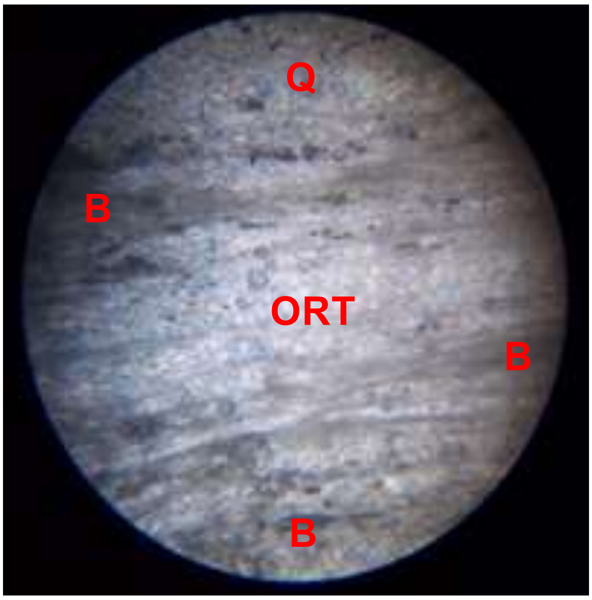

Plate XII A: Photomicrograph of Schist 3 under Cross Polars X72

(B-Biotite,Q-Quartz,ORT-Orthoclase)

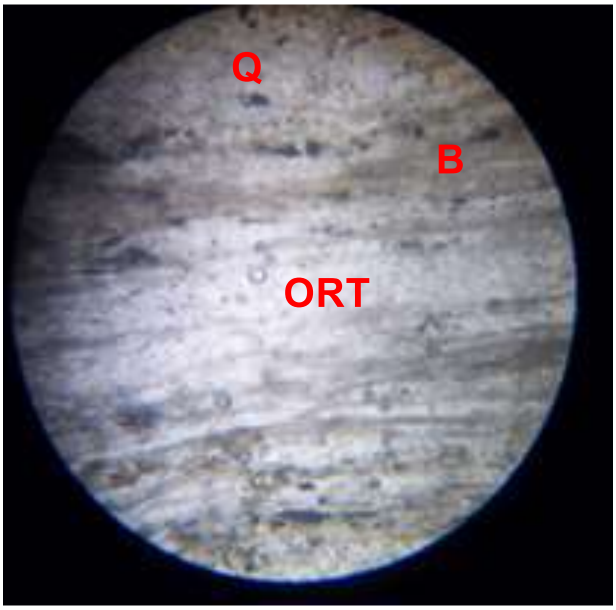

Plate XII B: Photomicrograph of Schist 3 under Plane Polars X72

(B-Biotite,Q-Quartz,ORT-Orthoclase)

4.4.3 Thin Section Petrography Modal Analysis and Description for Schist

Three (3) schist samples were selected for petrographic analysis so as to reveal the major or dorminant minerals present these were viewed under the petrological microscope and the following properties were observed also the modal analysis were done.

From the petrographical study the thin section shows both under the plane polarized light and cross polarized light, the predominant mineral present were Quartz, plagioclase and micas of varying proportions which confirm the XRD result mineralogical composition of the clay to be as a result of intensive insitu weathering of feldspar and mica.

Table 4.5: Detailed Explanation of the Thin Section of Schist 1

Mineral	Colour in PPL	Colour in XPL	Extinction Angle	Diagnostic Feature/Pleochroism	Micro Structure/Crystal Form	Twinning	% in Thin Section	Infered Rock Name
Quartz(Q)(SiO_2)	Colourless	Blueish to milky	Absent	Low pleochroic	Anhedral to Euhedral	Absent	50	Muscovite Schist
Plagioclase (ORT)($NaAlSi_3O_8$-$CaAl_2Si_2O_8$)	Colourless	Milky	Absent	Low pleochroic	Anhedral to Euhedral	Absent	20	
Biotite(B)	Dark	Brown/Dark	Absent	Absent	Euhedral	Absent	10	
Muscovite	Colourless	Pale yellow	0-3	Weak pleochroic	Well form tabular	Twins plane	20	

Table 4.6 Detailed Explanation of the Thin Section of Schist 2

Mineral	Colour in PPL	Colour in XPL	Extinction Angle	Diagnostic Feature/Pleochroism	Micro Structure/Crystal Form	Twinning	% in Thin Section	Infered Rock Name
Quartz(Q)(SiO_2)	Colourless	Blueish to milky	Absent	Low pleochroic	Anhedral to Euhedral	Absent	50	Muscovite Schist
Plagioclase(ORT)($NaAlSi_3O_8$-$CaAl_2Si_2O_8$)	Colourless	Milky	Absent	Low pleochroic	Anhedral to Euhedral	Absent	20	
Biotite(B)	Dark	Brown to Dark	Absent	Absent	Euhedral	Absent	10	
Muscovite(M)	Colourless	Pale yellow	0-3	Weak pleochroic	Well form tabular	Twin plane	20	

Table 4.7: Detailed Explanation of the Thin Section of Schist 3

Mineral	Colour in PPL	Colour in XPL	Extinction Angle	Diagnostic Feature/Pleochroism	Micro Structure/Crystal Form	Twinning	% in Thin Section	Infered Rock Name
Quartz(Q)(SiO_2)	Colourless	Blueish to milky	Absent	Low pleochroic	Anhedral to Euhedral	Absent	40	Muscovite Schist
Plagioclase(ORT)($NaAlSi_3O_8$ -$CaAl_2Si_2O_8$)	Colourless	Milky	Absent	Low pleochroic	Anhedral to Euhedral	Absent	30	
Biotite(B)	Dark	Brown to Dark	Absent	Absent	Euhedral	Absent	10	
Muscovite(M)	Colourless	Pale yellow	0-3	Weak pleochroic	Well form tabular	Twin plane	20	

4.5 Geology of the Studied Area

Geology of Pandogari area consist of two different rocks which include Muscovite Schist and Biotite Granite, the schist occupies about 70% of the studied area and the granite occupies about 30% of the area as shown in the geological map (Figure 4.2).

The muscovite schist in the studied area has been subjected to intensive weathering and, the schist dips ranges between 10° to 80° and dip to the west direction (Table 4.1).

The schist generally occurred as flat lying dipped in NE-SW direction and has been subjected to intensive weathering in some location which is a typical of Ushama schist belt as suggested by Alabi (2017).

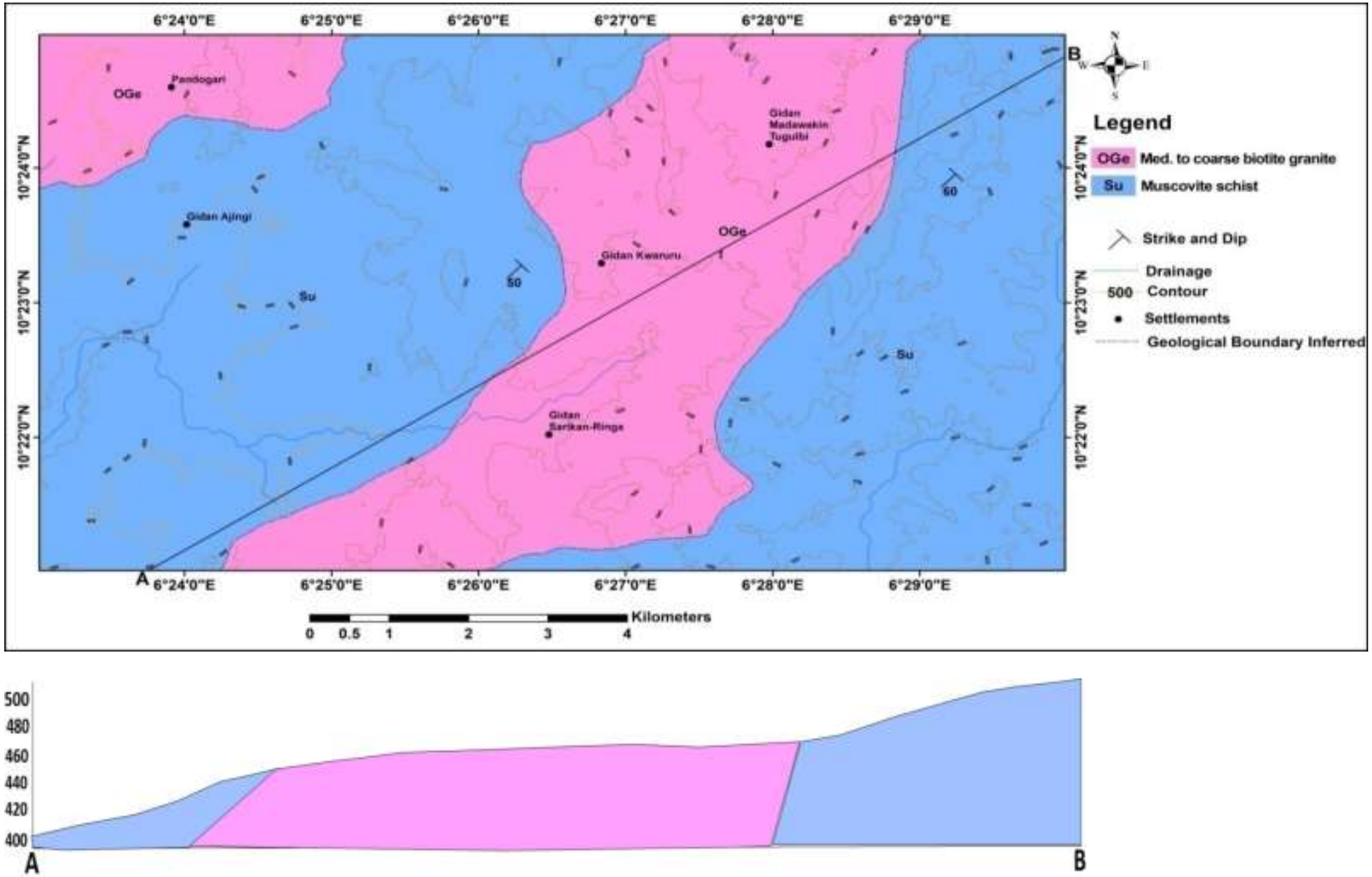

Figure 4.2 Geological Map of the Studied Area

Table 4.8: Strike/Dip of the Studied Area

Coordinate	Strike/dip	Rock Type
10° 23′41″	334°/80°w	Muscovite Schist
6° 26′ 41″	320°/10°w	
10° 23′ 43″	330°/60°w	Muscovite Schist
6° 26′ 40″	348°/62°w	
10° 23′ 38″		Biotite Granite
6° 27′ 58″		
10° 23′ 40″	330°/64°w	Muscovite Schist
6 °26′ 53″	340°/58°w	
10° 24′ 3″	10°/40°w	Muscovite Schist
6° 29′ 6″	358°/50°w	

From the above strike and Dipping direction of the schist, it explain the stress pattern in the deformation of the schist which is dipping west at an angle ranging from between 10° to 80°, in mineral formation alignment will also be in west direction of mapped area which is corresponding to the Rose diagram Figure 4.1

4.6 Clay Occurrence and Field Relationship

Clay in the studied area occur within schist lithology and are laterally extensive and exposed thickness is between 3-8m along Pandogari-Alawa road cut which is about 10m away from the road, also it is overlaid by lateritic overburden of about 1.2-1.5m thick.

The colour of clay ranges from white, gray and brownish from the base of the exposure and gritty between fingers in handspecimen.

Plate XIII: Exposed Clay by the Road Cut Around Ringa (N10°24′ 06″, E006° 29′ 04″)

Plate XIII: Lump and Powder Form of Clay in Handspecimen

(N10°24′ 03″, E006° 29′ 06″)

Plate XIV: Abandoned Clay Mining Pit (N10°23′ 41″, E006° 26′ 41″)

Also there is also powdered form of the white clay in some parts of the mapped area which was also studied in hand specimen (Plate XIII and XIV) to observe the physical parameter like the grain sizes, the textures and the gritty feel of the clay. The powdered form studied carefully and analyses were done to reveal both the mineralogical composition and the major elemental compositions.

4.9 Mineralogical Composition of Pandogari Clay

Based on the X-Ray Diffraction analysis which were carried out on the four (4) selected samples from each representative of the mapped area, it reveal the various minerals present in the samples the (Figure 4.3 to 4.6) shows the various representative diffractogram of the clay samples revealing the minerals present.

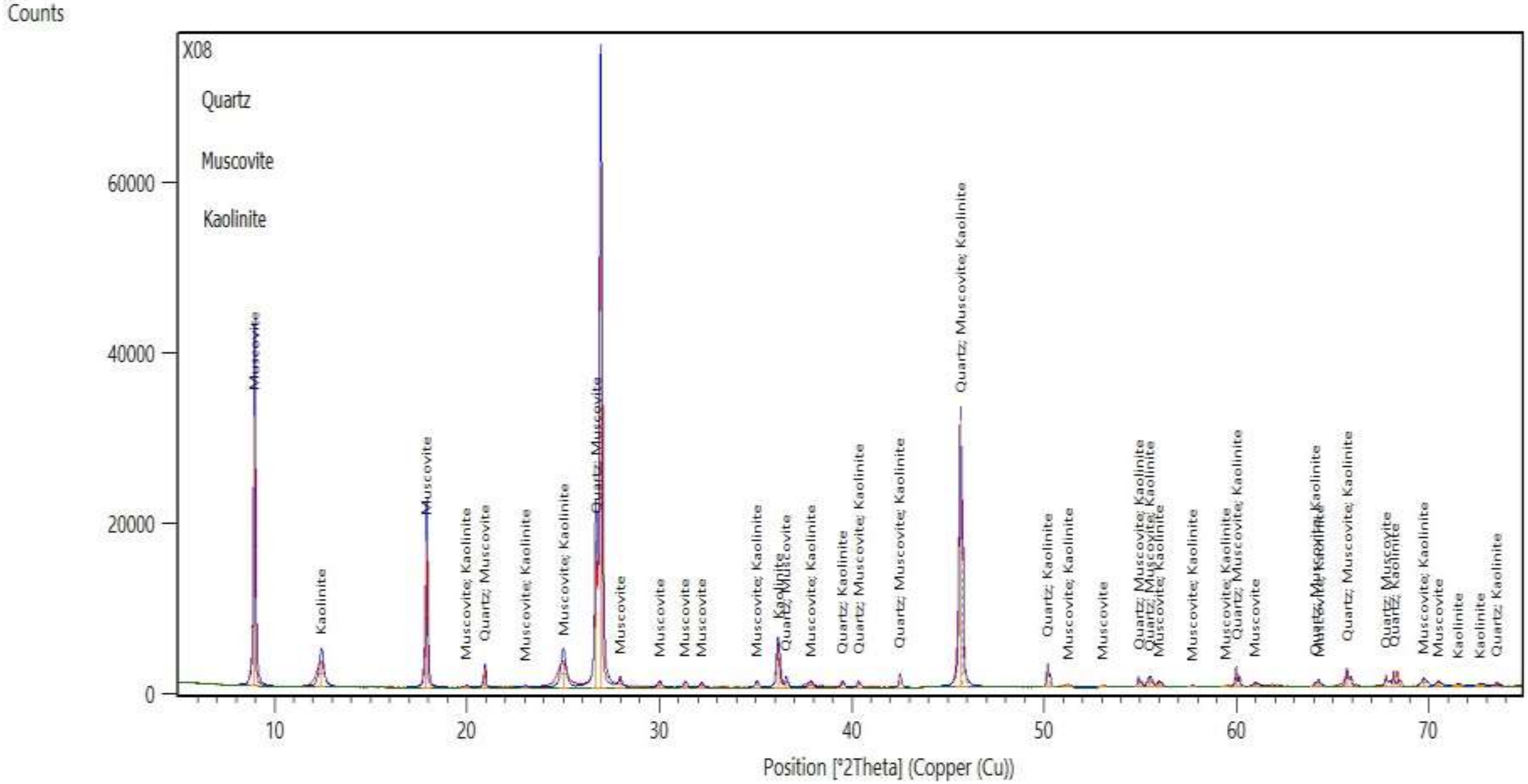

Figure 4.3: Diffractogram of clay sample X08

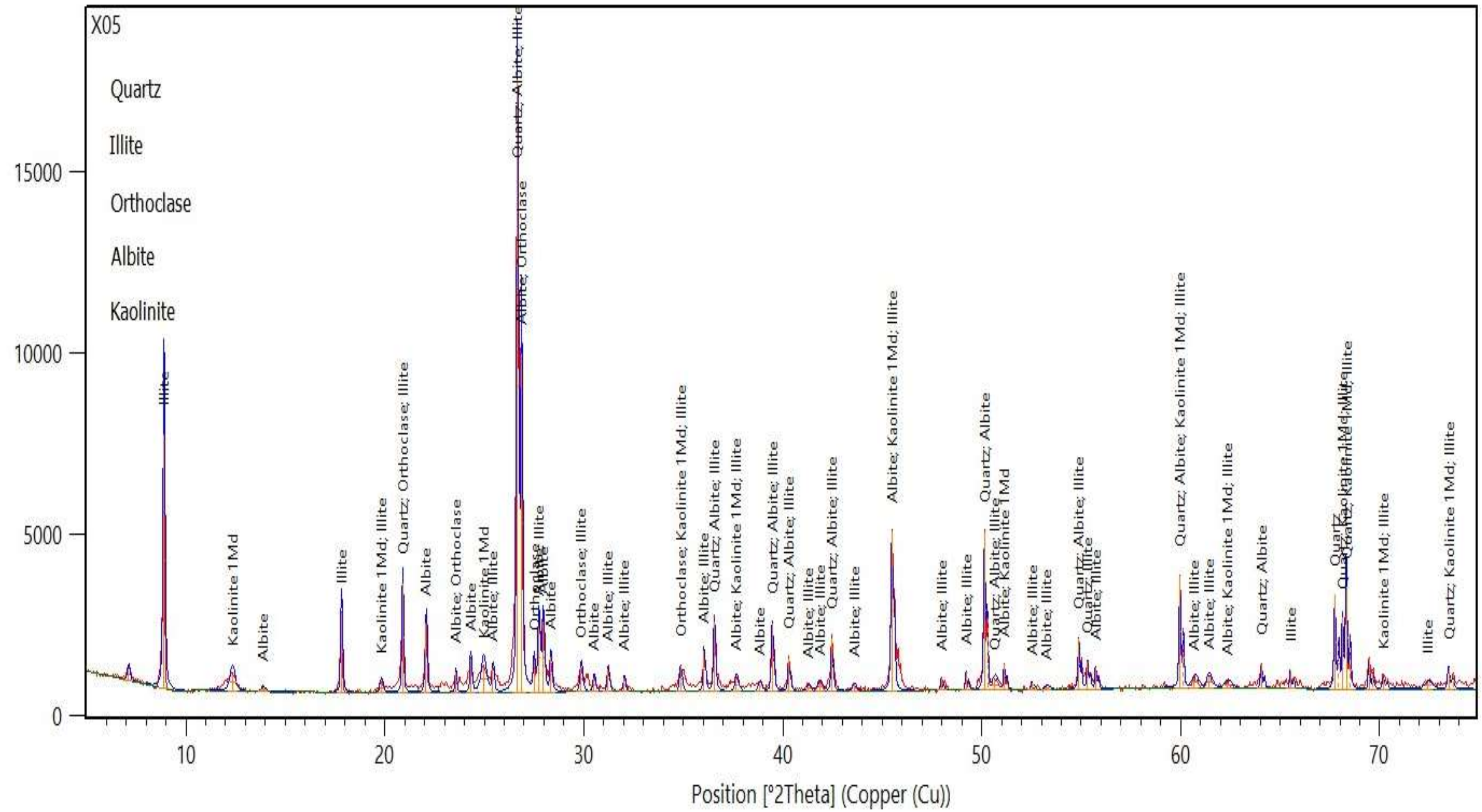

Figure 4.4: Diffractogram of clay sample X05

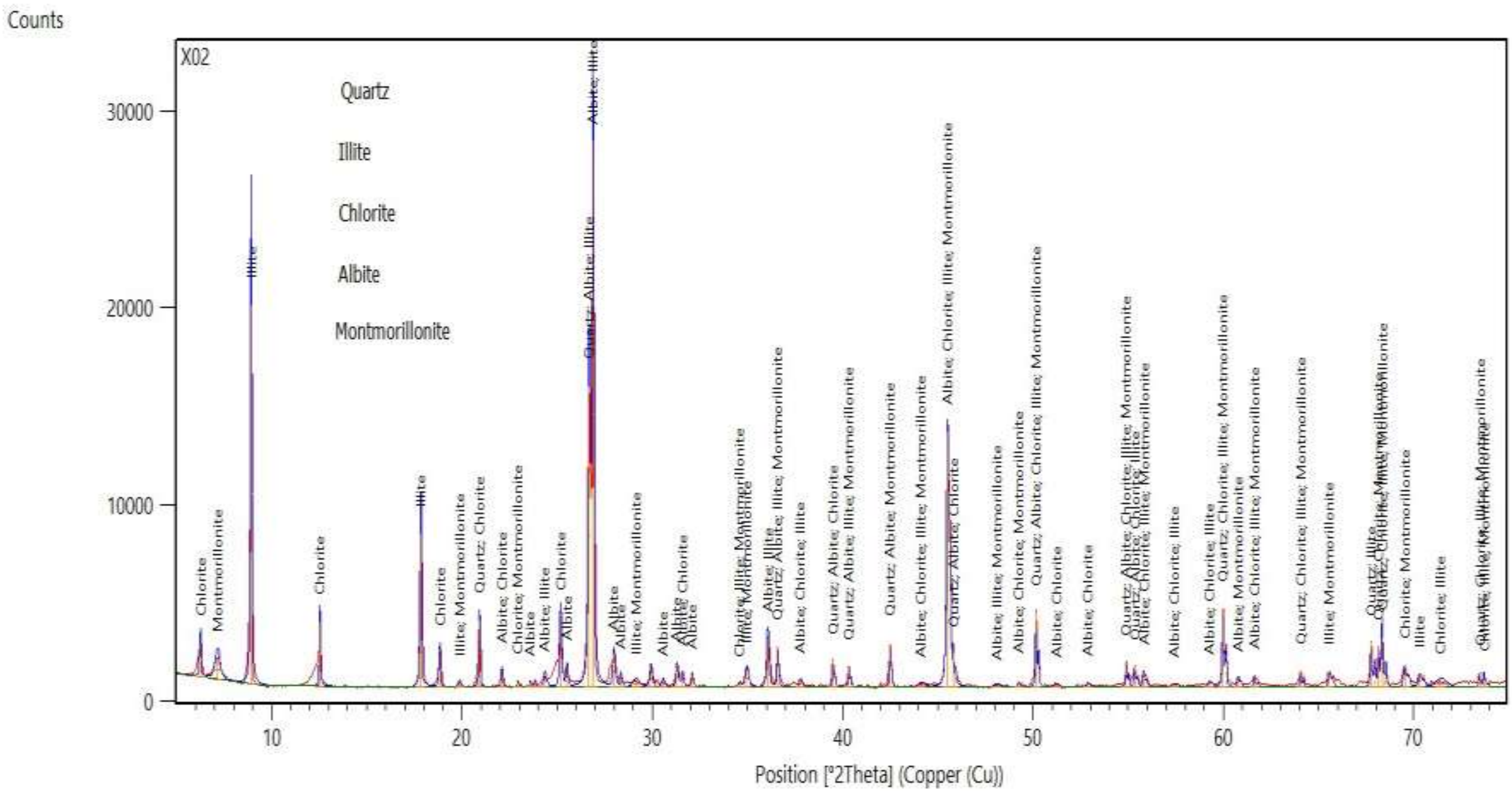

Figure 4.5: Diffractogram of clay sample X02

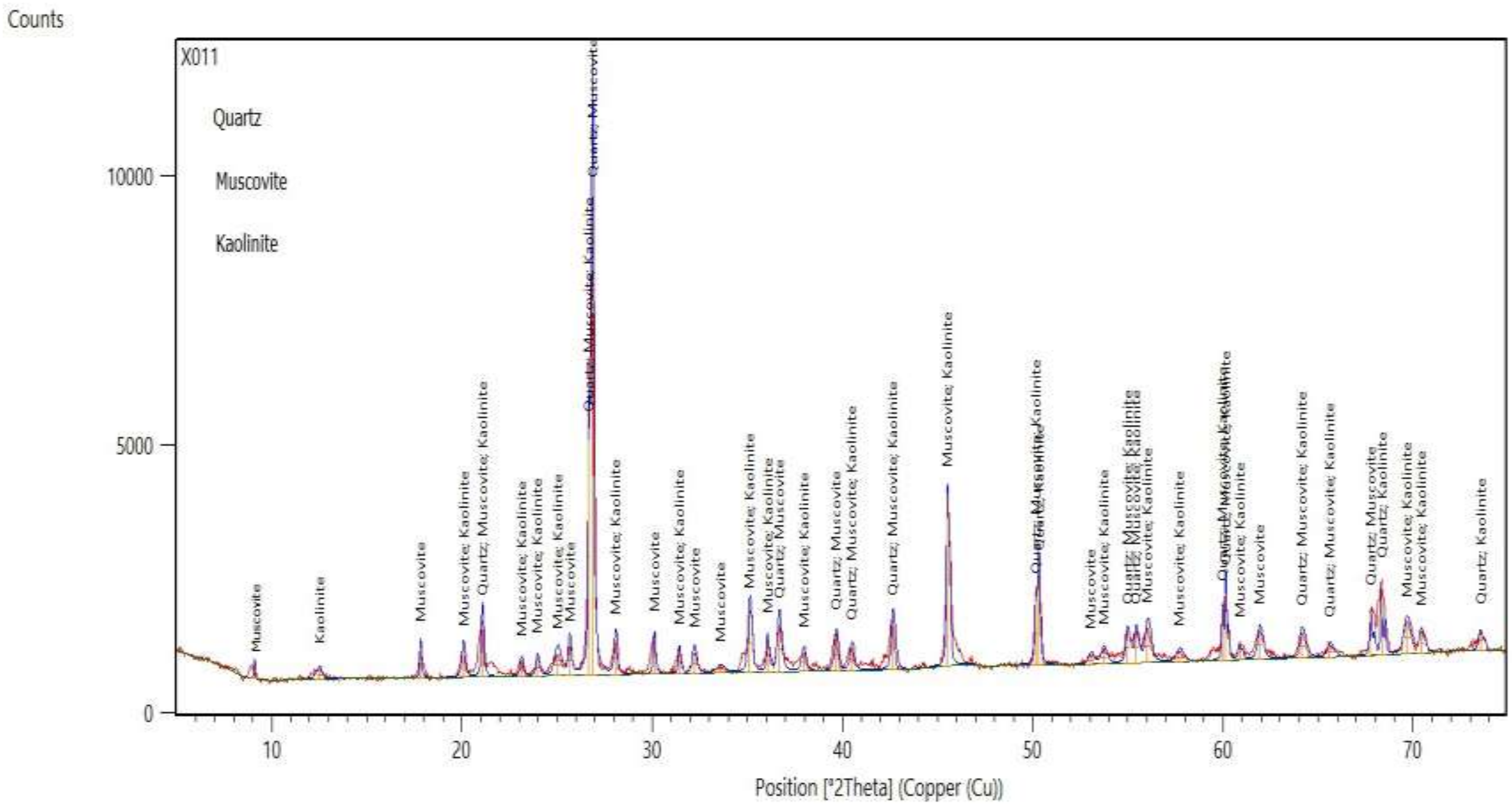

Figure 4.6: Diffractogram of clay sample X011

The X-Ray Diffraction of the sample shows the various mineral counts given the Quartz as the highest percentage confirming the X-Ray Florescence results which gives the highest percentage to be Quartz too, the presence of mica as seen in the petrography which reveals the incomplete weathering of mica flakes from the table 4.2, the most of the samples orthoclase and albite could not be detected probably due to total destruction or weathering process of the feldspar as a result of the weathering process in the mapped area.

The dominance of kaolinite in the clay suggest early stage (near surface weathering) of K-feldspar (Orthoclase) alteration to kaolinite in response to intensive weathering and leaching of K^+

$$2KAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2K^+$$

K-feldspar Water Kaolinite sillicic acid potassium

Table 4.9: Mineralogical Composition of Pandogari Clay Samples

Location	**Quartz**	**Kaolinite**	**Muscovite/ Illite**	**Mortimorinolite**	**Orthoclase**	**Albite**	**Chlorite**	**Total%**
X02	38.35	-	13.69	10.95	-	18.49	18.49	99.97
X05	33.13	16.86	22.67	-	9.30	18.02	-	99.98
X08	55.26	20.17	24.56	-	-	-	-	99.99
X11	42.60	17.39	40	-		-	-	99.99

From Table 4.9, the samples contains quartz, kaolin, Muscovite/illite, ortholclase, albite, chlorite and they varies in proportions, Quartz being the highest is between 38.5-55.26, Kaolinite (16.86-20.17), illite(13.69-40.0), Albite contain (18.02-18.49), orthoclase 9.30 only one analyzed samples sample X05 contain this. The presence of chlorite suggests alteration of muscovite or mica while illite and mortimorinolite may suggest modification and addition of k^+ ion during burial.

From the Figure 4.8 chart the presence of Quartz which has the highest percentage suppresses all other chemical composition which could be as a result of the ongoing insitu weathering and the illitization process in the area (Alabi, 2015).

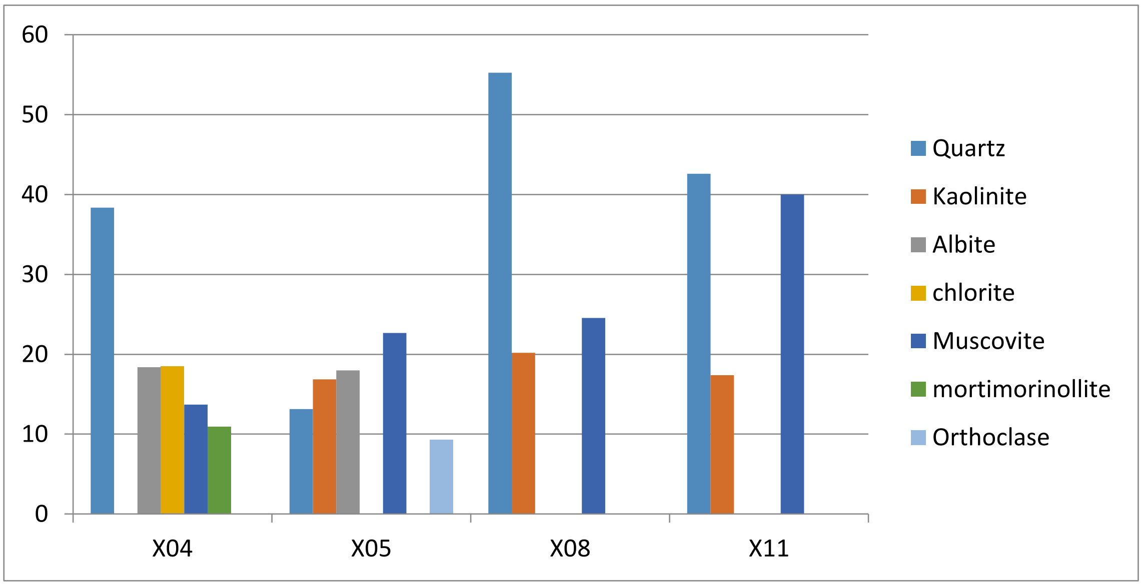

Figure 4.7: Mineralogical Variation in the clay samples

Based on the mineralogical composition the clay minerals and their chemical content shows some of the clay samples meet the technological properties of the main clay types used in tiles making according to Dondi (2001).

4.6 Geochemistry of Pandogari Clay

Thirteen (13) clay samples were analyzed for both major oxides and trace elements; these were done so as to determine the chemistry of the clay samples (Table 4.10) that were taken from the field.

Table 4.10 Major Oxide of Pandogari clay

MAJOR OXIDE %	L1	L2	L3	L4	L5	L7	L8	L10	L12	L13	L14	L15	L18
SiO_2	74.6	65.2	53.1	93.6	69.2	68.8	76.5	81.6	76.8	74.3	68.0	75.1	76.3
Al_2O_3	13.04	15.1	20.0	13.36	15.1	14.0	14.18	14.80	12.42	14.36	14.10	12.0	14.18
Fe_2O_3	12.7	4.54	5.02	1.24	4.32	5.09	2.80	2.42	2.10	3.72	5.10	2.27	2.07
CaO	ND	ND	ND	0.60	ND	ND	0.81	0.06	0.05	ND	ND	ND	0.36
MgO	ND	ND	0.10	0.50	ND	ND	0.11	ND	0.002	ND	ND	ND	0.035
TiO_2	0.86	0.57	0.57	0.49	0.77	0.23	0.54	0.66	0.68	0.55	0.42	0.91	0.64
Na_2O	1.04	1.03	1.08	ND	1.18	1.0	0.79	ND	1.40	1.04	1.00	1.09	ND
K_2O	2.02	3.94	3.84	ND	3.00	3.46	1.20	ND	2.00	3.02	3.70	2.50	ND
LOI	3.40	3.60	4.00	1.01	4.10	4.12	4.30	3.06	4.30	3.00	3.15	5.46	4.80

Result of the oxides of the elemental composition of clay sample show Na_2O is between 0.79 to 1.09% of which some were not detected in the samples, those that are rich in sodium Na_2O are albite plagioclase in compositional variation of Alkali Feldspar, some of the samples as revealed in XRD ranges from 18.02-18.49%, so also MgO ranges from 0.035 to 0.5% and some e were not detected in some sample, the analyzed result of the clay samples suggests intensive weathering and destruction of feldspar which give rise to the high silica content SiO_2 ranging from 65.2 to 93.6%,also from the diffractogram result (Figure. 4.4 to 4.7) explain further the intensity of the weathering process which diagrammatically explain the illitization process (Figure 4.8).

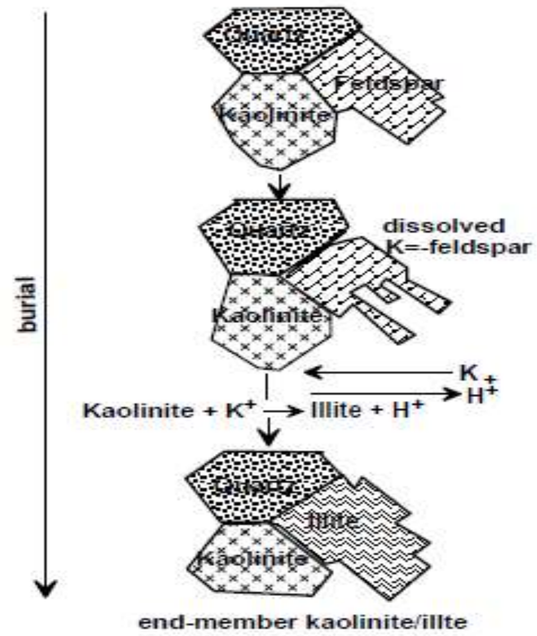

Figure 4.8: Idealized schemes of the illitization process (Alabi, 2015)

The X-Ray Fluorescence result Table 4.10 shows the concentration of K_2O is higher compare to MgO which suggest the presence of muscovite in the parent rock and felsic nature of the rock (Figure 4.10).

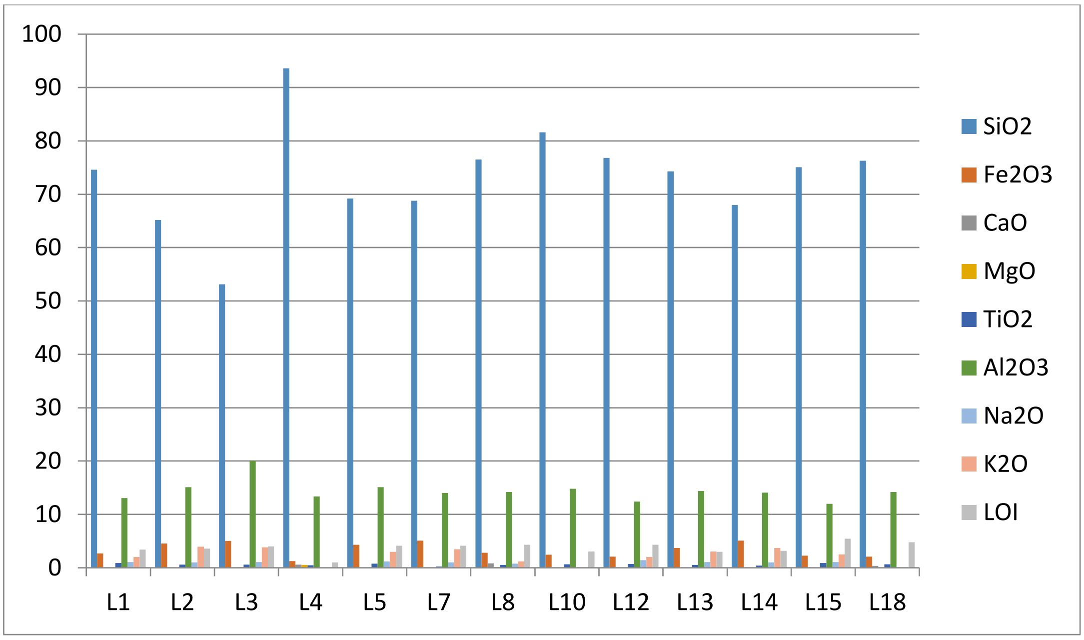

Figure 4.9: Major oxide variation in the Pandogari clay samples

The barchart (figure 4.9) explain the varying proportion of the major oxide and Quartz being the highest followed by Aluminium oxide. Alabi (2017) suggested that LOI for insitu clay ranges between 0.5-5.5% and for sedimentary clay >6%, the study clay LOI is between 1.01 and 5.46 which suggest insitu clay formation.

Plotting the major oxides on A-CN-K diagram (Figure 4.10) suggest Pandogari clay ranges from intermediate weathering to strong weathering intensity (L4,L10,L18) of which the larger percentage is of intermediate weathering and from the XRD result of the clay shows the presence of illite which suggest near surface formation of clay occurrence in the surface area.

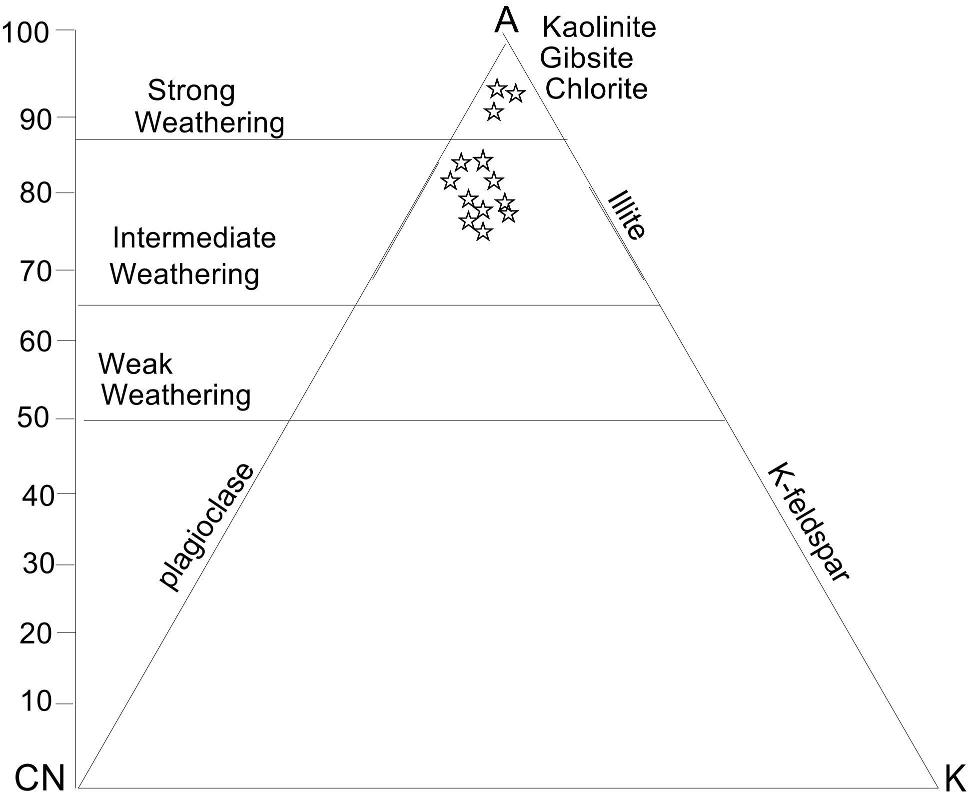

Figure 4.10: A-CN-K Diagram (Nebsitt and Young, 1982) with Plots of Pandogari Clay

Nebsitt and Young, 1982 used CIA (Chemical Index of Alteration=$Al_2O_3/Al_2O_3+CaO+Na_2O+K_2O$) to deduce intensity of clay weathering.

Also, Ratcliffe *et al.*(2007) used ternary plot of Fe_2O_3Vs MgO to differentiate marine clay from non-marine clay.

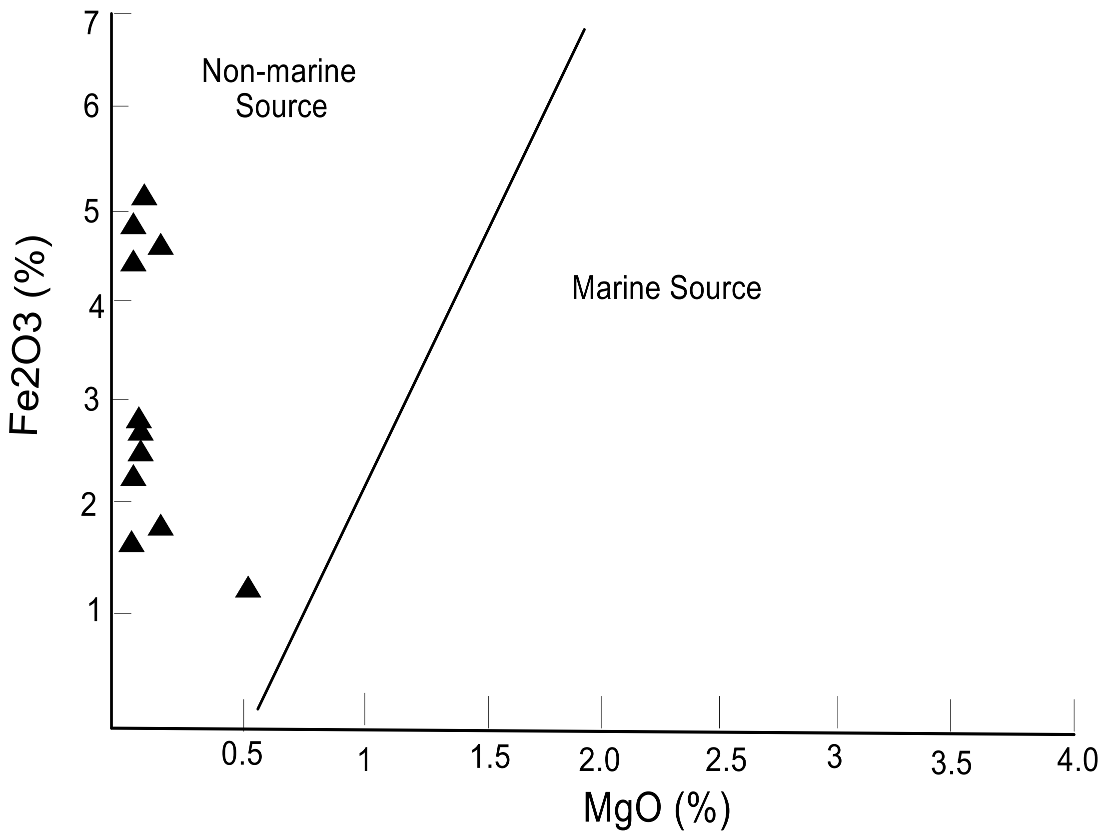

Figure 4.11: Binary Diagram of Depositional Environment Differentiation (Ratcliffe *et al.,* 2007) with Plots of Pandogari Clay

From Figure 4.11 the depositional environment shows that Pandogari clay belongs to Non-marine source and they are low in MgO and high percentage of Fe_2O_3.

The trace oxide as represented in Table 4.11 shows the various oxide present in the clay samples analyzed, ZrO_2 has the highest oxides which ranges from 0.03 to 0.21(Figure 4.14) which also suggest the mobility of the elements and it confirm the intense weathering activities taking place. Also the presence of Copper oxide is also low which ranges from 0.03 to 0.06 and all the sample analyzed contain this oxide (Figure 4.13),some of the clay sample contains PbO (Figure 4.15) which in pharmaceutical industries find it as not suitable if the threshold limit has been reached. Chromium oxide present in the clay samples (Figure 4.16) is very useful as a colouring agent in the production of some paints.

Table 4.11 Trace Oxide Present in Each Sample

Oxide	L1	L2	L3	L4	L5	L7	L8	L10	L12	L13	L14	L15	L18
SO_3	0.01	0.02	0.01	ND	0.02	0.03	0.01	0.03	0.03	0.11	0.30	0.04	0.01
V_2O_3	0.04	0.08	0.05	ND	0.08	0.06	ND	0.06	0.03	0.00	0.11	0.04	0.02
Cr_2O_3	ND	0.03	0.04	ND	0.02	0.03	ND	0.02	ND	ND	0.02	0.01	ND
CuO	0.04	0.06	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.05	0.05	0.06	0.03
ZnO	0.02	0.01	ND	0.00	0.01	0.08	0.00	0.03	0.00	0.02	0.03	0.01	0.01
Ga_2O_3	0.01	ND	ND	0.00	ND	ND	ND	0.02	0.01	0.02	0.02	0.02	0.02
Rb_2O	0.01	ND	ND	ND	ND	ND	ND	0.01	0.01	0.11	0.10	ND	ND
SrO	ND	0.04	0.03	0.02	0.03	ND	0.03	0.02	0.02	ND	0.04	ND	0.02
PbO	0.02	ND	ND	ND	ND	0.11	ND	0.03	0.00	0.03	0.20	0.04	0.03
BaO	ND	ND	0.02	0.06	ND	0.20	0.08	0.17	ND	ND	ND	ND	ND
As_2O_3	0.01	ND	ND	ND	ND	ND	ND	0.00	0.01	0.00	ND	0.00	ND
HfO_2	0.04	0.14	0.00	0.01	0.00	0.00	0.02	0.04	0.02	0.01	0.03	0.03	0.10
ZrO_2	0.21	0.03	0.08	0.20	0.09	0.12	0.16	0.23	0.18	0.08	0.13	0.22	0.21
Co_3O_4	0.04	ND	ND	0.03	ND	ND	0.03	0.02	0.02	0.04	0.02	0.04	0.02
MoO_3	0.02	ND	ND	0.01	ND	ND	ND	ND	ND	ND	ND	ND	0.01

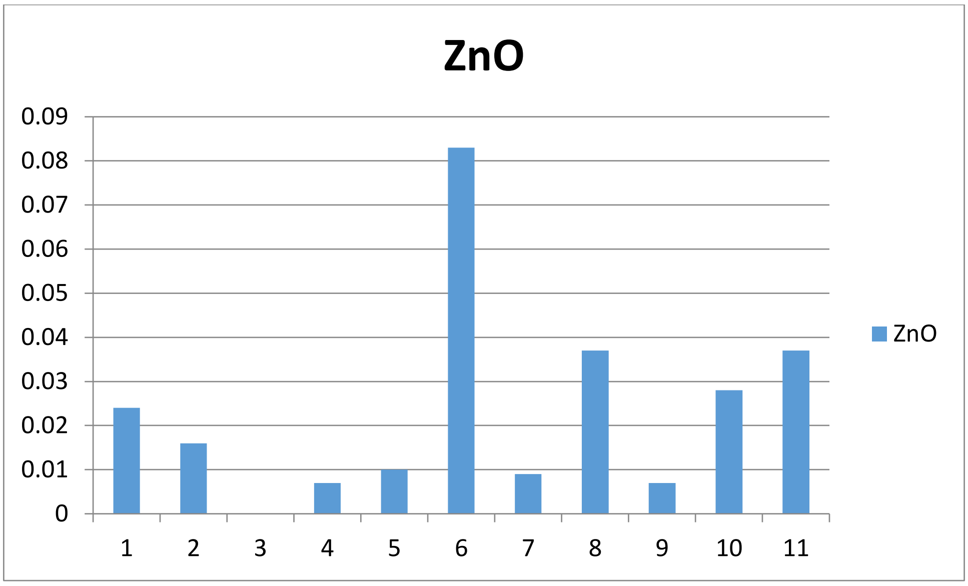

Figure 4.12: ZnO Present in the Pandogari Clay Samples

Zinc oxides are usually added into materials production which includes plastic, glass, paints, cements, rubber and ceramics.

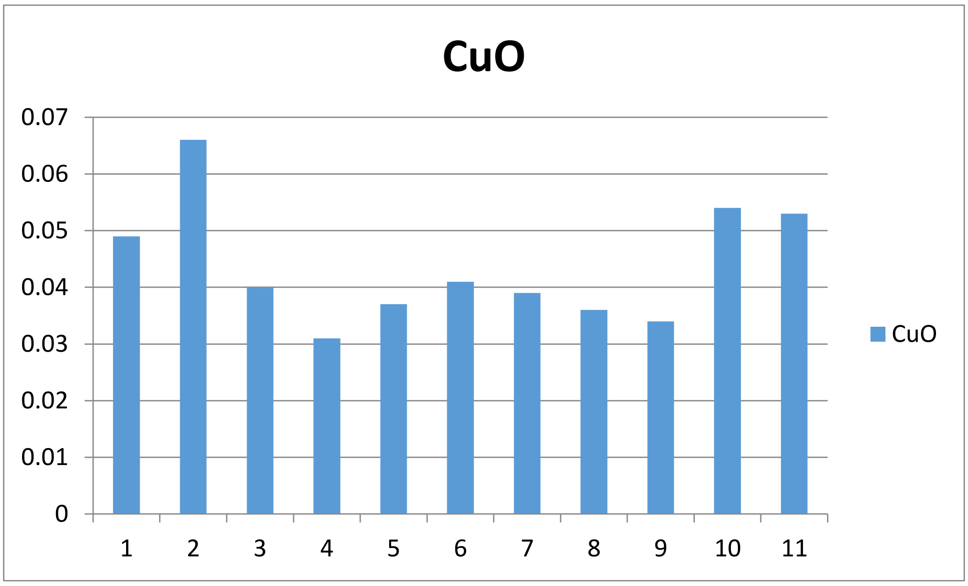

Figure 4.13: CuO Present in the Pandogari Clay Samples

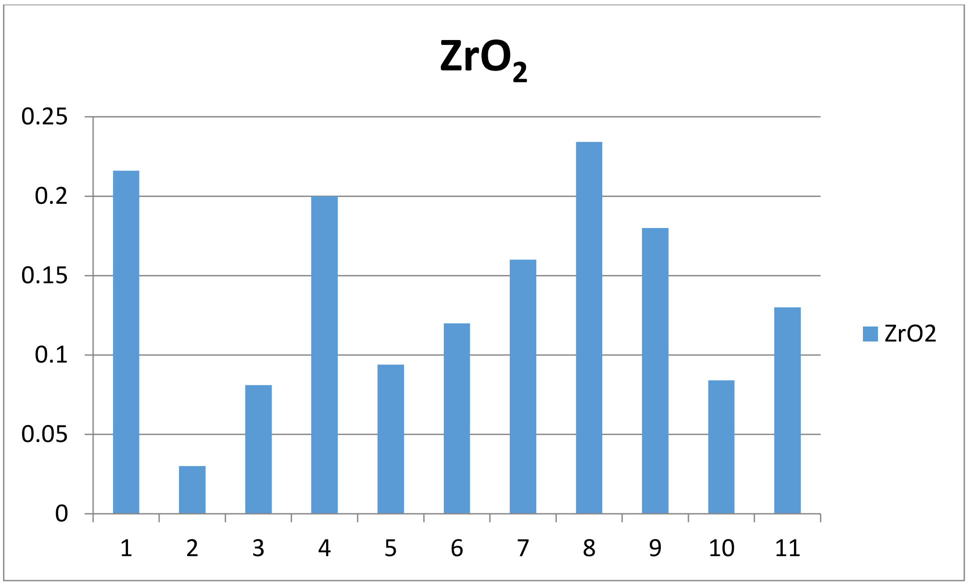

Figure 4.14: ZrO_2 Present in the Pandogari Clay Samples

Zircon plays a large role in the effect of ceramic materials (Figure 4.14). Porcelain ceramic tiles were originally unpainted and their body had to be coloured in mass, using pure raw materials (low iron and titanium content) and "bleaching" materials (zirconium or corundum) to improve the result of the ceramic pigments, (Dondi, 2001).

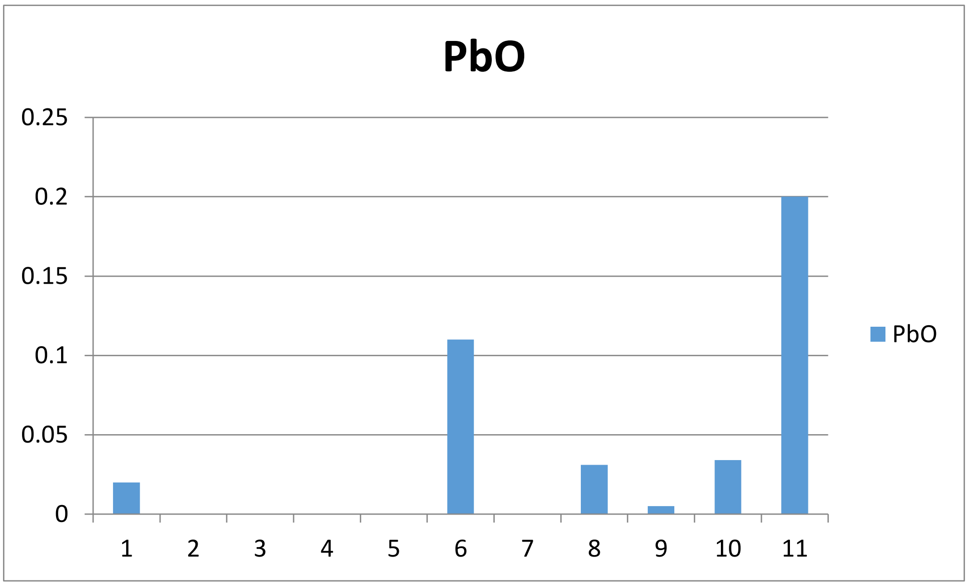

Figure 4.15: PbO Present in the Pandogari Clay Samples

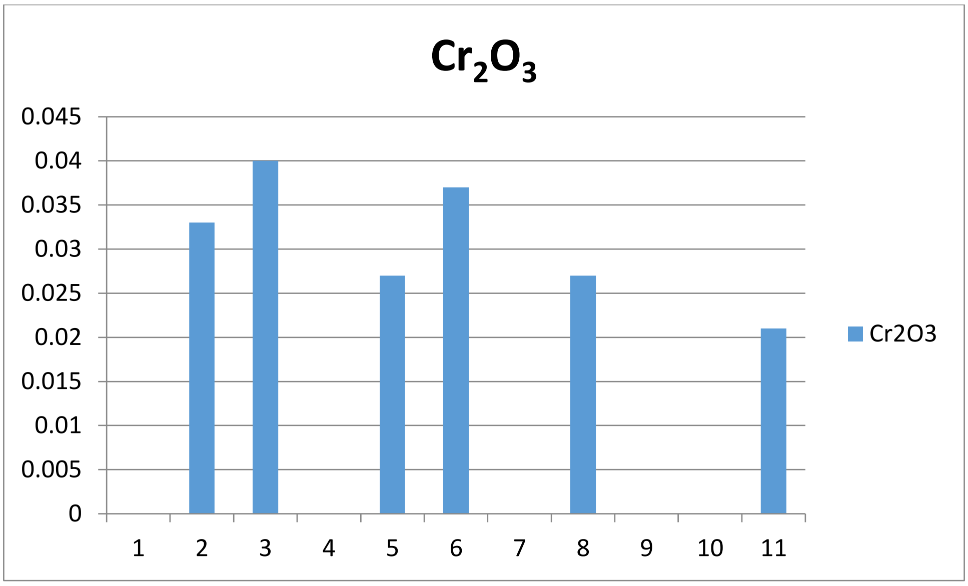

Figure 4.16: Cr_2O_3 Present in the Pandogari Clay Samples

Chromium oxide is majorly used as pigment in the making of paints, ink and glasses and this could be as a colouring agent; based on the trace oxide present in the samples, the presence of some element could have some medical effects on the industrial usage especially in the pharmaceutical or cosmetics industry if the threshold limits has been reach.

4.8 Classification of Pandogari Clay Based on Industrial Usage

Table 4.12 Compositional Comparation of the Main Clay Types (Dondi, 2001)

Oxide wt%	Marly Clays (wt%)	Kaolinitic Loam (wt%)	Pandogari clay (wt%)
SiO_2	46-52	64-75	73.31
Al_2O_3	12-15	14-20	14.35
Fe_2O_3	4-6	1-6	3.33
MgO	3-4	<1	0.14
CaO	8-13	<1	0.37
Na_2O	-	-	1.06
K_2O	2-3	2-4	2.86
TiO_2	<1	<1	0.60
LOI	11-15	3-6	3.71

Based on (Dondi, 2001) classification (Table 4.12), the average oxide concentration is kaolinitic loam clay type and about 50% of the represented clay samples which were analyzed using XRD techniques fall under kaolinitic loam, Typical ball clays for white wares met satisfactorily the new requisites and entered in use for white monocottura, together with a different class of unconventional clay materials: white- firing, coarse-grained, illite-kaolinite loams with a considerable quartz content.

Kaolin is found in large quantities, mainly in form of clay beds, and is white and yellowish to light brown in colour. In its various forms it can be used in a range of applications such as ceramics, toothpaste and paint additives to soothe upset stomachs, similar to the way it was first used by South American parrots (and later humans) (Morland, 2014).

4.9 Standard Specifications for Industrial Application of Pandogari Clay

Table 4.13: Standard Specifications of the Concentrations (in %) of Oxides in Clays for Various Industrial Usage.

Oxide %	A	B	Pandogari Clay
SiO_2	67.50	68.47	73.31
Al_2O_3	26.50	14.94	14.35
Fe_2O_3	0.5-1.20	8.96	3.33
MgO	0.1-0.19	1.14	0.14
CaO	0.18-0.30	1.61	0.37
Na_2O	0.20-1.50	0.03	1.06
K_2O	1.10-3.10	2.04	2.86
TiO_2	0.1-1.0	-	0.60

(A) Ceramics (Singer & Sunja, 1971); (B) Refractory Bricks and ceramics (Malu *et al*., 2013).

The Table 4.13 compares the average oxides standard specifications concentrations (in %) of the studied clays for different industrial usage, some of the oxide does not conform to concentration according to the specification but if beneficiation is carried out to reduce SiO_2, it may be useful in both for ceramics and refractory bricks.

Table 4.14 Comparation of Standard for Paper Coating, Paper Filler and Ceramics (Siddiqui *et al*.,2005)

Chemical Composition	Paper Coating	Paper Filler	Ceramics	Pandogari Clay	Remarks
SiO_2	45-49	46-48	48-50	73.31	Not suitable
Al_2O_3	36-38	37-38	36-37	14.35	Not suitable
Fe_2O_3	0.5-1.0	0.5-1.0	0.6-1	3.33	Not suitable
MnO	-	-	-	-	Not suitable
MgO	-	-	-	0.14	Not suitable
CaO	-	-	-	0.37	Not suitable
Na_2O	-	-	-	1.06	Not suitable
K_2O	0.5-1.5	0.5-1.5	1.2-2.7	2.86	Not suitable
TiO_2	0.5-1.3	0.5-1.5	0.02-0.1	0.60	Not suitable
P_2O_5	-	-	-	-	Not suitable
L.O.I	-	-	11.2-12.5	3.71	Not suitable

Table 4.15 Comparation of Standard for Pandogari Clay Pharmaceutics and Cosmetics (Lopez-Galindo *et al*., 2007)

Chemical Composition	Pharmaceutics and Cosmetics	Pandogari Clay	Remarks
SiO_2	44.6 - 46.4	73.31	Not suitable
Al_2O_3	38.1 - 39.5	14.35	Not suitable
Fe_2O_3	0.1- 0.2	3.33	Not suitable
MnO		-	Not suitable
MgO	0.1- 0.2	0.14	suitable
CaO	0.1- 0.2	0.37	Not suitable
Na_2O	0 - 0.1	1.06	Not suitable
K_2O	0 - 0.2	2.86	Not suitable
TiO_2	0 – 1.4	0.60	suitable
P_2O_5	-	-	Not suitable
SO_2	-		Not suitable
L.O.I	13.8 – 13.9	3.71	Not suitable

According to Siddiqui *et al*. (2005) pandogari clay does not satisfy the standard specification for the manufacturing of Paper Coating, Paper Filler and Ceramics materials (Table 4.14), also the work of Lopez-Galindo *et al*. (2007) also shows that pandogari clay does not satisfy the specification of the production of pharmaceutics and cosmetics (Table 4.15).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Studied area falls within Ushama schist and Kushaka schist belt according to Ajibade *et al.*(2008) of which the lithology represented are phyllites, micaschist, quartz mica schist, amphibolites, the occurrence of clay in the studied area is a result of weathering of orthoclase feldspar in the granite and mica schist. Several intrusions of granitic rocks are common within the Nigerian schist belts as they are also found within Kushaka schist belt and Ushama schist. Pandogari clay is residual clay formed from in-situ weathering of feldspar and mica from the schist that make up the Ushama and Kushaka schist belt.

Field observation shows the area extent of clay occurrence, the relationship with the host rock the muscovite schist which are well exposed and is intruded by the granitic rocks with varying proportion of grain sizes that ranges from medium to fine grained.

According to the mineralogical composition, the analysis of the Pandogari clay shows that Quartz is the highest, between 38.5-55.26, kaolinite (16.86-20.17), illite (13.69-40.0), Albite contains (18.02-18.49), and orthoclase 9.3. XRD and XRF analyses show that the Pandogari clay is composed of quartz and kaolinite, while illite and dolomite are trace, and the basement rocks are classified as dolomite schist and granite.

The presence of chlorite and illite indicates that intermediate weathering and structural alteration of the clay minerals occurs with the depth of occurrence. The results of the elemental analysis indicate that the clay needs to be beneficiated to increase its kaolinite content to meet industrial specifications for tiles, paint and ceramics.

The Pandogari clays vary in colour from pure white, light brown and gray, which may be the result of the degree of weathering, which ranges from strong to intense (Figure

4.10), and these clays are of non-marine origin and they have a low MgO content but a high percentage of Fe_2O_3 (Figure 4.11).

Geochemically, the clays have a high silica content, ranging from 65.2% to 93.6%, and the high silica content is as a result of the intensity of the continuous weathering process (Alabi, 2017), and some of the clay samples analyzed were classified as kaolinite (Dondi, 2001), which was used in the production of ceramics, toothpaste and paint additives to soothe uncomfortable stomach, similar to the parrot used it (and later humans) in the same way (Morland, 2014).

The geochemical composition of clay satisfies the industrial applications of ceramics and refractory bricks (Singer and Sunja, 1971) (Malu *et al*., 2013), and if some clay samples are beneficiated to reduce the silica content, it can also be used as a lustrous binder for clay particles to give strength to the finished pottery body (Alabi, 2017).

5.2 Recommendation

The economic situation of the country needs more diversification to improve the nation gross domestic profit and some of these mineral resources could be harness for the development of the nation, various products could be gotten from this clay and Pandogari clay is one of them.

The clay could be mined locally in doing this it will improve the livelihood of the surrounding communities. In view of the study, beneficiation is recommended to up-grade the industrial uses of the studied clay and reserve estimation is required to establish the occurrence as deposit.

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