# GEOLOGY AND GEOCHEMISTRY OF SHA AREA, PART OF SHEET 189 KURRA SW, NORTH-CENTRAL NIGERIA.

**BY**

**AHMAD MUAWIYA YAHUZA**

**DEPARTMENT OF GEOLOGY,**

**FACULTY OF PHYSICAL SCIENCES,**

**AHMADU BELLO UNIVERSITY,**

**ZARIA, NIGERIA**

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**AHMAD MUAWIYA YAHUZA**

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**DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN GEOLOGY**

**DEPARTMENT OF GEOLOGY,**

**FACULTY OF PHYSICAL SCIENCES,**

**AHMADU BELLO UNIVERSITY,**

**ZARIA, NIGERIA**

**JANUARY, 2022**

## Declaration

I declare that the work in this dissertation titled "GEOLOGY AND GEOCHEMISTRY OF SHA AREA, PART OF SHEET 189 KURRA SW, NORTH CENTRAL NIGERIA" has been performed 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 in this or any other institution.

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| Name of student | Signature | Date |

## Certification

This dissertation titled, “GEOLOGY AND GEOCHEMISTRY OF SHA AREA, PART OF SHEET 189 KURRA SW, NORTH CENTRAL NIGERIA” by Ahmad Muawiya Yahuza meets the regulation governing the award of degree of Master of Science Geology (Mineral Exploration) of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation

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## Dedication

This dissertation work is dedicated to the Almighty Allah. The All-knowing God for his guidance, protection and inspiration. My parents, Mr and Mrs Yahuza Ahmad, this journey is indeed a long one, you made me saw reasons why I should not give up my dreams.

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## Abstract

The geology and geochemistry of Sha area, north central Nigeria was investigated solely to determine the nature of occurrence, petrography, geochemistry and evaluate the mineralization potential of the granitic pegmatites. The area was underlain by granitoid rocks. The granitoids varied in texture and mineralogy, they comprised of coarse - medium – fine grained biotite granite, diorite and pegmatites which occured as minor rock in form of dykes and knots. Field mapping on a scale of 1:50,000 and petrographic studies were carried out, while geochemical analysis of the granitoids, K feldspar and biotite extracted from pegmatites were undertaken using XRF and lithium metaborate/tetraborate fusion ICP-MS. Petrographic studies revealed that the major mineral in the biotite granite are quartz, biotite, plagioclase, orthoclase. Analytical geochemical data showed that the rocks are peraluminous (A/CNK >1) to slightly metaluminous S-type granite. The pegmatites are commonly zoned and are hosted by biotite granite. Geochemical data further indicated that Rb, W, Cs, Y and Sn contents increases from the host granitoid inwards. The elements (Rb, W, Cs, and Y and Sn) increases with decreasing K/Rb and K/Cs ratio. Sn content ranged from 2-16ppm in K-feldspar and 555-696 ppm in biotite, Nb concentration also ranged from 2-4 ppm in K-feldspar and 391-684 in biotite extracted from pegmatites. The variations are consistent with enrichment via fractionation processes. The pegmatites represented the last stage fraction of liquid of fractional crystallization of the magma from which the rocks were formed. The potential of the pegmatites were evaluated using K/Rb and ratio below 100 is indicative of mineralization. The discrimination diagram Rb vs K/Rb, Cs vs K/Rb show limited ranged of fractionation thus suggesting that the pegmatites in Sha area belong to the rare metal mineralized pegmatite type.

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# CHAPTER ONE

# 1.0 INTRODUCTION

## 1.1 Background of the Study

Nigeria is endowed with abundant mineral resources that occur in distinct rock units of the country. It has been established that this mineral resources endowment is associated with certain metallogenic provinces/epochs. In a broad sense, four important metallogenic and gemological "Eras" related to the formation of important mineral deposits corresponding to Paleoproterozoic, Neoproterozoic, Mesozoic and Cenozoic have been identified in Nigeria (Abimbola *et al,* 2018). The Paleoproterozoic synformational schist belts which resemble the Archean greenstone belt are associated with orogenic gold, manganese and Algoma type banded iron formation (BIF).

The Neoproterozoic Pan-African orogenic cycle related to amalgamation of western Gondwana culminated in the formation of some mineralized pegmatite fields in Nigeria. This broad pegmatite belt also refers to as "the Older Tin Belt" is rich in Sn, Nb, Ta and world class gemstones including tourmaline, aquamarine, kunzite and spessartine garnet.

The emplacement of silica saturated A-type granites (the Younger Granites) generally believed to be roughly coeval with the opening of the Atlantic Ocean in Jurassic, led to the formation of significant Sn-Nb-W mineralization and gemstones (emerald, topaz and fluorite). The Cretaceous Benue Trough in eastern Nigeria which forms the western part of the west and central African rift system (WCARS), hosts significant lead-zinc-barite mineralization and coal.

Pegmatites are among the regular and most varied in shape and texture of all rock bodies. The wide diversity of pegmatites can be attributed to a number of factors, including the depth of formation, the mechanical properties of the host rock at that depth, and the tectonic and metamorphic processes that took place at the time of formation (London, 2011).

Pegmatites are known worldwide to host economically important mineral deposits such as gemstones and rare metals such as tantalum, niobium, tin and tungsten; and academic interest in them stemmed in large measure from scientific quest to understand ore-forming processes. Precambrian pegmatites of Nigeria occur mostly as dyke-like intrusions which vary from few meters to several kilometers in length and few centimeters to meters in width. Many types of granite are associated with pegmatites which may form pods within the granite or coalesce upward and segregate toward the roof of the parent granitic pluton. Pegmatite may also intrude in form of dykes into the surrounding rocks and emanate from the carapace of the pluton, and are in this case defined as epigenetic pegmatite. The origin and evolution of pegmatites continue to be debated on some fronts. According to ˇCerný and Ercit (2005), different models that have been proposed by the early decades of 20$^{th}$ century are

i. Precipitation from an aqueous fluid phase
ii. Crystallization of silicate liquid through an aqueous fluid interface
iii. Crystallization from a hydrous silicate gel
iv. Crystallization from a flux-rich silicate liquid, and
v. Crystallization of the granitic melt from margins to center.

Each of these models has its advocate (London, 2011). However, most researchers believe that pegmatites are product of fluid-saturated residual melt with near-haplogranitic composition. These melt evolved from granitoids intrusion at a last stage and at emplacement depth sufficient to prevent vapour loss typical of volcanic and near surface magmatic system (Anderson *et al.,* 2013).

The composition of pegmatites reflects an association mostly with two granite types, the S-type and the A-types. The very popular classification of pegmatite which combines depth of emplacement, metamorphic grade and minor element content as proposed by ˇCerný (1991) has four (4) categories namely: the abyssal (high grade, high to low pressure), muscovite (high pressure, lower temperature), rare-element (low temperature and pressure),

and miarolitic (shallow level). The Rare-Element classes are further subdivided largely by their distinctive patterns of enrichment in rare-element (Li, Cs, and Ta; or Nb, Y, and F) into LCT and NYF types. The acronyms LCT and NYF are for Lithium, Cesium and Tantalum enrichment and Niobium, Ytrium, and Flourine enrichment respectively. ˇCerný and Ercit, (2005) now ascribed a small fraction of the LCT and NYF pegmatites to I-type granite source. Pegmatites of the LCT family, especially those enriched in Li, Cs, B and P greatly predominate over all others. ˇCerný *et al*., (2012) have reported that the metamorphosed juvenile sediment from which S-type granites arise are particularly prone to yielding pegmatite-forming melt.

The prosperity of our societies and our standards of living are directly related to our ability to find, exploit, and manage our metal and mineral resources. Metal and mineral deposits are, in fact, geochemical anomalies and, as such, geochemistry plays a critical role throughout the mineral resources value chain, from early stage exploration to mine closure. The fundamentals of element mobility (i.e. transport and fixation) in the near-surface environment are used by geochemists to detect mineral deposits at depth, reveal element distributions in and around deposits, assess the total geochemical environment, and refine effective and begins extraction and waste disposal techniques, both pure- and applied-research ventures play fundamental roles in providing the techniques to manage metal resources and thereby benefit society.

Pegmatites are important in this study because they often contain rare-metal minerals and gemstones, such as aquamarine, tourmaline, topaz, fluorite and apatite. In Sha area, topaz is being extracted by artisanal miners. However, there is no detailed work that describes its geochemistry and mode of occurrence.

There are many processes of geochemical enrichment leading to the formation of mineral deposit, and they are often the result of a complex series of such processes acting over a long period of time.

## 1.2 Location and Accessibility of the Study Area

The study area is located in north central Nigeria, and forms part of Sheet 189 Kurra SW. It is bounded by latitudes 9° 00' 00"N and 9° 15' 00" N and longitudes 8° 45' 00" E and 9° 00' 00" E (Figure 1.1). It covers an estimated area of about 770 $km^2$ and tranversed by a tarred secondary road that connects the town to Bokkos. Other untarred motorable road enhances accessibility to villages.

## 1.3 Climate and Vegetation

The area lies within the tropical climate zone and is characterized by two distinctive main seasons (wet and dry seasons). The wet season starts from April with the peak in August and ends in October. Average annual precipitation is 131.75cm in the southern part to 146cm in the northern part (Ostaficzuk, 1996). The rains are commonly accompanied by thunderstorms and hardly last for more than five hours at any given time. The effective precipitation is appreciably reduced by high rate of evaporation and evapotranspiration. By contrast, the dry season usually last from November to March. Cold night is experience in December and January when temperatures in the range of $13^0$ to $22^0$C are commonly recorded (Baba, 1990). The harmattan period (November to February) is commonly characterized by low humidity which is associated with prevalence of NE-SW trade winds. During this period the trade winds are laden with appreciable amount of dust particles which frequently obscure sunlight and lead to poor visibility (Ostaficzuk, 1996). The NE-SW trade wind and its associated dust commonly cause irritation and discomfort. The hottest days occur between March and April and during this period temperatures of over $34^0$ C could be recorded. The prolonged dryness and lack of rainfall coupled with high rate of evapotranspiration limit the rock-water interaction which results in relatively low chemical weathering of the rocks.

The primary vegetation is characterized by grasses, shrubs and a few scattered trees. Along the stream and river channels are tall trees and well covered undergrowth are common. However, the vegetation has been greatly modified by the agricultural activities of the inhabitants and consequently a mixture of grasses and short trees of the derived Guinea Savannah type now cover the area.

### 1.4 Statement of the Research Problem

The world economy at present is growing at a rate comparable to technological development that necessitates an increasing demand for gemstones and rare-metals, with this trend likely to continue in future. Most gemstones have been reported to occur within pegmatites which display unique geological and mineralogical features (Simmons, 2007).

There has been renewed interest in the study of pegmatites globally because of their attractive economic potentials. The increase in the global demand for economic minerals has led to keen interest in prospecting for new deposit from different areas in Nigeria (Okunlola and Oyedokun, 2009).

Pegmatites in Nigeria are known to have generated great interest because they are known to host a good number of economic minerals which include beryl, tantalum, niobium, tourmaline, topaz among others. Several studies such as those of Garba, (2002), Okunlola (1998, 2005, 2008), Okunlola and Jimba (2006), Akintola and Adekeye, (2008), Okunlola and Oyedokun, (2009), Okunlola and Akintola, (2010) have been carried out on some pegmatites in Nigeria, in an attempt to describe in detail the petrography and determine the geochemical features and economic potential of rare metal mineralization of the pegmatites. Most of these studies are restricted mainly to the occurrence and mineralization potentials of rare-metal pegmatites in south western and central Nigeria. However, there is no detailed report on the evolution and mineralogical characteristics of the topaz -bearing pegmatites in Sha area. The motivation for this research stems from the activities of artisanal miners who

have been extracting and exploiting topaz mineral in the study area. The research work aims at a better understanding of how the gem deposit formed.

This is essential in order to maintain and benefit from cumulative investment in the knowledge of geology and mineral resource potential of the country. Furthermore, efforts to update the existing geological data through systematic re-investigation of the compositional trends, as it relates to the geochemical differentiation or evolution of the pegmatite which is the major source of gemstone will be in consonance with the government drive to ensure availability of reliable exploration guide.

### 1.5 Justification of the Study

As far as it can be ascertained there are scanty document data on the account of evolution through geochemical and mineralogical characteristics of pegmatites in Sha area. The pegmatites in the area are known to host large deposits of gem minerals; the occurrence of the gem minerals will be studied with a view to establish its evolution through the studies of its geochemical and mineralogical characteristics. This work would therefore contribute in developing a model for the evolution of pegmatites and also determine mineralization potentials of the study area.

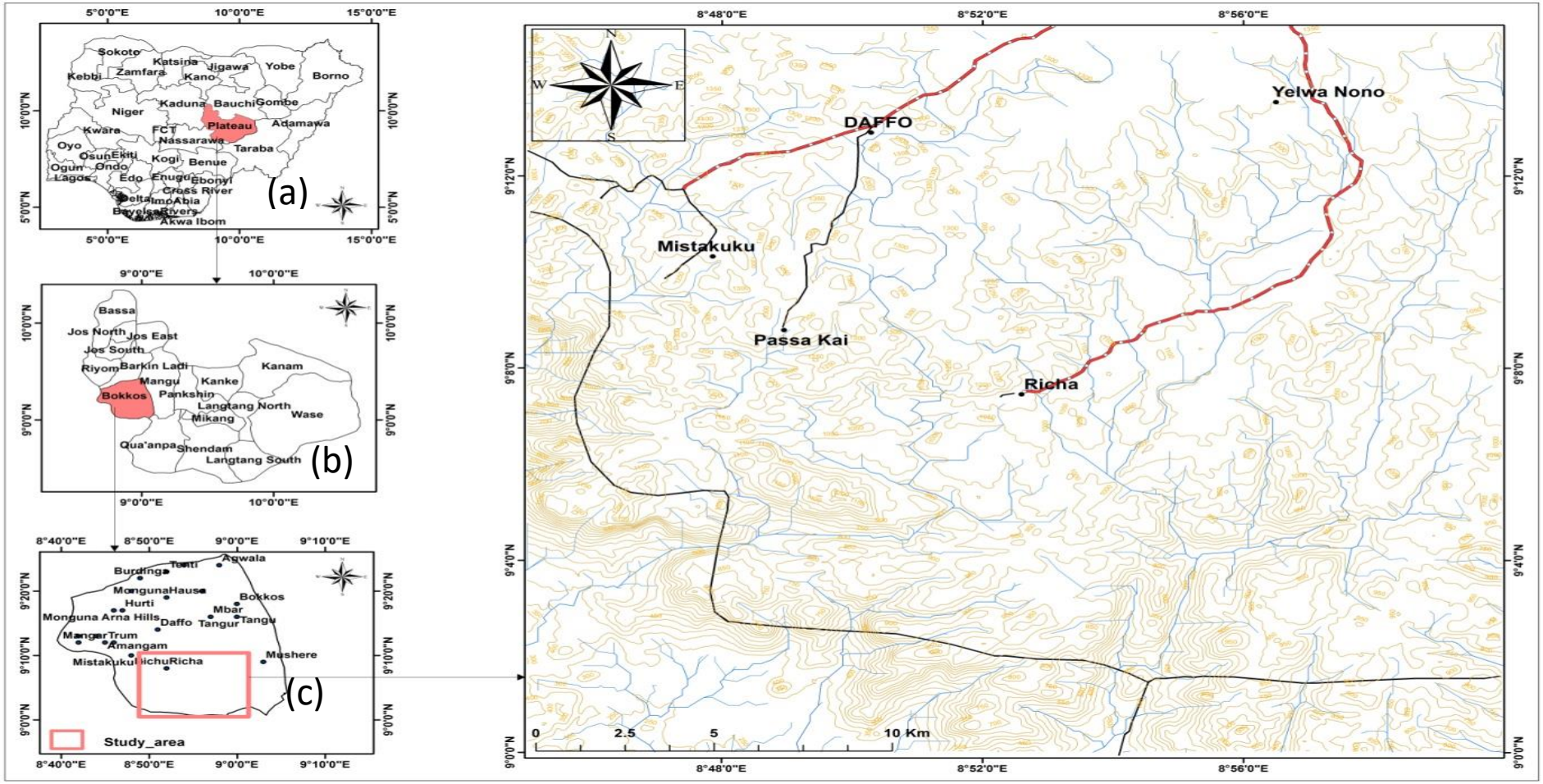



**Figure 1.1: Location map of the study area. Insets: (a) Political map of Nigeria indicating location of Plateau State. (b) map of the LGAs in Plateau State . (c) map of Bokkos LGA**

## 1.6 Scope of the Present Work

The present work involved geological mapping of the study area on a scale of 1:50,000, petrographic studies of major lithological units constituent whole rock and mineral analyses of representative samples of the granite suites, feldspar and biotite that were extracted from pegmatites using ICP-MS. Variation in concentration of major, trace and REEs in the granite suite was used to determine the geochemical features of the rocks as well as the mode of evolution and rare-metal mineralization potential of pegmatite in the study area.

## 1.7 Aim and Objectives

The aim of this research is to determine the geochemical characteristics, provide detailed geochemical and mineralogical data of the rocks of the Sha area. This would be accomplished through the following objectives

i. Produce geological map of study area on a scale 1:50,000.
ii. Provide detailed geochemical and mineralogical data on rocks of the study area
iii. Assess rare-metal mineralization potential of the pegmatites in the area
iv. To establish the petrogenesis of the rocks in the study area
v. To provide geochemical evolution using major, minor and rare earth element

# CHAPTER TWO

# 2.0 LITERATURE REVIEW

## 2.1 Introduction

Nigeria lies within the Pan–African reactivated mobile belt east of the West African craton which has been stable since approximately 2.0 Ga (Küster, 1990). This mobile belt extends from Algeria across the southern Sahara into Nigeria, Benin and Cameroon. The Pan-African mobile belt continues into northeast Brazil and consists of the set of Orogenic cycle that lasted from about 850-550Ma (Burke and Dewey, 1972; Dada, 2006).

The Nigerian basement rocks are believed to be the results of at least three major orogenic cycles, metamorphism and remobilization corresponding to the Liberian (2,700Ma), the Eburnean (2,000Ma), and the Pan-African cycles (600Ma). The three cycles were characterized by intense deformation and isoclinal folding accompanied by regional metamorphism, which was further followed by extensive migmatization. Within the Basement Complex of Nigeria, four major Petro-lithological units have been recognized by Grant, (1970); Ajibade *et al*., (1987); Dada (1998). These are:

i. The migmatite-gneiss – quartzite complex
ii. The schist belts (metasedimentary and metavolcanic rock)
iii. The older granites
iv. The Volcanics

### 2.1.1 Migmatite-gneiss complex

The migmatite-gneiss complex is generally considered as the basement complex "Senso Stricto" (Rahaman, 1988; Dada, 2006). About half of the Nigerian basements consist of the migmatite-gneiss complex (Kröner *et al*., 2001). It is heterogeneous assemblage including migmatized gneisses, banded gneisses and a series of metamorphosed basic and ultra-basic rocks. These rocks strongly resemble the tonalite-tetrondhjemite granodiorite

(TTG) suites of Archean and early Proterozoic terrains elsewhere in the world (Dada *et al*., 1993a). Petrographic evidence indicates that Pan-African reworking led to recrystallization of many of the constituent minerals of the migmatite-gneise complex during partial melting, and most display medium to upper amphibolite facies metamorphism (Dada, 2008). The gneisses of the migmatite gneiss complex are interleaved with amphibolites that may have been derived from Mg-rich rocks such as continental basalts (Caby *et al*., 1990; Dada, 1999; Dada, 2008).

However, there are no conclusive age and isotopic data to elucidate their origin (Dada, 2008). Oyawoye (1972), noted that the banded gneisses are possibly the oldest rock in the country, older than granite gneiss that yielded a Rb-Sr whole-rock isochron age of 2190+ 30 Ma. Ajibade (1988) distinguished the ancient migmatite in northern Nigeria from the Pan-African migmatite by their complex polyphase deformation and mylonitization. Possibly because of their mixed and, therefore, complex nature, it has been difficult to define the protolith of the banded gneisses (Kroner *et al.,* 2001) although some authors suggested that they were metasediments derived from greywackes and shales (Freeth, 1971; Burke and Dewey, 1972), whereas other interpreted them as orthogneisses (Onyeagocha 1986; Ekwueme 1991; Kroner *et al*., 2001).

Many workers agree that migmatization occurred during upper amphibolite-facies regional metamorphic segregation, partial melting and injection of leucogranitic materials contributed to the formation of the banded gneisses and migmatites (Kroner *et al*., 2001) According to Dada (1999; 2008) some gneisses and amphibolites in Nigeria formed a bimodal association whose petrological and geochemical characteristics indicate a primary igneous origin.

### 2.1.2. Schist belts

Attention has been given to the evolution of the metasediments (Annor, 1995; Adekoya, 1996; Olobaniyi, 1997; Danbatta, 1991; 1999, 2001; 2003). The main point of contention that concerns the evolution of the Schist belt (meta-sediment) include timing of formation of the basin deposition, their age relationship, origin of the mafic and ultramafic rocks associated with some of them, and structural control. All the models proposed over the years for the evolution of the metasediment could be classified under ensialic and ensimatic processes.

Ensimatic model of evolution has also been proposed to explain the evolution of metasediments (Ogezi, 1977; Holt *et al* 1978; Danbatta, 1991; Elueze 1992). Earlier proponents of this model attributed the formation of some metasediments (e.g. Anka, Ife-Ilesha and Zuru metasediment belts) the closure of some oceanic basins. They proposed that some marginal back-arc basin floored by oceanic materials were first formed and in which some sediments were subsequently deposited (Danbatta, 1991).

### 2.1.3 Older granites

The older granites comprise the syntectonic to late tectonic granitoids. They intrude both migmatite-gneiss complex and metasediments. The granitoids include rock varying in composition from granite to tonalites and charnockites with smaller bodies of syenites, gabbros and pegmatites (Ajibade *et al*., 1987). The granitoids have yielded radiometric ages in the range of 750-500Ma which lie within the Pan-African spectrum. These Pan-African granitoids are referred to as the Older Granites of Nigeria to distinguish them from the Mesozoic anorogenic granite ring complexes (the Younger Granites).

Based on the orogenic criteria, Trustwell and Cope (1963) grouped the Older Granites into synkinematic and late-kinematic types. The synkinematic rocks are usually coarse grained, foliated bodies with gradational contact and contain xenoliths of their country rocks,

while the late kinematic types are commonly fine grained and have sharp contacts with the surrounding country rocks.

Jones and Hockey (1964) have, on the bases of field relationship, mineralogy and texture, recognized three phases of the Older Granite suites:

i. Early phase which comprised rocks of high colour index and relatively complex mineralogy. The phase comprises of closely intermingled gabbro, doleritic and granitic rocks usually intruded by acid veins.

ii. Main phase includes the most dominant and extensive units of the Older Granite suites. The rocks, predominantly medium grained biotite-hornblende granite and porphyritic biotite granite, are readily distinguished from others by their characteristic large subhedral pinkish to redish (occasionally whitish) alkali feldspar set in a medium to fine grained groundmass of quartz, microcline, oligoclase, biotite and hornblend. In many cases the feldspar megacrysts are commonly aligned with the biotite which imparts a gneissose appearance to the rock. Rahaman (1976) equated this phase to the synkinematic type of Trustwell and Cope (1963). The foliation is usually developed at the margins of the rock bodies which indicate some degree of movement during emplacement.

iii. Late phase comprises of homogenous granites, as well as pegmatites and aplite dykes. Homogenous granites comprise of fine to medium grained biotite and biotite muscovite granites and granodiorites. Although the homogenous granites are generally equigranular in some varieties the feldspar crystals locally develope to megacrystic size. The homogeneous granites are second to the coarse porphyritic granites in abundance and topographic expression. The rocks of this phase generally lack foliation and are evidently intrusive.

### 2.1.4 Volcanics

The undeformed acid and basic dykes are high level magmatic rocks, intruded during epirogenic uplift and fracturing in the final stages of the Pan-African orogeny.

The volcanics are the youngest rocks and belongs to the late to post-tectonic Pan-African intrusions, which cross–cut the Migmatite-Gneiss complexes, the schist belts and the Older Granites. The undeformed acid and basic dykes include

i. Felsic dykes that are associated with Pan-African granitoid on the terrain such as the muscovite, tourmaline-and beryl-bearing pegmatite, microgranite, aplites and syenite dykes (Dada, 2006).
ii. Basic dykes that are generally regarded as the youngest unit in the Nigerian basement such as dolerite rhyolitic, porphyries and the less common basaltic, felsite and lamprophyric dykes.

### 2.1.5 Younger granites

The Mesozoic Younger Granites ring complexes of Nigeria form part of a wider province of alkaline anorogenic magmatism. They occur in a zone 200 km wide and 1,600 km long extending from northern Niger to south central Nigeria. The Younger Granites have been studied in most detail in Nigeria, partly for their intrinsic interest, providing comparative data for study of similar formations elsewhere in the world, but mainly because in the early 1900s they were recognized as the source of rich alluvial cassiterite deposits that had long been known to exist on and around the Jos Plateau.

The most striking petrographic feature of the whole province is the overwhelmingly acid nature of the rocks and the similarity of the rock types found in all areas. Over 95% of the rocks can be classified as rhyolites, quartz-syenites or granites, with basic rocks forming the remaining 5%. Many of the rocks have strongly alkaline to peralkaline compositions; others are aluminous to peraluminous. More than 50 complexes occur in Nigeria varying from < 2 to >25 km in diameter (Kinnaird, 1981). The ring complexes cover a total area of

about 7,500 $km^2$. The Younger Granites are discordant high level intrusions emplaced by means of piecemeal stoping through the collapsed central block. Initial stages in development of the complexes involved intrusion of vast amounts of acid lavas, tuffs and ignimbrites, now only partly preserved as a result of subsidence along ring faults.

Granitic ring dykes are the major component of most complexes, ranging from 5 km or less to over 30 km in diameter, and varying in plan from the polygonal to circular or crescent, and through more irregular shapes to simple stocks and bosses.

**2.2 Pegmatites of the Study Area**

Nigeria has a large pegmatites environment and the pegmatites are widely distributed with a marked concentration of mineralized pegmatites in the basement complex terrain. The pegmatites, both rare-metal mineralized and non-mineralized, are associated with the Older Granites. The pegmatites were initially thought to be concentrated in a NE-SW trending belt extending from Ago-Iwoye in the southwest through Wamba-Jema'a to Bauchi area in the north- east. This point of view was refuted by the work of Garba, (2003) and Okunlola, (2005).

Other pegmatite fields have been described in Zuru-Gusau area in the northwest by (Ekwueme and Matheis, 1995). (Garba, 2002; Okunlola, 2005), and Obudu area in the southeast of Nigeria. Majority of previous studies on the Nigerian pegmatites were concentrated on geochemistry, petrology and mineralogy with emphasis on the rare-metal mineralization potential of the pegmatites (Küster 1990; Ekwueme and Matheis 1995; Garba 2002; Akintola and Adekeye 2008; Okunlola and Ocan, 2009).

Several pegmatite bodies in Nigeria are known to host economically important mineral deposit such as gemstone and rare-metals (Matheis, 1987). By far the most important zones for mineral production are Mesozoic alkaline granites and Younger Granites magmatism (Abaa, 1991).

Both the barren and mineralized pegmatites occur within the Nigerian Basement Complex (Garba, 2001). The structural and tectonic framework of the Nigerian Basement Complex has been documented by several researchers such as Annor and Freeth, (1985) and Annor *et al*., (1990). The delineation of the pegmatite zone was given by Rahaman *et al.,* (1984) as being in the ENE-WSW direction. Woakes (1981) investigated the metallogenetic features of the basement while Küster, (1985) highlighted the economic viability of the pegmatites of central Nigeria (Wamba in particular) in his detailed geological work.

Matheis and Cean- Vanchette, (1983) were able to distinguish between the barren and the mineralized pegmatites. Adediran *et al*, (1989) established the presence of emerald, aquamarine, topaz and tourmaline in the Wamba pegmatite of central Nigeria. Others include the works of Van Breeman *et al*, (1977) and Ogezi, (1977) on the barren and mineralized pegmatites of central and southwestern Nigeria formed over a time span from 562-534 Ma and indicating that pegmatite emplacement occurred at the end of Pan-African magmatic activity.

Omada *et al.*, (2014), in their study of pegmatite bodies in parts of Lokoja, Central Nigeria, noted that the mineralogy and composition of the pegmatite bodies are indicative of post tectonic anorogenic acidic igneous protolith which underwent alkali metasomatism involving selective enrichment of trace elements and REE fractionation and rock–fluid interactions

Within the Younger Granites province, occurrences of pegmatitic knots have been reported in many ring complexes of the Jos Plateau (MacLeod, 1971). Among these is the Sha-Kaleri Complex, especially Hotum arfvedsonite-aegrine granite which is a marginal intrusion along the northern limb of the Complex. The arfvedsonite aegrine granite is reported to contain a pegmatite which extends for nearly 1 ½ km in length and about 440 meters in width, representing different phases of the intrusion. Sheets of pegmatites were

reported to occur in abundance at Buji Complex towards the northwestern part of the Plateau. In the Amo Complex, also at the northwestern part of Jos, many pegmatitic knots were reported containing moderate amount of columbite and tin (Imeokparia, 1983).

Jacobson and Webb (1946), reported that the pegmatites are of the complex category and that the rare-metal pegmatites of Nigeria are confined to a 400 km long NE-SW trending belt. Okunlola and Ofonime (2006) studied the geological setting, petrochemical features and age of rare-metal (Ta-Nb) mineralization of pegmatite of Komu area south-western Nigeria and concluded that the pegmatites are not cogenetic with surrounding Pan-African granitoids. The pegmatites in Komu area are mineralized and compare favourably with other mineralized pegmatites.

Akintola and Adekeye (2008) studied the mineralization control and petrogenesis of the rare-metal pegmatites of Nasarawa area central Nigeria and proposed that extreme igneous fractionation aided by fluids rich in boron, phosphorus and flourine led to the concentration of rare-metals in residual melt that formed the pegmatites as it ascended through reactivated ancient fracture.

Okunlola and Ocan, (2009) worked on rare-metal (Ta-Sn-Li-Be) distribution in pegmatites of Keffi area central Nigeria and reported that the pegmatites are complex with varied mineralogical zonations. Okunlola and Akintola, (2010) studied the petrochemical characteristics of rare-me tal pegmatites of Oke-Asa area, south-western Nigeria and concluded that the pegmatites are of the rare-element class lepidolite subtype, and are variably enriched in rare-metals. Akintola, *et al*., (2011), in their work on petrographic and geochemical evaluation of the rare-metal (Ta-Nb) potential of Precambrian pegmatites of Awo area south-western Nigeria, noted that the pegmatites are of the LCT petrogenetic family (Rb, Cs, Li, Ga, Sn, Ta) and of the beryl subtype with moderate to high Ta-Nb mineralization. Akintola *et al.,* (2012) worked on the petrochemical evaluation of the

pegmatites in Apomu area south-western Nigeria and found that the pegmatites are barren when compared with other rare-metal pegmatite across the world.

Akoh and Ogunleye, (2014) studied the geochemical evolution of micas and Sn- Nb-Ta mineralization associated with the rare metal pegmatites in Angwan Doka, central Nigeria and found that the pegmatites are magmatic and zonation in the pegmatites bodies resulted from the same petrogenetic process. Usman, (2015) studied the geology and geochemistry of rare-metal enriched pegmatites south-western Nigeria and found that the pegmatites are siliceous with a peraluminous composition, genetically linked to peraluminous S-type granites and are moderately evolved compared with highly mineralized pegmatites. Girei, (2015) studied the pegmatites in nothern parts of Mandara hill north-eastern Nigeria and concluded the pegmatites are primitive to moderately fractionated but barren and probably formed from anatexis of granitic rocks at shallow depth.

The pegmatites group in Sha area consists of discrete dykes and knots which are genetically linked to the late - orogenic Pan-African (600Ma) granitic host rock. It is part of the rare-metal pegmatites occurring in a SW-NE trending belt. The pegmatites sometimes occur as tiny veins or as dyke crosscutting other rocks. Gemstone occurrences have been recorded in this pegmatites area Obaje, (2009). Wright (1970) was of the opinion that regional fault had some influence on the direction of migration of hot spots within the mantle that culminated in the formation of the Mesozoic ring-complexes. The foregoing review of the previous works on the pegmatites in Nigeria show that comparatively more attention has been focused on the rare -metal potential of the Nigerian pegmatite zone. Detail geochemical study is required to establish the gemstone bearing potential of the pegmatites in Sha area.

# CHAPTER THREE

# 3.0 MATERIALS AND METHOD

## 3.1 Introduction

The methodology adopted for this research work consists of desk study where relevant materials were consulted. Systematic geological mapping of the area using a base map extracted from the topographic map of Kura SE on a scale of 1:50,000. Petrographic analysis of the rocks was also carried out, followed by geochemical analysis of the rocks and mineral samples and finally, interpretation of the data obtained using computer packages.

## 3.2 Desk Study

Prior to detail field mapping and geochemical analyses, review of research works done on the geology of north central Nigera and Nigeria as a whole was carried out. In this regard, relevant materials like textbooks, journal articles, published and unpublished reports were consulted and the findings from these works reviewed.

## 3.3 Field Methods

Reconnaissance survey of the area of study principally for logistical planning prior to detailed geological field mapping which involved study of the field occurrences, contact relationships and structural features of all the rocks types was carried out. The field study and systematic geological mapping were done on a scale of 1:50,000 as extracted. The field mapping was accompanied with collection of rock and mineral samples. Field data measurements involved measuring strike and dip directions of structural features with compass clinometers, documentation of geographic co-ordinates of every sample point using Global Positioning System (GPS). Particular attention was paid to the location, mineralogical composition and physical characteristics of the pegmatite veins and dykes. For each vein and dyke the structural attitude, length and width, as well as the co-ordinates were carefully measured and documented. Dimensions of pegmatite veins and dykes were measured with

the aid of a measuring tape. The study of the pegmatites was preceded by careful study of lineaments. Other structural imprint like joint trends and the trends and dips of rocks were measured. Representative rock samples were collected from rock exposures with the aid of a geological hammer and were assigned numbers; thereafter outcrops were observed and described in order to determine their textural and structural characteristics. Careful observation of lithological boundaries was made by observing changes in the rock exposure, nature of soil, vegetation and topography.

### 3.4 Laboratory Methods

#### 3.4.1 Petrography

For petrographic studies, fifteen (15) representative rock samples were cut into chips with a cutting machine and subsequently polished using carborundum powder to obtain slides with thickness of 0.03mm and mounted between glasses cover as a microscope slide with perfectly smooth surface. The prepared slides were examined under the petrological microscope to observed features such as relief, cleavages that were not hitherto seen, with the aid of magnifying lens that help to identify the minerals. This study was carried out in the thin section laboratory of the Department of Geology University of Jos, Nigeria.

#### 3.4.2 Analytical techniques

As part of the measure to ensure quality of the analytical data, fifteen (15) whole rock and mineral samples (K-feldspar and biotite) were carefully extracted and cleaned to remove contaminated grains from the pegmatites. Selected rock and mineral samples (K-felsdpar and biotite) were pulverized to fusible fineness in a tungstem carbide mill at the Department of Geology, Ahmadu Bello University, Zaria, Nigeria. The samples were thoroughly homogenized to obtain a representative portion and thereafter pulverized in a disc mill. The pulverized samples were then shipped to Activation laboratories, Ancaster, Canada and analyzed for major oxides using XRF. The identification of elements by x-ray fluorescence

methods is possible due to the characteristic radiation emitted from the inner electronic shells of the atoms under certain conditions. The XRF is based on the principle that individual atoms, when exited by an external energy source, emit X-ray photons of a characteristic energy or wavelength. By counting number of photons of each energy emitted from a sample, the element present may be identified and quantitated. The analysis is rapid and usually sample preparation is minimal or not required at all. Therefore, by determining the energy (wavelength) of the x-ray light (photon) emitted by a particular element, it is possible to determine the identity of that element.

Minor and trace elements were analyzed using lithium metaborate/tetraborate fusion ICP-MS technique. In addition sodium peroxide fusion ICP-MS was employed in the analysis of Rb. The solution was heated and allowed to cool. After cooling, the solutions were pumped into the sample introduction system, comprising a spray chamber and a nebulizer. The sample emerged as an aerosol. The excitation of the outer electrons produced photons of light with specific wavelength from which the concentrations of the elements were then determined.

Quality assurance and quality control (QA/QC) measures in the analytical technique employed include duplicate and analysis of blank to estimate analytical precision while analytical accuracy was determined by analysis of different certified standard reference materials that have similar matrices with the sample, using identical analytical condition for the sample. Duplicate analyses were within ±2% of each other for the REE and other key trace element and result of analysis of blank sample were below detection limit, while results of analysis of the SRM were consistent with accepted value.

### 3.4.3 Data analysis and interpretation:

Data derived from the fieldwork was treated using multivariate statistical technique and discrimination plots using geo-analytical computer package Surfer and Geochemical data tool

Kit (GCDKit). The results obtained were presented as Tables, Figures, and interpreted based on geological knowledge.

The chemical composition of the rocks were used to determine their geochemical signature while variation in the concentration of major, minor and rare earth elements in the pegmatite were used to extablish the geochemical evolution and degree of fractionation of the pegmatites.

# CHAPTER FOUR

## 4.0 RESULTS

### 4.1 Field Geology and Petrography

Detailed geological field mapping on the scale of 1:50,000 shows that the study area is underlain by granitoid rocks. The major rock types comprise of coarse grained biotite granite, medium grained biotite granite, fine grained biotite granite and diorite (Figure 4.1), while the minor rocks are pegmatites and quartz vein. Xenoliths as a rock fragments that enveloped in a larger rock during development and solidification. The pegmatite and quartz veins in the coarse grained biotite granite and the medium grained biotite granite host the gem quality topaz mineralization.

Outcrops of the fine grained biotite granite as undulating hills commonly trending NE-SW. Intense weathering has decomposed and disintegrated the gem-bearing rocks to form eluvial and alluvial deposits within which mining of quartz, aquamarines and tin is currently going on by digging at a depth of 14-17 metres and then tunneling to connect the pit underground. The Sha alluvial and eluvial gem deposit field composed of sub-recent alluvial with sand and streak of heavy mineral like casseterite associated with gem deposit. The gem bearing layers in alluvial deposit are heterogeneous exhibiting a variety of shapes and size that indicate frequent change in stream courses and velocity. Plates I and II shows the local mining and the alluvial gem topaz.

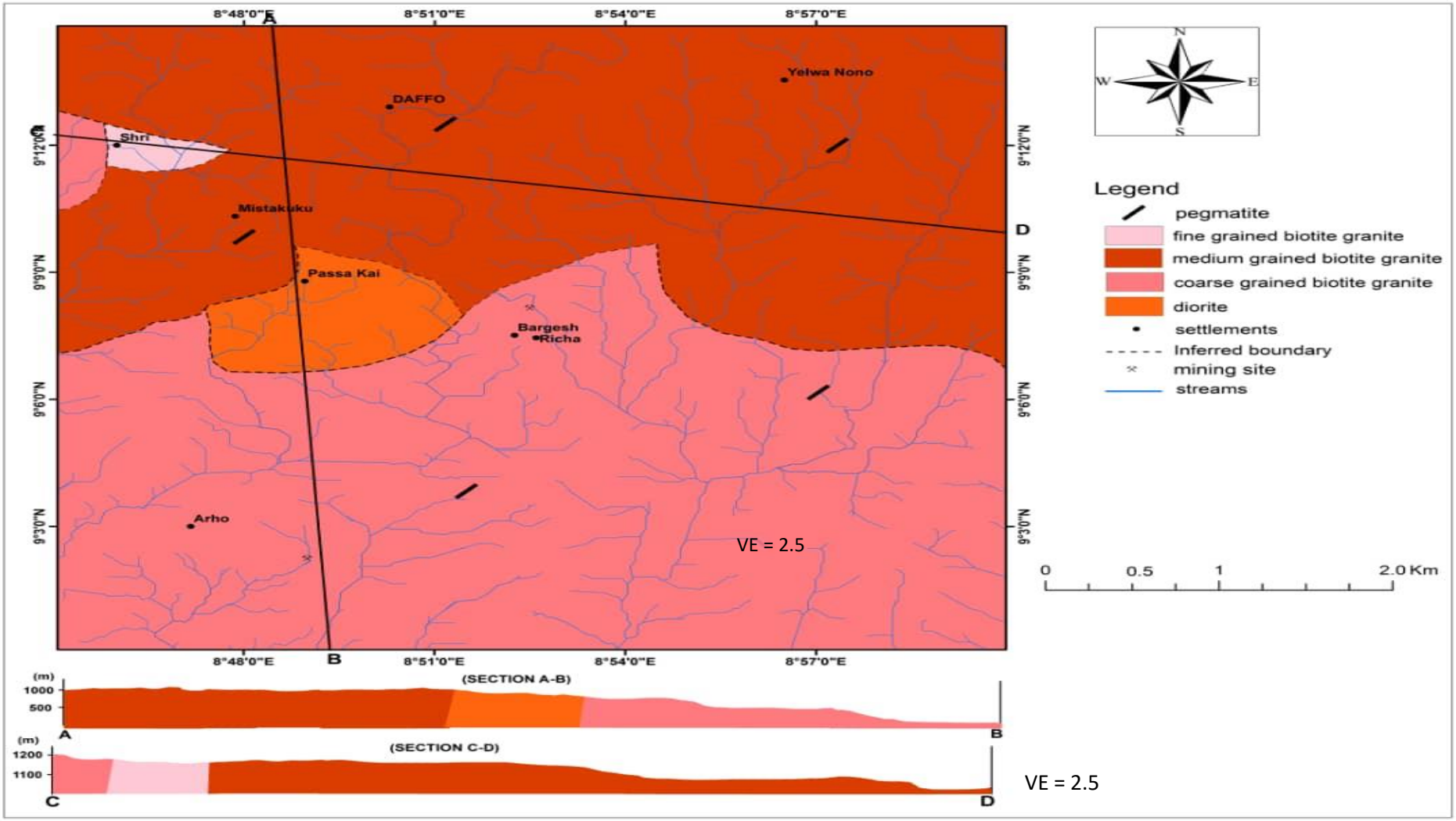



**Figure 4.1: Geological Map of the Study Area**



**Plate I: Field photograph of a local mining pit from which topaz was mined in the study area (Longitude 09° 2' 50" and Latitude 08° 48' 20")**



**Plate II: Topaz crystals from alluvial deposit of the study are**

### 4.1.1 Coarse grained biotite granite

The coarse grained biotite granite is the most abundant rock type covering the southern part of the study area (Figure 4.1). It is well exposed as low hills and in large boulders (Plate III). The rock hosts simple pegmatite veins and is mostly weathered although fresh outcrops were observed in rock quarries. In hand specimen, the rock appears pinkish in colour. Under the microscope the coarse grained biotite granite (Plate IV) is seen to be composed of quartz, feldspar, biotite, apatite and zircon as accessory minerals. Under plain polarized light, quartz is colourless with no pleochroism and twinning. The habit is subhedral to anhedral.

Feldspar appears colourless and cloundy in plane polarized light with low relief, and it has first-order grey interference colours between crossed polars with oblique extinction and carlbad twinning. Biotite occurs largely as poikilitic crystals. It is brownish in colour and has prismatic subhedral to anhedral habit with perfect cleavage. It shows no twinning and occurs in patches with moderate to high relief. Biotite lamellae have brown pleochroism. Birefringence is first order and the mineral possesses extinction.

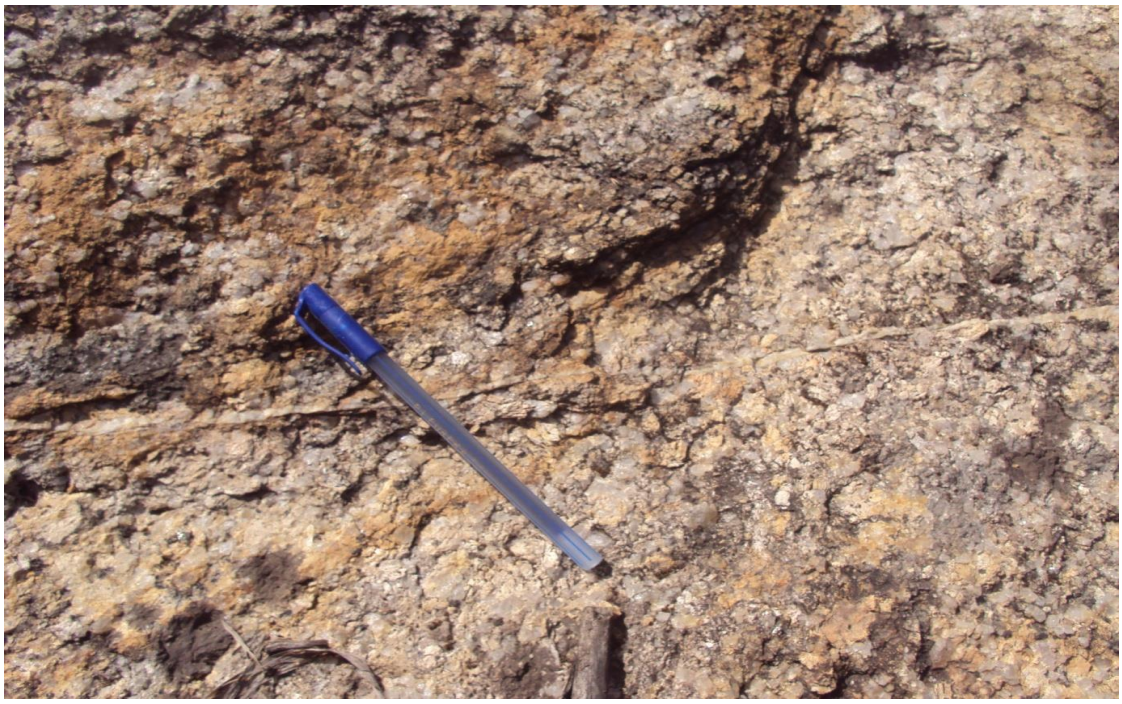


**Plate III: Field photograph of an outcrop of coarse grained biotite granite in the study area (Longitude 09° 02' 45.7" N Latitude 08° 51' 02" E)**

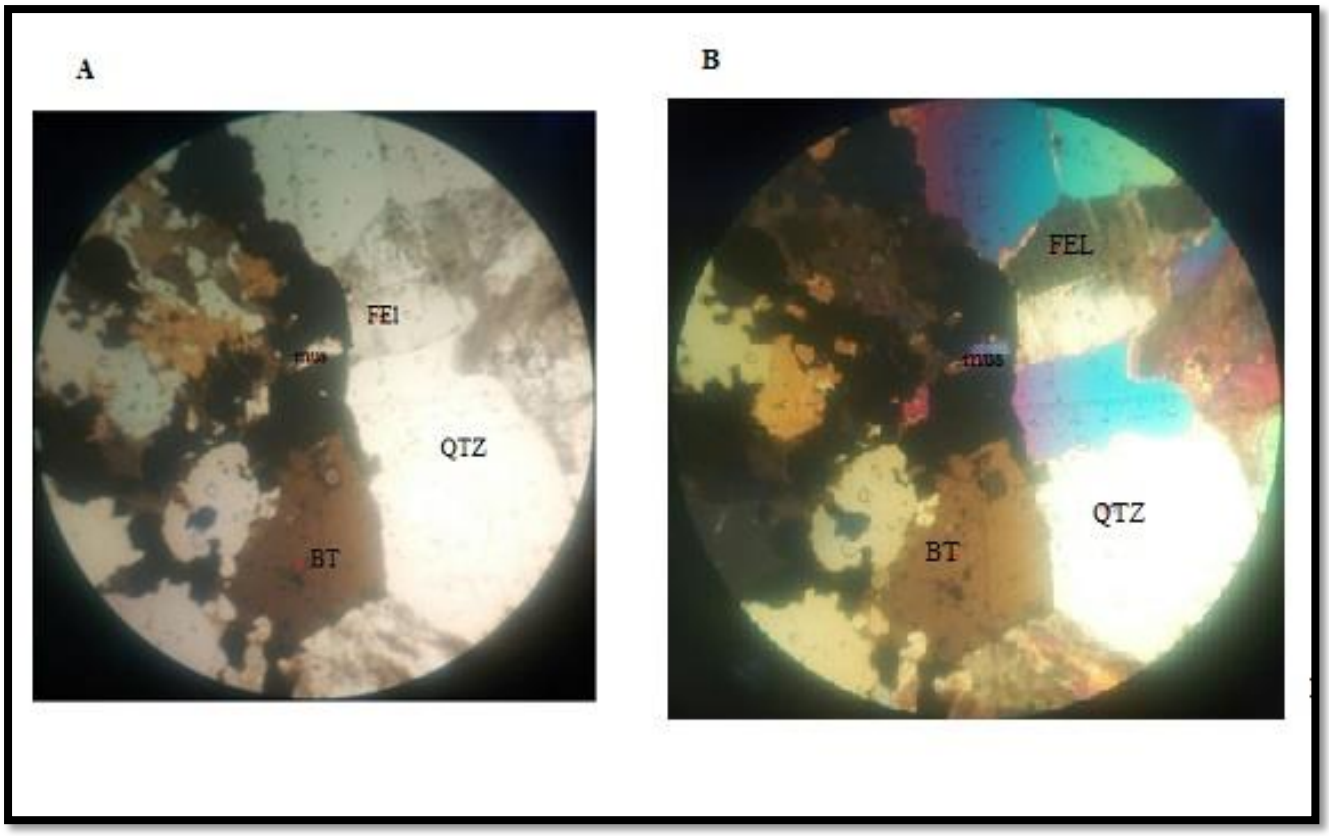



**Plate IV: (a) Photomicrograph of coarse grained biotite granite under PPL(b) Photomicrograph of coarse grain biotite granite under XPL; QTZ=quartz, BT=biotite, FEL=Feldspar, MUS= Muscovite (Magnification X40)**

### 4.1.2 Medium grained biotite granite

This rock occupies the northern part of the study area (Figure 4.1). It is the second most abundant rock and it is well exposed especially near Sha village. It is medium grained and outcrops in most places as low lying bodies/hills (Plate V). Petrographic studies showed that the major minerals present in the rock are plagioclase, quartz, feldspar, biotite (Plate VI). Quartz occurs as discrete crystals characterize by very faint undulatory extinction. Plagioclase is the dominant mineral in composition and it ranges from albite ($An_{0-10}$) to sodic oligoclase ($An_{10-30}$) and occurs as discrete crystals with carlsbad twinning. Biotite constitute small portion of the major mineral. Under PPL it is light brown in colour and pleochroic from light brown to dark brown (Plate VI).



**Plate V: Field photograph of an outcrop of medium grained biotite granite in the study area (Longitude 09° 12' 43.0" N and Latitude 08° 45' 42" E)**

**A** **B**

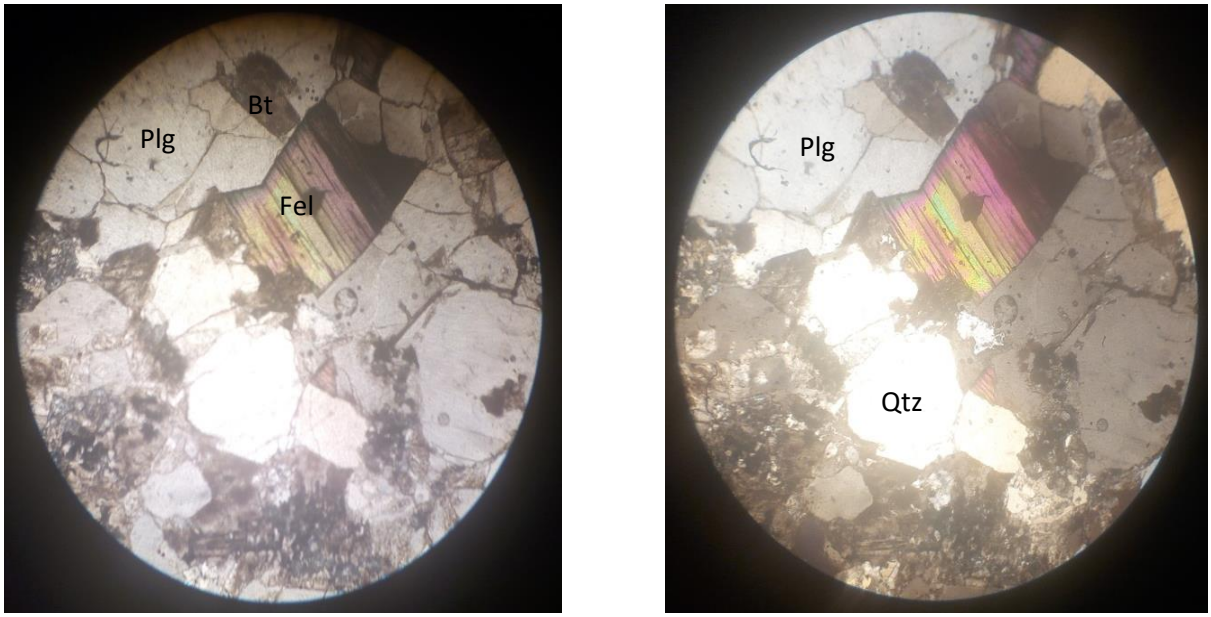



**Plate VI: (A) Photomicrograph of medium grained biotite granite under PPL. (B) photomicrograph of medium grain biotite granite under XPL; QTZ=quartz, PLG= Plagioclase, BT=biotite, FEL = Feldspar (Magnification X40)**

### 4.1.3 Diorite

This rock constitutes a minor rock unit in the study area. It occurs as low lying outcrop (Plate VII). It is medium grained mesocratic rock with phenocrysts of plagioclase. Petrography study of the diorite contains; biotite, quartz, and plagioclase (Plate IV). Plagioclase is colourless, subhedral in form and low relief with good cleavage in plane polarized light (PPL) and cross polarized light (XPL). It has low birefringence. Orthoclase is ash grey colour under XPL and light ash under PPL. It's has subhedral crystal form with some inclusions of biotite grains. Quartz is colourless PPL and XPL, its display's anhedral in form, low relief, displays no pleochroism, alteration or cleavage in plane polarized light. It is cloudy to light (weak birefringence), and exhibit a characteristics undulose extinction in cross polarized light. Biotite is dark brown colour in PPL and XPL, it exhibit anhedral crystal habit, low relief, fibrous extinction and it occur as an intergrowth with quartz crystal. (Plate VIII).



**Plate VII: Field photograph of outcrop of diorite in the study area (Longitude 09° 07' 19.7" N and Latitude 08° 48'24.5" E)**

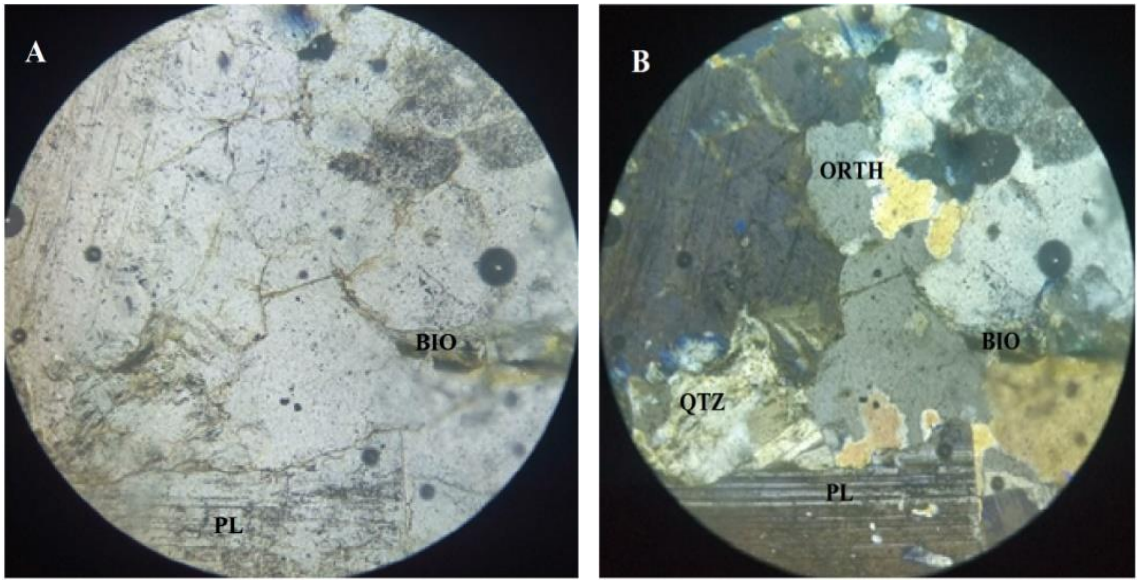



**Plate VIII: (a) Photomicrograph of diorite under PPL (b) Photomicrograph of diorite under XPL; PL= Plagioclase, QTZ= Quartz, ORTH= Orthoclase, BT= Biotite (Magnification X40)**

### 4.1.4 Fine grained biotite granite

The fine grained biotite granite is the least exposed rock in the study area. It outcrops as oval shaped body and appears pink to grey in colour. The rock has been affected by weathering, wide and narrow veins are common features of this rock unit (Plate IX).



**Plate IX: Field Photograph of outcrop of fine grained biotite granite in the study area (Longitude 09° 12' 43.0"N and Latitude 08' 45' 42.0" E)**

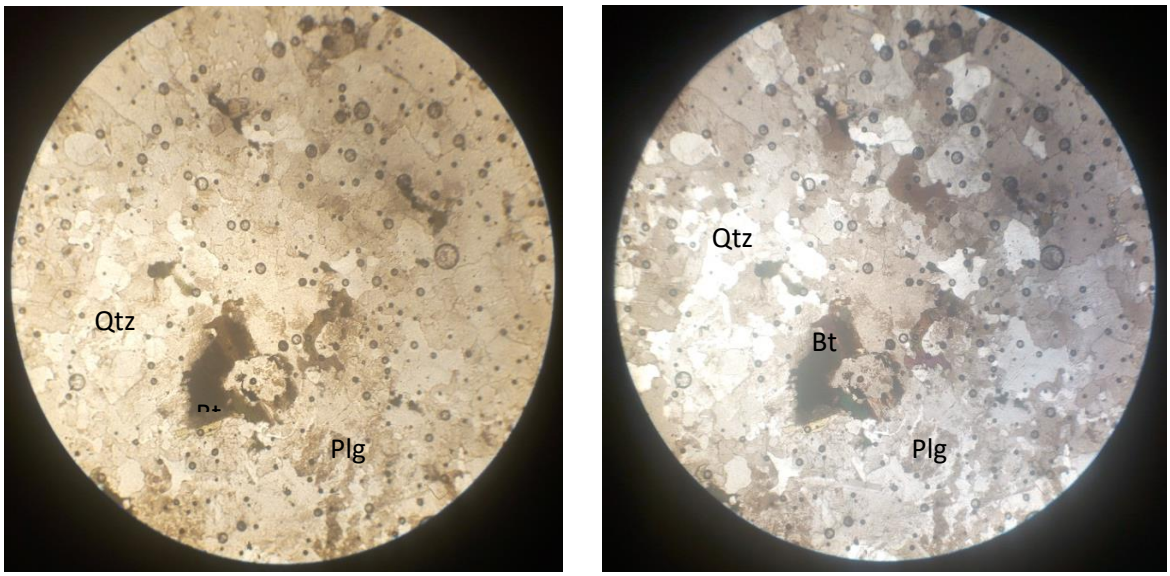



**Plate X: (A) Photomicrograph of fine grained biotite granite under PPL. (B) Photomicrograph of fine grained granite: Pl=plagioclase, Qtz=Quartz, Bt=Biotite under XPL (Magnification X40)**

### 4.2 The Pegmatites of Sha and Wuland

Pegmatites occur majorly in two areas; Sha and Wuland. In the Sha area, north western part of the study area discrete dykes of pegmatites occur in the granitoids especially in the coarse grained biotite granite. The dykes varied greatly in size up to 30 cm in length and 20 cm width in mineralogical composition. The pegmatite dykes are generally poorly exposed and their attitudes are better observed in the areas small scale mining activities are ongoing. The most abundant pegmatite dykes have nearly vertical dip the others occur as knots in the coasrse-medium grained biotite granite. Small size quartzofeldspathic veins are common (Plate XI). The dominant strike direction of the pegmatites is NE-SW, while minor sets occur in N-S and NW-SE trend (Figure 4.2).

The pegmatites in Wuland locality also occur as dykes. Fresh sample can only be found in the mining pit. The presence of massive dykes outcropping along the escarpment between surrounding environment was recognized. Based on field observation the place is

adjudged to be poorly mineralized, but some mineralized section has been discovered recently by artisanal miners.




**Plate XI: Field photograph of a pegmatite Knot in the study area area (09° 3' 20" N and 08° 48' 10" E).**

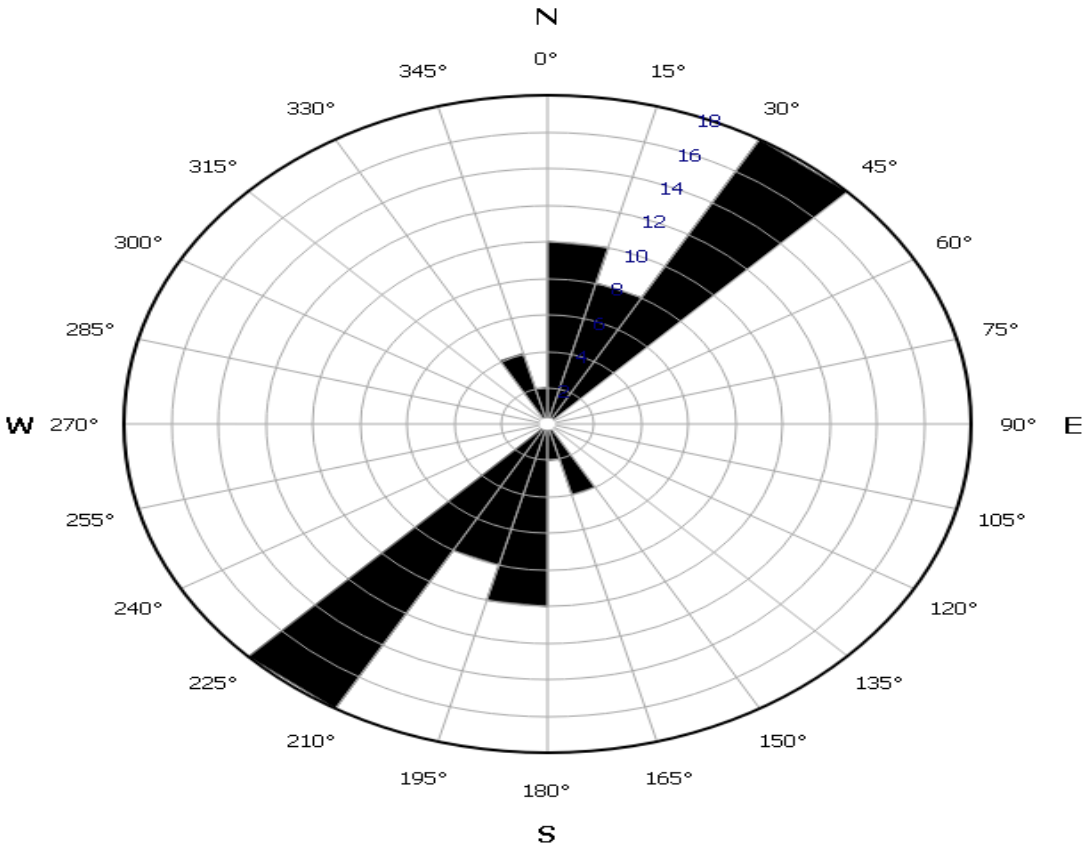



**Figure 4.2: Rose diagram displaying the general orientation of pegmatites in the study area**

Zoning is common in the pegmatites rock bodies, with two zones being prominent. Which are quartz core and feldspar rich margin. The biotites together with large crystals of alkali feldspar are concentrated in the wall zone. The border zone is characterized by smaller grain of sodic plagioclase. Giant quartz core zone was exposed by miners (Plate XII). Field relationships, textural characteristics and common silicate mineralogy indicate four distinct lithological units in the pegmatites suite. These are: (1) Alkali feldspar unit (2) graphic granite unit (3) quartz albite-biotite unit (4) sacchroidal albite-biotite unit.

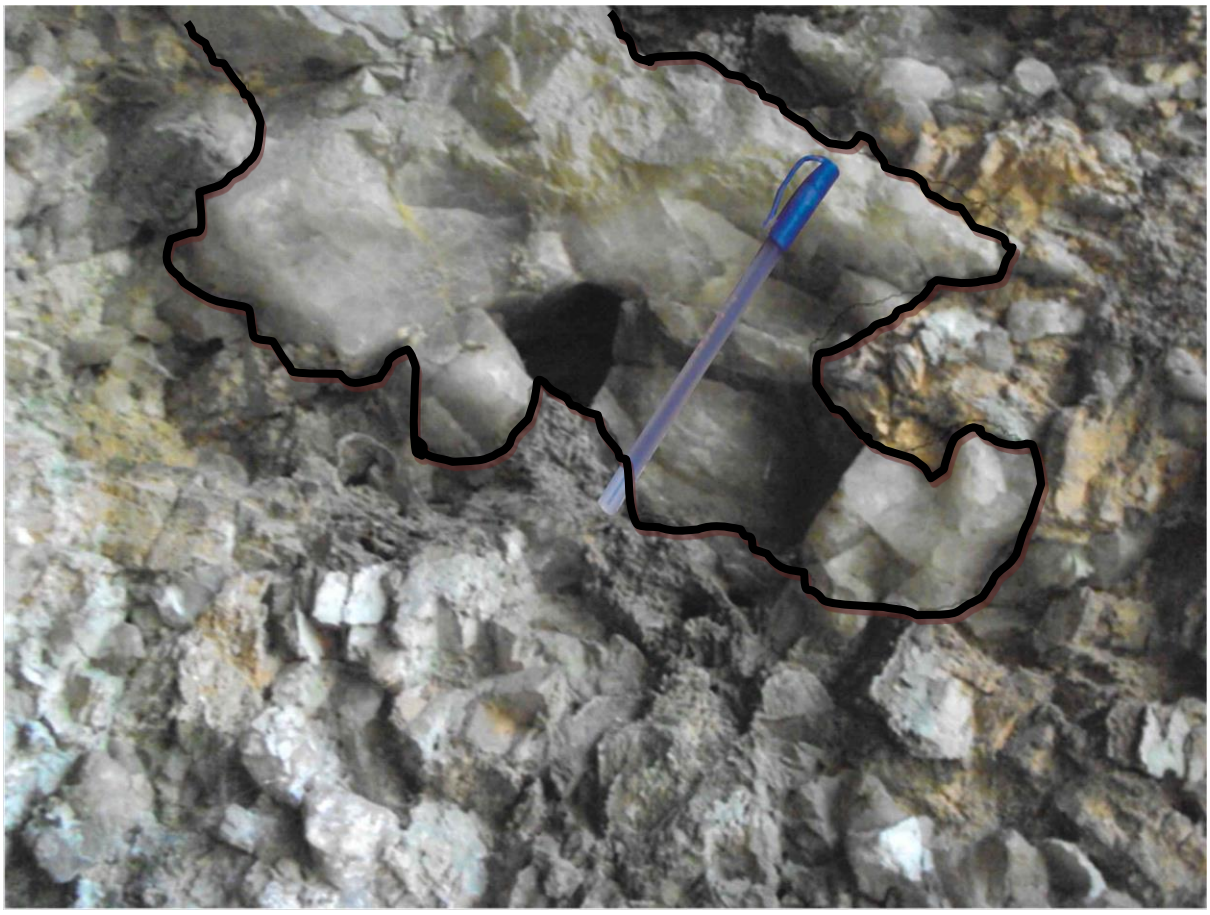


**Plate XII: Field photograph of pegmatite knot indicating quartz core zone in pegmatites at Wuland (09° 4' 00" N and 08° 51' 20" E)**

The alkali feldspar and graphic granite unit occur as autolith (cognate intrusion) in the quartz-albite-biotite unit while the sacchroidal-albite-biotite unit encloses other lithological units. These relationships suggest multiple phases of pegmatite crystallization. The earliest

generation of pegmatite (alkali feldspar and graphic granite) were probably intruded by the younger quartz albite -biotite unit before the introduction of the sacchroidal -albite -biotite unit. In other parts of the world, blocky feldspars and graphic granites constitute distinct zones of complex pegmatites (e.g. Matheis *et al.*, 1979; ˇCerný and Meintzer, 1988; ˇCerný, 1991; Breaks *et al.*, 1999).

### 4.2.1 Alkali feldspar unit

This lithological unit occurs as angular and irregularly shaped autoliths in quartz–albite–biotite–unit. It is composed of microcline and crystals of quartz. The crystals of alkali feldspar are largely visible in hand specimen in most cases the feldspar have string of exsolved albite phase giving it perthitic texture (Plate XIII).



**Plate XIII: Hand specimen indicating alkali feldspar unit of pegmatite hosted by medium grained biotite granite (09° 14' 30" N and 08° 50' 40" E)**

### 4.2.2 Graphic granite unit

Graphic granite unit also occurs as angular and irregularly shaped autoliths in quartz–albite–biotite– unit. Its field relationship with the alkali feldspar pegmatite could not be

established, because the two lithological units were not found together in a single outcrop. The main minerals of the unit are quartz and microcline (Plate XIV).



**Plate XIV: Field photograph of graphic granite unit of pegmatite hosted by coarse grained biotite granite**

### 4.2.3 Quartz–albite-biotite unit

This is the most dominant lithological unit of the pegmatite in the study area. The texture of this pegmatite unit varies from coarse-grained to very coarse-grained. The unit contains quartz, plagioclase and biotite. Smoky varieties of quartz are common while euhedral crystal of colourless topaz is extracted as a gem from the coarse grain portion (Plate XV).

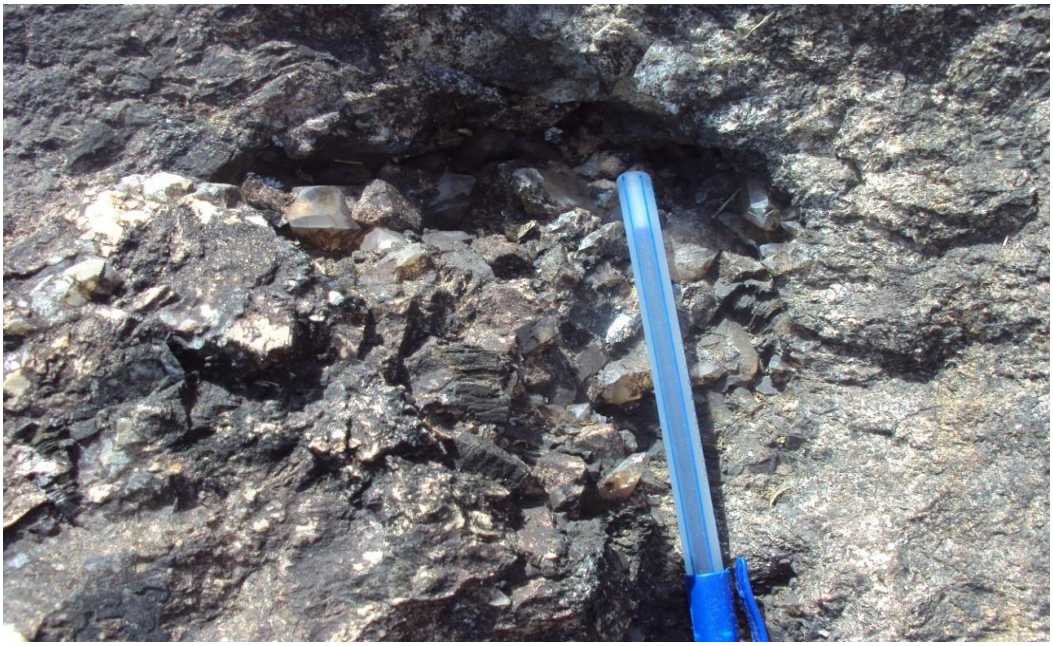


**Plate XV: Field photograph of quartz-albite-biotite unit of the pegmatites hosted by coarse grained biotite granite (09° 6' 10" N and 08° 54' 00" E)**

### 4.2.4 Saccharroidal- albite–biotite unit

This is a fine-grained rock and occurs in close association with all other pegmatite units in the western half of the study area. These lithological units are albite, biotite, and niobium-tantalum ores. Elsewhere around the world, this type of rock has been described as the replacement unit of pegmatite body (e.g. Küster, 1990; ˇCerný, 1991). The rock is not restricted to any particular zone but appears to be the product of primary magma and this cannot be described as a replacement unit (Plate XVI). Mining activities in the area until now are artisanal in nature. The site was opened by miners using drill diggers, shovels and tunnels to find the gem mineral along the strike of the pegmatites.

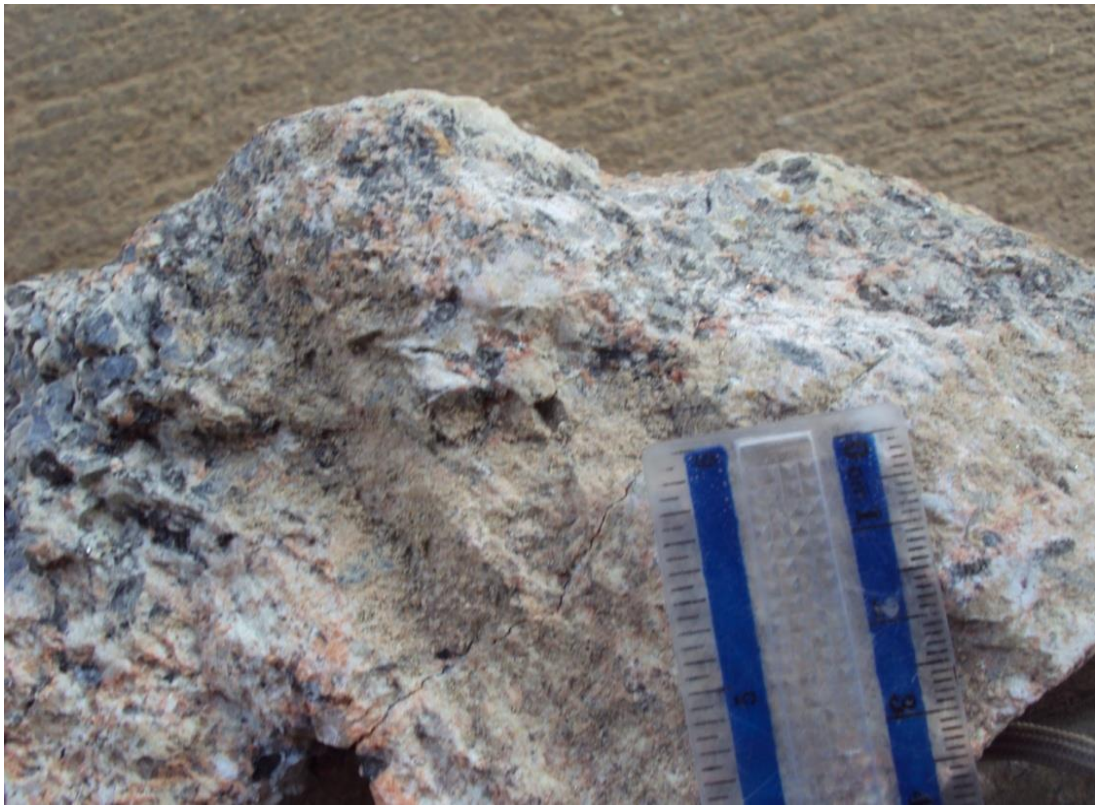


**Plate XVI: Hand specimen of saccharroidal albite biotite unit hosted by the fine grained granite near Mistakuku village (09° 12' 20" N and 08° 47' 10" E)**

### 4.3 Quartz veins

Quartz veins occur as fracture and joint filling in the granites. Quartz is the major mineral forming fracture and joint filling. Most of these veins are fine to medium grained. The veins are of various dimensions ranging from few centimeters in in length the granite. The quartz vein exhibit pinch and swell, regular in size some are wide and some are thin along their longer axis.

### 4.4 Xenolith

Xenolith is a foreign rock or is a rock fragment that becomes enveloped in a larger rock during the latter's development and solidification. Granite host small number of xenoliths of dolerite that occurred as a pod. They rework granite material in various orientations (Plate XVII).



**Plate XVII: Field photograph of xenoliths in the medium grained biotite granite ( 09° 11' 40.3" N and 08° 45' 13.6" E)**

### 4.5 Structural Features

#### 4.5.1 Joints

Displacements are seen in nearly all lithologies in different directions within the study area. According to McCurry, (1971) and Danbatta (1991) joints often result from contraction of crystallizing melt upon cooling. Joints occur in all rocks although they are more prevalent in the granites. The joint spacing within the fine grained biotite granites range from few millimeters to 10cm in areas where they occur as joint set. Field evidence shows that there is more than one generation of joints. The orientation of the joints in the field does not follow any particular trend, but they are multidimensional, suggesting several phases of deformation. However some joints are parallel to each other indicating their cogenetic relationship, and that they are products of same deformation episode in (Plate XVIII), clear cut joints can be recognized.



**Plate XVIII: Field photograph of outcrop of medium grained biotite granite with joint (09° 14' 30"N and 08° 50' 00"E)**

### 4.5.2: Faults

Faulting is minor structural features observed in the study area. A NE-SW trending strike slip fault with a dextral movement was mapped in the area for over 10cm displacing quartz vein (Plate XIX)

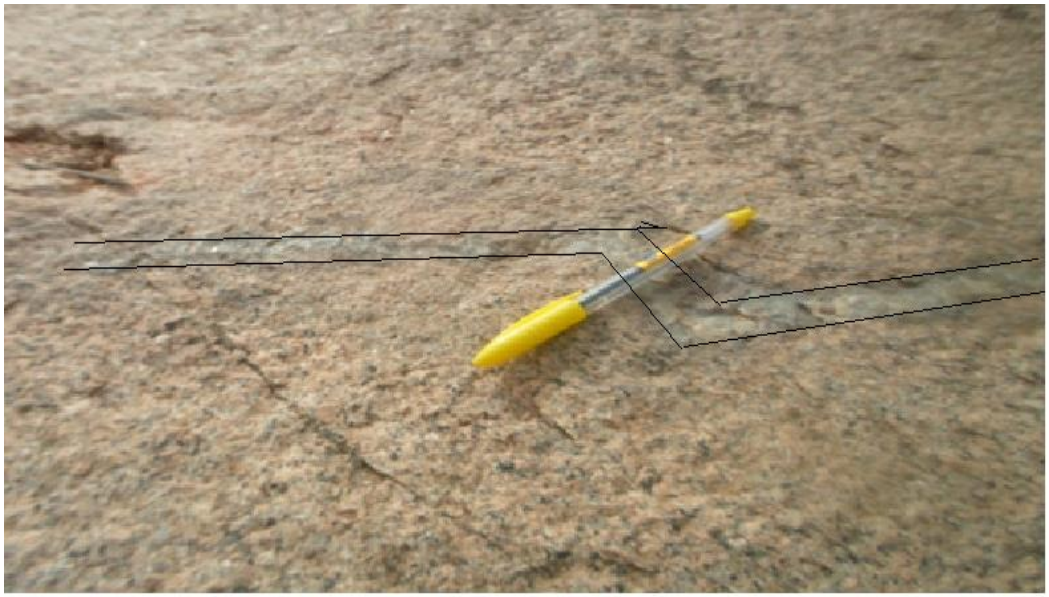


**Plate XIX: Field photograph of a strike slip fault in an outcrop of medium grained biotite granite (Longitude 09° 10' 32.2"N and Latitude 08° 4' 03.8"E)**

## 4.6 Geochemistry

Geochemistry is a study of the chemistry of the constituents of the earth that is generally used to establish how elements are distributed among the components of the earth, why the elements are distributed the way they were and the principles that govern the distribution. Comparative evaluation of the geochemical data on the host granitoids and pegmatites (K-feldspar and biotite) in the study area was carried out. This is to determine and use the chemical signature of the granitoids and K-feldspar to establish gem mineralization potential, the differentiation degree and genesis of pegmatite.

### 4.6.1 Geochemical data

The analytical data comprising major oxides, trace elements including rare earth elements in the rocks, K-feldspar and biotite samples are presented in Tables 4.1 – 4.4. The data were presented on appropriate discrimination plots in order to clearly identify the main geochemical signatures of the rocks, K-feldspar and biotite extracted from the rocks.
The data were then discussed on the basis of rock types and mineral paragenesis for better understanding of the variation in the composition and lithology.

### 4.6.2 Geochemistry of the Granitoids

#### 4.6.2.1 Major oxide composition

The geochemistry of the granitoids in the study area was studied to characterize and classify them. The granitoids or granitic rocks in the area of study are coarse-medium-fine grained, and mineralogically composed predominantly of quartz, feldspar and biotite. In order to understand the behavior of magma generated from partial melting, binary and ternary diagrams were used to classify the origin and type of magma. The analytical data comprising major oxides and, trace elements, including the REE composition of the granites and pegmatites are presented in Tables 4.1, 4.3 and 4.4.

**a. Ganitoids**

The major oxides composition of the granitic rocks is presented in Table (4.1). The granites are characterized by relatively high silica ($SiO_2$) content generally higher than 70% in all the rocks ranging from 73.50 -74.68wt%. However, $Al_2O_3$ is moderately enriched and ranges from 12.34 - 13.95wt% in the granites, while $Fe_2O_3$ varies from 1.64 - 4.34wt%. The low CaO content ranges from 0.19 - 0.64wt%. MgO varies from 0.02 - 0.27wt%. $Na_2O$ ranges from 1.58 - 3.34wt%, while $K_2O$ content ranges from 3.90-5.08wt%. MnO ranges from 0.025 - 0.75wt%, $TiO_2$, from 0.036 – 0.215 wt. %, and $P_2O_5$ from <0.01 – 0.06 wt%. The high content of $SiO_2$ in the granites is an indication of acidic nature and enrichment in common rock forming minerals such as quartz and feldspar.

**b. Diorite**

In this study, silica $SiO_2$ content in diorite is 73.59wt%. While $Al_2O_3$ is 13.75wt%, $Fe_2O_3$ content is 1.55wt%. The CaO content is 0.63wt%, while MgO is 0.27wt%. The $Na_2O$ and $K_2O$ is 3.98wt% and 4.63wt% respectively. $TiO_2$ content is 0.103wt% while $P_2O_5$ is 0.06wt%.

**Table 4.1: Major element wt % data in granitoids**

| | Coarse grained biotite granite | | | Medium grained biotite granite | | | | Diorite | Fine grained biotite granite | K- Feldspar | | | Biotite | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Element | GRA1 | GR1B | GR1C | GR2A | GR2B | GR2C | GR2D | GR3 | GR4 | KF1 | KF2 | KF3 | BT1 | BT2 | BT3 |
| $SiO_2$ | 73.50 | 74.68 | 73.13 | 74.95 | 74.41 | 75.14 | 74.71 | 73.59 | 75.16 | 69.90 | 64.40 | 64.24 | 42.49 | 42.42 | 44.54 |
| $Al_2O_3$ | 12.44 | 13.95 | 12.34 | 12.05 | 12.28 | 12.46 | 12.46 | 13.73 | 12.52 | 18.46 | 19.45 | 19.30 | 20.93 | 21.47 | 17.64 |
| $Fe_2O_3(T)$ | 2.43 | 2.28 | 2.44 | 2.50 | 2.28 | 1.64 | 4.34 | 1.55 | 1.47 | 0.92 | 0.93 | 0.76 | 20.04 | 19.03 | 18.3 |
| MnO | 0.033 | 0.041 | 0.025 | 0.037 | 0.034 | 0.027 | 0.075 | 0.043 | 0.23 | 0.012 | 0.015 | 0.001 | 0.633 | 1.022 | 1.737 |
| MgO | 0.16 | 0.21 | 0.15 | 0.07 | 0.07 | 0.02 | 0.02 | 0.27 | 0.03 | 0.11 | 0.25 | 0.34 | 0.35 | 0.94 | 1.50 |
| CaO | 0.64 | 0.52 | 0.46 | 0.58 | 0.55 | 0.50 | 0.19 | 0.63 | 0.48 | 0.12 | 0.15 | 0.15 | 0.16 | 0.26 | 0.03 |
| $Na_2O$ | 3.25 | 3.34 | 3.23 | 3.53 | 3.51 | 3.84 | 1.58 | 3.98 | 3.91 | 1.99 | 1.59 | 1.57 | 0.32 | 0.11 | 0.13 |
| $K_2O$ | 5.35 | 4.29 | 5.17 | 4.99 | 5.08 | 4.63 | 3.90 | 4.63 | 4.67 | 12.17 | 11.51 | 11.86 | 9.09 | 8.49 | 9.96 |
| $TiO_2$ | 0.215 | 0.361 | 0.214 | 0.170 | 0.149 | 0.056 | 0.056 | 0.103 | 0.043 | 0.003 | 0.009 | 0.001 | 0.836 | 0.932 | 1.064 |
| $P_2O_5$ | 0.02 | 0.01 | 0.02 | 0.02 | <0.01 | <0.01 | 0.02 | 0.06 | <0.01 | 0.02 | <0.01 | 0.02 | <0.01 | 0.01 | 0.02 |
| LOI | 0.46 | 0.4 | 0.46 | 0.26 | 0.31 | 0.30 | 0.87 | 0.39 | 0.35 | 1.36 | 1.23 | 1.46 | 3.35 | 2.55 | 2.43 |
| Total | 98.48 | 98.64 | 97.64 | 99.16 | 98.69 | 98.62 | 98.20 | 98.98 | 98.83 | 98.24 | 99.67 | 99.71 | 98.24 | 97.27 | 97.41 |

Using the feldspar triangle of O'Connor (1965), An-Ab-Or diagram as modified by Baker (1979), the granitoids plotted within the granite field (Figure 4.3).

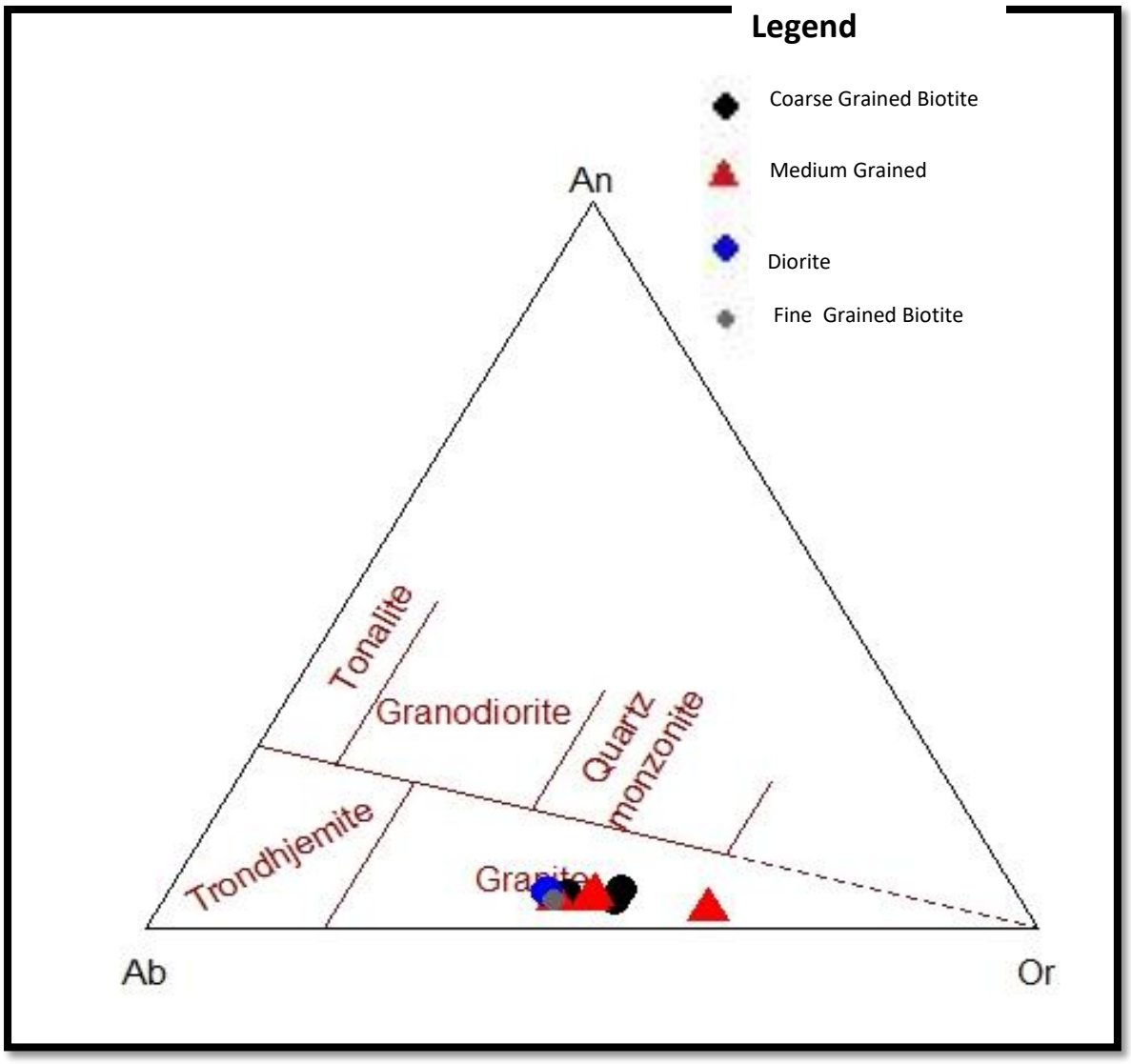



**Figure 4.3: Classification of the granitoids based on their normative composition (after O' Connor, 1965)**

On total alkalis versus silica (TAS) plot (after Middlemost 1985), all the granite plotted within the granite field (Figure 4.4).

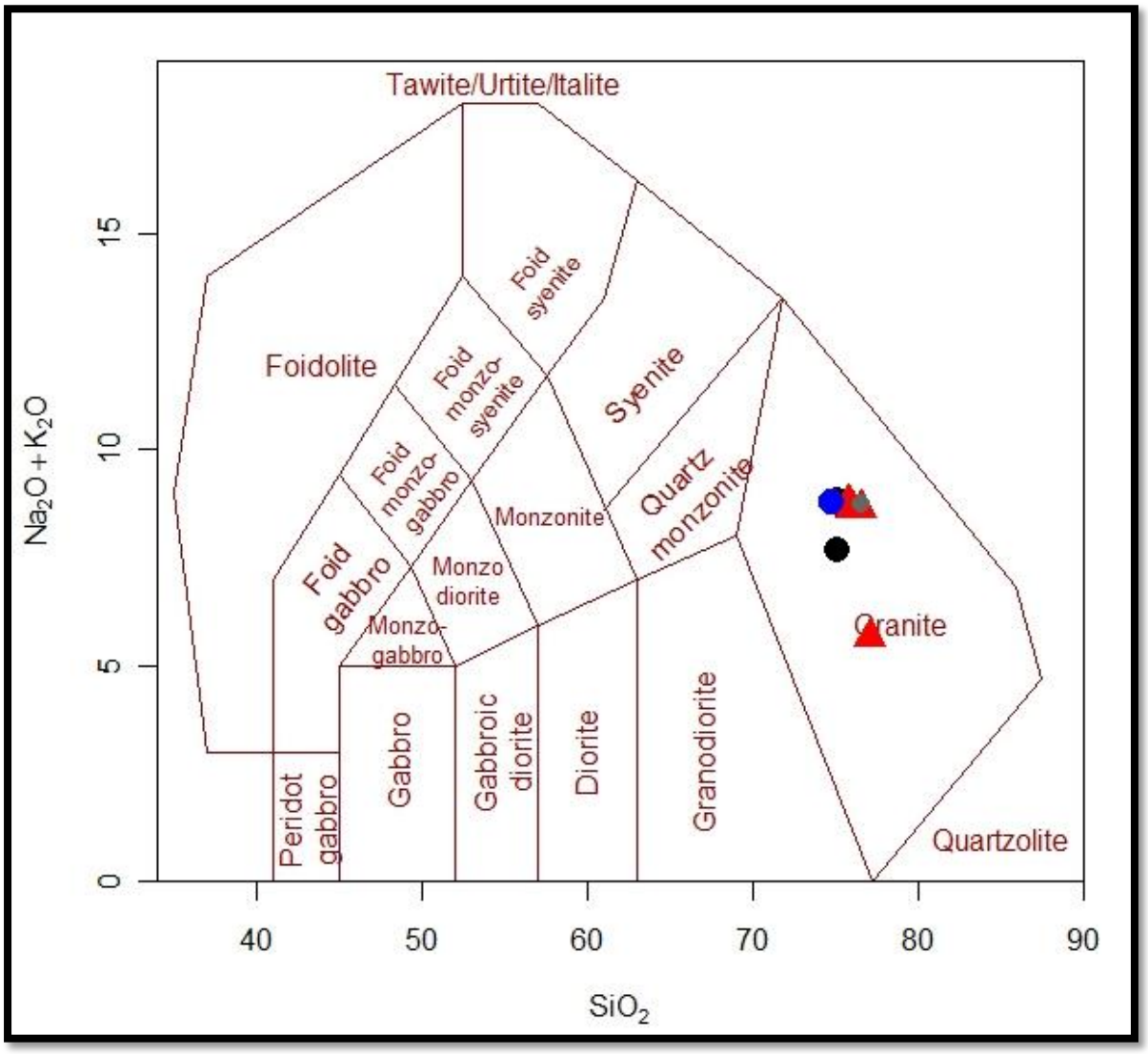



**Figure 4.4: TAS classification diagram ($Na_2O+K_2O$ versus $SiO_2$) (after Middlemost, 1985). (Symbols are the same as in Figure 4.3)**

Discrimination based upon the molecular ratio of alumina to alkalis [$Al_2O_3/(Na_2O+K_2O)$] versus alumina to lime and the alkalis [$Al_2O_3/CaO+Na_2O+K_2O$] after Shand (1943), was used to classify the rocks into peralkaline, peraluminous and metaluminous. The plot of A/NK versus A/CNK (Figure 4.5) shows that all the rocks have

A/CNK above unity and accordingly are classified as peraluminous in composition with exception of medium grained biotite granite that is slightly metaluminous. Therefore, the investigated rocks have a peraluminous to slightly metaluminous trait. Furthermore, the most distinctive and simple chemical property that characterizes I-type and S-type granitoids is their [$Al_2O_3$/CaO+$Na_2O$+$K_2O$] ratio which is <1.1 for I-type and >1.1 for S-type granites (Chapell and White 1974). The biotite granites in the study area have A/CNK ratio to be >1.1.

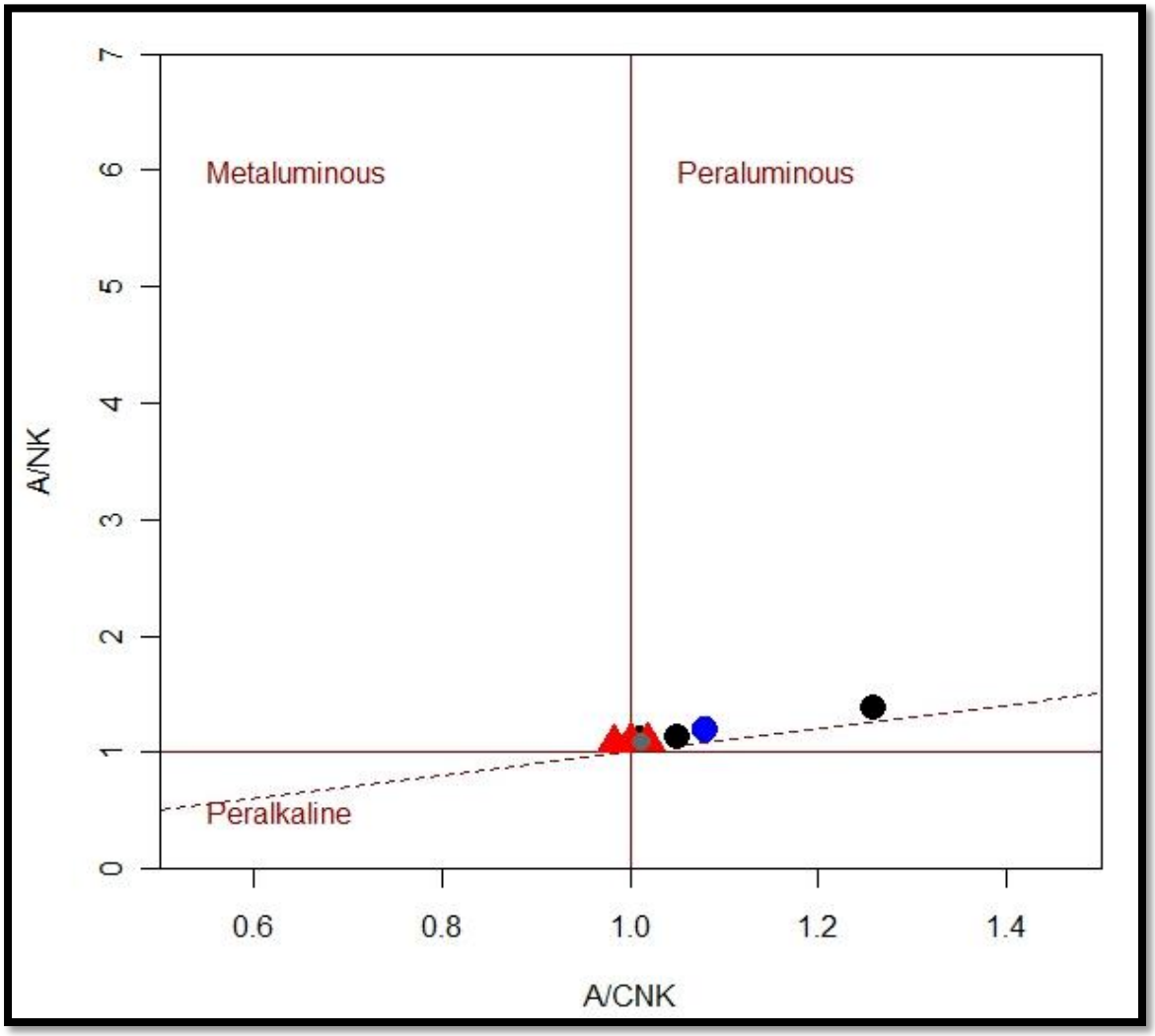



**Figure 4.5: Chemical classification of granitic rocks using the molecular ratio of alumina to alkalis $Al_2O_3$/($Na_2O$+$K_2O$)] versus alumina to lime and alkalis $Al_2O_3$/(CaO+$Na_2O$+$K_2O$)] after Shand (1943) (Symbols are the same as in Figure 4.3)**

Fe-number (FeOtot/ (FeOtot + MgO = Fe*) distinguishes ferroan granites, which manifest strong iron enrichment, from magnesian granites which do not (Frost *et al.*, 2001). The plot of the granitoids on FeOtot/ (FeOtot + MgO) versus $SiO_2$ discrimination diagram after Frost *et al.*, (2001), Figure 4.6, revealed that all the granitoids have higher values of Fe-number and therefore plot within the ferroans field. Plot of $Na_2O + K_2O$ - CaO versus $SiO_2$ discrimination reveals that all the granitoids are alkali- calcic except the coarse grained biotite granite and fine grained granite that plotted in field of calc-alkali and calcic respectively (Figure 4.6).

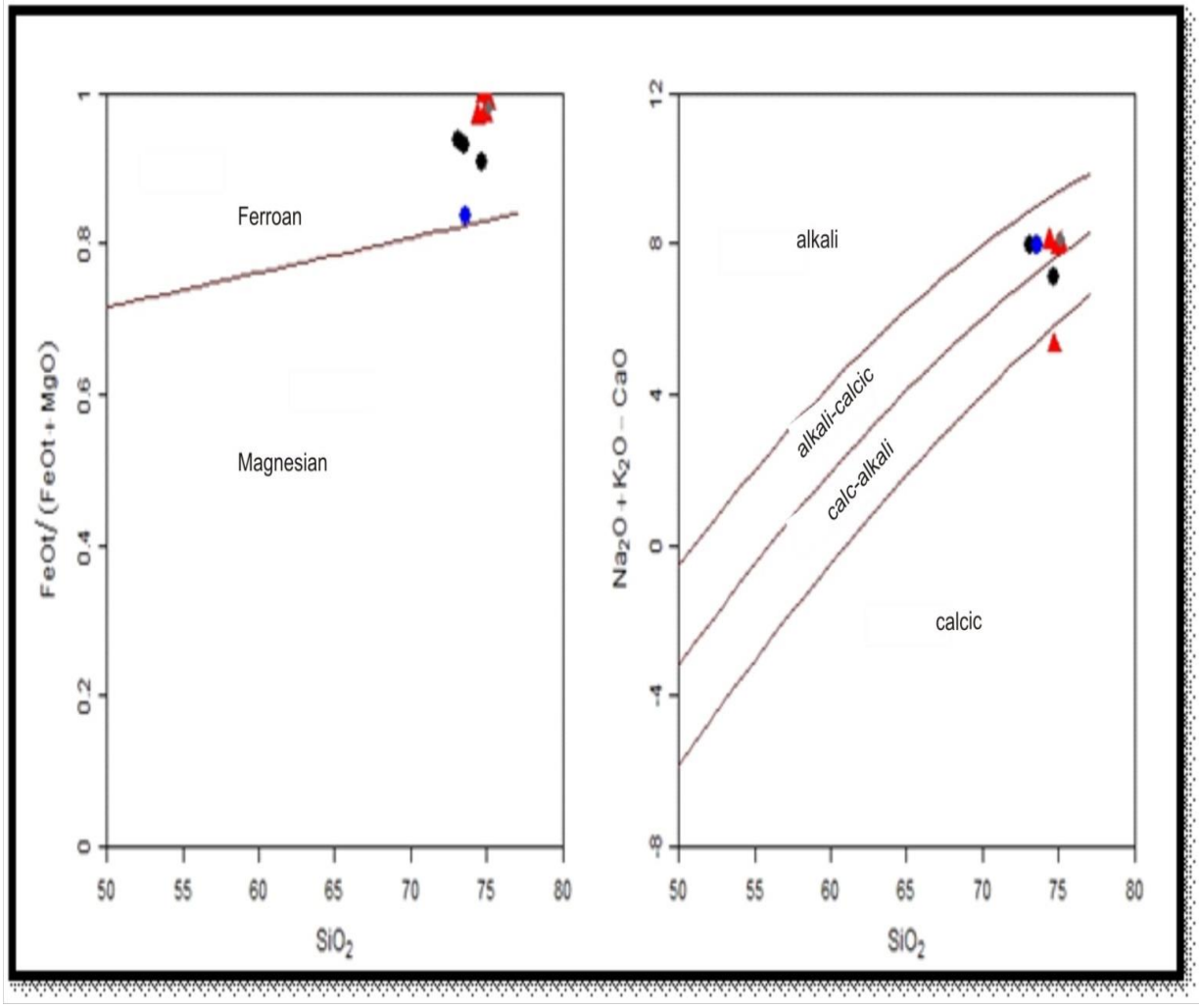



**Figure 4.6: a= FeOt/ (FeOt+MgO) Vs SiO2 discrimination diagram after Frost *et al*, (2001), b=$Na_2O+K_2O$-CaO Vs $SiO_2$ discrimination diagram after Frost *et al.*, (2001) (Symbols are the same as in Figure 4.3)**

### 4.6.2.2 Binary Plot $SiO_2$ vs major oxide

Major oxides data plotted against $SiO_2$ on Harker diagram was used to access the compositional variations, classify the rocks and determine the trend of crystallization. These bivariate plots did not show well defined trend thus indicating that igneous processes other than fractional crystallization must have played important role in the formation of the granites. However partial melting most probably played a contributing role in the generation of the melt which the rocks were formed (Figures 4.7 to 4.8). The scattered nature of the samples is an indication that the granites were from different source. The content of MgO is generally low in most of the rocks which is an indication of fractionation. The compatible elements do not produce clear trend $Al_2O_3$, $Na_2O$ and $K_2O$ exhibit considerable variation in different granitic rocks.

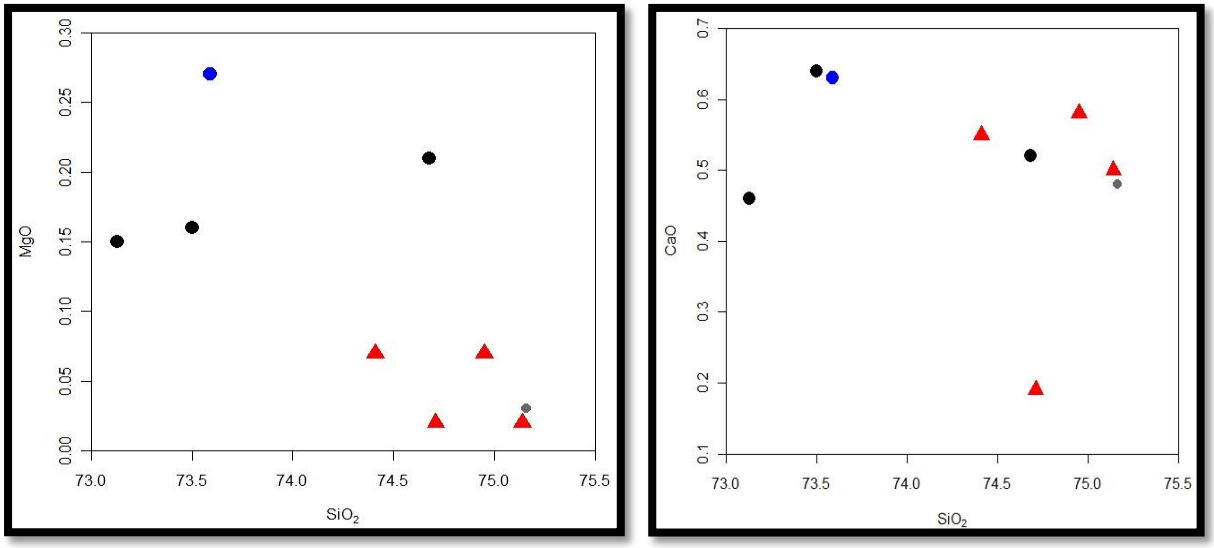



**Figure 4.7: Plot of the major oxides MgO and CaO against Silica ($SiO_2$) for the granite in the study area (after Harker, 1909). (Symbols are the same as in Figure 4.3)**

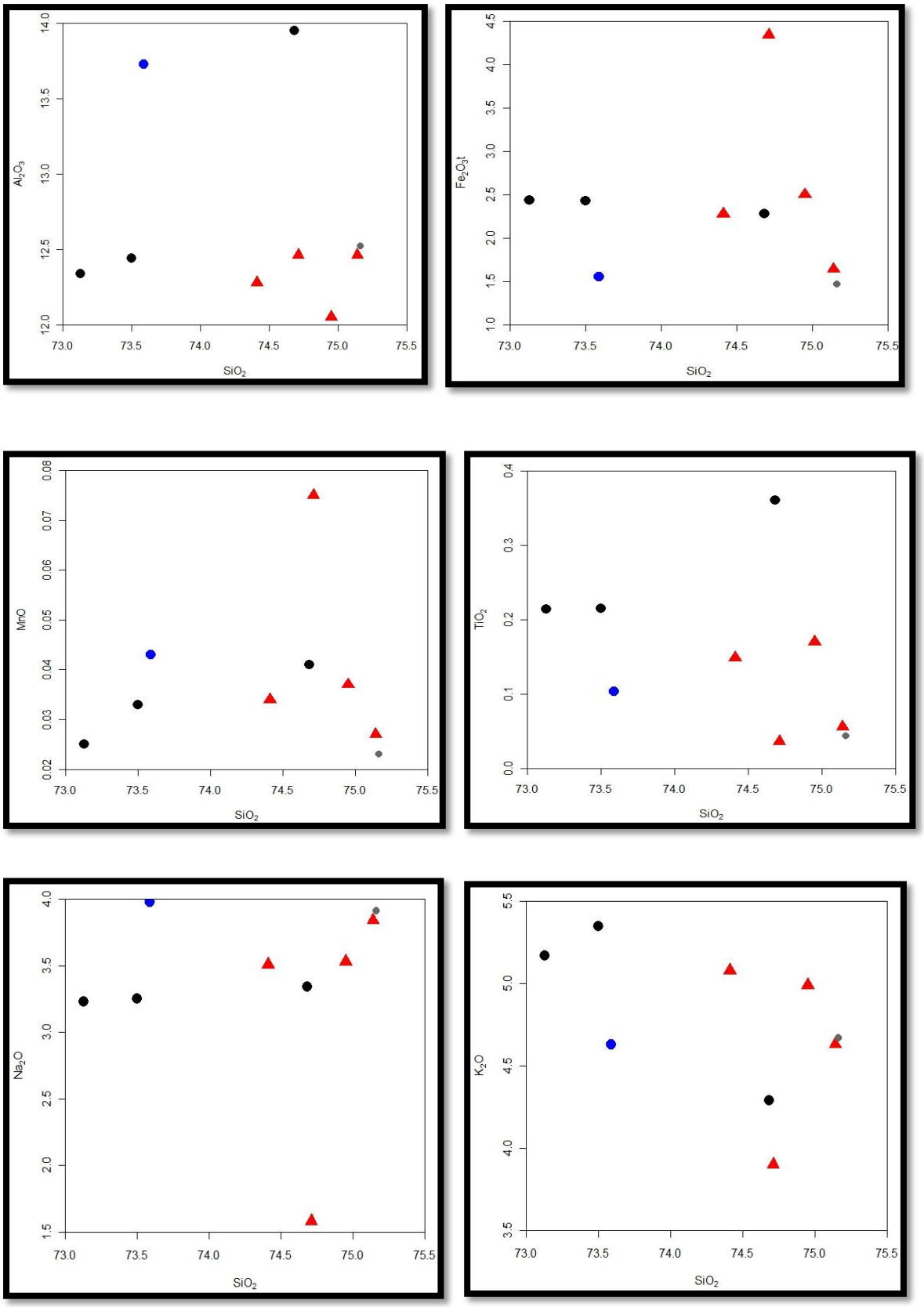



**Figure 4.8: Plots of the major oxides $Fe_2O_3$, $Al_2O_3$ MnO, $TiO_2$, $Na_2O$ and $K_2O$ against Silica ($SiO_2$) for the granite in the study area (Harker, 1909). (Symbols are the same as in Figure 4.3)**

### 4.6.2.3 Trace element geochemistry

Trace elements are elements present in concentration <0.1wt %. They commonly substitutes for major or minor elements. Trace elements were used to determine the origin of the rocks and their evolutionary process in order to constrain the magma source and discriminate between magmatic processes because they are sensitive to igneous fractionation process. The trace element analytical data of the rocks of the study area are presented in Table (4.2). Spider diagram of the trace elements for the granitic rocks was normalized to chondrites values of Thompson (1982) displayed in as Figure 4.9 depict the chemistry of granites particularly the pronounced enrichment of Rb, Nb, Y, Ga and Zr in the biotite granite relative to diorite. The biotite granites are depleted in Ba, Sr and Ti. The diorite is enriched in Ba, Sr, W, U but depleted in Rb, Y, Pb, Ti, Ta and Sn.

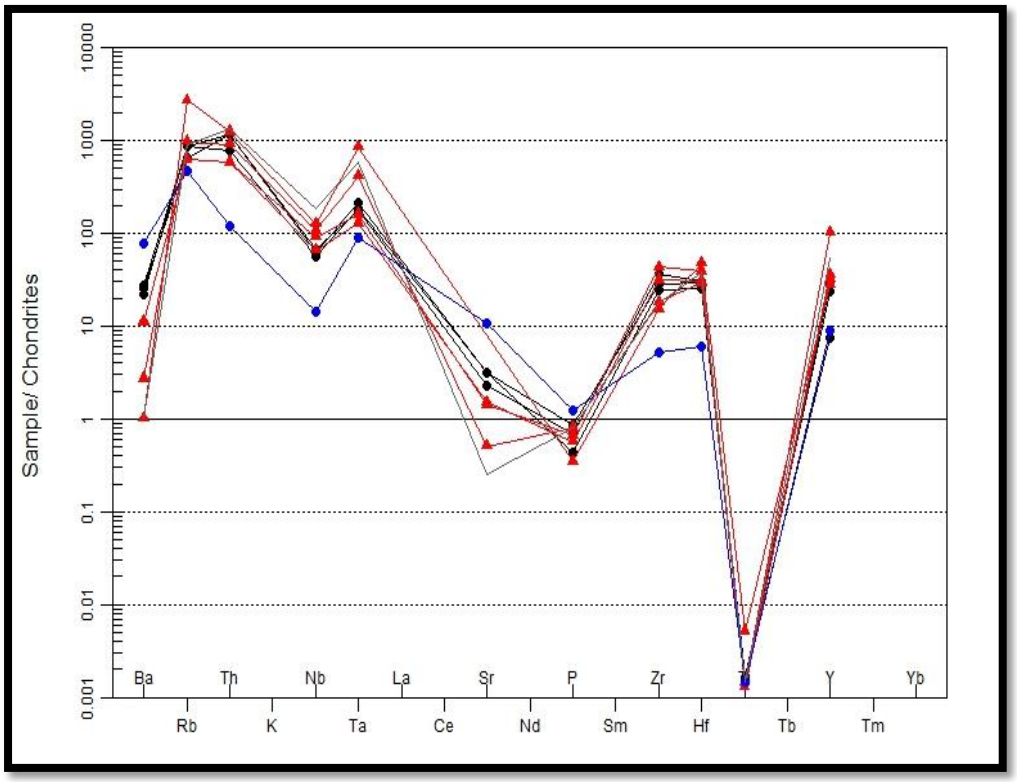



**Figure 4.9: Spider plots of trace elements in the granites of the study area. All plots are normalized to chondrite values after Thompson (1982). (Symbols are the same as in Figure 4.3)**

## Table 4.2: Trace element ppm data of granitoids

| | Coarse grained biotite granite | | | Mediun grained biotite granite | | | | Diorite | Fine grained biotite granite | K-Feldspar | | | Biotite | | | Global Average in low-Ca granite |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Element | GR1A | GR1B | GR1C | GR2A | GR2B | GR2C | GR2D | GR3 | GR4 | KF1 | KF2 | KF3 | BT1 | BT2 | BT3 | |
| Sc | 3 | 3 | 2 | 1 | 1 | <1 | <1 | 4 | <1 | <1 | 2 | 4 | 13 | 85 | 103 | |
| Be | 6 | 4 | 9 | 5 | 4 | 8 | 12 | 3 | 6 | 4 | 2 | 8 | 42 | 12 | 15 | |
| V | 5 | 5 | 5 | <5 | <5 | <5 | <5 | 7 | <5 | <5 | <5 | 6 | 8 | 15 | 6 | |
| Ba | 186 | 176 | 153 | 78 | 76 | 19 | 7 | 540 | 7 | 46 | 70 | 61 | 24 | 36 | 58 | 340 |
| Sr | 37 | 27 | 37 | 17 | 18 | 6 | <2 | 128 | 3 | 9 | 11 | 14 | 8 | 17 | 14 | 100 |
| Zr | 194 | 251 | 166 | 295 | 217 | 125 | 105 | 36 | 120 | <2 | 2 | 5 | 46 | 32 | 24 | 175 |
| Co | 58 | 72 | 69 | 81 | 60 | 50 | 50 | 84 | 65 | 34 | 25 | 20 | 16 | 56 | 54 | |
| Zn | 80 | 90 | 50 | 80 | 90 | 40 | 140 | 60 | 30 | <30 | 10 | 25 | 940 | 680 | 550 | 39 |
| Ga | 27 | 23 | 27 | 28 | 28 | 33 | 48 | 18 | 35 | 59 | 25 | 27 | 153 | 124 | 171 | 17 |
| Ge | 1 | 1 | 1 | 1 | 1 | 1 | 4 | <1 | 2 | 2 | 4 | 6 | 4 | 8 | 9 | |
| Rb | 308 | 228 | 305 | 221 | 222 | 343 | 950 | 163 | 319 | 5441 | 5783 | 2901 | 3680 | 5050 | 4260 | 170 |
| Nb | 20 | 24 | 22 | 32 | 23 | 37 | 44 | 5 | 65 | 3 | 4 | 2 | 597 | 684 | 391 | 21 |
| Sn | 24 | 10 | 6 | 8 | 6 | 10 | 77 | 5 | 6 | 2 | 6 | 16 | 685 | 696 | 555 | 3 |
| Cs | 6.8 | 3.2 | 4.8 | 5.0 | 5.0 | 77 | 20.5 | 7.7 | 2.2 | 10.2 | 11 | 12 | 291 | 380 | 490 | |
| Hf | 5.8 | 6.2 | 5.1 | 7.9 | 6.1 | 5.8 | 9.5 | 1.2 | 7.7 | <0.2 | <0.2 | <0.2 | 7.7 | 1.7 | 6.5 | 3 |
| Ta | 3.7 | 3.6 | 4.3 | 3.2 | 2.6 | 8.3 | 17.0 | 1.8 | 11.9 | 2.7 | 3.8 | 1.6 | 265 | 253 | 129 | 4 |
| W | 392 | 304 | 466 | 566 | 425 | 3.75 | 592 | 581 | 486 | 219 | 255 | 310 | 142 | 134 | 154 | 2.2 |
| Ti | 1.0 | 1 | 1.0 | 0.8 | 0.8 | 0.9 | 3.2 | 0.9 | 0.9 | 3.3 | 1.1 | 3.9 | 7.0 | 11.4 | 22.4 | 19 |
| Pb | 40 | 32 | 20 | 31 | 26 | 37 | 16 | 57 | 37 | 22 | 20 | 17 | 15 | 22 | 29 | 17 |
| Th | 33.1 | 48.4 | 48.4 | 24.2 | 24.8 | 38.4 | 52.4 | 5.0 | 56.1 | 2.3 | 1 | 3 | 25.6 | 7.6 | 20 | |
| U | 8.3 | 10.7 | 10.7 | 5.5 | 5.5 | 11.4 | 14.3 | 6.6 | 22.9 | 13.7 | 18.7 | 11.2 | 10.5 | 15.3 | 5.2 | 3 |
| Bi | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | 1.1 | <0.4 | <0.4 | 225 | 325 | 298 | 28 | 32 | 27 | |
| Y | 57 | 15 | 48 | 72 | 66 | 203 | 57 | 18 | 107 | 0.65 | 0.231 | 0.206 | 0.116 | 1.547 | 2.84 | 40 |
| | | | | RATIO | | | | | | | | | | | | |
| Rb/Ba | 1.65 | 1.29 | 1.99 | 2.83 | 2.92 | 18.05 | 135.33 | 0.30 | 45.57 | 335.67 | 82.60 | 47.57 | 153.33 | 140.24 | 71.00 | 12.65 |
| Rb/Cs | 45.29 | 71.25 | 63.54 | 44.20 | 44.4 | 4.45 | 46.34 | 21.17 | 145.00 | 533.43 | 525.64 | 241.75 | 13.29 | 8.69 | | |
| Nb/Ta | 5.41 | 6.41 | 5.12 | 10.00 | 8.85 | 4.46 | 2.59 | 2.78 | 5.46 | 1.11 | 1.05 | 1.25 | 77.53 | 2.66 | 3.01 | |
| Th/U | 3.99 | 4.52 | 4.52 | 4.40 | 4.51 | 3.37 | 3.66 | 0.76 | 2.45 | 0.17 | 0.05 | 5.67 | 2.44 | 0.50 | 3.85 | |
| Zr/Hf | 33.4 | 40.48 | 32.55 | 37.34 | 35.57 | 21.55 | 5.12 | 30.00 | 15.58 | 10.00 | 10.00 | 25.00 | 2,47 | 18.82 | 0.04 | |
| Rb/Sr | 8.32 | 8.44 | 8.24 | 13.00 | 12.33 | 57.17 | 158.33 | 81.50 | 106.33 | 604.00 | 525.64 | 207.21 | 460.00 | 297.05 | 74.44 | |
| Ba/Rb | 0.60 | 6.29 | 0.50 | 0.35 | 0.34 | 0.06 | 0.01 | 3.31 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | |
| K/Rb | - | - | - | - | - | - | - | - | - | 35.05 | 19.15 | 44.36 | 19.15 | 13.38 | 20.51 | |
| K/Cs | - | - | - | - | - | - | - | - | - | 163.31 | 21.75 | 50.68 | 60.24 | 28.09 | 21.75 | |

The geochemical signatures of the granite samples from Sha are similar to anorogenic granitoids of the Younger Granite province. The main chemical characteristics of the granites are its high concentration of $SiO_2$ (>73wt%), with elevated content of Rb, Zr and W and low content of CaO, MgO, $TiO_2$, Sr (Hapaala, 1997). Tectonic discrimination diagrams based on trace elements have been devised for granitoid rocks (Pearce *et al*, 1984). These plots indicate the setting in which the protholith were formed. On the Nb versus Y diagram (Pearce *et al*, 1984), the granitic rock largely plotted in within the plate granite field which suggest that the granite was probably generated from interaction between mantled-derived magma and continental crust (Eby, 1990). The dscrimination plots (after Pearce *et al*, 1984), clearly distiguish the granite formed within plate field (anorogenic) and granite associated with tectonic activities (Figure 4.10).

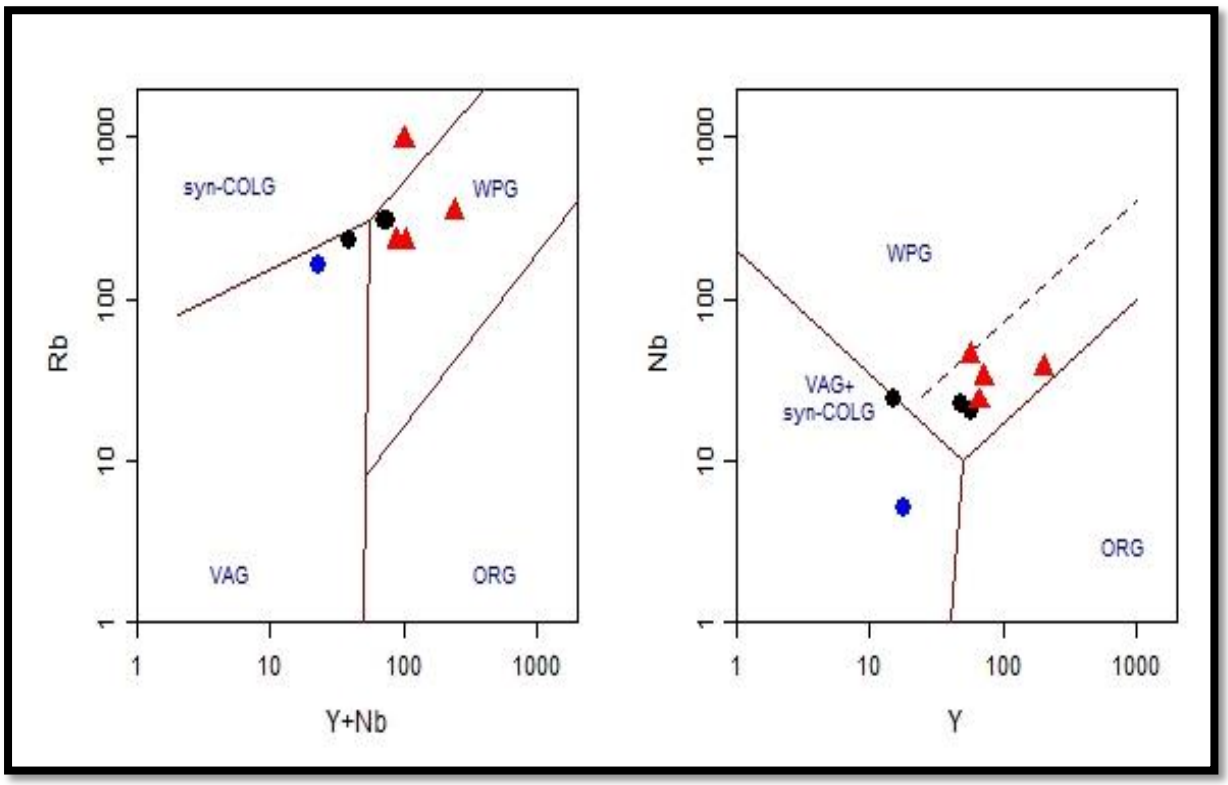



**Figure 4.10: Tectonic discrimination diagrams of rocks of the study area (after Pearce *et al.*, 1984). Syn COLG= syn- collision granite, WPG= within-plate granite, VAG=volcanic-arc granite and ORG=oceanic-rigde granite) (Symbols are the same as in Figure 4.3)**

### 4.6.2.4 Tectonic discrimination R1-R2 Plot

Tectonic discrimination diagrams use the concentrations of various chemical components to suggest environments for granite formation. On R1-R2 tectonic discrimination diagram (based on De La-Roche 1985) where R1=6Ca + 2Mg + Al, while R2= 4Si-11(Na+K) - 2(Fe+Ti) presented in Figure 4.11, the highly fractionated granitoids plot in the field of overlap of syn-collision and post-orogenic. However one of the medium grained biotite granite plot within mantle frantionates.

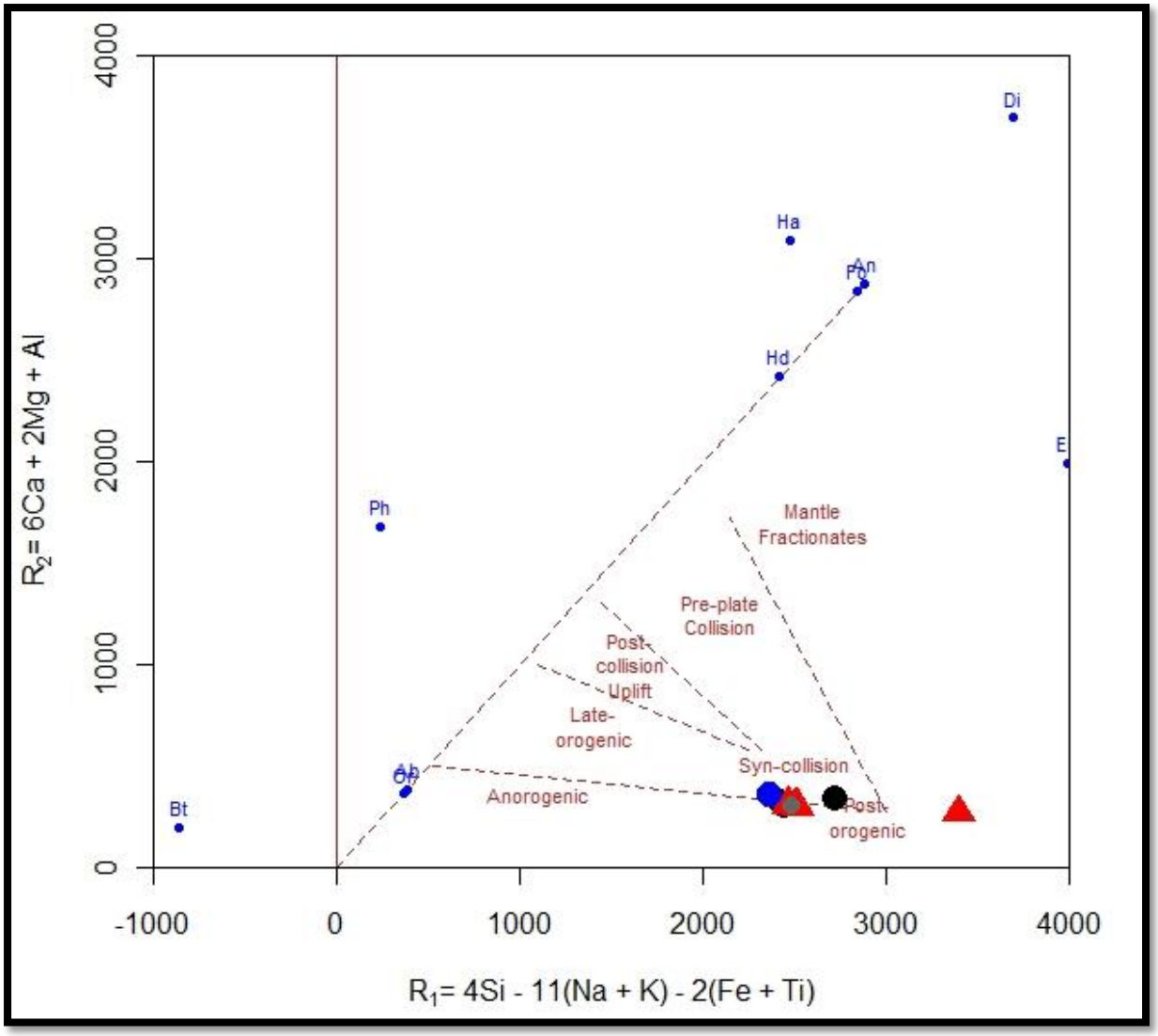



**Figure 4.11: R1-R2 tectonic discrimination diagram for the granitoids after Batchelor and Bowden (1985). (Symbols are the same as in Figure 4.)**

#### 4.6.2.5 Rare earth elements geochemistry

The REEs are group of 14 elements (La, Ce, Pr, Nd, Sm, Eu,Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu) with atomic number ranging from 57-70 which occur naturally. Those with lower atomic numbers are generally referred to as light rare earth elements (LREE) and those with high atomic number are refers to as heavy rare earth elements (HREE). They are particularly used in petrogenetic studies through studying the overall shape of the REE distribution patterns and individual element anomalies in order to constrain the petrogenesis of the melt or the participation of specific minerals in the evolution of magma because they are geochemically similar and show similar distribution pattern. The analytical data of rare earth elements of the rocks of the study area are presented in Table (4.3). All the REEs were normalized to primitive mantle value after Boynton (1984), and plotted in spider graph (Figure 4.12).

The coarse grained biotite granite has sum of REE value (∑REE) with value ranging from 252.41 to 315.55 ppm and has similar distribution pattern. Medium grained biotite granite has REE value range from 156.28 to 320.66 ppm. However, all other granites are somewhat depleted in REE compared to the 250 ppm average value of REEs in granite which is reported by Emmermann *et al.*, (1975). The sum of REE (∑REE) value is 149.99 ppm in fine grained biotite granite and 65.87 ppm in diorite.

The principal carriers of most REEs in granite are accessory minerals such as zircon and apatites (Gromet and Silver, 1983; Saleh *et al.*, 2002; Moghazi *et al*., 2004). Therefore, fractionation of such accessory minerals would result in lowering of REEs content in granites (Saleh and El-Nisr, 2013). Furthermore, with the exception of the diorite and fine grained biotite granite which show weak fraction of LREE relative to HREE (La/Yb value of 5.62 and 1.34 respectively), all the granite show high degree of fractionation of LREE to HREE (La/Yb value ranging from 7.64 to 10.43) in coarse grained biotite granites. The granites also

exhibit prominent negative Eu anomalies with $Eu/Eu^*$ value of 0.34 in biotite granite and 0.68 in diorite. The medium grained biotite granite has the lowest $Eu/Eu^*$ value as a result of its higher absolute REE concentration (REE 331.65) while diorite has the highest $Eu/Eu^*$ value as a result of its lower absolute concentration of REE (∑REE = 65.87). The biotite granite of the study area reveal moderate enrichment in LREE content which is preferentially partitioned into apartite, zircon and alkali feldspar of the rocks (Ercit, 2005; London 2008). The highly negative Eu anomaly can be interpreted as evidence of earlier separation of mineral phase, plagioclase in unoxidixed magma thus suggesting that the rock forming materials was produce in a reduce environment.

The biotite granites both coarse grained to medium grained are enriched in both the LREE and HREE with significant depletion on Eu.

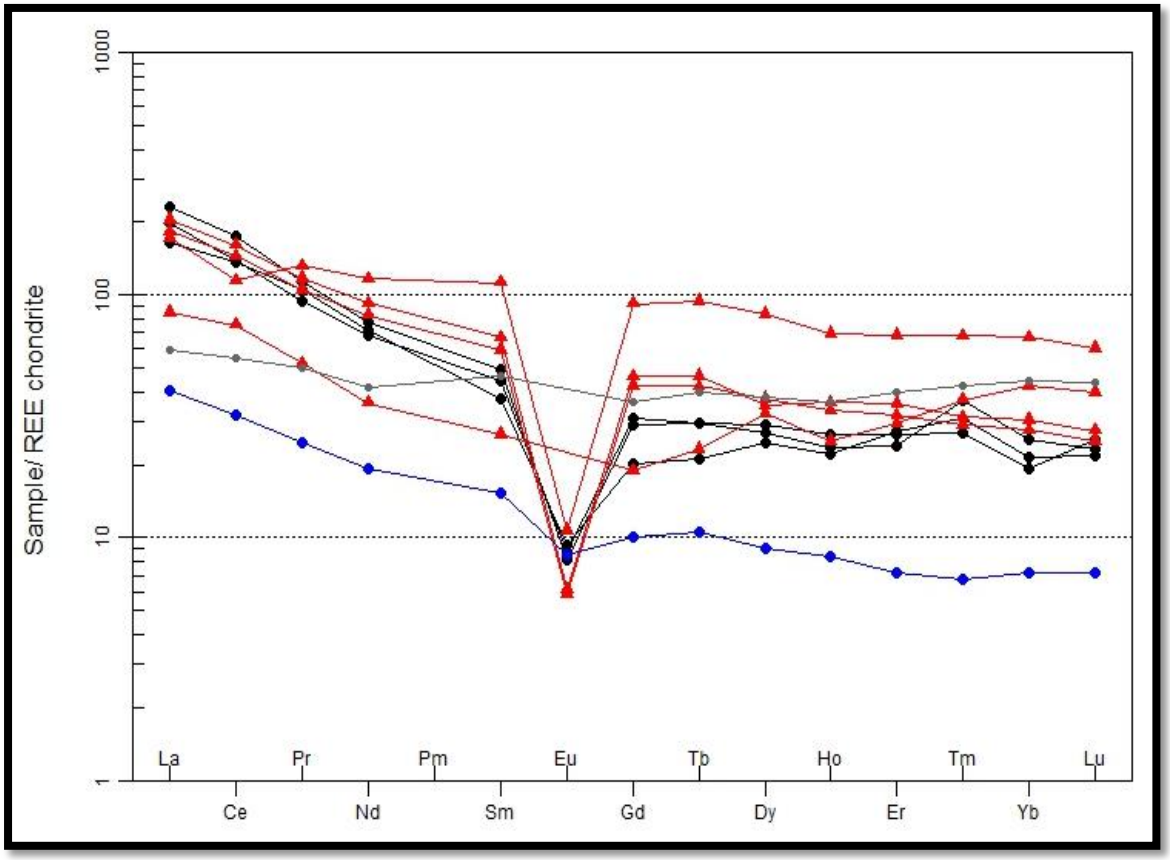



**Figure 4.12: Spider plots of REE in the granite of the study area. All plots are normalized to chondrite values after Boynton (1984). (Symbols are the same as in Figure 4.3)**

**Table 4.3: Rare earth element ppm composition of rocks in the study**

| | Coarse grained biotite granite | | | Medium grained biotite granite | | | | Diorite | Fine grained biotite granite | K-Feldspar | | | Biotite | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Element | GR1A | GR1B | GR1C | GR2A | GR2B | GR2C | GR2D | GR3 | GR4 | KF1 | KF2 | KF3 | BT1 | BT2 | BT3 |
| La | 61.9 | 51.0 | 75.2 | 63.4 | 56.5 | 53.7 | 26.3 | 12.5 | 18.5 | 1.7 | 1.4 | 7.5 | 6.1 | 12.8 | 49 |
| Ce | 112 | 110 | 141 | 130 | 117 | 92.9 | 61.0 | 26.1 | 44.6 | 3.5 | 8.4 | 19.6 | 20.6 | 23.5 | 20.9 |
| Pr | 11.6 | 12.8 | 13.8 | 14.3 | 12.9 | 16.1 | 6.40 | 3.00 | 6.11 | 0.54 | 0.35 | 2.22 | 2.11 | 2.63 | 19.7 |
| Nd | 40.7 | 42.8 | 46.7 | 55.5 | 49.7 | 70.0 | 21.6 | 11.5 | 25.2 | 1.4 | 1.4 | 8.1 | 9.1 | 9.4 | 69.9 |
| Sm | 8.7 | 7.3 | 9.6 | 13.1 | 11.6 | 22.0 | 5.2 | 3.0 | 9.0 | 0.3 | 0.5 | 3.4 | 2.2 | 1.8 | 22.8 |
| Eu | 0.64 | 0.68 | 0.60 | 0.45 | 0.43 | 0.79 | <0.05 | 0.62 | <0.05 | 0.05 | 0.08 | 0.38 | 0.72 | 0.13 | 2.59 |
| Gd | 8.0 | 5.23 | 7.6 | 12.0 | 11.0 | 23.9 | 4.9 | 2.6 | 9.4 | 0.3 | 0.5 | 3.4 | 1.3 | 1.2 | 18.4 |
| Tb | 1.4 | 1.0 | 1.4 | 2.2 | 2.0 | 4.5 | 1.1 | 0.5 | 1.9 | <0.1 | 0.1 | 0.7 | 0.3 | 0.2 | 4 |
| Dy | 9.4 | 3.9 | 8.7 | 13.5 | 12.1 | 26.9 | 10.5 | 2.9 | 12.3 | 0.4 | 0.9 | 3.2 | 1.4 | 1.8 | 18.7 |
| Ho | 1.9 | 1.6 | 1.7 | 2.6 | 2.4 | 5.0 | 1.8 | 0.6 | 2.6 | <0.1 | 0.6 | 0.1 | 0.3 | 0.4 | 3.6 |
| Er | 5.6 | 5.8 | 5.0 | 7.5 | 6.7 | 14.4 | 6.2 | 1.5 | 8.3 | 0.2 | 0.5 | 1.8 | 1.5 | 1.2 | 11.3 |
| Tm | 0.87 | 1.0 | 1.2 | 1.02 | 0.95 | 2.21 | 1.20 | 0.22 | 1.37 | 0.05 | 0.11 | 0.27 | 0.28 | 0.28 | 2.22 |
| Yb | 4.0 | 4.5 | 5.3 | 6.4 | 5.8 | 14.0 | 8.8 | 1.5 | 9.3 | 0.2 | 1.4 | 1.9 | 2 | 4 | 17 |
| Lu | 0.82 | 0.70 | 0.75 | 0.89 | 0.81 | 1.95 | 1.28 | 0.23 | 1.41 | 0.1 | 0.25 | 0.29 | 0.27 | 0.67 | 3.49 |
| ∑REE | 267.53 | 252.41 | 315.55 | 320.66 | 289.89 | 331.65 | 156.28 | 65.87 | 149.99 | 8.01 | 16.9 | 52.86 | 48.18 | 60.01 | 263.6 |
| | | | | NORMALIZED RATIO | | | | | | | | | | | |
| $Eu/Eu^*$ | 0.023 | 0.34 | 0.21 | 0.11 | 0.12 | 0.11 | NA | 0.68 | NA | 0.05 | 0.05 | 0.34 | 1.31 | 0.27 | 0.38 |
| La/Yb | 10.43 | 7.64 | 9.18 | 6.68 | 6.57 | 2.59 | 2.01 | 5.62 | 1.34 | 5.67 | 0.67 | 2.63 | 2.03 | 2.13 | 1.92 |
| La/Sm | 4.48 | 4.39 | 4.73 | 3.04 | 3.06 | 1.54 | 3.18 | 2.62 | 1.29 | 3.49 | 1.72 | 1.36 | 1.71 | 4.37 | 1.32 |
| Ce/Yb | 7.24 | 6.32 | 6.88 | 5.25 | 5.22 | 1.72 | 1.79 | 4.50 | 1.24 | 4.45 | 1.53 | 2.62 | 2.62 | 1.49 | 0.31 |
| Eu/Yb | 0.45 | 0.43 | 0.32 | 0.20 | 0.21 | 0.16 | NA | 1.18 | NA | 0.07 | 0.02 | 0.57 | 1.03 | 0.09 | 0.42 |
| Ce/Sm | 3.11 | 3.64 | 3.54 | 2.35 | 2.43 | 1.02 | 2.83 | 2.10 | 1.02 | 2.74 | 3.94 | 1.35 | 2.20 | 3.06 | 0.22 |

## 4.7 Mineral Chemistry

Elemental concentration of the minerals extracted from the pegmatites was used to correlate the chemistry of the minerals with associated rare metal mineralization in terms of mineralizing process, degree of fractionation, classification and petrogenesis of the pegmatites. Major elements are reported in weight percent (wt %) while trace elements in parts per million (ppm). The major element composition of the K-feldspar and biotite is presented in Table 4.2. Silica ($SiO_2$) is relatively high in the pegmatites. It ranges from 64.24 to 69.90 wt% in K-Feldspar. The pegmatites have low content of $Fe_2O_3$ and $P_2O_5$. $Fe_2O_3$ and $P_2O_5$ ranges from 0.76 to 0.92wt% and <0.01 to 0.02wt% respectively in K-Feldspsar. Tenary plot of $K_2O$, $Na_2O$ and CaO show that all the pegmatites are $K_2O$ enriched (Figure 4.13)

The variation in K/Rb vs Rb and K/Rb vs Cs and Rb vs Ba are presented in Figure 4.14, 4.15 and 4.16 while the spider plots for trace elements and REEs of minerals extracted from pegmatite are presented in Figures 4.17 and 4.18 while the

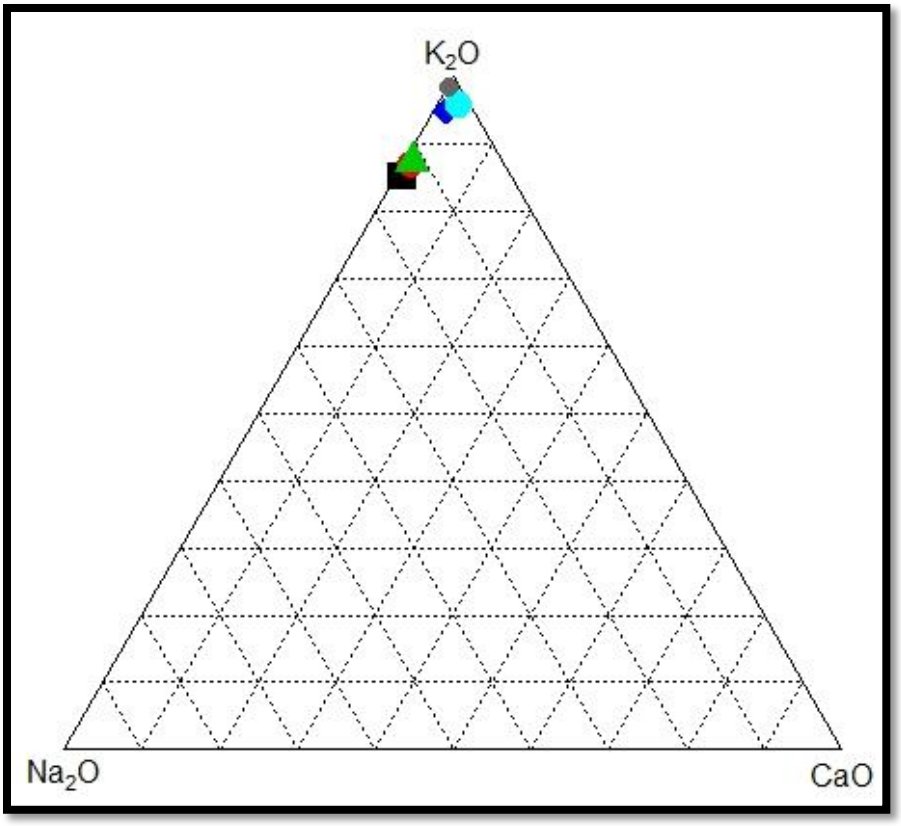



**Figure 4.13; Ternary plot showing the distribution of $K_2O$, $Na_2O$ and CaO in wt % of k-feldspar and biotite extracted in pegmatites (after, Shearer *et al.*, 1985)**

### 4.7.1 Petrogenesis of Pegmatite

#### a. K-Feldspar

Some trace elements have long been use as indicator of pegmatites evolution. The K/Rb in K-Feldspar constitute a good indicator of pegmatites body's evolution (˘Cerný, *et al.;* 1985). The K/Rb ratio is 35.05 for pegmatite in Wuland (KF1), 19.15 for the pegmatite in Arho (KF2) and 44.36 for pegmatite in Sha (KF3) Table 4.2. The content of most trace elements in K -Feldspar of the study area correlate negatively with this ratio.

K-Feldspar exhibits a marked Rb enrichment. The rubidium content in Sha is low with the value 2901ppm relatively to that of Wuland and Arho with the values 5441 and 5782 ppm respectively. Those values are typical of K-Feldspar from evolved pegmatite bodies (Gordiyenko 1971;

ˇCerný, *et al.;* 1985). Cesium increases although it is not very abundant and attains a maximum of 12 ppm in Sha. Such Cs value is typical of modestly evolved pegmatite (Cerný, 1994). Similar Cs content has been documented by Nuhu (2017) in pegmatite from Badafi. Table 4.2 shows that the Ba content is less than 100 ppm, typical of fractionated pegmatites (ˇCerny´ *et al.*, 1985). Ba content is commonly used as indicator of the evolution in granite and pegmatites (ˇCerny´ *et al*. 1985, Roda *et al*.1999, Morteani *et al*. 2000) and decreases with fractionation. Rb versus Ba plot was used to indicate a fractionation trend from granites to pegmatites in the study area. Rb enrichment is accompanied by Ba depletion with fractionation (Figure 4.16).

**b. Biotite**

Trace element compositions of biotite extracted from pegmatite have been reported to be useful indicator of the extent of fractionation of rare-metal pegmatites (Tischendorf *et al.,* 2001). In highly fractionated pegmatites, the concentration of Rb, Cs, Ga, Ti, Sn and Ta in biotite increase, whilst K/Rb, K/Cs, ratios show a concomitant decrease. The Ta and Cs content of biotite have also been used as an exploration tool to identify the potential for Ta–Nb mineralisation in pegmatites (Selway *et al.,* 2005). Pegmatites containing biotite with a Ta concentration greater than 65 ppm and a Cs concentration above 500 ppm are highly likely to contain Ta–Nb mineralisation (Selway *et al.,* 2005). Biotite in pegmatites from Wuland, Sha and Arho were analysed for major, trance and rare-earth elements for comparison with those in highly fractionated pegmatites that have potential for Nb-Ta mineralisation.

The representative samples of biotite from Wuland, Sha and Arho are rich in Rb, Nb, Sn, Ta, Y, Zn, Ga Cs but low in Ba, and Sr contents. K/Rb ratios are generally lower in biotite from

Arho (BT2) with a value 13.35 ppm, compared to higher value of Sha (BT3) 20.51 ppm and Wuland (BT1) with value 19.15 ppm (Table 4.2).

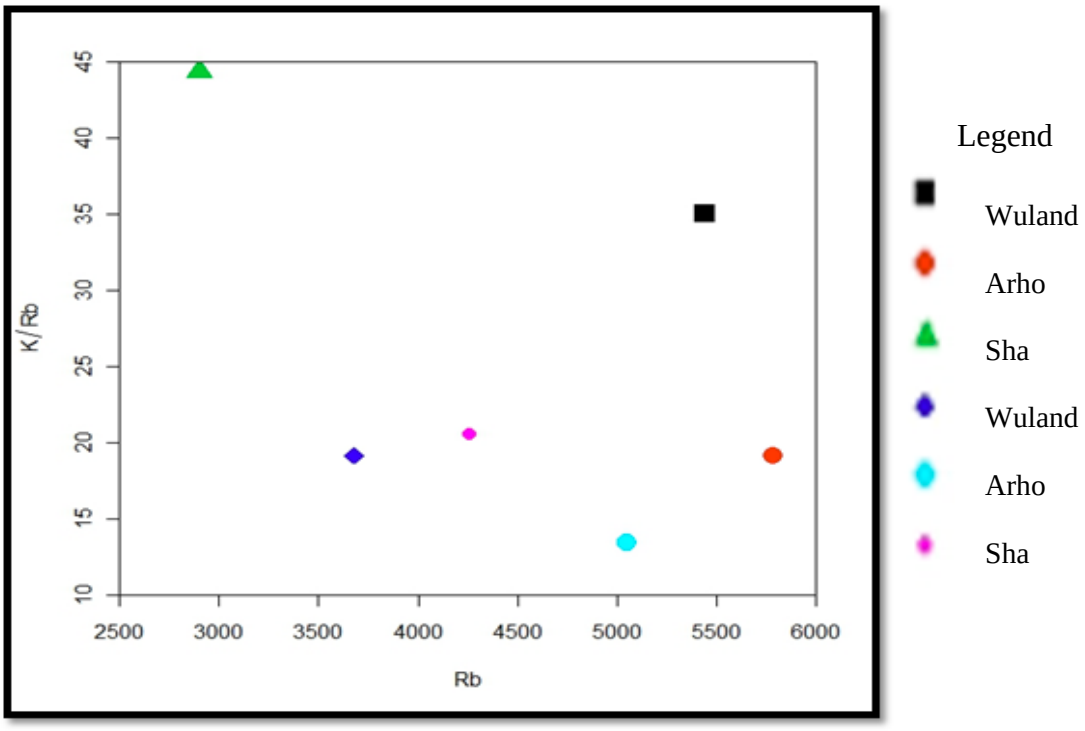



**Figure 4.14: K/Rb versus Rb plot of samples from the study area**

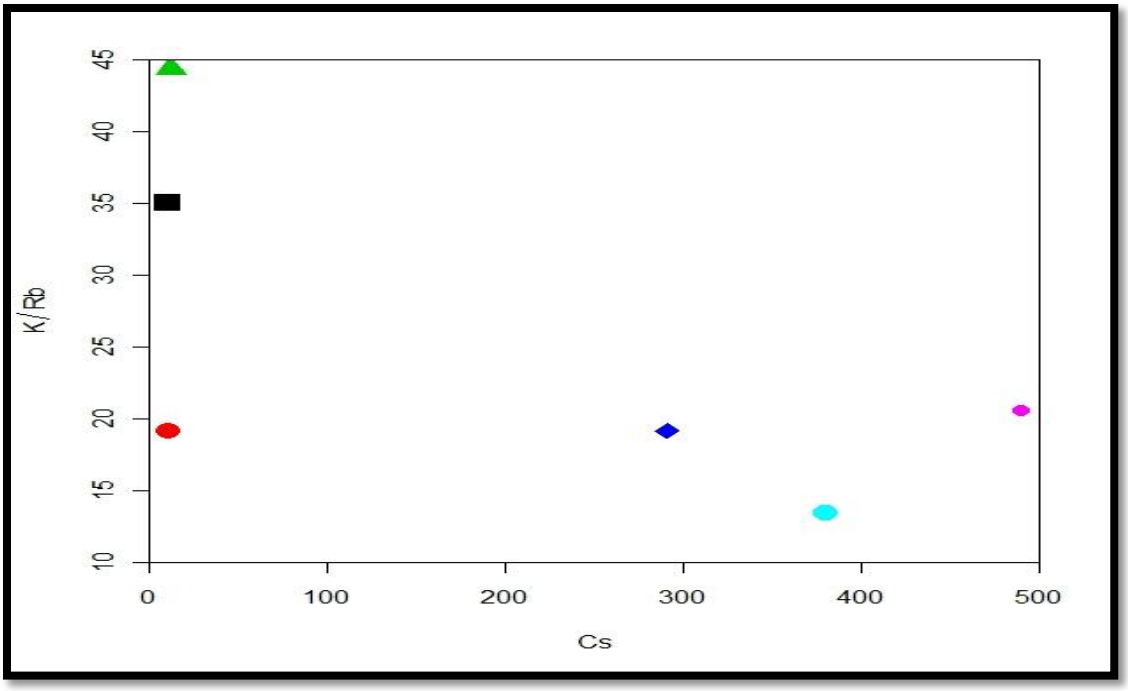



**Figure 4.15: Plot of K/Rb/ versus Cs in samples showing the degree of fractionation and mineralization of the pegmatite. (Symbols are the same as Figure 4.14)**

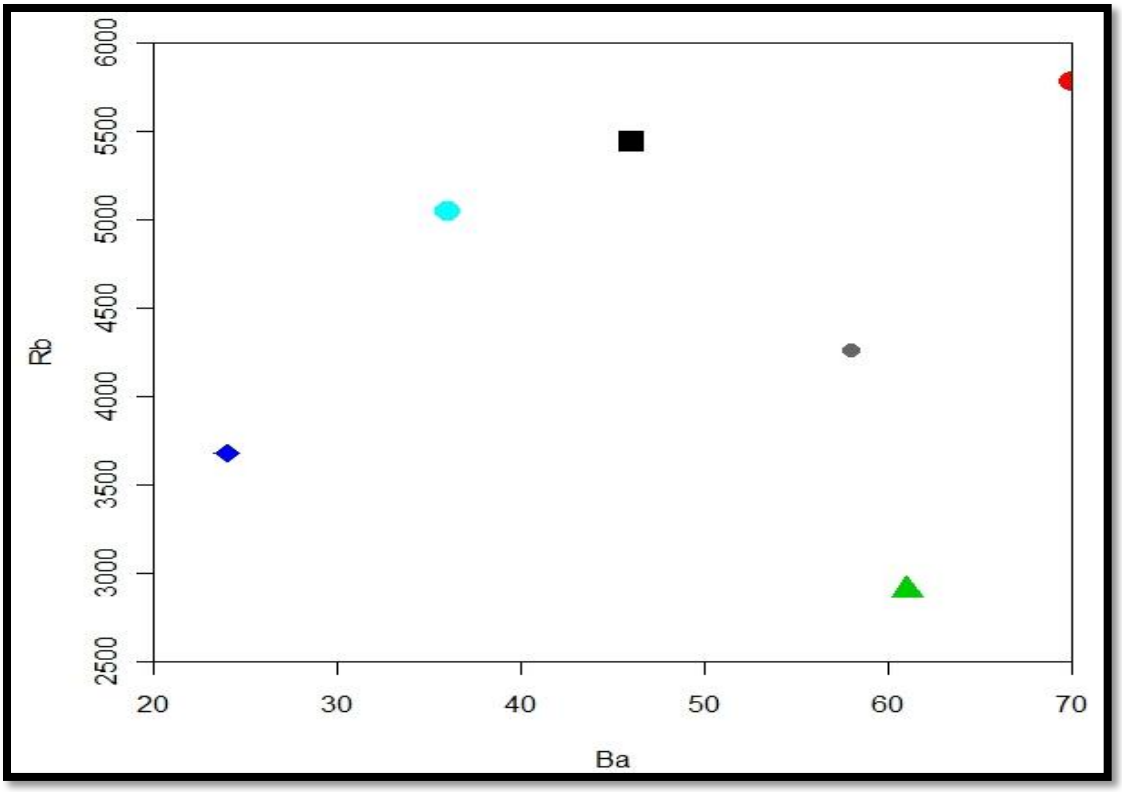



**Figure 4.16: Rb versus Ba plot minerals from the study**

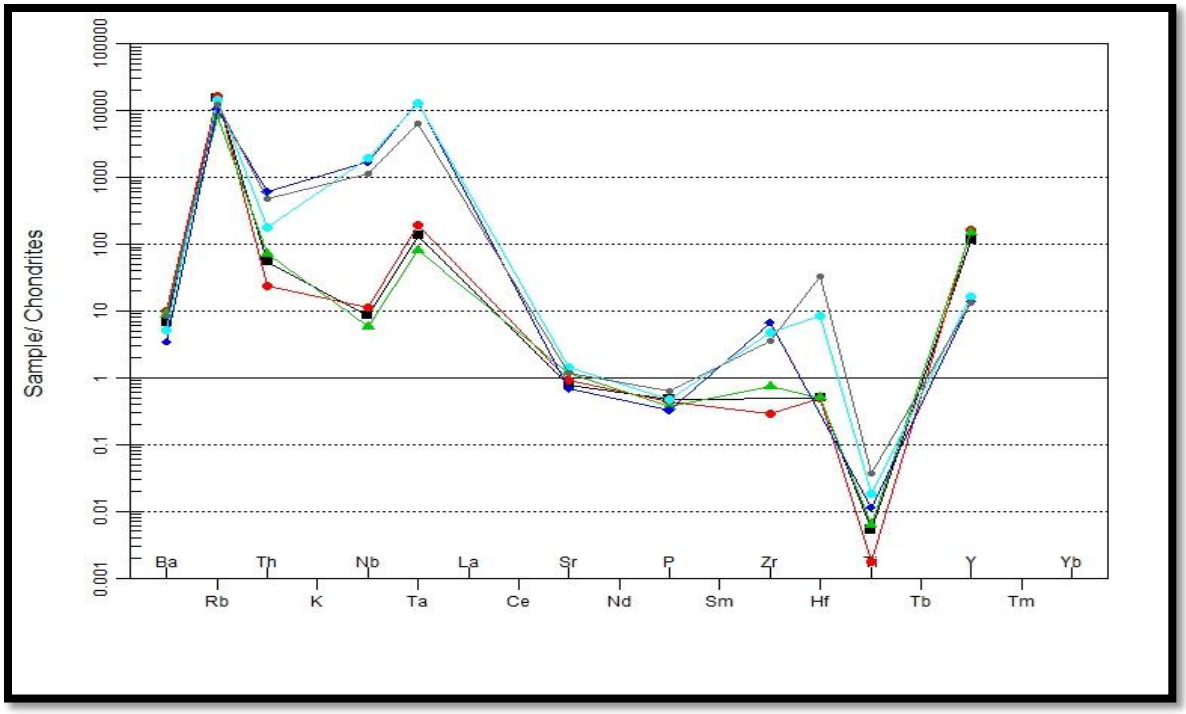



**Figure 4.17: Spider plot for trace elements in the minerals from pegmatites. (Symbols are the same as Figure 4.14**

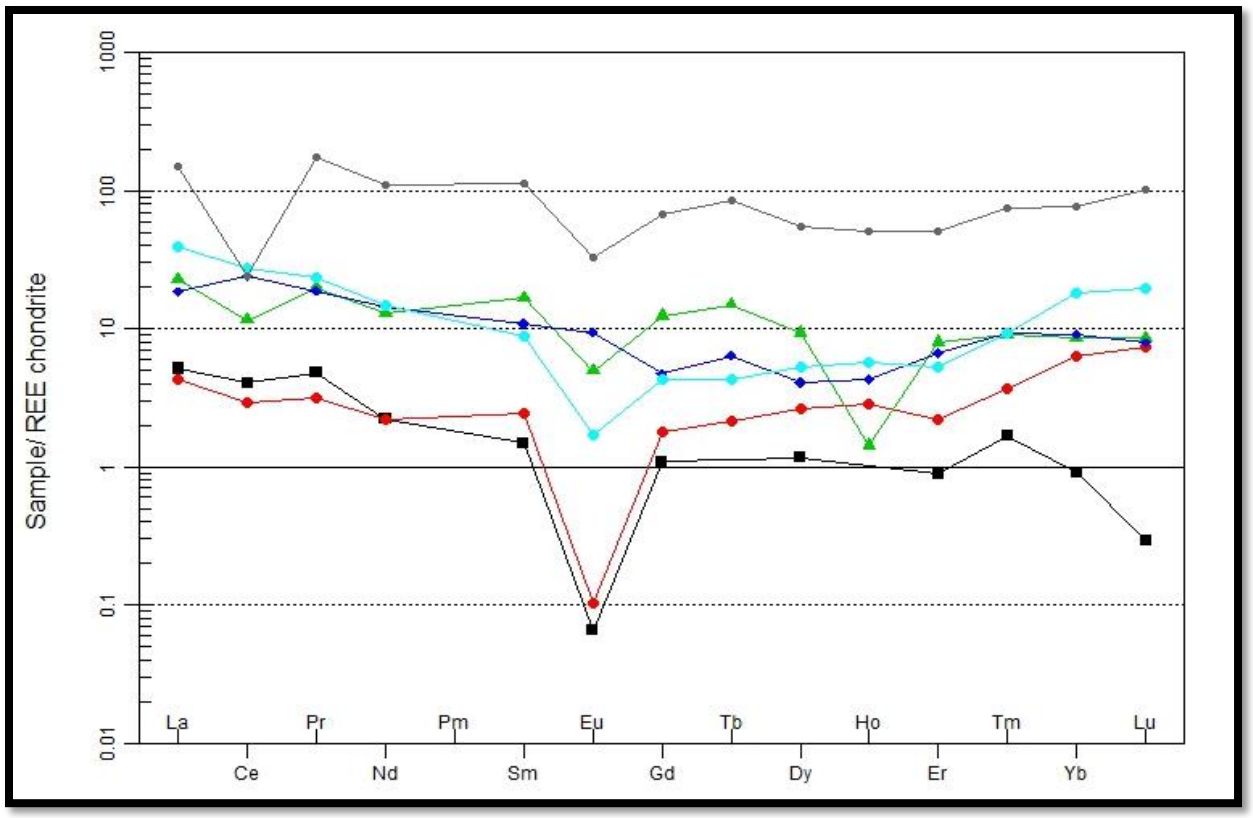



**Figure 4.18: Spider plots of REEs of minerals within the pegmatites of the study area. All the plots are normalized to chondrite values after Nakamura (1974). (Symbols are the same as Figure 4.14)**

# CHAPTER FIVE

# 5.0 DISCUSSION

## 5.1 Introduction

Field relationship, petrography and geochemical characteristics of the major rock unit as well as the mineralization potentials of pegmatites in the study area are discussed in this chapter.

## 5.2 Geologic Evolution of the Study Area

Geological mapping of the Sha area has revealed that the major rock units comprises of coarse grained biotite granite, medium grained biotite granite and fine grained biotite granite. The coarse–medium grained biotite granite is the major lithologic unit hosting the pegmatites. Other minor rocks mapped in the study area include diorite, quartz veins and pegmatites. Petrographic studies have revealed that almost all the rocks are composed of quartz, feldspar, biotite, plagioclase, and apatite and zircon as accessories minerals.

Geochemical study revealed that the granitoids are peraluminous to metaluminous and mainly S-type granite. This suggests that the granitoids probably formed from anatexis of rock of sedimentary origin. The original sedimentary rock probably consists mostly of clay-rich material produced by extensive chemical weathering of continental rocks (Chappell and White 2001). The sources of the fertile granitoids including the pegmatites which host semi-precious stone mineralization were formed.

Geochemical and mineralogical data further revealed relatively high $K_2O$ and $Na_2O$ content in the rocks thus suggesting that the granite suites belong to alkali-calcic peraluminous granite (Eleftheriadis and Koroneor, 2003). Major element composition also shown that the granites are ferroans, (having Iron number (Fe#) which range from 0.86 to 0.98), mainly alkali-

calcic (as shown on the $Na_2O + K_2O$ - CaO Vs $SiO_2$ discrimination diagram (Figure 4.6) Ferroan magmatism is a characteristic feature of the Proterozoic eon. The end products of this magmatism are feldspathic rocks that are extremely enriched in FeO relative to MgO (FeO/(FeO + MgO) > 0.8) (Frost and Frost, 2013).

On Harker diagrams using $SiO_2$ as index of differentiation MgO, CaO, $Al_2O_3$, $Fe_2O_3t$, $TiO_2$, MnO, $K_2O$ and $Na_2O$ are all negatively correlated with $SiO_2$ and did not show well defined trend (Figure 4.7 - 4.10). Fractional crystallization of partial melted rocks played contributing role in the process that led to the formation the of rocks (Hassanen *et al.*, 1996). However the depletion of MgO and CaO with increasing $SiO_2$ content is consistent with plagioclase fractionation (Eleftheriadis and Koroneos, 2003). The decrease in MnO, $TiO_2$ and FeO during magmatic evolution indicates separation of apatite and mafic mineral (such as biotite) during differentiation (Maulana *et al*., 2012).

Early fractionation of accessory was supported by the systematic decreasing trend of MnO and $TiO_2$ along with FeO with increasing $SiO_2$, respectively (Figure. 4.8 and 4.9). There is enrichment of Rb, Cs, Sn, Nb with depletion in Ti, Sr, P in the course of evolution from coarse grained biotite granite to medium grained biotite granite to a fine grained biotite granite. Ti is strongly depleted in all the rocks while Sr, P and Ba which are strongly compatible in granitic system show less depletion. Sr decreases readily during the course of fractional crystallization most probably due to substitution of Rb for K in the feldspar and biotite as fractionation progressed. According to (Janousek *et al.*, 2002), the decrease in Ba with increase in $SiO_2$ also indicate the important role of fractionation, dominated by biotite while depletion of CaO and Sr with increase $SiO_2$ content, and negative Eu anomally is consistent with K-feldspar fractionation because feldspar is the only mineral phase that is known to be able to effectively, simultaneously

and consistently fractionate Eu and Sr from other element (Sun *et al.*, 1974, Niu and Ohara, 2009). Therefore, variations of these lithopile elements in the granite suggest that fractional crystallization was probably responsible for their evolution.

The REE fractionation pattern of granite is characterized by enrichment of both the light (La-Sm) and heavy (Ga-Lu) rare earth elements and a significant negative Eu anomaly. The medium grained biotite granite is however preferentially more enriched in the light REE relative to the diorite. This suggests that the melt from which these rocks were formed equilibrated with the high concentration of zircon which is responsible for the retention HREE (Compton, 1978). Moreover, enrichment in LREE is the hallmark of crustal and alkali calcic rocks in general and the depletion in HREE in diorite are due to their concentration in zircon (O"Nions and Pankhurst, 1974).

### 5.3 Geochemical Features of Minerals Extracted from Pegmatites

The major element data show that the pegmatites are low in $SiO_2$, $Na_2O$, and $K_2O$ content but high in $Al_2O_3$ and $Fe_2O_3$ content compared to values for other mineralized pegmatites in Nigeria (Garba, 2003; Okunlola, 2005; Akintola, 2010; Akintola *et al.*, 2011). However other major element such as MgO, CaO, MnO, $TiO_2$, $P_2O_5$ are comparable. The pegmatites are peraluminous in their bulk composition of (A/CNK >1.1). The pegmatites are moderately fractionated as indicated by their high Rb values (2901 - 5783 ppm) and low K/Rb (13.38 – 44.36).

These trace elements are excellent fractionation indicators and most highly fractionated pegmatites will have high values of these elements. It is believe that the higher their contents, the higher the degree of fractionation and the higher the economic potential of the pegmatites

(Breaks *et al.,* 2003). The values of the elements K and Rb are higher compared to their average continental crust values of Taylor and McLennan (1985). The pegmatites have low K/Rb, K/Cs, Rb/Ba, Rb/Cs, Nb/T, Th/U ratios. This trend most probably indicates progressive fractionation and possible mineralization. It is also believed that these elemental ratios are excellent fractionation indicators and can be used to assess economic potential of pegmatites (Breaks *et al.,* 2003).

Furthermore, pegmatites of the study area are chemically enriched in Rb, Cs and Ta. These pegmatites are however depleted in Ba and Sr thus indicating that they are product of progressive fractionation. Late-stage progressive fractional crystallization leads to enrichment in Rb and a depletion of Ba in these pegmatites. Taylor *et al.,* (1986) had also suggested that where there is a negative Ce anomaly and a negative Eu anomaly as in the case of these pegmatite samples it is an evidence of considerable fractionation and metasomatism.

Similarly, Piper, (1974) and Garba, (2003) believe that negative Ce anomaly of rare metal pegmatite is taken to indicate oxidizing condition during mineralization and interaction between, melt fluids and host rocks sometimes over long distance. The negative Europium (Eu) anomaly, according to Taylor *et al.,* (1986) suggests fractionation and indicates a late metasomatic effect. The negative Ce anomaly observed in the pegmatites may also suggest their rare metal mineralization.

The pegmatites also exhibit negative Ce anomaly which is an indication of the prevailing oxidizing conditions during the formation of the rock and the interaction between magmatic melt-fluids and host rocks over great distances (Garba, 2003).

Geochemical data on the pegmatites have revealed moderately high concentration of Ta with values above global average of low-Ca granite. The enrichment of Ta, Cs in these pegmatites and their association with some peraluminous S-type granite suggest that they have affinities with the LCT pegmatite family which is typically considered to comprise the most highly fractionated part of S-type or peraluminous granitic suites formed during crustal thickening (Černý *et al*., 2012). The low K/Rb ratios of the pegmatites attest to their granitic origin.

The study of trace element distribution in feldspar and biotite is a tool in evaluating the degree of fractionation and evolution of pegmatite (Gordiyenko, 1971; Trueman and ˇCerný 1982; ˇCerný *et al.,* 1985). The importance of composition of K –feldspar and biotite as a clue to internal evolution of pegmatite has been discussed by ˇCerný, (1982). The K/Cs and the K/Rb ratios in K-feldspar and biotite are considered as the indicator of pegmatite evolution (ˇCerný *et al.,* 1985; Joliff *et al*., 1987). These indicators are used in assessment of rare element pegmatite before expensive drilling programs are carried out.

The trace elements composition of the feldspar and biotite extracted from the pegmatites presented in (Table 4.3) were employed in order to classify pegmatites, evaluate their potentials for mineralization, outline the degree of evolution and as well trace their petrogenesis. K-feldspar and biotite in the pegmatites derived from granitic precursor by fractionation and show enrichment in Rb, Nb, Sn, Ta, Zn, W U,Pb Hf and Ga with decrease in Cs, Nb, Zn and Hf in K-Feldspars. The assessment of the mineralization potential and degree of evolution of the pegmatite of Sha area have been based on the K/Rb value and Rb versus K/Rb plot and other fractionation indices. The plots of K/Rb against other fractionation indicators are shown in the (Figures 4.15 and 4.16).

There is a wide scatter of data with a general negative correlation between the two fractionation indicators. Spider diagram (Figure 4.18) of the minerals shows enrichment in Rb, Ta, Nb, Sn W, U and Ga with depletion in Ba, Sr, P, Zr and Ti.

Pegmatite display extreme fractionation and accumulation of lithophile elements beyond the limits observable in granitic rocks. Cs and Rb are incompatibles within silicate and so they partitioned into the melt (London, 1999). The enrichment of these element leads to their precipitation in highly fractionated pegmatite. According to ˇCerný, (1985) main carriers of Cs are K-feldspar and biotite. The moderate / relatively high value of Cs, Ta and Rb, Sn, Nb and Zn in K-feldspar and bioite and the positive correlation between these element in the minerals K-feldspar and biotite suggest that the pegmatite belongs belongs to lithium- cesium- tantalum (LCT) and NYF family of rare element. The degree of fractionation is very important in determining the potential and the types of mineralization with which the granite suites is associated.

The knowledge of the behaviour of rare earth element in aquous solution during hydrothemal fluid-interaction is critical for the intepretation of REE patterns in hydrothermal minerals. Both REE mobility and immobility have been advocated by many workers e.g. Menzies *et al.,* (1979); Muecke *et al.,* (1979); Michard and Albarede,(1986). The REE distribution pattern of pegmatite is controlled by the REE chemistry of its source and crystal-melt equilibria which have taken place during its evolution. The REE pattern has important application in identification of the way in which fractionation of individual minerals occurred during magma evolution. The rare earth element composition of the minerals extracted from the pegmatites of the study area is presented in Table (4.3) and their normalized REE distribution pattern is show in Figure (4.19). The mineral samples have relatively equal enrichment of LREE

and HREE with negative Eu (Eu/Eu* <1) and Lu anomalies. The degree of fractionation of LREE relative to HREE (La/Yb) values is generally low ranges from 0.67 to 5.67.

Evidence from REE geochemistry of Sha granitic rocks and pegmatites revealed that the pegmatites and the granitoids have very similar chemical and mineralogical composition suggesting that they are genetically related to the granites. As noted by Garba (2005), the REE pattern of the pegmatite shows more similarity with Younger Granite than the typical Pan African granitoids. It is characterized by co- enrichment of both LREE and HREE with strong Eu anomally (Garba, 2005). Similarly the REE pattern of the granitoids of Sha is characterized by an enrichment of both LREE and HREE and high Eu anomaly The negative Eu/Eu* anomally in pegmatite suggest that it crystallized at an oxidized environment probably in lower continental crust (Samson and Wood 2005).

Inter-lithophile elements ratios have shown that fractional crystallization is the most plausible model that explains the evolution of pegmatites. For instance, the decrease in K/Rb and increase in Rb/Ba and Rb/Cs from KF3 to KF1 is consistent with fractional crystallization. According to Shearer *et al*., (1985), potassium feldspar (the most dominant minerals in the studied pegmatites) most probably crystallized from a minimum melt (Albite-K-feldspar-Quartz) from the wall zone to the core of the pegmatite. This is further supported by the decrease in Cs and Ho from the wall zone to the intermediate zone. This suggests that fractional crystallization played an important role in the evolution of the pegmatite.

However, fractional crystallization cannot provide any good explanation for the large crystals of feldspars (e.g. the blocky crystals of microcline) that were recorded in the intermediate zones of the pegmatites. According to London (2008), P and B (fluxes) among other functions play a vital role in suppressing successful nucleation of some crystals (minerals). Inhibited nucleation

of crystals reduces the number of competing crystals, which makes the development of relatively few but gigantic crystals that comprise most pegmatites possible.

Although the proportion of fluxes in the pegmatites is rather small to warrant any significant role in suppressing crystal nucleation which led to the developments of the gigantic crystals, London (1999, 2005, 2008) is of the opinion that accumulation of such fluxing components in a boundary layer of liquid along crystal growth front can provide a means of reconciling the low concentrations of fluxing components in pegmatites with their important role in promoting the growth of giant crystals. Hence fractional crystallization of a flux-bearing rather than flux-rich granitic melt is the most "preferred" model for evolution of Sha pegmatite since this accounts for both the mineralization zonation and the occurrence of some gigantic crystals observed in the pegmatites.

### 5.4 Gemstones Mineralization in the Pegmatites

Gem minerals in particular topaz occurs in pockets within the pegmatites in the study area. Artisanal miners working in the area have learned that each pegmatite is unique with its own set of pocket indicators. It is also the general belief that despite careful attention to these clues, the location of productive gem pockets is still largely a matter of luck and hardwork. Certain mineralogical aspects such as presence of biotite and muscovite are indicators of the presence of pocket bearing pegmatite. The change in mineralogy either as distinct mineral species or chemical changes within a specific crystal may indicate close proximity or presence of economically important cavity of gem minerals.

# CHAPTER SIX

## 6.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

### 6.1 Summary

The study area is part of the north-central Younger Granite complex of Nigeria. The rock mapped in the area includes coarse grained biotite granite, medium grained biotite granite, fine grained biotite granite and diorite. The structural features in the area such as joint veins and dykes have N-S, NE-SW, and NW-SW trend direction.

Geochemical plots of A/NK versus A/CNK show that all the rocks with the exception of medium grained biotite granite have A/CNK above unity and accordingly are classified as peraluminous nature. In general therefore, the investigated rocks are peraluminous to slightly metaluminous in terms of bulk chemistry. The plot of K/Rb ratio, REE chemistry and the gradual increase in Rb, Nb, Cs, Sn, K,Ga,W indicate that fractional crystallization lead to late stage concentration of rare metals. The high Nb, Sn, Cs, Ta Y values in the K-Feldspar and biotite suggest that the pegmatites belong to both NYF and LCT families.

The contents of Rb, Cs, F, Sn, Ta, Nb, and B placed the pegmatites in albite, lepidolite subclass as proposed by ˇCerný and Ercit (2005). The pegmatites are highly fractionated and enriched in rare metal as well gem minerals. The rare metal and the gem mineralizations are comparable to other mineralized pegmatite in Nigeria and from different parts of the world.

Based on the element variation observed from the granites to pegmatites, it is obvious that magmatic and post magmatic differentiation processes were involved in their formation. In light of the available geochemical evidence, it appears that fractional crystallization in combination with varying degree of wall rock assimilation is the dominant process in operation during the

differentiation of the magma. It is therefore proposed that the pegmatites in Sha area are the product of extended fractional crystallization of granitic magma that was contaminated by the country rock and other external fluids.

**6.2 Conclusion**

The study area comprises of granitoid rocks. The granite suites vary in texture and composition and comprise of coarse grained biotite granite, medium grained biotite granite, fine grained biotite granite and diorite. Pegmatites have been mapped which occurred in form dyke vein and knot dorminantly trending in NE-SW direction. Petrographic studies revealed that; quartz, plagioclase, orthoclase, microcline and biotite constitute the major minerals in the rocks, while apatite and zircon occur as the accessory minerals presentin the rocks.

Geochemical studies show that the granite suites in the study area are peraluminous to slightly metaluminous. In addition, the granite suites are ferroan, alkali-calcic in composition and were emplaced in a syn to post tectonic collisional setting. It is believed that the granite suites formed from partial melting of crustal igneous rocks. Based on the value of K/Rb, Cs/Rb, REE distribution pattern and other geochemical indicators, there is a clear co-genetic relationship between the granites and pegmatite. The pegmatite can be considered to be moderately mineralized in gem stones especially topaz, when compared to others from other part of the country

The high Nb, Y, Cs,Ta content of the K-feldspar and biotite suggests that the pegmatites in Sha area belongs to the NYF and LCT family of the rare element class and the content of Rb, Sn, Ta, Nb in the pegmatite places the group under albite, lepidolite sub-class as proposed by ˇCerný and Ercit (2005). Biotite is good geochemical monitors using trace element such as Li,

Rb, Ta, Sn, and their ratio to evaluate the rare metal mineralization potential of pegmatites. Topaz from study area were primary deposit that have been weathered and eroded and then buried under ground, transported by erosion as alluvial and eluvial form, their presence is indicated by crystallized melt inclusion entrapped in some topaz. Topaz may also form during the greisenization process arising from the interaction of high temperature acidic silica and fluorine-rich hydrothermal fluid with the aluminium leached from feldspar in the granitic rocks to produce the gem mineral topaz.

### 6.3 Recommendations

There should be detailed evaluation of economic potential of the entire pegmatites in the study area as more commonly; each group caries several economic mineral. It is recommended here that exploitation of minerals should be based on bulk mining production of all primary minerals without any unnecessary wastage in view of a growing demand for these minerals eg. Feldspar in ceramic and glass industries, mica in the cosmetic industry and rare-metals. Further this is to discourage the selective mining method that lead to unstable and unsafe for working condition

The conclusion drawn from this work regarding the mineralization potential of pegmatites is based on the study of trace elements composition of the K-feldspar and biotite extracted from the pegmatites. It is therefore recommended that more detailed studies of the trace elements composition of muscuvite in the pegmatites should be carried out to confirm some of the observation made in this work. Isotopic studies should also be carried out in order to propose the petrogenetic model.

The scope of certain mining in Nigeria is still limited by the inadequate knowledge on the available resources and the capacity of the local market. These therefore, call for proactive approach that would engender value addition by way of providing relevant minerals assessment data which make the business more attractive to foreign investors and export market.

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