PETROGENETIC STUDY OF THE TALC MINERALIZATION IN KAGARA AREA (SHEET 142 SE AND PART OF SHEET 142 SW) NORTH CENTRAL, NIGERIA

BY

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DECLARATION

I declare that the work in this thesis entitled ‘‘**PETROGENETIC STUDY OF THE TALC MINERALIZATION IN KAGARA AREA (SHEET 142 SE AND PART OF SHEET 142 SW) NORTH CENTRAL, NIGERIA**’’ was carried out by me in the Department of Geology, Faculty of Physical Science, Ahmadu Bello University, Zaria, Nigeria. The information derived from the literature has been dully acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

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CERTIFICATION

This thesis entitled **''PETROGENETIC STUDY OF THE TALC MINERALIZATION IN KAGARA AREA (SHEET 142 SE AND PART OF SHEET 142 SW) NORTH CENTRAL, NIGERIA''** by Akintola Ojo Adeoye meets the regulations governing the award of the award of the degree of Masters of Science in Geology of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to Almighty God, the Ominipresent, the Beneficient, the most merciful for His endless guardian and protection, who has given me the will and the wisdom to write, strength to endure and the courage to face all challenges and to all who have contributed to my success.

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ABBREVIATIONS AND SYMBOLS

et al	- - - - -	and others
M	- - - - -	metre
Cm	- - - - -	centimetre
Km	- - - - -	kilometre
Mm	- - - - -	millimetre
N	- - - - -	north
NE	- - - - -	north-east
NW	- - - - -	north-west
<	- - - - -	less than
%	- - - - -	percentage
Σ	- - - - -	summation
Ma	- - - - -	million years ago

Abstract

The study area is part of the Kushaka schist belt of the Northern Nigeria Basement Complex. It lies within latitudes 10° 00′N and 10°15′N and longitudes 6°10′E and 6°30′E, Sheet 142 SE and part of Sheet 142 SW.

The major rock units in the area are migmatitic gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolite, talcose rock, phyllite, granodiorite, porphyritic granite, fine-medium grained granite, and pegmatite. Petrographical studies revealed that quartz, microcline, plagioclase and biotite constitute the major minerals present in the migmatitic gneiss, porphyritic granite, fine-medium grained granite, meta- arkosic rocks and pegmatite with epidote as the dominant accessory mineral. The talcose rock contains in addition to talc, appreciable amount of chlorite, magnesite, anthophyillte with magnesite and quartz forming the accessory minerals. X-Ray Diffraction of the talcose rock also revealed talc as major mineral. Other constituent minerals of the talcose rock are chlorite, tremolite, actonilite, magnesite, and magnetite while spinel and quartz are the accessory minerals.

Geochemical characterization of the talcose rock shows SiO_2 (28.63-34.99) wt %, MgO (29.21- 35.13) wt %, Fe_2O_3 (6.36 - 13.20) wt %, and variable proportion of CaO (0.02-0.18) wt % and Al_2O_3 (0.58-13.20) wt % are characteristic of the rock. The talcose rock also shows negative Eu anomaly and therefore paucity of plagioclase. High Ni (210-1850 ppm), Co (82-91 ppm), and Cr (170-1930 ppm) values indicate that the talcose rock was derived from an ultramafic protolith which has undergone moderate degree of metamorphism.

KEYWORD: Talc, petrogenesis, mineralization, protoliths, Kagara, North central Nigeria.

TABLE OF CONTENTS

Title Page - - - - - - - - - - i

Declaration - - - - - - - - - - ii

Certification - - - - - - - - - - iii

Dedication - - - - - -- - - - - iv

Acknowledgements - - - - - - - - - v

Abbreviations and Symbols - - - - - - - - viii

Abstract - - - - - - - - - ix

Table of contents - - - - - - - - - x

List of Figures - - - - - - - - - xiv

List of Tables - - - - - - - - - - xvi

List of Plates - - - - - - - - - xvii

List of Appendixes - - - - - - - - - - xix

CHAPTER ONE: INTRODUCTION

1.1 General Introduction - - - - - - - 1

1.2 Location and accessibility - - - - - - - 7

1.3 Relief and Drainage - - - - - - - 8

1.4 Climate and Vegetation - - - - - - - 10

1.5 People, Settlement and land use - - - - - - 10

1.6 Previous work - - - - - - - 11

1.7 Statement of the problem - - - - - - - 12

1.8 Justification - - - - - - - 12

1.9 Aim and Objectives - - - - - - - 13

1.10 Scope of present work - - - - - - - 14

CHAPTER TWO: LITERATURE REVIEW

2.1 Regional Geological Setting - - - - - - 15

2.2 The Nigerian Basement Complex - - - - - - 15

2.2.1 The Migmatite - Gneiss – Complex- - - - - - 17

2.2.2 The Younger Metasediments (Schist Belts) - - - - 17

2.2.3 The Older Granites - - - - - - 19

2.2.4 The Younger Granites - - - - - - 20

2.2.5 Tertiary– Recent Volcanics - - - - - - 22

2.2.6 Talc Deposits in Nigeria and their characteristics - - - - 22

2.2.7 Industrial Specifications of Talc - - - - - - 24

CHAPTER THREE: METHODOLOGY

3.1. Methodology - - - - - - - - 25

3.2.0 Remote Sensing Techniques - - - - - - 25

3.2.1 Band Rationing - - - - - - 26

3.2.2 Crosta Technique - - - - - - 26

3.2.3 Principal Component Analysis (PCA) - - - - - 26

3.3. Field Investigation - - - - - - - 26

3.4. Laboratory Work - - - - - - - 27

3.4.1 Thin section preparation and analysis - - - - - - 28

3.4.2 X-Ray Diffraction analysis - - - - - - - 29

3.5.0 Geochemical analysis - - - - - - - 29

3.6 Data handling and interpretation of results - - - - - 30

CHAPTER FOUR: RESULTS

4.1. Remote Sensing - - - - - - - 31

4.1.1 Band Rationing - - - - - - - 31

4.1.2 Principal Component Analysis (PCA)- - - - - - 35

4.1.3 Crosta technique and Ls- Fit Technique - - - - 38

4.1.4 Threshold Values- - - - - - - - - 40

4.2 Geology of the Study Area - - - - - - - 42

4.3. Petrography of the rock units - - - - - - - 45

4.4 X-Ray Diffraction Analysis - - - - - - - 59

4.5.0 Structures - - - - - - - 60

4.5.1 Foliations - - - - - - - 60

4.5.2 Lineations - - - - - - - 60

4.5.3 Joints - - - - - - - 61

4.5.4 Faults - - - - - - - 62

4.5.6 Lineaments - - - - - - - 63

4.6.0 Metamorphisms and tectonic activity in the study area - - - 69

4.7.0 Geochemistry - - - - - - - - 73

4.7.1 Major Elements composition - - - - - - - 73

4.7.2 Trace Elements composition - - - - - - - 81

4.7.3 Rare Earth elements composition - - - - - - 84

CHAPTER FIVE: **DISCUSSION**

5.1 Remote Sensing - - - - - - - - 91

5.2 Geology of the study area - - - - - - - 92

5.3 Mineralogy of talcose rock from Kagara - - - - - 94

5.3.1 Mineral paragenesis of talcose rock from Kagara - - - 95

5.3.2 Mineralization process and deposition of talcose rock in the study area - 97

5.4 Structures - - - - - - - - 99

5.5 Geochemistry - - - - - - - - - -

101

5.6.0 Petrogenesis - - - - - - - 108

5.7 Mining, Processing and Economic Geology - - - - 113

CHAPTER SIX: **CONCLUSIONS AND RECOMMMENDATIONS**

6.1 Conclusions - - - - -- - - - 116

6.2 Recommendations - - - - - - - 118

6.3 Contributions of the work to knowledge - - - - 118

References - - - - - - - - 120

Appendices - - - - - - - - 134

LIST OF FIGURES

Figure 1.1 Various processes leading to talc formation. Sources: Abeysinghe (1996); Kehinde - Philips and Gerd (1995) - - - - - 3

Figure 1.2 The Structural similarities of talc and chlorite after Luzenac, (2009)- 3

Figure1.3 Major World Producers of Talc, (1994 – 2008) Source: Industrial Minerals (2009); O'Driscoll (2008); Virta (2009) - - - - 5

Figure 1.4 A triangular classification of world producer of talc with composition (Luzanec, 2007) - - - - - - - 5

Figure 1.5 Major African producers of Talc (1994 – 2008) Source: Industrial Minerals (2009); O'Driscoll, (2008); Virta (2009) - - - - 6

Figure 1.6 Major uses of Talc, from (1975 – 2007); Source: Industrial Minerals (2009); O'Driscoll (2008); Virta (2009) - - - - 7

Figure 1.7 The application of talc as raw materials in industries by (Roe, 1975); Piniazkiewicz *et al;* 1994b; Luzanec 2010). - - - 7

Figure 1.8 Location Map of the study area - - - - - 9

Figure 2.1 Generalized geological map of Nigeria within the framework of the geology of West–Africa (Adapted from Wright, 1985) - - - 16

Figure 2.2 Generalized geological map of Nigerian- Dahomeyan subregion: The Migmatite Gneiss complex (mgc); Schist Belts, Older Granites (og), (After Woakes *et al.,* 1987) - - - - - - 19

Figure 4.1 Band 5/7 image displaying clay minerals alteration as light tone - 32

Figure 4.2 Band 5/4 image displaying ferric iron alteration as light tone - 33

Figure 4.3 Band 3/1 image displaying ferrous iron alteration as light tone - 34

Figure 4.4 False colour composite from principal component analysis of residue image **7:**4:1 displaying areas of high alterations as blue.- - - - 36

Figure 4.5 False colour composite of band ratio 5/7, 5/1, 3/1 image - - 37

Figure 4.6 Crosta technique of principal component analysis displaying area -- 39

Figure 4.7 Threshold image of Principal component analysis for lithological discrimination of the study area - - - - - - 41

Figure 4.8 Detailed geological map of the study area - - - - 44

Figure 4.9 Lineaments Map of the study area - - - - 64

Figure 4.10 Rose diagram for the Lineaments of the study area- - - - 65

Figure 4.11 Rose diagram for the structural trend of joints- - - - 67

Figure 4.12 Rose diagram for the structural trend of foliation - - - 68

Figure 4.13 Harkers varaition diagrams of the study area - - - 76

Figure 4.14 chemical classifications of the granitic rocks in the study using the molecular ration of alumina to alkalis after the (Shand, 1943) - - - 77

Figure 4.15 Chemical classfication of granitic rocks (plutonic) in the study area adapting the total alkali versus silica (TAS) of Cox et al., (1979) - - 78

Figure 4.16 The SiO versus K_2O diagram (after Perccerrillo and Taylor 1976) - 79

Figure 4.17 Iron Index discrimination diagram of the granitic rocks after Frost *et al., 2001)* - - - - - - - - - 80

Figure 4.18 Variation of Al_2O_3 with (FeO/(FeO + MgO) w / % ratio in talcose rock (after Naldrett and Cabri, 1976). - - - - - 80

Figure 4.19 Classification of volcanic rocks after Jensen (1976) - - - 81

Figure 4.20 Spider diagram of trace elements from the study area plots are normalized to the average crustal value (after Weaver and Tarney, (1984) - - 83

Figure 4.21 Rb versus Y+Nb, and Rb versus Ta+Yb, discrimination diagrams for granitic rocks in the area (after Pearce *et al.*,1984)- . - - - 84

Figure 4.22 Rare earth elements distribution pattern of the rock from the study area normalized to the average crust. Normalizing value are those of Nakamura, (1974) - - - - - - - -. 87

Figure 4.23 Spider diagram for whole rock samples from Kagara area. Normalizing value are those of McDonough and Sun (1995).- - - - - 89

Figure 4.24 The distribution pattern of REE in amphibolites and talcose rock Normalizing value are those of Nakamura, 1974)- - - - - - 89

Figure 4.25 The distribution pattern of REE in phyllite and talcose rock (Normalizing value are those of Nakamura, 1974 - - - - - 90

Figure 4.26 The distribution pattern of REE in phyllite and ampihbolite (Normalizing value are those of Nakamura, 1974). - - - - - 90

Figure 4.27 Temperature gradient of the talc from Finland - - - 99

Figure 4.28 Chondrite- normalized REE patterns of the talcose rocks in comparison with data from typical ultramafic rocks of komatiitic affinity - - - 108

LIST OF TABLES

Table 1.1 Physical Properties of Talcs (Rayner and Brown, 2004)- - - 4

Table 2.1 Summary of occurrences of talc in various locations in Nigeria - 23

Table 2.2 Talc properties for specific market (Ogunbanjo and Amoka, 2005) - 24

Table 4.1 Principal component analysis (PCA) of bands 1/4; 5/7 - - 38

Table 4.2 Principal component analysis (PCA) of bands 1/3; 4/7 - - 38

Table 4.3 Threshold values and basic statistics- - - - - 40

Table 4.4 Modal composition of talcose rock and host rocks - - - 58

Table 4.5 Composition of the Samples from the XRD Analysis - - 59

Table 4.6 Eigen vectors and Eigen values of the PCA of the Landsat ETM data- 66

Table 4.7 Sequencical order of events in rocks types from the study area- - 72

Table 4.8 Major Elements composition of major rocks in the study area - 75

Table 4.9 Fe- number in granitic rocks - - - - - 79

Table 4.10 Trace Elements composition of major rock types in the study area - 82

Table 4.11 Rare Earth Elements composition of major rock types in the study area - 86

Table 4.12 The REE chondrite – normalised value of talcose rock from Kagara and the host rocks (chondrite values obtained from Nakamura, (1974) - 88

Table 5.1 Comparison of mineralogical compositions of talcose rock from Kagara area with similar talcs from other locations - - - - 96

Table 5.2 Mineral paragenesis of talcose rock from Kagara and host rocks - 96

Table 5.3. Chemical composition of talcose rock from Kagara area compared with some commercial talcs -- - - - - - 102

Table 5.4 Trace elements data of talcose rock from Kagara and data from typical examples of ultralmafic rocks of komatiitic affinity (ppm) - - 106

Table 5.5 Rare earth elements data of talcose rock from Kagara and data from typical examples of ultramafic rocks of komatiitic affinity (ppm) - - - - 107

Table 5.6 Summary of Industrial specification for Talc **(**Harben, 1995) - 115

LIST OF PLATES

Plate I Photomicrograph of migmatite gneiss under (a) plane polarized light (PPL) and (b crossed polarized light (XPL) - - - - - 46

Plate I1 Photomicrograph of banded gneiss under (a) plane polarized light (PPL) and Crossed polarized light (XPL)- - - - - - 47

Plate 1II Photomicrograph of granitic gneiss under (a) plane polarized light (PPL) and (b) crossed polarized light (XPL) - - - - - 48

Plate IV Photomicrograph of Meta arkosic rock under PPL (a) and XPL (b) - 49

Plate V Photomicrograph of amphibolites from Teri in (a) plane polarized light (PPL) and (b) crossed polarized light (XPL) - - - - 49

Plate VI Photographs of talcose showing (a) lenticular shape (b) dark green variety (c and d) pods of talc within a talcose rock, (e) general appearance on the field with vein plunging NE direction, (f) octahedral crystals of Magnetite in talcose rock from Kagara area - - - - - 51

Plate VII Photomicrograph of talcose rock in (a) plane polarized light (PPL) and (b) crossed polarized light (XPL); (A) = Anthophyllite; (C) = Chlorite, (M)=Magnetite;Ac= Actinolite - - - - - 52

Plate VIII Photomicrograph of talcose rock in (a) plane polarized light (PPL) and (b) crossed polarized light (XPL); (A) = Anthophyllite; (C) = Chlorite, (M)= Magnetite, Ac= Actinolite - - - - - - 52

Plate IX Photograph of phyllite at Gora displaying the cleavages along the bedding plane - - - - - - -- - - 53

Plate X Photomicrograph of phyllite under (a) plane polarized light (PPL) and (b) crossed polarized light (XPL) - - - - - - 54

Plate XI Photomicrograph of porphyritic granite under (a) plane polarized light (PPL) and (b) Crossed polarized light (XPL) - - - - 56

Plate XII Photomicrograph of Fine-medium-grained granite under (a) plane polarized light (PPL) and (b) crossed polarized light (XPL) - - - 56

Plate XIII Photomicrograph of granodiorite under (a) plane polarized light (PPL) and (b)
crossed polarized light (XPL) - - - - - - 56

Plate XIV Pegmatite vein trend N-S 6 cm long with 3 cm width North of Gora-
- - - - - - - - - - - - 57

Plate XV Photomicrograph of pegmatites from Gora area - - - 58

Plate XVI A Foliation on banded gnesis North of Gora-- - - - 60

Plate XVII Photograph of lineations in migmatite around Madaka - - 61

Plate XVIII Photograph of joints in (a) granite displaying crosscutting relationship South of Tegina- Ogu (b) Conjugate joints North of Supana (c) Joints running parallel to Pegmatite intrusions south of Dawaki, (d) Joint run parallel to foliations North of Ogu - - - - - - - - - -61

Plate XIX Photograph of a normal fault that observed in the amphibolite - 63

Plate XX photograph of amphibolite displaying stratified and deformation - 71

Plate XXI A Recumbent fold in amphibolite sequence with pegmatitic material along the nose of the fold North of Gumna - - - - 71

Plate XXI1 Photograph of the contact between talcose rock and amphibolites South of Kumunu,a few Km to Tegina (Latitude 10^0 13’57’’N and Longitude 006^0 17’56’’E)- - - - - - - - - 71

LIST OF APPENDICES

Appendix1 Lineament trends of the structures from Kagara area - - - - - - - - - - - - - -134

Appendix 1I X-ray diffraction (XRD) patterns for amphibolite - - -- - - - - - - - - - - 135

Appendix 111 X-ray diffraction (XRD) patterns for amphibolite - - -- - - - - - - - - - - 136

Appendix 1V X-ray diffraction (XRD) patterns for talcose rock - - - - - - - - - - - - - -137

Appendix V X-ray diffraction (XRD) patterns for talcose rock - - - - - - - - - - - -138

CHAPTER ONE

INTRODUCTION

1.1 GENERAL INTRODUCTION.

The study area is bounded by latitudes 10° 00′N and 10°15′N and longitudes 6°10′E and 6°30′E. It is a part of the basement complex of Nigeria and it is located towards the central part of the N-S trending Kushaka Schist belts.

The Kushaka belt occupies a belt of about 50 Km wide and stretches from Minna area up to Tsohon Birnin Gwari area in northwestern Nigeria. The rocks in this area for the most part occur as well-defined group of ridges whose patterns are predominantly elongated north-southwards (Ajibade *et al.,* 1979; Ajibade, 1980; Ajibade, 1982; Ajibade *et al.,* 1987; Ajibade and Wright, 1989). The distribution of ultramafic rocks within the Kushaka schist belt is generally uneven (Truswell and Cope, 1963).

The occurrences of talc in ultramafic rocks in Kagara area of the Kushaka schist belt have previously been reported (Truswell and Cope, 1963; Elueze, 1982; MSMD, 1997; RMRDC, 2010; Ogunbanjo and Amoka, 2005, 2006). None of these studies on the deposits (conducted prior to this research) contain information on the origin of the talcose rock. The talcose rock from Kagara area is the largest in Nigeria and has been the source of supply of high quality talc since the late 1970s when its exploitation commenced (Durotoye and Ige, 1991).

Talc is a hydrated silicate of magnesium $Mg_3Si_4O_{10}$ $(OH)_2$, (31.89% MgO, 63.36% SiO_2, 4.75% H_2O). It is an alteration product of original or secondary magnesian minerals or rocks resulting from mild hydrothermal processess, aided by simple dynamic metamorphism but never from weathering (Moine *et al.,* 1989, Huston *et al.,* 1993, Hecht *et al.,* 1999).

Minerals commonly associated with talc are serpentine ($3MgO.2SiO_2.2H_2O$), chlorite (MgO.FeO. $Al_2O_3.3SiO_2.4H_2O$), quartz (SiO_2), Scheelite ($CaWO_4$) Calcite $Ca(CO_2)_3$.

anthophllite ($7MgO.7FeO.16SiO_2.2H_2O$), pholopite ($5MgO.8SiO_2$), tremolite ($5MgO.2CaO.8SiO_2.H_2O$), diopside ($MgO.CaO.2SiO_2$), magnesite ($MgO.CO_2$), dolomite ($MgO.CaO.2CO_2$), Enstatite ($5MgSiO_3$ tourmaline ($Na_2O.6MgO.6Al_2O_3$), $Na_2O.6MgO.6Al_2O_3.3B_2O3.12SiO_2.4H_2O$), Garnet($Ca_3Al_2Si_3O_{12}$), muscovite ($MgO.K_2O.2Al_2O_3.6SiO_2.2H_2O$), pyrophillite ($Al_2O_3.4SiO_2.3H_2O$), Actinolite ($Ca_2Fe_5(Si_8O_{22})(OH)_2$ among others depending on the rocks from which the talc is derived (Devore, 1973; Piniazkiewicz *et al.,* 1994a, McCarthy, 1998).

Talc deposits are generally classified according to origin and mode of occurrence as ultramafic, mafic, metasedimentary or metamorphic. Talc occurrences have been categorized according to their different lithologies in many different geological environments worldwide. These environments include retrograde metamorphism and metasomatism of Si-rich dolomites (Moine *et al.,* 1989; Anderson *et al.,* 1990; Schandl *et al.,* 2002), ultramafic associations (Naldrett, 1966; Linder *et al.,* 1992), hydrothermal systems (Huston *et al.,* 1993; Hecht *et al.,* 1999), progressive metamorphism of Mg-rich silicates and supergene formations in lateritic rocks (Noack *et al.,* 1986). Figure (1.1) shows the various processes leading to formation of talc which depends essentially on the nature of the parent rock that undergoes transformation**.**

Talc deposits may also be classified according to the parent rock as magnesium carbonates, serpentines, alumina - silicate, or magnesium sedimentary (Hecht, et al., 1999). Each of these types of talc deposit yields variety of ores that differ in mineralogical composition colour, and crystalline structure (compact or platy).

TALC FORMATION

Talc may be formed by one of the following processes:

(i) from any magnesian amphibole or pyroxene acted on by CO_2 and H_2O:

$4MgSiO_3 + CO_2 + H_2O \longrightarrow Mg_3Si_4O_{10}(OH)_2 + MgCO_3$ …(i)

Enstatite + carbonic acid + vapour ——> talc + magnesite

(ii) Conversion of serpentine to talc by the addition of carbon(iv) oxide:

$2Mg_2SiO_4 + CO_2 + H_2O \longrightarrow 2Mg_3OSi_2O_5(OH)_4 + MgCO_3$. ……..(ii)

Forsterite + carbonic acid +vapour —> serpentine + magnesite

(iii)From carbonate-hosted talc deposits:

$3CaMg(CO_3) + 4SiO_2 + H_2O \longrightarrow Mg_3Si_4O_{10}(OH)_2 + 3CaCO_3 + 3CO_2$… …….(iii)

Dolomite + silica + vapour——> talc + marble + carbonic acid

(iv)In sedimentary-hosted magnesite deposits:

$MgCO_3 + 4SiO_2 + H_2O \longrightarrow Mg_3Si_4O_{10}(OH)_2 + 3CO_2$… ……..……..(iv)

Magnesite + silica + vapour——> talc + carbonic acid

Figure 1.1: Various processes leading to talc formation. Sources: Abeysinghe (1996); Kehinde - Philips and Gerd, (1995).

These three parameters, in turn, govern the specific nature of each commercial talc grade as well as its industrial application (Figure 1.2).

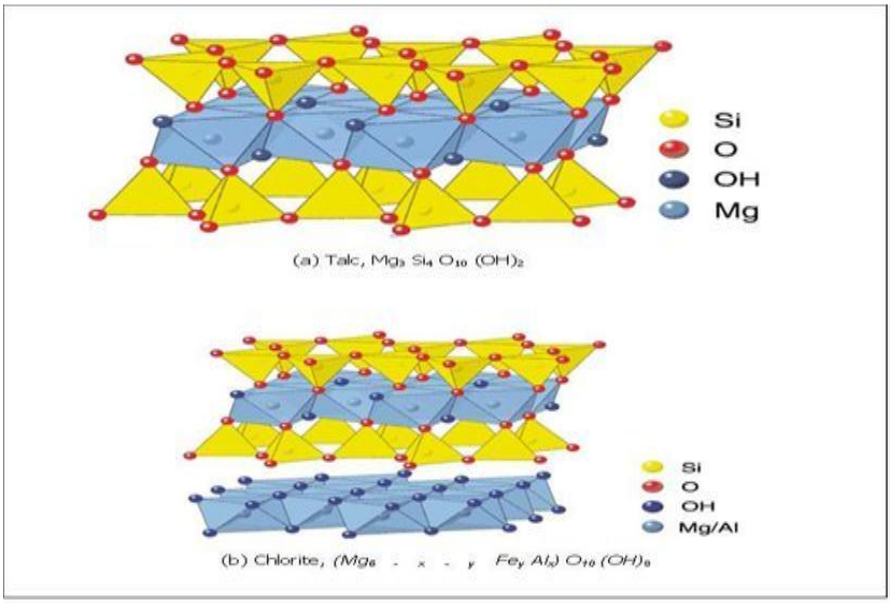


Figure 1.2: The structural similarities of talc and chlorite after Luzenac, (2009).

Any theory about the origin of talc and the possibility of finding them anywhere must take into cognizance their characteristics. The variations in optical properties shown by talc specimens may result from small amounts of substituents such as Ti, Mn, Al etc. or from adsorbed water. The details of physical properties of talcs are presented in Table (1.1).

The leading world producers of talcs are China, United States, Brazil, and India Figures 1.3 and 1.4 while major Africa producers are presented in (Figure 1.5). The low production from African countries has been attributed to the relatively small domestic market (RMRDC, 1992; Consulate General of Nigeria, 2007).

Table (1.1) Physical Properties of Talcs (Rayner and Brown, 2004).

Chemistry	Magnesium Silicate Hydroxide $Mg_3Si_4O_{10}(OH)_2$
Class	Silicates
Sub-Class	Phyllosilicates
Group	Clays and sometimes Montmorillonite/ Smectite Group
Colour	Green, gray, silver, and white are the most common colours
Luster	Dull to a greasy pearl
Crystal System	Monoclinic; 2/m
Transparency	Masses of talc are usually opaque; while crystals are translucent
Cleavage	Basal, or perfect in one direction
Fracture	Uneven to lamellae
Hardness	1 on Mohn's hardness scale
Specific Gravity	2.7 to 2.8; this is considered around average
Field Indicators	Colour, softness, soapy feel, cleavage, and luster

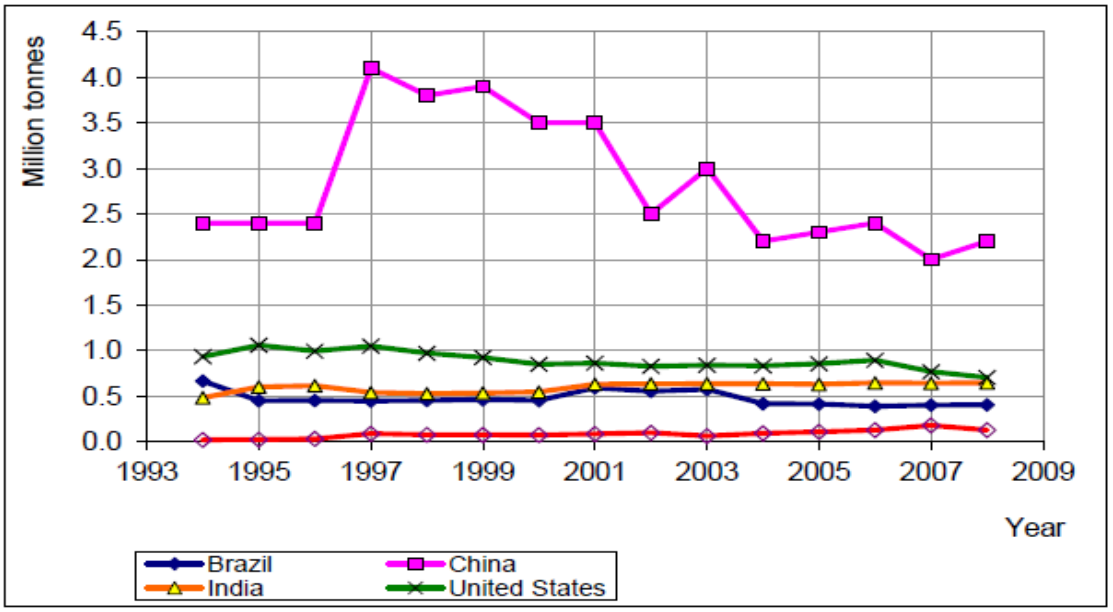


Figure 1.3: Major World Producers of Talc, (1994 – 2008) Source: Industrial Minerals (2009); O'Driscoll (2008); Virta (2009)

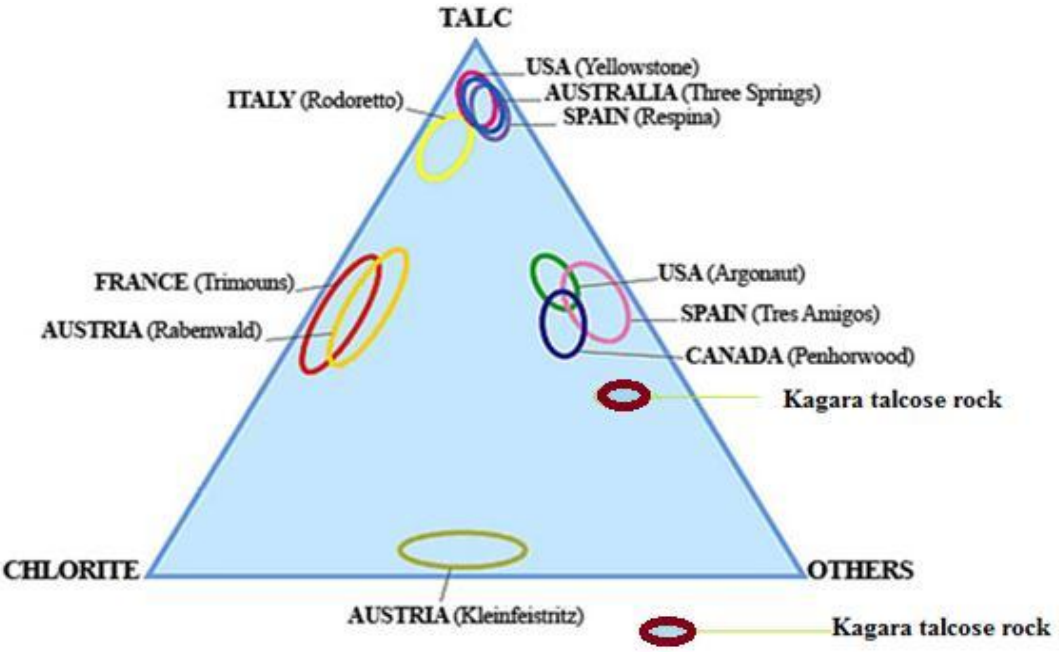


Figure 1.4: A triangular classification of world producer of talc with composition (Modified after Luzanec, 2007).

Talc is one of the most important industrial minerals. It is the most common mineral for daily use in cosmetics as body and face powder. It is a versatile mineral having very wide range of other industrial applications. The numerous uses of talc include pharmaceuticals, paper, paint, ceramics, rubber, and roofing (Bates, 1969; Jensen and Bateman, 1981; Gribble, 1991).

Estimated reserve in several states in Nigeria which are considered as being capable of sustaining a virile talc industry in the country to satisfy local and export demands is put at 837 538 million metric tons (RMRDC 1989; Aliyu and Aluko, 1996).

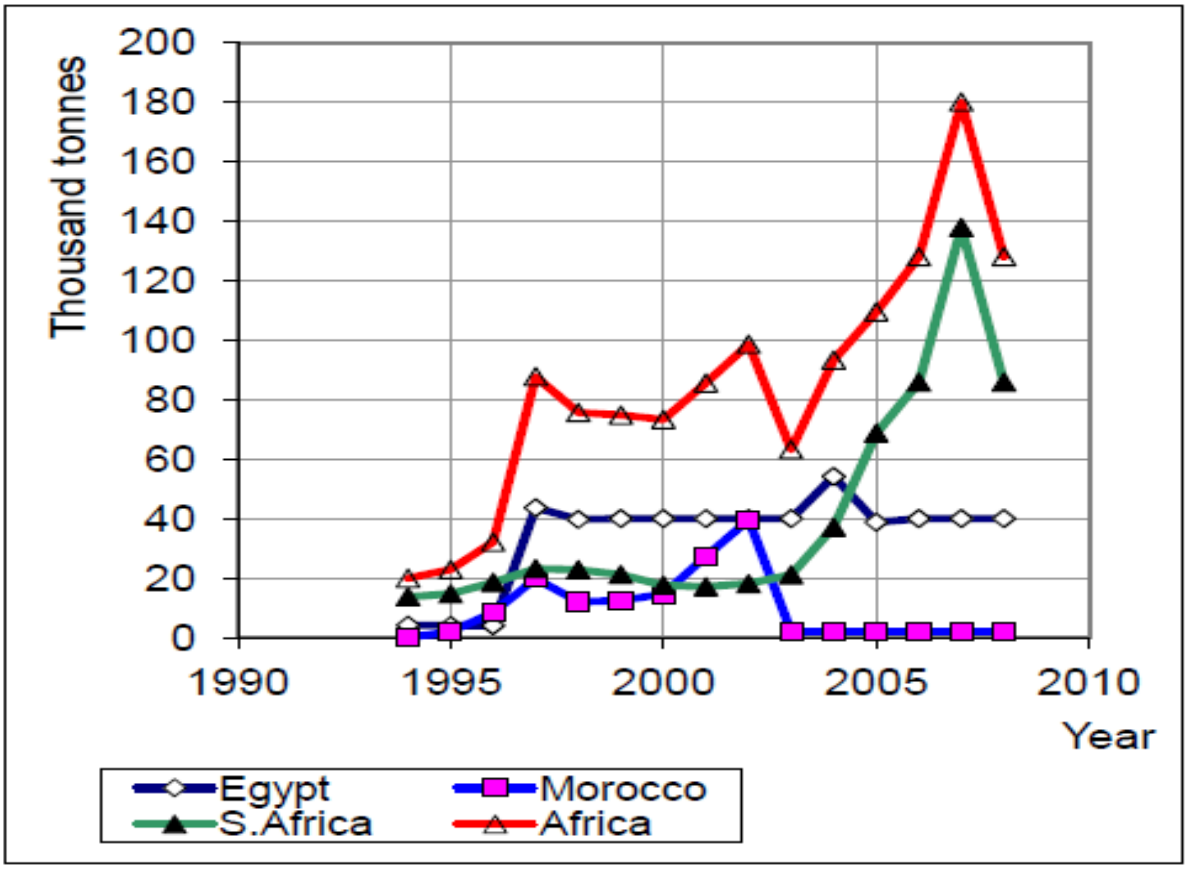


Figure 1.5: Major African producers of Talc (1994 – 2008) Source: Industrial Minerals, (2009); O'Driscoll, (2008); Virta, (2009).

Particular attention has been paid to deposits of talc because of its extensive use in nano-composites (Menczel and Varga, 1983; Ferrage *et al.*, 2002). Figures 1.6 and 1.7 show some major end uses of talc and general application of talc.

This research work focuses on the petrological, mineralogical and geochemical characteristics of talcose rock from the study area with the aim of estabilishing its petrogenesis and composition as basis for assessing its quality as raw materials for industrial application.

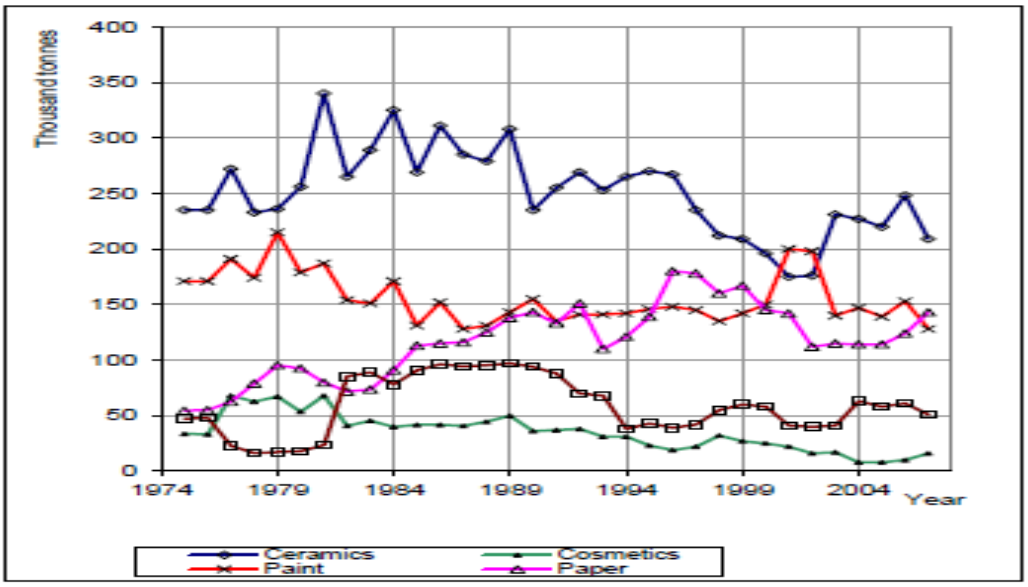


Figure 1.6: Major uses of Talc, from (1975 – 2007); Source: Industrial Minerals (2009); O'Driscoll (2008); Virta, (2009).

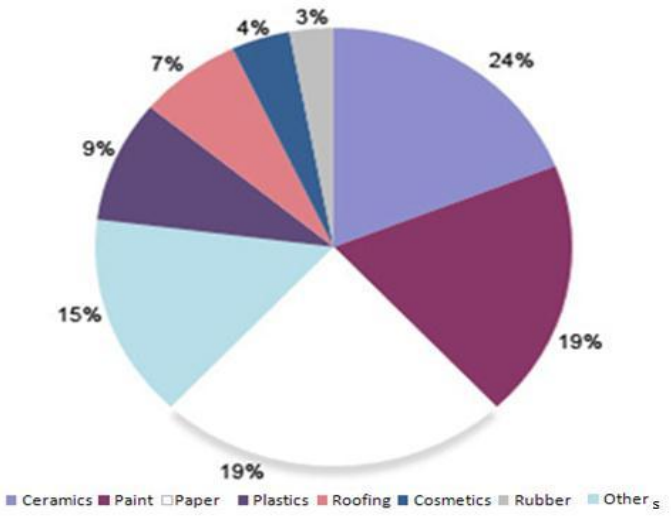


Figure 1.7: The application of talc as raw materials in industries by (Roe, 1975); Piniazkiewicz *et al;* 1994b; Luzanec, 2010). "Others" include art sculpture, pharmaceuticals, textiles, electrical insulators, asphalt filler, auto body filler, construction caulks, flooring, insecticides, fertilizer, refractories, dry lubricants, flour wax, shoe polish and print ink.

1.2 LOCATION AND ACCESSIBILTY

The study area lies within Tegina Sheet 142 and is delineated by latitudes 10° 00′N and 10° 15′N and longitudes 6°10′E and 6° 30′ E. Kagara is located about 15 km

northeast of Tegina along Tegina – Pandogari –Birnin Gwari road (Figure 1.8). The study area is assessible from the north and south through Lagos - Tegina - Kaduna highway (Trunk A125). The study area can also be accessed from Abuja – Minna– Zugeru en - route Tegina, while the Lagos rail line which trasverses Ibadan – Ilorin - Jebba – Mokwa - Tegina, also provide good access to Kagara and environs. Good accessibility is also provided by numerous untarred roads, foot paths, cattle tracks as well as streams and rivers channels.

1.3 RELIEF AND DRAINAGE

The study area is generally undunlating lowland. The eastern half of the area rises a gradual from plain to gently sloping highlands with height ranging from 350 to 365m above the sea level. The terrain on the western half of the area is dominated by lowland with elevation well below 300 m. Most of the rivers in the area are ephemeral and usually dry up during the dry season; very few of them flow all the year round. At the northwest, River Luga with many tributaries flow from northwest area and River Durumi from north central have many tributaries from the northeast which later joined River Luga, the tributaries from Supana also joined the main River Luga which flow southwest ward. Many tributaries of river flow from Kwakwanka towards northwest while tributaries from Kukoki flow toward River Durumi. The pattern of these rivers seems to suggest features of structural significance, which tend to drain almost radially from the central part. These rivers as well as their tributaries make up the drainage system in the area and display a dendritic pattern of flow.

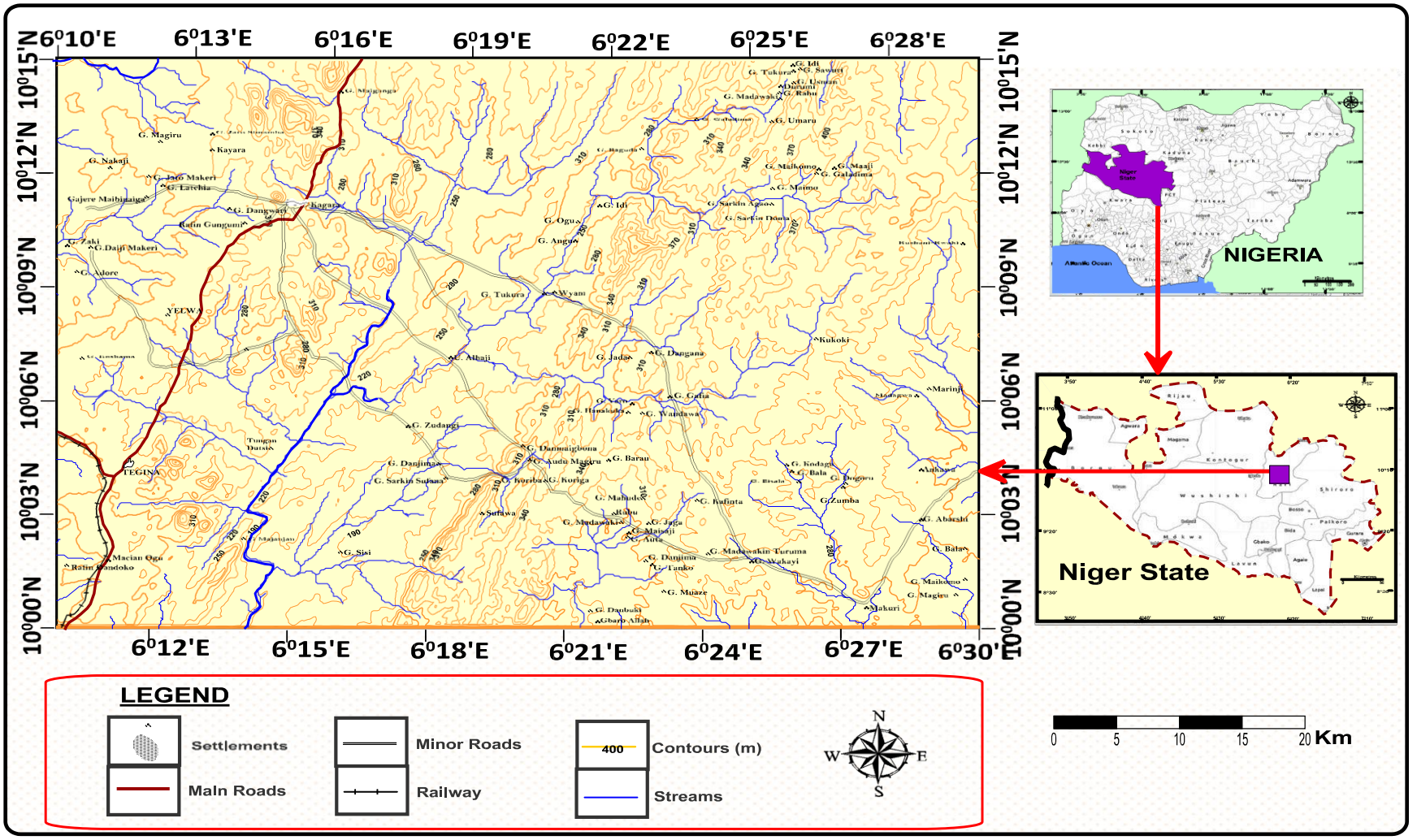


Figure 1.8: Location map of the study area.

1.4 CLIMATE AND VEGETATION

The climate of the study area is wet - tropical climate. The area experiences two distinct seasons; the wet and dry seasons. The wet seasoned begins from mid – April and lasted till October, with its peak in July, while in the period November to early April dry season predominate. Mean annual temperature remains high, hovering around 32°C (Reuben, 1978).

However, the lowest temperatures occur usually between December and January when most of the study area comes under the influence of the dry, tropical continental air mass which blows from the northeast southwards. This period is commonly referred to as the harmattan season.

The annual rainfall varies from about 1,100 mm in the north to 1250 mm in the south. The duration of the rainy season ranges from 180 - 210 days or more from the north to the south (Reuben, 1978).

The vegetation type in the study area is typically the Guinea Savannah. This vegetational belt is found in the north of deciduous forest zone, and it is characterized by tall grasses. This belt receives up to 1,100 mm of rainfall annually and the duration of rainfall is not less than 5 - 6 months (Bunnett and Okunrotifa, 1984; Iwena, 2008).

Economic trees in this area include; Acacias, Baobab, locust beans, shea- butter and Doka.

1.5 PEOPLE, SETTELEMENT AND LAND USE:

The inhabitants of the area are basically the Hausa, Nupe, Fulanis, and Gwari ethnic groups. The Gwari people are very hospitable and have a rich and diverse cultural heritage which finds expressions in music, dance and clothing. The major settlements of the study area are Tegina, Kagara, Luga, Durumi and Supana with several other villages among which are kwamakwa, Godo, Kukoki, and Madaka.

The main occupation of the people is farming which is practiced both in the wet and dry seasons. The area is endowed with fertile grassland that for most parts is suitable for agricultural practises (arable, citrus; and pastoral farming) which is the backbone of the local economy. A great majority of the populace are farmers; producing crops like yam, rice, groundnut, Mango, orange and cashew. Worthy of mention is the pastoral grazing that is carried out by the nomadic Fulani's, whose activities are widespread because of the search for green pastures all round in the vicinity of the rivers. The study area experiences large influx of people as a result of artisan mining of alluvial along the river channels.

1.6 PREVIOUS WORK

The occurrences of talcose rock in ultramafic rocks in Kagara area have previously been reported by Truswell and Cope, (1963); Elueze, (1982); Elueze and Dosunmu (1987); MSMD, (1997); RMRDC, (2010). Elueze (1983; 1986) were speculated on tectonic affinity of the amphibolites in the area. Other works done in the past were related to the geochemistry and general geology of the area without special preference to deposits like talcose occurring within the Kushaka schist belt (Ajibade, (1982); Garba, 2002).

Recently, geochemical studies by Ihaza *et al.,* (2014) focused on appraisal of talcose bodies in the area with emphasis on its industral application while Amoka (2000); Ogunbanjo and Amoka (2005, 2006) worked on decolourization of talcose rock from Kagara using magnetic separation and acid bleaching as route for colour enhancement; Since strong colours are objectionable in most industrial applications, most of the talc deposits require bleaching before usage.

Apart from the aforementioned previous studies, no further work has been done on talcose deposits in this area. This research therefore seeks to address the unresolved

issue of petrogenesis of talc mineralization in Kagara area and its suitability for industrial used.

1.7 STATEMENT OF PROBLEM

The investigations carried out on talcose rock from Kagara area by Amoka (2000); Ogunbanjo and Amoka (2005, 2006) focused on mining, beneficiation of talc and processing while the work of Ihaza *et al.,* (2014) worked on industral application of talcose rock in the area. From the available literature no account of the origin was done. The geochemical attributes of the talcose rocks from Kagara area will be examined so as to bring out more details relating to the origin and mineralization potential of the rocks.

This research would be of significance as the results of various tests would contribute to knowledge through provision of information on economic value and exploitation viability of talcose deposits from Kagara area. The findings of this research would contribute to the general awareness of government and prospective investors with respect to the status and potentials of talc exploitation and investment in Nigeria.

1.8 JUSTIFICATION

Since the Federal Government banned importation of fertilizer in 2005, high priority attention has been given to exploration and exploitation of the talcose deposits in the country. As part of the efforts of Federal Government towards stepping up mineral resources development and improving the contribution of the sector to national economy, various policies and reforms are being put in place to attract investors, with special emphasis on private participation.

The talcose rock mined in Nigeria is presently consumed by fertilizer and paints industries. Aside from this, the demand for fertilizer to improve agriculture production

has remained strong. The demand for talc will continue to grow giving the fact that further exploitation and development of companies whose raw material base in talcose rock will increase and consequently boost talcose consumption.

As far, as can be ascertained, there has not been any detailed work on the petrogenesis of talc mineralization in Kagara area, yet there has been discovery of large deposits of talcose rock in the area by the Nigerian Geological Survey Agency (2010) and Raw Material Research and Development Councils (2010).

Existing and prospective mine and plant operators involved in talc exploration, mining and processing in Nigeria would find useful information from this research that could improve production through beneficiation process and product diversification. The data would therefore be useful to researchers, and manufacturers in talc beneficiation process.

1.9 AIM AND OBJECTIVES

The aim of this research is to undertake detailed field mapping, mineralogical and geochemical investigations of the talcose rock and host rocks in Kagara area in order to determine the origin of talcose rock and its mineralization potential.

The objectives of this research work, therefore, are to:

(i). produce geological map of the study area on the scale of 1:50,000.
(ii). identify the lithological units and structural elements / features of the study area using remotely sensed data.

(iii). establish the origin of the talc mineralization

(iv). update mineralogical and geochemical data of the basement rocks in the study area.

(v). document the physical and chemical characteristics of the talc mineralization.

(vi). determine the suitability of the talc mineral for industrial applications.

1.10 SCOPE OF PRESENT WORK

In line with the set objectives, this research essentially involved elaborate desk studyn to review the existing literature on the study area. Field work commenced with reconnaissance survey followed by detailed field mapping. Talcose rock and host rocks were sampled, collected during field mapping and subjected to laboratory analyses. The results obtained were interpreted based on geochemical principles. The nature of the mineralization was established by comparing the talcose rock from Kagara with similar studies on talc mineralization in Nigeria and else where in the world.

Variation in concentration of major, trace and rare earth elements (REE) in talcose rock and its host rocks was used to determine their geochemical features and petrogenesis of the talcose rock from Kagara Area.

CHAPTER TWO

LITERATURE REVIEW

2.1 REGIONAL GEOLOGICAL SETTING

The study area is lies within the Pan – African complex of the north-central part of Nigeria, which is a part of an Upper Proterozoic mobile belt, extending from Algeria across the Southern Sahara into Nigeria, Benin and Cameroon. The Pan-African belt continues into north-eastern Brazil, where talcose rocks are also known to occur (Elueze, 1981, Olobaniyi and Annor, 2003). It is situated between the Archean - Paleoproterozoic blocks of West African Craton in the west, the Congo Craton in the southeast and the east Sahara block in the northeast (Annor; 1981, Durotoye and Ige,

1991).

The Pan-African belt is divided into two major units: (Figure 2.1)

i). A segment of Juvenile Proterozoic to Archean crust (Pharusian) in the Western Hoggar/ Iforas domain of Southern Algeria and Mali.

ii). Lower Proterozoic to Archean crust, which was reworked during the Pan-African, in the central Hoggar domain and the Benin – Nigeria oceanic closure subduction, during an oblique collision between the West African Craton and the Hoggar-Nigerian Shields (Black, 1984) and crustal thinkening (Black, 1984; Kuster, 1990). The basement complex of Nigeria forms parts of this Pan-African mobile belt and lies between the southern parts of the Trans – Saharan mobile belt of Neoproterozoic age (750-450 Ma) (Caby, 1989).

2.2 THE NIGERIAN BASEMENT COMPLEX

The Basement Complex of Nigeria comprises mainly of migmatite- gnesis, meta- - gnesis, meta-sediments and metavolcanics and the Pan-African granitoids (Older Granites). It is intruded by the Mesozoic alkaline (anorogenic) ring complexes (the Younger Granites) of

Northern Nigeria and unconformably overlain by Cretaceous and younger sediments (Kuster, 1990; Garba, 2002).

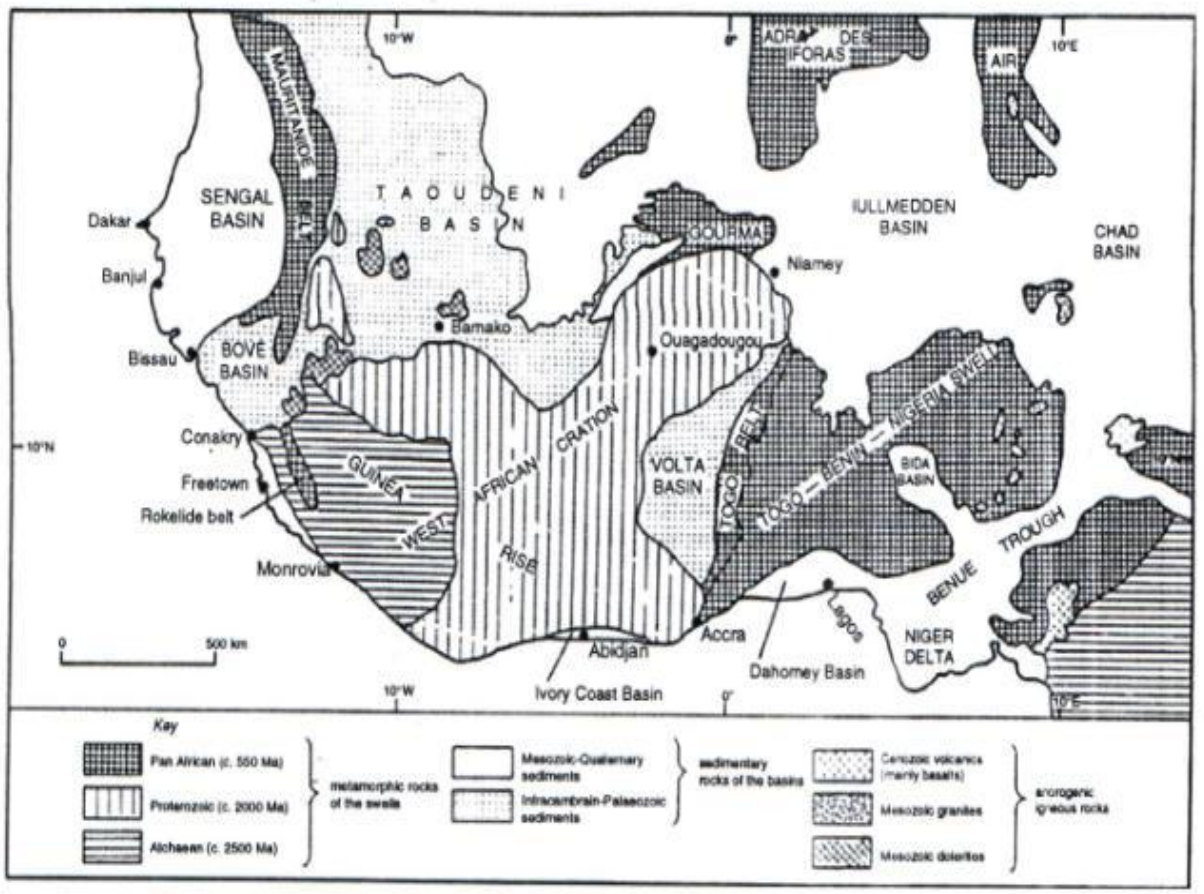


Figure 2.1: Generalized geological map of Nigeria within the framework of the geology of West –African (adapted from Wright, 1985).

The rocks constituting the basement complex are categorized into three major groups (Ekwueme and Matheis, 1995; Dada *et al.*, 1989; Elueze, 2000; Obaje, 2009). These are:-

1.) The Migmatite-Gneiss comlplex + relics of metasedimentary, metavolcalnic and calc-silicates rocks.

2.) The Metasedimentary and Metavolcanic rocks / Younger metasediments (the Schist belts),

3.) The Pan-African Granites and their associated minor rocks.

These lithologies have yielded Archean and Proterozoic ages (Annor, 1995; Dada, 2008) and bear the imprints of Liberian (ca 2700Ma), Eburnian (ca 2000Ma) and Pan-African (ca 600Ma) orogenic events.

2.2.1 MIGMATITE-GNEISS COMPLEX

This is the most widespread and abundant rock type in basement (Ogezi, 1988). It constitutes about 50 % of the Nigerian Precambrian basement rocks (Ajibade *et al.,* 1987) and occupies 30% of the total surface area of the country (Rahaman, 1988). Ajibade, *et al.,* (1987) concluded that the relationship noticed between the gneisses and the granitic gneiss suggests a common deformational episode. However, Rahaman, (1988) observed that the deformation and migmatitic processes that affected the basement tend to have dragged rocks of different lithologies, ages, and origin in parallelism such that differentiating these basement rocks into periodic episodal granitic additions becomes a problems. Age determination from various parts of the country indicates that the gneiss complex has gone through at least four major tectonothermal events namely; the Liberan (2,700 Ma. Oversby, 1975); Eburnean (2000 Ma, Grant, 1970); Kibarian (1100 Ma. Grant *et al.*1972) and Pan –African 600 Ma (Ogezi, 1977). Other reasonable age determinations are those by Rahaman (1988), Dada (1989), Oyinloye (2006). It is a generally accepted view that Archaen, Proterozoic, Kibaran and Pan-African orogenies have affected the Nigeria basement geology.

2.2.2 YOUNGER METASEDIMENTS (SCHIST BELTS)

Nigerian Schist belts are underlain by belts of roughly N-S trending slightly metamorphosed ancient Precambrian sedimentary and volcanic rocks (Dada, *et al.,* 1988; Ajibade and Wright, 1988). They are essentially low- grade metasediments and

metabasic rocks that crop out in a series of distinctly N-S trending synformal troughs infolded into the crystalline migmatite - gneiss complex (Elueze, 1981; 1982; Ige and Asubiojo, 1991) (Figure 2.2). The younger metasediments are the best studied group of rocks in Nigeria because of the mineralization such as gold, Banded Iron Formation (BIF), tin, tantalite and marble, associated with them Russ (1957); Truswell and Cope (1963); Dada *et al.,(* 1988); Oyinloye (2006).

The lithological framework, deformation and metamorphism of the basement rocks are established in the work of Ajibade (1976, 1980); Odeyemi (1988); Rahaman (1976, 1988); Egbuniwe (1982); and Elueze (1981). Olade and Elueze (1979) consider the schist belts to be fault-controlled rift-like structures. Grant (1978), Holt (1982) and Turner (1983), based on structural and lithological associations, suggest that there are different ages of sediments. However, Ajibade *et al.,* (1979) disagree with this conclusion and show that both series contained identical deformational histories. McCurry (1989) observed that the main structural trends in especially northern Nigeria have been resolved into an early ENE to WSW trending moderately dipping foliation planes that have been transgressed by a more dominant deformation N-S steeply dipping structures. The structural relationships between the schist belts and the basement were considered by Truswell and Cope (1963) to be conformable metamorphic fronts and it was Ajibade *et al.,* (1979) who first mapped a structural break. The northern sector of the Nigerian schist belts are separated from each other by migmatite-gneiss complex (Ajibade and Fitches, 1989).

The geochemistry of the amphibolite within the schist belts has generated much controversy. Klemm *et al.,(*1984) confirmed the sedimentary sourced through enisimatic process. Olade and Elueze (1979), Ogezi (1977b) and Ajibade (1980) have favoured dominantly ensialic processes in the evolution of the schist belts while Ajayi

(1980), Rahaman (1981) and Egbuniwe (1982) have stressed that some include oceanic materials with tholeiitic affinities.

Rahaman (1988) reported that there exist similarities between the Nigerian schist belts and those of other parts of the world. Hubbard (1975) and Turner (1983) also compared the belts with those of Archean greenstone terrains but Ajibade (1980) observed that they differ in their bulk composition.

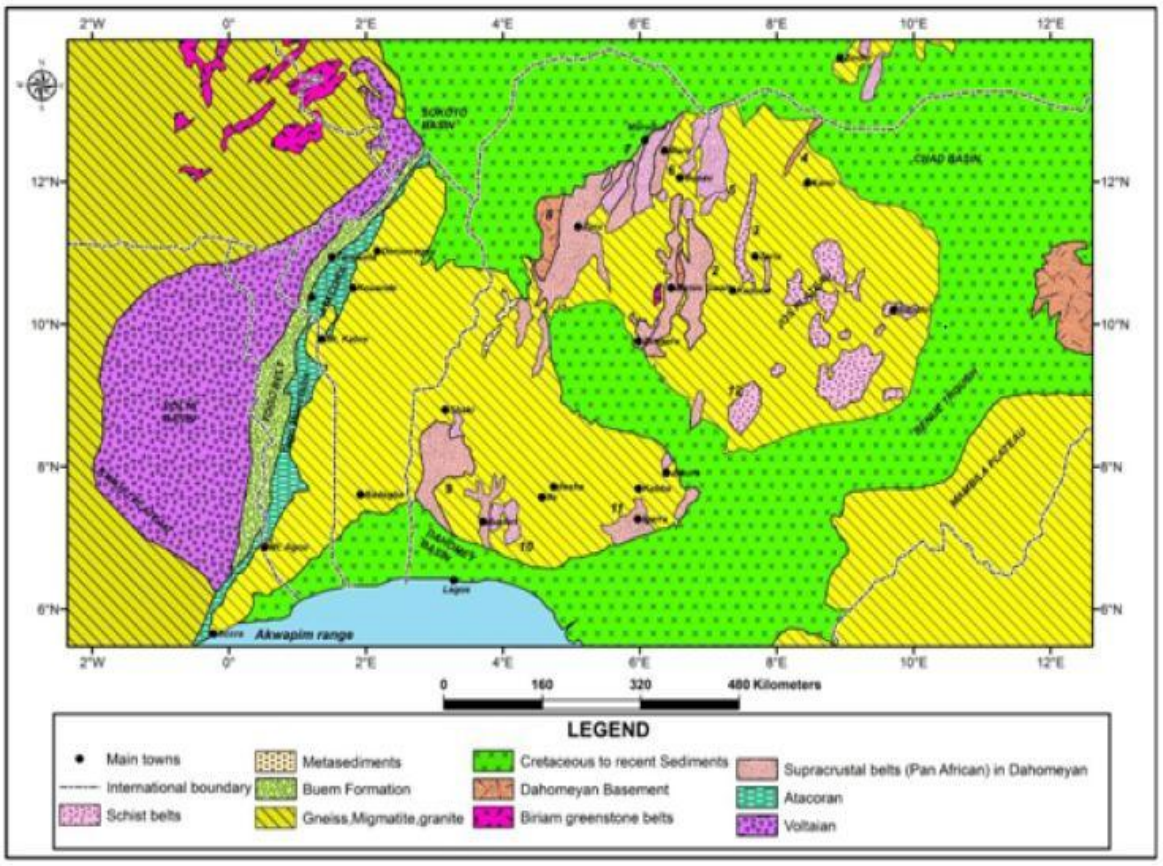


Figure 2.2: Generalized geological map of Nigerian- Dahomeyan subregion:The Migmatite–Gneiss comlplex (mgc); Schist Belts **(**Sb); Older Granites (og), (after Woakes *et al.*, 1987)**.**

2.2.3 OLDER GRANITES

In Nigeria, the Pan-African Granites were named Older Granites by Falconer, (1911) to distinguish them from the Jurrasic, tin-bearing, anorogenic, volcanic and hypabyssal rocks in the Jos Plateau, which he named the Younger Granites. The first systematic study of some Older Granites of Nigeria was made by Truswell (1960);

Truswell and Cope (1963) around Kusheriki area of Northern Nigeria. Jones and Hockey (1964) following the works of Truswell and Cope (1963) have evoked metasomatism and granitization in explaining the origin of the porphyritic Older Granites while describing unequilvocal evidence of magmatic intrusion in many. Kayode (1978) studied the chemistry of the phenocrysts in small –and–large- feldspar porphyritic Older Granites in the Igbo-Ora southwestern Nigeria. He concluded that the feldspar megacrysts in both variants were formed by phenocrystic crystallization from melt. The association of porphyritic granite and charnockite are a common occurrence in the basement (Oyawoye, 1972; Ocan, 1991; Oyinloye, 2006).

The 'typical' Older Granites is a coarse-grained to very coarse porphyritic rock whose composition ranges from tonalite through granodiorite to granite and syenite. Granodiorite composition is the most common with large, white, or pink megacrysts of potash feldspar (Kayode, 1978). Available age determination on the Older Granites shows that granite plutonism is episodic during a period ranging from 800 to 500 Ma Van Breeman *et al.*, (1977), Ogezi (1977), Grant (1978) all of which fall in the Pan-African spectrum. Danbatta (2002) suggested a lower crustal source for the granitic rocks of the Older Granites in Kazaure Schist belt northwestern Nigerian Basement.

2.2.4 THE YOUNGER GRANITES

The Younger Granites are represented by a well- defined suite of intrusive biotite and riebeckie granite in the north-central Nigeria (Falconer, 1911, 1921). The Younger Granite province comprises of Precambrian to Lower Paleozoic Basement Complex rocks into which the Younger Granites suites are emplaced (MacLeod *et al.*, 1964). Basement rocks cover about three quarters of the Younger Granites province and consist of ancient sediments which are made up of granulitic gneiss, dioritic rocks,

migmatites, granite-gneiss, Older Granites and granodiorites (MacLeod *et al.,* 1964, Oyawoye, 1964 and Oyawoye, 1972). Cone sheets and ring dykes are widely distributed in the province. The ring dykes show outward dips both on the inner and outer contacts but some have steep or vertical contacts (Jacobson *et al.,* 1958, Turner, 1989, MacLeod *et al.,* 1964).

The Younger Granite complexes trend in an N – S belt with the ages of the complexes decreasing southwards. Rahaman *et al.,* (1984) showed that major local magmatic activities were concentrated along ENE and WSW zones. The age pattern suggests that the parent magma were locally derived from several simultaneous high level magma chambers connected to a common deeper source. The emplacement of these ring complexes was controlled by fracture systems in the basement.

The main phase of acid magmatism in the Nigerian Younger Granite province commenced during Triassic times and continued to migrate in a generally southerly direction until the close of the Jurassic (Turner,1989). The cessation of magmatism might have been synchronous with the initiation of the South Atlantic.

Turner, (1989) proposed three stages of development of the Nigerian ring complexes:

1. Early stage of a large rhyolite volcano which prior to the end of its stage, large amount of magma accumulated in the synvolcanic reservoir about 5 km beneath the surface.
2. Caldera and ring dyke stage when the centre of the volcanic structure within a ring fault collapsed, magma arose along the fault and crystallized as granite porphyry which was extruded into the caldera rocks.
3. Intrusive stages were the warming phase of igneous activity when smaller granite intrusions were emplaced at increasing depth levels. The magma evolved and crystallized at lower temperatures and as lower assemblages. The rocks are composed

of biotite granite.

The Younger Granites are underlain by Older Granites, migmatites and meta-sediments of the Basement Complex.

2.2.5: TERTIARY– RECENT VOLCANICS.

The most extensive outcrops of Tertiary – Recent Volcanic are on the Biu and Longuda Plateaux of north eastern Nigeria and of Jos Plateau (Dada, 2006; Grant, 1970). Scattered occurences exist within the Benue Trough. The dominant rock type is basalt with alkaline affinities (Dada, 2006). Grant, *et al.,* (1972) showed that the basaltic rocks range in age from 22 Ma to 0.7 Ma. The more recent activity is probably related to the event along the Cameroon volcalnic zone.

2.2.6 TALC DEPOSITS IN NIGERIA AND ITS CHARATERISTICS

So far, seven deposits of talc have been reported in various parts of the Nigeria where they are associated with the mafic and ultramafic complexes and metasediments of the Basement Complex (Truswell and Cope 1963; Elueze, 1982; Ige, 1982; Akin-Ojo, 1992; Okunlola, 2009).The talc deposits are generally of low grade except the deposit at Isanlu – Makutu (Ajibade *et al.,* 1987; Akpanika *et al.,* 1987; Adekeye, 2001; Olobaniyi and Annor, 2003; Olorunfemi *et al.,* 2009; Olobaniyi and Mucke, 2011). In these deposits talc occurs as fibrous aggregates (Okunlola, *et al.,* 2003) and sometimes as platy talcs and are commonly associated with amphibolites from which they are thought to have been derived (Kehinde - Philips and Tietz, 1995).

However, the mineralizations are mostly of poor grade, and thus require some processing to improve quality for industrial uses. Table (2.1) gives the summary of the major talc occurrence in Nigeria.

Table (2.1) Summary of occurrences of talc in various locations in Nigeria,

State	Location	Composition	Grade	Estimated Reserve (Tons).	References
Ekiti	Ijero-Ekiti	Tc,Tm,Ac,C, Ap,Ot	Low	ND	Okunlola *et al.,(* 2011)
.Oyo	Iseyin,	Tm,Ac,C,Ap	Low	ND	Elueze and Awonaiya, (1989)
	Igbo-Agbon	Tm,Tre,Dol, C,Ot	Low	-	Ayemo, (2003)
	Asegbon	-	-	5 495	Durotoye and Ige, (1991)
	Obaluru-Araromi	Tm,Ac,C,Ph	Low	55 650	Akin-Ojo, (1992)
	Baba-Ode	Tc,Tm,C,Ap, Ot	Low	3 000 000	Okunlola *et al.,(* 2002)
Kwara	Oro –Ijan	Tm,Ac,C,ph	L-M		Adekeye, (2001)
	Oro-Agbamu	T,Ac,Ch,ph	L-M	-	Adekeye, (2001)
	Esie	T+A,C,A	Low	-	Olorunfemi *et al.*, (2009)
	Erin-Omu	Tm,Ac,C,Ap	Low	-	Okunlola andAnikulapo, (2006)
Osun	Wonu-Apomu	Tm,Ac,C,Ap,	Low	1 669 500	Elueze A.A, (1982)
	Ile-Ife	Tm,Ac,C,Ap,	Low	-	Elueze, (1982)
	Ila(Oke)	Tm,Ac,C,Ap,	Low	-	Bolarinwa, (2001)
Kogi	Yagba-Isanlu	-	Low	2 500 400	RMRDC, (2010)
Niger	Kagara, Kumunu,	-	Low	83 475 000	RMRDC,(2010); Amoka, (2000).
	Assaya	T,C	Low	1500	Ihaza *et al* ., 2014
	Tugan Bako	-	Low	1 288	
	Yarada	-		ND	
Kaduna	Zonkwa, Fadankaje		Low	-	RMRDC, (2010)

Tc =Talc, Tm =Tremolite, Ph = Phlogopite, C = Chlorite, Ac = Actinolite, Ap =Anthophyllite, Dol = Dolomite,Ot= other Opaque),L-M= Low- Medium, ND= Not Determined.

2.2.7 INDUSTRIAL SPECIFICATIONS OF TALC.

The usefulness of talc in so many industries is attributed to its numerous distinguishing properties, which depend on its mineralogy. Further details of the properties determined by Ogunbanjo and Amoka (2005) which include whiteness, brightness, flaky habit, inertness, thermal conductivity among others are presented in Table (2.2).

Table: 2.2 Talc properties for specific market (Ogunbanjo and Amoka, 2005)

Property	**Industry**							
	A	B	C	D	E	F	G	H
Whiteness	×	×		×	×	×		
Brightness	×	×				×		
Flaky habit	×	×		×	×	×	×	×
High oil absorption	×	×		×		×		
Inertness	×	×	×	×	×	×	×	×
Low abrasion	×	×		×	×			×
Greasy feel				×			×	×
Opacifying power	×	×		×				
Fragrance retention				×				
High fusion point			×	×				
Fluxing action			×					
Low shrinkage			×					
Thermal conductivity			×					
Electrical resistivity			×		×		×	×

A=Paint, B=Paper, C= Ceramics, D= Cosmetics, E=Plastics, F=Roofing, G= Automotive, H= Rubber

CHAPTER THREE

METHODOLOGY

3.1 METHODOLOGY

The methodology adopted in the execusion of this research work consists of acquisitions and interpretation of satellite images using different remote sensing techniques; field study and laboratory analyses.The field study involved geological mapping on a scale of 1:50 000 which was undertaken with topographic map, geologic hammer, compass - clinometers and Global positioning system (GPS). The laboratory work involved sample preparation, petrographic study and geochemical analysis.

The petrographic study was undertaken with the petrological microscope at petrographic laboratory, Department of Geology, Ahmadu Bello University, Zaria. Mineral identification was carried out using X-ray powder diffraction techniques while the geochemical analysis involved the use of ICP-AES for analysis of major oxides and ICP-MS in the determination of trace including rare earth elements at Acivation Laboratories Limited (ACTLAB), Ancaster, Ontario, Canada.

3.2. REMOTE SENSING TECHNIQUES

Remote sensing was applied in the generation of lineaments of the study area from Landsat Earth Thematic Mapper (ETM) + imagery using PCI geomatica line module. Generation of the lineaments was followed by construction of rose diagram to determine their dominant direction. The following techniques of spectral analysis were also applied.

3.2.1 BAND RATIONING

In this study, band rationing with band rations of 3/7, 5/7, 5/4 were analysed for iron oxide and hydroxyl bearing minerals. Band ratio 5/7 was used to study the distribution of clay minerals while band ratio 5/4 and 3/1 was used to study distribution and presence of hydrothermal alteration within the study area.

3.2.2 CROSTA TECHNIQUE

Crosta technique was applied to bands 1/3, 4/5 and 1/4, 5/7 to enhance appearance of iron and clay minerals within the study area. This technique was applied on four and six selected bands of Thematic Mapper (TM) data.

3.2.3 PRINCIPAL COMPONENT ANALYSIS (PCA)

The Principal Component Analysis was performed on two sets of band combination 1/4; 5/7 and 1/3: 4/7.The PC analysis was used to remove redundancy in multispectral data. Sabins (1996) successfully adopted PCA of Band sets 1/3; 4/7 and 1/5; 4/7 separately to determine the presence of iron-oxide and hydroxyl-rich minerals respectively. PC1 mapped albedo and topographic information while PC2 displayed the VIS/IR versus SWIR bands in contrasting signs. The eigenvectors of PCs 3 and 4 were checked to see if they contain substantial loadings in opposite signs from input bands of 1and 3 and 5and 7 of 1 and 3 and 5 and 7, since these band pairs are expected to display contrasting response for iron and hydroxyl-rich minerals respectively.

3.3 FIELD INVESTIGATION

The field work started with a reconnaissance survey of the area principally to determine traverse route and for logistic planning. This was followed by the detailed

geological mapping on a scale of 1:50,000 using traverse method. Collection of representative rock samples from outcrops, road cuts e.t.c alongside the field mapping was also undertaken. Altogether, seventeen (17) representative rock samples were collected from exposures in the study area. In the field, each outcrop was observed and described based on it's mode of occurrence, macroscopic characteristics, structural elements and field relation with adjacent outcrops.

Hand specimens were described based on the following macroscopic features: colour, texture, mineralogy and carefully labelled and the sample location plotted on the base map. Fresh samples were taken during the field work with the aid of sledge hammer and chisel and examined with hand lens. Germain Global positioning system (GPS) was used to determine the elevation, longitudes and latitudes of the samples. Careful observation of lithological boundaries was made by observing changes in rock exposures, nature of soil, vegetation and topography. A Silva compass clinometer facilitated traversing and was also used to take strike and dip values of the various structures. Linear measurements were taken with the aid of meter rule. Other materials that were used for the field work are digital Camera to obtain photographs of the rocks and important features where possible. The field note book was used to record the daily activities and rocks description on the field. All the samples were labelled so as to prevent mis-identification and later bagged for sample preparation.

3.4 LABORATORY WORK

3.4. 1 THIN SECTION PREPARATION AND ANALYSIS

Seventeen samples of talcose rock and associated rocks were prepared for petrographic study. These consist of four (4) representatives samples of talcose rock, one (1) pegmatite, one (1) granodiorite, one (1) fine-medium-grained granites, one (1) porphritic granites, two (2) amphibolites, one (1) phyllite, one (1) granitic gneiss, one

(1) banded gneiss, one (1) migmatitic gneiss and one (1) meta-arkosic rock. Samples taken from the field were prepared as thin section by using a rock cutting machine. Rock chips were then placed on a glass slide and marked using diamond pen. Both glass slide and rock chip are then placed on the source of heat then glued together in order to remove the air bubbles, and allowed to dry and cooled for 10-15minutes. The rock chips and the slides were then clamped on a grinding machine and grind gradually. The slides were further then thinned with carborandum powder while observing under the microscope. The thinned glass slide is heated and scrapped to size. Air bubbles were further eliminated by gently smoothing the surface. The thin sections were dried for 2 days and gum debris scrapped off. The slides were finally washed using methylated spirit, labelled and ready for petrographic studies using polarizing microscope.

The prepared slides were examined using a petrological microscope to identify minerals and others features that were not hitherto seen with aid of magnifying lens under plane polarized Light (PPL) and crossed polarized light (XPL). Photomicrographs of the thin sections were produced at the Petrographic Laboratory, Department of Geology, Ahmadu Bello University, Zaria, Nigeria.

3.4.2 X-RAY DIFFRACTION ANALYSIS

Four (4) selected samples consist of two (2) representatives samples of talcose rock and two (2) samples of amphibolites were analysed for X-Ray Diffraction (XRD) . About 1 kg of each sample was broken into pieces with a hammer and crushed into smaller piece with a jaw crusher. The samples were thereafter pulverized in a disc mill for about two minutes. Each pulverized sample was thoroughly homogenized to obtain a representatative portion. The samples were thereafter shipped for X-ray diffraction analysis at ACTLAB analytical Laboratory Ontario in Canada.

X-ray Diffraction analysis was performed on a Panalytical X'Pert Pro

diffractometer, equipped with a Cu X-ray source and an X'celerator detector, operating at the following X-ray settings: voltage: 40 kV; current: 40 mA; range: 5-70 deg 2θ; step size: 0.017 deg 2θ; time per step: 50.165 sec; divergence slit: fixed, angle 0.5°. The crystalline mineral phases were identified in X'Pert High Score Plus using the PDF-4 Minerals ICDD database.

3.5 GEOCHEMICAL ANALYSIS

A total of thirteen (13) selected samples were analysed for major oxides and trace element composition. These consist of two (2) representatives samples of talcose rock, three (3) samples of amphibolites, two (2) granites and seven (7) others rock types. All the rock samples were crushed and ground to obtain fine rock powders (-200 mesh size) at Laboratory of Geology, Ahmadu Bello University, Zaria. The samples were thereafter packaged and shipped to Acivation Laboratories Limited (ACTLAB), Ancaster, Ontario, Canada ACTLAB analytical Laboratory Ontario in Canada for whole rock analyses of major and trace elements.

The analytical techniques for the whole rock geochemical analysis were performed on the powdered samples. The major elements were analysed using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). As a means of dissolving the mineral constituents, the analytical procedure involved addition of 5 ml each of perchloric acid ($HClO_4$) and trioxonitrate (V) HNO_3 acid and 15 ml Hydrofluoric acid (HF) to 0.5 g of sample. The solution was stirred and allowed to evaporate to dryness after it was warmed at a low temperature for some hours. Four (4) ml of hydrochloric acid (HCL) was added to the cooled solution and warmed to dissolve the salts. The solution was cooled; then diluted to 50 ml with distilled water. The solution was then introduced into the ICP torch as aqueous – aerosol. The emitted light by the ions in the ICP was converted to an electrical signal by a photo multiplier in

the spectrometer. The intensity of the electrical signal produced by emitted light from the ions were compared to a standard (a previously measured intensity of a known concentration of the elements) and the concentration were then computed. Analytical presicions vary from 0.1 % to 0.04 % for the major elements.

Trace elements were analyzed by inductively- oupled Plasma Mass Spectrometry (ICP - MS) from pulps after 0.2 g of rock powder was fused with 1.5 g $LiBO_2$ and then dissolved in 0.1 ml of trioxonitrate (V) (HNO_3) acid. Analytical presicions vary from 0.1 to 0.5 ppm for trace elements The rare–earth elements (REE) contents were determined by Inductively - Coupled Plasma Mass Spectrometry (ICP - MS) from pulps after 0.25 g rock- powder was dissolved with 5 ml of perchloric acid ($HCIO_4$) and trioxonitrate (V) (HNO_3) acid, and 15 ml of hydrofluoric acid (HF). Analytical presicions vary from 0.01 to 0.5 ppm for rare earth elements.

3.6 DATA HANDLING AND INTERPRETATION OF RESULTS

Data derived from field work and laboratory analyses were subjected to statistical analysis using statistical, mapping and geo-analytical computer software namely: Microsoft Excel, Rose net, Sufer, and Geochemical Data Tool Kit (GCDKit). The results obtained were interpreted based on geological principles complemented by geological knowledge.

CHAPTER FOUR

RESULTS

The result presented in this chapter are those of remote sensing, macroscopic and microscopic description, structural characteristic and field relationship, mineralogical, geochemistry of the rocks types and talcose rock in the study area.

4.1 REMOTE SENSING

The results of remote sensing of spectral analysis using various techniques are given below:

4.1.1 BAND RATIONING

Band ratio 5/7 was used to study the distribution of clay minerals while band ratio 5/4 and 3/1 was used to study distribution of ferrous and ferric iron within the study area. Application of Abraham's ratio where band 5/7, 3/2, 4/5 were assigned to red, green and blue channels respectively reveals hydrothermally altered iron as green, and clay minerals as red colours resulting ration image display distribution of clay minerals as light tone on tone on band 5/7 and distribution of ferrous and ferric iron as light tone on band 5/4 and 3/1 (Figures 4.1, 4.2, 4.3, respectively). The combination of these images in the red, green and blue channel, display distribution of clay minerals as red, ferrous iron as green and ferric iron as blue (Figure: 4.3)

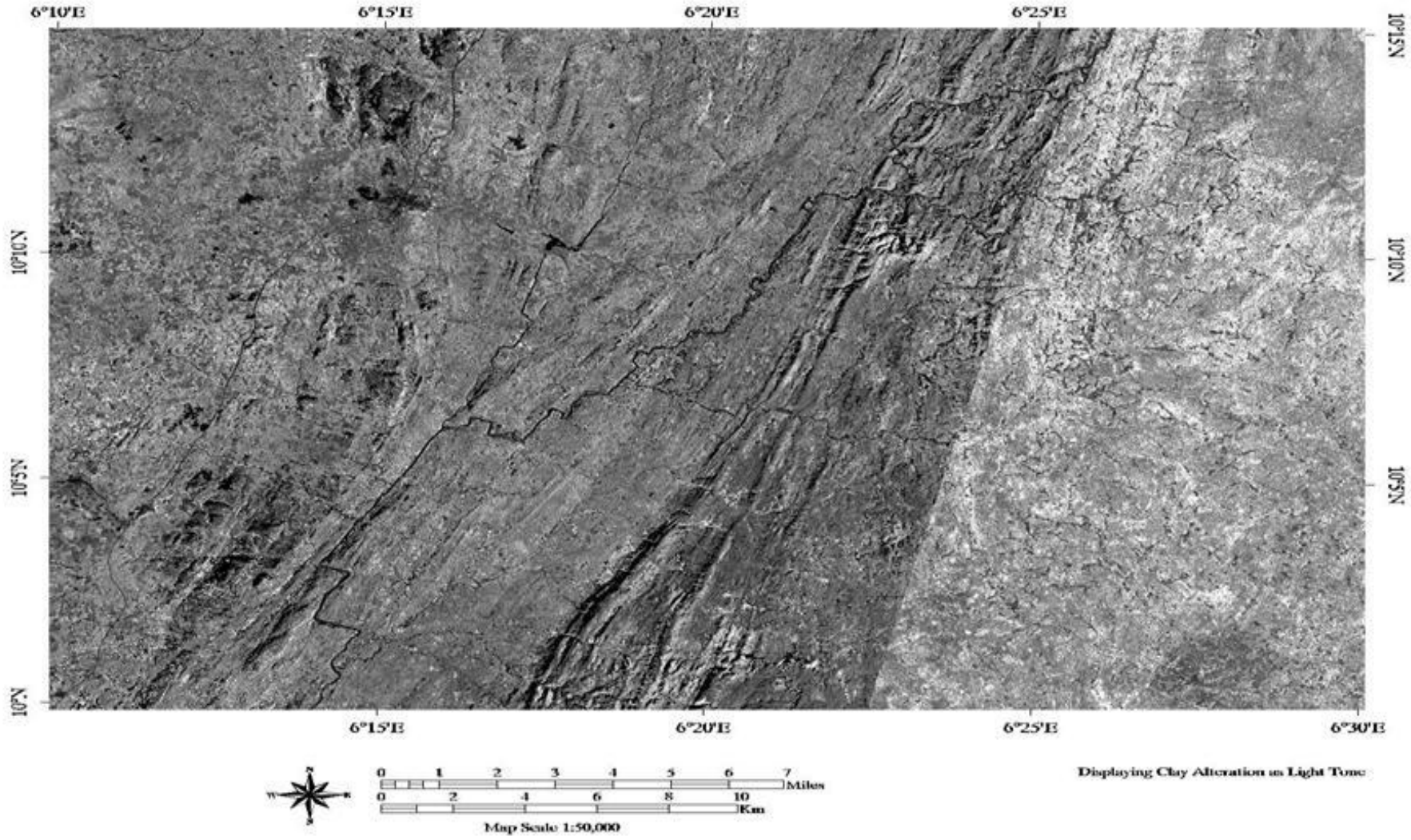


Figure 4.1: Band 5/7 image displaying clay minerals alteration as light tone

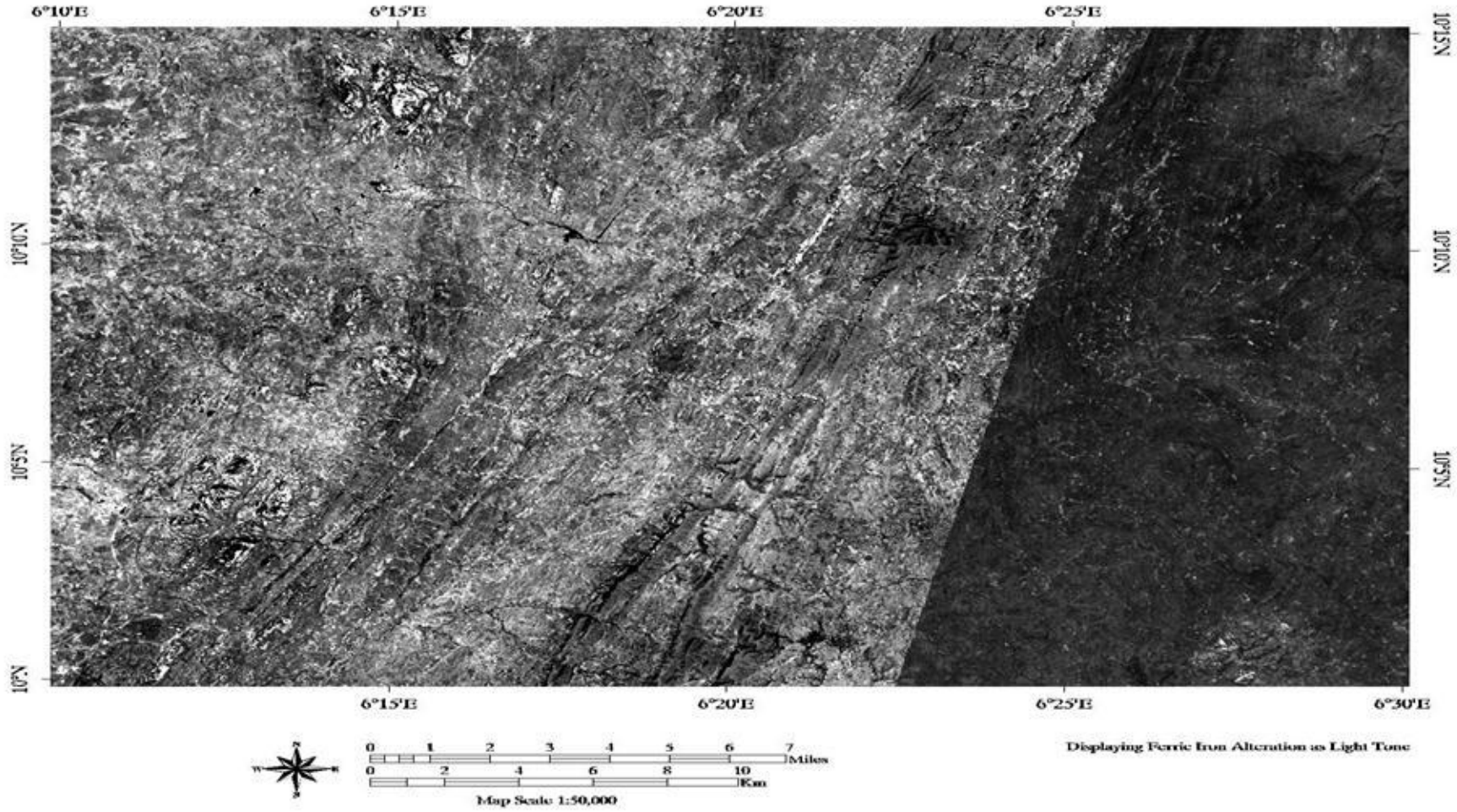


Figure 4.2: Band 5/4 image displaying ferric iron alteration as light tone

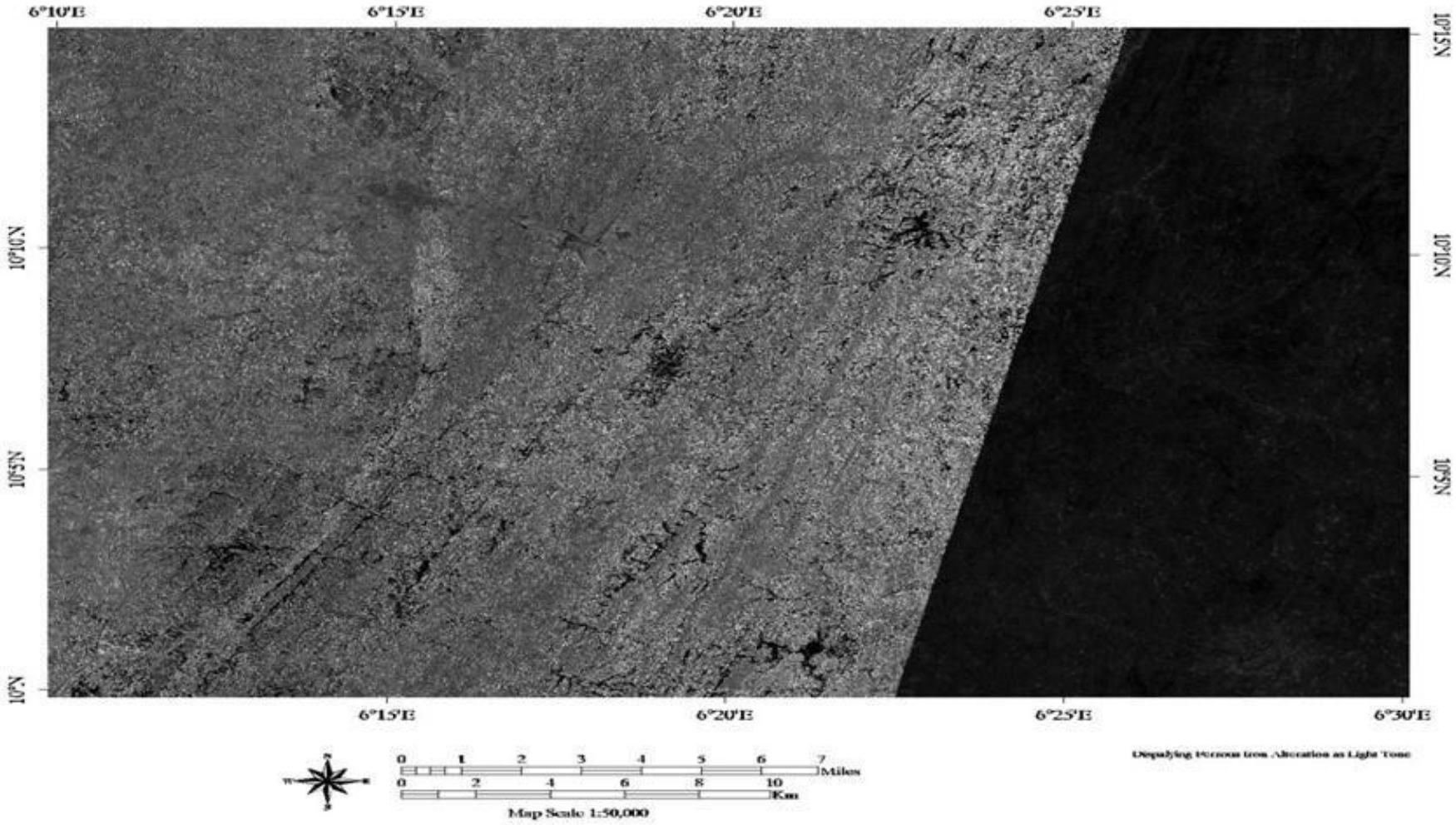


Figure 4.3: Band 3/1 image displaying ferrous iron alteration as light tone.

4.1.2PRINCIPAL COMPONENT ANALYSIS (PCA)

This technique was used to display the iron-oxide and hydroxyl minerals in bright pixels, the negative of each image was taken Figures 4.1 and 4.2. In the resulting image bright pigmentation (Figure: 4.4) was due to the high reflectance of iron-oxide in band 3 and absorption minima in band 1; this image is called F-image. The bright pixels of hydroxyl mineral (Figure: 4.5) was due to the high reflectance in band 5 and absorption in band 7 this image is called H-image.

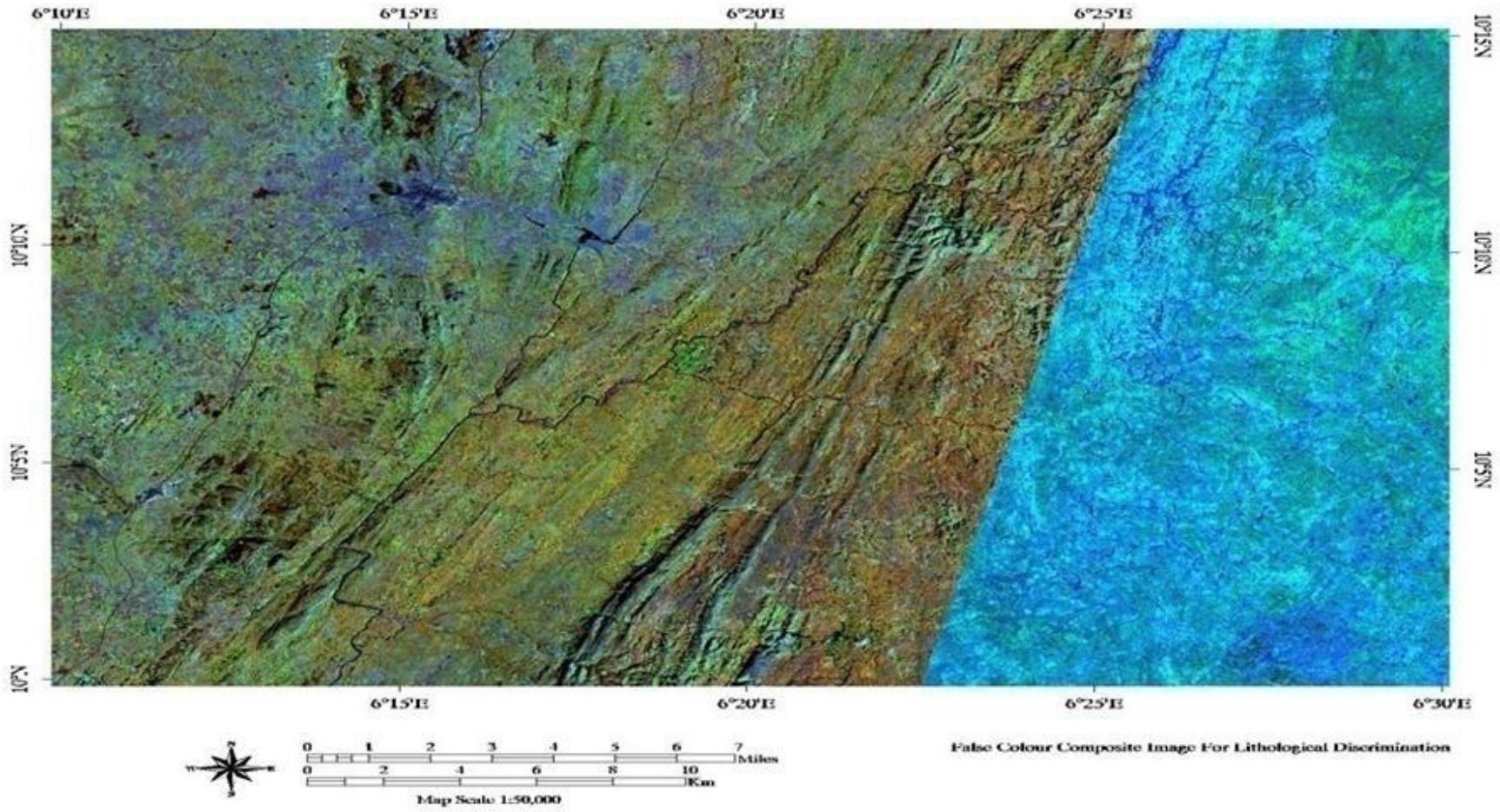


Figure 4.4 False colour composite from principal component analysis of residue image 7:4:1 displaying areas of high alterations as blue

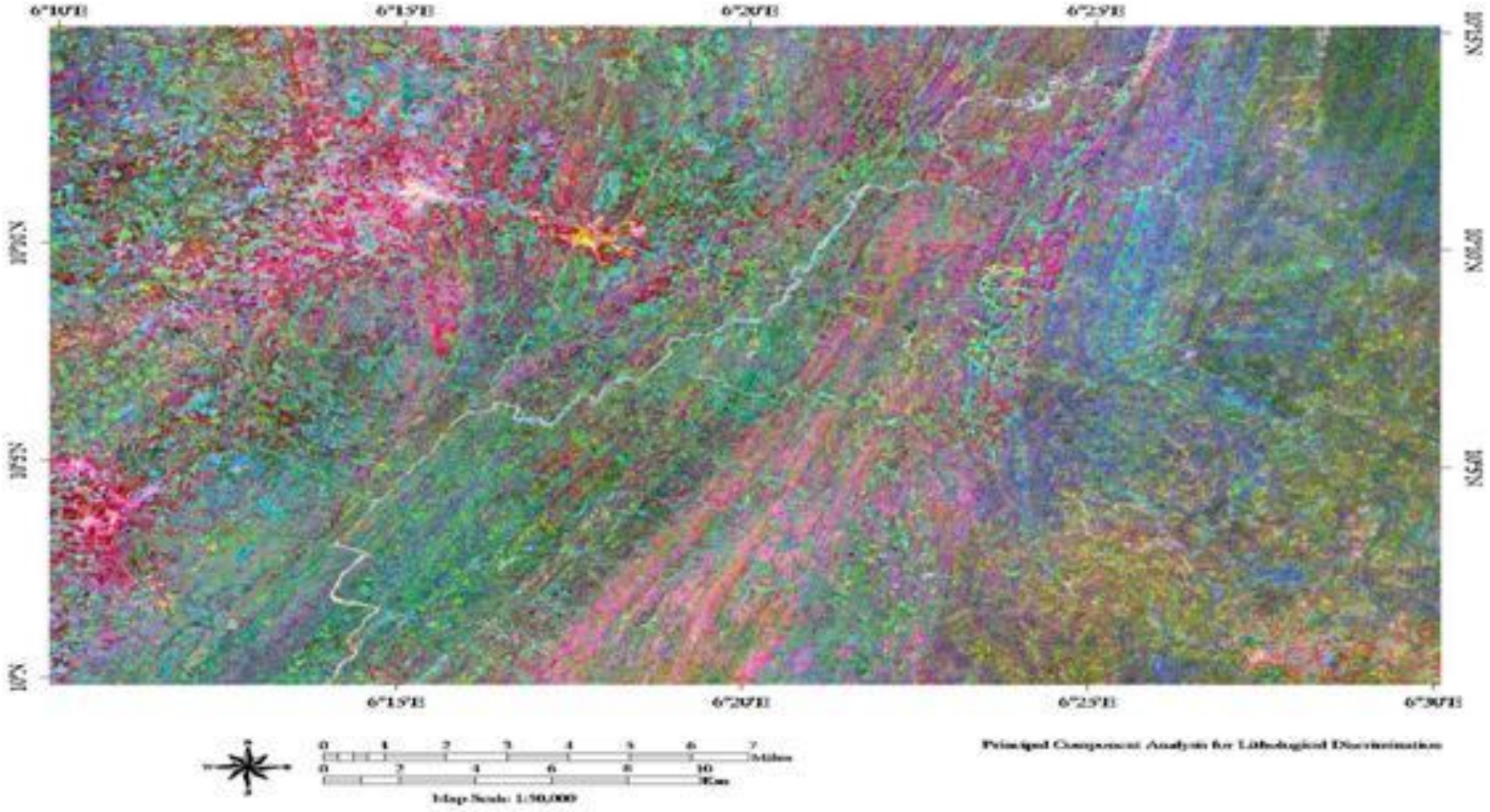


Figure 4.5: False colour composite of band ratio 5/7, 5/1, 3/1 image displaying clay mineral alteration as red, ferrous iron distribution as green and ferric iron as blue.

Table (4.1 and 4.2) gives sericitisation values during the alteration process, with the highest concentration in the northeast; southwest and southeast with little effect in the northwest.

Table 4.1: Principal component analysis (PCA) of bands 1/4; 5/7 for hydroxyl minerals

Eigen values	**Band 1**	**Band 4**	**Band 5**	**Band 7**
PC1	0.382319	0.610790	0.607731	0.333812
PC2	0.297129	0.579880	-0.4244331	-0.628806
PC3	0.823226	-0.343280	-0.337910	0.300457
PC4	-0.296388	0.415733	-0.580019	0.634742

Table 4.2: Principal component analysis (PCA) of bands 1/3; 4/7 for Fe-oxides mineral

Eigen Vector	**Band 1**	**Band 4**	**Band 5**	**Band 7**
PC1	0.445965	0.381777	0,712609	0.384122
PC2	0.177587	-0.142172	0.434724	-0.871358
PC3	-0.826092	-0.146589	0.530668	0.120308
PC4	0.295211	-0.901413	0.146950	0.280555

4.1.3 CROSTA TECHNIQUE AND LS- FIT TECHNIQUE

Crosta Technique and Ls-fit technique was performed on the satellite image in order to map spectral signatures of hydrothermal alterations (clay minerals and iron oxides) in the study area by using residue of band 3, 7, 1 to predict the selected band as a linear combination of the predictor band (Figure 4.6)

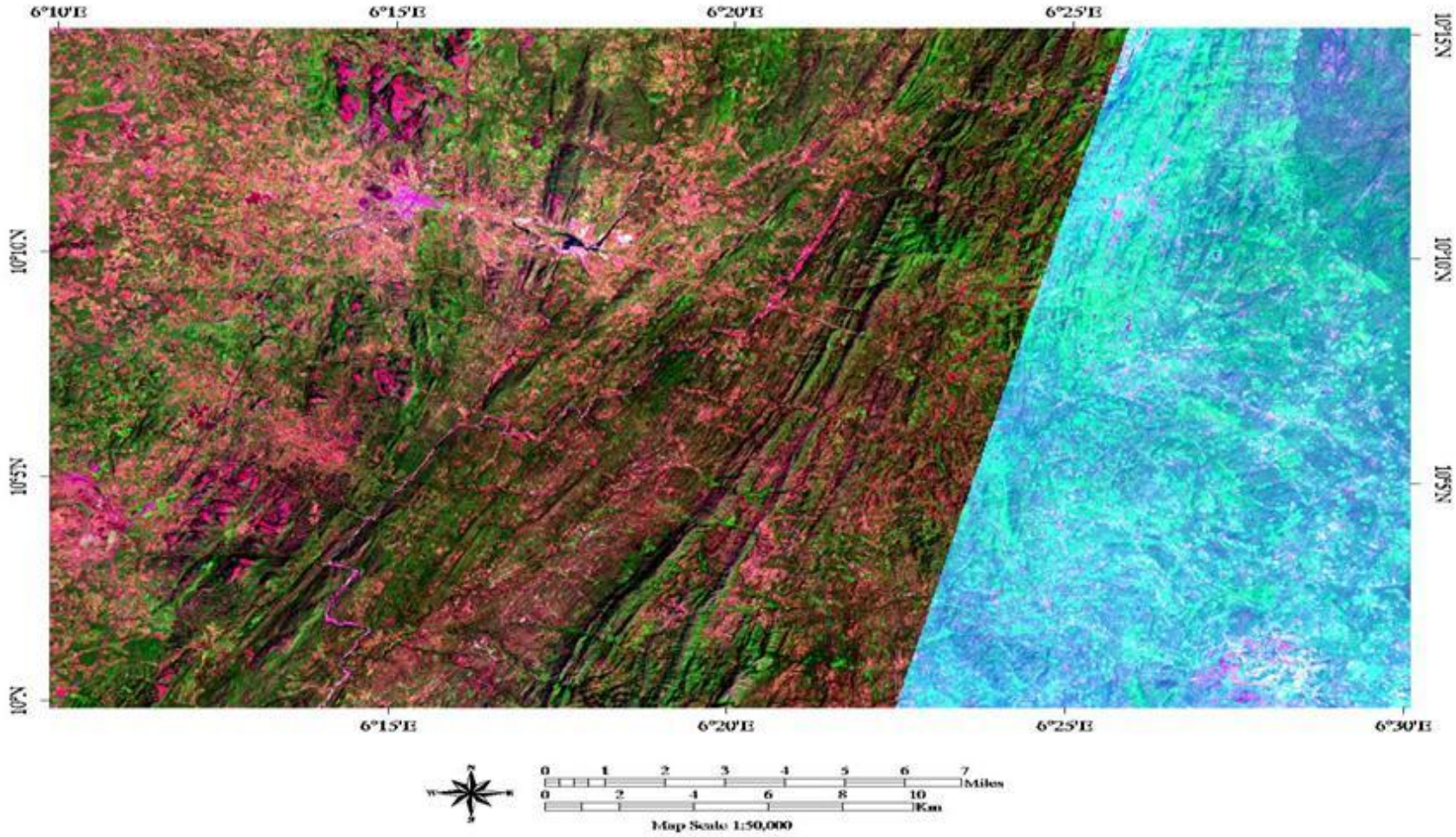


Figure 4.6: Crosta technique of principal component analysis displaying area of high clay alteration as red, ferric alteration as green, high ferrous alteration as blue.

4.1.4 THRESHOLD VALUES.

In order to target highly altered areas, alteration threshold values for the different ration images was calculated using the formula below,

Threshold= Mean + 2 × Standard deviation.

From this formular threshold values and basic statistics are applied in Table 4.3 and the following threshold values were obtained.

Table 4.3 Threshold values and basic statistics.

Ratio image	Minimum	Maximum	Mean	Std. Deviation	Threshold
5/7	0.0	84.0	1.568698	1.794196	5.074483
5/4	0.0	84.0	1.387689	1.979456	5.34661
3/1	0.0	24.5	0.865685	1.678983	4.223651

Using the threshold values, the highly altered areas were segregated and displayed on Figure 4.7.

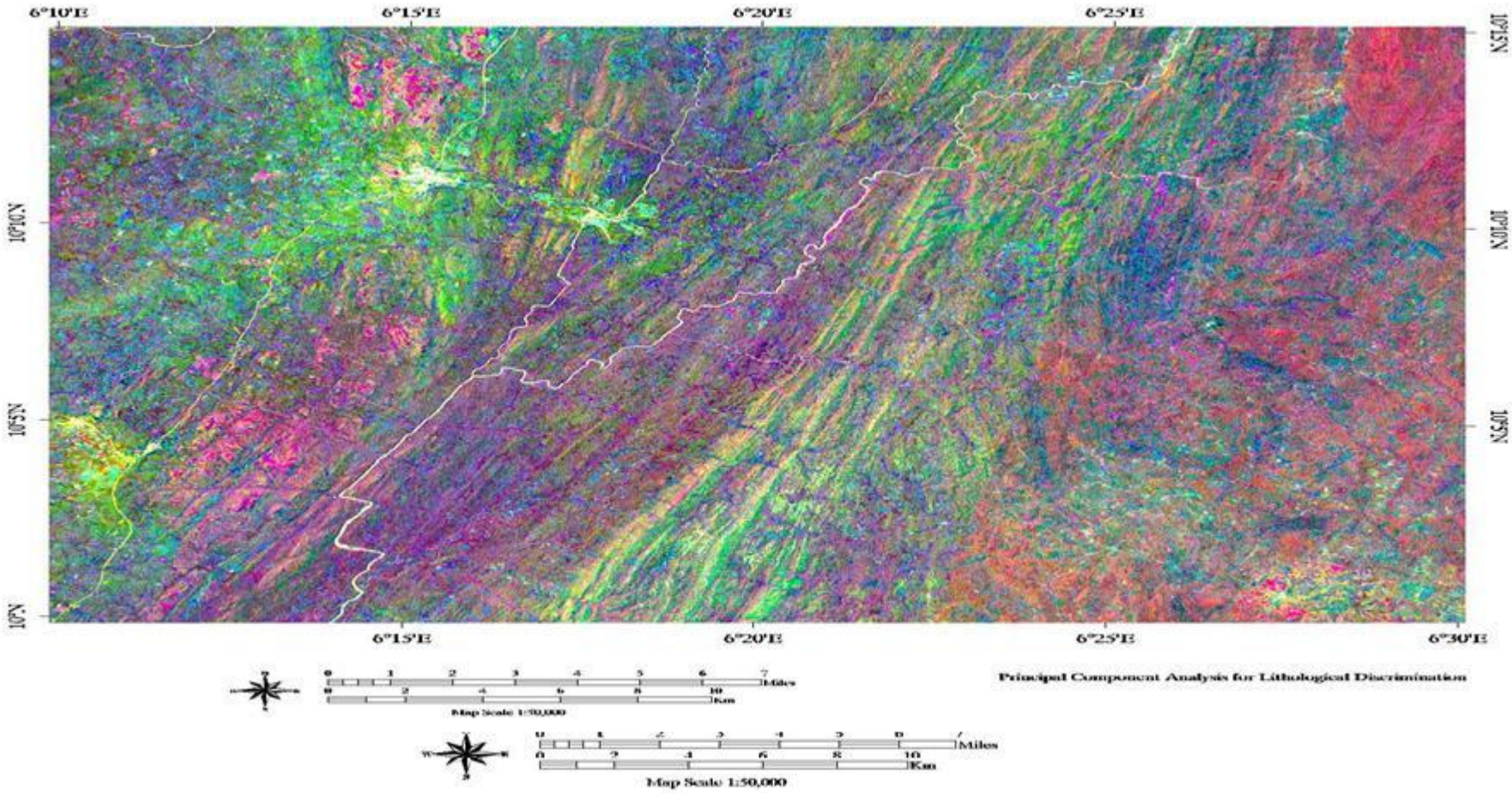


Figure 4.7 Threshold image of Principal component analysis for lithological discrimi-nation of the study area displaying granitic gneiss, talcose rock and phyllite as green; banded gneiss, granites, granodiorite as pink; migmatitic gneiss, meta-arkosic rock as purple.

4.2 GEOLOGY OF THE STUDY AREA

The major rock units in the area are migmatitic gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolites, talcose rock, phyllite, granodiorite, porphyritic granite, fine-medium grained granite, and pegmatite. Migmatitic–gneisses are extensive in the area, intruded by the Older Granites at the northern part truncating its massive extension from the western part of the area to the eastern. It constitutes well over 52% of the rock types in the study area. The Older Granites in the study area are porphyritic and fine-medium grained granites. The porphyritic granites intruded the other rocks in the area especially in the southwestern axis and central part northwards, covering about 30% of the entire area while fine- medium grained granites covers 4% of the area notably in the northeast and toward the central part of the study area. The amphibolites and phyllites consititute about 8% of the rock types in the area. Outcrops of the amphibolites in are lenticular, texturally distinctive and well oriented sub - parallel to the N-S foliated trend.

The talcose rocks constitute about 6% of the rocks in the study area and occur in the northwestern part close to Kagara in Tsaunin Agwaru area in a ridge surrounded by amphiobolites and the Older Granites. Outcrop of the talc occurs as lensoid bodies of moderate size and length. It extends to the southwestern part having contacts with the migmatitic–gneisses and the Older Granites in an oval shaped outcrops of about 15 m above the surrounding ground surface. In the southern part of Kumunu, talcose rocks occurs as large inselbergs and massives exposures, and are bounded by the Older Granites and migmatitic gneiss in the western and eastern sides. The talcose rock truncate the linearly elongated north - south amphibolite bodies (Figure 4.8).The talcose bodies are largely extensive in Kagara area with different grade, colours, sizes,

and textures. The colour of talc varies from grey, white to pale brown colour with a soapy feel when handled.

There are metamorphosed meta-arkosic rocks mainly of sandstone containing at least 55 % of feldspar. This unit runs in N-S direction in the southeastern part of the study area and also occurs in the north towards the east, though not as massive as in southeastern part of the study area. The geological map of the study area is presented as (Figure 4.8).

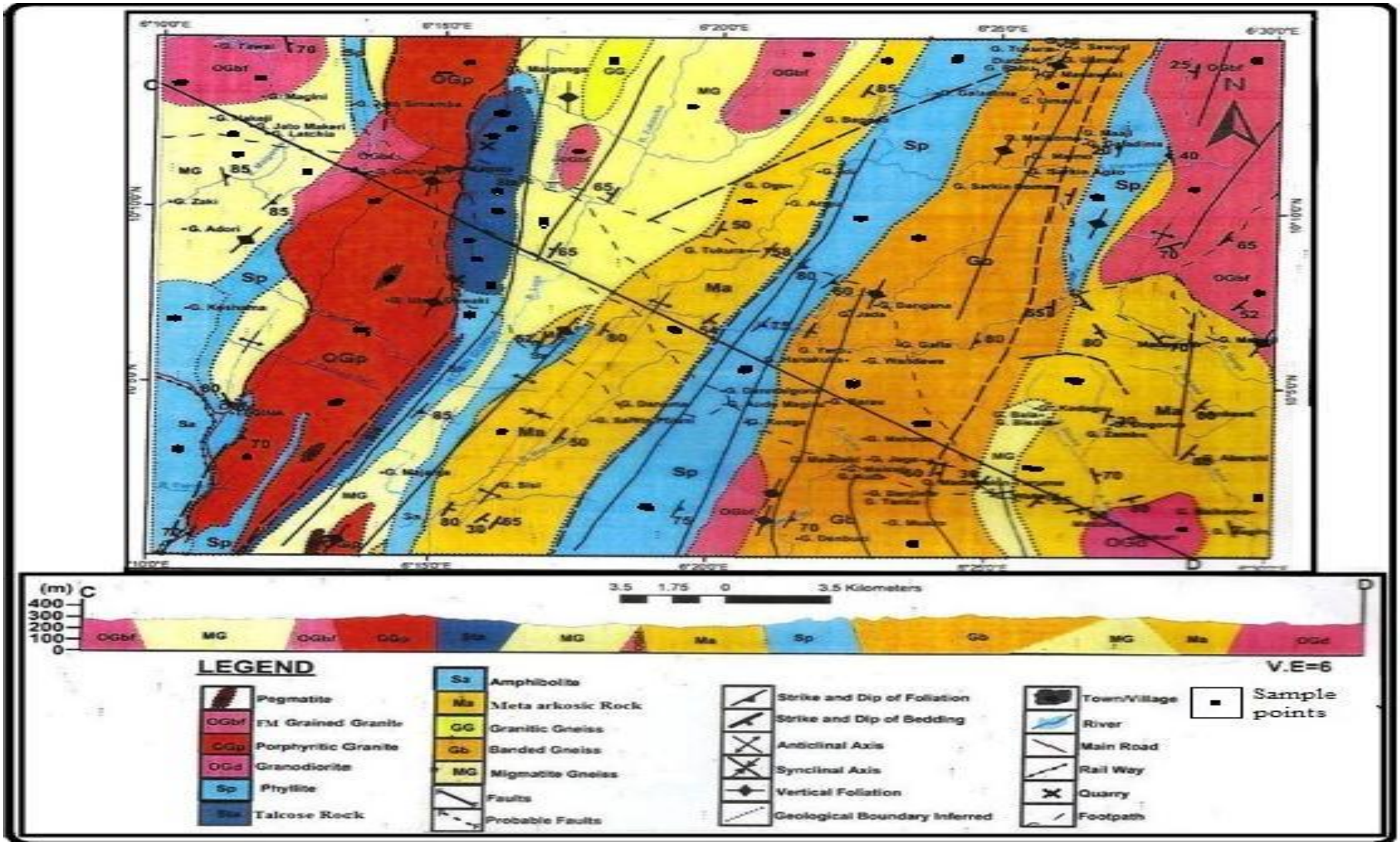


Figure 4.8: Geological map of the Kagara area

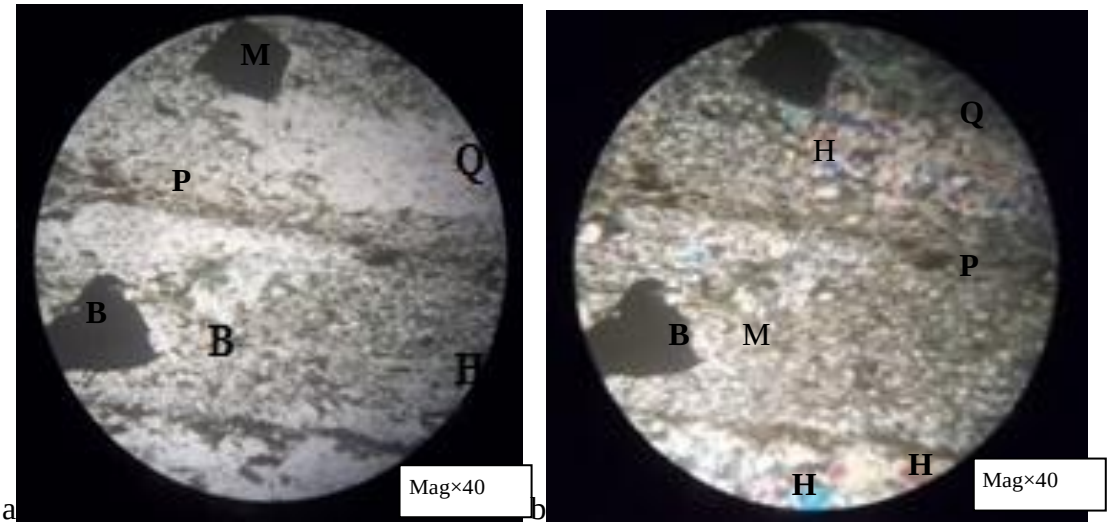
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4.3 PETROGRAPHY OF THE ROCK UNITS

Megascopic features such as mineralogic character and the general pattern of the distribution of minerals were determined by field observations in all outcrops. Field observations were complimented by laboratory examination of selected hand specimens. Thin sections were prepared for all the rock types obtained from the field to decribe the texture, mineralogy, alteration and deformation. Petrographic study can be useful in classification of rocks and their correlation with the whole rock chemical data. On the basis of the petrographic investigation; the rocks in the study area are described below while the result of modal analysis of these rocks is presented in Table (4.4).

MIGMATITIC GNEISS

The rock displayed a migmatitic texture marked by the development of foliations and lineations. The foliations are defined by the parallel arrangement of melanocratic leucocratic and light coloured minerals while the lineations are defined by low, sub parallel ribs and furrows on the cleavage surface of the rocks. The mineral grains have been highly deformed and occur as sub-anhedral to anhedral deformed grains. Under the microscope, the rocks show euhedral and anhedral crystals of dark and light coloured minerals. The migmatitic gneiss from Kagara is composed of quartz (38%), plagioclase (24%), hornblende (10%), microcline (8%), biotite (8%), muscovite (6%), pyroxene (5%) and opaque (3%). The dark coloured minerals are hornblende and biotite while plagioclase and quartz are the light coloured minerals. The orientation of the dark and light coloured minerals defines the foliations and lineations in the rock. Biotite is pale brown in colour and also exhibits pleochroism from pale brown to dark brown. Note the characteristic prismatic habit of hornblende and its preferred orientation. (Plate I).

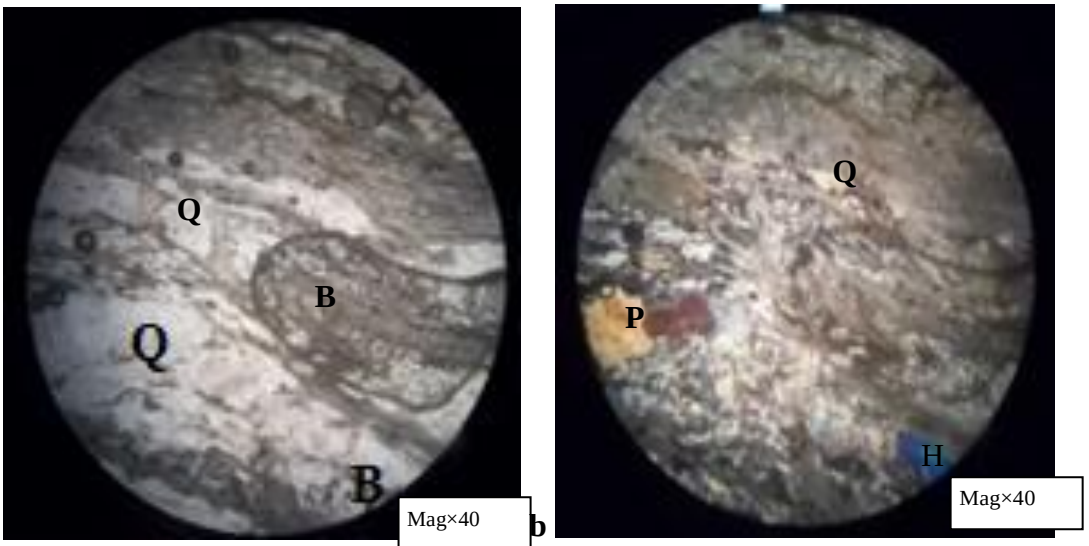


a b

Plate I: Photomicrograph of Migmatitic gneiss under (a) plane polarized light (PPL) and (b) crossed polarized light (XPL). (P)=Plagioclase (B)=Biotite, (Q)= quartz, M= Muscovite and (H)=hornblende.

BANDED GNEISS

In hand specimen the grains are medium-grained with major mafic /fesic layering, which confers strong foliation on the rock and grey in colour. The foliation is defined by streaks of biotites having narrow bands of about 0.1cm. Felsic bands are typically 5 to 10 mm apart. In thin section the banded gneiss from Kagara area is composed of quartz (28%), biotite (17%), Microcline (16%), plagioclase (15%), hornblende (13%), Muscovite (8%) and opaque (3%). Quartz is observed as sub-hedral colourless crystals exhibiting concordant fracture. Plagioclase is cloudy forms subhedral grains and displays polysynthetic twinning. Concordant fracture filled with well formed intergrowth of quartz can be observed is observed in the central and top right part of the field of view. Biotite is pale brown in colour and also exhibits pleochlorism from pale brown to dark brown. Microcline is invariably an essential mineral in this rock.The crystals of biotite are subhedral, brown in colour and of high relief (Plate I1).

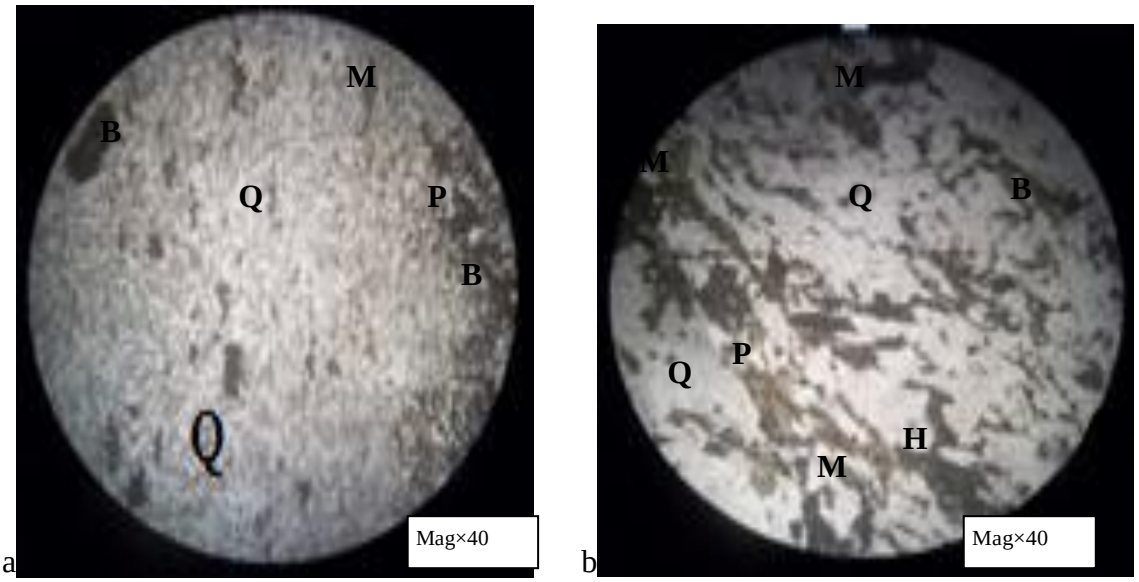


a **b**

Plate 11: Photomicrograph of banded gneisses under (a) plane polarized light (PPL) and b) crossed polarized light (XPL) P=Plagioclase, B)= Biotite, Q= quartz , H=Hornblende and with accessory minerals.

GRANITIC GNEISS

This rock type occurs mainly in the northern parts of the area close to the major shear zones (faults), (Figure 4.8). In hand specimen the rock is medium –grained, pale grey to whitish in colour largely due to abundance of quartz and fesic minerals. These rocks are foliated with strong planar preferred orientation of the constituent minerals especially, quartz (40%), microcline (40%), plagioclase (10%), biotite (5%) and hornblende (3%), magnesite (1%), opaque mineral (1%). Quartz forms colourless anhedral crystals and exhibits non- uniform extinction. Accessory minerals include zircon and magnetite. Some chlorites also occur as partial replacements of plagioclase and biotite, respective under the microscope (Plates 1II).

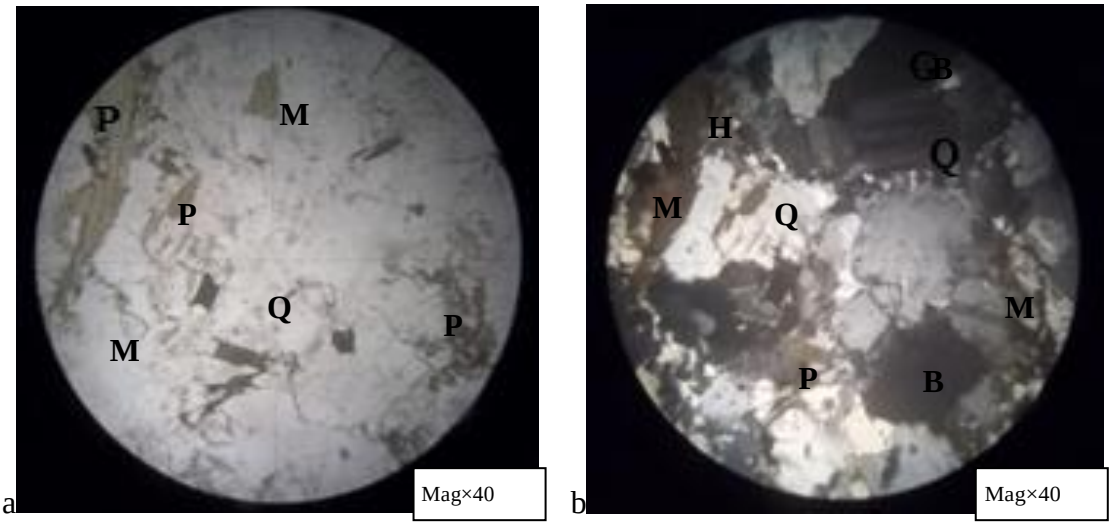


a b

Plate 1II: Photomicrograph of granitic gneiss under (a) plane polarized light (PPL) and (b) crossed polarized light (XPL) P= plagioclase, Q= quartz , M=microcline,B= biotite and H= hornblende.

META-ARKOSIC ROCK

In hand specimen the rock consists of quartz and feldspar. It displays an even texture though individual grains are irregularly shaped. Under the microscope, the rock shows variable grains of minerals closely packed showing preferred orientation. In thin section the meta-arkosic rock from Kagara area is composed of microcline (45%), quartz (35%), plagioclase (10%), biotite (5%), magnetite (3%), opaque mineral (2%), The quartz forms colourless subhedral crystals and exhibiting undulose extinction. The plagioclase occurs as a colourless mineral, which is sub-hedral to euhedral in shape. It shows pleochroism from dark brown to black. Biotite appears pale green in colour, pleochroic, with moderate- low relief (Plate IV).

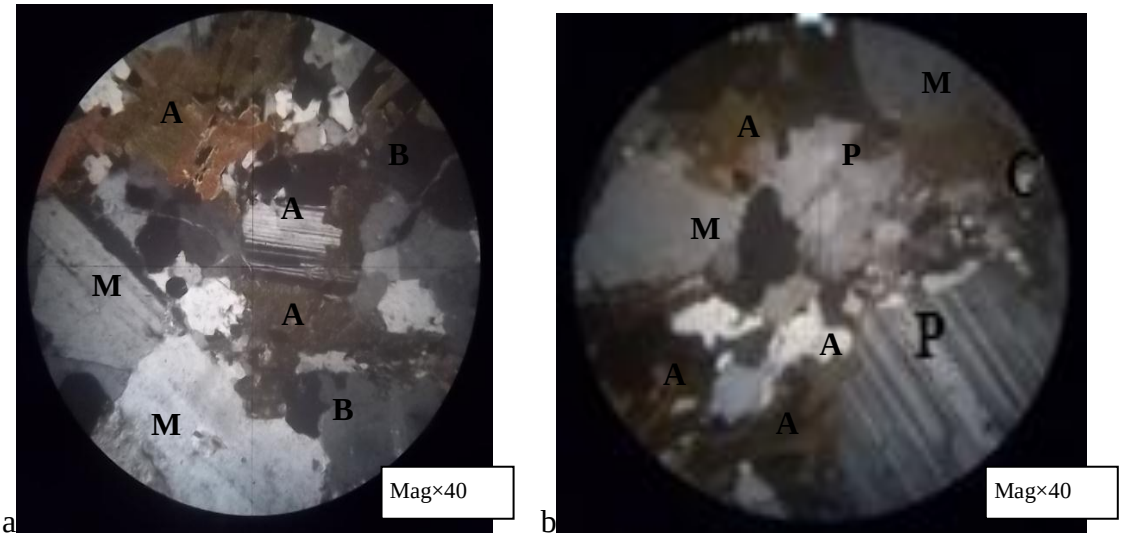


a b

Plate IV: Photomicrograph of Meta arkosic rock under PPL (a) and XPL (b) (B) = biotite, (Q) = quartz, (P) = plagioclase, H=hornblende

AMPHIBOLITE

In Kagara area, N-S trending lenticular, massive, and strongly foliated amphibolite varieties occur. In hand specimen, the rocks are medium grained, well foliated; with very little segregation banding occurs in the rocks sampled. Under the microscope, the rock is composed of amphibole (40%), plagioclase (28%), quartz (15%), clinochore (7%), as essential mineral constituents while Magnetite (2%) with epidote (1%) forming the accessory minerals (Plate V)

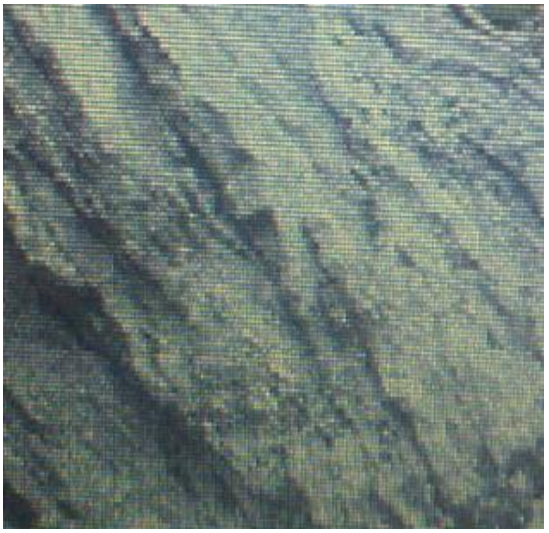


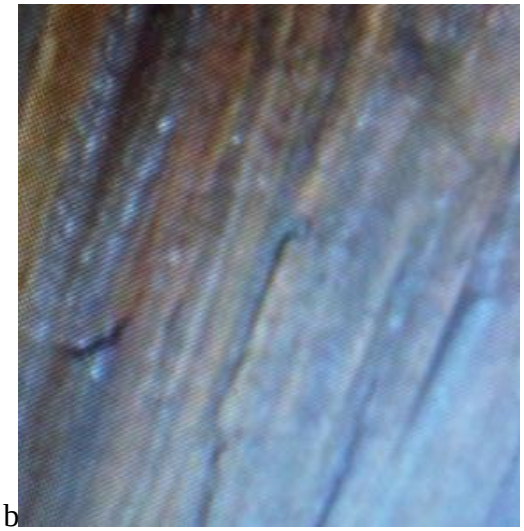
a b

Plate V: Photomicrograph of amphibolite from Teri in (a) plane polarized light (PPL) and (b) crossed polarized light (XPL), (C) = Chlorite, Q= quartz, P= Plagioclase, A= Amphibole, B=Biotite, M=Muscovite and accessory minerals.

TALCOSE ROCK

The colour of the talc varies from grey, white to pale brown and green depending on the relative mineral constituent with a soapy feel when touched. The chlorite content of the talcose rock is reflected in its green colour, Plate $V1_a$ where anthophyllite dominates the samples are white while the tremolite is indicated by brown colour where present Plate $V1_b$; Chlorites are observed as long – rod crystals with talc minerals. In thin section talcs are the most abundant minerals constitute (38 – 40) %. Talc occurs as thin colourless fibrous minerals, scattered green, pleochroic minerals with moderate relief as long, thin, grains showing some evidence of preferred orientation of the long axes Plate $V1_{c-d}$. The chlorite constitutes (17 - 20) %, and magnesite are octahedral in shape constitute (9- 10) % Plate VI_f. Tremolite (10 - 11) %, occurs as coarse-grained crystals up to 1cm long of prismatic habit. Most of tremolite is partly or completely replaced by talc. A decussate arrangement of short and long prismatic anthophyllite (7- 8) %, within talc matrix in crossed polarized light (XPL) Others are actinolite (11-13) % and magnisite (9-10) %, magnetite (1-2) % and quartz (1-0) % and opaque minerals Plates (VII) and Plate VIII).



b 

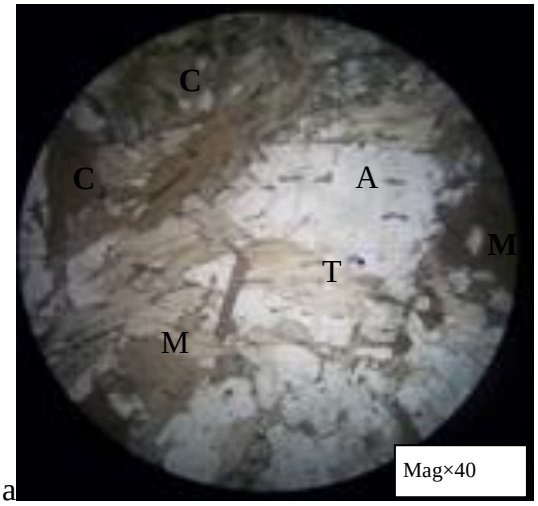
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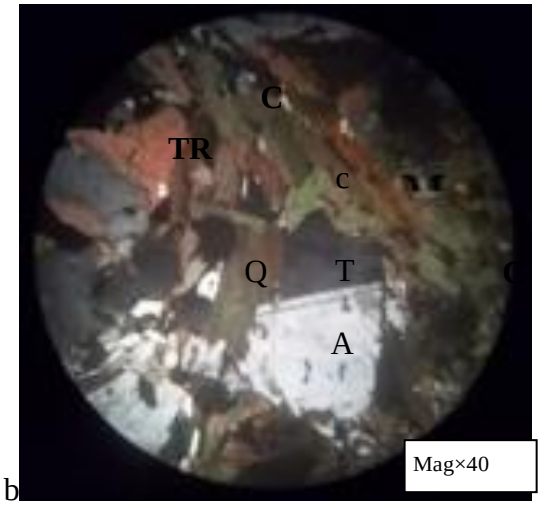
e 

f 

Plate VI Photographs of talcose showing (a) lenticular shape (b) dark green variety (c and d) pods of talc within a talcose rock, (e) general appearance on the field with vein plunging NE direction, (f) Octaheral crystals of Magnetite in talcose rock from Kagara area.



a

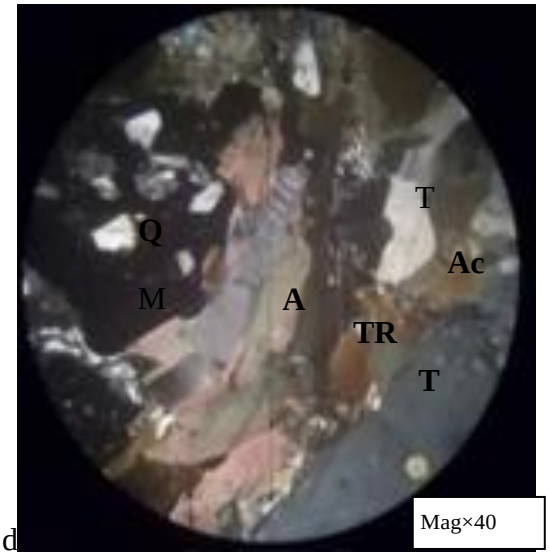


b

Plate VII: Photomicrograph of talcose rock in (a) plane polarized light (PPL) and (b) crossed polarized light (XPL); (A) = Anthophyllite, (C) = Chlorite, (M) = Magnetite, Ac= Actinolite, Q=Quartz, (TR)=Tremolite.



c



d

Plate VIII: Photomicrograph of talcose rock in (a) plane polarized light (PPL) and (b) crossed polarized light (XPL); (A) = Anthophyllite; (C) = Chlorite,(M)=Magnetite;Ac= Actinolite, Q=Quartz, (TR)=Tremolite

PHYLLITES

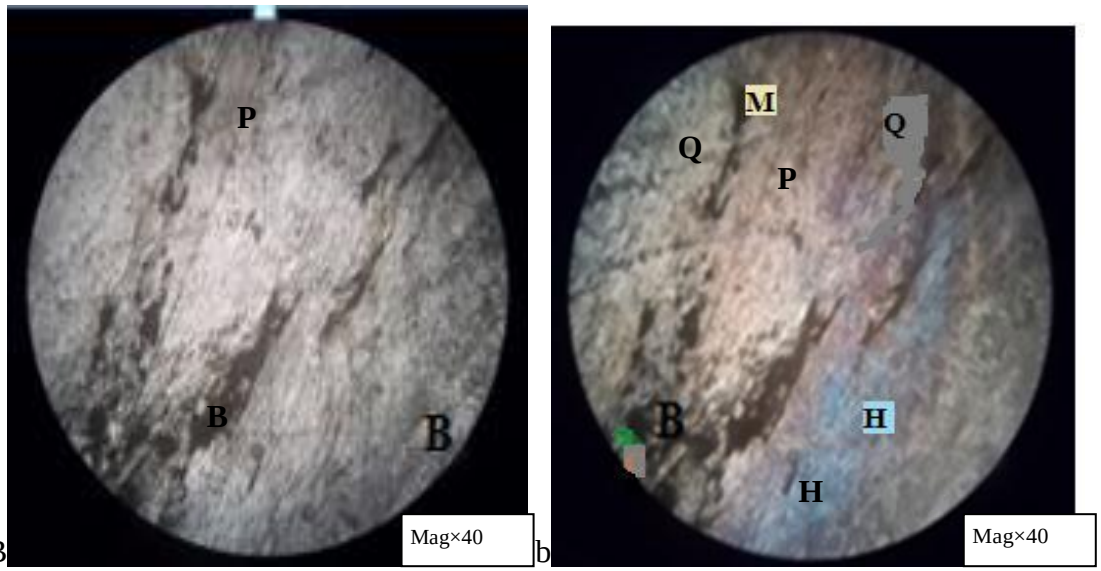
Megascopically, the rock is fine grained and show well developed foliation. It is widespread in Galadima - Sarkin Fulani of the study area where it outcrops in a N-S trending show and show a variable of colours such as light grey, dark grey, green and brown/red. The phyllite layers vary from those made up of homogeneous fine-grained chlorite with some pyrite to those containing rounded particles of chlorite (12 mm in

diameter) in a chloritic matrix (Plate IX). Study of thin sections reveals that it is composed of quartz (25%), biotite (20%), hornblende (20%), plagioclase (15%), pyroxene (14%), muscovite (2%), epidote (1%) and opaque minerals (3%) as essential minerals. In most cases, pyrite, is altered to limonite (pseudomorphs) and is characterized by the presence of tails of non-ideal simple stress.



Plate IX: Photograph of phyllite at Gora displaying the cleavages along the bedding plane (Latitude $10^0$14'56''N and Longitude $006^0$27'28''E)

The sub rounded quartz grains in the phyllite are generally separated by the chloritic matrix, with many grains exhibiting fuzzy boundaries and undulatory extinction (Plate X).

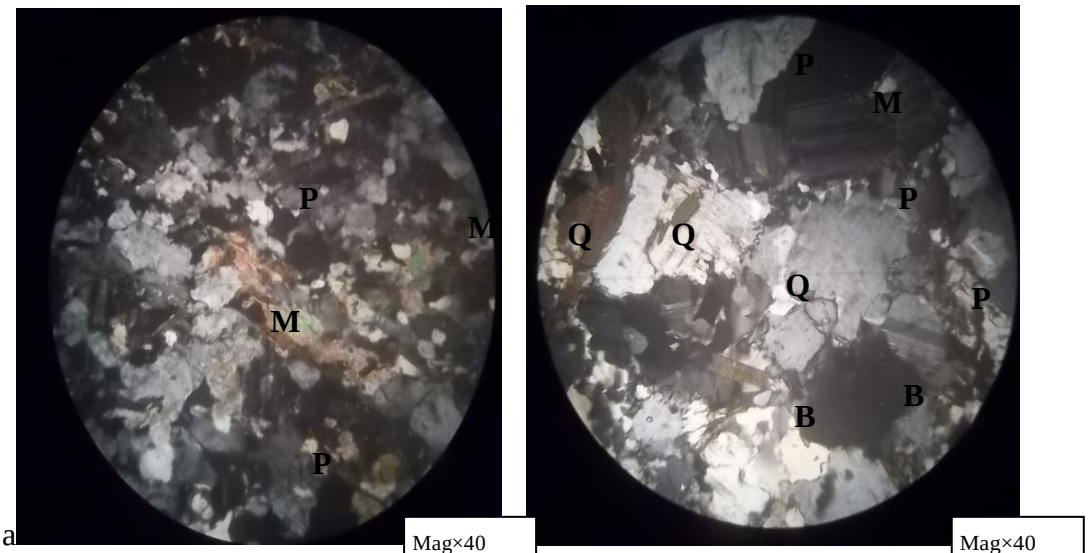


B b

Plate X. Photomicrograph of phyllites under (a) plane polarized light (PPL) and (b) crossed polarized light (XPL) (B) = Biotite, (Q) = quartz, H= Hornblende, (M) =Microcline, and (P) =plagioclase.

PORPHYRITIC GRANITE

In hand specimen, it is composed of interlocking feldspars and quartz crystals, and biotite all in shades of dark grey through grey to white. The rocks have very large feldspar crystals set medium-fine grained groundmass, thus in giving the rock a porphyritic texture. In some places, the quartz and feldspar form pairs of crystals growing through each other in a complex pattern resulting in an intergrowth. Under the microscope, the rock is seen to be composed of quartz (33%), plagioclase (29%), microcline (17%), biotite (10%), pyroxene (9%) and opaque minerals (2%). Quartz is the most abundant mineral and is easily distinguishable from other minerals due to the unaltered nature and lack of twining and cleavage. It occurs as a colourless mineral with a low relief and does not exhibit pleochroism. Under XPL, twining is observed in plagioclase crystals, characterized by polysynthetic twining of plagioclase. Biotite is relatively characterized by its anhedral shape, pleochroic in nature and a high relief (Plates XI). Under XPL revealed anhedral quartz crystals with variable interference colours sandwiching plagioclase and other minerals (Plate XI).

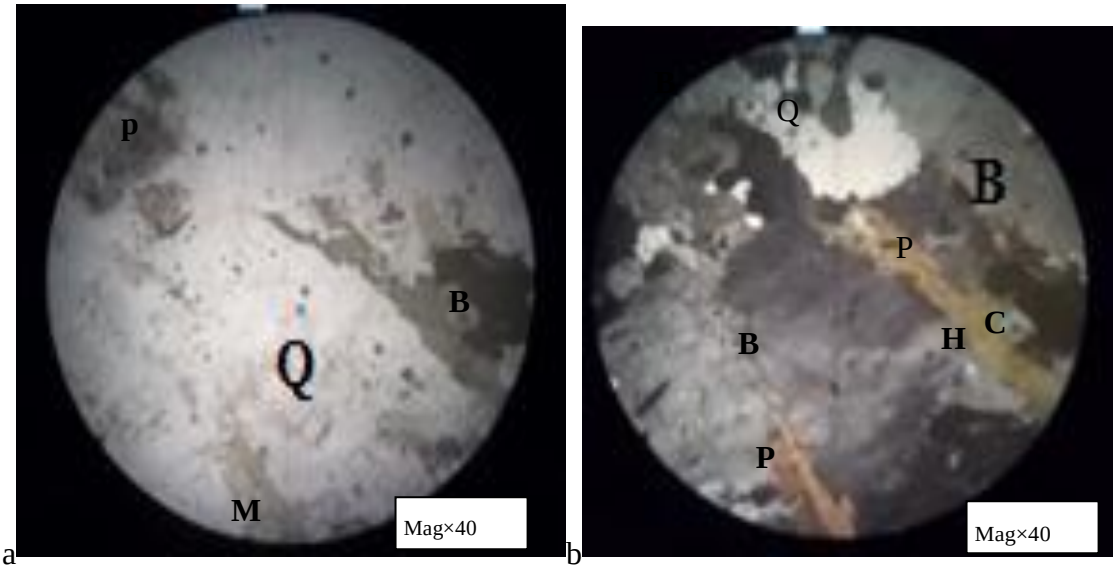


a

Plate X1. Photomicrograph of porphyritic granite under (a) plane polarized light (PPL) and (b) crossed polarized light (XPL) P= Plagioclase, B=Biotite, M=Microcline and Q=quartz.

FINE - MEDIUM GRAINED GRANITE.

In hand specimen, the rock consists dominantly of feldspars, quartz and biotite and is generally pink in colour. Under the microscope, the rock is seen to contain quartz (38%), biotite(17%), microcline (24%), pyroxene (11%), plagioclase (6%),and opaque moinerals(4%), together with small amounts of hornblende and biotite accounting for (16%) of the total mineral content. Accessory minerals include magnetite and epidote. Hornblende and biotite are the main dark coloured minerals in the rocks. Due to shearng most of the crystals have preferred orientation resulting in ribbon shaped fabrics (Plates XII).

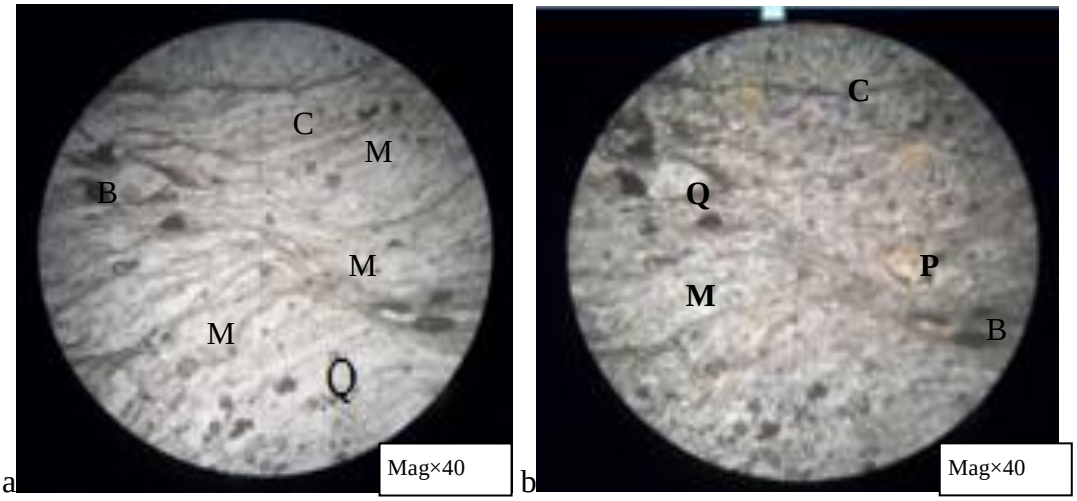


a b

Plate XII: Photomicrograph of Fine -Medium-grained granite with Q= quartz, P = Plagioclase, B=Biotite, M=Microcline.

GRANODIORITE

In hand specimen, the rock is medium grained in texture and occurs as large boulders of low lying hills. The rock is composed of essentially feldspars, biotite and quartz. Microscopic observation indicates that the rock is composed of essentially plagioclase (35) %, quartz (25%), biotite (20%), and microcline (20%). Epidote and magnetite occur as accessory minerals (Plate XIII).



a b

Plate XIII: Photomicrograph of granodiorite under (a) plane polarized light (PPL) and (b) crossed polarized light (XPL); (P)= Plagioclase, Q=quartz and B=biotite

PEGMATITE

The pegmatite occurs as N–S trending veins in the granite especially along Tegina – Majanja - Gora in the southwestern part of the study area. A pegmatite vein trending NE-SW is exposed along Durumi stream channel (northeast of Kagara) where it intrudes medium- grained granite. It is fractured and composed of very coarse alkali feldspar with crystal measuring up to six centimetre (cm) long, quartz measuring up to two centimetre (cm) and mica measured up to one centimetre (cm) long (Plate XIV). Under the microscope the microcline feldspar exhibits characteristic strong cross hatched (multiple) twinning. Plate (XV) reveals anhedral quartz crystals with variable interference colours.



b

Plate XIV: Pegmatite vein North of Gora trend N-S (Latitude 10^0 07’40’’N and Longitude $10^0$14’56’’E)

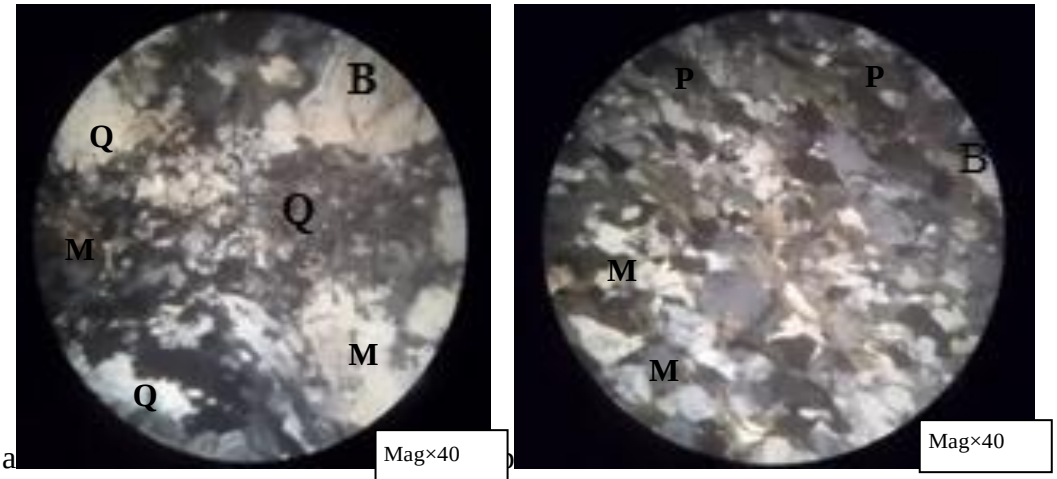


Plate XV: Photomicrograph of pegmatite from Gora area in (a) plane polarized light (PPL) and (b) crossed polarized light (XPL) B= Biotite, (Q) = Quartz

Table: 4.4 Modal compositions of talcose rock and host rocks from the study area (%)

P=Pegmatite; GD =Granodiorite; FM=Fine- Medium-grained granite; PG = Porphyritic granite, AM =Amphibolite, PY=Phyllite, TS= Talcose rock; GG=Granitic Gneiss, BG =Banded gneiss, MG= Migmatitic gneiss, MR= Meta-arkosic rock

Minerals	**GD**	**FM**	**PG**	**AM**	**PY**	**TS**	**TS**	**GG**	**BG**	**MG**	**MR**
Quartz	24	38	33	15	25	2	1	40	28	36	35
Plagioclase	35	6	29	28	15	-	-	10	15	24	45
Microcline	10	24	17	-	-	-	-	40	16	8	10
Muscovite	-	-	-	-	2	-	-	-	8	6	-
Biotite	20	17	10	-	20	-	-	5	17	8	5
Hornblende		-	-	-	20	-	-	3	13	10	-
Clinochlore	-	-	-	7	-	1	-	-	-	-	-
Amphibole				40							
Pyroxene	10	11	9	-	14	-	-	-	-	5	-
Talc	-	-	-	-	-	38	40	-	-	-	-
Actinolite	-	-	-	-	-	13	11	-	-	-	-
Anthophyllite	-	-	-	-	-	8	7	-	-	-	-
Chlorite	-	-	-	5	-	20	17	-	-	-	-
Magnesite	-	-	-	-	-	9	10	-	-	-	-
Magnetite	1	-	-	2	-	1	2	1	-	-	3
Epidote	-	-		1	1	-	-	-	-	-	-
Tremolite	-	-	-	-	-	10	11	-	-	-	-
Opaque(others)	-	4	2	-	3	1	1	1	3	3	2
Total	100	100	100	100	100	100	100	100	100	100	100

4.4 X-RAY DIFFRACTION ANALYSIS

X-ray diffraction studies were carried out in order to determine the mineralogical compositions of talc and host rocks. The mineralogical compositions of talcose rock and the host rocks from Kagara are shown in Table (4.5) while the mineral assemblages developed in individual samples including talc are listed in Appendices (II-V)

The result of X-ray diffraction show conspicuous peaks of talc, chlorite and magnetite in assemblage of the talcose rock, while Clinochlore / Ferroan and quartz are major constituents in the amphibolites. Other minor peaks include those with spinel structure, magnesite and biotite minerals from biotite group.

Table 4.5: Composition of the Samples from the XRD Analysis.

Sample Code	**Fomular**	**Mineral**	**Percentage (%)**
$L8_a$ (amphibolites)	$(Mg, Fe)_6(Si,Al)_4O_{10}(OH)_8$	Clinochlore,/ Ferroan	48
	SiO_2	Quartz	52
$L11_a$ (amphibolites)	SiO_2	Quartz	48
	$(Na,Ca)Al(SiAl)_3O_8$	Albite	6
	$H_2KAl_3(SiO_4)_3$	Muscovite	3
	$KMg_{1.3}Ti_{0.3}Fe_{1.7}Al_{1.2}Si_{2.8}O_{11(OH)}$	Biotite	27
	$(Mg,fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	Clinochlore / Ferroan	18
$L13a_2$ (talcose rock)	$Mg(CO_3)$	Magnesite	20
	$(Mg,Fe)Al)_6(Si,Cr)_4O_{10}(OH)_8$	Clinochlore,/ Ferroan	40
	Fe_3O_4	Magnetite	3
	$Mg_3Si_4O_{10}(OH)_2$	Talc	38
$L15_a$ (talcose rock)	SiO_2	Quartz	5
	$(Na,Ca)Al(SiAl)_3O_8$	Albite	3
	$KMg_{1.3}Ti_{0.3}Fe_{1.7}Al_{1.2}Si_{2.8}O_{11(OH)}$	Biotite	7
	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	Clinochlore	37
	$Mg_3Si_4O_{10}(OH)_2$	Talc	45
	$KA_{l2}(Si_{3Al}O_{10}(O)_{10}(OH,F)_2$	Muscovite	3

4.5 STRUCTURES

The structures mapped and interpreted in the study area consist of those formed due to ductile deformation (foliations and lineations) and brittle deformation (joints and faults). The major structural trend is NE-SW with minor NW-SE.

4.5.1 FOLIATION

Foliation is common in banded and migmatitic gneisses in the study area, It occurs as simple banding of dimentional oriented minerals. In the gniess, foliation is defined by parallel alignment of alternating quartz and mafic minerals (Plate XVI). The predominant trend observed is NE-SW with average dip of 40^{o}NE.



Plate XVI: A foliation on banded gneiss North of Gora displaying the trends in NE-SW (Latitude 10^{0} 11’57’’N and Longitude 10^{0}13’56’’E)

4.5.2 LINEATION

Lineation is common in migmatitic gneiss in the study area. Lineation in the rocks is displayed by the parallel crystal arrangement or preferred orientation of dark and light coloured minrals in. The dark coloured minerals are the ferromagnesian minerals

(hornblende and biotite) while the light coloured minerals are the quartzo-feldsparthic minerals (quartz and feldspar) (Plate XVII).



Plate XVII: Photograph of lineations in migmatite around Madaka Latitude 10^0 02'' 50'''N and Longitude 006^0 27''50''E).

4.5.3 JOINTS

These structures occur in all the rock types although very pronounced in the granites. The joint spacing was within the range of a few millimetres to 10 cm in areas where they occur as a joint set. In some places, they cross-cut the rocks horizontally while in others vertically which indicates complex tectonism. The general orientations of joints are E-W and ENE-WSW thus suggesting dominant N-S or NNW-SSE directed stresses. Next to the dominant strike dircetions are N-S, NE-SW and minor NW-SE orientation joints. The strike direction of joint values recorded in the field ranges from 10^0-35^0. In some places, the joints have been filled with silica material probably quartz resulting in the cross cutting relationship which enables one to determine their order of formation (Plate XVIII)

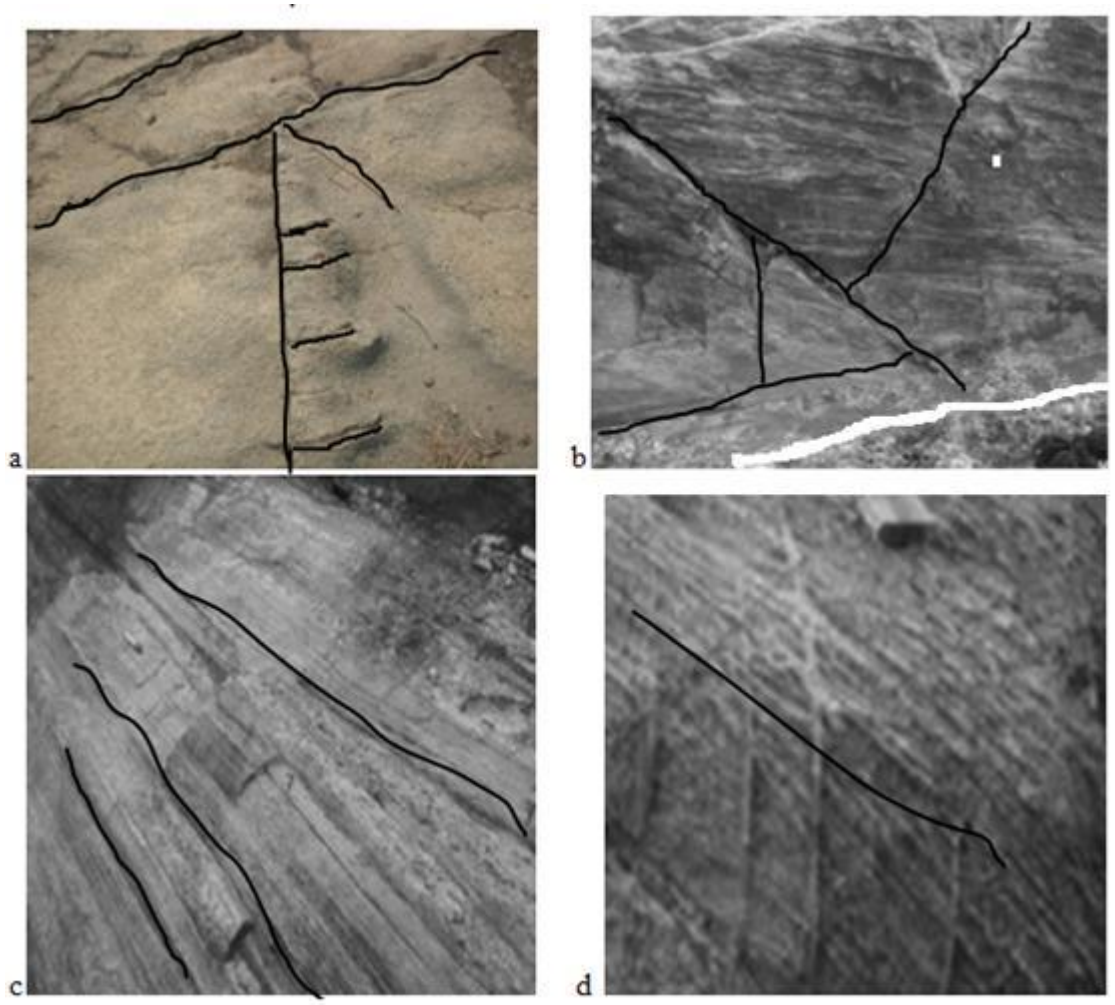


Plate XVIII: Photograph of joints in (a) granite displaying crosscutting relationship that provided a guide to the recognition of the two generation of joints on the outcrop South of Tegina- Ogu (Latitude 10^0 07'40''N and Longitude $006^0$13'55''E),(b) Conjugate joints North of Supana (Latitude 10^0 09'24''N and Longitude $006^0$15'55''E) (c) Joints running parallel to Pegmatite intrusions south of Dawaki (Latitude 10^0 07'10''N and Longitude $006^0$12'50''E), (d) Joint run parallel to foliations North of Ogu (Latitude 10^0 07'40''N and Longitude $006^0$17'30''E)

4.5.4 FAULTS

The faults in the study area are part of the major transcucurrent fault system known in Nigerian Precambrian basement trending mostly in the NE-SW and NNE-SSW (Figure 4.8). Faults which are of regional extent have been mapped in the study area. Two northward-trending steeply dipping faults (sinistral) with more than hundreds of km displacement have been mapped by Cope and Truswell, (1963). Theses faults appear to have appreciable horizontal components of displacement in the study area,

also normal faults with small displacements of the order of 5-25 cm were obeserved in the field (Plate XIX).



Plate XIX: Photograph of a normal fault recorded that occurred in the amphibolite (Latitude 10^0 07 ''11''N and Longitude 006 ^{0} 12''56''E).

4.5.5 LINEAMENTS

Principal Component Analysis was applied to the six bands (1/5 and 7) of Landsat ETM image to compress the information into three bands (Figure 4.9) (Appendix I). The prevalence of lineaments is an indication of high tectonic activity which in turn may indicate a possibility of mineral deposition (Table 4.6) presented the statistics of the principal components (PCs) within the study area. This table shows the anomaly of the Eigenvalues decreasing with variance in successive principal components. The first principal component contains 87.108 % of the total variance. The first three components contain 96.5% percent of the total variance within the whole volume of data of six bands details in Table (4.6) for Eigen values of PrincipalComponent Analysis (PCA) (Figure 4.10)

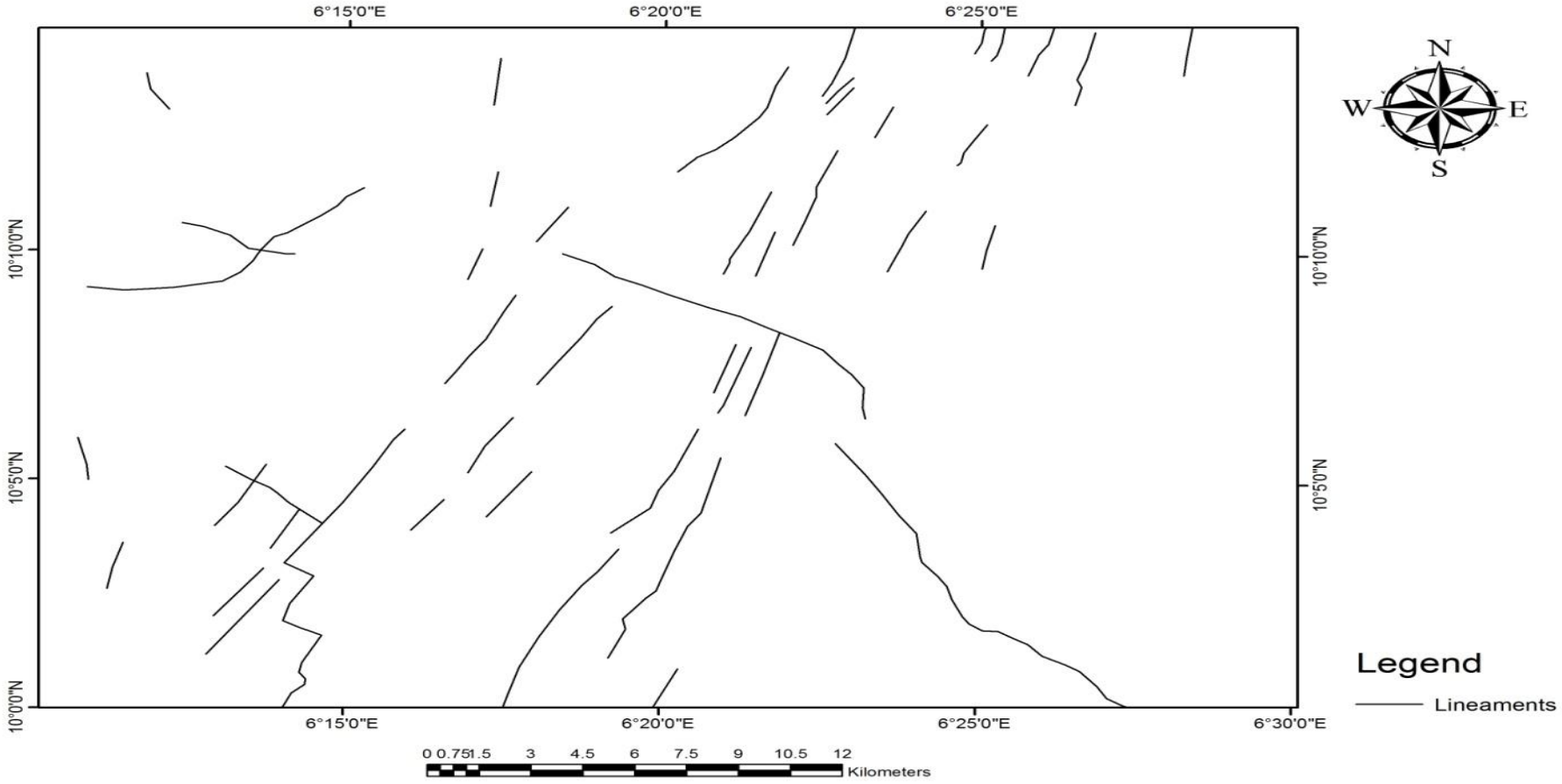


Figure 4.9: Lineaments map of the study area,

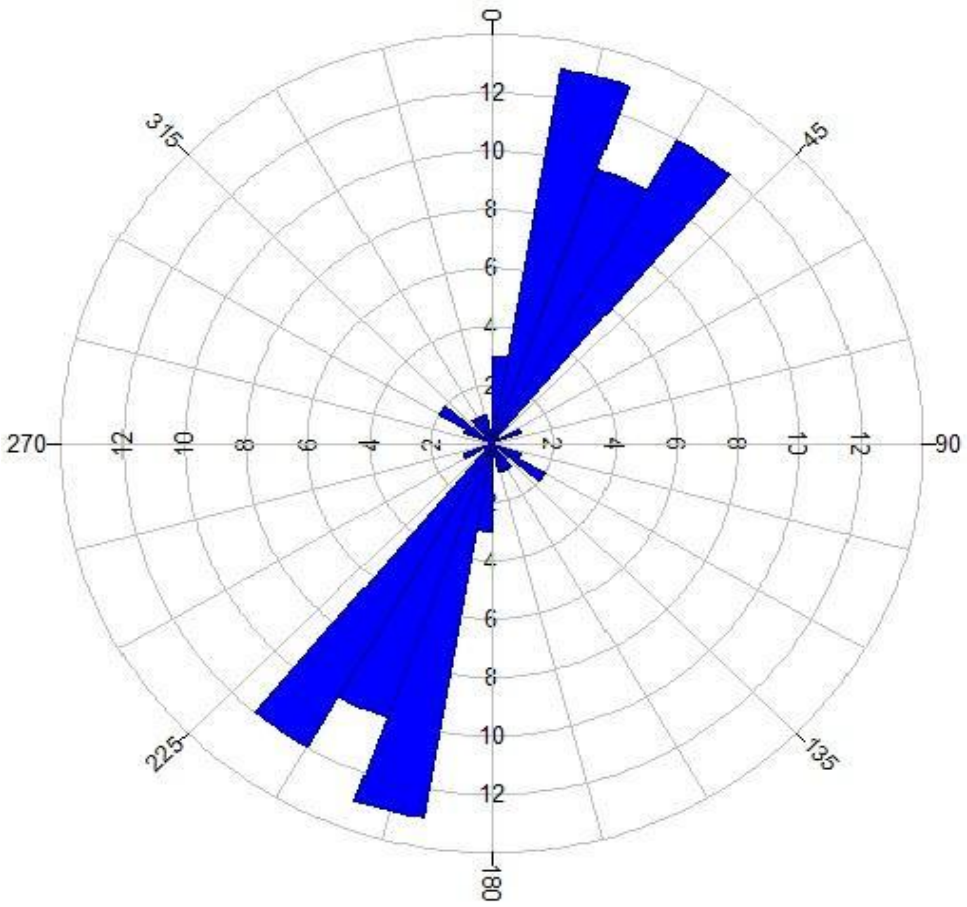


Figure 4:10: The rose diagram for the Lineaments of the study area

Table 4.6: Eigen vectors and Eigen values of the PCA of the Landsat ETM data

Eigenvector	ETM 1	ETM 2	ETM 3	ETM 4	ETM 5	ETM 6	Eigen value	Eigenvalue (%)
PCA 1	0.065	0.108	0.259	-0.118	0.665	0.679	180.735	87.108
PCA 2	0.071	0.020	0.225	-0.818	-0.474	0.226	13.641	6.574
PCA 3	0.071	0.319	0.697	0.441	-0.339	0.062	5.846	2.818
PCA 4	0.390	0.134	0.259	-0.339	0.457	-0.663	3.192	1.538
PCA 5	0.821	0.095	-0.512	0.048	-0.100	0.207	2.543	1.226
PCA 6	-0.258	0.927	-0.259	-0.076	-0.006	-0.031	1.527	0.736

A convolution filtering algorithm involving Directional Gradient-Sobel filters was applied on the False Colour Composite image of the PCA bands in N-S, E-W, NE-SW and NW-SE directions to increase frequency and contrast in the image.

All the lineaments extracted from the satellite map were labelled from the NE anticlockwise back to the starting point. Other linear structures on the maps correspond to major roads, footpath and fence line. Lineaments were picked with high degree of certainty on the basis of their colour contrast relative to their environment of occurrence.

The rose diagram (Figure 4.11) shows the directional frequency of the mapped lineaments in the study area. The dominant orientation of the lineaments is NE-SW, while the less dominant is NW-SE, and minor is ENE-WSW direction.

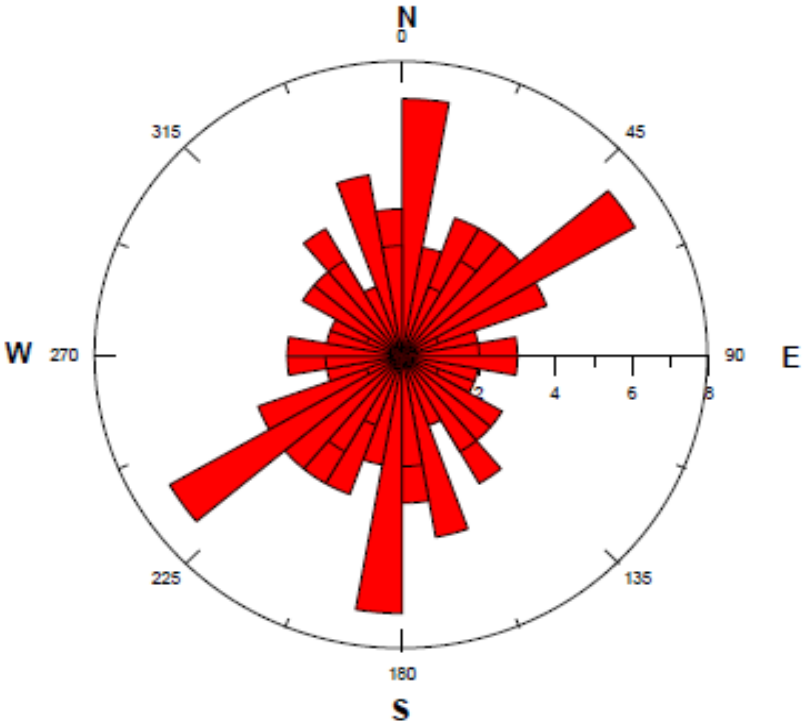


Figure 4.11: Rose diagram for the structural trend of joints in granitic rocks in the study area.

On the basis of the strike of the lineament, the area was subdivided into two structural domains; NE-SW and NW-SE oriented lineaments. Structural domains

contain lineament facies i.e. lineaments that trends in the same direction and were produced by same tectonic event Figure (4.26)

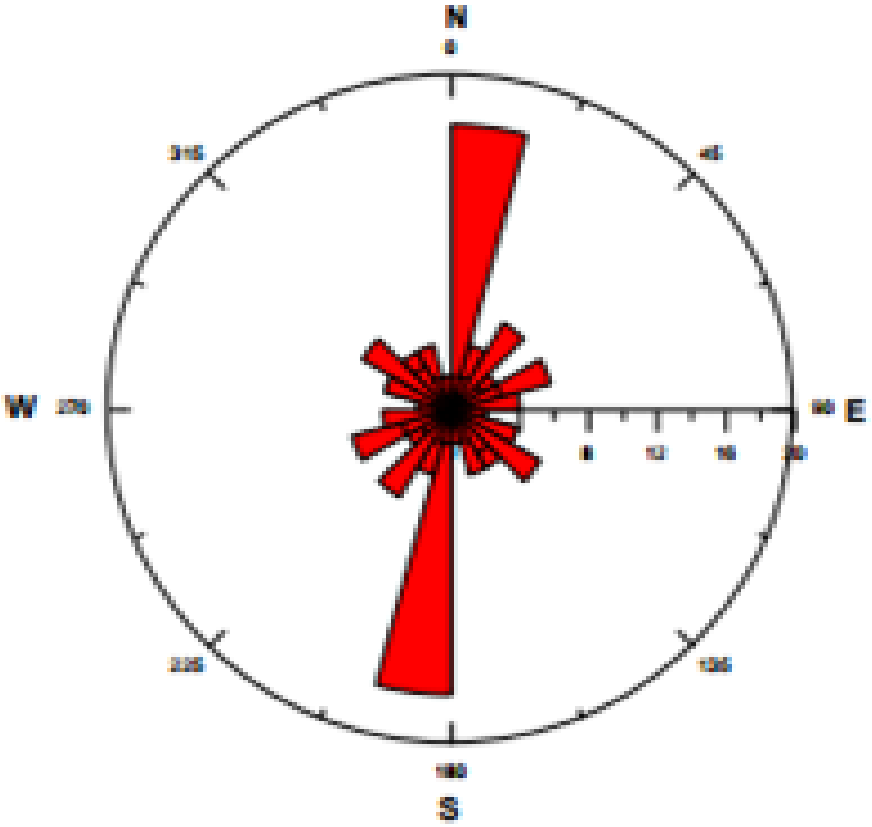


Figure 4.12: Rose diagram for the structural trend of foliation in metasedimentary rocks in the study area.

Two major structural domains were identified from the lineament map. These are NE-SW and NW-SE with dominant orientation of lineament being NE-SW, suggestive of NW-SE tectonic (extensional forces), minor ENE-WSW and E-W orientation suggestive of shearing evidenced by conjugate joints sets were also recorded. Evidence from the lineament density map suggest that the NE and NW parts of the study area were highly dense while the SW and E-SE parts were less dense or near zero relative to lineament concentration. This same trend was earlier observed during the ground mapping by Ihaza *et al.*, (2014). There is overlap between the minor NW-SE / ENE-WSW orientations in lineaments and joints. This implies that these fractures in both cases were produced by similar tectonic events while other orientations are product of

dissimilar tectonic events / regimes.

4.6 METAMORPHISM AND TECTONIC ACTIVITY IN THE STUDY AREA

The study area has been affected by dynamic metamorphism and this is largely reflected in the main phase of deformation of the rocks (Plate XIX). Fracturing is generally intense on amphibolite (Plate XIX). In thin section, it is commonly observed that the amphibolite has been altered to sequences of protomylonite and cataclastite with intensively transposive cataclastic fabrics (Plate V). The prevalent structures in the study area are laminations on which strong and penetrative stretching lineations is developed (Plate XIX). Locally, near the margins of the granites at Dangwari, metamorphism and metasomatism have been superimposed on Banded gneiss.

The rocks in the study area are believed to be the result of the Pan-African deformation and accompanying regional metamorphism, migmatization, extensive granitization and gniessification which produced syntectonic granites and homogenous gneisses. Late tectonism and emplacement of granites, granodiorites and associated contact metamorphism accompanied the end stages of this last deformation episode (Table 4.7). Field observation reveal that the contact of the amphibolite with the surrounding rocks is marked by development of cataclastite which represent a major fracture zone with either joint or fault as the structural elements (Figure 4.8).

The foliation recorded on outcrop of gneiss is related to the metamorphic events which were observed as segregation of minerals into mafic and felsic bands. This event can be related to recrystallization of minerals during regional metamorphic episode. The foliation planes which were later folded into recumbent / asymmetrical folds by apparently E-W directed maximum stress is at attributed to the process of regional metamorphism (Plate XX). The metamorphism in the study area is reflected through

deformation that linked with recumbent folding (Plate XXI) of the dominant vein in NE-SW suggesting of a NW-SE directed minimum stress that result to sharp contact of the amphibolite and the talcose rock (Plate XXII).

The minerals in the study area are characterized with high pressures and variable temperature equations (i) and (ii) below

quartz + albite + muscobite +chlorite——> amphibolite……..……..(i)

chlorite + tremolite / actinolite + quartz ——> talcose rock…….…….…….(ii)

The study area lies within the Kushaka belt that composed of low-grade deformed metasediment and metavolcalnic that are intruded by granitoids whose metamorphism grades varies from low to middle amphibolites (Ajibade, 1980, Fitches *et al;* 1985, Danbatta, 2001). The presence of chlorite and tremolite are clear indication of greenschist facies. The greenschist facies comprises of rocks formed under low temperature (low grade) and as a result, greenish minerals predominates

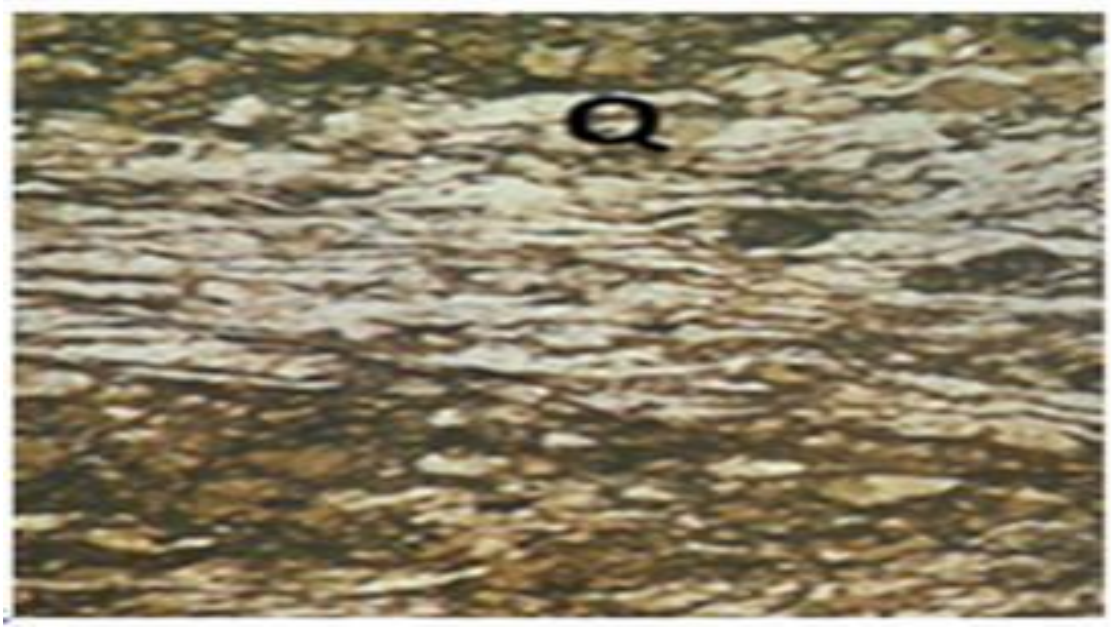
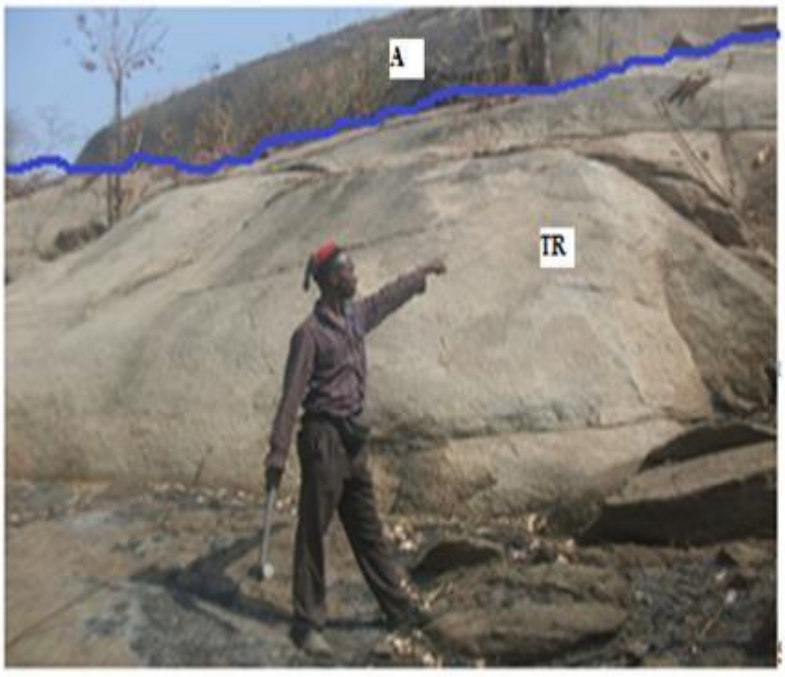


Plate XX: Photograph of amphibolite displaying planar arrangement of dimensionally oriented mineral in the rock.



Plate XXI: Recumbent fold in amphibolite with granitic material along the nose of the fold South of Gumna-Supana Latitude 10^0 04'' 50''N and Longitude $006^0$27''50''E).



KEY

A: Amphibolite

TR:Talcose rock

Plate (XXII): Photograph of the contact between talcose rock and amphibolite North of Kumunu, a few Km to Tegina (Latitude 10^0 13'57''N and Longitude 006^0 17'56''E).

TABLE 4 .7: SEQUENCICAL ORDER OF EVENTS IN ROCKS FROM THE STUDY AREA (Danbatta, 2002).

EVENT	GEOLOGICAL HISTORY	ROCK TYPES
Late Pan-African	Granite intrusion and fracturing	Older Granites, joints, faults, pegmatite vein
Early Pan-African (metasediment; Metavolcanic)	Orogenesis, deformation and metamorphism.	phyllite, amphibolite, and talcose rock. Meta-arkosic rock
Kibaran / Eburnean	Deposition, deformation, Metamorphism.	migmatitic gneiss; Banded gneiss

4.7 GEOCHEMISTRY

4.7.1: MAJORELEMENTS COMPOSITION

Major elements composition provides information on theelemental concentration for use in establishing the geological, geochemical and thegeotectonic processes that have takes place in the study area.

Oxide of the major elements concentration provides the basis for a comprehensive rocks classification. Major elements composition of the samples of talcose rock and other rocks from the study area are presented in Table (4.8). The major elements compositions of the rocks in the study area are discussed below:

SiO_2 concentration ranges from 28.63 - 74.28 wt %, Al_2O_3 ranges from 0.58 -18.27 wt %, Fe_2O_{3T} ranges from 0.98 – 8.88 wt %, MgO ranges from 0.19 .15 wt %, L.O.I ranges from 0.40 – 22.60 wt %, from the rocks in the study area. In addition, the concentration of CaO, Na_2O, K_2O, MnO, TiO and P_2O_5 from the study area also varies from 0.02-5.38 wt %, 0.33 – 8.14 wt %, < 0.01 – 3.49 wt %, 0.033 -0.155 wt %, 0.02 – 1.213 wt %, < 0.01 – 0.25 wt % respectively. SiO_2 content is greatly high in migmatitic gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolite, phyllite, granodiorite, porphyritic granite, and fine-medium grained granite from the study area but poor in talcose rock.

Al_2O_3 concentration in the host rocks does not show a strong variation as they relatively close to each other indicating a close relationship between the rocks wheras talcose rock show a strong variation of Al_2O_3 that range from 0.58 - 17.11 wt %.

The chemical composition of talcose rock from Kagara area shows that talcose rock

is rich in MgO and L.O.I but poor in migmatitic gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolite, phyllite, granodiorite, porphyritic granite, and fine-medium grained granite from the study area (Table 4.8).

Concentration of Fe_2O_{3T} is higher in talcose rock than other rocks from the study area. The stability of iron – bearing minerals is dependent on the oxygen fugacity $f(O_2)$ in a system. Total iron increasing with decreasing in silica reflects the late crystallization of iron oxides in the study area.

The compositions of CaO, Na_2O, K_2O, P_2O_5 and TiO_2 are generally low in talcose rock compared to values obtained in other rocks from the study area (Table 4.8).

Table 4.8: Major elements composition of major rock types in the study area (all values in wt %).

	Granodionite	Fine-Medium grained granite	Porphyritic granite	Porphyritic granite	Amphibolite	Amphibolite	Phyllite	Talcose rock	Talcose rock	Granitic gneiss	Banded gneiss	Migmatitic gneiss	Meta- arkosic rock
Code	**L27**	**L16**	**L12**	**L8**	**L10**	**L11**	**L22**	**L13a**	**L15**	**L6**	**L24**	**L25**	**L18**
Oxides													
SiO_2	69.20	72.11	66.39	65.42	59.01	62.57	67.89	34.99	28.63	74.28	71.93	65.95	66.97
Al_2O_3	14.13	14.82	15.62	15.9	18.27	16.08	13.4	0.58	17.11	14.85	15.42	15.69	16.52
Fe_2O_{3T}	0.98	2.38	6.84	7.24	8.88	8.51	7.46	6.36	13.2	1.39	3.48	6.76	6.01
MnO	0.04	0.148	0.09	0.136	0.151	0.155	0.103	0.077	0.062	0.017	0.033	0.09	0.064
MgO	0.80	0.78	2.03	2.05	1.78	3.17	0.76	35.13	29.21	0.19	0.33	2.09	0.73
CaO	1.72	2.01	1.53	1.69	5.38	2.34	2.77	0.18	0.02	2.84	0.55	1.56	0.32
Na_2O	7.02	4.26	2.65	2.69	3.31	2.47	2.78	0.03	0.01	5.24	8.14	2.66	7.44
K_2O	0.02	3.46	3.45	3.43	1.92	2.77	4.1	0.02	<0.01	0.86	0.25	3.49	1.68
TiO_2	0.039	0.313	0.791	0.84	1.213	1.004	0.843	0.014	0.614	0.022	0.381	0.795	0.295
P_2O_5	0.13	0.08	0.21	0.21	0.31	0.23	0.25	<0.01	0.01	<0.01	0.05	0.20	0.05
L.O.I	3.57	0.40	1.46	1.38	0.69	2.15	0.38	22.6	10.98	0.41	0.36	1.51	0.55
Total	99.6	100.9	101.0	101.0	100.9	100.9	100.8	99.99	99.86	100.6	100.9	100.8	100.6
CaO/Al_2O_3	1.52	0.85	0.10	0.11	0.30	0.15	0.21	0.31	<0.01	0.19	0.04	0.10	0.02
****FeO**	0.88	2.14	6.15	6.51	7.99	7.65	6.71	5.72	11.87	1.25	3.13	6.08	5.41

** FeO = Fe_2O_3 /1.112

GEOCHEMICAL CHARACTERIZATION BASED ON MAJOR ELEMENTS COMPOSITION.

Major elements versus SiO_2 plots were used to evaluate trends of the rocks. The major element composition revealed different evolutionarty trends for the various rock units as evidenced in (Figure 4.13). The plots show that SiO_2 is negatively correlated with Al_2O_3, MgO, P_2O_5, TiO_2, FeOt while CaO, Na_2O, K_2O, is positvely correlated

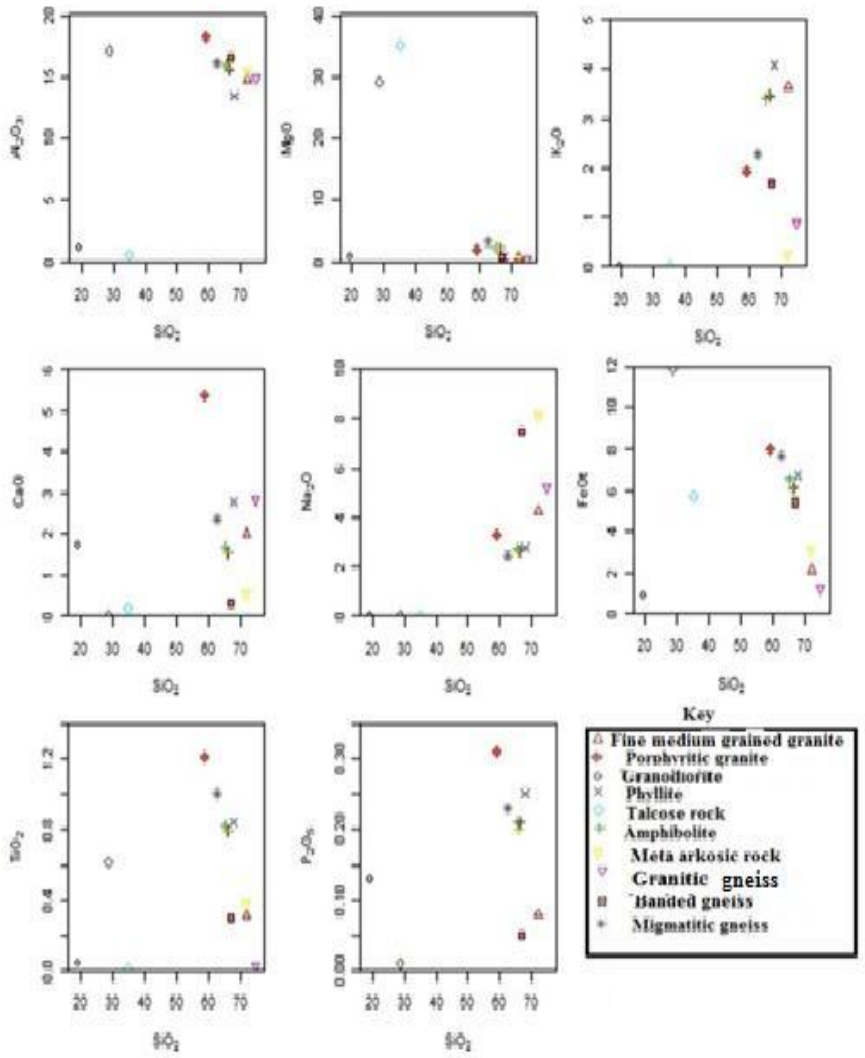


Figure 4.13: Harkers varaition diagrams (SiO_2 Versus Al_2O_3, MgO, CaO, Na_2O, K_2O, TiO_2, P_2O_5, FeOt) for migmatitic gneiss, banded gneiss, granitic gneiss, meta - arkosic rock, amphibolite, talcose rock, phyllite, granodiorite, porphyritic granite, and fine-medium grained granite, within the study area.

ALUMINA VARIATIONS

Alumina saturation is based on comparing the mole proportion (mole proportion = weight pecentage of oxide / molecular weight of the oxide) of the alkalis to alumina in the rock. In order to determine the petrogenetic trait, the samples were plotted on classification diagram of A/CNK versus A/NK (where A/CNK = molar Al_2O_3 / (CaO + Na_2O + K_2O) and A/NK= molar Al_2O_3 / (Na_2O + K_2O) (after Shand 1943). The granitic rocks plot within the peraluminous field (Figure 4.14). An overall peraluminous character is inferered from A/NK and A/CNK.

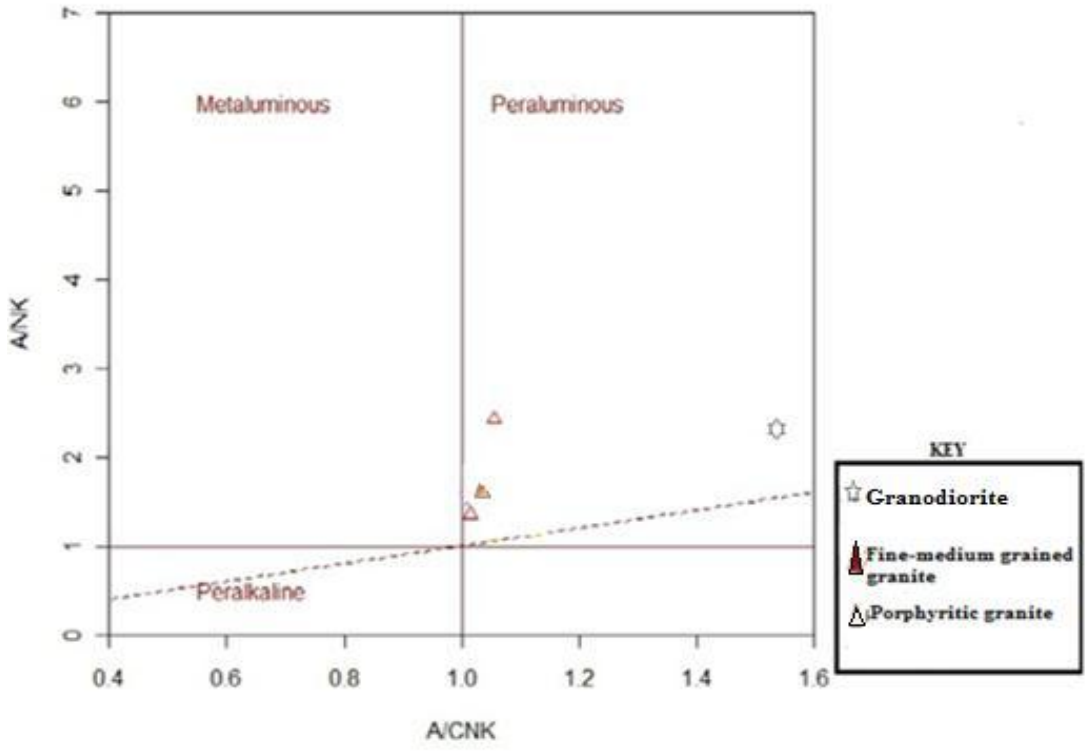


Figure 4.14: Chemical classification of the granitic rocks in the study using the Molecular ration of alumina to alkalis (after Shand 1943). (Al_2O_3/ (Na_2O + K_2O) A/NK versus alumina to lime and alkalis (Al_2O_3 / (CaO + Na_2O + K_2O) A/C/NK plot.

TOTAL ALKALI SATURATION (TAS)

The total alkali saturation (TAS) is a useful tool for classification of igneous rocks and for distinguishing between two types of magmatic series. These are alkaline

series and sub-alkaline series/ Tholeiitic series. Granites samples were plotted on a binary plot of $Na_2O + K_2O$ versus SiO_2 (after Cox *et al* ., 1979). The analyzed rocks plot within the tholeiitic series / Sub - alkaline magma series and lies within granite, quartzdiorite, and diorite fields (Figure 4.15).

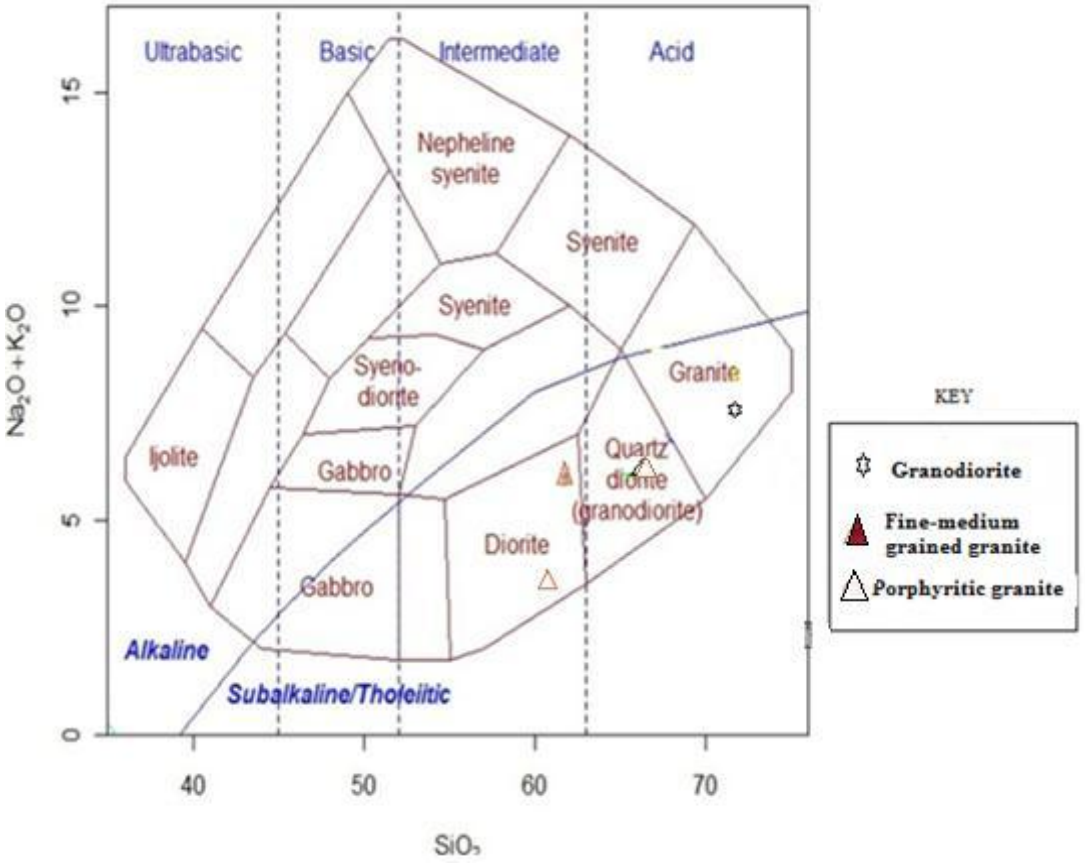


Figure 4.15 : Chemical classfication of granitic rocks (plutonic) in the study area adapting the total alkalis versus silica (TAS) of Cox *et al.*, (1979).

K_2O VERSUS SiO_2 PLOT

K_2O versus SiO_2 plot after Perccerrillo and Taylor, 1976 was used to determine the calc-alkaine and tholetiitic charateristic of the granitic rocks. The potassic compostion of the granites decrease with increase in SiO_2 contents and reveal that the granites are of medium to high – K affinity. Specifically, the granodiorite lies, mainly into the calc – alkaline field while the granites belong to high – K calc – alkaline series (Figure 4.16)

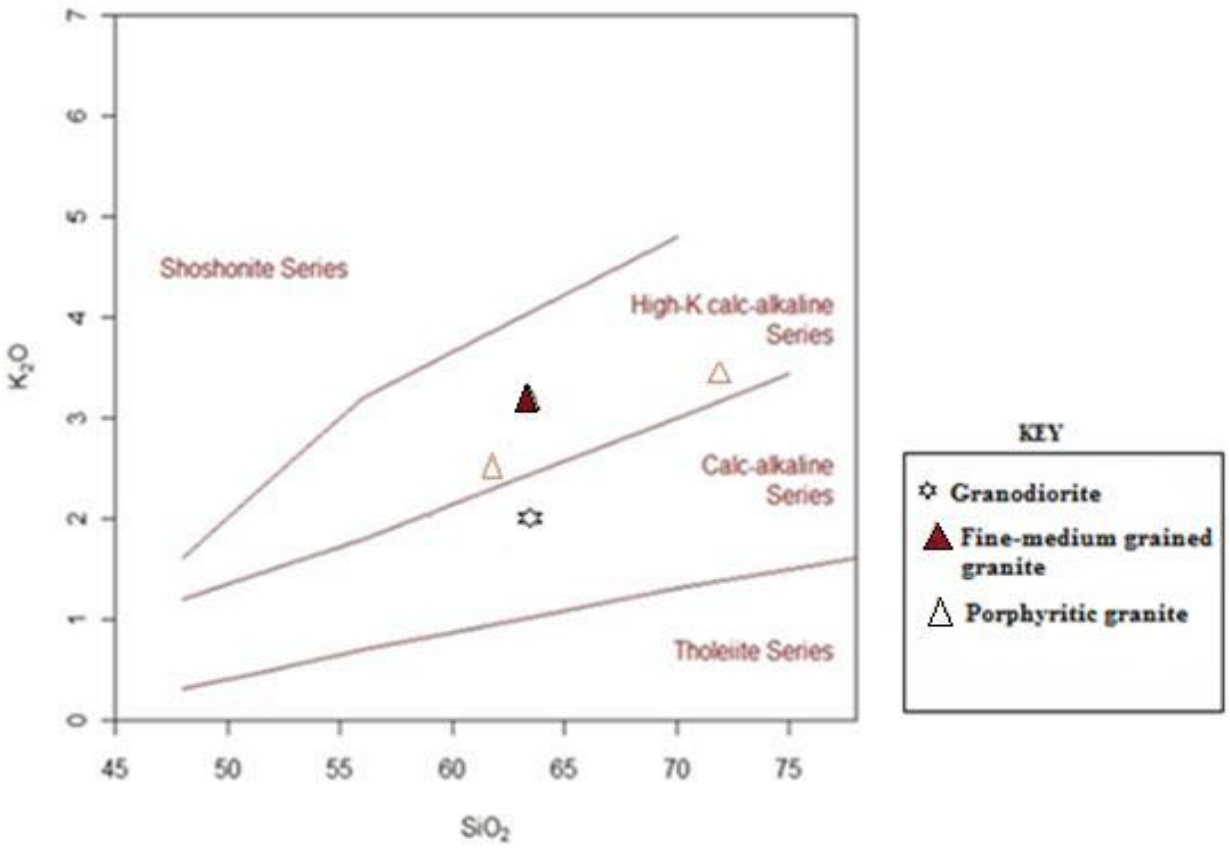


Figure 4.16: The SiO versus K_2O diagram (after Perccerrillo and Taylor,1976) the classification of Sub-alkaline rocks from the study area on the basis of potassium enrichment.

IRON INDEX DISCRIMINATION

Fe- number (FeO_{tot} / FeO_{tot} + MgO = Fe*) called iron index discrimination diagram after (Frost *et al.*, 2001) was used to classify the granitic rocks based on their ferroan and magnesian content. Bivariate plot for this diagram is shown on Figure 4 .17) while Table 4.9 gives Fe- number in the granitic rocks from the study area.

Table 4.9: Fe- number in granitic rock

Rock(s)	**Fe – number**
Granodiorite	0.67
Fine-medium grained granite	0.86
Porphyritic granite	0.97
Porphyritic granite	0.98

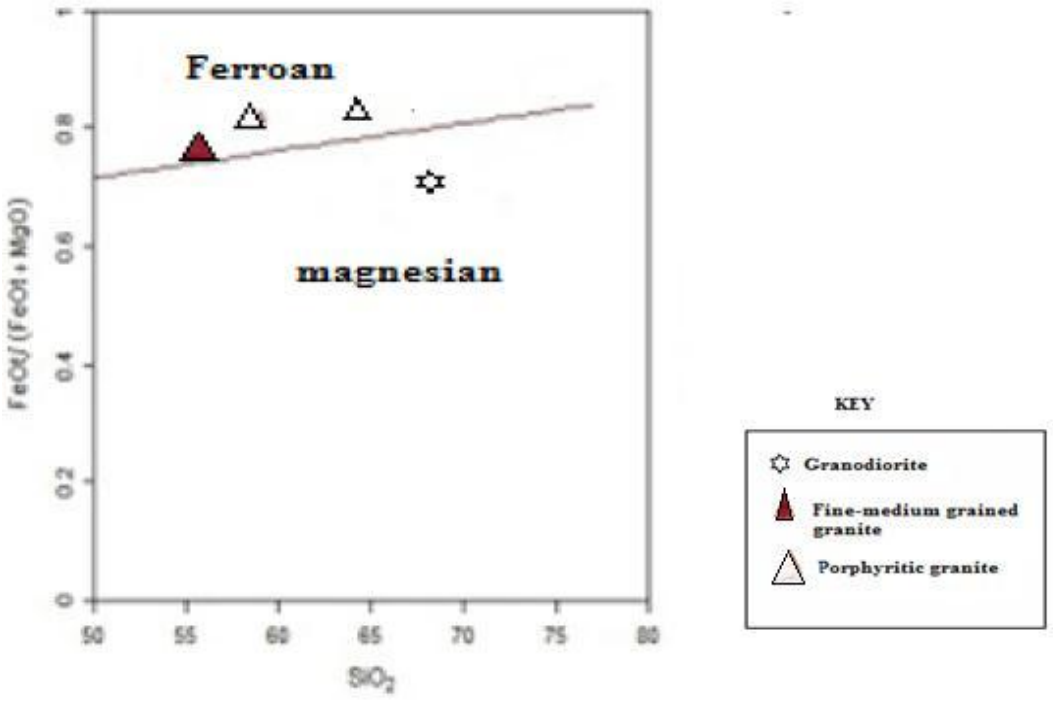


Figure 4.17: FeO_{tot} / FeO_{tot} + MgO versus SiO_2 discrimination diagram (after Frost *et al.*, 2001), for the granitic rocks and talcose rock in the study area.

Variation of Al_2O_3 Versus (FeO/(FeO + MgO)W % AND FeO+ TiO_2 Versus Al_2O_3, MgO.

This petrogenetic affinity of talcose rock were also demonstrated on bivariate plots of Al_2O_3 versus (FeO/(FeO + MgO)w % after Naldrett and Cabri, 1976) and FeO + TiO_2 versus Al_2O_3, MgO after Jenson 1976) (Figures 4.18 and 4.19).

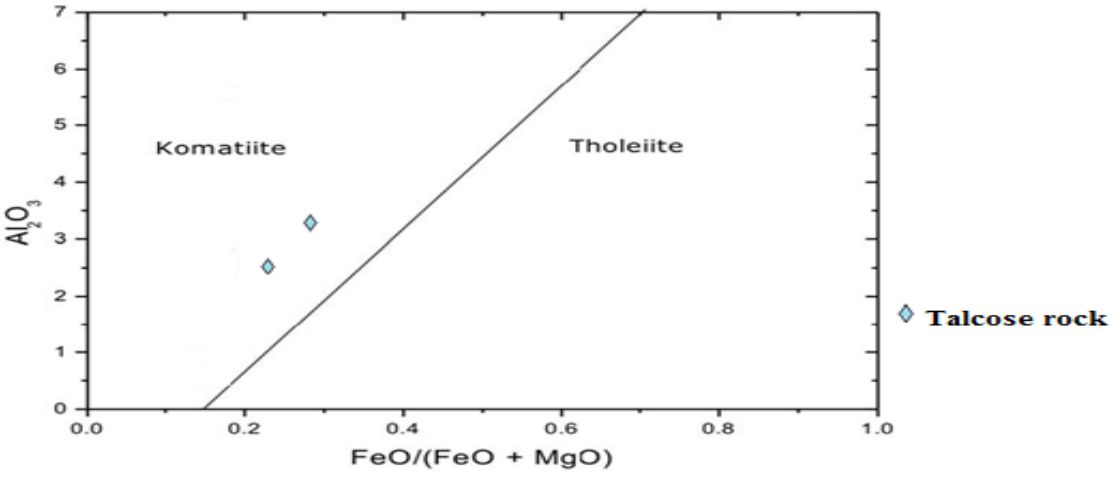


Figure 4.18: Variation of Al_2O_3 with (FeO/(FeO + MgO) w % ratio in talcose rocks (after Naldrett and Cabri, 1976).

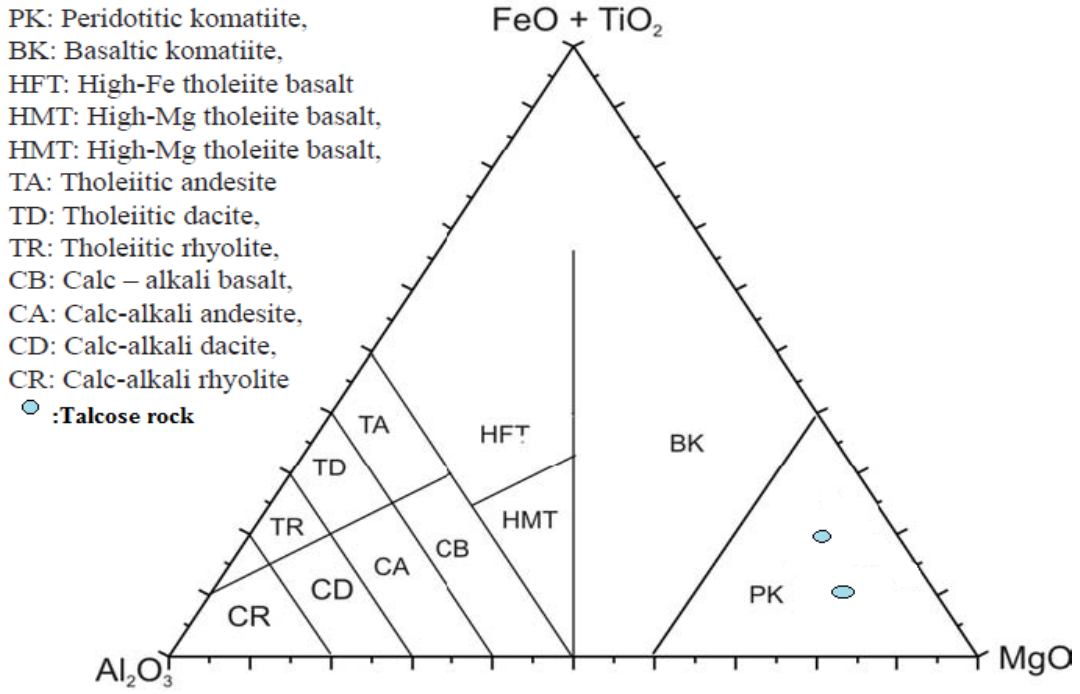


Figure 4.19: Classification of volcanic rocks after Jensen (1976).

4.7.2: TRACE ELEMENTS COMPOSITION

Trace elements composition is useful in finger printing of the origin of igneous rocks and igneous processes because they exhibit a range in concentration far greater than major elements (Frost and Frost, 1999). The trace elements composition of the rock samples obtained from the study area is presented in Table (4.10).

Table 4.10: Trace Elements composition of Major rock types in the study area (all values in ppm)

	Granodionite	fine-meduim grained granite	Porphyritic Granite	Porphyritic granite	Amphibolite	Amphibolite	Phyllite	Talcose rock	Talcose rock	Granitic gneiss	Banded gneiss	Migmatitic gneiss	Meta-arkosic rock
CODE	L27	L16	L12	L8	L10	L11	L22	L39	L15	L6	L24	L25	L18
Symbol													
Sc	1	4	18	13	13	13	12	4	63	<1	7	21	17
Be	<1	3	2	3	3	3	3	<1	<1	6	1	1	2
V	<5	26	82	97	101	101	51	17	353	5	7	150	150
Ba	7494	1172	577	837	832	842	973	5	<2	121	249	668	463
Sr	383	461	671	196	172	175	217	<2	<2	443	154	192	58
Y	9	8	17	24	24	24	46	<1	5	5	41	26	58
Zr	7	133	623	219	195	194	390	4	8	66	295	191	371
Cr	30	180	140	9	350	320	<2	1930	170	260	<20	360	<20
Co	32	56	46	31	32	31	42	82	91	33	24	37	27
Ni	30	<20	20	40	50	50	<20	1850	210	20	<20	60	20
Cu	130	10	40	40	50	40	10	<10	20	30	<10	50	10
Zn	200	60	130	80	80	90	100	40	70	<30	60	90	130
Ga	45	31	29	24	23	22	23	2	10	27	14	20	25
Ge	2	1	2	2	2	2	2	1	<1	1	1	2	1
As	355	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	6
Rb	<2	107	69	120	124	123	152	<2	<2	30	6	68	52
Nb	1	6	22	14	14	14	21	<1	<1	<1	7	10	9
Mo	7	<2	4	<2	7	6	<2	<2	<2	8	<2	6	<2
Ag	<0.5	<0.5	1.6	0.5	<0.5	<0.5	<0.5	1	<0.5	<0.5	0.6	<05	0.9
In	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<02	<0.2
Sn	<1	1	2	3	3	3	5	<1	<1	2	2	2	3
Sb	15.8	0.6	0.6	0.6	0.5	0.6	0.5	<0.7	0.5	0.5	0.6	0.7	1.3
Cs	<0.5	2.6	3.4	9.3	9.5	9.7	4.7	<0.5	<0.5	1.2	<0.5	3.4	1.3

Trace element compositions were normalized to average upper continental crust (UCC) values of Weaver and Tarney (1984). Trace elements composition in phyllite is very similar to those of the average upper continental crust though with deplection in Zr and Nb Figure (4.20).

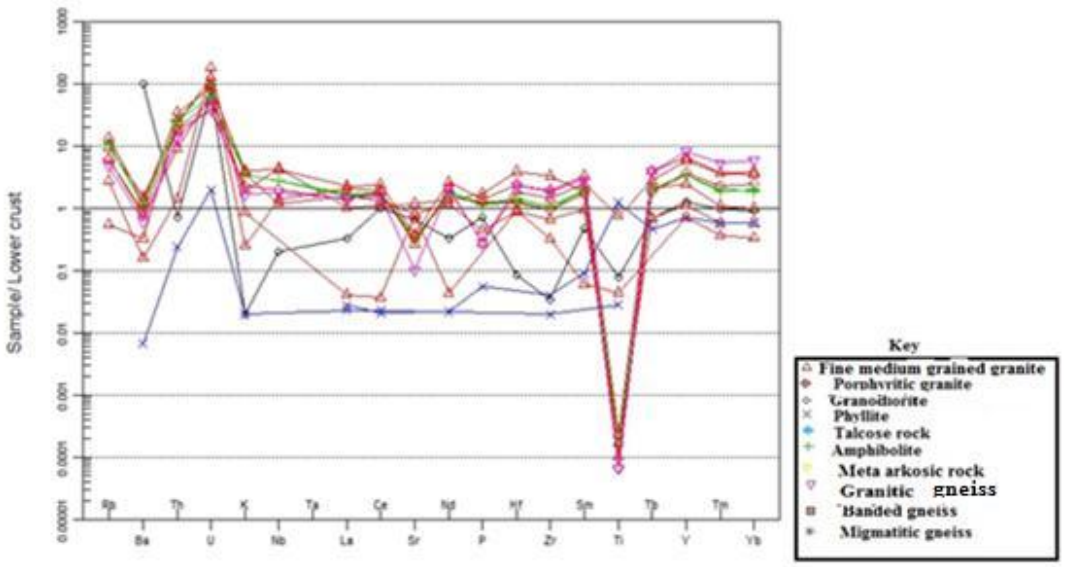


Figure 4.20: Spider diagram of trace elements from the study area plots are normalized to the average crust (after Weaver and Tarney, 1984).

Ti and K are strongly enriched in talcose rock but deplected in amphibolite, fine – medium grained granite and granitic gneiss. Trace elements Ni, Co, Cr, and V, concentrations show enrichment in talcose rock followed by the amphibolite while Be, Sr, Cu and Zn are generally lower than average upper continental crust.

There is a significant variation in trace elements concentration among the rock units. The variation in Ba, Sr, and Rb content is very useful in determining whether magmatic evolution was controlled dominantly by fractional crystallization, partial melting or more complex processes (Dall *et al.,* 1999). The Ba (<2 - 5ppm), Zr (4-8ppm), Sr (< 2 ppm) and Rb (< 2ppm) concentrations in the talcose rocks are generally low compared with other rocks within the study area (Table 4.10).

Bivariate plots of Rb versus Y+Nb, and Rb versus Ta+Yb of (after Pearce *et al.*,1984) were used to distinguish the granites based on their intrusive setting into four groups namely: Oceanic Ridge Granite (ORG), Volcanic Arc Granite (VAG), Within Plate Granite (WPG) and Collision Granite (COLG) Figure (4.21). The granitic rocks were plotted within Volcanic Arc Granite.

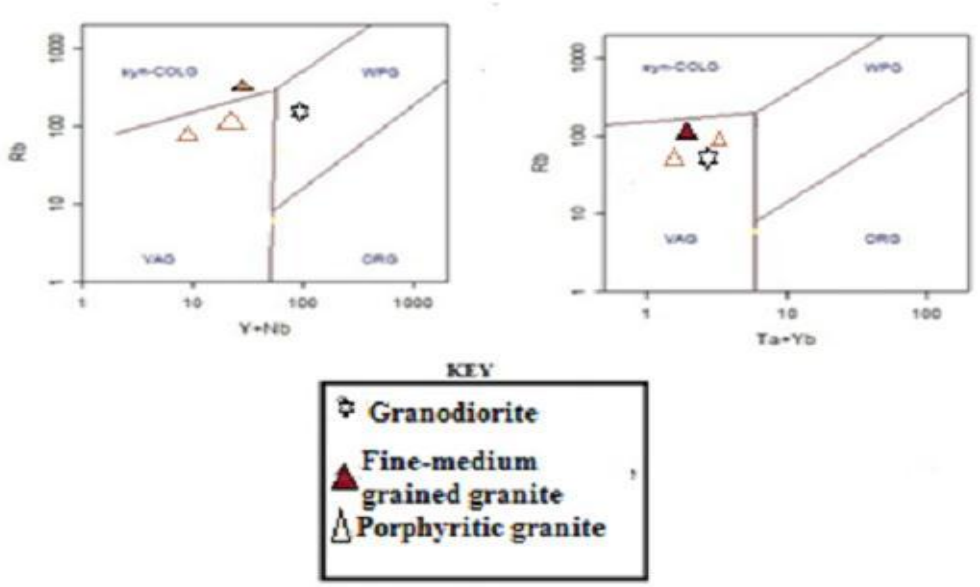


Figure 4.21: Rb versus Y+Nb and Rb versus Ta+Yb discrimination diagrams for granitic rocks in the area (after Pearce *et al.*,(1984).

4.7.3: Rare Earth Elements Composition.

The rare earth elements (REE) are usually sub-divided into the light rare earth elements (LREE) and heavy earth elements (HREE) classes. The LREE consist of La to Sm (atomic numbers 57- 62) and the HREE are Gd (atomic numbers 64 -71). The rare earth elements (REE) data from the Kagara area is presented in Table 4.9. The ΣREE varies from 2.15 to 265.1ppm. The talcose rock from Kagara area has the lowest ΣREE of 2.15 whereas the highest ΣREE value was recorded in phyllite (265.1ppm). The rare earth elements data are normalized to chondrite values of Nakamura (1974).The REE

pattern of talcose rock and its host rocks displays a steep slope from LREE to the HREE and a negative Eu anomaly (Figure 4.22). Specifically, the Negative europium anomaly (Eu/Eu)* relative to chondrite in talcose rock ranges from 0.10 - 0.65. The similarity in REE patterns suggests that the rocks were derived from a common source.

The normalized (La/Yb)n range from 1.5 - 32.76. The talcose rock from Kagara area has the lowest (La/Yb)n (1.5) with the highest value (La/Yb)n recorded in fine - medium grained granite (32.76) Table (4.10).

Petrochemical trends of the rare earth elements of talcose rock reflected some subtle relationships to the amphibolites in the Kagara areas (Figure 4.23). The analysis of the different distribution patterns are presented in figures (4.24 to 4.26)

Table 4.11: Rare earth elements concentration of major rock types in the study area (all values in ppm)

	Granodionite`	Fine-Medium-grained granite	Porphyritic granite	Porphyritic granite	Amphibolite	Amphibolite	Phyllite	Talcose rock	Talcose rock	Granitic gneiss	Banded gneiss	Migmatitic gneiss	Meta- arkosic rock
Code Symbol	**L27**	**L16**	**L12**	**L8**	**L10**	**L11**	**L22**	**$L13_a$**	**L15**	**L6**	**L24**	**L25**	**L18**
La	7.1	34.4	22.7	35.2	37.9	36.2	50.2	0.5	0.6	0.9	45.7	30.3	31.5
Ce	44.3	57.5	47.6	73	78.6	74.8	105	1.0	0.9	1.6	85	60.2	69.9
Pr	1.42	6.4	5.91	8.32	8.79	8.28	12.3	0.1	0.09	0.17	10.4	6.97	8.84
Nd	6.2	21.7	25.2	31.8	33.6	31.5	49.4	<0.4	0.4	0.8	39.3	27.4	37.7
Sm	1.6	3.1	6.2	6.5	6.6	6.3	11	0.1	0.3	0.2	8.1	5.7	9.5
Eu	0.42	0.88	3.17	1.51	1.55	1.5	2.31	0.05	0.05	0.23	1.7	1.53	2.37
Cd	1.7	2	5.9	5.4	5.8	5.4	11	0.1	0.6	0.3	7.4	5.3	9.6
Tb	0.3	0.3	0.9	0.8	0.9	0.8	1.7	0.1	0.2	<0.1	1.2	0.8	1.7
Dy	2.1	1.2	4	4.6	5	4.5	9.9	0.1	1.1	0.6	7.4	5	10.9
Ho	0.4	0.2	0.9	0.9	0.9	0.9	1.9	<0.1	0.3	0.1	1.5	1	2.3
Er	1.3	0.8	1.5	2.5	2.6	2.4	4.9	<0.1	0.7	0.4	4.6	3	6.7
Tm	0.18	0.11	0.21	0.38	0.38	0.35	0.7	<0.5	0.11	0.07	0.69	0.43	1.01
Yb	1.1	0.7	1.2	2.2	2.3	2.4	4.2	0.1	0.7	0.4	4.7	3	7
Lu	0.15	0.1	0.18	0.36	0.38	0.36	0.59	0.01	0.11	0.06	0.77	0.45	1.13
Hf	0.3	3.2	14.1	5.3	4.8	4.7	8.7	<0.2	<0.2	3.3	6.8	4.4	8.4
Ta	0.5	1.2	1.7	1.4	1.5	1.3	2.3	0.1	0.1	0.4	0.9	1	0.9
W	5	361	223	96	99	93	230	9	4	219	139	106	156
Ti	<0.2	0.5	0.3	0.5	0.5	0.5	0.7	<0.1	<1	<0.1	<0.1	0.2	0.9
Pb	<5	39	17	22	23	22	26	<5	38	38	13	12	14
Bi	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Th	0.3	7.7	3.9	10.4	11.2	10.8	14.7	0.1	<0.1	0.6	10.4	7.50	5.60
U	4	2.7	3.3	5	4.9	3.1	4.5	0.1	<0.1	9.1	6.3	1.9	2.30
ΣREE	68.27	129.39	125.57	173.7	185.30	175.6	265.0	2.15	6.16	5.83	218.4	151.1	200.15
Σ*LREE*	60.6	123.1	107.61	154.82	155.49	157.8	222.9	2.1	2.29	3.67	188.5	130.6	157.44
Σ*HREE*	7.65	6.29	17.96	18.65	28.22	18.61	2.2	0.05	3.87	2.16	29.96	20.51	42.71

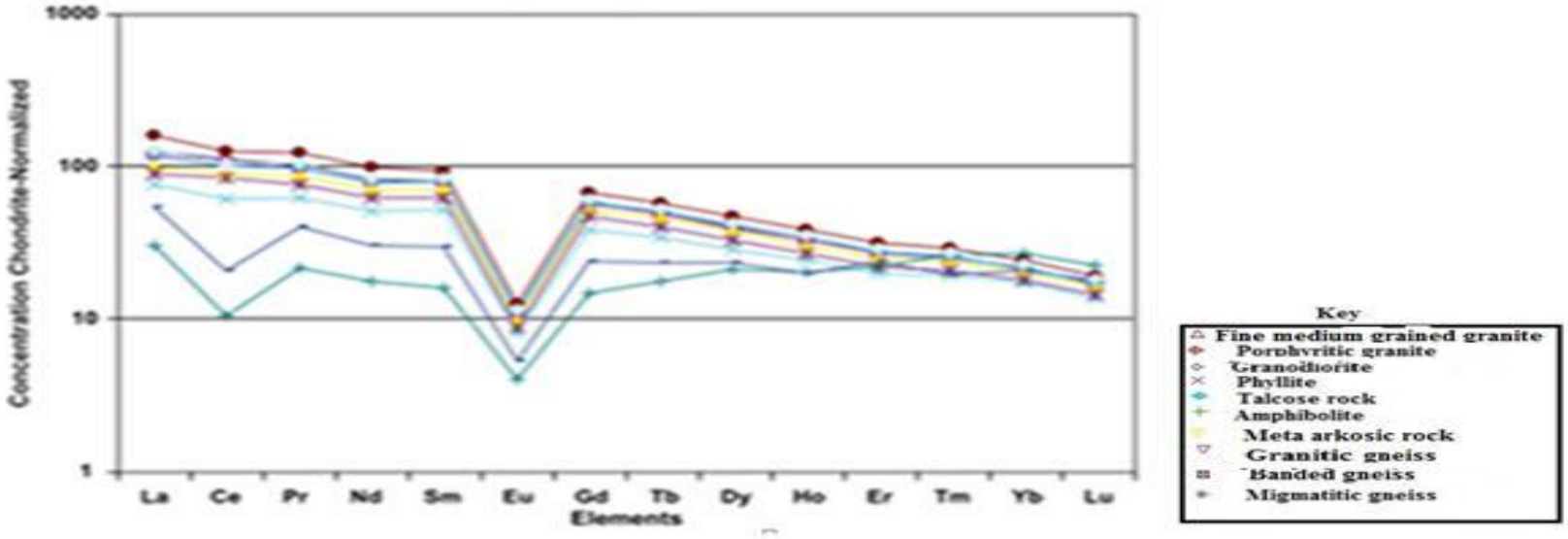


Figure 4.22: Rare earth elements distribution pattern of the rock from the study area normalized to the average crust. Normalizing value are those of Nakamura, (1974).

Table 4.12: The REE chondrite –normalised value of talcose rock from Kagara and the host rocks (chondrite values obtained from Nakamura, (1974).

	Granodorite	Fine-Medium-grained granite	porphyritic granite	Porphyritic granite	Amphibolite	Amphibolite	Phyllite	Talcose rock	Talcose rock	Granitic gneiss	Banded gneiss	Migmatitic gneiss	Meta- arkosic rock
Symbol													
	L27	**L16**	**L12**	**L8**	L10	**L11**	**L22**	**$L13_a$**	**L15**	**L6**	**L24**	**L25**	**L18**
La_N	21.52	104.24	68.79	106.67	114.85	109.70	152.12	8.0	1.82	2.73	138.48	91.82	95.45
Ce_N	51.21	66.47	55.03	84.39	90.87	86.47	121.39	1.52	1.04	1.85	98.27	69.60	80.81
Pr_N	12.68	57.14	52.77	74.29	78.48	73.93	109.82	1.16	0.80	1.52	92.86	62.23	78.93
Nd_N	9.84	34.44	40.00	50.48	53.33	50.00	78.41	0.89	0.63	1.27	62.38	43.49	59.84
Sm_N	7.88	15.27	30.54	32.02	32.51	31.03	54.19	0.63	1.48	0.99	39.90	28.08	46.80
Eu_N	5.45	11.43	41.17	19.61	20.13	19.48	30.00	0.13	0.65	2.99	22.08	19.87	30.78
Cd_N	6.16	7.25	21.38	19.57	21.01	19.57	39.86	2.11	2.17	1.09	26.81	19.20	36.17
Tb_N	6.38	6.38	19.15	17.02	19.15	17.02	36.17	3.51	4.26	-	25.53	17.02	31.78
Dy_N	6.12	3.50	12.24	3.41	14.58	13.12	28.86	2.68	3.21	1.75	21.57	14.58	32.86
Ho_N	5.71	2.86	10.00	12.86	12.86	12.86	27.14	3.16	4.29	1.43	21.43	14.29	29.78
Er_N	5.78	3.56	6.67	11.11	11.56	10.67	21.78	3.26	3.11	1.78	20.44	13.33	33.67
Tm_N	6.00	3.67	7.00	12.67	12.67	11.67	23.33	3.08	3.67	2.33	23.00	14.33	31.82
Yb_N	5.00	3.18	5.45	10.00	10.45	10.91	19.09	2.94	3.18	1.82	21.36	13.64	33.24
Lu_N	4.41	2.94	5.29	10.59	11.18	10.59	17.35	0.63	3.24	1.76	22.65	13.24	6.73
Total	154.14	322.33	375.48	474.69	503.63	477.02	759.51	33.7	33.55	23.31	636.76	434.72	628.66
La_N/Yb_N	4.30	32.76	12.66	0.67	10.99	10.06	7.97	0.12	0.57	1.5	6.48	6.73	3.00
Ce_N/Sm_N	6.50	4.35	1.80	2.64	2.79	2.79	2.24	0.01	0.70	1.88	2.46	2.48	1.73
Ce_N/Yb_N	10.24	20.89	0.09	8.44	8.69	7.93	6.36	0.02	0.33	1.02	4.60	5.10	2.54
La_N/Sm_N	2.73	6.83	2.25	3.33	3.53	3.53	2.81	0.14	1.23	2.77	3.47	3.27	2.04
Eu/Eu*	0.78	1.09	1.61	0.78	0.77	0.79	0.65	0.10	0.36	2.89	0.67	0.89	0.79

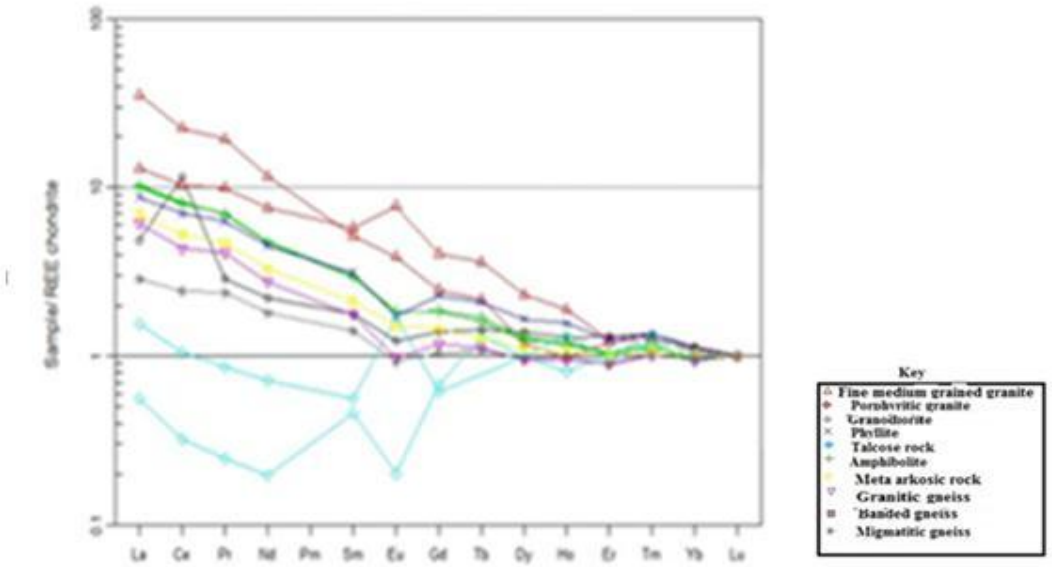


Figure 4.23: Spider diagram for whole rock samples from Kagara area.Normalizing value are those of McDonough and Sun (1995).

The plots of chondrite normalized REE for the different rocks showing distribution patterns are presented in Figures (4.18- 4.22).

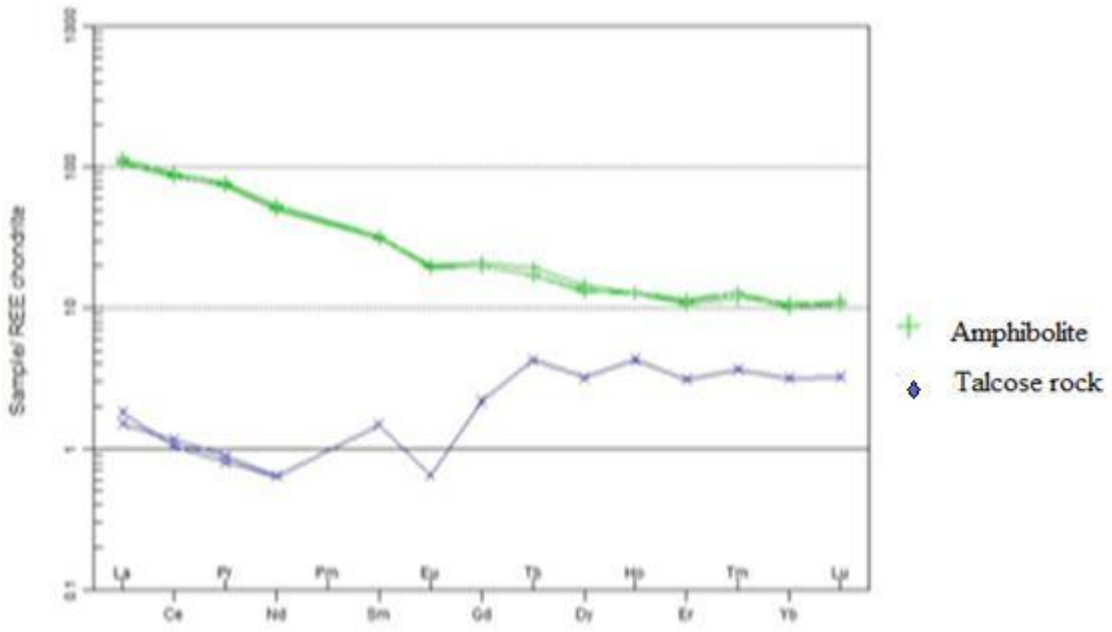


Figure 4.24: REE distribution pattern of amphibolite and talcose rock from the study area. Normalizing values are those of Nakamura, (1974).

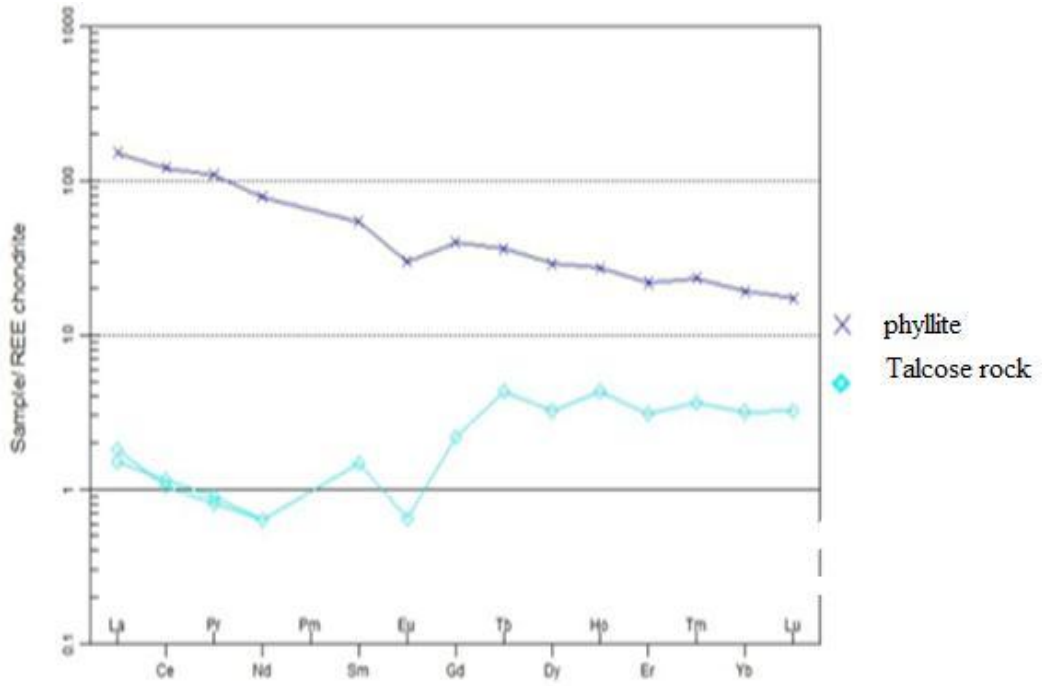


Figure 4.25: The distribution pattern of REE in phyllite and talcose rock.Normalizing value are those of Nakamura (1974)

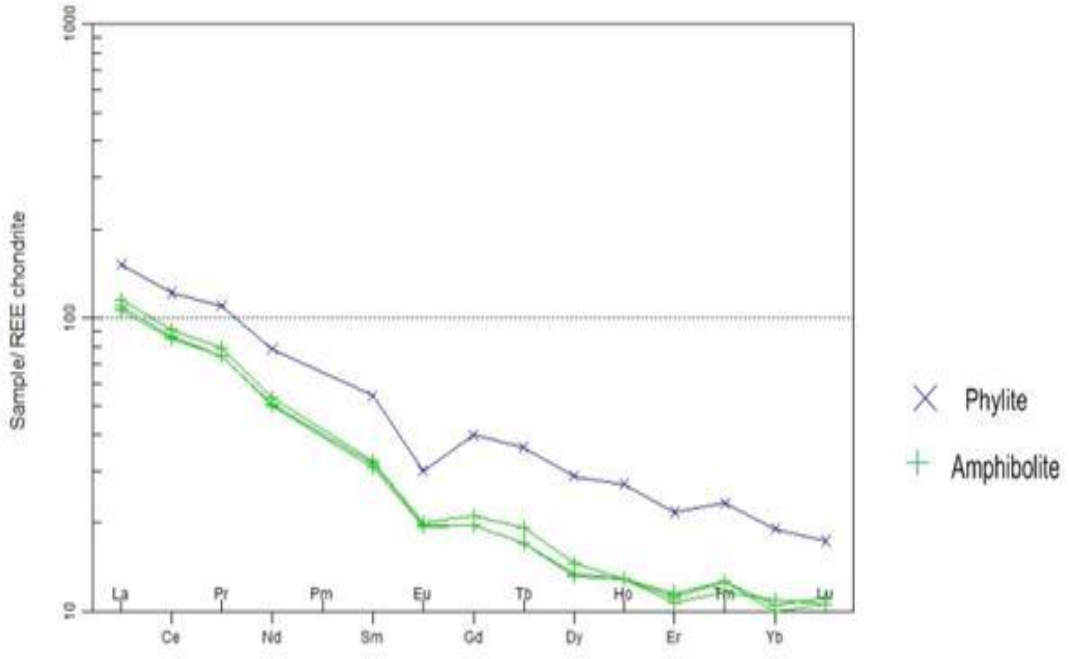


Figure 4.26: The distribution pattern of REE in phyllite and ampihbolite. Normalizing value are those of Nakamura (1974).

CHAPTER FIVE: DISCUSSION

5.1 REMOTE SENSING.

Several remote sensing techniques have been used to establish the spectral properties of rocks within the study area. With the aid of false composite, lithological mapping was made possible. False colour composite 3:4:5 was used to distinguish rock types occuring within the study area. Using this colour composite granites, granitic gneiss, talcose rock and phyllites appeared green; banded gneiss, granodiorite appeared pink while migmatitic gneiss, meta- arkosic rock as purple (Figure 4.7).

Utilization of band ratio techniques enabled identification of several hydrothermally altered areas. Band 5/7 highlights areas with clay mineral alteration **(**Figure 4.1) while Band ratio 5/4 and 3/1 (Figures 4.2 and 4.3), highlights areas with ferric and ferrous alteration respectively. Assigning these ratios (5/7, 5/4, 3/1) to red, green, and blue channel produced a hydrothermal altered image, in which the areas with hydroxyl or clay mineral alteration are displayed as red, ferrous iron as green and ferric iron as blue (Figure 4.4).

Ls - fit technique residue of band 3, 7, 1 in the red, green and blue channel display goethite + haematite + clay as light tone, haematite + clay as orange, goethite + clay as cyan, haematite + goethite as purple, clay as green and goethite as blue (Figure 4.5).The resultant image displayed area with hydroxyl mineral alteration as light tone while the F image displayed areas with iron alteration as light tone (Figure 4.5).

The uses of Crosta techniques facilitated the identification of specific alteration in the study area as argillized and iron stain zones were identified (Figure 4.6). Using the threshold image, areas of high clay alteration are displayed as red, areas of high ferric and ferrous alteration are displayed as green and blue (Figure 4.7).

5.2 GEOLOGY OF THE AREA

Geological studies of rocks in the field reveal lithologies with distinctive mineralogical, textural and structural characteristics which have implication on their overall geology. The talcose rock from Kagara varies in colour from dull white to grey and light green. The area is a typical metamorphic terrain with rocks of diverse nature, deformed with the presence of both planar and linear structures. The occurrence of chlorite and biotite in many of the rock samples further ascertained reinforces the fact that metamorphic terrain was intruded by an acidic magma. Talc- chlorite coexistence is common which suggests that ultra-mafic parent minerals were subjected to metamorphism. The rock types encountered in the study area are; migmatitic-gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolite, talcose rock, phyllite, porphyritic granites, fine to medium grained granite, granodiorite, and pegmatites as shown on the geological map of the area (Figure 4.8).

Migmatitic gneiss: This was formed by partial melting of gneissic rock, leading to mineral segregation into mafic and felsic minerals in response to intense high grade metamorphism. They are presumed to be the oldest rock in the study area (Plate I).

Banded gneiss: This unit form as a result of metamorphism of pelitic materials accumulated as older supracrustals. The banded gneiss is characterised by alternation of felsic and mafic bands.

Granitic gneiss: The granitic gneiss, composed of biotite, K-feldspars, quartz, occurs in close association with the migmatitic gneiss. This suggests that the migmatitic rocks in the area were also intruded by granitic bodies probably during the early Kibaran event and were later metamorphosed together with the older supracrustals. This is evident also by cataclastic deformation which produced multiple features found in granitic gneiss. The veins occurring within the granitic gneiss are believed to have occurred as a

result of syn deformational process during the last orogenic episode because it is concordant with the trend of the foliation.

Meta-arkosic rock: The Meta-Arkosic rocks formed from the crystalline materials which are rich in feldspar (mostly granite or gneiss) and a high relief due to rapid erosion with little or no weathering of the feldspar. The presence of granitic batholiths with surrounded down-faulted blocks help in the collection of the eroded clastic detritus rich in feldspar.

Amphibolite: The amphibolite in the study area was formed as a consequence of metamorphism of intrusive episode evidenced in the mineralogical contents similar to gabbro. The constituent minerals include hornblende, high temperature plagioclase and pyroxene. The protolith would have been gabbro or dolerite dykes that were intruded into the migmatitic and gneissic terrane.

Talcose rock: The talcose rocks in the study area were formed as the product of metamorphism of the ultramafic protolith was subjected. The emplacement of nearby granitic intrusions and subsequent metasomatism of the metasediments in the study area experienced led to the introduction of SiO_2 and H_2O into the talcose rock as all other constituents are inherited from the mafic parent.

Phyllite: The phyllite is spatially associated with the amphibolites and formed as the product of metamorphism of pelitic rocks (shale) as evidenced by the prescence of primary foliation planes which subsequently developed into phyllitic cleavage. It is considered that subsequent metasomatism, metamorphism through deformation of primary mineral have contributed to varying degree in the fabric of the host rocks.

Granodiorite: This rock in the study area formed as a consequence of intrusion from quartz-rich magma, which cools in the forms of batholiths. The granodiorite in the study area were exposed at the surface after erosion and uplift have occurred in the area.

Porphyritic granite: This rock in the study area formed as a product of intrusion of magma that cools, this magma is cooled slowly deep in the crust, creating the large crystal of grains, and solidifies within the crust. This rock is surrounded by pre-existing rock, (the migmatitic gneiss and the metasediments).

Fine - medium grained granite: This rock in the study area formed from intrusion of the magma as it cooled at relatively at a shallow depth, creating the fine-medium grains, and solidifies within the crust. This rock is intrusive into the migmatitic gneiss and the metasediments in the study area.

Pegmatites: They are formed during the late stage crystalization of the magmatic intrusion along fractures in fine-medium granite. It is the youngest rock unit in the study area.

5.3 MINERALOGY OF TALCOSE ROCK FROM KAGARA AREA.

The mineralogical composition of the talcose rock samples were determined by thin section and XRD analyses. Thin section study reveals that talc, chlorite and tremolite and magnesite are the major constutients while anthophyllite, actinolite and opaque minerals constituents are accessories (Plate VII and Plate VIII). In talcose rock, talc seen as as colourless and fibrous minerals and as well as foliated mass. Chlorite occurs as fine grained, green, pleochoric minerals with moderate relief**.** Tremolite occurs as columnar crystal while the magnetite filled the interstices of the platy talc in octahedral shape. Decussate arrangement of short and long prismatic anthophyllite within talc matrix is also a common feature of the talcose rock (Plate VIII).

The X-ray diffractogram confirmed identified minerals in thin section namely talc, chlorite, tremolite, magnesite, anthophyllite, and opaque minerals. XRD studies indicate ‘‘talc + chlorites’’ coexistence which indicate metamorphic terrains.

The association of magnesite with talcose rock from Kagara is a similar occurrence with Mondo talcs as well as some Canadian and U.S. talcs (Bates, 1969; Mondo, 2008; Pressacco *et al.,* 2010). The textural variation in the rocks is due to varying size and amount of feldspar crystals they contained. This in turn is a function of the petrogenesis of the individual rock type. The sub–rounded shapes of Magnetite in talcose rocks preclude a detrital origin for talc minerals. The mineralogy of talcose rock from Kagara is similar to that of talc from Finland Table (5.1).

Primary features of the country rocks and of the ultramafic rocks are largely observed by metamorphic recrystalization, but relict features, textural relations, and compositional variations provide clues to the nature and origin of the primary rocks. The nature of the processes by which rocks were altered to the present state must be deduced from the relationships between the inferred features of the original rock and observed features of the present rock.

5.3.1 MINERAL PARAGENESIS OF TALCOSE ROCKS FROM KAGARA

The wide variety of mineral assemblages at talcose deposits represents various stages of metamorphism in the area. Two distinct alteration assemblages were identified in the study area. Talc occurs in variable proportions in all the assemblages, and it is invariably the final product of alteration, replacing clinochlore, chlorite, magnesite, and tremolite. A trace amount of quartz is present in most rocks, Tremolite occur as coarse - grained crystals (up to 1 cm long) of prismatic habit, or as radiating aggregates. Mineral paragenesis of talcose rock has been determined by mineralogical analyses of the collected samples in the study area.

Table 5.1: Comparison of mineralogical compositions of talcose rock from Kagara with similar talcs from other locations: A= *Okunlola et al*, 2011; B= Bolarinwa and Adeola, 2007, D = Grogan and Montgomery, 1973); E= Macmillan, 1970; F = Moine, *et al.,* 1999; G= Agnello, 2005. L =This study

MINERAL	L	L	A	B	C	D	E	F	G
Talc	38	40	38.7	57	49	43	41	50	45
Tremolite	10	11	27.5	12	-	33	31	-	-
Actinolite	13	11	8.9	-	-	-	-	-	-
Chlorite	20	17	16.7	24	15	13	12	49	12
Magnesite	9	10	-	-	31	-	-	-	37
Dolomite	-	-	-	-	-	1.7	-	Trace	4
Anthophyllite	8	7	6.8	-	-	6	4	-	-
Serpentine	-	-	-	-	Trace	-	-	-	-
Magnetite	1	2	-	-	-	-	-	-	-
Quartz	-	1	-	-	-	-	-	-	-
Muscovite	-	-	-	-	-	-	2	-	-
Opaque	1	1	1.4	2	Trace	3.5	4	1	1
Total	100	100	100			100.2	94	100	99

Mineral paragenesis, which obtained from talcose rocks are presented in Table (5.2).

Table 5.2: Mineral paragenesis of talcose rock from Kagara

Sample number	Mineral Paragenesis
$L13_a$(Talcose rock)	talc + tremolite+ chlorite + magnesite + anthophyllite + magnetite
$L8_a$(Talcose rock)	talc + actinolite + chlorite + anthophyllite + quartz

5.3.2 MINERALIZATION PROCESS AND DEPOSITION OF TALCOSE ROCK IN THE STUDY AREA

The study area is a typical metamorphic terrain. The potential sources of the fluids are through dehydration and decarbonation processes, which occur during the metamorphic event in the area. The mineral constituents of talcose rocks are talc, chlorite, anthophyllite, tremolite /actinolite, and magnesite while the amphibolite contain clinochore and actinolite. Tremolite and actinolite are slightly to moderately altered to chlorite and or talc, where fine relics of actinolite laths are randomly distributed within the talc matrix Plate (VII). Chlorite occurs in the form of disseminated anhedral plates and massive lenses of very fine-grained mineral.

The excess water circulate through the surrounding rocks, scavenge and transport minerals to the sites where they can be precipitated as talcose rock Plate (V1Il). The chromite formed through alteration of the amphibolite. Change in temperature affected the grade of metamorphism and with low temperature, hydrous minerals recrystallized into new, higher temperature, anhydrous minerals. The order is from primary phases through alteration to final products as actinolite and clinochore altered to chlorite with talcose rocks as the final product from chlorite.

The major factor that control the mineral assemblage is the partial pressure of carbon (iv) oxide within the metamorphic fluid, here in designated as called the $^{X}CO_2$ which support talcose mineralization.

The role of mixed volatiles as a factor of metamorphsims has been highlighted by Winkler (1979) who observed that metamorphism of basalts to chlorite-greenshists or amphibolite is impoosible if sufficient amount of water is present during metamorphism. Decarbonation and dehydration reactions are examples of solid—> solid + vapour reactions.

a) Solid ——> solid + vapour reaction (dehydration process) where brucite liberates

water.

$Mg(OH)_2$ ——> MgO + H_2O……..(iii)
Brucite ——> Periclase + Vapour

b) Solid——> solid + gas reaction (decarbonation process) where magnesite liberates CO_2.
$MgCO_3$ ——> MgO + CO_2 ……..... (iv)
Magnesite Periclase

In the study area, amphibolite contains clinochore which developed as a consequence of the alteration of chromite grains and releasing of Al, Mg and Cr. Subsequently alteration of tremolite to talc as illustrated in equation (v), actinolite to chlorite and chlorite to talc equation as shown in equation (vi) are feasible.

$Ca_2Mg_5Si_8O_{22}(OH)_2 + 4CO_2$ ——> $Mg_3Si_4O_{10}(OH)_2 + 2CaMgCO_3 + 4SiO_2$ …….(v)

Tremolite + carbonic acid ——> talc + Dolomite + quartz

$Mg_5Al_2Si_3O_{10}(OH)_8 + SiO_2 + 2CO_2$—>$Mg_3Si_4O_{10}(OH)_2 + 2MgCO_3 + 2(AlOH)_3$…....(vi)

Actinolite + Silica + carbonic acid ——> talc + magnesite + spinel

In the study area, the effects of metamorphism on clinochlore at a low pressure proceed to the right. The crystallization of the tremolite was contemporaneous with reactions as successive metamorphic reactions have replaced or dissolved all primary minerals in the study area in the presence of carbon (iv) oxide that form magnesite ($MgCO_3$).The possible reactions are shown below;

$5Mg_5Al_3Si_3O_{10}(OH)_8$—>$7Mg_2SiO_4 + 2Mg_3Si_4O_{12}(OH)_2 + 5MgAl_2O_4 + 18H_2O$…..(vii)

Clinochlore ——> forsterite + talc + spinel + Vapour

For this study, serpentinization process may be ruled out since the talcose deposit (containing zoned chromite) was possibly formed directly from parent ultramafic rockswithout any suggestion of the occurrence of serpentinization, i.e. the zoning is presumably attributed to the magmatic reactions or regional metamorphism.

At lower temperature, both tremolite and chlorite may be converted to talc by CO_2 metasomatism but at still lower temperature talc is unstable in the presences of CaO and CO_2, and is replaced by magnesite. The associated clinochlore in talcose rock from Kagara is a magnesium-rich silicate variety of chlorite commonly formed along with talc in the retrograde metamorphism of ultramafic protoliths.

Nkoumbou *et al;* (2006) stated that talc can crystallize in wide temperature range as pressure varies **(**Figure 4.27). Therefore, metamorphism was accompanied by metasomatism of the protoliths which is reflected in compositions of the talcose rock in the study area **(**Table 5.2)

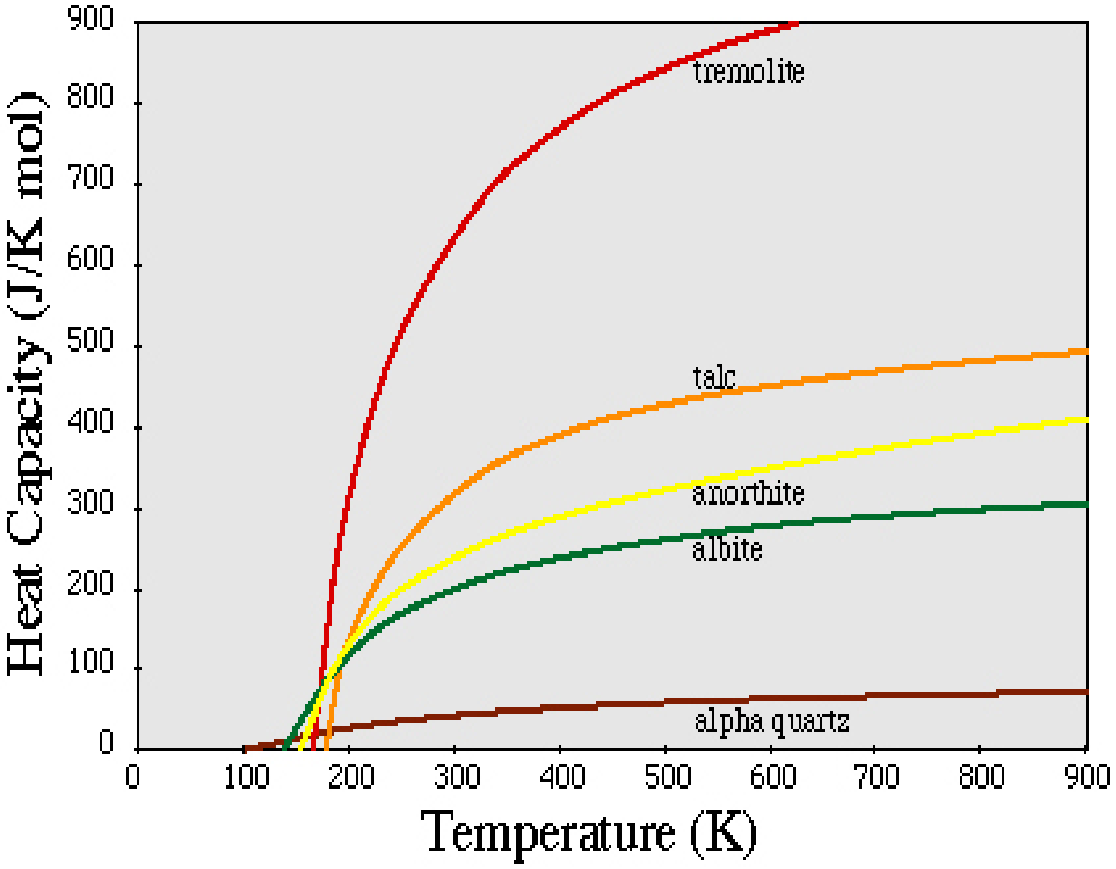


Figure 4.27: Temprature gradient of the talc from Finland (Nkoumbou *et al.,* (2006).

5.4. STRUCTURES

The presence of structures like faults and joints plays vital roles in formation of the

constituent minerals of talcose rock. Two types of faults occur in the area. These are normal and reverse faults. In the normal faults, the hanging wall has moved down relative to the footwall, distorting the schistosity on the schist. Based on the sense of movement, it is a dip-slip fault as the movement or displacement is in the dip direction. Due to decrease in length of rock material along the fault plane, it is a constrictional fault because distance is lost; Note the downward movement of the hanging wall relative to the footwall and distortion of the schistosity in the rock (Plate XIX).

Field evidence shows that the rocks in the study area have more than one generation of joints and the orientation of these joints in the field does not follow any particular trends (directions), as they trend in all directions (Figure 4.24). Two dominant structural trends were identified from the lineament map namely: NE -SW and NW – SE (Figure 4.25). The minor ENE - WSW direction suggestive of shearing of conjugate joints. The multiple orientations support the hypothesis of polycyclic nature of the rock types in the study area. The shear forces produced these fractures were operative at different time in the history of the area. Talcose rock is formed very close to the major fault in the area (Figure 4.23).

The prevalence of lineaments is an indication of high tectonic activity in the study area. Tectonics play a major role in the genesis of a talc deposit. It enables hydrothermal fluids to penetrate the rock, creating a micro-permeability that facilitates reactions in the mass. The size and shape of talcose deposits in the study area reflect the intensity of metamorphism. Pressure and deformations, both of which are concurrent with and subsequent to this transformation, determine the crystallinity of the talcose deposit. The extent of deformation in talcose rock from Kagara is expressed on occurrence and the magnitude of metamorphism and metamorphic structures of the area

like foliations, joints and minor faults. The faults and other structures are believed to be due to Late Pan–Africa brittle deformation that occurred on a continental scale (Ball, 1980). The close association of ultramafic and related rocks with the fault structures suggest that they are crustal sutures of Pan-African collision a earlier proposed by McCurry and Wright (1977), and Ajibade and Wright (1989).

The sutures they serve as structural control for mineralization as the mineralizing solutions percolate and crystallize in them during ascent from the interior of the earth. Also fractured rocks offer great prospect for groundwater. They are very important to engineers searching for groundwater since their presence ehances the development of good aquifers in fractured zones of the basement.

5.5 GEOCHEMISTRY

Major element data presented in Table 4.8 reveals that all rock samples have variable proportion of SiO_2 that range from (28.63 - 74.28) %, with the highest value recorded in granitic gneiss (L_6) while talcose rock have the lowest SiO_2 content(L_{15a}). The values of SiO_2 content in the talcose rock is the lower limit for ultra mafic rocks. Alumina ($Al_2O_{3)}$ content ranges from (0.58 - 18.27) % with the highest value recorded in amphibolites (L10) while talcose rock has the lowest (L13a). There is a wide range of Al_2O_3 concentration (0.58 - 17.11) % in the talcose rock. This may be attributed to the presence of chlorite.

Arndt (1976) has attributed the source of liquidus phase of melt with MgO > 20% to olivine and chromite source; He reported that MgO in the range of 2.0 to 12 % conotes Olivine + pyroxene source; and whereas MgO < 12 % represents pyroxene + plagioclase source. In the talcose rock concentration of MgO ranges from 29.21 % to 35.13 %, thus that talcose rock suggesting from Kagara area belong to olivine and chromite source. The L.O.I of the talcose rock is particularly high, (10.98 - 22.60) %

which may be attributed to expulsion of carbon (iv) oxide from carbonate (magnesite). Similar L.O.I values have been observed in commercial talcs by Agnello (2005); and Segnit (1963) details in Table (5.3).

The Harkers diagrams (Figure 4.13) show that SiO_2 is positively correlated with Na_2O and negatively correlation with Al_2O_3, MgO, P_2O_5 and TiO_2. The SiO_2 is positively and negatively correlated with FeOt and K_2O.

An overall peraluminus character is inferred from A/NK and A/CNK from (Figure 4.14), the high alumina content is consistent with the chemistry of Pan - African rocks, which implied that the rocks of the study area are peraluminous.

Table 5.3: Chemical composition of talcose rock from Kagara area compared with some commercial talcs: A = Harben, (1995); B = Luzenac mine, (2003);C= Norwegian talc mine, (1995); D = Jahn *et al.*,1980); E = Durotoye and Ige, (1991).

S/N	Location		Composition					
			SiO_2	MgO	CaO	Al_2O_3	Fe_2O_3T	L.O.I
1.	**Kagara i**	This study	34.99	35.13	0.18	0.58	6.36	22.60
2.	**Kagara ii**	This study	28.63	29.21	0.02	17.11	13.20	10.98
3.	**Vermont**	A	35.98	32.95	-	0.43	5.67	23.18
4.	**Luzenac**	B	47.50	26.05	1.05	13.25	2.68	9.00
5.	**Norway**	C	39.80	34.50	0.40	1.30	2.67	23.60
6.	**Finland**	D	3.61	25.32	6.86	7.71	10.45	6.15
7.	**Asegbon-Nigeria**	E	53.99	31.73	0.09	1.83	-	5.40

The Total Alkali Silica (TAS) diagram (Figure 4.15) shows that these rocks are granitic rocks and their chemical compositions are consistent with acidic igneous rock suite. Plot of the granites and granodiorite on K_2O versus SiO_2 discrimination diagram reveals that granites were ploted within the high calc-alkalic field while granodiorite falls to calc - alkaline field **(**Figure 4.16**).** The high calc-alkaline magma series (Figure 4.16), corroborates the view of Falconer, 1911, Burke *et al.*, 1976, Turner, 1983,

Dada *et al.*, 1995, Oyinloye, 1998 on rocks from other parts of the basement complex terrain of Nigeria.

Plot of the granites and granodiorite on FeO_{tot} / FeO_{tot} + MgO versus SiO_2 discrimination diagram after Frost *et al.*, (2001) **(**Figure 4.17) revealed that the granites Fe-number of 0.86 - 0.980, (Table 4.9) are ferroans. The granodiorite on the other hand has low Fe-number (0.67) hence it plots in magnesian field.

On the tholeiitic - komatiite classification scheme of Naldrett and Cabri (1976), the plots of Al_2O_3 versus FeO/(FeO + MgO)w % confirms the komatiitic petrogenetic affinity of talcose rock (Figure 4.18). The classification of volcanic rocks after Jenson (1976), the variation of FeO + TiO_2 with Al_2O_3 and MgO, the talcose rock from Kagara area were ploted predominantly in the fields of peridotitic – komatiite. The overall chemical composition of the major element is similar to rocks of komatiitic series and peridotitic affinity (Brooks and Hart, 1974; Elueze, 1982; Olorunfemi *et al.;* 2010). Figures (4.18 and 4.19)

It has been observed that major elements composition in rocks tend to be relatively uniformily distributed and it is the trace element compositions and ratios that provide clues to their unique difference and petrogenesis (Butler *et al.*, 1962). Trace elements compostion of the rocks normalized to the average crustal values for all the rock samples (after Weaver and Terney, 1984) is plotted on a spider diagrams (Figure 4.20).

The normalized abundance permits characterization of the rocks. The migmatitic gneiss, amphibolites and the granodiorite show similar paterns, these rocks are all characterized by negative anomaly of some the field strength elements (HFSE): Nb, Th, Hf, Zr; and positive anomaly of some heavy rare earth elements (HREE): Tb, Yb, and Y. The granodiorite is characterized by negative anomaly of some large ion lithophile elements (LILE) namely Sr and Ba, while the migmatitic gneiss show positive anomaly

of Ba and negaitive anomaly of Sr. The granites on the other hand is characterized by negative anomaly of some LILE (Ba and Sr) and some HFSE (Zr and Nb). Unlike the amphibolites and granodiorite that show positive Hf anomaly.The negative anomaly reinforces the calc-alkaline character suggested by the major element composition. Furthermore, the granites show positive U and La anomalies.

On the Rb versus Y + Nb and Rb versus Ta + Yb discrimination diagram **(**Figure 4.21) the granitic rocks plot in the syn- collisional and volcanic arc granite fields of Pearce *et al., (*1984). This is in agreement with the arc or syn- collisional origin of the Older Granites of Nigeria as proposed by Fitches *et al., (*1985), Odewumi and Olarewaju (2013). Similar granitic rocks with volcanic arc and syn- collisional affinity emplaced during the Pan - African orogeny has also been reported in various parts of northern Nigeria by Olarewaju and Rahaman (1982), southwestern Nigeria, by Okonkwo and Winchester (2004), Okonkwo and Folorunso, (2013) and in southeastern Nigeria by Ukwang and Ekwueme (2009); Obiora, (2012). These granitic rocks termed the '' Older Granites'' have been dated at 750 - 500 Ma by Rahaman *et al.,* (1983); Fitches *et al.,* (1985); and Ekwueme and Kroner, (1998).

The negative Eu anomalies in the talcose rock (Figure 4.22) indicate mineral fractionation and contamination within the basement rocks. The low Rb, Sr, Y, K, Ba and Zr contents of the rocks cannot be reconciled with the hydrothermal alteration, but point to depleted peridotites and pyroxenite as source rock. The concentration of Ni (210-1850) ppm and Cr (170-1930) ppm in talcose rock are similar to those of peridotites (Divakara Rao *et al*., 1975). Table: 5.3 which indicate the parental magma was formed from the mantle peridotite (Rollinson, 1975). The concentration of these elements in the talcose rock can be ascribed to their chemical mobility under the influence of hydrothermal alteration, which commonly produces talc and chlorite from

mafic and ultramafic rocks. This showed distinctive chemical enrichment trends in the talcose rock, rocks from the ore zone have variable and very low concentrations of Trace Elements Table (5.4).

The incompatible trace elements such as Ta, Hf, and Zr which are inert under most geological conditions (Schandl *et al.*; 1995, 1999, Gorton *et al.;* 1999), the low concentrations cannot be due to mobilization during metamorphism.

The REE abundances and the Chondrite-normalized patterns of the rocks studied using normalizing constants of Nakamura (1974) are broadly similar. The REE patterns for all rocks in Kagara area are characteristically skewed to the right except the talcose rock (Figure 4.23). This is also supported by $(Ce/Yb)_N$ ratios that range from (0.02 to 0.33). Moreover, $(La/Sm)_N$ ratio > 1 (0.14 –1.23) also reveal a source related LREE enriched nature of these rocks (Hart and Blusztajn, 2006). $(La/Yb)_N$ ratios range from (0.12 - 0.57) suggesting a partial fractionated REE pattern (Figure 4.24).

Talcose rock indicates absence of plagioclase as a negative Eu anomaly occurs in its chondrite normalized pattern (Figure 4.25). This is also supported by Eu/Eu* values which are remarkably < 1(0.10 - 0.36) for rock with negative Eu anomaly. The deplection in Ti content recorded in the granitic rocks suggests ilmenite fractionation. The host rocks of talcose rock from Kagara deposit is of high concentrations of mobile elements, such as Rb, Ba, U, K and Sr (Table 5.5); these elements are relatively mobile during metamorphism (Schandl *et al.*, 1995), which reflects the composition of the original rocks**.**

Table (5.4): Trace elements data of talcose rock from kagara and data from typical examples of ultramafic rocks of komatiitic affinity (ppm). - = Not Detected; K= This study; A = Ife meta-ultramafite: Ige and Asubiojo, 1991; B_1 = Komatiite from Finland: Jahn *et al.*, 1980; C_1 = Luzenac talc mine report, 2003; C_2 = Luzenac talc mine report, 2003.

Location		**Elements**															
		Sc	Be	V	Ba	Sr	Y	Zr	Cr	Co	Ni	Cu	Zn	As	Rb	Ag	Cs
Kagara i	K	4	<1	170	5	<2	<1	4	1930	82	1850	<10	40	<5	<2	<0.5	<0.5
Kagaraii	K	63	<1	353	<2	<2	5	8	1700	91	210	20	70	<5	<2	<0.5	<0.5
Ife	A	10	-	-	9.2	-	-	-	1969	57	446.5	-	15.9		1.4		-
Finland	B	-	-	150	-	29	-	7	3004	100	1171	-	-	-	1	-	-
Luzenac	C1	-	-	-	-	-	-	-	3380	86	1360	10	160	-	-	0	1.8
Luzenac	C2	-	-	-	-	-	-	-	3590	87	1420	0	140	-	-	0	2.4

Table (5.5): Rare earth elements data of talcose rock from kagara and data from typical examples of ultramafic rocks of komatiitic affinity (ppm) from other sources. K= This study; A = Ife meta-ultramafite: Ige and Asubiojo, 1991; B = Komatiite from Finland: Jahn *et al* ., 1980.

S/N	**Location**		**Elements**													
			La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
1	Kagara i	K	0.5	1.0	0.1	0.4	<0.1	<0.05	<0.1	<0.1	<0.1	<0.1	<0.5	<0.05	<0.1	<0.01
2	Kagara ii	K	0.6	0.9	0.09	0.4	0.30	0.050	0.6	0.2	1.1	0.3	0.7	0.11	0.7	0.110
3	Ife	A	24	0.6	2.25	0.5	0.10	0.100	0.32	<0.1	0.36	<0.1	0.23	0.05	0.23	<0.04
4	Finland	B	0.6	2.3	0.01	2.1	0.74	0.266	1.03	-	1.27	<0.1	0.82	<0.1	0.86	0.134

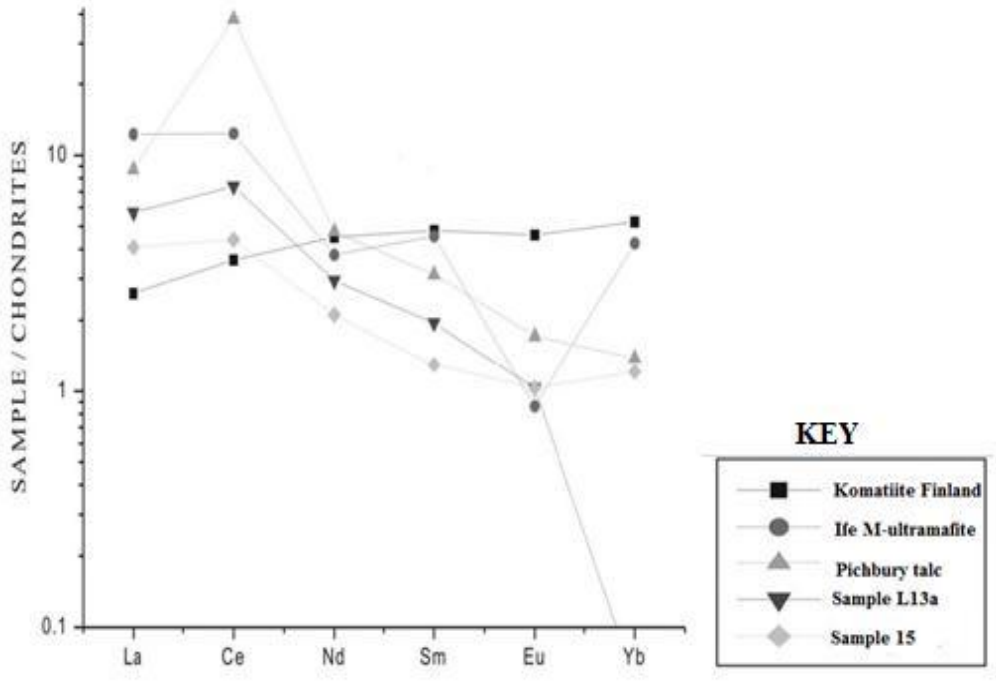


Figure 4:26 Chondrite- normalized REE patterns of the talcose rocks in comparison with data from typical ultramafic rocks of komatiitic affinity (Normalizing value are those of Nakamura, 1974).

5.5 PETROGENESIS

All models of evolution of the schist belts of Nigeria formulated over the years have been classified under ensialic and ensimatic processes of formation (Ogezi, 1977, McCurry and Wright, 1977; Holt *et al.,* 1978; Danbatta, 1991; Elueze, 1992). Danbatta (1991) presented a model that considered Kushaka and Zuru belts as a pair of belts that evolved through ensimatic processes.

Field, Petrographic and geochemical studies are the basic criteria for elucidating the petrogenesis of rocks. Petrographic study reveals that the modal composition of the ferromagnesian minerals (biotite and olivine) decreases from the mafic to less felsic end of the spectrum in the granitic body. This suggests that fractional crystallization dominated by fractionation of biotite and olivine, played a significant role in the evolution of the granitic rocks but less in talcose rock in the study area. The

decrease in the concentration of FeOt, Al_2O_3 and CaO with increasing acidity (SiO_2) in talcose rock supports the earlier observation.

Possible source rocks (protoliths) of igneous rock can be interpreted using trace and rare earth elements patterns in conjunction with some major elements discrimination (Maulana, *et al.,* 2003; Jahn and Sun, 1979).

A characteristic feature of the talcose rock is their very low Zr (4–8) ppm, and very low Al_2O_3 concentration (<1 wt % in one of thesamples of talcose rock), and TiO_2 (0.014 – 0.614) wt % content. This suggests a mantle source for this rock as Zr may replace Ti.

The high Ni (210-1850ppm); Cr (170-1930ppm) and MgO (28.63 - 34.99) wt % concentration in talcose rock samples in the study area suggests original magmatic partitioning and points to the existence of a high Ni – phase presumably olivine in the parent rocks (Hawkesworth and O'Nious, 1977). Nickel (Ni) and Co are normally concentrated in olivine minerals and Cr in spinel, clinopyroxene. The Low Ni, Co, Cr values in the granitic rocks suggests that the calc- alkaline rocks are well fractionated while as high concentrations of Ni, Co, Cr in the talcose rock indicate a mantle source and limited fractionation.

Rare earth elements feature as shown in the chondrite - normalized REE patterns for talcose rock rocks (Figure 4.25) reveal that almost all the samples are low in total REE abundance (2.15 - 6.16) ppm with an average value of 4.13 ppm (Table 4.9). This indicates that talcose rock is distinctly different from those of ophhiolite from an Orogan, but rather close to those of the ultramafic – Archean Komatiitic rocks Figure (23) (Ige and Asubiojo, 1991; Wang *et al.,* 2004). The talcose rock is enriched in LREE with (Ce/Sm)n ranging from 0.01 to 0.70 and moderate fractionation of source magma as shown by $(La/Yb)_n$ ratios (0.12–0.57). (Tables 4.12).

REE patterns of Ce in talcose rock exhibit negative anomaly. This may be due to the change in oxidation state of the Ce ion from trivalent to tetravalent as a consequence of metasomatic alteration (Ige and Asubiojo 1991) Positive anomalous Ce abundances have been reported in komatiitic rocks that have undergone metamorphism (Fryer, 1977).

Sample of the talcose rock with significant quantity of anthophyllite blasts / grains show least modification. The pattern show enriched LREE and almost flat HREE Figures (4.24 to 4.26). Judging from the complex REE patterns in Archean komatiitic rocks, Sun and Nesbitt (1978) and Olorunfemi (2007) proposed that the sources of spinifex textured komatiite must have originated from a depth greater than 400 km in the mantle. Early melts of low degree of partial melting may have concentrated more LREE and LIL elements. When these melts are separated, the residual mantle source would probably be depleted in LREE. Thus, if La, Ti and Sc abundances are controlled by partial melting or simple fractional crystallization process, a consistent co-variation or conformity should be observed in the three elements. However, if the LREE results from a complex melting process no consistent variation would be observed.The REE have been known to be immobile elements and are expected to reflect the primary petrogenetic characteristics of fresh and unaltered igneous rocks. Some certain trace elements like Ti, Y, Nb, Zr (Menzies, 1976) are in general considered to be immobile during rock alteration.

However, the investigations of basaltic rock samples by some workers (Wood *et al.,* 1976, Ludden and Humphris, 1978; Ludden and Thompson, 1978, 1979) have shown that in certain situations, especially during rock alterations, the REE are mobile.

Hellman *et al.,* (1979) identified the principal types of REE enrichment and discovered that to an extent, the most important problem is LREE or HREE group

mobility or selective mobility, mainly of La, Ce and most likely Eu especially during rock alteration.

The talcose rock from Kagara areas show extensive enrichment (La/Sm)n = 0.14 - 1.23 , (La/Yb)n = 0.12 - 0.57 relative to chondrite (Hellman and Henderson, 1977; Arth *et al.,* 1977) formulated a unified petrogenetic model where the tholeiitic and the komatiitic series were thought to be genetically related simply because of their intimate spatial relationship. They believe that the tholeiitic melts, having (La/Sm)n and Gd/Yb)n ratios >1.0, might be the early melts extracted from a mantle source, characterized by a flat chondritic REE pattern. The extraction leads to LREE-depleted nature in the residue which in turn serves as the source for some LREE-depleted komatiites. This could be a plausible mechanism for LREE depletion, at least in talcose rock from Kagara area. The extent of LREE mobility can also be shown by the ratios of (La/Sm)n, (Ce/Sm)n, (Ce/Yb)n and (La/Yb)n (Table 4.12). The (Ce/Sm)n ratios vary widely, indicating that Ce is relatively mobile. The (La/Sm)n ratios are fairly constant, regardless of the different states of the talcose rock, whether altered or not. From a closer look, apart from Ce, metamorphism itself has not thoroughly altered the REE patterns of the rocks. Similarities in (La /Sm)n ratios and the fact that the bodies are within the same area, could suggest that various talcose rock bodies originate from the same magmatic chamber and that possibly the LREE character is inherited from the parent rocks.

The SiO_2 concentration below 41% of the bulk composition confirmed ultramafic but preclude mafic igneous protoliths whereas their very low Zr, Hf, Th, Ta and REE concentrations coupled with the low - high Al_2O_3 content also preclude a felsic igneous protolith.

Logically, silica-rich fluid from surrounding granitoids has some amounts of Na, Rb, Ca, Sr, K, Ce and Ba. In an ultramafic medium, they may increase the

concentrations of the aforementioned elements by contamination or metasomatism that result to crystallisation.

The talcose rocks from Kagara have high Ni, Cr, Co and low Rb, Sr, Y and Zr contents (Table 4.10). These low concentration of Rb, Sr, Y and Zr well as the negative anomaly displayed by Th, Nb, K, Ta, Sr, and Zr, Hf on the spider diagram (Figures 4.20) likely reflect the nature of the protolith. The low concentration of Hf, Ta, Th and Zr in talcose rock from Kagara area are inconsistent with felsic igneous protoliths but high MgO concentrations with low Al_2O_3 in the talcose rock would be consistent with the geochemistry of ultramafic rocks.

The MgO concentration in the talcose rock is consistent with the geochemistry of ultramafic rocks, while the extremely high Cr, Ni and Co content of these rocks confirmed mafic or ultramafic igneous protoliths. The concentration of SiO_2 in talcose rocks which is below 41% of the bulk composition confirms its ultramafic charater but preclude mafic igneous protoliths as the source rock. Also the very low Zr, Hf, Th, Ta and REE content (Tables 4.11) confirms that it is not formed from a felsic igneous protolith. Furthermore, the compositional spectrum suggests that the rocks consist of iron materials diluted by trace-elements and silica. The relatively low level of Hf (<0.02 ppm), coupled with high concentrations of Ni, Cr and Co in the rock simply means that the iron component is likely to have been derived from mafic rocks during differentiation from upper mantle.

The very high concentration of trace and rare-earth elements and the low- high concentration of Al_2O_3 in talcose rock from the Kagara deposit suggest that the talcose rocks are product of metamorphism. The discriminant plots of Al_2O_3 versus with (FeO / (FeO + MgO), Al_2O_3 versus MgO and FeO + TiO_2 further confirms the peridotitic - komatiitic petrogenetic affinity of the talcose rock in the study area.

Metamorphism in the study area has been effective with slow hydrothermal activity as the solution derived from associated rocks are not rich in some elements like Na, Rb, K, Ba, U, and Th.

In support of this is the regional deformation and faulting which produced fractures that served as conduit for easy ingress of solutions during the process of metamorphism in the study area. The deformational textures of the study area were preserved in the talcose rock as most of the tectonism must have taken place at the time of the mineralization. The high Ni (210-1850 ppm), Co (82 - 91ppm), and Cr (170-1930 ppm) values indicate that talcose rocks from Kagara area were derived from an ultramafic protoliths which have undergone moderate degree of metamorphism.

5.7 ECONOMIC GEOLOGY

Mining of the talc deposit of Kagara was initially carried out by the convectional drilling and blasting method, but earth moving equipments was later introduced for excavation, overburden removal, hauling and dumping of ore to the quarry site (Ige and Asubiojo, 1991; RMRDC, 1990a). Four quarry sites were opened, and the material excavated was moved to the mill. This talc ore has since remained the feed material for the company's production of fertilizer tagged 'crystallizer' (RMRDC, 1990b)

At present, there are only two medium size plants (Crystal Talc Nigeria Limited and Crystalizer Nigeria Limited) for talc processing in Nigeria, both located in Kagara. However, only Crystal Talc Nigeria Limited is operational. Crystal Talc Nigeria Limited (CTNL) plant was installed for micronized minerals including talc (Aribisala, 1991, Tanko, 1996). The plant is a pendulum ring roll pulverizer designed to produce minerals according to user's specification with grain size ranging from 100 meshes (150um) to 600 mesh (25um). Floatation and acid bleaching were planned to treat

minerals that require improvement in brigtness to be above 90 %. The Company's attempts at beneficiating talc for pharmaceutical and other enhanced industrial purposes were however abandoned due to envisaged additional costs of floatation and bleaching (Ogunbanjo *et al.*, 1999, Amoka, 2000, Ogunbanjo and Amoka, 2005, 2006).

The geological materials of interest in the study area is essentially talcose rock and to a lesser extent gneisses, amphibolites and granites. The gneiss and granite fragments are quarried and used as building / construction materials. The total reserve estimates of talcose rock so far determined through the strike length of 4,220 m; width of 1,400 m and thickness of 520 m of the talc deposits in the study area is put to 837, 538 million metric tons while the total national demand of talc in Nigeria is estimated at 100, 000 ton per annum (Durotoye and Ige, 1991; Crystallizer, 2009; RMRDC, 2009). Talc prices varied depending on the quality and grade. The unit value of crude talc was estimated to be $26 per metric ton (Industrial Minerals, 2000a). The favourable accessibility of the Crystallizer Company to talcose deposit in Kagara offers easy transportation. With the functional mill in place, an end use has been created for the present grade of the talcose rock from Kagara. The only processing plant in the country located at Kagara produce a little above 29,009 metric ton per annum.Their is yet a wide supply gap (Crystallizer, 2009; Amoka, 2010). The magnesite content of talcose rock from Kagara is exploited by the Crystallizer Limited in the manufacture of crystallizer brand of fertilizer and has the capacity to deliver milled talc to customers on demand. The poor production of talcose rock in Kagara has been linked largely to limited market (Abeysinghe, 1996). The content of MgO, SiO_2 and L.O.I of talc are critical in determing its end use (Table 5.6). However, the talcose rock from Kagara fall within the range required for the manufacture of refractories, paints, ceramics, electrical insulator, textile filler and extender, even without elaborate beneficiation, other possible uses after comminution include insecticides and rubber **(**Table 5.6**)**.

Table 5.6: Summary of Industrial specifications for Talc (Harben, 1995).

Property	**Specifications / Grade**					
	Refractories	Paints	Ceramics	Electrical Insulator	Paper	Textile
SiO_2 %	>6.0		>6.0	> 6.0		< 20
MgO %	>3.0	8.8		>6.0		
CaO %	< 1		< 6	< 1.0	<5.0	
Al_2O_3 %	< 4.0		Low	< 2.5		< 0.05
$Fe_2O_{3\,\%}$	< 1.5		Low	< 1.5		
K_2O/Na_2O%	< 0.4		-	< 0.46		
L.O.I %	-	< 7.0	-	-	-	-
Acid in solution	-	< 1.0		-		-
Brightness	Good	>90.0		Good		Good
Oil absorption	Good	Good (ASTMD 281)		-		-
Consistency	-	Good		Good		-
Moisture %		<1		-		0.3
Mesh/ PH	92-95% (200 mesh)	99% (-325 mesh)		-		-
Others %	5.0-10.0 Impurities	No colourants	No colourants	>2.5	No gritty particle	No gritty particle

CHAPTER SIX

CONCLUSIONS AND RECOMMMENDATIONS

6.1 CONCLUSIONS

The study area is underlain by migmatitic-gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolite, talcose rock, phyllite, porphyritic granite, fine to medium grained granite, granodiorite, and pegmatite. Two distinct varieties of talcose rock are distinguished by colour (white and black). Green chunks of chlorite and bands of quartz veins were also observed in the field as megascopic examination shows typical greasy lustre and basal cleavage of talc.

Mineralogically, the talcose rock contains in addition to talc, appreciable amounts of chlorite, magnesite, and anthophyiltes with quartz and magnetite forming the accessory minerals. Talc mineralization is controlled by many factors particularly silica activity in the liquid phase. Fluid coming from the surrounding was most probably rocks may be rich in dissolved SiO_2 as shown in equations (i) and (ii).

$Ca_2Mg_5Si_8O_{22}(OH)_2 + 4CO_2 \longrightarrow Mg_3Si_4O_{10}(OH)_2 + 2CaMgCO_3 + 4SiO_2$ .....(i)

Tremolite + carbonic acid ——> talc + magnesite + quartz

$Mg_5Al_2Si_3O_{10}(OH)_8 + SiO_2 + 2CO_2 \longrightarrow Mg_3Si_4O_{10}(OH)_2 + 2MgCO_3 + 2(AlOH)_3$ ...(ii)

Actinolite + silica + carbonic acid ——> talc + magnesite + spinel

In the study area, the effects of metamorphism on clinochlore at low pressure proceed to the right as crystallization of the tremolite was contemporaneous with reactions as successive event. During metamorphism some of all primary minerals in the study area were replaced or altered the presence of carbon (iv) oxide that produced magnesite ($MgCO_3$). The possible reactions are as shown in equations (iii) and (iv).

$5Mg_5Al_3Si_3O_{10}(OH)_8 \longrightarrow 7Mg_2SiO_4 + 2Mg_3Si_4O_{12}(OH)_2 + 5MgAl_2O_4 + 18H_2O$....(iii)

Clinochlore ——> forsterite + talc + spinel + Vapour

$5Mg_5Al_3Si_3O_{10}(OH)_8$——>$7Mg_2SiO_4 + 2Mg_3Si_4O_{12}(OH)_2 + 5MgAl_2O_4 + 18H_2O$….(iv)

Clinochlore ——> forsterite + talc + spinel + Vapour

Mineral paragenesis obtained from metamorphosed mafic/ultramafic host rock including talc occurrences in the study area are: magnesite + clinochlore + ferroan+ magnetite + talc; carbonate + tremolite + talc; quartz + albite + biotite + clinochlore + muscovite + malc; serpentine + chlorite + talc; quartz+ albite+ muscovite + biotite + clinochlore; and quartz + chlorite + magnetite.

Geochemically, talcose rock has high SiO_2, MgO, Fe_2O_3, L.O.I contents and low CaO, Na_2O, K_2O contents with variable proportions of Al_2O_3. Silica-rich solutions derived from granites became rich in some elements like Na, Rb, Sr, K, Ba, U, and Th). In an ultramafic medium, these increased the concentrations of the aforementioned elements by contamination or metasomatisms that resulted to crystallisation. Talcose rocks have lower amounts of Ba, Sr, Th, U, Zr, and Y contents. These low concentrations as well as the negative anomalies displayed by Th, Nb, K, Ta, Sr, and Zr, Hf on the spider diagram likely reflect the character of the protolith. The Ni, Cr and Co concentrations can be assigned to high olivine and chromite contents of the original rocks. The high Ni (210- 1850 ppm), Co (82-91 ppm), and Cr (170-1930 ppm) content indicate that talcose rock was derived from a mafic or ultramafic rock in terms of parental affinity. Furthermore, the $(La/Sm)_N$ ratio > 1 (0.14 –1.23) also reveals a source related LREE enriched nature of these rocks while the $(La/Yb)_N$ ratio which ranges from 0.12 to 0.57 suggests a partial fractionated REE pattern. The talcose rock show negative Eu anomaly and therefore paucity of plagioclase (Figure 4.20). This is also supported by Eu/Eu* values which is remarkably low < 1(0.10- 0.36) for the talcose rock. All the aforementioned evidences suggest peridotitic komatiitic precursor that have undergone moderate degree of metamorphism of for the talcose rock from Kagara area. On the basis of the physical, mineralogical and

geochemical characteristics of the talcose rock, the other major findings of this project research are as follow:

(i).The chemical and mineralogical properties of the talcose rock from Kagara were compared to many existing commercial talcs globally, and are suitable for several low to medium grade industrial applications such as refractories, paints, electrical insulator, textile filler and extender.

(ii). The coexistence of chlorite with talc is not detrimental to talc for many applications because they have similar mineralogical composition.

The chemical compositions are important criteria for most of the industrial applications such as refractories; paints, ceramics, and textile are closely complied with in untreated samples from these deposits. The data set from present work provide a valid basis tool for choosing the beneficiation methods for specific applications.

6.2 RECOMMENDATIONS FOR FURTHER WORK INCLUDE:

(1) Detailed geotechnical tests on drill core samples from beneath the zone of superficial oxidation should be carried out on talcose rock from Kagara area so as to determine the superior end uses like dimension stone –work, sculpture and carving.

(2) Further work on beneficiation by means of froth flotation should be carried out on talcose rock from Kagara area should be undertaken to assess other areas of application e.g fillers for paper, production of insecticides and pesticides and textile.

6.3 CONRTIBUTION OF THE WORK TO KNOWLEDGE

The following are the major contribution of this work to knowledge:

(1) Production of geological map of the study area on a scale of 1:50 000

(2) Determination of the mineralogical / geochemical charatertristics and petrogenesis of talcose rock from Kagara area.

(3) This research work has established that talcose rock from Kagara is a product of metamorphic origin from ultramafic protolith (peridotitic komatiitic).

(4) This research work has established that the coexistence of chlorite with talc is not detrimental to talc for many applications because they have similar mineralogical composition and can substitute for each other for industrial uses, especially where colour demand is not too stringent.

(5) Geochemical attributes, varieties and quality of talcose rock from Kagara area have been documented.

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APPENDIX I

Lineament trends of granitic rocks from Kagara area.

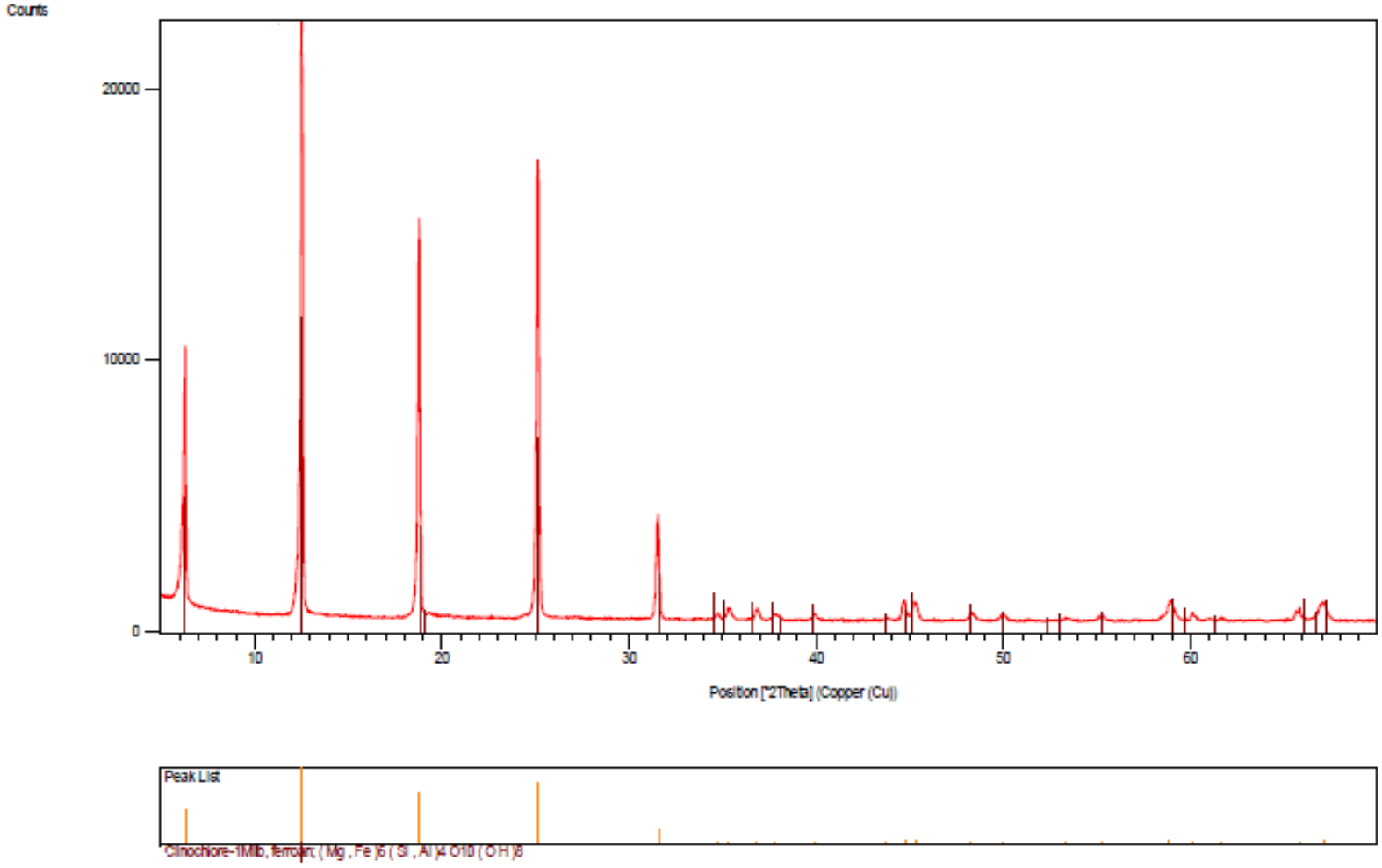
Lineament Trend	Interval	Frequency
23, 23, 59, 292, 295, 36,35,34,281	$0\text{-}90^0$	26
22; 51, 299, 19, 19, 72, 52, 67, 36,	$91\text{-}180^0$	1
34, 33, 31, 28, 28, 300, 300, 357,	$181\text{-}270^0$	1
70, 68, 61, 61, 29, 310, 346,344, 189, 121	$271\text{-}360^0$	8

Lineament trends of the structure in metasedimentary from Kagara area.

Lineament Trend	Interval	Frequency
56, 42, 45, 56, 34, 34, 26, 34, 48,	$0\text{-}90^0$	22
78, 29 297, 27, 48, 39, 39, 19, 7,	$91\text{-}180^0$	1
18, 336, 54, 11, 29, 11, 15, 57,	$181\text{-}270^0$	1
121	$271\text{-}360^0$	2

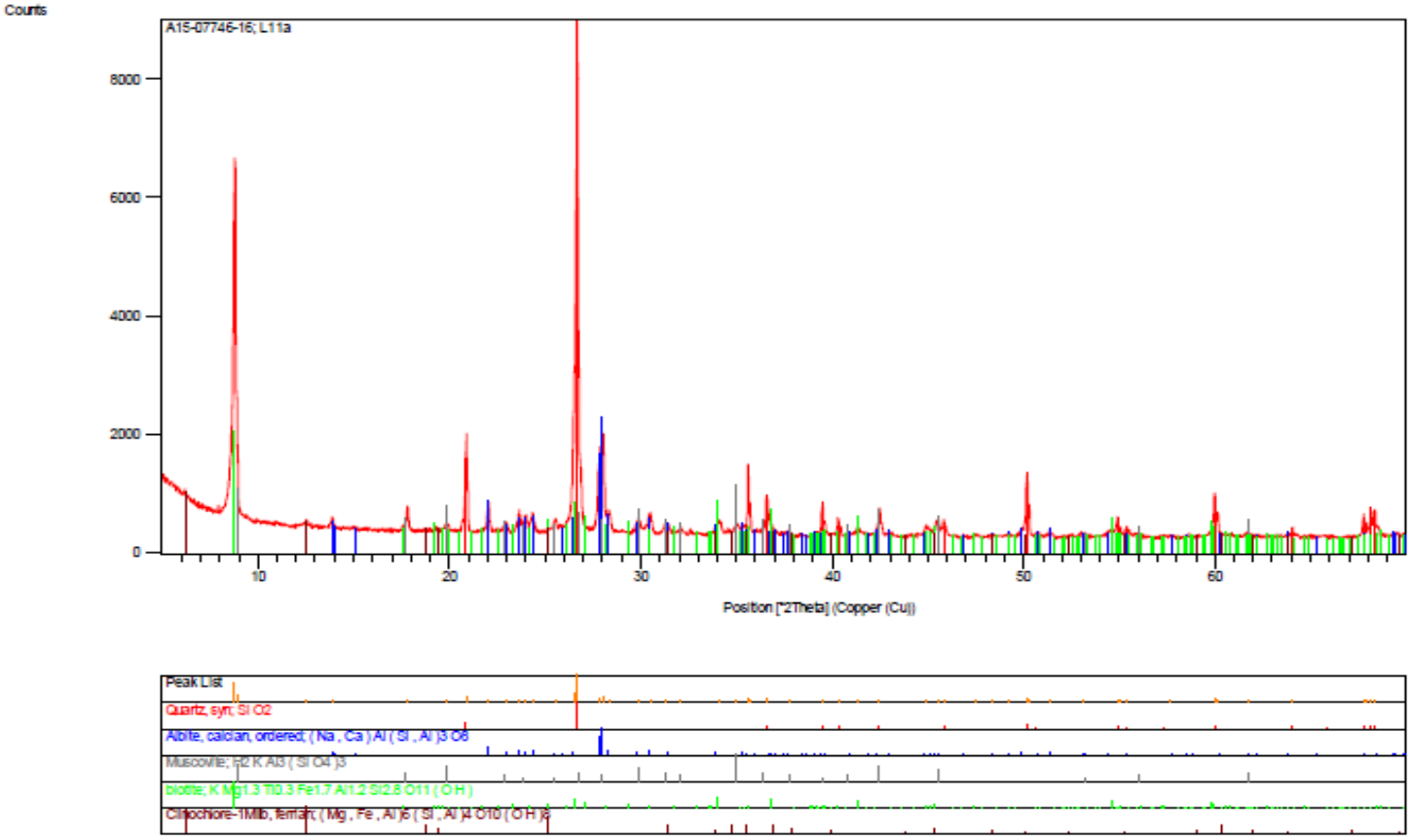
APPENDIX II

X-ray diffraction (XRD) pattern for amphibolite: Sample (L8a)



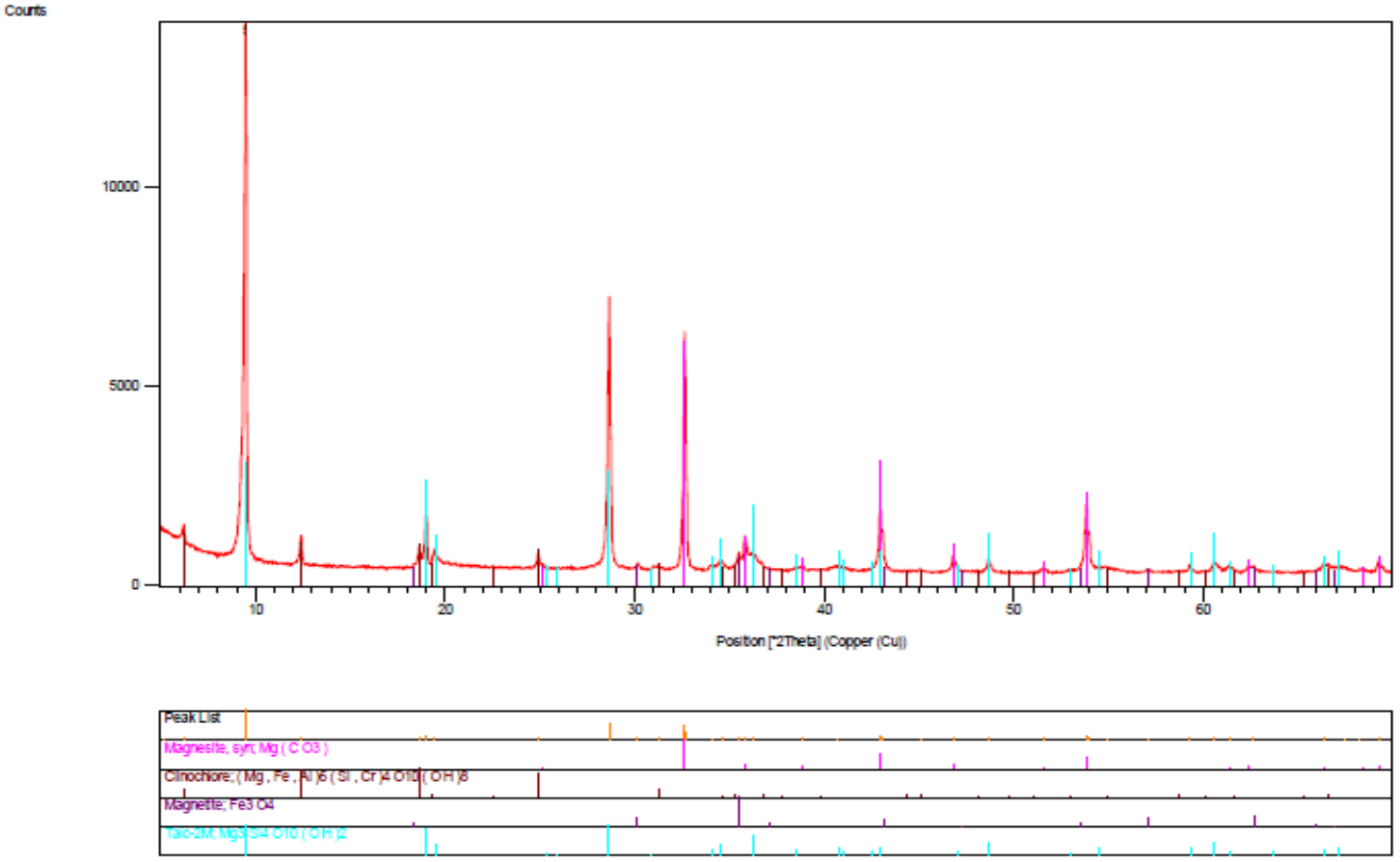
APPENDIX 1II

X-ray diffraction (XRD) pattern for amphibolite: Sample (L11a)



APPENDIX 1V

X-ray diffraction (XRD) pattern for talcose rock: Sample ($L13a_2$)



APPENDIX V

X-ray diffraction (XRD) pattern for talcose rock: Sample ($L15_a$)

