GEOLOGY OF SHEET 79 MALUMFASHI SOUTH EAST, GEOCHEMISTRY AND MINERALIZATION POTENTIAL OF TUDUN KAYA - DANZAU AREA NW, NIGERIA

BY

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ZARIA - NIGERIA

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JUNE, 2011

DEDICATION

To the living memory of my father Late Alhaji Ahmad Rufa'i who could not live to see the end of this course, may Allah grant him Aljannat Fiddaus

DECLARATION

I declare that the project Report/Thesis (“ Geology of Sheet 79 Malumfashi SE, Geochemistry and Mineralization Potential of Tudun Kaya – Danzau area NW Nigeria”) is a record of my own work and that it has not been submitted in any form to any other institution for the award of a degree or diploma. Information derived from published and unpublished works of other workers are acknowledged by means of reference.

…….. ……

Signature Date

CERTIFICATION

This project Report/Thesis entitled (“ Geology of Sheet 79 Malumfashi SE, Geochemistry and Mineralization Potential of Tudun Kaya – Danzau area NW Nigeria”) by RUFA’I Shafi’u Ahmad meets the regulation governing the award of the degree of M.Sc. Geology of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

Field mapping, petrographic and geochemical analysis of rocks in sheet 79, Malumfashi SE was carried out in this study. Field mapping on a scale of 1:50,000 reveals that the area is composed of banded gneiss, Older Granite, diorite as the major rock types. Pegmatite veins, aplite dykes and quartz veins occur as minor intrusives. Alluvium. Laterite and soil occur as superficial deposits. The pegmatite zone was further mapped on a scale of 1:10,000 for detailed study.

Structural analysis indicates that some of the rocks are deformed, either folded or faulted trending N-S to NNE-SSW, which coincides with the disposition of the Pan African Basement structures. North- East trending fractures and faults were also documented and are exploited by most of the pegmatitic veins and dykes.

Petrographic analysis using transmitted light microscopy shows that the granites contains quartz, feldspar(microcline) and biotites as the major minerals, the diorite is seen to contain oligoclase as the dominant feldspars with biotite, chlorite and quartz. The pegmatite also contains predominantly feldspar, quartz mica and beryl. The banded gneiss was highly weathered that they could not allow for a petrographic analysis of the rock.

Geochemical analysis of eleven representative samples of the major rock types granite,diorite and the pegmatite from the study area was carried out at the Activation Laboratories Ontario, Canada. The analytical methods used by Actlabs include the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for major and trace element analysis, the Instrumental Neutron Activation Analysis (INAA) for trace and rare earth elements analysis. The major elements from the analysis shows SiO_2 for Granites to be 72.3 – 74.3 wt%, Diorites 57.96 – 74.77 wt% and pegmatites 62.6 – 74.While K_2O for granites is 4.71 – 4.85 wt%, diorite 4.39 -5.02 wt% and 0.86 – 9.64 wt% for the pegmatites. TiO_2 in all the samples is between 0.01 -0.908 wt%.

The trace element composition for all the samples was Ba 27.4 – 2073ppm, Sr 14.0 – 603, Rb 41.0 – 1000ppm, Cs 5.1 – 30ppm. The rare earth elements in the samples are Ce 4.6 – 107, Eu 0.05 – 2.07ppm.

The granites were found to be peraluminous in nature and on a chondrite normalized REE pattern plots shows enrichment in LREE and a depletion in HREE. The Eu anomaly is negative

and well pronounced typical of the other granitic rocks from other parts of northern Nigeria. The pegmatites also show an enriched LREE and a more enriched HREE with a negative Eu anomaly. The K/Rb ratio and a plot of the discrimination diagram K/Rb Vs Rb suggest only a slight enrichment of the REE in the pegmatites.

An evolution model for the rock types and other intrusives in the study area is being proposed. As no major mineralization was observed on the major rock types yet the associated minerals most especially for the pegmatites could be exploited industrially, prospects for tapping the alluvium deposits, laterites and rock aggregates are high.

TABLE OF CONTENTS

Cover page i

Title page ii

Dedication iii

Declaration iv

Certification v

Acknowledgement vi

Abstract vii

Table of content viii

CHAPTER ONE GENERAL INTRODUCTION

1.1 Location and accessibility 1

1.2 Climate and Vegetation 1

1.3 Relief and Drainage 3

1.3.1 Relief 3

1.3.2 Drainage 4

1.4 Previous Work 6

1.5Present work 9

1.6 Aims and Objectives 10

CHAPTER TWO REGIONAL GEOLOGY

2.1 Introduction 11

2.2 Nigerian Pan – African Basement 11

2.3 The Schist Belts 15

2.4 The Older Granites 16

2.5 Pegmatites 17

2.5.1 Classification of pegmatites 17

2.5.2 Phases of pegmatites 18

CHAPTER THREE FIELD GEOLOGY AND PETROGRAPHY

3.1 Preamble 20

3.2 Banded Gneiss 20

3.2.1 Field relationship 20

3.2.2 Petrography 20

3.3 Medium grained granite 22

3.3.1 Field relationship 22

3.3.2 Petrography of granite 23

3.4 Quartz-diorite (Loc 2 / SA9) 25

3.4.1 Field relationship of quartz-diorite 25

3.4.2 Petrography quartz-diorite 26

3.5 Pegmatites 27

3.5.1 Field relationship of pegmatites 27

3.6 Aplite dyke 30

3.6.1 Field relationship Aplite dyke 30

3.7 Quartz vein 30

3.7.1 Field relationship of quartz vein 30

3.8 Superficial deposits 31

3.8.1 Laterite 31

3.8.2 Alluviums 31

CHAPTER FOUR STRUCTURAL GEOLOGY

4.1 Structural features 33

4.2 Foliation 33

4.3 Folds 33

4.4 Joints 34

4.5 Faults 35

4.6 Xenolith 36

CHAPTER FIVE GEOCHEMISTRY AND ECONOMIC GEOLOGY

5.1.Sample collection and Analytical techniques 37

5.2 Geochemistry of the medium grained granite 41

5.2.1 Major elements distribution 41

5.2.2 Trace element distribution 42

5.3 Geochemistry of the quartz diorite 44

5.3.1 Major elements distribution 44

5.3.2 Trace elements distribution pattern 46

5.4 Geochemistry of the pegmatites 47

5.4.1 Major elements distribution 47

5.4.2 Trace elements distribution 47

5.5 Mineralization potential of the study area 50

5.5.1 Beryl 50

5.5.2 Quartz, Feldspar and Clay 51

5.5.3 Hard rock (Building stones) 51

5.5.4 Sand and Gravel 51

5.5.5 Laterite 52

CHAPTER SIX SUMMARY AND CONCLUSION

6.0 Summary 53

6.1 Conclusion 55

REFERENCES 57

APENDIXES 59

LIST OF TABLES

Table 2.1 Generalised geochronology for the basement rocks of Nigeria 13

Table 3.1 Modal analysis of rock samples for minerals estimated in percentage 32

Table 5.1 Major Element concentrations 38

Table 5.2 Trace Element concentrations 39

Table 5.3 Rare Earth Element concentrations 40

Table 6.1 Proposed Evolution model 54

LIST OF FIGURES

Fig. 1.1 Location map of study area. 2

Fig. 1.2 Drainage map of part of study area. 5

Fig 1.3 Regional geology of the Pan- African Basement 8

Fig 2.1 Geological map of the Pan-African belt 12

Fig 3.1 Geological map of Sheet 79 Malumfashi SE 19

Fig 3.2 Geologic map Tudun Kaya, Dan Zau area 20

Fig.4.1 Rose diagram of joint trends in medium grained granite 35

Fig. 5.1 The geochemical range of the granite and diorite 41

Fig. 5.2 The peraluminous nature of the granitic rocks 42

Fig. 5.3 The tectonic nature of the granites and diorites from the study area 43

Fig. 5.4 Chondrite-normalized REE patterns for Tudun Kaya – Dan Zau granite 44

Fig. 5.5 A classification chart of rocks from the study area 45

Fig. 5.6 Chondrite-normalized REE patterns for the Dioritic rocks 46

Fig. 5. 7 Discrimination diagrams of the pegmatites 48

Fig. 5 .8 Chondrite-normalized REE patterns for Pegmatite 50

LIST OF PLATES

Plate i Photograph of highly weathered banded Gneiss at Malam Sani 21

Plate ii Photograph of medium grained Granite outcrop in Tudun Kaya village 22

Plate iii Photomicrograph of granite 23

Plate iv Photograph of a dioritic outcrop at Dan Zau 25

Plate v Photomicrograph of diorite(XPL X25) 26

Plate vi Photograph of the coarse grains of quartz and feldspars in the pegmatite veins 28

Plate vii Photograph of a typical pegmatite vein at MalamSani 28

Plate viii A mining pit dug on one of the pegmatite veins by artisanal miners at Danzau 29

Plate ix Photomicrograph of Pegmatite 29

Plate x Aplite dyke in the mapped area in the medium grained granite at Danzau 30

Plate xi Photograph of a hard, brown laterite at Danzau 31

Plate xii Photograph of a folded vein on a medium grained granite 33

Plate xiii The geometry of joints as observed on the medium grained granite 34

Plate xiv Photograph of a quartz vein being displaced by a fault 36

Plate xv Xenolith of dark basic rock in the medium grained granite at Ma village 36

APPENDIXES

Appendix 1: Joint readings (in degrees) in the medium grained granite 59

Appendix 2: Geochemical results. 59

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Location and accessibility

The study area lies between latitudes 11^0 30′ N and 11^0 45′ N and longitudes 7^0 45′ E and 8^0 00′ E. It has an overall land area of 924 square kilometers that includes part of Karaye, Rogo Local Government Areas of Kano state and Mahuta Local Government Area of Katsina State (Fig 1.1). The study area is shown in Fig. 3.1. A trunk B road from Karaye to Rogo traverse the area from East to West and the area is about 6km from Karaye. Other roads include the Tudun Kaya – Karaye road that traverse the area from N-S and Danzau – Mahuta-Malumfashi road. There is also a network of footpaths and cattle tracks which makes the study area very accessible by foot and by vehicle.

1.2 Climate and Vegetation

The area falls within the Tropical Continental Climatic Zone; with two distinct seasons: dry and raining seasons. This climatic zone is characterized by sultry conditions during the rainy season. Rainfall lasts for five months from May to September, with an annual average of about 835mm (Morgan, 1983). The relative humidity is frequently below 10% at midday while insulations and radiation are intense resulting in large daily range of temperatures. Maximum temperatures are very high (>40^oC), and minimum temperatures are very low (21^0c).

The dry season lasts for about seven months from October-April and is characterized by dismal range of temperatures and extreme dryness. This brings a succession of

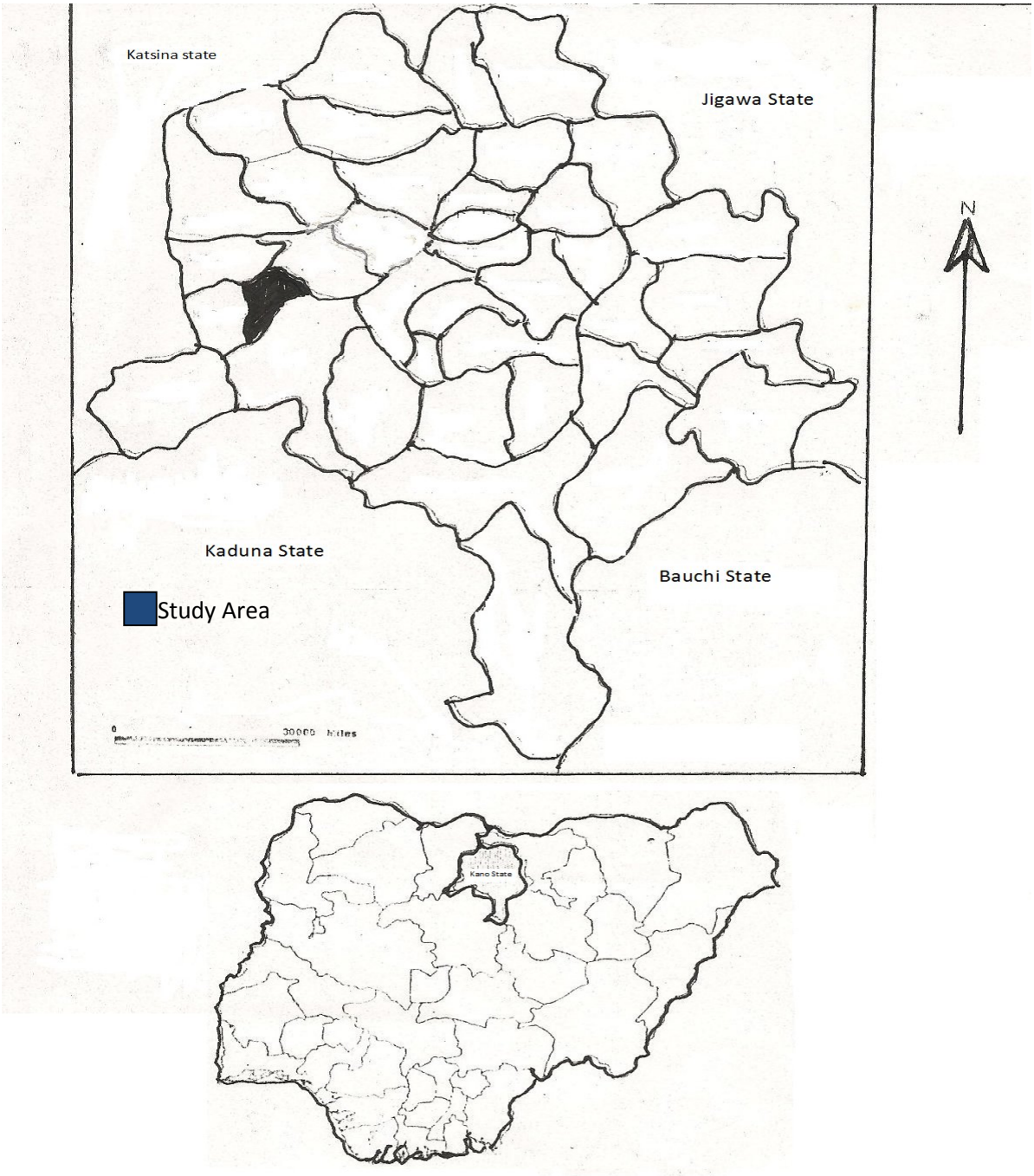


Fig 1.1 Map of Kano State showing the location of the study area and a map of Nigeria below showing the location of Kano state

sharp contrast. The area falls within the Sudan Savannah Vegetation type. The trees have small leaves or leaflet and thorns, such as the Acacia Specie that is characteristics of dry conditions, grasses are shorter and slender. Bush stunted trees and shrubs are very common near water courses. Natural vegetation covers less than 5% of the land area and even then degraded. Common species include Adansonia digitata(Kuka),Vitex domiana(Dinya) which provides edible fruits and leaves. Diospyros mespiliformis(Kanya) and tamarindus indica(tsamiya) provide edible fruits while moringa oleifera(zogale) provide edible leaves. Others include parkia clappertoniana(dorawa),leiocarpus(marke) and khaya segalensis(madaci) are popular fuel wood species.

1.3 **Relief and Drainage**

1.3.1 **Relief**

The Kano region occupies the southwestern rim of the Chad depression and shares physiographic divides with the Niger and Benue River systems to the south and with the Niger system to the southwest and west as the Chad – Sokoto Divide.

The elevation of the region above mean sea level ranges from about 400 metres (m) at the northeastern margin to over 1200m at the southern tip. That is the highest elevation occurs in the south, and elevations decrease both northwards and northeastwards. The region is part of the popular high plains of Hausa land except for the section east of the

Hydro-Geological Divide. The relief is greatly influenced by the geology because the highest elevations are associated with igneous structures and the lowest with the Chad Formation. The relief is better described under three types occupying three distinct zones:

1.3.2 **Drainage**

The drainage of the mapped area is part of the inland drainage system of the Chad Basin and consist of the head-stream of the river system known as the river system of Challawa. Both the drainage and the hydrology of the region are influenced by the climate, rock structure and human activities (fig. 1.2).

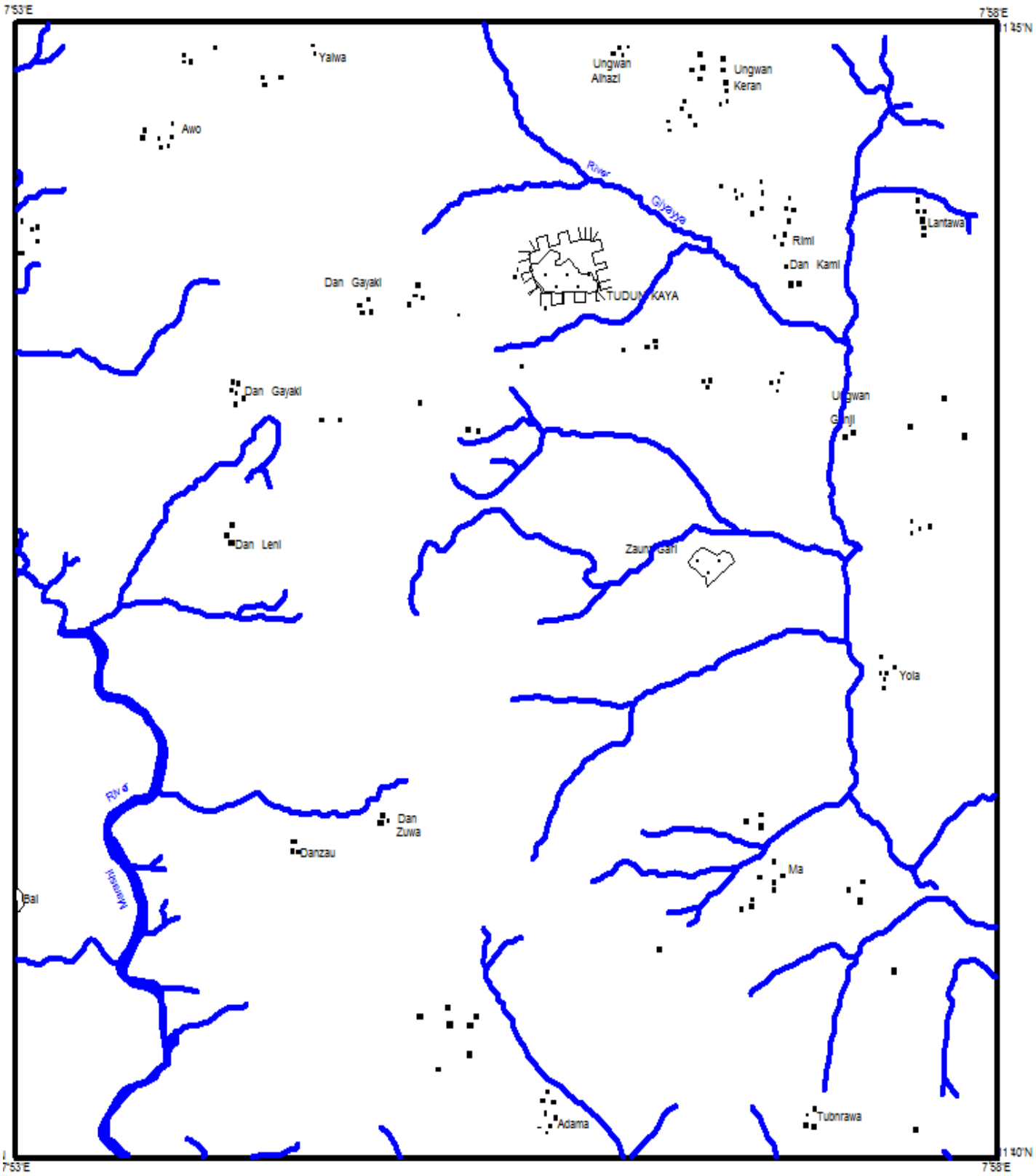


Fig. 1.2 Drainage map of part of the study area

The rivers in the mapped area drains essentially northeastwards to the Challawa and Jare rivers. River Marmanya ,Suran, Tukurwa, Maitakardu, and Kanoki all drains into River Jare. The Jare eventually drains into the major head stream Challawa.

The important headstream is the Chalawa and the streams rise and flow freely over the Basement Complex section only to lose their channels, at a short distance east of the Hydro-Geological Divide, into the unconsolidated sediments of the Chad Formation. Challawa which rises from a drier area and has a mean discharge of 22 m^3/s.

The drainage system is good and having a network of stream channels showing a dendritic pattern. River Marashi is the main river into which the others flow and is noted to be structurally controlled. It drains the western portion of the study area while the other rivers dominate the southeastern portion. The direction of flow is from North to South and and meets River Chalawa, River Jare and River Kwakwa at Dadin Kowa. The Marashi was dry as at the time of the field exercise.

1.4 **Previous Work**

A lot of work has been done on the Basement Complex of North Western Nigeria, particularly in the Malumfashi Sheet 79. The earliest work was reported by Fargher, (1961) and is on the geology of part of the Crystalline Basement of Northern Nigeria at 1:100,000. McCurry, (1970) however mapped a large area in Northern Nigeria, part of which is Malumfashi Sheet 79, where three groups of rocks were identified:

(a) the migmatite - gneiss complex as the oldest

(b) the Schist belt

(c) the Older Granites series of Pan African age which are the youngest and there are twelve of such schist belts in Nigeria, one of which is the Malumfashi belt which is situated around the present study area.

Danbatta, (2008) has formulated a theory on the evolution of the schist belt of Nigeria, where he assigned the Malumfashi belt to an ensialic origin during the Eburnean time.

Ajibade, (1982) described the silicified fault zone in the gneissic complex of the Malumfashi area and outlines the significance to the major rock types found in the area as indicating the presence of a fault. Two major dextral strike- slip NE-SW trending regional faults have been established in Nigeria (Fig.1.3). These are the Anka-Yauri-Iseyin (AYI) and the Kalangai – Zungeru – Ifewara (KZI) faults (Wright, 1976; Ball, 1986; Danbatta, 2003, 2008). The KZI traverses the Kazaure, Malumfashi; Zungeru-Birnin Gwari, Igarra-Kabba-Lokoja and Ife-Ilesha belts.

McCurry and Wright (1970) divided the granitic bodies on sheet 21 on a scale of 1: 100,000 into syntectonics and late tectonic granites on the basis of field observations. Tuner (1983) considered the Malumfashi belt as forming in a back - arc basin together with, Birnin Gwari, Kazaure and Wonaka schist belts.

The Department of Geology (1989) A.B.U. Zaria has carried out a Commission Research project around the Chalawa Gorge Dam area at Karaye as a consultancy work for Julius Berger Nigeria Ltd.

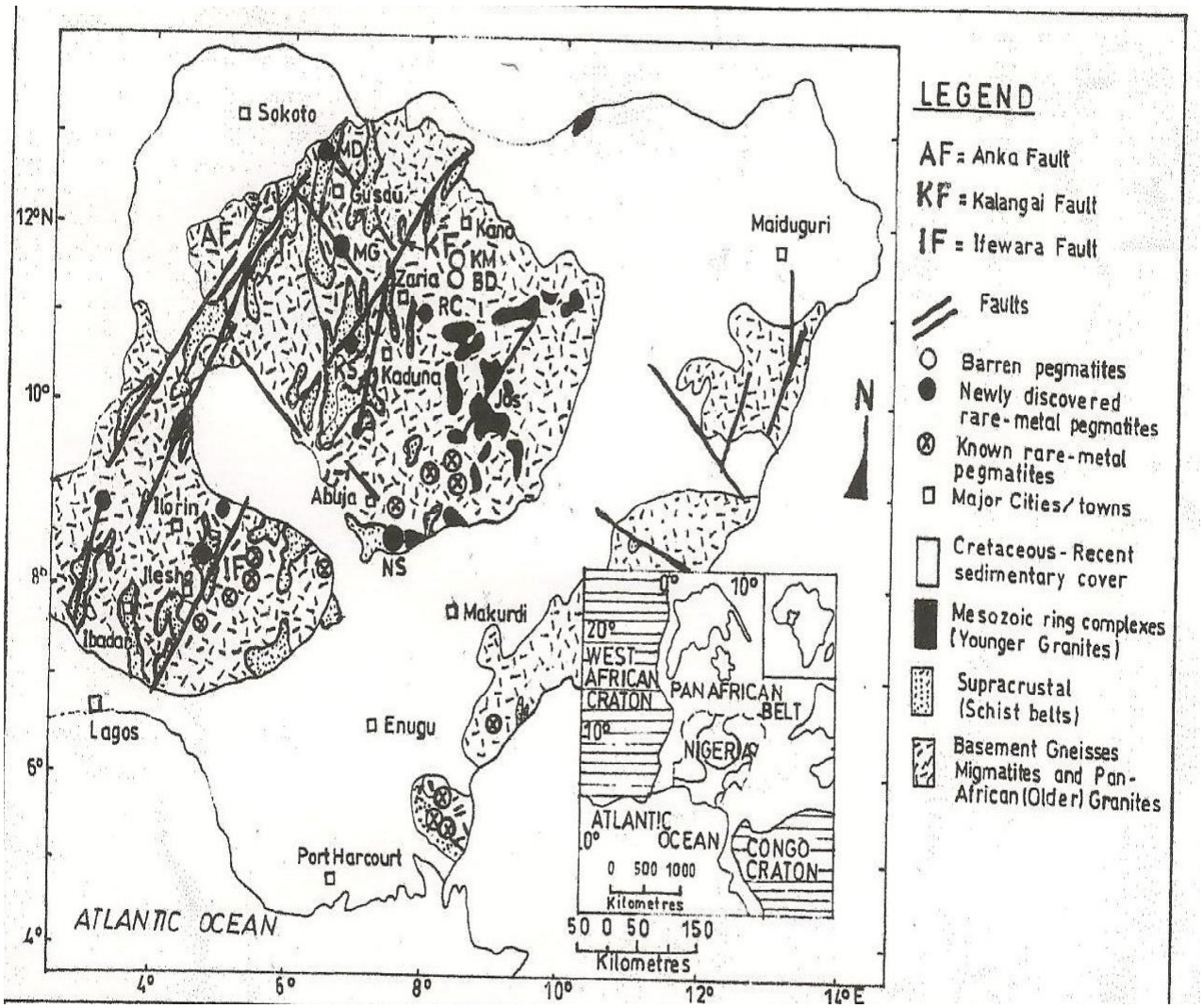


Fig 1.3 Regional geology of the Pan-African Basement showing the major faults established in Nigeria (Modified from the Geological Survey of Nigeria map, 1994).

1.5 Present work

The present work involved the mapping of the Sheet 79 Malumfashi SE on a scale of 1:50,000 as well as the detailed mapping of a small sub-area on a scale of 1:10,000. The mapping method is by Compass-GPS traverse method, where all the possible areas were traversed along roads, footpaths, rivers and streams. A Google Earth satellite imagery covering the project area was also used as part of the desk study.

The first of the phase one was the geological field mapping at a scale of 1:50,000 approximately covers an area of 924 km^2 while phase two of the detailed mapping of a smaller sub-area at a scale of 1:10,000 covers an estimated area of 64 km^2. The second phase of the fieldwork came up as a result of the discovery and location of mining pits that were dug about twenty metres (20m) deep in places by artisanal miners looking for beryl. They were dug on the pegmatite veins that occur along the river channels at Danzau village which joins the Marashi River. The Danzau stream and other adjoining areas around Tudun Kaya, Zanginawa, Ma, Adama and Unguwan Bawa villages were mapped on a scale of 1:10,000 .The first mining pit at Danzau is more than twenty metres (20m) deep and was first drained of its water using pumping machine. Rock samples were collected at intervals downstream along the stream where it joins river Marashi. The area is bounded by latitudes 11^0 40′N - 11^0 45′N and longitudes 7^0 53′E – $7^0$58′E.

During the mapping exercise, special emphasis was paid on the exact location of rock types, rock samples and boundaries. That was why the GPS instrument was indispensable. Thin section studies were carried out to corroborate visual estimation on representative fresh rocks samples that were collected in the course of the geological mapping.

1.6 AIMS AND OBJECTIVES

In addition to preparing the much needed geological map of the study area on a scale of 1: 50,000 , the present work is also intended:

(a) Studying the lithology and field relationship of the component rock units of the study area.

(b) Study the economic mineral resources of the study area with special emphasis on the pegmatites. This necessitated the mapping of the Danzau area at 1: 10,000 scale to bring out the structural control of any observed mineralization.

(c) Collect representative rock samples for petrographic and geochemical investigations.

(d) Systematic study of the geochemistry and petrography of the representative rock samples and relating it to the events connected with their genesis and evolution of the area.

CHAPTER TWO

REGIONAL GEOLOGY

2.1 Introduction

The Nigerian Basement lies in the area east of the West African Craton and Northwest of the Congo Craton, and South of the Taureg shield. The region was affected by the Pan-African Orogeny about 600 Ma ago. It is believed that the Pan-African belt evolved by plate tectonic processes which involved collision between the passive continental margin of West African Craton and the active continental margin of the Tuareg shield about 600 Ma ago, (Black et al., 1979 Ajibade et al.,1987). The collision at the plate margin led to the reactivation of the internal region of the belt. The Nigerian Basement Complex lies in the reactivated portion of the belt. The general geochronology of the Precambrian Basement rocks of Nigeria is shown in Table 2.1, (McCurry,1976).

2.2 Nigerian Pan – African Basement

The Nigerian Pan – African Basement is, on the basis of rock types, divided into three units Fitches et al., (1985); Ajibade et al., (1987), thus:

1. The gneisses and migmatites with entrained supracrustal relics whose metamorphism is generally in the amphibolites facies grade. These rocks are mainly quartzites, amphibolites, calcareous rocks, biotite-hornblende gneisses, quartz schist and biotite-hornblende schist.

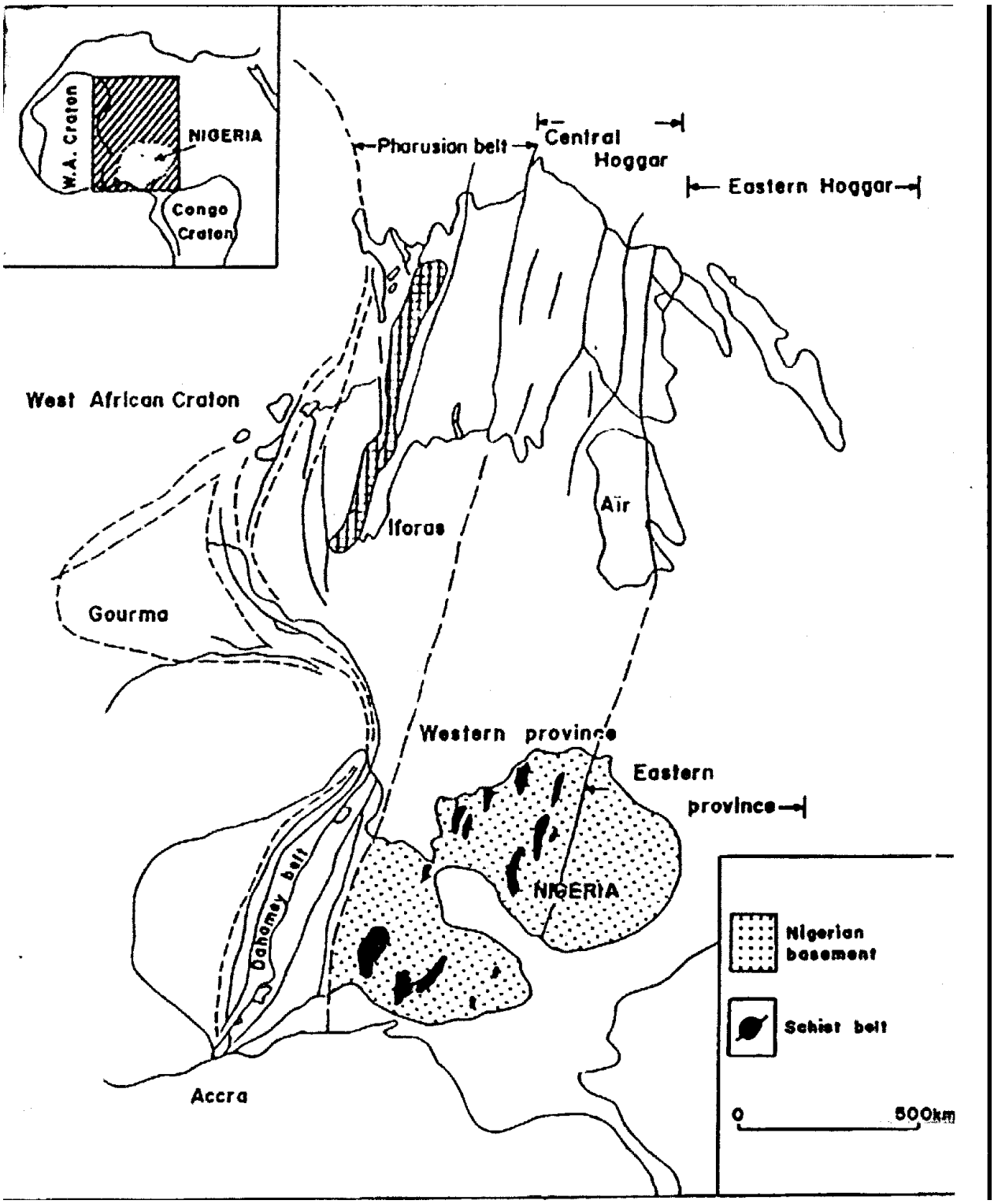


Fig 2.1 Geological map of the Pan-African belt east of the West African Craton showing the relative positions of the Nigerian basement and the Tuareg shield. After (Ajibade et.al,1987).

Table 2.1 Generalized geochronology for the basement rocks of Nigeria (modified after McCurry, 1976).

540+580 Ma	Late – Pan African	Uplift, cooling, faulting, high level magmatic activity	
650 – 580 Ma	Pan – African	Granitic instrusion, pegmatities and aplite development	Older Granites Magmatism
650 – 850 Ma	(Main phase)	Orogenesis: deformation, metamorphism, migmatsation and reactivation of pre-existing rocks	
800 – 1000 Ma	Katangan	Geosynclinal deposition, instrusion of hypersthenes – bearing rocks.	Katangan Metasediments
1900 ± 250 Ma	Eburnean	Granite instrusion Orogenesis: folding metamorphism and reactivation of pre – existing rocks.	Eburnean granite
2500± Ma	Birimian	Geosynclinal deposition	Birimian metasediments
2800 ± 200? Ma	Liberian cycle?	Possible formation of banded Gneiss complex near Ibadan	
>2800	Dahomeyan	Crystalline Basement	

2. The Schist belts: Composed of low-medium grade, deformed, supracrustal assemblages whose metamorphism is in the green schist facies. The belts are considered to be Upper Proterozoic rocks which have been infolded into migmatite gneiss complex. The schist belts are best developed in the Western half of Nigeria and are made up of poilitic and semi poilitic schist and phyllites, quartzites, conglomerates, iron formations, marbles, calc-silicate rocks and subordinate meta igneous rocks (Adekoya, 1996). These diverse rock types occur in varying proportions in the different belts.

3. The granitoid plutons of the Older Granite suite; They are considered as syntectonic to late tectonic Pan-African granitoids. They intrude both the migmatite gneiss complex and the schist belts. Earlier granitoids are foliated calc – alkaline granodiorite intrusions,

while later undeformed post tectonic intrusions are monzonitic, sub alkaline to alkaline in character McCurry, (1989). Other rock varieties are: diorites, gabbros, charnokites and late tectonic high level volcanic and hypabysal rocks.

The basement is also on the basis of spread and proportion of the rock suites divided into two provinces Ajibade et al. (1987).

1. The Western province, approximately west of latitude 8^0 E, comprising the schist belt in a predominantly migmatite gneiss Older basement, and the whole is intruded by large volumes of Pan-African granites and Mesozoic Younger Granites.

The Nigerian basement is on the basis of geochronology shown to be polycylic and include rocks of Archean (>2500); Ma) Eburmean (2000 ± 200Ma). (Turner, 1983; Fitches et al., 1985: Ajibade, (1989).

However the age of the last orogenic cycle especially as it affects the schist belts was a subject of controversy. Turner, (1983) considered the older schist belt as Kibaran (1100±200 Ma), and explained that the Pan-African tectonics imposed the N-S structural trends, and its magmatism led to the emplacement of granites and charnokites; and its thermal activity set mineral ages in the 500 – 600 Ma range in rocks in the area. He also considered Pan – African sedimentation to be uncertain in character and extent. He however, stated, "Deposits of Pan – African age are probably represented in the Northern Nigerian schist belts only. Fitches et al., (1985) supported this view with their work on Maru belt, which they considered to be part of the Kibaran basin. However Ajibade et al. (1987) regards the Kibaran event as questionable and not a major tectonic event in

Nigeria. The late Proterozoic to early Phanerozoic Pan – African Orogenic - cycle (750 – 450 Ma) is generally believed to be responsible for the emplacement of large volume of granitoids and the resetting of mineral ages in virtually all rocks types in the basement Ajibade et al. (1987).The basement is intruded by Mesozoic alkaline ring complexes of the Jos Plateau, (Younger Granites), and uncomformably overlained by Cretaceous to Recent sediment (fig.2.1).

2.3 The Schist Belts

The Nigerian schist belts occur in a 300 to 400 km wide zone, and predominantly west of longitude 8^0 E, which trends NNE, parallel to the boundary between the Pan – African province and the West African Craton Turner (1985); Fitches et al. (1985): Ajibade et al. (1987); Adekoya (1996).

The Schist belts zone is flanked by migmatites – gneisses – granites terrain, to the East and West, and the same terrain separate the individual belts within the zone Turner, (1983); Ajibade et al., (1987).

The schist belts are believed to be metasedimentary – volcanic, deformed, low grade (green schist facies) rocks that fall into two age groups. The earlier group for example, Maru and Kushaka belts contain assemblages of mafic igneous rocks, pylitic schist and phyllites, banded iron formation and locally coarse – grained clastics and carbonate rocks. These belts are intruded by granitic plutons belonging to the Pan – African magmatic suite. They are dated at approximately 1,100 Ma and are thought to belong to the Kibaran ensialic processes Fitches et al. (1985).

The later group of schist of belts for example, Anka Wonaka, Karu and Kazaure belts, is characterized by coarse to fine grained clastics, insignificant mafic igneous rocks, and absence of central granite plutons. These schist belts are believed to belong to the Pan – African marginal basin development Turner (1983); Fitches et al. (1985). However, the Nigerian Pan – African schist belts are believed to have evolved by plate tectonic processes. They are described as been deposited on a back – are basin, which developed after the onset of subduction at the cratonic margin at about 1000 Ma. Closure of the ocean at the cratonic margin about 600Ma and crustal thickening to the East led to the deformation and metamorphism of the sediments Ajibade et al. (1989).

2.4 The Older Granites

The Older Granites of Nigeria occur in all parts of the Nigerian basement and the extent of this Pan – African plutonism is still largely unknown, Ajibade et al.,(1987). The Older Granites are intrusions emplaced by stopping and diapiric processes Fitches et al.,(1985). They are generally regarded as late to post tectonic with respect to the main deformation of the Pan – African tectonism.

The Older Granites suite include a wide spectrum of rocks, wchich includes: monzonite, adamellite, tonalite, granodiorite, granite syenite and charnokitic rocks. These plutons are products of magma genesis at levels substantially below the present exposure level. To them, Ajibade et al. (1987) ascribed a mantle origin with minor crustal contribution. The most gneissic of the rocks is reported to contain angular xenoliths schist from adjacent belt.

The plutons also exhibit a certain degree of foliation. This foliation in the Older Granite is regarded by Fitches et al. (1985) to be due to flow of magma-tectonic processes rather than deformation. However, Ajibade et al. (1987) used evidences from crosscutting pegmatites and micro granites to show that the foliation is a result of post – emplacement deformation.

The older granites follow a calc – alkaline trend on an AFM diagram; and also except quartz syenites, are calc – alkaline on an alkalinity index diagram Fitches et al. (1985).

2.5 Pegmatites

Pegmatites are widely distributed throughout the Pre – Cambrian Complex in Nigeria ± 550 Ma (Jacobson et.al.,1946)

2.5.1 Classsification of Pegmatites

(a) Based on mineralogy:- It is possible to make a convenient sub-division of pegmatites accordingly, local variations in the environment and composition of the solutions inevitably results in anomalous variations. However when considered as a whole the pegmatites fall into three main groups:-

i. Microcline – quartz pegmatites

ii Microcline – quartz – mica pegmatites

iii Quartz – mica veins

Groups i and ii are basic types and may be called simple pegmatites. When they contain appreciable amounts of albite and other minerals deposited from late stage solutions they may be referred to as complex pegmatites in accordance with the classification suggested by Landes.

(b) Based on regional distribution:- The pegmatites are genetically connected with the Older Granites, and they may be divided into three groups according to their regional distribution in relation to the granites:-

i. Interior pegmatites (core pegmatites)

ii Marginal pegmatites (Hood pegmatites)

iii Exterior pegmatites (Root pegmatites)

2.5.2 Phases of mineralization

The solutions which gave rise to the pegmatites were exceedingly complex, and there are many factors which governed the precipitation of the solid phases,each varying in importance from place to place. It is to be expected therefore, that each pegmatite occurrence will posses it's own individual characteristics. This is undoubtedly so, but it is nevertheless possible to outline the general trends of differentiation of the pegmatitic liquor.

It is difficult to choose a satisfactory nomenclature for the phases of mineralization in the Nigerian pegmatites, as the precise nature of the pegmatite solusion is imperfectly unknown. The first phase of primary crystallization may be called magmatic and the final stage hydrothermal, but the exact nature of the solutions during the important transition period is uncertain.'' Magmatic'' and rather less implied by ''hydrothermal''. The terms pneumatolytic and pneumatohydatogenic imply an important gas or vapour phase, the existence of which is problematical. It is for these reason that the second phase has been termed ''intermediate''.

The phases of mineralization in the Nigerian pegmatites are briefly outlined below:-

i. Magmatic to Epi-magmatic stage of pegmatite formation.

ii. Intermediate stage of pegmatite formation.

iii. The hydrothermal stage

Study has shown that rare metal pegmatites in the Pan – African terrain of northern Nigeria can be distinguished from the barren ones by enrichment of Rb and Cs, while Ga, Be, and Li concentrations are variable. The pegmatites can also be classified into barren and rare metal types by K: Rb versus Cs fractionation trend while their K: Rb versus Rb trends can demonstrate their degree of fractionation

CHAPTER THREE

FIELD GEOLOGY AND PETROGRAPHY

3.1 Preamble

The major lithological units mapped in the study area include porphyritic granite, medium grained granite, banded gneiss and diorite (Fig.3.1). These rock units were also mapped in the sub-area on a scale of 1:10,000. Others include pegmatite veins and other minor intrusive such as aplites and quartz veins. Alluvium, laterite and soil occur as superficial deposit. The petrography of the rock unit is described both megascopically and microscopically.

3.2 BANDED GNEISS (Loc 30 : $N11^0$ 41′.551, $E7^0$ 54′.498)

3.2.1 FIELD GEOLOGY

The banded gneiss in the mapped area occurs as a weathered low lying unit, though the degree of weathering varies. In most cases it is highly weathered and may be mistaken for schist. It is generally dark to grey (when fresh) and light brown when weathered (Plate i). The brownish

appearance is as a result of absence of the dark ferromagnesian minerals which have been weathered away.

Texturally, it is generally medium grained when fresh and becomes coarse grained when weathered. Under hand lens observation, the rock contains feldspar and quartz as the light coloured minerals and dark ferromagnesian minerals. Both the light and dark coloured minerals are aligned (foliated).

Mineralogically the banded gneiss show variation in appearance even when it is fresh The pinkish coloured ones occur mainly in the northern portion of the mapped area (between longitudes 7^0 55′ E and $7^0$53′ E) as low lying exposures. The dark to grey coloured ones are located in the western portion of the area along river Marashi, Malam Sani, and Dan zau but are intensely weathered (fig. 3.1). The rock is intensely fractured and easily breaks along the fractures.



Plate i Photograph of a highly weathered banded gneiss at Malam Sani

3.2.2 Petrography

No thin section was made from the rock for modal analysis as no fresh sample of can be obtained..

3.3 Medium grained granite

3.3.1 Field Geology

The rock occurs as intrusions ranging in size from small outcrops to large whalebacks shaped outcrops. It is concentrated within the eastern portion of the mapped area and covers an estimated area of 60% of the area studied in detail (Fig.3.2). This rock displays both textural and mineralogical variations from one outcrop to another or even within the same outcrop. In hand specimen, the rock consists of plagioclase, alkali feldspar, quartz, and mica. The mica shows thin, long but discontinuous alignments (foliations).

Where Alkali feldspar dominates over plagioclase (i.e. granitic composition).It's medium grained in its texture and whitish or pinkish depending on mineralogy.



Plate ii Photograph of a medium grained granite outcrop around Tudun Kaya village

3.3.2 Petrography (Loc 17 / SA1: $11^{0}45'.508N$, $7^{0}55'.035$ E)

Under the microscope, the rock type displays medium grained texture with microcline while hornblende some of the quartz grains are also aligned paralled to the biotite. Minerals present include quartz, plagioclase, microline, biotite, hornblende, orthoclase, oligoclase and accessory minerals.

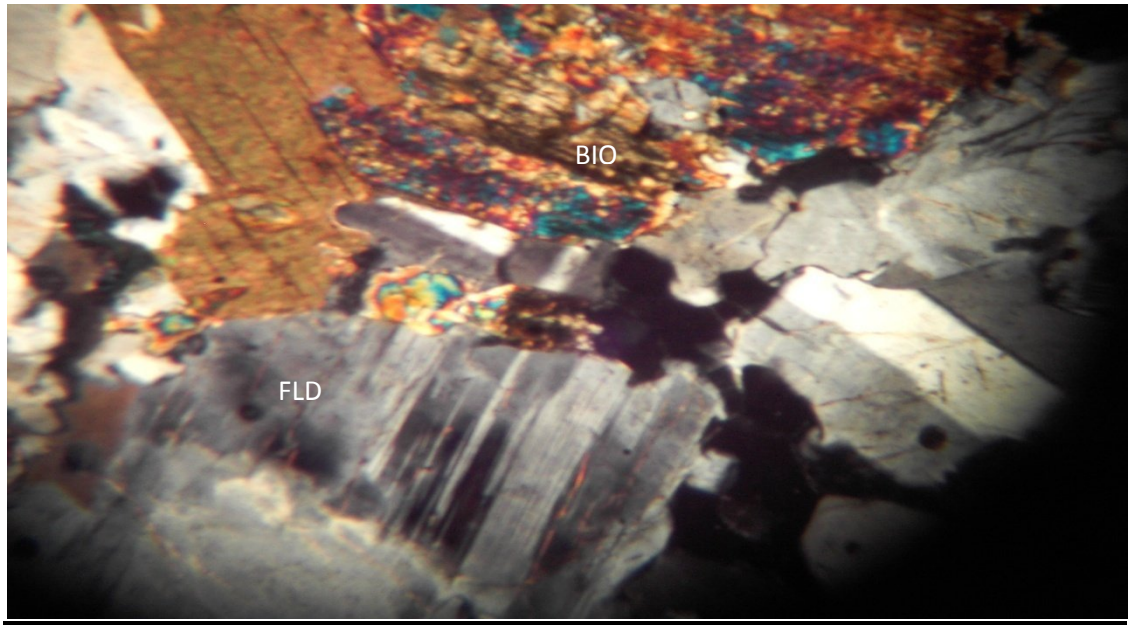


Plate iii Photomicrograph of a medium grained granite showing subhedral and enhedral pattern of mineral Biotite = BIO Quartz = QTZ Feldspar = FLD and the opaque mineral =OPQ XPL X 25

Quartz

It's grains are elongated parallel to the biotite grains. Some of the grains have been crushed. Some of the quartz also show wavy extinction. Quartz makes up to 35% of the minerals by visual estimation.

Microcline

This occurs mainly as phenocrysts. It is cloudy and show its characteristics cross – hatch twinning in two directions under crossed nicols. It is colourless with low relief under plane polarized light..It forms anhedral to subhedral grains and makes up about 25% of the mineral composition.

The microcline occurs as large subhedral tabular crystals with clear cleavage lines in one direction. Both the green and brown grains are present. They show strong pleochroism under plane polarized light and have a straight extinction some of the grains show goose flesh appearance at extinction provision. Microclines makes up to about 25% of the total minerals composition.

Hornblende

It occurs as a large prismatic grain with cleavage in one direction. It shows strong pleochroism under plane polarized light. Extintction is inclined with extinction angle between $22^{o} – 30^{o}$. It is also aligned and shows alteration to chlorite. Its relief is high and has moderate birefringence. It accounts for 10% of the total mineral composition, (plate iv) photomicrograph of the medium granite)

Orthoclase occur as fairly large anhedral grain showing carlsbad twining under crossed Nicols. It accounts for 25%. Plagioclase occurs in enhedral forms showing cross-hatch twining in two directions, it also accounts for 5%. Accessory minerals include zircon, chlorite and opaque minerals which all make up 5% all by visual estimation.

3.4 Quartz-diorite (Loc 2 / SA9 :N11^0 41′.27, E7^{0}54′.76)

3.4.1 Field geology of quartz-diorite

The rock occurs as small rounded bodies around Tudun Kaya, Unguwar Alhazai, Dan zau and Ma villages of the study area. It is generally dark and fine to medium grained. It has also been slightly weathered.



Plate iv Photograph of a dioritic outcrop at Dan Zau village

3.4.2 Petrography quartz-diorite

Minerals observed include plagioclase, biotite, quartz, chlorite, orthoclase and accessory minerals.

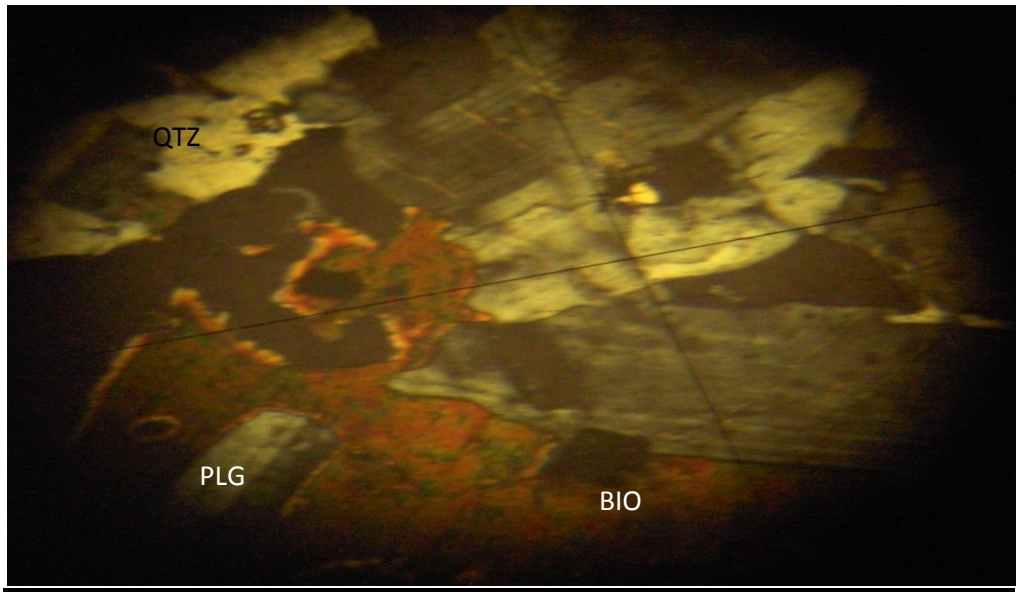


Plate v Photomicrograph of diorite showing some albite twinning Oligoclase = OLG
Biotite = BIO. XPL X25

Plagioclase

This is the dominant feldspars mineral in the rock. It accounts for 40% of the total minerals. It occurs mainly as large euhedral to subhedral grain and show fine (thin) albite twinning in one direction. Its birefringence is weak and its relief is low under plane polarized light.

Biotite

It occurs as very large but poorly formed tabular grains with clear cleavage lines. Both the brown and green crystals are present and they show strong pleochroism. Some of the brown grains contain zircon indicated by pleochroic haloes as the microscope stage is rotated. It shows straight extinction and makes up 25% of the minerals present.

Chlorite

It occurs as colourless to light green fibrous aggregates under plane polarized light. The light green ones show slight pleochroism. The extinction is also straight. This occurs when the fibrous grains are parallel to the cross – wire. Its relief is low. Chlorite makes up 10% of the minerals present.

Quartz

Quartz occurs mainly as the matrix and accounts for 10% of the minerals too. The accessory minerals are orthoclase (5%), Zircon and opaque minerals which make up the remaining 5%.

3.5 Pegmatites (Loc 52 / SA3: N11^{0}44′.22, E7^{0}55′.07)

3.5.1 Field geology of pegmatites

A prominent pegmatite field occurs and series of veins and spots of pegmatites occur along the valley of River Marashi, Danzau and Ma areas, the pegmatites are criss-crossing. Mineralogically, the pegmatite contains quartz, feldspar, mica and Beryl. The pegmatites are numerous range in size from a few centimeters to about 2 or 10 meters and their texture range between medium to coarse grained the general trend of the pegmatites is NE – SW Direction



Plate vi Photograph of the coarse grains of quartz and feldspars in the pegmatite veins



Plate vii Photograph of a typical pegmatite vein at Malam Sani



Plate viii Photograph of a mining pit dug on the pegmatite veins by artisanal miners at Danzau village

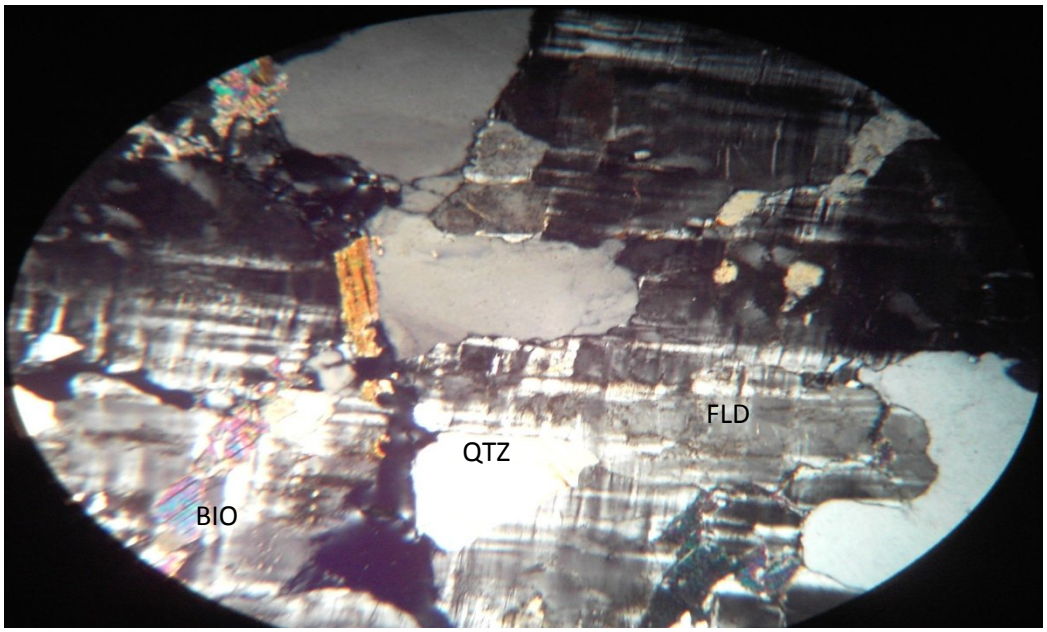


Plate ix Photomicrograph of Pegmatite dominantly composed of plagioclase feldspar and Quartz x25

3.6 Aplite dyke

3.6.1 Field geology of Aplite dyke

Aplite dyke was mapped in the area around Dan Zau (SAR 27). It has a width of 65cm and a strike of 026. It is fresh, fine grained and pinkish in colour as a result of abundant K – Feldspar



Plate x Photograph of an aplite dyke in the study area in the medium grained granite at Danzau

3.7 Quartz veins

3.7.1 Field geology of quartz veins

These occur as mono-mineralic and appear white in colour. The unit is mainly crystalline and is fine grained with some small crystals of quartz. They show a general N-S trend the vein varies in size from a few centimeters to about 15 cm.

3.8 Superficial deposits

3.8.1 Laterites

These are the low level laterites which occur extensively in the mapped area especially at Danzau and along River Marashi at the western part of the mapped area. Their occurrence is because the area is generally flat and falls within the zone of seasonal fluctuation of the water table (i.e. savanna zone).

They are brownish and hard, and up to 2m thick. They are termed the "Younger laterites" by McCurry and Wright, (1973).



Plate xi Hard, brown duricrust (Laterite) at Danzau village

3.8.2 Alluvium Deposit

These are deposits derived from weathering and erosion of the surrounding rocks and which have been transported and deposited along many stream and river channels (especially the broad ones) in the mapped area.

These deposits consists mainly of sands, but silt and clays also occur. When they reach a thickness of between 1- 3m, they are called older alluvium (McCurry, 1970).

Table 3.1 Visual estimate for minerals on the rock types from the study area in percentage

S/NO	**1**	**2**	**3**
Sample No.	**LOC 17/SA1 GRANITE**	**LOC2 / SA 9 DIORITE**	**LOC 52 / SA3 PEGMATITE**
Microcline	**5%**		**10%**
Orthoclase	**30%**	**5%**	**30%**
Plagioclase	**10%**	**40%**	**15%**
Quartz	**25%**	**10%**	**20%**
Biotite	**20%**	**25%**	**5%**
Muscovite	**5%**	**5%**	**5%**
Opaque oxides		**5%**	
Others	**5%**	**10%**	**5%**
Total	**100%**	**100%**	**100%**

CHAPTER FOUR

STRUCTURAL GEOLOGY

4.1 Structural features

Both ductile and brittle deformational structures have been mapped in the study area. The ductile structures are foliations and folds while the brittle structures include joints and faults.

4.2 Foliation

Foliation in the banded gneiss is defined by alternating quartz-feldspathic material and biotite flakes. The foliations have dip ranging from 45^0 to 50^0N. Most of the foliation strikes NNE – SSW and follow the general tectonic North -South trend. Subparallel aligned muscovite, biotite flakes and some quartzo-feldspathic material define the foliation in the medium grained granite.

4.3 Folds

Folds are not well developed in the area, as the one observed occur at Loc.36. The folds are displayed by pegmatite veins which occur as discordant E-W trending intrusion into the medium grained granite at outcrop Loc. 36 near Malam Sani village



Plate xii Photograph of a folded vein on a medium grained granite

4.4 Joints

Joints are abundant structural features observed in the field. They have been observed in most of the exposures, but the granitic rocks displayed a comprehensive jointing pattern with a NNE – SSW trend. Some of the joints were mapped cross-cutting each other showing that they are formed from different orogenic events.

According to McCurry, (1971) and Danbatta, (1999) the joints often result from contraction on cooling and are believed to be associated with a single episode of cooling and fracturing during epirogenic uplift.

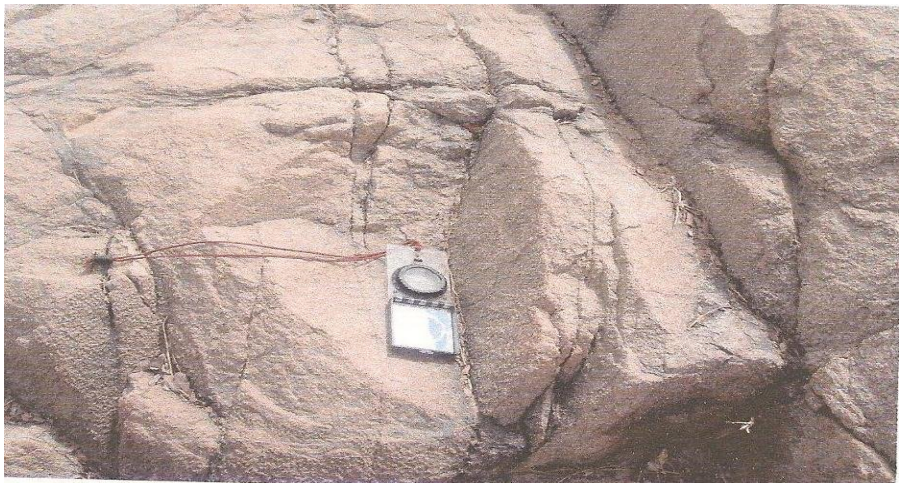


Plate xiii Photograph of geometry of joints as observed in the medium grained granite at Loc 21on Lat.N11^{0} 41^{1},447 and Long. E7^{0} 55^{1}.212 of the study area.

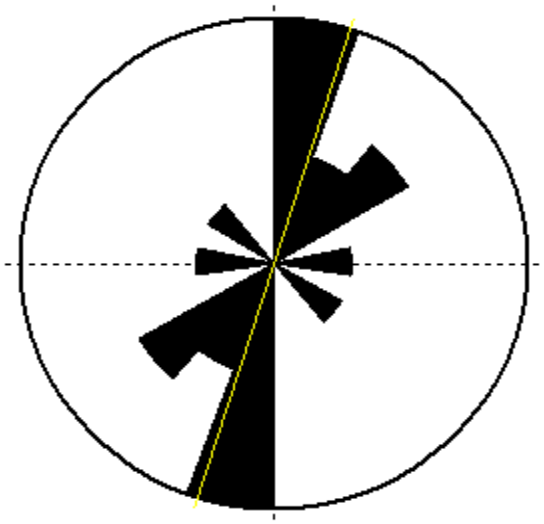


Fig.4.1 Rose diagram of joint trends in medium grained granite

The rose diagram in the medium grained granite of the study area Fig 4.1 indicated that the major stress is in the North – South direction while the minimum stress is in the East – West direction.

4.5 Faults

Faults in the study area are not well exposed but their effects on rocks and some quartz veins have been documented (Plate xiv). Minor localized faults were observed in few localities such as displacement of pegmatite veins that are more of sinistral than dextral. Some of the rivers and streams in the area are possibly flowing along the fault planes.



Plate xiv Photograph of a sinistral fault on a quartz vein at Tudun Kaya

4.6 Xenolith

Xenoliths of lensoidal shape occur mainly in the medium grained granite. They are numerous and were observed many exposures. They range from few centimeters to about 80 cm and a width of few centimeters to about 15 cm. The xenoliths shows a general trend of N-S (Plate xv)



Plate xv Xenolith of diorite in the medium grained granite at near Ma village

CHAPTER FIVE

GEOCHEMISTRY AND ECONOMIC GEOLOGY

5.1. Sample collection and analytical techniques

A total of eleven (11) samples were collected from Dan zau, Ma and Tudun Kaya for this study. All the samples were sent to Canada for whole rock geochemical analysis. Whole rock analysis of Basement complex rocks two for granitic rock (SA01, SA02 and Quartz Diorite (SA9, SA10) and seven pegmatite samples from the different areas (SA3, SA4, SA6, SA7, SA8, and SA11) were carried out. The limited number of samples is constrained by lack of funds and lack of relevant analytical technique especially in the country.

The rock samples were crushed and pulverized into fine powder, packed into polythene bags at the laboratories of the Department of Geology, Ahmadu Bello University, Zaria, Nigeria and shipped to Activation Laboratories (Actlabs), Ancaster, Ontario, Canada where major, trace , rare earth elements (REE) analyses were carried out.

The analystical methods used in this study by the Activation Laboratories (Actlabs). include the Inductively coupled Plasma Mass Spectrometry (ICP-MS) for major and trace element analysis, the instrumental Neutron Activation Analysis (INAA) for trace and rare earth elements analysis. Detail result from Activation laboratories are in Appendix I

Major elements are reported in weight percent (wt%) while Trace elements reported in parts per million (ppm). The analystical data obtained are presented in Table 5.1, 5.2 and 5.3 (See also Appendix I).

Rock type	**GRANITE**		**DIORITES**		**PEGMATITES**						
Sample No. (wt%)	SA01	SA02	SA09	SA10	SAO3	SAO4	SA05	SAO6	SAO7	SAO8	SA11
SiO_2	74.33	72.30	58.78	57.96	74.77	72.46	72.46	76.56	72.23	72.1	62.60
Al_2O_3	13.70	14.88	13.96	13.14	13.73	15.09	15.99	12.7	14.71	15.29	20.77
Fe_2O_3(T)	1.55	2.26	6.83	7.33	1.91	0.46	0.38	0.7	0.52	0.93	1.65
MnO	0.052	0.052	0.12	0.136	0.01	.005	.003	0.01	0.03	0.023	0.038
MgO	0.22	0.61	4.61	5.94	0.07	0.03	.02	0.06	0.05	0.04	0.72
CaO	0.60	1.37	5.31	6.39	1.57	0.13	0.1	0.95	0.23	0.34	2.90
Na_2O	2.87	3.81	2.77	2.42	5.68	2.71	2.03	4.09	2.03	3.43	8.19

TABLE 5.1: MAJOR ELEMENTS COMPOSITION OF THE ROCK SAMPLES IN THE STUDY AREA

K_2O	4.79	4.85	5.02	4.39	0.86	9.24	11.29	3.36	9.64	7.85	1.08
TiO_2	0.14	0.27	0.908	0.882	0.102	.006	0.01	0.041	0.01	0.01	0.123
P_2O_5	0.05	0.11	0.57	0.57	0.01	.06	0.01	<0.01	0.08	0.01	0.11
LoI	0.65	0.36	0.36	0.82	0.37	0.21	0.19	0.37	0.26	0.24	0.81
Total	**98.95**	**100.4**	**99.25**	**99.98**	**99.08**	**100.4**	**99.22**	**98.85**	**99.78**	**100.3**	**98.98**

TABLE 5.2. TRACE ELEMENTS COMPOSITION OF THE ROCK SAMPLES IN THE STUDY AREA

Rock type	**GRANITE**		**DIORITES**		**PEGMATITES**						
Sample No.(ppm)	SA01	SAO2	SA09	SA10	SAO3	SAO4	SA05	SAO6	SAO7	SAO8	SA11
Ba	27.4	454	2153	2073	58	135	54	82	243	60	173
Sr	89.0	136	603	588	55	48	19	36	61	14	186
Y	32.0	24	30	29	145	6	13	26	8	10	9
Sc	3	5	14	18	4	<1	<1	4	<1	1	10
Zr	128	214	219	200	155	15	05	29	13	22	87
Be	5.0	12	5	4	60	5	4	39	19	16	114
V	<5	18	119	129	16	<5	<5	<5	<5	8	12
Cr	<20	<20	240	340	<20	<20	<20	<20	<20	20	40
C0	40	47	38	42	40	35	30	41	40	39	33

Ni	<20	<20	70	80	<20	<20	<20	<20	<20	70	<20
Cu	<10	<10	60	30	<10	<10	<10	<10	<10	<10	<10
Zn	40	<30	60	60	<30	<30	<30	<30	<30	<30	<30
Ga	19	25	20	19	36	28	35	35	36	40	63
Ge	<1	1	2	1	2	2	3	3	3	3	3
As	<5	<5	<5	38	<5	<5	<5	>100	<5	<5	<5
Rb	314	310	204	177	41	561	>1000	291	449	>1000	145
Nb	23	31	17	14	233	36	22	65	37	23	19
Mo	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ag	5.6	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
In	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sn	26	18	6	4	13	5	1	6	11	3	12
Sb	<0.5	<0.5	0.8	1	<0.5	1	1	<0.5	<0.5	0.7	0.8
Cs	6.3	21.4	5.1	6.6	3.3	15.7	14.3	12.8	8.8	22.7	30
Hf	4.5	7	5.6	5.9	12.3	0.7	0.3	1.4	0.8	1.1	6.4
Ta	3	5.2	1.5	1.3	78	7.9	5.8	18.1	26.9	4.8	7.2
Tl	2.2	1.9	1.2	0.7	0.3	3.8	6.6	0.9	2.4	6.1	0.9
Pb	34	54	27	14	37	46	152	26	30	85	37
Bi	<0.4	0.9	12.9	14.9	511	6.3	1.1	8.8	0.7	2	164
Th	3.07	35.7	11.4	13.1	53.6	2.7	6.4	13.2	3.6	5.6	19.3
U	8.3	22.2	2.8	3.6	106	2.8	4.2	21.7	4.9	3.6	3.9

TABLE 5.3: RARE EARTH ELEMENTS COMPOSITION OF THE ROCK SAMPLES IN THE STUDY AREA

Rock type	**GRANITE**		**DIORITES**		**PEGMATITES**						
Sample No. (ppm)	SA01	SA02	SA09	SA10	SAO3	SAO4	SA05	SAO6	SAO7	SAO8	SA11
La	41.1	57.1	51.3	51.8	3.0	2.4	4.4	2.7	7.6	1.8	22.9
Ce	92.6	107	99.8	104	8.2	32	5.9	6.4	14.9	4.6	32.5
Pr	10.3	11.9	10.9	11.4	2.32	0.36	0.62	0.76	1.48	0.28	3.77
Nd	36.3	33.9	38.5	40.1	17.7	1.6	2.8	4.6	5.6	1.3	11.5
Sm	8.1	6.4	8.2	8.6	8.0	0.4	0.8	1.6	1.3	0.3	2.0

Eu	0.55	0.64	2.1	2.07	0.3	0.14	0.12	0.14	0.2	0.05	0.39
Gd	7.0	5.5	8.0	8.0	9.6	0.6	1.0	2.2	1.3	0.5	1.8
Tb	1.2	0.9	1.2	1.2	2.3	0.2	0.2	0.5	0.3	0.1	0.2
Dy	6.3	4.5	6.0	6.l	18.2	1.1	1.4	3.9	1.7	1	1.3
Ho	1.1	0.8	1.1	1.1	4.5	0.2	0.3	0.9	0.3	0.2	0.2
Er	3.1	2.3	3.2	3.2	16.5	0.7	1.2	3.3	0.9	0.3	0.7
Tm	0.41	0.35	0.47	0.145	0.14	0.29	0.70	0.70	0.15	0.24	0.13
Yb	2.4	2.2	2.7	2.9	30.5	1.1	2.5	5.8	1.0	2.2	1.0
Lu	0.35	0.32	0.40	0.41	5.590	0.17	0.44	1.0	0.14	0.38	0.19

< (less than) or > (greater than) values indicates below or above detection limit of analytic equipment . (Actlabs, 2009)

5.2 Geochemistry of the medium grained granite

5.2.1 Major elements distribution

The major elements data of the granite samples from the mapped area are presented in Table 5.1 From the geochemical data plotted on the classification diagram total alkalis (TA) the SiO_2(S) (Cox et al. 1979). The result revealed the geochemical range of the granitic rock and the broad classfication of the rock.(Fig.5.5)

The granites show a slightly small variations in their SiO_2 content (72.3-74.33), with a high alkali – oxide content (Na_2O+ K_2O>07 wt %), high Na_2O content > 3.34 wt%, low

CaO and MgO with subordinate Fe_2O_3(Total). The granites were plotted in $SiO_2 - K_2O$ plot after (Peccerillo and Taylor, 1976). The result shows that the Granites follows a trend shown by other Pan African granitic rocks in northwestern Nigeria (e.g. Fitches et al. 1985). Fig. 5.1

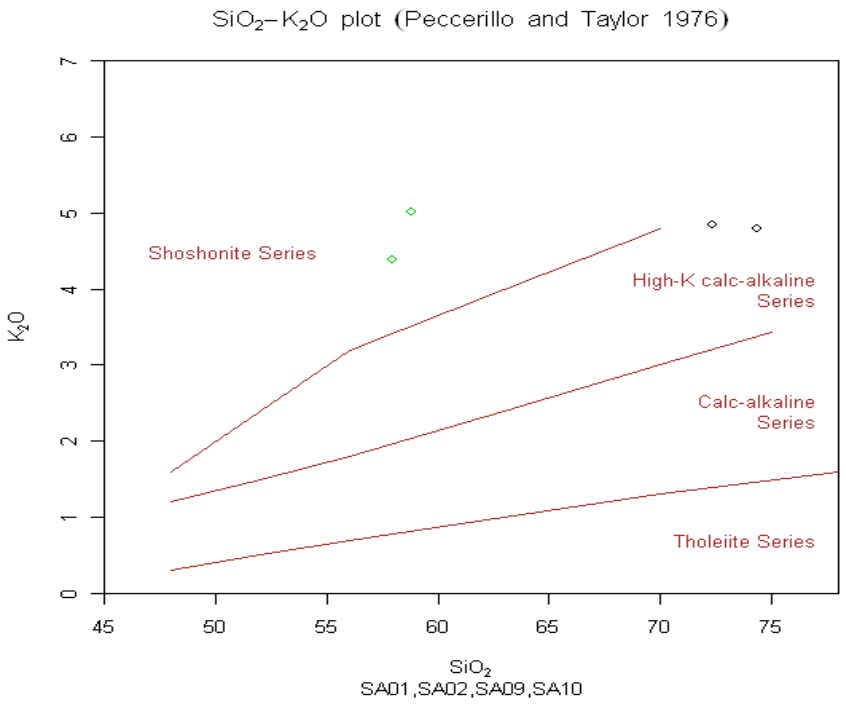


Figure 5.1 The geochemical range of the granite and diorite

However, on an alumina saturation diagram (Fig.5.2) the (Al_2O_3/CaO + Na_2O + K_2O) molar ratios (A/CNK – A/NK, Shand index) does not exceed 1.4 indicating the slightly peraluminous tendencies of the studied granitic rocks. The absence of normative corundum in the granitic specimen is an indicator of their igneous parentage (Blackburn,1974).

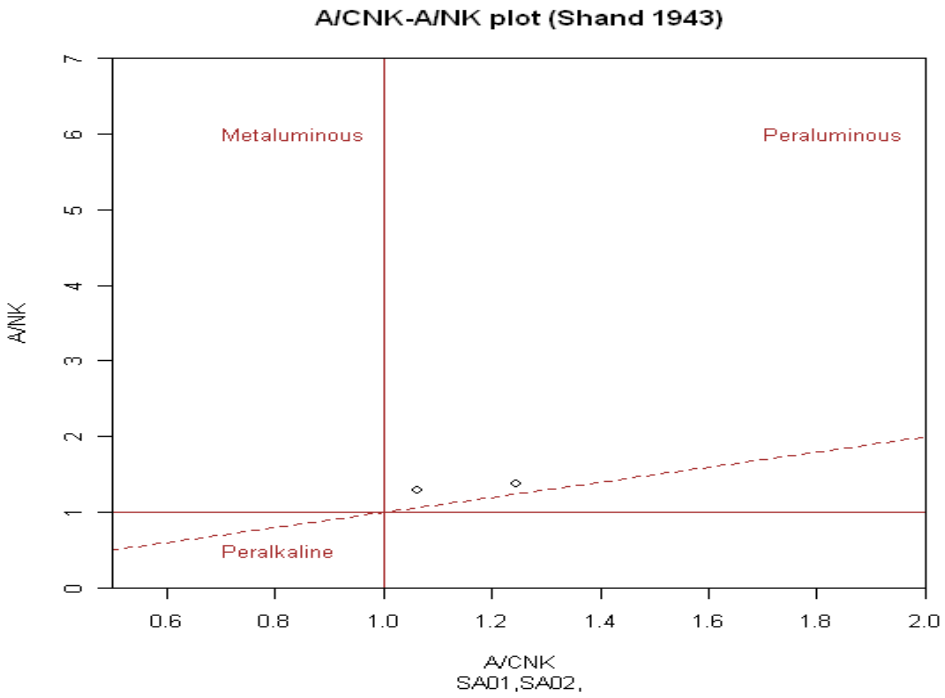


Figure 5.2 Compositional plot showing the peraluminous nature of the granitic rocks from the study area.

5.2.2 Trace element distribution

The geochemical data of the granite samples show variation of trace elements (Table 5.2) and some of these could be used in tectonic discrimination diagram. There is also a similarity in average Zirconium (Zr) content of 177 ppm for all granitic specimen when compared with an average of 180 ppm for granitic rocks. Niobium(Nb) values range from 23 – 31 ppm indicating a distinctive " Arc/ or Syn-collisional fields" signature (Pearce and Gale 1977).The silica saturated granites were therefore probably formed through syn- collisional processes related to subduction related magmatism.

Lithophile elements (K,Ba,Rb,Sr) concentrations can also be used to show the fractionation pattern of these elements in the rocks and pegmatites studies. There appears to be a slight

depletion of Ba in the granites (274 – 454) when compared to the mean crustal average of 425 ppm. Rb is markedly enriched 310 – 314 ppm when compared to mean crustal average of 90 ppm . The syn collisional nature of the granites in the study area was further confirmed in Fig. 5.3 $R_1 - R_2$ (De la Roche et al., 1980) which shows the tectonic classification of the rocks from the study area.

The granite sample have a slight decrease in the concentration of Yttrium(32ppm) when compared with an average of 40 ppm Y for granites(Taylor,1965). This might be due to the differentiation of the granitic melt.

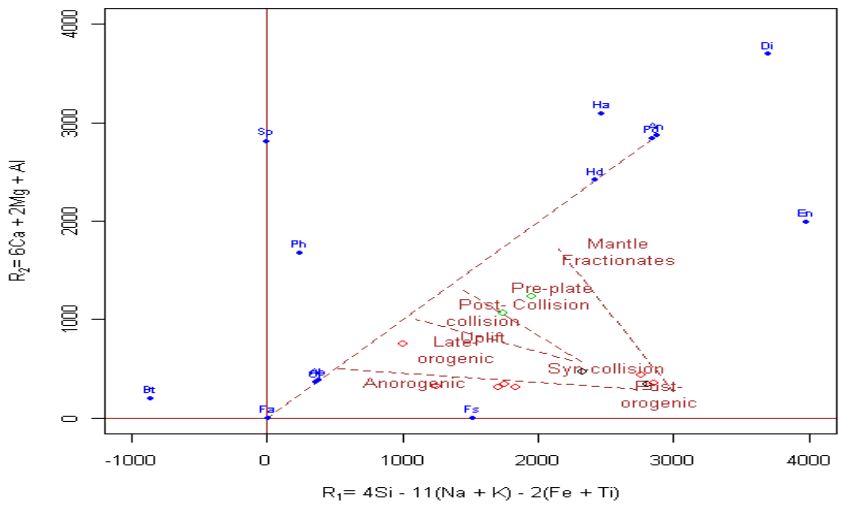


Figure 5.3 The tectonic nature of the Granites and Diorites from the study area (De la Roche et al.,1980)

The REE in the granites were studied in order to understand the protolith rock type and the character of the source area. All the rare earth elements (REE)were normalized to values given by Nakamura (1974) and then plotted in a spodergraph (Fig.5.4). The REE fractionation pattern of the granites is chracterized by a distinct enrichment of the light rare earth element (LREE)

and defletion towards the heavy Rare Earth Elements (HREE).There is also a significant negative Eu anomaly for all the granite samples plotted.

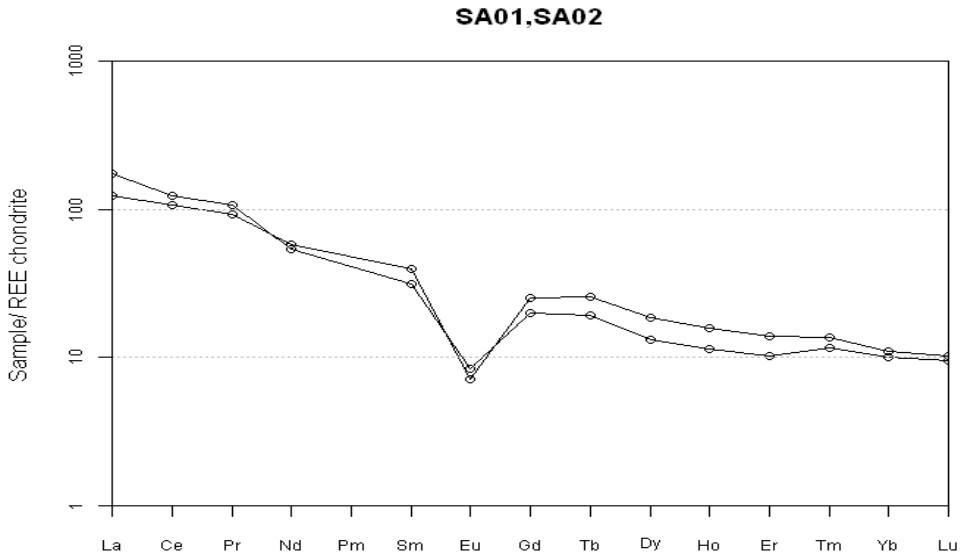


Figure 5.4

Chondrite-normalized REE patterns for Pan- basement rock of Tudun Kaya – Dan Zau granite showing an enriched LREE, a depleted HREE and pronounced negative Eu anomaly (Granite= black)

5.3 Geochemistry of the quartz diorite

5.3.1 Major elements distribution

The geochemical data obtained on the major elements of the quartz diorite is presented in table 5.1. The geochemical data is plotted on the classification diagram of total alkalis and silica (TAS, Cox et al. 1979). The compositional range of the dioritic rock and the broad classification is presented in Fig. 5.5

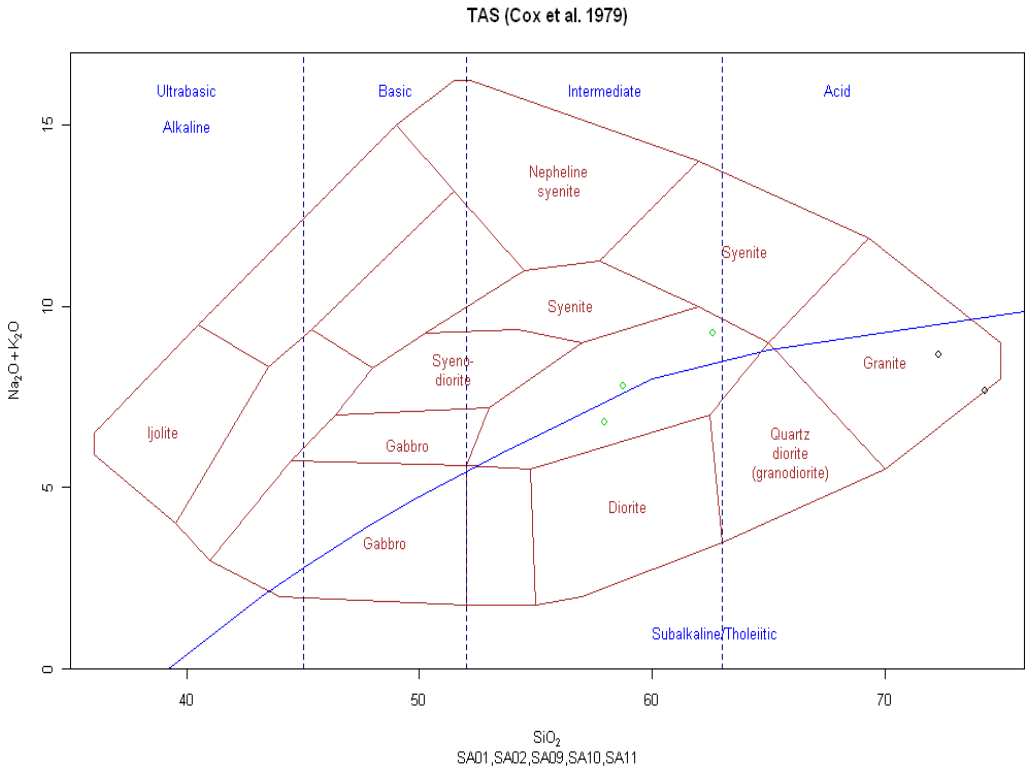


Figure 5.5 A classification of rocks from the study area (Granite=black, Diorite=green)

The total alkalis – silica diagram is one of the most useful schemes available. Chemical data – the sum of the Na_2O and K_2O content (Total alkalis, TA) and the SiO_2 content (S) – are taken directly from the rock analysis as weight percent oxides and plotted on to the classification diagram.

The diorites show a marked enrichment in SiO_2 content (57.96 – 62.6wt%), enrichment in CaO (5.39 – 6.39 wt%). There is also a significant enrichment of Al_2O_3 and Fe_2O_3 (T) in the diorite sample. The samples of the diorite and granite were plotted on $R_1 _ R_2$ (De la Roche et al., 1980). Fig. 5.3 shows the tectonic classification of the rocks as a product of pre – plate collision,

indicating that the diorite is older than the granite in the area under study which was a product of syn – collision.

5.3.2 Trace elements distribution pattern

The trace element data of the diorite samples is presented in Table 5. 2. From the table, the trace elements show a consistent variation of trace elements and could be used in tectonic discriminationn. Lithophile elements (K, Ba, Rb, Sr) fractionation pattern in the rocks can therefore be determined, thus there is a remarkable enrichment of Ba in the diorites (2173 – 2153 ppm) when compared to the mean crustal average of 425 ppm (Garba, 2002). There is also a marked enrichment of Rb (177 – 204 ppm) when compared to the mean crustal average of 90 ppm for Rb (Table 5.2). The diorite samples have inter – lithophile element ratios revealing a systematic trend across the diorite sample, K/Ba ratio of 18.5 and a high K/Rb ratio of 204 and a low Rb/Sr ratio of 11.3.

Chondrite normalized Rare Earth Elements (REE) patterns of the dioritic rocks are shown in Fig. 5.6. The REE fractionation pattern of the diorite is characterized by an enrichment of the light Rare Earth Elements (LREE) and slight defletion in the heavy Rare Earth Elements (HREE). All the REE abundances were normalized to chondrites (Nakamura,1974) and then plotted in Fig. 5.6. The REEs in the diorites were studied in order to understand the protolith rock type and the character of the source area. The samples show a weak negative Eu anomaly.

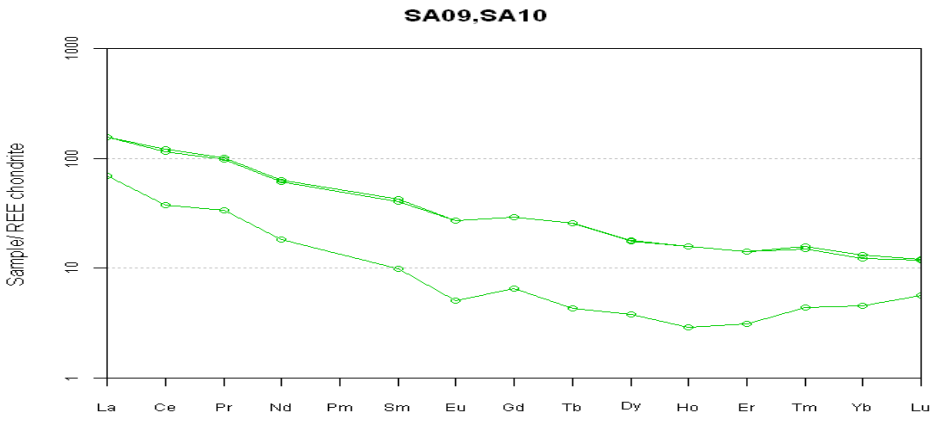


Figure 5.6 Chondrite-normalized REE patterns for the dioritic rock of Tudun Kaya – Dan Zau area showing an enriched LREE, a depleted HREE and weak negative Eu anomaly(Diorite= green)

The geochemical data obtained on the pegmatite samples from the mapped area are presented in Table 5.1. The pegmatites show a slightly small range of variation in their SiO_2 content (69.2 – 76.55 wt %). The alkali – oxide content of the pegmatites is >13 which shows it's quite high. The pegmatites have low CaO and MgO with subordinate Fe_2O_3 (total) as compared to the work of Garba, (2003) on the barren and rare metal pegmatites of northern Nigeria.

5.4.2 Trace elements distribution

The geochemical data on the pegmatite samples from the study area show variation of trace elements concentration (Table 5.2). The data could be used in tectonic and geochemical discrimination between barren and mineralized pegmatites. The rare earth elements (REE) and lithophile elements systematic could be used in tracing the origin of ore mineralization processes in the Basement terrain (Garba, 2002). Lithophile elements (K, Ba, Rb, Sr) concentrations and ratios (Table 5.2) can be used to show the fractionation pattern of the lithophile elements in the pegmatites from the study area. There appears to be a distinct depletion of Ba in the pegmatites (19 – 136ppm) when compared to the mean crustal average of 425ppm.

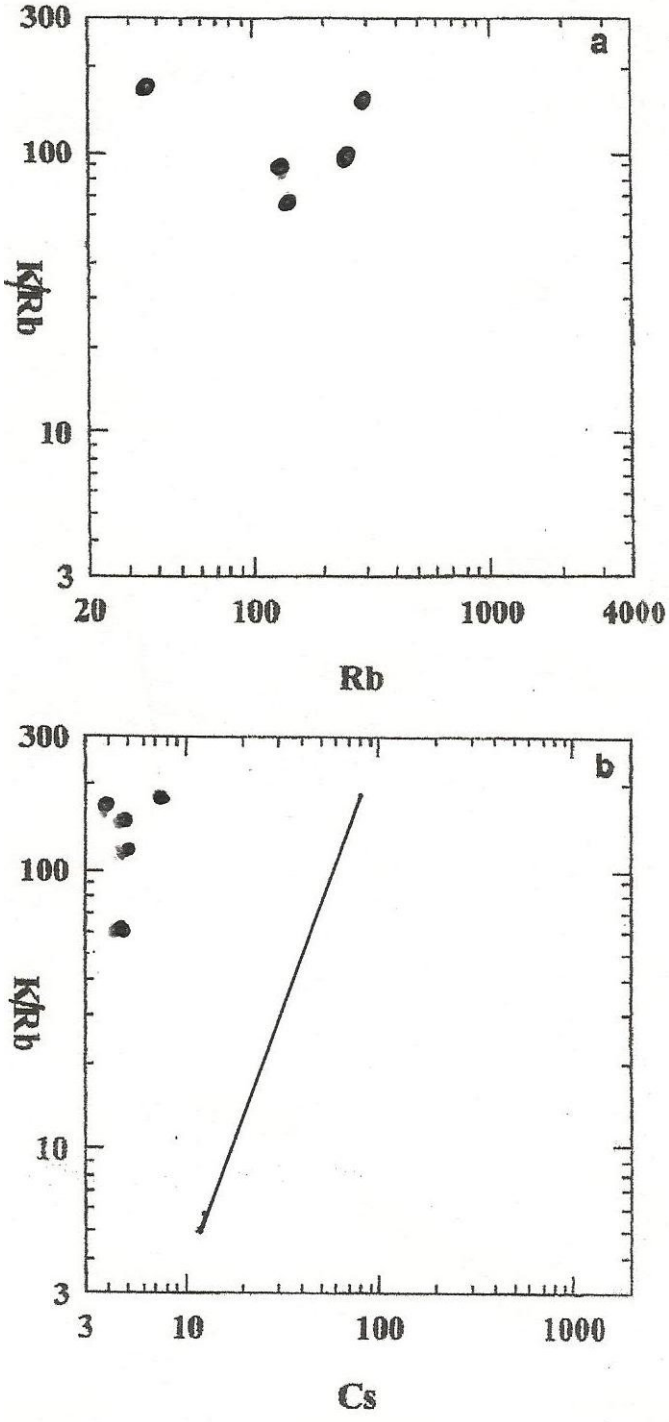


Fig.5. 7 Discrimination diagrams showing the degree of fractionation of the pegmatites : (a) K/Rb Versus Rb (b) K/Rb Versus Cs Adapted from Cerny and Morteani et al.,(1985).

Rb is enriched in the pegmatites (41 – 561 ppm) when compared to the mean crustal average of 90ppm. Also as with Ba, Sr is also depleted in the pegmatites from the study area. The inter – lithophile ratios also a systematic trend across the pegmatites samples from the study area. K/Rb ratios (96 – 178 ppm) are higher. Also K/Ba in the pegmatite samples (121 – 568 ppm) are also low. The Rb/Ba (0.69 – 4.16ppm) and Ba/Rb (0.28 – 8.08ppm) ratios have similar pattern with K/Rb and K/Ba but with different orders of magnitude (Table 5.3). Rb/Sr is also low.

The Rare Earth Elements were traditionally normalized to chondritic meteorites, as these are thought to represent relatively unfractionated samples of the solar system. The REE fractionation is still commonly expressed in terms of chondrite normalized ratio of a light REE over the concentration of heavy REE. The REE abundances were normalized and plotted in fig. 5.8 The REE in the pegmatites were studied in order to understand the protolith rock type and the character of source area. The REE fractionation pattern is characterized by enrichment in both the light rare earth elements (LREE) and the heavy rare earth elements (HREE) with the HREE being more enriched. The fractionation pattern also show pronounced or distinct Eu anomaly which is indicating the degree of fractionation of the plagioclase.

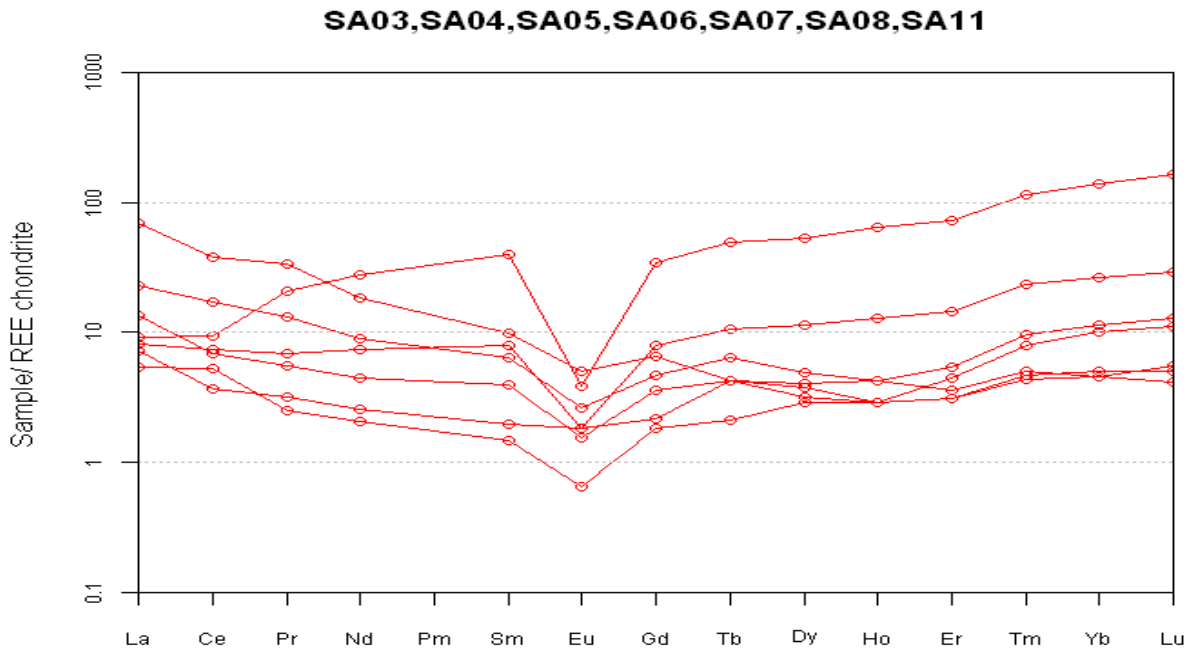


Figure 5 .8 Chondrite-normalized REE patterns for Pegmatite of Tudun Kaya , Dan Zau, Marashi areas showing an enriched LREE, a more enriched HREE and a pronounced negative Eu anomaly in most of the Pegmatites. (Pegmatite= red)

5.5 Mineralization potential of the study area

The major rock types from the study area do not present any major mineralization potential for economic minerals based on the trace element ratios as compared to the barren pegmatites from some parts of northern Nigeria from the works of Garba,(2003) , but the associated minerals could be used industrially.

5.5.1 Beryl

Beryl is found in prevalent association within the pegmatite vein. It is blue in colour with a well developed crystal form. The crystal form ranges from prismatic to tabular and it's being mined by artisanal miners.

Beryllium is alloyed with copper to impart greater strength, conductivity and corrosion resistance. Beryllium metal is also used in various components of nuclear reactors and aerospace components. Because of it's utilization in the nuclear industry beryllium is considered a strategic commodity, and the U.S. Defence Department maintains a strategic stockpile of beryllium ores (Cunningham, 2002)

5.5.2 Quartz, Feldspar and Clay

Quartz from quartz veins and pegmatite characterizing the area could be used in the glass industry to manufacture glass and lenses. It can also be used to in the production of silicon chips for computers.

Feldspars from the pegmatites are useful in ceramic industry. Soil clays which are weathered products of K-feldspars are also useful in ceramic, paint and pharmaceutical industries.

5.5.3 Hard rock (Building stones)

The granites, diorites, and the gneisses from the study area could be quarried and crushed into stones and fragments, could be used as building stones, facing stones and road construction materials.

5.5.4 Sand and Gravel

Sand and gravel which are products of weathering of quartz and hard rocks occur as alluvium along the stream and river channels in the study area.

Sand may be important source of glass sand and some placer deposits. Together with gravel, it could be used for concrete making and building works.

5.5.5 Laterite

Laterite occurs extensively in the area as the terrain is flat and falls within the zone of seasonal fluctuation of the water table. It may be used as aggregates for construction purposes such as building /road construction.

CHAPTER SIX

SUMMARY AND CONCLUSION

6.0 Summary

Underlying the study area are rocks of the Nigerian Basement Complex which are products of series of orogenic events (Mc Curry, 1976). The rocks mapped include banded gneiss, medium grained granite, quartz-diorite, pegmatites, aplites and quartz veins.

Age determination from different parts of the Basement Complex shows that it has witnessed at least three orogenic events from Archean to Pan African. Hence, it is poly-cyclic in nature. The Birrimian orogeny 2500(M.a) probably resulted in the evolution of the banded gneiss. The Pan African orogeny resulted in the emplacement of the Older Granite series. The early phase of the orogeny marked the emplacement of the quartz-diorite and other basic rocks. The diorites occur inform of irregular masses or as basic xenoliths within the surrounding syn to late tectonic granites. Their occurrence suggests they were large masses prior to granites emplacement (McCurry, 1973). This is in support of field evidence, because the quartz-diorite mapped occurs both as large intrusions and as xenoliths within the medium grained granite.

The main phases of the orogeny was characterized by intense deformation and isoclinal folding (foliation) in a E-W direction accompanied by regional metamorphism and extensive migmatization (McCurry 1973). A second deformation episode accompanied also by regional metamorphism and extensive migmatization refolded the earlier isoclinal folds along N-S axes and produced foliation in the same direction. This led to the extensive granitization and

gneissification of the original gneiss complex, which then produced the potassic syn-tectonic granites and homogenous gneisses (McCurry, 1970 and 1973). These rocks were not mapped in the study area.

Table 6.1 Proposed Evolution model of rocks of the basement complex of sheet 79 Malumfashi SE modified after Danbatta,(2008).

Age(Ma)	Period (or epoch)	Events	Orogenic Episode
540 + 40	Mid Cambrian	Upift, cooling, faulting, high level magmatic activity, fracturing	Pan-African (600+150)
650-580	Cambrian-precambrian	Granitic intrusion, pegmatite and Aplite intrusions, development of Older Granites	
650-850	Upper proterozoic	Orogenesis, deformation, metamorphism, Granitization, migmatization and reactivation of pre-existing rocks	Pan-African (600+150)
800-1000	Katangan	Geosynclinal sedimentary deposition, intrusion of igneous rocks.	Katangan
1900 +250	Eburnean	Granite intrusion, orogenesis, folding, metamorphism and reactivation of pre-existing rocks, Quartz-diorite formation	
2800+200	Liberian	Ancient gneisses-schist complex, Banded-gneises, migmatite gneisses	

The late-tectonic phases of the orogeny resulted in the emplacement of the late-tectonic granites (McCurry, 1973), which in the study area are represented by the medium grained granite which intruded the quartz-diorite. Field evidence supports this fact, as various sizes of xenoliths occur within the granitic rock. Since the intruding granitic melt was hot, it stopped and assimilated part of the dioritic host rock. This phase was followed by the emplacement of aplites, pegmatites and quartz veins into weak zones during the lower Cambrian (Grant, 1971; McCuury, 1973).

This indicates imprints of the Pan-African event in the study area. Pegmatites being regarded as rocks derived from magma that may have crystallized in the presence of a magmatic acqueous fluids. They are typically associated with granites and comprising the major granite rock forming minerals. The large crystals of quartz, feldspar and muscovite that make up the bulk of most pegmatite are often extracted for industrial purposes. In addition they provide a wide variety of minor minerals of more exotic and semi precious character such as tourmaline, topaz and beryl. Origin of pegmatites provides a fruitful area of research because of the clues they provide for ore-forming processes and igneous petrogenesis in general.

6.1 Conclusion

Evidence from field mapping and petrographic studies show that the mapped area is underlain by rocks of the undifferentiated basement complex as well as Older-Granite suites. The evolution of the rocks has been linked to at least three past tectonic events ranging from Archean to Pan African.

Structural elements such as joints, folds, foliations etc. showing either N-S or E-W trends, therefore confirms the stress direction of the Pan African orogeny. Therefore in the mapped area, the banded gneiss is the oldest followed by the quartz-diorite, the medium grained granite and the minor intrusive respectively.

The pegmatites have also shown an enrichment in the REE when comparing the level of REE distribution pattern on the normalized chondrite plots and the lithophile elements

distribution has shown an enrichment in Rb when compared to crustal mean average suggesting a relative fractionation in the pegmatites.

Having observed only minimal enrichment in the REE the pegmatites could said to be not mineralized in these minerals. Major element data shows that the pegmatite is enriched in SiO_2 and Al_2O_3. Interlithophile element ratios show a high K/Rb and K/Ba and the REE pattern of the pegmatite sample and of the rocks mimics those of other parts of NW Nigeria.

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APPENDIX 1

Joint r eadings (in degrees) on the medium grained granite.

30 90 130 7 10 180 20 8 10 10 8 12 45 45 49 34 38 34 322 358 320 355 352 20 38 320 322 310 38 26 310 20 22 320 25 310 26 12 22 34 356 356 358 26 14 352 45 12 350 345 345 340 18 15 10 10 8

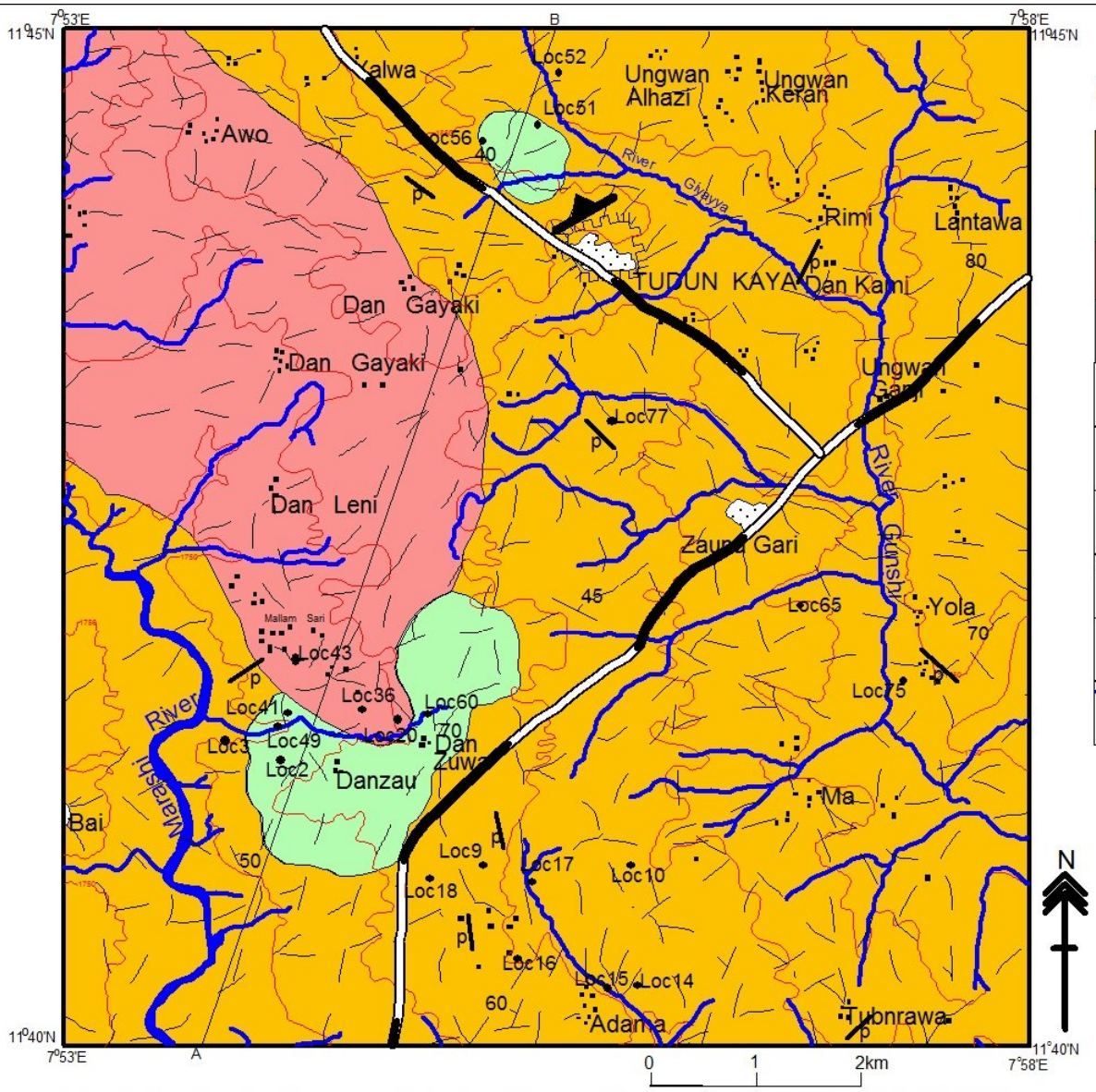
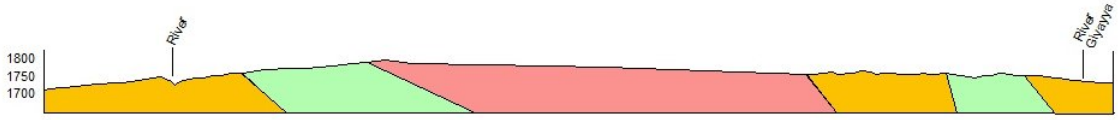
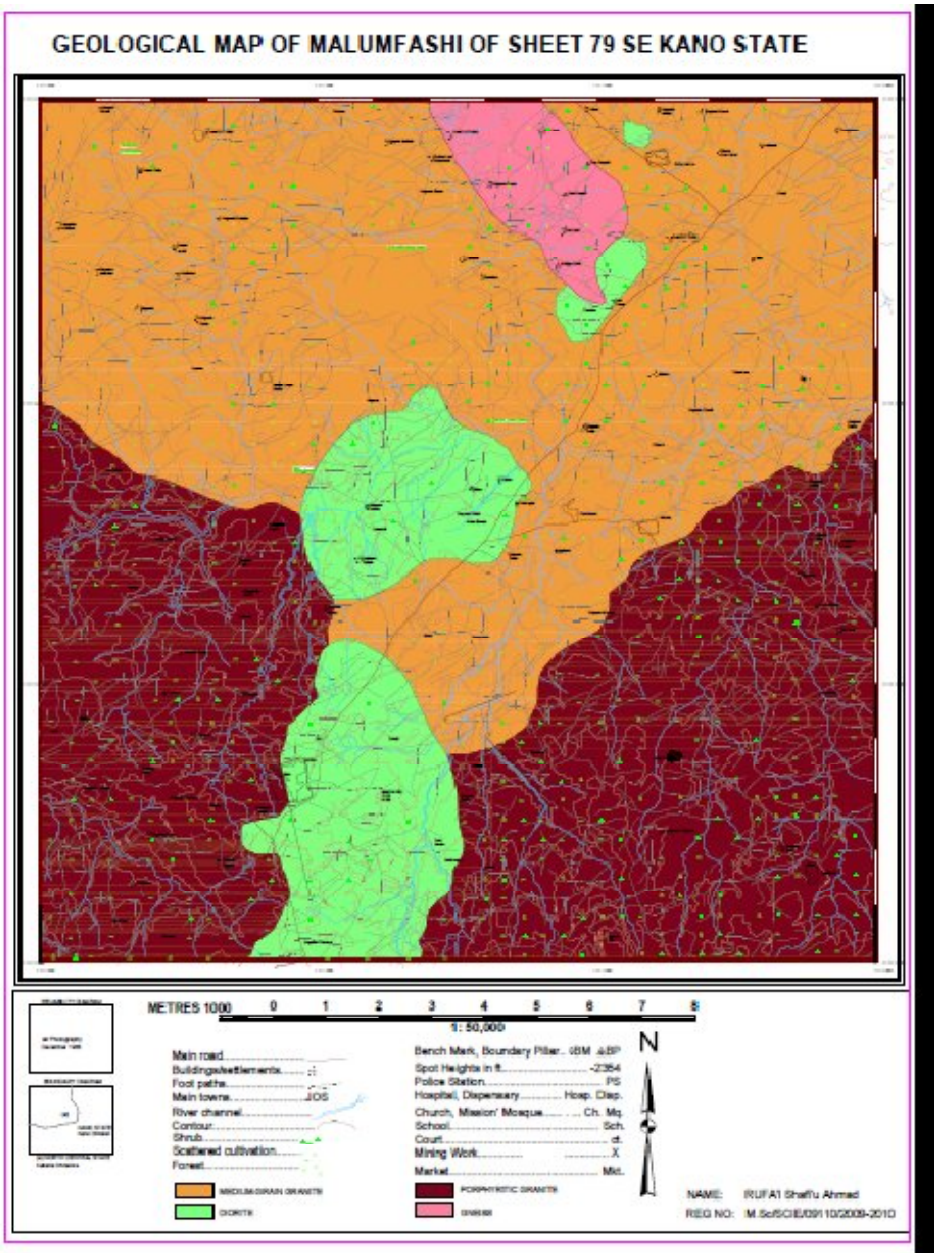


Fig. 3.1: Geologic map of Tudun Kaya - Danzau at a scale of 1:10,000




GEOLOGICAL MAP OF MALUMFASHI OF SHEET 79 SE KANO STATE
METRES 1000 0 1 2 3 4 5 6 7 8
1: 50,000
Main road
Buildings/settlements
Foot paths
Main towns JOS
River channel
Contour
Shrub
Scattered cultivation
Forest
Bench Mark, Boundary Pillar.. IBM BP
Spot Heights in ft -2354
Police Station PS
Hospital, Dispensary Hosp. Disp.
Church, Mission' Mosque Ch. Mq
School Sch.
Court ct
Mining Work X
Marked Mkt.
N
NAME: RUFAI Shaffu Ahmad
REG NO: M.Sc/SCIE/0910/2009-2010