GEOLOGY, GEOCHEMISTRY AND PETROTECTONIC SETTING OF IDANRE GRANITE COMPLEX, SOUTHWESTERN NIGERIA

AKINOLA OLUWATOYIN OLAGOKE

FACULTY OF SCIENCE
UNIVERSITI MALAYA
KUALA LUMPUR

2020

GEOLOGY, GEOCHEMISTRY AND PETROTECTONIC SETTING OF IDANRE GRANITE COMPLEX, SOUTHWESTERN NIGERIA

AKINOLA OLUWATOYIN OLAGOKE

THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

FACULTY OF SCIENCE
UNIVERSITI MALAYA
KUALA LUMPUR

2020

UNIVERSITI MALAYA

ORIGINAL LITRARY WORK DECLARATION

Name of Candidate: **AKINOLA OLUWATOYIN OLAGOKE**

Matric No: **SHC 160011**

Name of Degree: **DOCTOR OF PHILOSOPHY**

Title of Thesis ("this Work"):

GEOLOGY, GEOCHEMISTRY AND PETROTECTONIC SETTING OF IDANRE GRANITE COMPLEX, SOUTHWESTERN NIGERIA

Field of Study:

ECONOMIC GEOLOGY

I do solemnly and sincerely declare that:

1) I am the sole author/writer of this Work
2) This Work is original;
3) Any use of any work in which copyright exists is done by way of fair dealing and for permitted purposes and any excerpt of extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this work;
4) I do not have any actual knowledge, nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
5) I hereby assign all and every right in the copyright to this work to the University of Malaya, who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
6) I am fully aware that if in the course of making this Work, I have infringed any copyright whether internationally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date:

Subscribed and solemnly declared before

Witness's Signature Date:

Name:

Designation:

GEOLOGY, GEOCHEMISTRY AND PETROTECTONIC SETTING OF IDANRE GRANITE COMPLEX, SOUTHWESTERN NIGERIA

ABSTRACT

During Neoproterozoic, Nigeria like many other Pan-African countries witnessed extensive magmatic activities which resulted in emplacement of granite popularly referred to as Older Granite in Nigeria. The study area is characterized by a large population of this rock type than any other part of Nigeria, so these rocks are investigated in this research. Idanre is underlain by migmatite-gneiss, charnockite and granite. Migmatite form the country rock and are low-lying, charnockite was surrounded by granite, while the granite forms large inselbergs. Three textural types of granite occur in the area, they are coarse-grained granite (undifferentiated) (OGu), porphyritic granite (OGp) and the fine-grained granite (OGf). Analytical results revealed the siliceous nature of the basement rocks, the range of silica contents are migmatite (55.90 - 65.32%), charnockite (60.62 - 63.70%) and granite (62.97 - 74.52%). Geochemical result also showed the granitoids range in composition from alkali granite to granodiorite, they are metaluminous ferroan I-type late orogenic suites with shoshonitic to high-K alkali calcic signatures. Na_2O/Al_2O_3 versus K_2O/Al_2O_3 diagram showed the protolith of the granite rocks have extensive data plot spread within igneous field revealing the granite originated from anatexis of igneous rocks. The occurrence of igneous structures like poikilitic textures, sphene and myrmekite are petrographic evidence of igneous origin for the granite. All the granites exhibit similar geochemical coherence between their trace elements distribution evidenced by similar shape for the chondrite normalized REE pattern. The gneiss units are also characterized by similar geochemical features. All the granite samples showed LREE enrichment, HREE depletion and plagioclase fractionation with evidence from negative Eu anomaly ($Eu/Eu^{*}<1$). Geochemical appraisal revealed the granitoids are of "*within-plate*" tectonic setting. Zircon U-Pb geochronology showed migmatite with 1065.1 ± 7.1 Ma age represents the oldest rock in Idanre area. This was subsequently followed by charnockite (590.3 ± 5.3 Ma), fine-grained granite (588.4 ± 5.5 Ma) and porphyritic granite (584.5 ± 5.8 Ma) while the last magmatic episode produced the Undifferentiated granite (581.8 ± 5.5 Ma) which is the youngest member of the suite. $^{176}Hf/^{177}Hf$ ratios in OGu vary between 0.281724 and 0.281843 with initial $^{176}Hf/^{177}Hf$ between 0.281715 and 0.281782, $\varepsilon_{Hf}(t)$ values range between -22.2 to -23.5 and tDM_2 age 2800 ~ 2990 Ma. $^{176}Hf/^{177}Hf$ ratios in OGp range between 0.281692 and 0.281863, initial Hf values between 0.281683 and 0.281848, $\varepsilon_{Hf}(t)$ values between -22.5 to -25.5, tDM_2 age range between 2850 ~ 2950 Ma. In OGf, $^{176}Hf/^{177}Hf$ values range between 0.281712 to 0.281813 with initial values from 0.281708 to 0.281802, $\varepsilon_{Hf}(t)$ lies between -22.4 to -25.7 and tDM_2 age 2880 ~ 3000 Ma. These tDM_2 values all indicated that the inherited zircons were separated from the "Depleted Mantle" around 2.8 ~ 3.0 Ga. Negative $\varepsilon_{Hf}(t)$ values symbolized derivation from crustal source, while tDM2 age implied magma source originated during Mesoarchean.

Keywords: Older granite, Idanre, metaluminous, zircon U-Pb geochronology, Depleted Mantle

GEOLOGI, GEOKIMIA DAN SEKITARAN PETROTEKTONIK KOMPLEKS IDANRE GRANIT, BARAT DAYA NIGERIA

ABSTRAK

Semasa Neoproterozoic, sama seperti banyak negara Pan-Afrika yang lain, Nigeria menyaksikan aktiviti magma yang luas di mana perletakan granit dikenali sebagai Granit Lama di Nigeria. Kajian dilakukan terhadap batuan tersebut memandangkan kawasan kajian terdiri daripada populasi granit yang besar berbanding tempat lain di Nigeria. Idanre terdiri daripada batuan migmatit-gneis, karnokit dan granit. Migmatit membentuk batuan dasar yang rendah, manakala karnokit dikelilingi oleh granit yang membentuk inselbergs yang besar. Tiga jenis tekstur granit yang terdapat di kawasan kajian iaitu granit berbutir kasar (tidak dibezakan) (OGu), granit porfiritik (OGp) dan granit berbutir halus (OGf). Hasil analisis menunjukkan sifat bersilika dari batuan dasar mengandungi pelbagai kandungan silika iaitu migmatit (55.90 - 65.32%), karnokit (60.62 - 63.70%) dan granit (62.97 - 74.52%). Hasil geokimia juga menunjukkan batuan granitoid tergolong dalam komposisi granit alkali ke granodiorit dan metaluminus besi jenis-I pada suit orogenik akhir dengan ciri-ciri shoshonitik ke siri tinggi-K alkali kapur. Diagram Na_2O/Al_2O_3 lawan K_2O/Al_2O_3 menunjukkan protolit batuan mempunyai data plot yang luas tersebar di dalam kawasan igneus serta mendedahkan granit berasal daripada anateksis batuan igneus. Kejadian struktur igneus seperti tekstur poikilitik, sfen dan mirmekit adalah bukti petrografi untuk asalan igneus bagi batuan granit. Kesemua granit menunjukkan koheren geokimia yang sama di antara sebaran unsur surih yang turut disokong oleh bentuk yang sama pada pola REE kondrit normalan. Batuan gneiss turut mempunyai ciri-ciri geokimia yang sama. Semua sampel granit menunjukkan pengayaan LREE, penyusutan HREE dan fraksionasi plagioklas seperti yang ditunjukkan oleh negatif anomali Eu (Eu/Eu* <1). Penilaian geokimia menunjukkan batuan granitoid berada pada tetapan tektonik "*within-plate*". Geokronologi zirkon U-Pb menunjukkan migmatit dengan usia 1065.1 ± 7.1 Ma mewakili batuan tertua di kawasan Idanre. Ini kemudiannya diikuti dengan karnokit (590.3 ± 5.3 Ma), granit berbutir halus (588.4 ± 5.5 Ma) dan granit porfiritik (584.5 ± 5.8 Ma), manakala episod terakhir magmatisme menghasilkan granit yang Tidak Dapat Dibezakan (581.8 ± 5.5 Ma) yang juga merupakan ahli termuda suit. Nisbah ^{176}Hf/^{177}Hf pada OGu terdiri daripada 0.281724 and 0.281843 dengan permulaan ^{176}Hf/^{177}Hf di antara 0.281715 and 0.281782, nilai εHf(t) tergolong di antara -22.2 ke -23.5 dan usia tDM$_2$ ialah 2800 ~ 2990 Ma. Nisbah ^{176}Hf/^{177}Hf pada OGp tergolong di antara 0.281692 dan 0.281863, permulaan nilai Hf ialah di antara 0.281683 dan 0.281848, nilai εHf(t) berada antara -22.5 ke -25.5, manakala usia tDM$_2$ dalam lingkungan antara 2850 ~ 2950 Ma. Untuk batuan OGf, nilai ^{176}Hf/^{177}Hf berada dalam lingkungan antara 0.281712 kepada 0.281813 dengan nilai permulaan dari 0.281708 ke 0.281802, εHf(t) berada di antara -22.4 ke -25.7 dan usia tDM$_2$ ialah 2880 ~ 3000 Ma. Nilai-nilai tDM$_2$ ini menunjukkan zircon warisan terpisah daripada "Depleted Mantle" semasa 2.8 ~ 3.0 Ga. Xilai negatif εHf(t) menunjukkan bendalir magmatik berasal dari sumber kerak, manakala usia tDM$_2$ menyatakan sumber magma terbentuk semasa Mesoarchaen.

Kata kunci: Granit Tertua, Idanre, metaluminus, Geokronologi zircon U-Pb, Mantel Tersusut

ACKNOWLEDGEMENTS

I am grateful to God Almighty in whose hands my life and destiny is. His love, protection guidance and provisions throughout this research and the sound health I have enjoyed are inestimable. His Kingdom is an everlasting one that rules through all ages. All glory honour and adoration be unto our God who is abundantly able, His Mighty powers at work within us enables us to accomplish infinitely more than we might ask. I wish to convey my immense appreciation to my supervisor, Professor (Dr) Azman Abdul Ghani for his efforts, mentorship, encouragement, and contributions at every stage of the research work and towards the success of this thesis. May the good Lord continue to bless him and his family and reward him with good health and long life.

My appreciation goes to the management and staff of Ekiti State University (EKSU), Ado-Ekiti, headed by Professor Oye Bandele (The Vice Chancellor) for granting approval for my study leave with pay, and Mr. Emmanuel Ogunyemi (Former Registrar, EKSU), and Mr. Arogundade (The Current Registrar) for communicating the approval to me in good time, and to the Tertiary Education Trust Fund (TETFund) for sponsorship. I am also grateful to Professor E. I. Adeyeye (The Dean, Faculty of Science) and Professor Akin Oyinloye (Former Head of Geology Department, EKSU) who signed my bond forms. I cannot but mention this unforgettable assistance, may God reward you richly. Professor Lawrence Olofintoye (Former Dean, Faculty of Science) is acknowledged for his numerous assistances. Members of academic staff of the Department of Geology, EKSU, including Professor Femi Ojo, Professor Lawrence Ademilua, Dr O. F. Adebayo, Dr R. A. Obasi, and Dr A. O. Talabi (Ag. Head). Others are Dr(s) S. A. Akinyemi, O. A. OlaOlorun, A. O. Aturamu, O. L. Afolagboye, A. B. Eluwole, and Y. C. Ajisafe. All other academic and non-academic staff of the Department are acknowledged for showing me much love. This acknowledgement will be incomplete without specifically mentioning Dr A. K. Adegoke who assisted me during my application to study in

Universiti Malaya, his wealth of experience as a former student of the institution tremendously assisted me in logistics particularly when I had to defer the first two admissions. I am very grateful and pray God grant his heart desires.

I wish to acknowledge fellow research students in persons of Hatta Rosellee Muhammad, Elvaene Anne James, and Nur Nadwa S. AiZamruddin for the collaboration and others on Ph.D. journey that shared same office with me, the likes of Terfa Garba, Nurudeen Yelwa, Usman, Gerald Ejiga, Muktar Lawal, Liang Ye, Nadzmi, Fauzan, Syazwani, and Nadzirah. You have all been wonderful for making my stay pleasant. Messrs. Nasiruddin, Zamrut, Mohd Yusri, Ms Zaleha Abdullah and other administrative staff of Department of Geology, Universiti Malaya (UM) are acknowledged with gratitude for not denying access to the laboratories and equipment. Worth mentioning are two of my students, David Omagba and Tope Aderibigbe who assisted during fieldwork and data acquisition, may God bless you all. Pastor and Pastor (Mrs) J. K. Olaade (The Regional Pastor, Redeemed Christian Church of God, Asia Region 2, HQ, Malaysia), and other anointed ministers of God in Mercy Seat Sanctuary are greatly appreciated. I wish to specially appreciate my flat mates who eventually became brothers and good friends, especially, Lanre Asiwaju, Daniel Amos, Boluwatife Fatokun and Frank Enyinnaya Nzeadibe who made my stay in Malaysia an interesting and memorable one. Other friends who contributed in one way or the other to this academic success are all acknowledged.

Lastly, I say thank you to my dear wife, Ifeoluwa, for her love, care, support, encouragement and understanding and to my lovely children, Emmanuel, Benedict, and David. I pray Almighty God grant us sound health and long life to reap the fruit of our labour.

I am dedicating this thesis to the Almighty God, the father of life and to our Saviour Jesus Christ, who reigns from a dateless past to an endless future, unto Him who protects,

guides, sustains and from whom all wisdom and inspiration originates be all Honour, Power and Majesty; and to my wife, (Ifeoluwa) and children (Emmanuel, Benedict and David) whose forbearance and understanding I have enjoyed particularly when most of the family resources had to be channelled into making this research and my stay in Malaysia a success.

To God be the Glory, great things He has done…

Oluwatoyin O. Akinola

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

amsl	Above mean sea level
Ar-Ar	Argon-argon isotopic dating method
Avg.	Average
BIF	Banded Iron Formation
Ch	Charnockite
CL	Cathodoluminescence
Cm/sec	Centimeter per second
C^o	Degree Celcius
cpl	Cross polarized light
Eu/Eu*	Measured Eu divided by expected Eu assuming a smooth chondrite normalized REE pattern (Eu*). Values deviating significantly from 1.0 are termed positive Eu anomalies (Eu/Eu*>1) and negative Eu anomalies (Eu/Eu*<1)
Felds	Felspar
Fig	Figure
F^o	Degree Fahrenheit
fO2	Oxygen fugancity
Ga	Billion years ago
GDUM	Geology Department, Universiti Malaya
GPS	Global Positioning System
GSN	Geological Survey of Nigeria
Hbld	Hornblende

HREE	Heavy rare earth elements
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ID/SID	Sample Identification number/ Number tag of samples
IGC	Idanre Granite Complex
K bar	Kilobar
K-Ar	Potassium-Argon dating technique
LA-U-Pb zircon	Laser Ablation Uranium-Lead zircon geochronology
Loc.	Location
LOI	Loss on Ignition
LREE	Light Rare Elements
M	Migmatite
m/sec	Meter per second
Ma	Million years ago
MSWD	Mean square of weighted deviates
NGSA	Nigeria Geological Survey Agency
-nd-	Not determined
NTU	National Taiwan University, Taipei
OGf	Fine-grained granite
OGp	Porphyritic granite
OGu	Coarse-grained granite (Undifferentiated)
ORG	Ocean Ridge Granite
Pa s	Pascal sec (unit of viscosity)
ppl	Plane polarized light

ppm	Parts per million
P-T-t	Pressure-Temperature time regime
Pyrx	Pyroxene
Qrtz	Quartz
Rb-Sr	Rubidium -Strontium isotopic dating
REE	Rare Earth Elements (La, Ce, Pr, Nd, …Eu, …Lu)
STP	Standard temperature and pressure
Syn-COLG	Syn-collision Granite
TOT/C	Total Carbon (%)
TOT/S	Total Sulphur (%)
UNESCO	United Nations Education Scientific and Cultural Organization
U-Pb	Uranium-Lead isotopic dating/method
VAG	Volcanic Arc Granite
Vol. %	Volume percent
Vs	versus
WPG	Within plate Granite
(W.R)	Whole rock
Wt. %	Weight percent
XRF	X-Ray Fluorescence

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 General Introduction

In Nigeria, masses of granite outcrop within the basement complex, however, the number and size of such masses vary from one place to another. Falconer, (1911) in his pioneering work recognized two generations of granites in Nigeria which he designated 'Older Granite' and 'Younger Granite'. As the names imply, the Older Granites are Precambrian (750 - 450 Ma) in age and are generally believed to symbolize Pan-African Orogeny in Nigeria. They are widespread and form notable topographic feature that characterizes the country's basement complex, they occur as prominent residual hills and as inselbergs. The Younger Granite on the other hand, occur as ring dykes and represents high-level magmatic intrusions that are associated with cauldron subsidence and piston faults. They are anorogenic granites of Jurassic (160±25Ma) age and are confined to the Jos Plateau in north central Nigeria. In many parts of southwestern Nigeria, Older Granite suites occurs as batholiths and plutons that are now exposed by erosion forming residual hills. On many instances, these batholitic masses are sometimes known by specific names. In southwestern Nigeria alone, such include the Olumo rock (Abeokuta), Mapo Hills (Igbeti), The Orole Hills (Ikere), The Idanre Hills (Idanre) and the Somorika Hills (Igarra) among others. My research findings show that towering granite inselbergs can be found in areas like Okenne, Akoko area of Ondo state and towards the far northern part of the Nigeria such as Niger State and Abuja. Other place where these granites can be found in Nigeria include Igarra, Iwo, Akure, Ikare and Ado-Ekiti (Oyinloye and Obasi, 2006). Voluminous granite masses also occur in other parts of the country, such as the Obudu Hills, south-eastern Nigeria (Ekwueme and Kröner, 2006); Solli Hill, northcentral Nigeria (Ferré et al., 1998); Abuja Batholith, northern Nigeria (Goodenough et al., 2014).

The Idanre Granite Complex (sometimes referred to as Idanre Batholith or Idanre Hills) makes the landscape of Idanre area a magnificent and breath-taking scenery. However, each of the granite unit is distinctly recognizable and identifiable. The different granite units vary in size and outlook and each is given its own local name. Within this domain, the granitic masses which is quite extensive are exposed along a belt measuring about 27 km along its main axis (northwest-southeast) and over 25 km in width. The Idanre Granite forms the most southerly extension of the elongate granitic bodies that extends in a north-south direction cutting through Akure, Iju, Ita-Ogbolu, Ikere-Ado Ekiti and terminating in Omu-Aran area in Kwara State (Kolawole and Anifowose, 2011).

1.2 Problem Statement

While the origin of granites from countries in sub-Sahara Africa may have been relatively profiled, Nigeria with her numerous granite domains has insufficient information about geodynamic setting of granites in its terrains particularly those in Idanre area. Relevant literature observed that Idanre granites constitutes one of the largest granite domains in Nigeria, while the extension of granite across national borders into neighbouring countries to form notable topographic entities has constantly arrested the curiosity of geologists. The argument among the geological community is that there is a major problem linked with inconsistencies that greeted the geochemical characterization as well as the spatial and geodynamic setting of most Nigeria granites (Odeyemi, 1990) and the impediment constituted to geological research by the rugged granite terrains (Ekwueme and Kröner, 2006).

However, the geologic processes which controls the prevalence of this rock is not well known because there was no previous scientific research or geological documentation that investigated the geology, geochemistry, geochronology, and tectonic study of Idanre granite. The only previous research work on age of charnockite in Idanre area (Tubosun, 1981) was not comprehensive because only one component out of the many rocks was dated. This has made complete interpretation of geochronological record which is crucial to solving the problem impossible. This study attempts to investigate the geology, geochemistry and petrotectonic setting of these granites and the result is aimed at producing a proper profiling of the granites particularly in terms of their evolution. The research will present to Nigerian geological community and future researchers the first profiling of Idanre Granite Complex (IGC) so that future works in this area can be advanced.

1.3 Objectives

During this research work, the researcher intended to accomplish various goals on Idanre granites having been the first major work carried out in the area. However, among others, specific objective of the research is listed below:

1. to identify the rocks in the study area and evaluate their mineralogical and textural features,
2. to elucidate the petrochemical characteristics of the rocks,
3. to determine age relationship of the rocks,
4. to determine holistically, the tectonic setting of Idanre Granite Complex, using Hafnium isotope.

1.4 Location of the study area

Spread out between latitudes 7°00' N to 7°14' N and longitudes 5°00' E to 5°14' E, the study area covers southwestern corner of the topographic map sheet of Akure, it stretches out along an approximate of 676 km^2.

Idanre is a major town and the capital of Idanre Local Government area in Ondo State, Nigeria. The Geographical location of Idanre is such that it lies SSW of Akure (the Ondo State Capital), it is situated in the eastern part of Ondo town and southeast of Owena.

Figure 1.1: Map of Africa indicating study location (Idanre) in SW Nigeria

Idanre area is accessible and has major road links with Alade and Akure in the north and Owena in the northwest. The roads connecting these towns are the major roads and extend to Agosile, Ojadale and Ojota areas which form the major commercial centres of the town. The minor roads connect various localities like Opa-Idanre, Apefon, Kajola-Asoko, Legbira and Omi-Alaja that are situated along the eastern part. In the west flank is an old road linking Odoji, Obatedo, Ago-Moferere, Onipepeye and Ipinlerere. There are also footpaths connecting various farm settlements and cocoa plantations in the area. It shares its eastern boundaries with the people of Benin separated by the Orosun River which represents the border between Ondo and Edo State. The western side is occupied by the Ondos which is demarcated by River Owena as boundary. Its southern part is occupied by the indigenes of the Old Bendel State, Onishere and Ikale, also of Ondo State ancestry. The location of the study area in relation to Nigeria and Africa continent is shown (Fig. 1.1).

1.5 Geomorphology

The topographic map (Fig. 1.2) shows that conical hills form the main relief feature of Idanre area. The general terrain has an elevation ranging between 180 - 620 m above the mean sea level. "*Idanre, lying approximately between about 286 to 500 m above sea level, represents one such topographically unique landscape located within the forest zone of south-western, Nigeria*" (Ige et al., 2011, pp.180). This spectacular characteristic feature indicates that Idanre town is situated on flat terrain surrounded by dome-shaped, steep-sided, and sparsely vegetated lofty hills (Fig. 1.3). The hills, being charming scenic beauty of the town has also attracted the attention of geologists and tourists in the recent time. The Idanre Hills spreads out into a vast expanse of land extending beyond the present-day built-up areas of the town. The northern, western, and eastern parts of the study area form relatively flat terrain.

This topographic variation reflects some lithologic control as low-lying and highly denuded rocks of gneissic composition occupy the lowlands and plains while the granitoid form prominent hills. The Orosun Hill (Fig. 1.4) which forms the highest peak in the study area is constantly covered by clouds for most part of August and December during which the top of the hill becomes almost invisible.

1.6 Thesis organization

The present study has been divided into six parts (Chapters 1-7). All these chapters are mutually connected in such a way that they lead to final conclusions in assessing overall

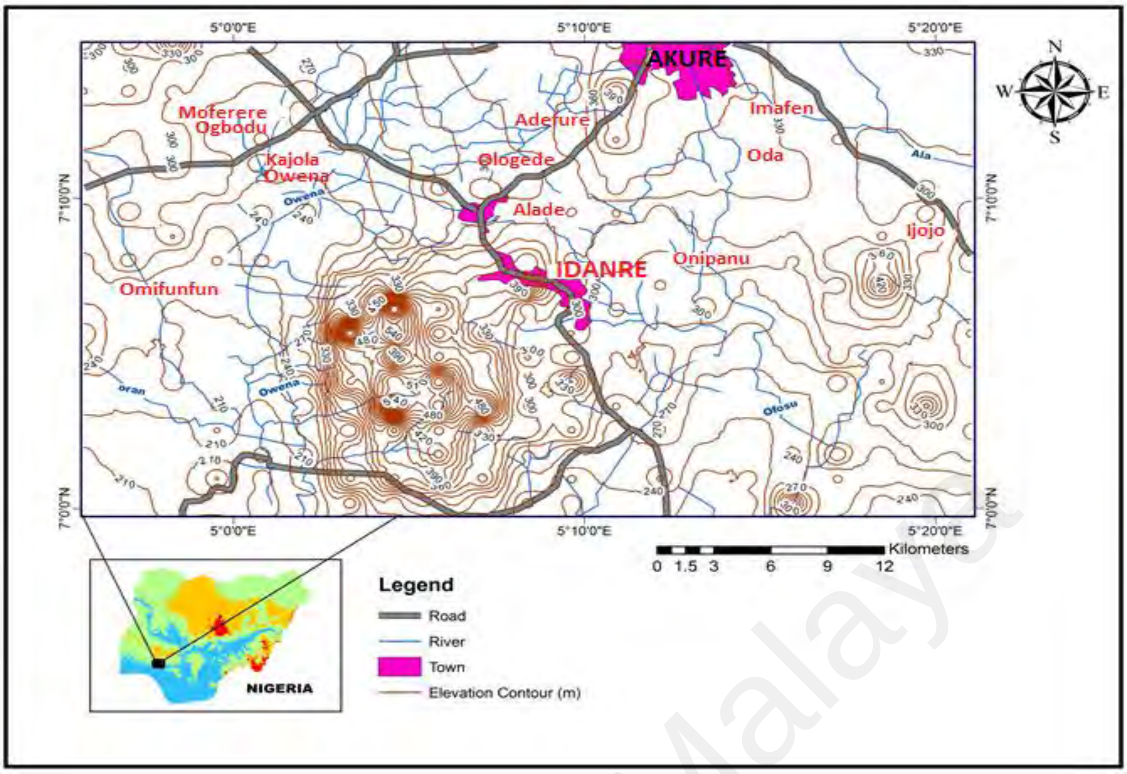

Figure 1.2: Topographic Map of Idanre area showing the relief and major road network

Figure 1.3: A panoramic view of Idanre town located on the pediment surrounded by granite inselbergs

mineralogical, textural, and general structural features, petrochemical characteristics, and the geochronology of rocks in the granite complex. The above is linked together primarily to expand the understanding of the origin, tectonic development, and geological implication of the granite complex.

Chapter 1 deals with introduction of the study, such as justification, objectives, limitations, general analysis of the study area, as well as the review of the previous studies carried out in the area. Chapter 2 comprises reviews on regional geology, the geology of Basement Complex of Nigeria and the study area. A general multidisciplinary methodological approach and instrumentation adopted to achieve the objectives of the research is presented in chapter 3. Chapter 4 comprises of results and outcome of fieldwork and description of each lithologic unit in the study area, their structural attributes, petrology, and petrography (optical microscopy) and geochemistry. Chapter 5 comprises of zircon-U-Pb geochronology and Lu-Hf isotopic study. Chapter 6 presents discussion of results, lithologic relationships, optical microscopy, tectonic setting, plagioclase fractionation, petrogenesis and geochronology of the area. The significant findings from the research are summarized and collated, this with the conclusions based on these findings are presented in chapter 7.

1.7 Review of previous works

Between 1905 to 1908, the Mineral Survey of Nigeria undertook one of the earliest works on the regional geology of Nigeria Precambrian rocks. During this period, reconnaissance survey of mineral deposits associated with the Nigeria schist belts yielded positive results. Some of the important outcomes of the investigation include; the discovery of gold in Ilesha (Oshun State), tinstone and columbite in Ijero-Ekiti (Ekiti State), limestone in Ewekoro (Ogun State), marble in Igbetti (Oyo State) and clay deposits scattered all over southern Nigeria. The Geological Survey of Nigeria (GSN) now called (Nigeria Geological Survey Agency) (NGSA) was inaugurated in 1919, following the disbanding of the Regional Mineral Surveys which carried out among others, the evaluation of gold mineralization in Ilesha area. The gold mineralization which occur in

Figure 1.4: Orosun Hill (a) forms the highest point in Idanre (at the background, with spot height 908 m), (b) a closer view of Orosun Hill

Iperindo near Ilesha (50 km NNW of Idanre) attracted attention of geologists to many parts of southwestern Nigeria including Idanre.

The basement rocks in southwestern Nigeria were mapped and its geology described in detail by Jones and Hockey (1964). The regional geology of southwestern Nigeria has been described in the works of Russ (1957), Oyawoye (1964), Turner (1983), and Rahaman, et al., (1988). Results of exhaustive regional geological assessments, structural geology, petrology, economic geology, mineralization, geochemical and geochronological evaluation of the basement rocks were compiled in a publication by Geological Survey of Nigeria (GSN) in 1982. The compilation was titled Precambrian Geology of Nigeria, where a team of sixty eminent Nigerian geologists actively participated. Odeyemi et al. (1999) on geological setting, stated that the Idanre is underlain by rocks of Precambrian age which consist of a complex of migmatite gneiss, Neoproterozoic metasediments and intrusive Older Granites. Anifowose and Kolawole, (2012) reported that migmatite gneisses represent the oldest rock in Idanre area and other parts of the country. The rock is a distinct unit and tectono-stratigraphically basal to all subsequent suprajacent lithologies and orogenic events. The duo believed that the Idanre batholith is a member of Older Granite suite of Pan-African (750 ~ 450Ma) age, they believed it is emplaced discordantly to semi concordantly within the migmatite-gneiss basement rocks. Nigeria granite batholiths comprise porphyritic or porphyroblastic, one-mica granitoid with compositions ranging from granites through adamellite to granodiorite (Rahaman, 1988). It intrudes migmatites and gneisses that exhibit complex deformation styles and structures that are attributable to its polycyclic nature.

To contribute to the understanding of regional geological features, Ige et al. (2011) applied remote sensing techniques and satellite images to analyse lineament directions and densities over Idanre area. Remote sensing technique and satellite images has always produced better geological information about any area even though its quality is largely influenced by climate and terrain morphology. However, Drury, (2001) believed satellite images and aerial photographs are extensively useful for the interpretation of lineaments in any terrain. In an earlier study, Anifowose and Kolawole, (2012) cited (Casas et al., 2000) as indicating that electromagnetic spectrum output show images from different wavelength intervals. However, lineament analysis as a routine in regional geological mapping are based on remotely sensed information retrieved from satellite images and these satellite images reveal more information because they are based on variation in electromagnetic spectrum (Ray, 1960). These satellite images produce better information because the application of aerial photograph to obtain reliable geological information including structures is primarily dependent on the nature of terrain, climate, and geomorphology (Suzen and Toprak, 1998).

The history of ancestry of Idanre people have been traced to the one of the hills which contain remains of antiquities of ecological and cultural interest. At present, plans are on to make it a globally recognized tourism centre by various levels of Government and non-governmental organizations in Nigeria. The area has become a tourist attraction after it was designated as a World Heritage Site (Kolawole and Anifowose, (2011).

The Geological Survey of Nigeria (GSN) published a map in 1966 showing Idanre area on a scale of 1:250,000 in Akure Sheet 61. As pointed out in literature, Jeje, (1974), believed, the development of various landforms in Idanre area were controlled by litho-structural constraints. According to Oyawoye, (1972), Idanre granite-charnockite association represent one example of charnockite intrusion occurring at the core of granites. He indicated that Idanre granite marks southern limit of a granite-charnockite belt which extends over 200 km into Osi area in Kwara State, Nigeria.

Lying relatively above 150 to 250 m sea level, Idanre town spread out on pediment sections within Western Nigeria (Ige et al., 2011). Furthermore, the researchers reported on the inventory of rock types constituting the Idanre Hills, the workers indicated that different textural types of granites occur in Idanre area and this include the coarse-grained, the porphyritic and fine-grained granite. They believed that the fine-grained granite formed a minor intrusion towards east of the granite suite. Granite outcrops in the study area are accessible because many are devoid of vegetation cover. However, navigating the gneiss-granite terrain was tasking due to the steep slopes of some outcrops which occurs as voluminous inselbergs standing above the general low-lying migmatite basement. Inselbergs of this kinds have been reported around Isan-Ekiti where its downslope movement initiate rock-boulder landslide Durotoye, (1976). Burke and Durotoye, (1970) reported that inselberg terrain like Idanre area was found in Imesi-Ile, Jeje, (1979) also indicated that Olusoye area near Ile-Ife contains similar rock types. Based on empirical evidence presented by Ige et al. (2011), Idanre granite is emplaced into the host (country rock) as intrusive bodies of felsic magma. The evidence show that the intrusion took place during Neoproterozoic. He noted that consolidated product of the process is today exposed at the surface after agents of denudation removed the overburden. The authors believed that because of this exposure, the rocks were subjected to fracturing resulting into development of crevices subsequently filled with a set of silicate melt which rapidly crystallized and formed fine-grained granite. In 1981, U-Pb data on zircon geochronology was published by Rahaman and others who reported that charnockite from the study area was emplaced at 580±12 Ma (Neo-Proterozoic) (Rahaman et al., 1981). In these earlier studies, workers have not presented a complete geochemical assessment of the entire basement rocks, geochronological data only existed for the charnockite, again the scanty data are very old and has not been reinvestigated recently, so the petrogenetic synopsis of the rocks has largely remained unclear. Due to these inadequacies, the present study is set to give a comprehensive field report on structural attributes of the rocks and their geochemical features in order to bridge the petrogenetic gap by subjecting each rock to isotopic dating. This will also capture the sequence of emplacement and clearly explain the holistic tectonic evolution of the rocks and give a comprehensive assessment of Idanre Granite Complex.

CHAPTER 2: GEOLOGICAL SETTING

2.1 REGIONAL GEOLOGICAL SETTING

2.1.1 Geology of Africa

Crystalline and sedimentary rocks occur in the continent of Africa in almost equal proportion. The crystalline rocks form the Basement complex of mainly Precambrian age and constitute the structural framework of the continent. Within the basement complex are cratons which represents special nuclei that are older than 1500 Ma. The seven cratons that formed the foundation of Africa occur in south, central, and west Africa (Jelsma and Dirks, 2002) (Fig. 2.1).

Generally, these cratons are demarcated by mobile belts which are active in Paleoproterozoic and have been stable since Neoproterozoic (600 ± 150 Ma). These belts are made up of rocks that are virtually deformed, metamorphosed and reworked by thermo-tectonic events accompanied by series of granitic additions. According to Cahen et al., (1984), seven major orogenic events have been recorded in Africa, namely: Leonian (3000 Ma), Liberian (2600 ± 100 Ma), Eburnean (1850 ± 250 Ma), Kibaran (1100 ± 200 Ma). Others are Pan-African (600 ± 150 Ma), Variscan (300 Ma) and the Alpine orogeny of the Atlas Mountains. The basement rocks form large domes while extensive interior basins lie in braided basement warps, the sedimentary sequences occupy these broad shallow basins and overly the metamorphosed basement rocks with prominent unconformities.

2.1.2 Geology of West Africa

About 65% of the landmass of West Africa is covered by crystalline rocks comprising metamorphic, extrusive and intrusive igneous rocks (mainly granites) while the remaining is covered by combinations of very old (early Palaeozoic), young (Jurassic-Cretaceous) and recent (post Cretaceous) sediments (Schluter, 2008). Aicard (1965) reported that the

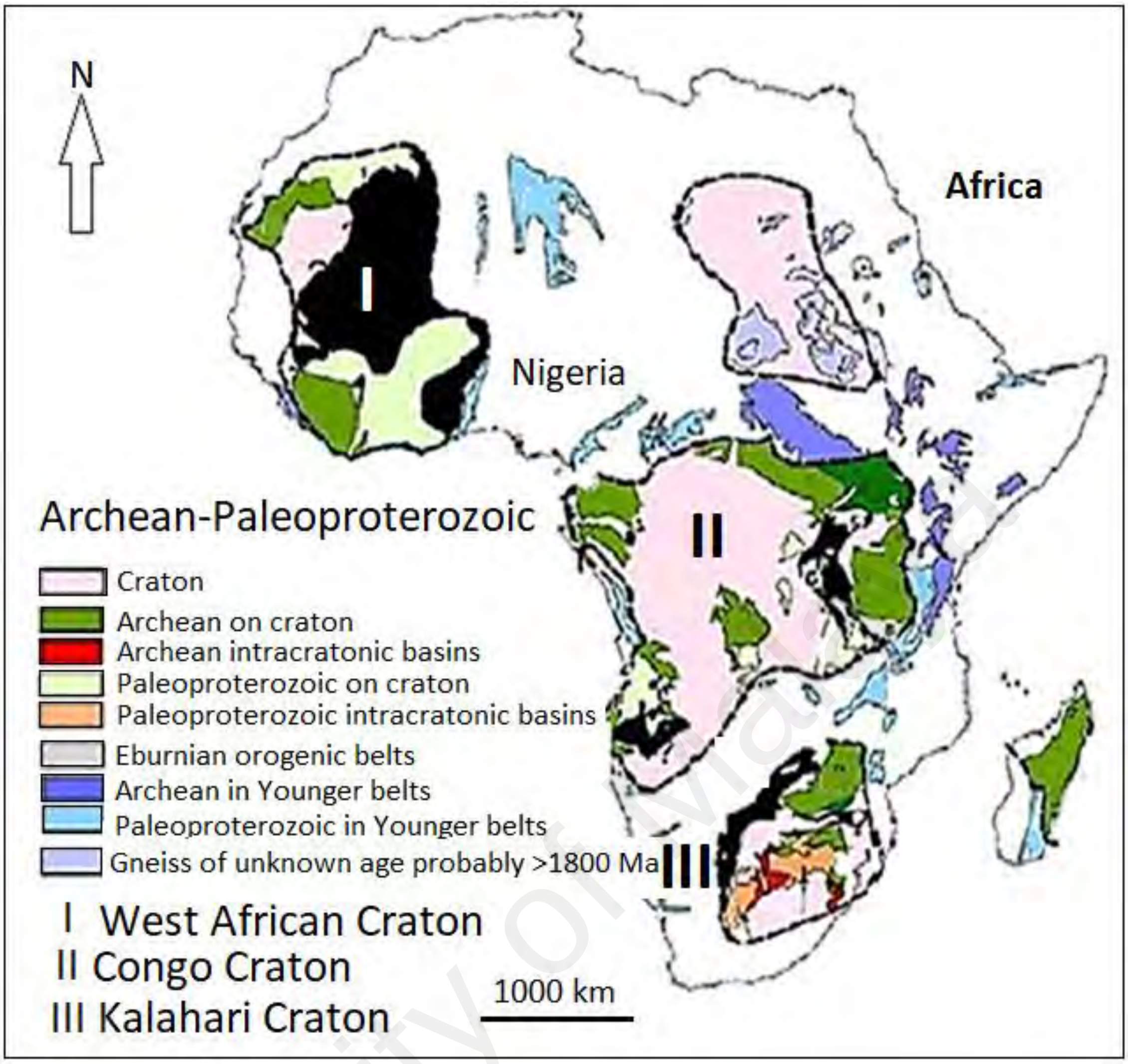

Figure 2.1: Geological Map showing the cratons in Africa (after Jelsma and Dirks, 2002)

early geological investigation of the crystalline rocks in the Benin-Nigerian-basement were generally considered an ancient basement which was called the Dahomeyan in Benin and Togo. However, since the publication of the first age determinations, awareness of the much younger age of many of these rocks has grown steadily. The rock types in the basement include migmatites, gneisses, granitoids, sedimentary schist, various amphibolite, pyroxenite and metagabbro (Cahen et al., 1984). The Precambrian evolution of West Africa is believed to have been through four major thermo-tectonic events; these are: the Liberian (Archaean), Eburnean, Kibaran and Pan-African. The geological framework of West Africa is dominated by deformational impact of the late Precambrian (Neoproterozoic) activity, which affected the entire region.

Dada, (2008) believed that warping and diverse reworking of the entire ancient landscape were consequences of the effects of widespread Pan-African tectono-thermal activities that resulted in deformation, migmatization and addition of granitoid units into the basement. The development of dominant north-south foliation direction defining the main structural fabrics that manifested in folds, schistosity, foliation and general regional lineament of rocks in southwestern Nigeria is attributed to the intrusion of granitoids accompanying major phases of Pan-African plutonic activities (Dada, 2006).

The metamorphic units at the centre of the craton are the oldest while additional younger igneous rocks (mostly granites) are emplaced around it. There are two main segments exposed in the West African craton, these are: The Man Shield (Guinea rise) occur in the south and Reguibat occur in the north (Fig. 2.2). The West African craton is delimited in the north and east by the Pan-African mobile belt (Liegéois et al., 2005). The Man Shield is an Archaean nucleus which lies in the southern corner of the Guinea Rise known as the Der Sal de main shield. In common with many Archaean nucleus elsewhere, the West African craton is a granite-greenstone association. The basement comprises of migmatite and several types of gneisses, while the granite is more enriched in quartzo-feldspartic, biotite and hornblende bearing granitoids. Reguibat Shield on the other hand comprises of Archaean rocks in the west and centre while lower Proterozoic rocks dominate the east (Fabre, 2005). These Archaean rocks are high-grade and include Amega and Elallamn Groups to the east; they are made of granulite and granite gneiss with ages between 2700-2400 Ma (Cahen, et al., 1984).

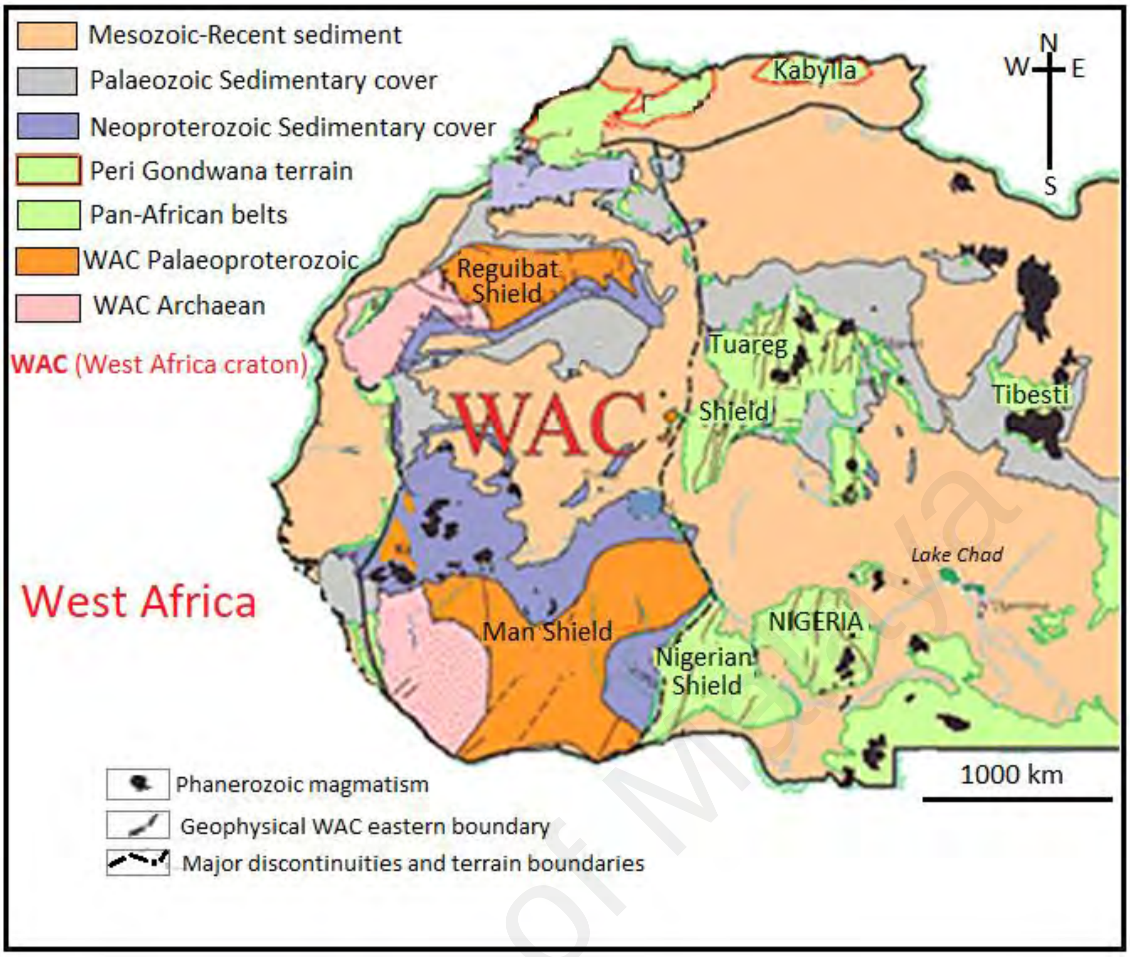

Figure 2.2: Map showing main geological units in West Africa- Man shield, Reguibat shield, the Tuareg Shield, and the Nigeria basement in the Pan African belt. (after Fabre, 2005; Liégeois, et al., 2005). (WAC: West African Craton)

2.1.3 Origin of basement complex of SW Nigeria

Nigeria occupies a unique position within the Precambrian orogenic terrain which formed during Late Proterozoic. The orogenic belt which spread across the continent of Africa extends into the South American Amazonian terrain of NE Brazil (Goodenough, et al., 2014). The origin of Nigeria Pan-African terrane has been a subject of conflicting geodynamic models. However, two main school of thoughts have been recognized regarding the evolution of the Nigerian Pan-African terrain (Haruna, 2014). According to Ogunmola et al., (2015), the first and the most widely accepted view was that Nigeria terrane evolved as a result of plate tectonic process when the edge of Pharusian belt (Tuareg shield) was pressed against craton nucleus located in West Africa during Pan-African times. This interpretation reconciles with the occurrence of a structural divide located in the eastern side of the craton and of mafic and ultramafic assemblages which symbolized remnants of mantle-originated diapirs and ancient crust underlying the ocean (Kröner and Stern, 2005).

Elueze, (1992) believed that crustal extension was initiated and subsequently followed by series of marginal rift systems thereafter, a graben-like structure developed in eastern segment of the craton leading to eventual derivation of rocks which are dominantly composed of schistose assemblages in western Nigeria. It was visualized that when the ocean closed against the craton edge around 600Ma, thickening of the crust which took place around this area was initialized (Ugwuonah et al., 2017) which resulted in continuous distortion, warping, and finally to eventual buckle of the sedimentary sequences, reworking of the lithological sequences and intrusion of the Pan-African granites (McCurry, 1976). Kröner and Stern, (2005) indicated that migmatization, deformation and metamorphism of the rocks was occasioned by inclined thrust and intersection between Nigeria terrain and cratonic nucleus of West Africa which was sequentially followed by up arching and twisted faulting.

The second view which was overwhelmingly supported by Ajibade and Wright., (1989) who believed that the orogenic process which characterized Late Precambrian period was an episode of accretion of extensive crustal masses and ancient continental remnants rather than an ordinary thrust of cratonic entities against a mobile belt. The second interpretation was established based on occurrence of volcanic rocks of calc alkaline affinities, ultrabasic and mafic rocks associated with two prominent structural discontinuities in southwestern Nigeria]. Despite extensive support for the collision view, some workers e.g. (Black, 1980; Turner, 1983) and several others have noticed recently that the Pan-African granite belts which spread across Nigeria into the Cameroon (approximately 1500 km) from the suture could not have been connected to the same subduction zone (Goodenough et al., 2014).

2.1.4 Geology of Nigeria basement complex

Approximate position of Nigeria is defined by Latitudes 4°N and 15°N and Longitudes 3°E and 14°E. Specifically, located in Pan-African Trans-Sahara belt, Nigeria occupy eastern segment of West African Craton, it is situated SW of East Saharan block and NW of the Congo craton (Black et al., 1979). Like Africa, the landmass of Nigeria is shared almost equally by sedimentary and crystalline rocks. The sedimentary rocks delineate the basement complex and occupy either the intracratonic or marginal sag basins. The sedimentary rocks are largely Cretaceous-Recent in age and are deposited on the crystalline basement with recognizable unconformities.

The basement rocks are exposed in five areas, two of these are extensive and are surrounded by sedimentary basins. These are North central and Southwestern zones, while other three occur in the eastern flank of the country, these are: extension of the Bamenda Massif into Nigeria (Eastern Nigeria zone). The Hawal Massif/Adamawa Highland (North-eastern zone) and the Oban Massif (South-south eastern) (Obiora, 2005; Obaje, 2009). In the current study, the research area constitutes part of the basement complex of southwestern Nigeria (Fig. 2.3). Afolagboye et al., (2015) indicated that the rocks constituting the basement complex falls into one of the three categories: migmatite-gneiss quartzite unit, schistose assemblages, and granitoids. According to Elueze, (2000) and Obiora, (2005), other associated minor lithologies occur as intrusive bodies within the main rocks and are mainly by dominated dolerite and pegmatite. The basement complex consists of migmatite gneiss, schist belts, Pan-African granitoid and dykes (Dada, 2006; Obaje, 2009). However, in northcentral Nigeria around the Jos plateau area, Jurassic granite of anorogenic origin, (formed by cauldron subsidence and ring dykes) popularly called the Younger Granite are known.

2.1.4.1 Migmatite-gneiss quartzite complex

Despite the prevalence of migmatitic rocks in the basement complex, it appears there is a perceptible difficulty trying to classify the rocks, and this seems persistent throughout the whole basement area (Hockey et al., 1986). The pan-African thermo-tectonic event had a homogenizing effect on the rocks, while the combined effects of metasomatism, dynamic metamorphism and magmatism have produced the various rock types depending on the original composition (Dada, 2006). As noted by Harme, (1965) and Didier, (1973), the origin of the popular migmatite of Finland is linked to the intrusion of potassic granite of deep-seated origin into crystalline schists and older igneous rocks. Oluyide et al., (1998) believed that migmatites, particularly those with lit-par-lit structures, are produced from injection of felsic low-temperature mobile components into older rock bodies and the segregation of such leucocratic component into bands. Migmatite complex being oldest unit in the basement is tectono-stratigraphically basal to all subsequent suprajacent lithologies and orogenic events (Anifowose and Kolawole, 2011); it is dominated by heterogenous assemblage of migmatites, gneisses and granite-gneiss (Obaje, 2009) that exhibits complex deformation styles which define its polycyclic nature.

The gneissic complex covers the largest area, it is regarded as the most frequently encountered rock type in the basement (Udensi et al., 1986; Ogezi, 1988). The rock accounts for approximately half of the Precambrian rocks in Nigeria (Ajibade et al., 1988) and covers approximately three tenth of the country’s land mass (Rahaman, 1988). It is associated with talc schist, and amphibolite which represents metamorphic equivalents of basic and ultrabasic rocks (Elueze, 1981). According to Oyinloye, (2002), the gneisses and schists are tectonically related, and evidences as observed in the field indicates that the lithologic boundaries between the migmatite-gneiss complex and the metamorphosed sedimentary sequences are gradational. However, sharp, and sheared boundaries have

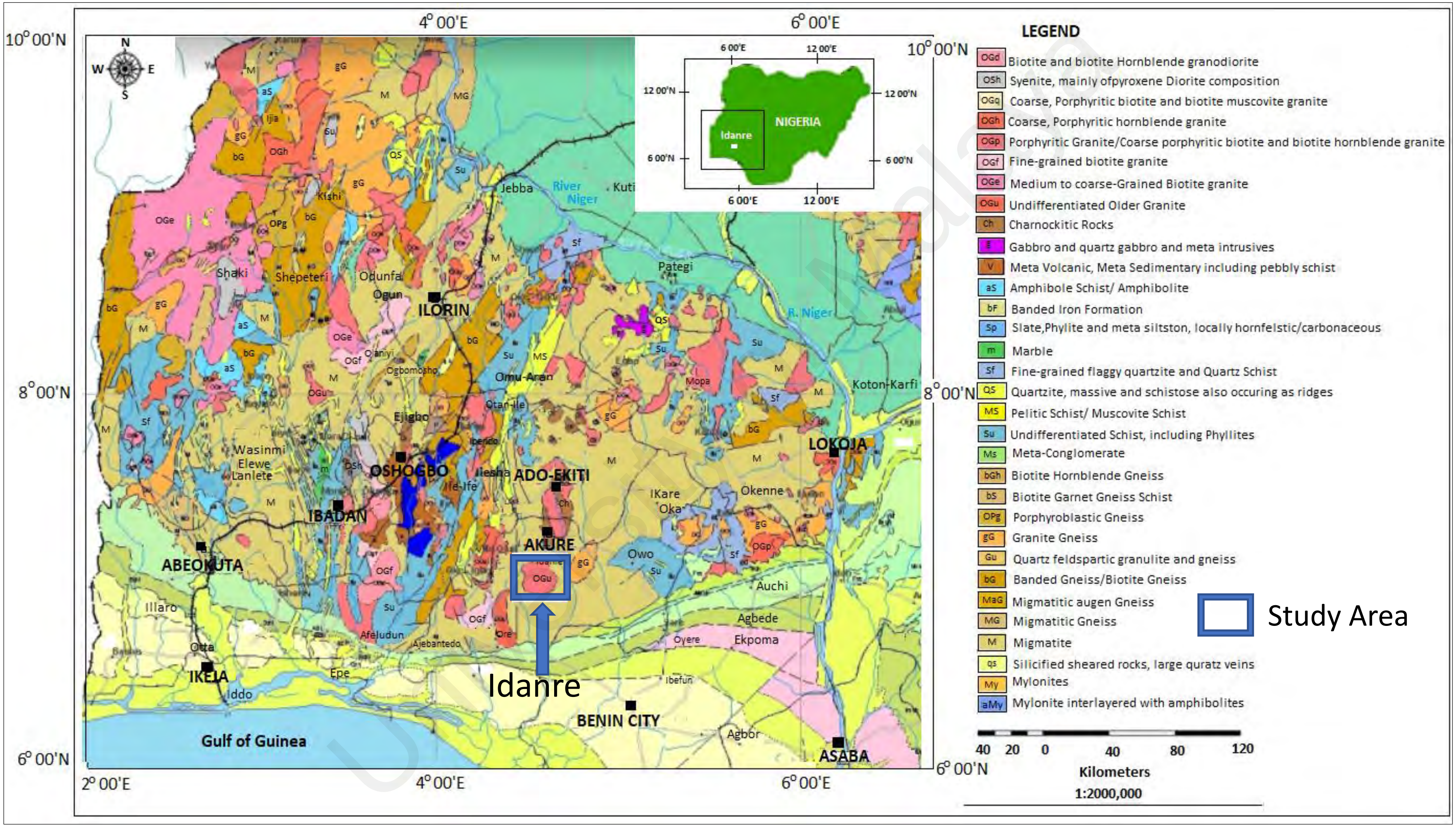

Figure 2.3: Detailed geological map of SW Nigeria showing the basement complex and location of the study

been observed in other places (Obiadi, 2012). Based on field structural relationship, there are indications that both gneissic rocks and the associated quartzite went through common deformational episodes (Ajibade et al., 1987). However, Ajibade and Fitches, (1988) believed migmatite gneiss unit is the oldest rock in all parts of the country. The duo believed further that the unit had gone through histories of successive sedimentation, deformation, metamorphic modifications, and phases of intrusive igneous activities.

Following the earlier works of Grant, (1970) on zircon U-Pb systematics, Grant et al., (1972) believed migmatite gneiss was Eburnean (2000 ± 200 Ma) in age. Subsequently, Rahaman, (1988) considered the whole rock Rb-Sr date by Ogezi, (1977) as a metamorphic age and believed crust formation was initiated about 2500 Ma culminating in the Eburnean Orogeny. Other age determinations (Dada et al., 1989) on U-Pb, and (Oyinloye 2006, 2007) on ^{206}Pb-^{207}Pb systematics indicate that the complex might have been formed around 2750 ± 50 Ma. It is a generally accepted view that Archaean, Proterozoic, Kibaran and Pan African orogenic episodes have all affected the geology of Nigeria basement. Elueze, (1982) believed the features of these rocks pointed in the direction that they form part of the Archaean shield that was later modified by Proterozoic crustal activities. Isotopic age data confirms that migmatite represents oldest rock group in the basement. For instance, whole-rock (W.R) Rb-Sr age of 3883Ma was yielded by the Ibadan banded-gneiss (Grant, 1970) (Paleoarchean), migmatite from Gwari road, Kabala, Kaduna, yielded (W.R) Rb-Sr age of 3032 ± 160Ma (Ogezi, 1977) (Mesoarchean); Badarawa Migmatite, Kaduna yielded 2800-2550 Ma (Neo-Archaean) on (W.R) Rb-Sr isotopic age (Ogezi, 1977), Early Grey Gneiss (University of Ife Campus) U-Pb on zircon 2317 ± 112 Ma (Rahaman and Lancelot, 1989); Migmatite (Muslim Cemetery, Kaduna) whole-rock Rb-Sr 2220 ± 30 Ma (Hurley et al., 1966) (Paleoproterozoic), Granite gneiss (from 224 km on Kaduna-Sabon-Birnin-Gwari road west of Kaduna) (W.R) Rb-Sr 1159 ± 70 Ma (Grant et al., 1972), Phyllite (from the Maru belt) (W.R) Rb-Sr 1110 Ma (Ajibade, 1980). Granite from the basement yielded ages around 600 Ma (Neoproterozoic) (Grant, 1970; Oversby, 1975; Dada, 1989; Dada et al., 1993, 1998) from different locations using combinations of Rb-Sr, U-Pb, K-Ar. However, mineral dating from granitoids include feldspar from aplite (Ibadan) U-Pb 590 Ma (Oversby, 1975); biotite from grey granite, (Odo-Ogun, near Iseyin) Rb-Sr 501 Ma (Rahaman, Unpublished); amphibole from granite (Ibadan) K-Ar 499 ± 20 Ma (Grant 1970). Isotopic ages as indicated above shows that the Nigerian migmatite gneiss terrane include Liberian, Eburnean, Kibaran, and Pan-African rocks thus confirming its polycyclic nature.

2.1.4.2 Schist belts

Compared with other regions in Nigeria, schist belts are widespread in western half of the country (Ogunmola et al., 2015), initially, it was believed that they are confined within longitudes 3^{o} E and 8^{o} E and latitudes 7^{o} N and 13^{o}N. However, Ekwueme, (2003) reported some poorly developed schist belts east of longitude 8^{o} E with evidence form Toro district, Jalingo and Oban Massif. Key et al., (2012) reported that the thought agrees with the views of Elueze, (1982) that indicated emplacement of voluminous granitic rocks that resulted in migmatization of the schists as observed in north-western Nigeria specify that those belts were not restricted to their current map boundaries.

Schist belt is one of the most notable features of the basement complex, the rock unit as observed by various workers is dominated by schistose assemblages (Rahaman, 1976; Dada, 1989; Oyinloye, 1992; Okunlola, 2001; Dada, 2008). The schistose units associated with the migmatite terrain were designated 'the Older Metasediments' while the distinct N-S trending schist belts which are clearly younger than the gneisses and migmatites were called the younger metasediments (Obiora, 2005). Younger meta-sediments (schist belts) are dominated by pellites and schists which are interlayered with quartzite, iron-enriched quartzite, calc-silicate gneiss and metamorphosed carbonaceous rocks and metavolcanics

(Ige et al., 1998). In some places especially the southwestern part of the country, schist belts are associated with marbles e.g. (Igbetti), dolomites, calc-silicate, schists, and meta-conglomerates e.g. (Igarra). These are the products of metamorphism of limestone, marls, calcareous sediments, and conglomerates, respectively. Anike et al., (1990) reported that Banded Iron Formation (BIF) is also sometimes associated with the schist belts sighting the Muro schist belt as example. Oyinloye, (2006) reported that in Ilesha, Sokoto, Minna and Birnin-Gwari areas, the schist and amphibolite of the schist belts are the host rocks for the Nigerian alluvial gold deposits in some parts of the country.

Iseyin-Oyan and Ife-Ilesha are among four of the major schist belts in southwestern Nigeria others include Egbe-Isanlu and Igarra schist belts (Odeyemi, 1977; Moutoh et al., 1988, Annor et al., 1996). Others which occur in northern Nigeria are the Zungeru, Zuru, Kushaka, Anka, Maru and Wonaka schist belts. Okunlola, (2001) and Ekwueme, (2003) indicated the Toto-Gadabuike and Jalingo belts are the recently highlighted belts. Although Elueze (1981) recognized that the geochemical signature of these rocks confirm they were originally sedimentary in nature. However, the author did not explain how the original protoliths were intermingled to produce the basic rocks commonly associated with them. Hence, the source of basic and ultrabasic units in these rocks have generated many controversies. The lithologic framework, deformation and metamorphism of the schist belts have been reported by Ajibade, (1976). The main lithologies, structures and metamorphic grades of the schist belts in north-western Nigeria and southwest are comparable (Ajibade et al., 1979; Dada et al., 1989). According to Elueze (1981), metasediments intercalated with minor mafic-ultramafic rocks, iron deposits and carbonate dominate the schist belts in southwestern Nigeria. However, Ajibade and Fitches, (1988) indicated that the schist belts in northern Nigeria composed essentially of metasediments and metavolcanics that occupy discrete belts separated from each other by migmatite gneiss complex. Klemm et al., (1984) reported that the geochemical signatures of the komatiitic metapyroxinites and metabasalts found in Ife-Ilesha schist belt typically resemble rocks formed during early earth history. Annor et al., (1996) reached similar conclusion for rocks in the Egbe-Isanlu area. 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) indicated that these belts are comparable to those of Archaean Greenstone terrains. However, Ajibade, (1980) observed that they differ in their bulk compositions, Turner, (1983) believed that the Archaean Greenstone belts unlike the Nigeria schist belts composed more clastic sediments than volcanic rocks.

Burke et al., (1976), Rahaman et al., (1988), and Ekwueme, (1990) suggested an origin related to a model involving the Wilson Cycle with ocean opening and closing. Ogezi, (1977); Olade and Elueze, (1979); and Ajibade, (1980) thought the evolution of these belts were governed by ensialic processes. However, due to the presence of tholeiitic basalts in some of the schist belts like Ilesha, Egbe-Isanlu, Iseyin-Oyan, and Maru belts, Ajayi, (1981); Rahaman et al., (1988) and Bafor, (1988) considered the schists to have evolved by ensimatic processes which involved micro continental subduction and collision, whereas, Elueze, (1981) believed it originated by ensialic process with subduction related tectono-genesis.

The geochemical status of these schistose assemblages confirm that rocks in the Nigerian schist belts are dominantly pelites, semi-pelites, and greywackes and the mafic rocks now believed to be largely of igneous origin are amphibolite with variable tectonic settings including Island arcs (Fitches et al., 1985), Island arcs and ocean floor (Ekwueme, 2003), within-plate to Mid- ocean ridge (Obiora, 2008).

Based on isotopic studies, many workers, for example (Russ, 1957; Grant, 1970; Oyawoye, 1972; Oversby, 1975; Elueze, 1982; and Rahaman, 1988) believed these rocks are Archaean, Mid-late Proterozoic age. However, as noted by Annor, (1998), the Pan-African re-homogenization was largely responsible for the observed disturbed isotope systematics. Many authors including (Ogezi, 1988) and (Caen-Vachette and Ekwueme, 1988) also maintain that fractionation recorded in the isotopic systematics of metasediments of Nigeria is attributed to the Pan-African thermo-tectonic event.

2.1.4.3 Older Granites

Nigeria basement complex is comparable to other Pan-African orogenic belts which extend into Hoggar region in Algeria, Central Africa due to the occurrence of large volumes of granitoid of Pan-African age (Grant, 1970, 1978; Bertrand and Davison, 1981). Odeyemi, (1981) reported that the Older Granite was introduced by Falconer, (1911) as a term for Precambrian suites of plutonic gneissic granites, coarse-porphyritic and porphyroblastic granitoids and charnockites etc. which occur as batholiths in Nigeria basement terrain.

Generally, Older Granite is characterized by widespread tectono-structural fabrics signifying plutonic activities attributed to the Pan-African thermo-tectonic events. Typically, Older Granites sometimes display textural and compositional variations. They are coarse to porphyritic in texture, while their composition spread across tonalite, granodiorite, to adamellite and granite (Afolagboye et al, 2015). Most of the Older Granite suites which are characterized by large white or pinkish phenocrysts of potash feldspar are largely of granodioritic composition (Kayode, 1976).

Even though the rocks lumped together by Falconer's 'Older and Younger Granite' term seems very broad, strictly speaking, adamellite was originally suggested for a type now distinguished as tonalite. Hatch et al., (1972) pointed out that adamellite is a widely distributed rock which are often called biotite-granite or biotite-hornblende-granite in Nigeria, while granodiorite is a coarsely grained siliceous rock containing plagioclase or alkali feldspar not exceeding one-third of the total feldspar content. It may also contain varying proportions of coloured silicate of which biotite and hornblende are dominant; and accessories sphene, apatite and magnetite (Hatch et al., 1972).

One of the first systematic study of Older Granites of Nigeria was made by Truswell, (1960); Truswell and Cope, (1963) around Kusheriki in Nigeria. The association of porphyritic granite with charnockite is a common occurrence in Nigeria (Oyawoye, 1972). Localities in which such associations are manifested include Idanre, Ado-Ekiti and Ikere-Ekiti (Olarewaju, 1981; Oyinloye and Obasi, 2006), Bauchi (Oyawoye, 1972), and these associations have been interpreted differently. Oyawoye, (1964) believed that the charnockite (fayalite-quartz-monzonite) in Bauchi area of Northern Nigeria was derived through infusion of basically high Fe- silicate melt into olivine, pyroxene, hornblende, quartz, and plagioclase-rich biotite granites.

Other researchers (e.g. Holt, 1982; Egbuniwe, 1982) subscribed to the opinion that Older Granites intruded into the country rocks. According to Pitcher, (1979) and Leake et al., (1980), the origin of large volumes of granitoids is related to a deep-seated phenomenon. Pitcher, (1979) reviewed the processes of granitic emplacement to include nudging and up-doming of the host rocks. Older Granites of Nigeria are products of granite plutonism during a period ranging from 750 Ma to 450 Ma (Van Breemen et al., 1977; Ogezi, 1977; Grant, 1978) as all the ages are spread within the limits of Pan-African. The intrusive suites comprise mainly granites and granodiorites with subordinate pegmatites (Akoh and Ogunleye, 2014). Aplite and associated minor rocks include charnockites, syenites and Bauchites, (Olarewaju, 1999), and intrusive hypabyssal bodies (notably dolerite dykes) which represents terminal stage of the Pan-African magmatism (Elueze, 2002). Based on isotopic U-Pb, Rb-Sr and K-Ar ages, Late Precambrian (638-510 Ma) age was assigned to granitoids which are located in schist belt regions of Nigeria (Umeji and Caen-Vachette, 1984) and (Dada, 2006).

2.1.4.4 Younger Granites

Nigeria Younger Granites occur in a belt (the Younger Granite Province) (Ogunleye et al., 2005) which covers about 400 km long and 160 km wide between Latitude 8°-12°

and Longitude 8°-10°. The Younger Granites are alkali feldspar granites of Jurassic (≈160 Ma) age which occur in sub-volcanic intrusive complexes that are associated with ring dykes, cauldron subsidence and cylindrical intrusions. The ring complexes which consists of approximately 50 Younger Granite Massifs is an anorogenic granite province whose origin is linked with high-level magmatic intrusions and piston faults (Falconer, 1911; Jacobson et al., 1958; Bowden and Turner, 1974; Turner 1976). The complexes occur in Northern Nigeria around the Jos Plateau (Turner, 1976; Badejoko, 1986; Ogunleye et al., 2005). The Younger Granites of Nigeria are post orogenic features of the Precambrian basement around Jos (Hatch et al., 1972). Ogunleye et al., (2005) reported that the Nigeria Younger Granites is composed of "*arfvedsonite-granite, aegirine-arfvedsonite granite and albite-arfvedsonite granite"* (pp. 284).

Younger granite complexes have stirred general interest for two main reasons; firstly, the economic tin mineralization of Nigeria is associated with the granite; secondly, the light which the intrusive centres might throw on speculations concerning continental plate movements, since they appear to represent some possible stationary hot spots of magmatic generation now exemplified over many hundreds of kilometres (Hatch et al., 1972). It was apparent from available age data that the Younger Granites of Nigeria had been emplaced over a relatively short interval. However, studies on the Höggar granites (Boissonnas et al., 1969; Boissonnas et al., 1970) and on the Nigeria and Aïr Granite (Badejoko, 1986; Rahaman et al., 1984) show that widespread ages are significant and appeared to progress from Early Palaeozoic in the north around Höggar through Ordovician Silurian and Devonian in Niger Republic and finally Jurassic in Jos Plateau, Northern Nigeria. The progressive difference in age of these units may indicate that specific positions on the earth continental crust are in constant motion with respect to the underlying asthenosphere which can be explained through the plate tectonic theory.

CHAPTER 3: METHODOLOGY

3.1 Methodological approach

To achieve the objectives of this research, an interdisciplinary method was adopted. The application of integrated field petrology, petrographic studies, geochemical techniques and U-Pb zircon geochronology was used to characterize a carefully selected representative outcrop samples from the study area. The geological and geochemical information obtained from these analyses were further collated and interpreted using multiple approach. The methods adopted in the research work involves separate stages, these are: precursory investigations and preliminary study, reconnaissance survey, fieldwork, sampling and sample preparation, laboratory works and experimentation, analysis of data and results interpretation.

3.1.1 Preliminary work

This investigation involved examination of different geological reports on the Precambrian Basement Complex of Nigeria with special attention on southwestern Nigeria and Idanre area. It also involves interpretation of available aerial photographs, satellite images and topographic maps.

3.1.2 Reconnaissance survey

Reconnaissance survey consists of two phases, the first being a preliminary visit to the study area for the first time. This visitation lasted for one week between 16th to 22nd November 2017. During this time, the researcher visited the palace of the King of Idanre Land for a formal introduction. The King and the community Chiefs were notified of the intention of the researcher by publicly declaring that the intended research is a personal, non-governmental and non-profit oriented scholarly investigation about the rocks in and around Idanre. At the palace, two indigent members (one male and one female) from the community were assigned to assist, direct and guide the researcher throughout his stay for the fieldwork. These people in addition to two other students that accompanied the researcher during the fieldwork eventually became helpful field assistants whose cooperation and company the researcher enjoyed throughout the fieldwork. The lady represents the interest of Idanre community in matters relating to the Idanre Hill Tourist's Centre and the Resort which is located at the base of Oke-Idanre which is one of the spectacular hills. At this stage, plans about the main fieldwork were outlined so that the systematic geological mapping could be carried out without any hitch. Notable spots of geological interest within the Idanre town and villages around it were visited for the first time to ensure smooth interconnectivity and linkage within the area. During this time, sketchy pieces of geological information were gathered, and a date of convergence was also fixed for the second visitation.

The second stage of reconnaissance entails mobilizing geological tools (a generating set, Hammer drill, sledge hammer, cutlass, chisels, compass clinometers, GPS, Digital Camera, 150 pieces of cotton sample bags, jungle boots, thick coverall, gloves, safety goggles, a 50m- measuring tape and other accessories) to the study area. It also involves travelling through the length and breadth of the study area to be more familiarized with the terrain. At this stage, some permanent features on the topographic map are linked with their actual positions on the ground. Major centres that would serve as collection points for sample gathering during detailed mapping are outlined. Hotel accommodations are booked in advance and permission was sought to visit other areas that may be tagged "restricted". The second visit also lasted one week spanning between February 20th to 25th 2017. Different types of rock that are exposed along river valleys, quarry sites, road-cuts, and hill sides are noted at this stage.

3.1.3 Field geological mapping

Geological mapping of the study area which is located between Latitudes 7°00' N to 7°14' N and Longitudes 5°00' E to 5°14' E was undertaken. The area covered approximately 675 km² measuring 27 km in length and 25 km in width. Based on preliminary interaction with the available topographic map, the entire study area is divided into equal-area grids for easy mapping. The strike direction of major lithologies in Nigeria basement is North-South, so mapping was conducted along east-west direction. Main fieldwork was carried out through the entire study area by walking along the terrane making use of the footpaths, major and minor roads to targeted outcrops. For the measurement of angle of tilt and inclination of geological structures, a Silva-type compass clinometer was used. Reading of strike values, directions of dip and their measurements, orientation of geological structures and lineaments with respect to the north direction were undertaken with the help of compass clinometer, it also helps in fixing the direction of navigation to any target outcrop, while a hand-held Global-positioning system (GPS) (GARMIN GPS *Map* 76 CSX Model) guaranteed accurate location of positions and points in the field. The GPS is also adjusted to function as an altimeter to determine altitude (height) of the hills. Other accessories used during the mapping exercise include measuring tape (25 m), hand lens and a topographical map upon which a tracing paper was mounted for plotting. Strike and dip values obtained were plotted on the overlay, however, precautions were taken to ensure accurate readings. During mapping, all the structural elements such as lineaments, mineral lineation, fabrics characteristics and textures were documented.

The fieldwork took place during dry season to allow greater accessibility. Access to many remote parts of the study area was gained by walking along dry river channels through the rugged terrain. The study area was divided into forty-nine equal (grids) areas (Fig. 4.1) and each was mapped separately. As geological mapping progresses, lithological boundaries which are the main target of any geological mapping is noted and well-documented. By taking note of any abrupt or transitional change in composition, texture and structure of different rock types encountered in the field, rocks are sampled appropriately, and boundaries plotted correctly on the map. During the field mapping, daily activities are recorded in the field notebook where the rock outcrops are described in detail and in relation to their locations, sizes, elevations, texture and mineral components. In situations where texture of rocks is too fine for direct observation and description, a magnifying hand lens was used. Snapshots of exposures were taken using a high-resolution (Nikon COOLPIX L820) digital camera wherever possible for precise representation and for a detailed documentation. The fieldwork lasted for six weeks between March 6th, 2017 to April 15th, 2017.

3.1.4 Sampling techniques

Standard geological sampling techniques was adopted for the research work taking cognizance of all the precautions of field sampling. Since the granite rocks are the focus of the research, it was envisaged that more samples will be needed to obtain a holistic appraisal of the granitic rocks, so the entire study area was delineated into two regions based on the interrelationship between lithologies and landforms: the hilly areas (underlain by granite), and the plains (underlain by gneisses), each region was mapped and sampled differently. A German robust head sledgehammer was used for sampling. However, in areas where the edges of a rock do not guarantee easy sampling, a (Makute Hammer) drilling machine was used for sampling. Altogether, one hundred and eleven (111) samples are collected during the fieldwork. These comprise of seventy-six (76) representative samples of the granite, twenty-seven (27) samples of the gneissic country rocks, and eight (8) charnockite samples. Each sample is described in relation to its location (longitudes and latitudes), mineralogy (particularly when the rocks are coarse enough to be described), textural characteristics and structures.

3.1.5 Sample Preparation

Rock samples were cut into 10 cm x 6 cm x 5 cm and transported to geology department University of Malaya. Geochemical analyses involving major, trace and REE composition was carried out. Zircon dating of different lithologic units (migmatite-gneiss, granites and charnockite) in the study area were undertaken. The granitoids were also subjected to Hf isotope evaluation. For each of these determinations, samples are subjected to different sample preparation techniques before analysis. For example, mineralogical determination was based on optical microscopy. For geochemical analysis, samples are pulverized, dried, and sieved.

3.1.6 Laboratory Procedures

Among the laboratory procedures followed in the research are thin section petrographic analysis (optical microscopy), geochemical analytical procedure and geochronology.

3.1.6.1 Petrographic analysis/Optical microscopy

For petrographic analysis, thirty-five (35) slides were prepared altogether. The slide comprises twenty-five (25) thin sections for the granite rocks, and ten (10) for the other basement (gneisses and charnockite) rocks. The slides were examined on the stage of (Leica DMLP) polarizing microscope which has its optic systems linked to a computer for adjustment, filtering, and fine-tuning. A camera was also attached to the microscope to capture the image of thin section placed on the microscope stage. Apart from identifying the minerals, the other target was to use optical microscopy to decide the rock's modal composition in order to compare mineralogical features of Idanre rocks with similar rocks. Some of the rock glass slides were prepared and examined at Department of Geology laboratory, University of Ibadan, Nigeria. Thereafter, the optical examination and snapshots of the remaining slides were undertaken at the Petrology laboratory of Department of Geology, University of Malaya. Results of thin sections are presented as photomicrographs in chapter 4.

3.1.6.2 Geochemistry

Geochemical investigation of the rock samples was carried out. For convenience and consistency purposes, the different textural varieties of the granite are tagged as follows: fine-grained granite (OGf); porphyritic granite (OGp); coarse-grained granite which is (undifferentiated) (OGu); Charnockite (Ch) and Migmatite (M). A total of forty (40) samples (OGf- 3 samples; OGp- 12 samples; OGu- 17 samples; M- 5 samples and Ch- 3 samples) was analysed for their elemental composition. Major elements composition was investigated using X-Ray Fluorescence Spectrometer (XRF), while trace and REE composition was determined using analytical device known as Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) at the Bureau Veritas, Vancouver, Canada. Minor rocks such as pegmatite dykes and aplite dykes encountered in the field are not included in the geochemical analysis.

Even though, geological mapping in the current work indicates that the basement gneissic rocks which was generally categorized as migmatite in the previous works of the Geological Survey of Nigeria (GSN 1966) are structurally heterogenous. Based on compositional variations in terms of mineral contents and textural differences, the granitic units which occur together in the granite suite of the Idanre Granite complex are categorized into three main members. These are coarse- grained undifferentiated granite (OGu), porphyritic granite (OGp) and the fine-grained granite (OGf). Five samples representing the basement gneisses were generally given the nomenclature migmatite (M), while Ch was adopted for charnockite. Migmatite gneiss are represented by samples designated by (B6, C1, C5, C7, and C11); OGu is represented by (A1, B12, B14, B15, C4, D3, D13, D14, D24, D26, D32, D33, D34, D35, D36, D39 and D40); while OGp is represented by (A15, B8, B9, B11, B16, B19, B20, B23, D2, D11, D19 and D25); OGf is represented by (B10, A17, and A10) and Ch represented by (D28, D29 and D30). The sequence of numbering does not follow a serial order as some samples are omitted due to the research time frame. Analytical result is presented in Tables 4.3a and 4.3b.

3.1.6.3 Analytical Techniques

Among several techniques for quantitative evaluation of elemental composition of rocks, XRF is identified as one of the most used. Whole-rock geochemistry of the samples were determined at Bureau Veritas Analytical Laboratories, Vancouver, Canada.

Major element analysis was determined on Philips PW 1404/10 X-ray spectrometer by fusing the samples with lithium tetraborate and the product is cast into glass discs. Trace elements and rare earth elements (REE) were determined by ICPMS.

3.1.6.4 Geochronology

In the current study, U-Pb dating method which involve extraction of zircon for age determination was adopted. LA-ICP-MS U-Pb zircon geochronology was conducted on the gneiss (sample A 17), charnockite (sample D 29), and the three granite samples each representing the three members of the granite suite which are: coarse-grained undifferentiated granite (sample B 15), the porphyritic granite (sample B 9) and the fine-grained granite (sample C 5). Before they were subjected to U-Pb dating, transmitted light and reflected light zircon images were captured using optical microscope that is coupled with facilities for cathodoluminescence (CL) imaging, using JEOL JSM- 6510, Scanning Electron Microscope (SEM) attached with a GATAN mini-CL detector (Appendix 5). Cathodoluminescence (CL) and Back Scatter Electron (BSE) image was processed at SEM facility of the Department of Geosciences, National Taiwan University, Taipei. However, due to variations in morphological feature of zircon grains, only the BSE images that are informative were selected as ablation spots for Lacer Ablation measurements on New Wave UP213 laser ablation system (Appendix 5) combined with an Agilent 7500s quadrupole ICPMS.

CHAPTER 4: RESULTS

4.1 Fieldwork

In Nigeria, production of geological maps is the exclusive right of the Geological Survey of Nigeria (GSN). Rocks in the basement terrain of southwestern Nigeria has been mapped and classified in segments. The body, now known as Nigeria Geological Survey Agency (NGSA) reported that Idanre and it environ is underlain by migmatite, charnockite and granite. The migmatite according to the survey, represent undifferentiated rocks that have been subjected to various stages of migmatization and are essentially biotite-hornblende-gneiss with intercalated amphibolite. However, in the current study, systematic geological mapping of Idanre area reveals that undifferentiated migmatite-gneiss rock reported as a single lithologic unit by GSN are composed of three different sub-units which are: (i) Migmatite-gneiss (MG), (ii) Biotite-hornblende gneiss (BHG), and (iii) Banded gneiss (BG). The granite types are (i) the coarse-grained undifferentiated Older granite (OGu), (ii) the porphyritic granite (OGp), (iii) the fine to medium-grained granite (OGf). Charnockite (Ch) occurs as a minor lithology within the core of the porphyritic granite (Fig. 4.1)

4.1.1 Field Relationships.

The boundaries between these shades of gneiss are not well-defined as they grade into one another.

4.1.1.1 Migmatite (M)

Migmatite gneiss forms the main country rock, it occurs as masses of low-lying units commonly exposed at the periphery of the intrusive granitic masses which now occur as towering inselbergs. Essentially, the migmatite unit has gneissose and granitic components forming as layers or pods. Weakly developed compositional banding in migmatite manifested alternations of irregularly spaced leucocratic (feldspar-quartz dominated) and melanocratic (ferromagnesian aggregates typified by biotite and hornblende) components (Fig. 4.2a). Idanre migmatite is a fine to medium-grained rock, the outcrops are mainly exposed in areas where erosion activities are intense such as along river valleys. The rock display series of complex and closely spaced antiformal and synformal structures. Fold geometry range between non-complicated open fold types through shear folds to composite ptygmatic folds types that are accompanied by disharmonized tortuous veins. While migmatite show intense foliation in few places, in other areas, the foliation is obscurely transformed into a disappearing mineralogical band with indiscernible remnant of light and dark minerals. Among the structural elements in the rock are fractures, joints, quartz vein intrusions and veinlets. The size of the quartz veins varies significantly, and several authors believed their origin is dominantly attributed to fracture fillings by quartz injections. Quartz veins vary from tiny stringers of few millimetres in width to others measuring up to 15cm in width. Hand specimen sample of migmatite shows quartz and feldspar in abundance while muscovite and biotite mica are present in subordinate amounts.

Quartz occurs as irregularly shaped clear grains, while biotite occurs as flaky masses which sometimes form clusters that gives the rock some characteristic dark appearance. Mineral alignment is sometimes discontinuous and poorly developed in some samples particularly in places where minor component is dominated by hornblende instead of biotite. Quartz and feldspar alone constitute a substantial percentage (about 60 %) of the rock in hand specimen. Generally, this rock type exhibits the most complex structures due to its polycyclic deformation history among other the basement rocks. On a general geological context, migmatite is known to form on a regional scale in areas of high-grade metamorphism. The strike values of Idanre migmatite falls between 036^{o} and 061^{o} while most outcrops have general westerly dip values ranging from 20^{o} to 60^{o}**.**

4.1.1.2 Biotite-Hornblende-Gneiss (BHG)

Outcrops exposure occur in a small area around eastern segment of the study area. On a general morphological outlook, outcrops of biotite-hornblende gneiss are like those of migmatite in that they rarely, if ever, form high relief features. Biotite-hornblende gneiss in Idanre area, however, differ from the migmatite by being of finer textures and are more conspicuously foliated. Even though, this kind of gneiss appears to be the most diverse in terms of structural attributes, mineralogical composition of hand specimen samples tends to be more closely related. In some instances, the foliation is more pronounced being marked by parallelism of the mica flakes, while in other occurrences, such foliation is rather weak, and the fabrics homogenized. Mineralogically, hand specimen samples of the biotite-hornblende gneiss (BHG) reveals similarity with the migmatite gneiss. However, it is easy to differentiate the two on structural basis. Idanre biotite-hornblende gneiss apart from being darker in colour, it is a metamorphic rock enriched in biotite mica flakes merged into planes which are distinct from the light-coloured quartzo-feldspartic portions (Fig. 4.3). Essentially, four principal minerals (feldspar, quartz, biotite, and hornblende) are evidently recognizable constituents of the rock in hand specimen. Blades of biotite are arranged such that they are aligned in the same direction. Outcrops of Idanre biotite-hornblende gneiss are generally low-lying and rarely form prominent hills. They are conspicuous along the river channels and deep river valleys where they form the bedrock. The general trend of foliations in the rock is NE-SW with dip angles ranging from 35^{o}W -70^{o}W. The rock appears in few places as highly foliated, folded and fractured, and in other places, they are migmatized and weathered too. In general, the metamorphosed gneissic rock is intensely deformed, with well-defined planar orientation of biotite flakes which impacts a conspicuous alignment or parallelism of some feldspar phenocrysts. On a general reconnaissance scale, the biotite-hornblende gneiss in the study area was reported as migmatite by the Geological Survey of Nigeria.

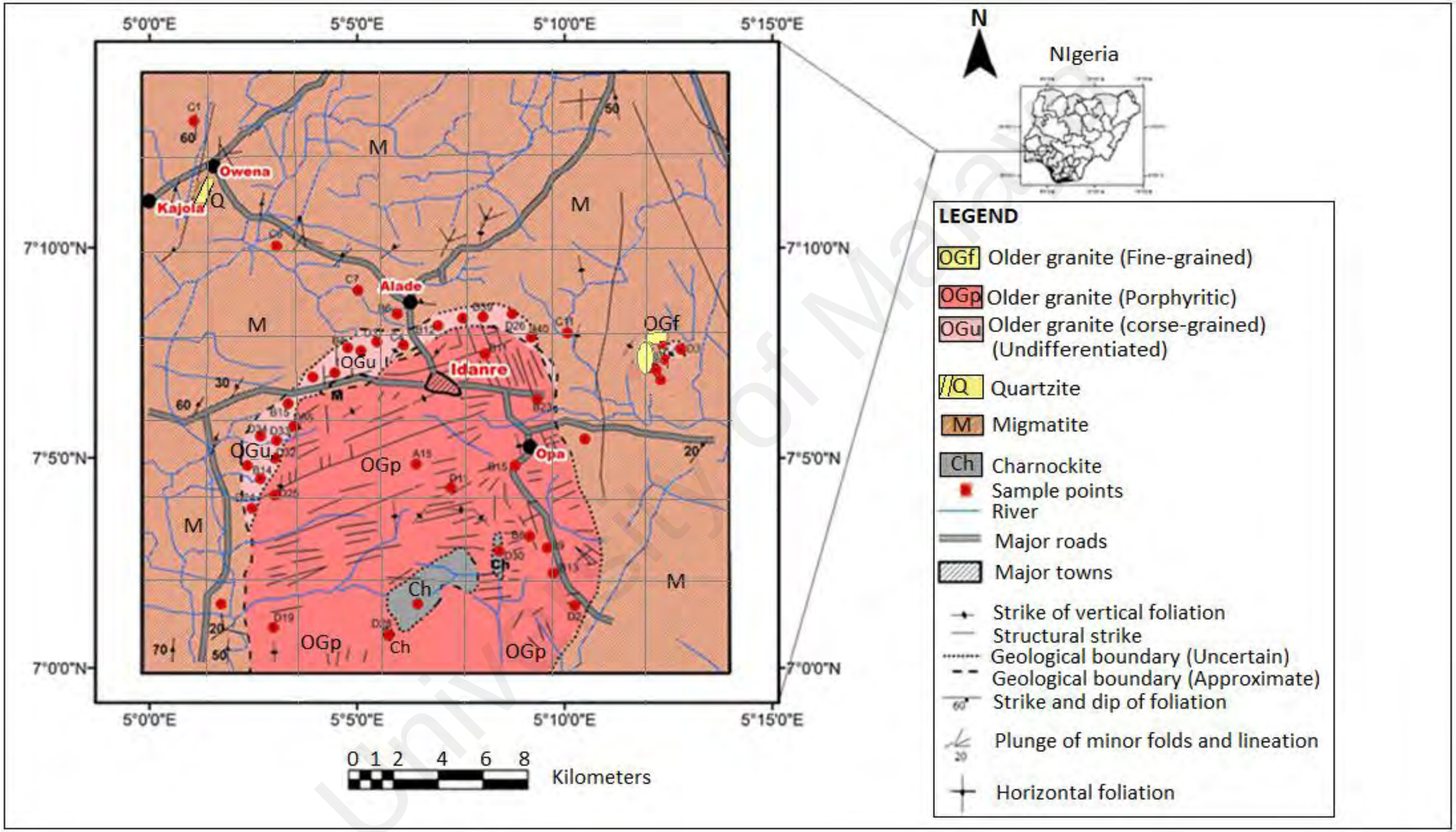

Figure 4.1: Geological map of the study area showing the sampling point

Table 4.1: Sampling points and location of the lithologies in Idanre.

ID	Coordinates	Name	Texture/ Description of rocks	Mineralogy	Location/locality	Nature
B6	N 07° 07'30" E 05° 06'10"	Migmatite.	Med-grained, light toned, slightly foliated metamorphic rock	Qtz, feldspar, muscovite, and biotite	Anglican Church, near Alade-Idanre road junction	Low-lying
C1	N 07° 13' 25" E 05° 00' 01"	Migmatite.	Fine-grained, with strong foliation foliated, dark colored gneiss	Qtz, K-feldspar, biotite, and few dark minerals	Ayede area, west of Alade Idanre	Low-lying
C5	N 07° 01' 48" E 05° 01' 50"	Migmatite.	Fine-grained, weak foliation, dark colored metamorphic rock	Qtz, feldspar, biotite, hornblende	Aruwajoye village, south of Onipepeye, Idanre	Low lying
C7	N 07° 09' 04" E 05° 05' 12"	Migmatite.	Fine-grained, weakly foliated rock with black pods	Qtz, K-feldspar, biotite, hornblende	Near River Olotu bridge, Owena Road, Alade Idanre	Low-lying
C11	N 07° 08' 25" E 05° 10' 00"	Migmatite.	Fine-grained, thinly laminated banded gneissic rock	Qtz, orthoclase, biotite, and muscovite	Bolorunduro village area, NE of Opa, Idanre	Low-lying
A1	N 07° 08' 30" E 05° 07' 51"	OGu	Medium to coarse-grained greyish granite	Qtz, orthoclase-feldspar, biotite	3 km East of Alade-Idanre road roundabout.	Massive outcrop
B12	N 07° 08' 10" E 05° 07' 30"	OGu	Fine to medium grained, slightly foliated	Qtz, orthoclase, biotite, traces of pyroxene	1km east of Rock Valley Hotel, Oke-Agunla Qtrs.	Average height rock
B14	N 07° 05' 00" E 05° 07' 09"	OGu	Medium to coarse grained, non-foliated granite (biotite clustered)	Qtz, orthoclase, biotite, plagioclase feldspar	2km SE of Abababodu-Ago-Moferere junction	Massive outcrop
B15	N 07° 06' 10" E 05° 03' 32"	OGu	Medium grained, feldspars weakly-aligned, granite is grey in color.	Qtz, orthoclase feldspar, and biotite	Around Obatedo and Odoke villages	Massive outcrop
C4	N 07° 07' 25" E 05° 06' 23"	OGu	Medium to coarse-grained, slightly foliated grey granite	Qtz, orthoclase, plagioclase biotite	Behind Rock valley hotel, Odo-Ode Road.	Extensive
D3	N 07° 07' 44" E 05° 13' 08"	OGu	Coarse grained biotite granite with poor foliation	Qtz, orthoclase, biotite, muscovite	Kajola area Ago-Onigba-gbo, along River Olosun	Extensive
D13	N 07° 07' 18" E 05° 12' 42"	OGu	Coarse grained biotite granite with poor foliation	Qtz, orthoclase, biotite, hornblende	Ododin-Ipinlerere, near Ajegunle	Highly elevated
D14	N 07° 08' 10" E 05° 12' 39"	OGu	Medium to coarse grained, non-foliated biotite granite	Qtz and orthoclase feldspar dominant, biotite is minor	No named locality around the sampling point	Highly elevated
D24	N 07° 04' 06" E 05° 02' 37"	OGu	Coarse-porphyritic biotite granite, highly biotitic, feldspar porphyries	Qtz, orthoclase dominant, biotite in abundance	Owomofewa area of Aiyefemi village	Extensive and high
D26	N 07° 08' 22" E 05° 09' 07"	OGu	Porphyritic biotite granite porphyries randomly arranged	Qtz and feldspar ~ 85% of rock, biotite is clustered	Ago-Okeluse	Extensive low-lying

Table 4.1, continued.

ID	Coordinates	Name	Texture/ Description of rocks	Mineralogy	Location/locality	Nature
D32	N 07° 05' 09" E 05° 03' 15"	OGu	Medium to coarse grained, weakly foliated biotite-hornblende granite	Qtz, orthoclase feldspar and biotite	2 km NE of Owomofewa	Massive
D33	N 07° 05' 24" E 05° 03' 20"	OGu	Medium to coarse grained greyish non-foliated biotite granite	Qtz, orthoclase feldspar, and biotite	NE of Owomofewa	Low-lying
D34	N 07° 58' 30" E 05° 02' 51"	OGu	Medium grained non- foliated biotite-hornblende granite	Qtz, orthoclase, with few scattered biotite grains	Eastern part of Ago-Oba Motula village	High
D35	N 07° 05' 53" E 05° 03' 38"	OGu	Medium-grained, light toned, grey, non-foliated granite	Qtz, feldspar, muscovite, and biotite	Obatedo area	Low-lying
D36	N 07° 07' 27" E 05° 05' 00"	OGu	Fine-grained, with minor foliation dark colored granite	Qtz, K-feldspar, minor orthoclase, and biotite	2km South of Akolo and East of Ago Ireti	Low-lying
D37	N 07° 07' 40" E 05° 05' 34"	OGu	Coarse-grained, weak foliation, dark colored	Qtz, feldspar, biotite, hornblende	1.5km NE of Odoji	Low lying
D40	N 07° 08' 10" E 05° 09' 30"	OGu	Medium-coarse-grained, grey-granite	Qtz, K-feldspar, biotite, hornblende	Ago Olugede	Low-lying
A15	N 07° 04' 52" E 05° 06' 19"	OGp	Porphyritic granite, greyish in colour, biotite flakes are visible	Qtz, orthoclase feldspar, biotite, and hornblende	Igorin Itaja, SE direction of the Old-Idanre	Massive high
B8	N 07° 03' 08" E 05° 09' 21"	OGp	Coarse/porphyritic greyish biotite-hornblende granite, pinkish plag-feldspars are prominent	Qtz, orthoclase-feldspar, plagioclase feldspar, biotite	Igbo-Olokun village	Massive
B9	N 07° 02' 52" E 05° 09' 33"	OGp	Coarse/porphyritic slightly foliated biotite-hornblende granite	Qtz, dominant orthoclase feldspar, biotite hornblende	Omiwonja, along River Owena tributary	Average
B11	N 07° 07' 32" E 05° 08' 29"	OGp	Medium-grained, non-foliated biotite -hornblende granite	Qtz, orthoclase feldspar, biotite mica / hornblende	Ago-Olugede village	Massive
B16	N 07° 07' 32" E 05° 08' 29"	OGp	Porphyritic non- foliated biotite granite feldspar mainly pinkish	Qtz, orthoclase, biotite, plagioclase dominant		Massive
B19	N 07° 04' 23" E 05° 07' 30"	OGp	Porphyritic biotite-granite, high feldspar content, biotite prominent	Qtz, orthoclase, plagioclase biotite	Odo Isa village area	Extensive
B20	N 07° 04' 23" E 05° 07' 30"	OGp	Porphyritic biotite-hornblende granite with large porphyries of feldspar mainly grey in color	Qtz grains few, orthoclase dominant, mica, muscovite and hornblende		Extensive
B23	N 07° 06' 30" E 05° 09' 15"	OGp	Very coarse/porphyritic biotite-hornblende granite with pinkish feldspar	Qtz, orthoclase, biotite, hornblende, size of quartz grains is small	Opa area, Idanre	High

Table 4.1 continued.

ID	Cordinates	Name	Texture/ Description	Mineralogy	Location	Nature
D2	N 07° 01' 48" E 05° 10' 20"	OGp	Porphyritic granite, biotite-rich, faintly foliated, with pinkish feldsp	Qtz, orthoclase, minor plagioclase feldspar, biotite	Oke Olasan south of Ilu Romaba, Legbira road.	Extensive and Highly elevated
D11	N 07° 04' 23" E 05° 07' 30"	OGp	Coarse-porphyritic biotite granite, highly biotitic, prominent feldspar porphyries are greyish to pinkish	Qtz, orthoclase, plagioclase less abundant, biotite	Ilemo-Itaja	Extensive and highly elevated
D19	N 07° 07' 42" E 05° 13' 06"	OGp	Porphyritic biotite-hornblende granite, feldspar porphyries and biotite are randomly arranged	Qtz, orthoclase, biotite and hornblende are prominent	Igbo-Epo-Owomofewa village, eastern part of Ajegunle Arun	Extensive and highly elevated
D25	N 07° 04' 10" E 05° 03' 15"	OGp	Very coarse/ porphyritic biotite hornblende granite, pink feldspar phenocrysts are dominant	Qtz, biotite, orthoclase plagioclase, hornblende	Eastern part of Owomofewa village	Massive with high elevation
B10	N 07° 07' 42" E 05° 13' 06"	OGf	Porphyries reduced greatly in size number and abundance, biotite-rich faintly show alignment, feldspars are pinkish in colour	Qtz, biotite, orthoclase plagioclase, hornblende	Ododin Ipinlerere near Ago-Onigbagbo	Rounded/ average height
A17	N 07° 07' 09" E 05° 13' 10"	OGf	Medium to fine grained biotite granite, highly biotitic, prominent feldspar porphyries are greyish to pinkish	Qtz, biotite, orthoclase, plagioclase, hornblende	Omi-Olosun near Ajebandele	Rounded/ average height
A10	N 07° 06' 54" E 05° 13' 08"	OGf	Fine grained biotite-hornblende granite, pinkish feldspar and biotite are randomly arranged	Qtz, orthoclase, biotite plagioclase, hornblende	Ajipowo-Dalode area	Rounded/ average height
D28	N 07° 02' 45" E 05° 08' 51"	Ch	Medium to coarse- grained texture, greyish green in colour, minerals in the rock are non- foliated, glassy appearance of freshly cut surface.	Qtz, biotite, orthoclase plagioclase, pyroxene	Apokin- Idanre located in the western part of Ilu-Romaba	Low-lying
D29	N 07° 01' 42" E 05° 06' 27"	Ch	Coarse grained, highly biotitic, prominent feldspar porphyries are greyish to pinkish	Qtz, biotite, orthoclase plagioclase, pyroxene	Akinbani area near Idanrore village	Low-lying
D30	N 07° 00' 56" E 05° 05' 49"	Ch	Porphyritic biotite-hornblende granite, feldspar porphyries and biotite are randomly arranged	Qtz, pyroxene, orthoclase plagioclase, hornblende	Ago-Lagbawo	Low lying

Figure 4.2: Field occurrences of Migmatite from the study area (a) showing intermix of palaeosome (light) and melanosome (dark colour) components, (b) an outcrop of migmatite showing a homogenous appearance

Figure 4.3: Field occurrences of biotite-hornblende gneiss (a) wrinkled surface of the gneiss opposite Alade Baptist Church, Alade-Idanre, (b) nucleation of quartzo-feldspartic minerals in biotite hornblende gneiss outcrop beside Rocky Corner Hotels, Alade-Idanre road

4.1.1.3 Banded Gneiss (BG)

The banded gneiss outcrops occur as low-lying isolated masses with conspicuous display of foliation in which the components are segregated into fanciful display of alternating light and dark-coloured minerals (Fig. 4.4a). In some localities, the remarkably perfect bands of leucocratic and melanocratic minerals are traceable for many meters while the lit-par-lit structure makes this rock type unmistakable and typically unique. The medium-grained banded rock is essentially dominated by quartz, feldspar, biotite and hornblende and subordinate pyroxene. The felsic bands are enriched in quartzo-feldspartic aggregates while the mafic minerals are dominated by biotite and hornblende. Grains of quartz and feldspar exhibits porphyroblastic structures which is evidently visible in hand specimen. Typical greyish colour of the rock reflects preponderance of felsic minerals as against the mafic. Thin laminae of foliation (Fig. 4.4b) and tortuous veins are common structural elements in the rock in some localities. Others are fractures, joints and veinlets. Banded gneiss in the study area exhibits variable fold patterns. Some of the complex folds are characterized with tight fold axes to those with parallel limbs and thickened crests. All these structural features that are superimposed indicate Idanre basement experienced multiple deformations during different orogenic activities.

The orientation of foliation in Idanre basement gneisses distinctly indicates that N-S trending tectonic signature is dominant and many of the tectonic fabrics are related to late Proterozoic shear zones movement. Regionally, the N 12^{o}E to N 20^{o}E strike direction of the migmatite-gneiss units is replicated in other parts of Nigeria basement. Generally, gneissic rocks of Idanre and the entire basement of Nigeria comprises intensely deformed metamorphic rocks which have been affected by reactivation and remobilization during the Pan-African thermotectonic activities.

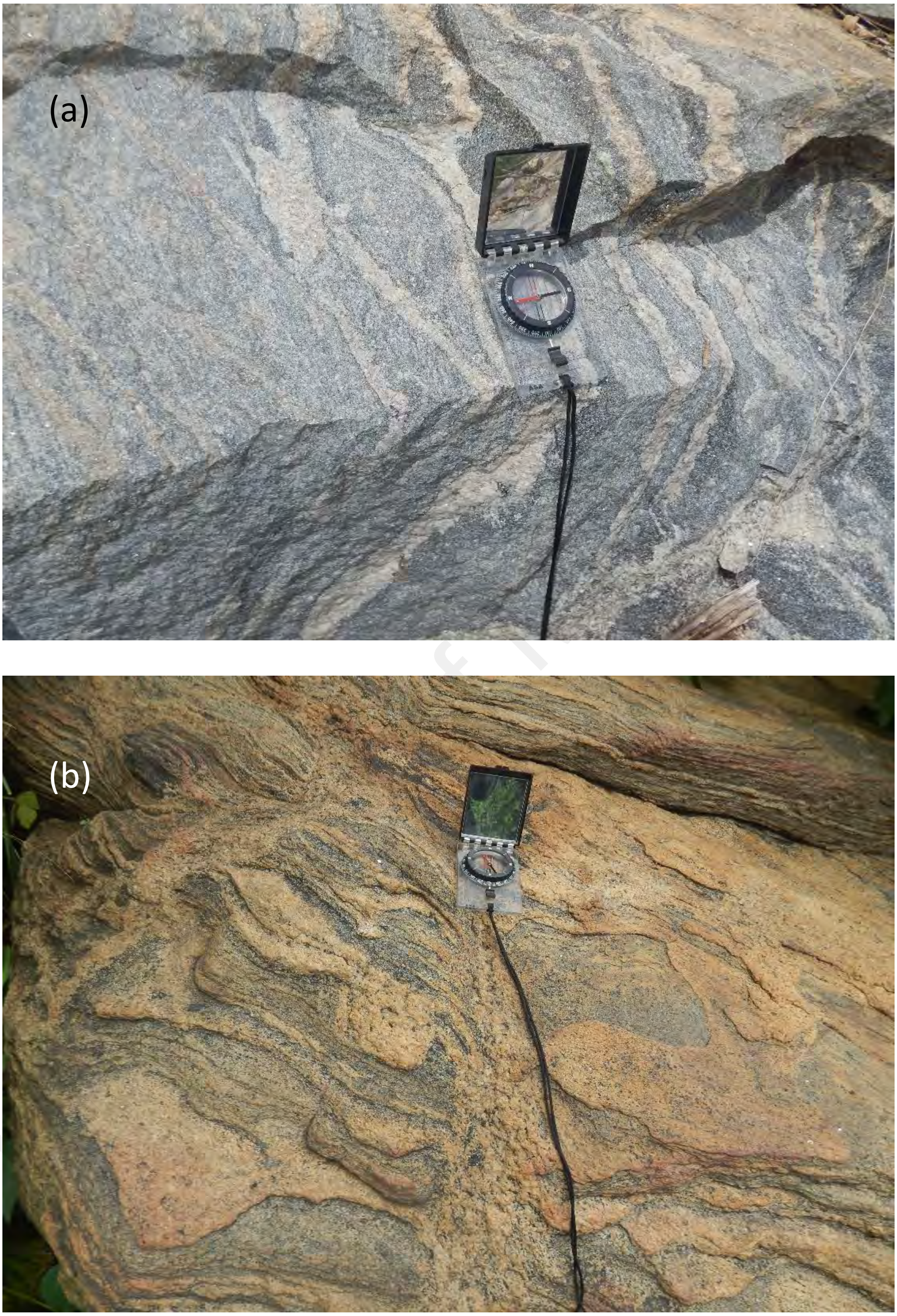

Figure 4.4: Field occurrences of Idanre banded gneiss (a) display of mineralogical banding with coarse lamination (the rock surface is exposed by blasting), (b) banding (interlayering of felsic and mafic minerals) in a finely laminated banded gneiss exposed along a dry river channel

4.1.1.4 Coarse-grained Granite (Undifferentiated) (OGu)

This unit forms border around the porphyritic granite in the northern part, it makes sharp lithologic contact with the country rock. Outcrops of the rock unit are extensive but with moderate elevations. Mineral contents are quartz, feldspar (orthoclase), biotite and hornblende. Quartz grains are transparently greyish-white in colour and smaller in size, it occurs as irregularly shaped interstitial masses heavily interlocked with other minerals. Sometimes, the quartz grains occur in clusters while orthoclase feldspars are large rectangular grains that are mainly greyish in colour. Biotite is black in colour with flaky habits. Hornblende occur as small dark prismatic minerals with fibrous habit. Some outcrops of this granite are charged with small xenoliths of the country rock particularly at the margin where it makes contact the gneissic host rock. Many of the massive undifferentiated granite outcrops exhibit unloading joint which is apparently the main reason they are highly susceptible to weathering. Boulders which resulted from joint-induced weathering are commonly seen on the shoulder many larger outcrops (Fig. 4.5a). Close examination of a fresh surface of the rock reveal the rock has a grey to whitish colour and a conspicuous coarse grain texture (Fig. 4.5b). The grey to whitish appearance reflects the dominance of plagioclase feldspar whereas a weathered surface reflects a seemingly large feldspar grains with rounded shapes (Fig. 4.5c). The slightly varying textural features may be the reason the granite was referred to as undifferentiated Older granite by the Geological Survey of Nigeria. Among other granite members within the suite, this unit appear distinct for its morphological attributes, texture, and colour. It forms major outcrops that line the Idanre-Alade main road. Few of the outcrops are fractured and sparingly vegetated. However, the massive and whaleback appearance appear to be common to all their exposures.

Figure 4.5: Field occurrences of the coarse-grained granite (Undifferentiated) (a) massive outcrop undergoing intense physical weathering in the study area (b) a closer view of the undifferentiated granite showing greyish-white feldspar grains (surface of rock was exposed through blasting). (c) a weathered surface of the undifferentiated granite showing feldspars that are rounded in shape

4.1.1.5 Porphyritic Granite (OGp)

Morphologically, porphyritic granite is distinctive in the entire area in that it forms the most spectacular towering inselbergs surrounding the Idanre town (Fig. 4.6a). The outcrops are massive and are often devoid of major structures such as foliation or folding. This granite unit occupies the central part of Idanre and forms main topographic feature of the town. Some of the granite bodies are chattered into boulders, so it is common to see many gigantic boulders undergoing weathering in and around the base of many hills. The granite masses occur as steep-sided conical hills of different heights. The high gradients along the slopes also allow accelerated weathering to take place consequent on new surfaces being continually exposed to denudation. The porphyritic granite is easy to distinguish from other granite types in the area due to the presence of large porphyries of feldspars (Fig. 4.6b) and most other minerals can be identified with confidence without a hand lens (Fig. 4.7a). The coarse-grained texture and chaotic interlock of grains in the granite may be evidence of magmatic crystallization in which the feldspar porphyries had enough time to grow. From Oke-Idanre where a snapshot of most parts of the town is taken, it became evident that most of the porphyritic granite masses has rounded to conical outlook. Typically, the porphyritic granite has two major types of occurrences, which are: (i) those with mainly pinkish feldspar, and (ii) those dominated by greyish feldspar type. Even though the two are porphyritic, the pink feldspar variety is less common while the greyish type is widespread. The feldspars apart from accounting for almost 65% of the rock's composition in hand specimen, the sizes of the feldspar phenocrysts are highly different. In some localities, the porphyries bulge out prominently (Fig. 4.7b). The weak alignment in some of the feldspar porphyries (Fig. 4.7c) is probably why this unit was referred to as porphyroblastic granite by authors like Oyawoye, (1964). Majority of the samples have quartz accounting for over 20% of the constituent minerals in hand specimen.

Figure 4.6: Field occurrence of the porphyritic granite (a) as inselbergs outcropping within the study area, (Idanre town is in the foreground), (b) a closer view of a weathered surface of the phenocrysts in the porphyritic granite

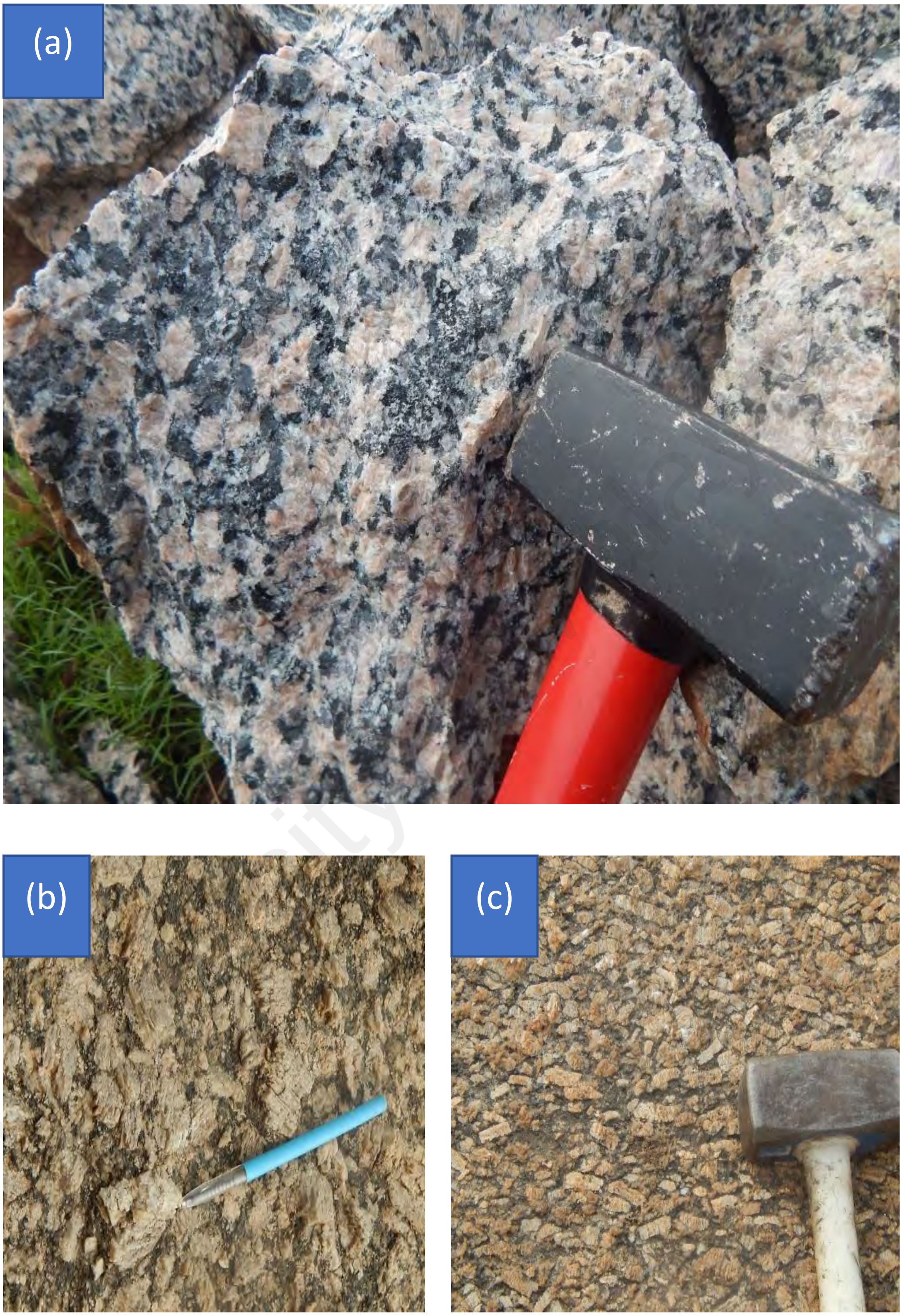

Figure 4.7: Textural features of the porphyritic granite (a) Fresh hand specimen samples, (b) bulging feldspar phenocrysts as exposed by weathering and erosion, (c) a seemingly weak alignment of the feldspar grains

4.1.1.6 Fine-grained Granite (OGf)

This granite was first encountered at latitude 07° 07' 42" and longitude 005° 13' 06" in north-eastern part of Opa area of Idanre (Fig. 4.8a). A blasted outcrop in the outskirt of town revealed the rock is typically fine to medium-grained (Fig. 4.8b). The relative size of feldspar is drastically reduced although they persist as dominant and clearly visible constituent of the rock. The pinkish feldspar typically impacted a general hue on the rock. A closer view shows the mineralogy of this rock is dominated by quartz, feldspar and biotite. Biotite content is relatively low in the rock and the few grains sometimes form isolated masses, on rare cases however, they are clustered together. Because of the drastic reduction in the grain sizes of the feldspar, the quartz grains appear seemingly prominent in hand specimen. Quartz grains appear as irregularly shaped, silvery-white, interstitial minerals. The fine-gained textured rock is very difficult to reduce by hammer.

4.1.1.7 Charnockite (Ch)

Charnockite from the study area has olive-green colour and vitreous to greasy lustre. The medium- grained rock apart from its restricted occurrence, is distinguished from other basement rocks by its colour, texture and mineralogical composition. Although, three different textural varieties of charnockite have been recognized in Nigeria basement. However, during the fieldwork for this research, only the medium to coarsely grained variety was identified in Idanre. Three morphological associations of charnockite is also recognized in the basement terrain of Nigeria based on proximity and relationship with granite bodies. The field associations are (i) at the core of granitic bodies, (ii) within the proximity of the granite host, and (iii) as discrete bodies far isolated from granitic units (Oyawoye, 1964). Idanre charnockite lacks any structural lineament or observable foliation, the rock unit occurs at the centre and surrounded by the porphyritic granite. Charnockitic rock in the study area rarely form prominent inselbergs but smooth rounded

Figure. 4.8: Field occurrences of the fine-grained granite (a) outcrop exposure (with a rounded outlook) in the study area, (b) a fresh and newly blasted outcrop of the fine-grained granite

Figure 4.9: Field exposures of Idanre charnockite, (a) residual hills shattered into boulders by denudation, (b) a fresh and newly blasted low-lying outcrop of the charnockitic rock

low-lying outcrops and residual hills of average elevation which often forms oval to sub-circular and elongate bodies (Fig. 4.9a). In hand specimen samples recovered from a freshly blasted outcrop (Fig. 4.9b) the rock exhibits light bluish-green minerals, feldspars are mainly green. Other minerals include biotite, pyroxene (hypersthene) and magnetite.

4.2 Structural Geology

Among the prominent structures are folds, fractures, joints, exfoliation (spheroidal weathering), quartz vein intrusions, aplitic and pegmatite dykes, contact relationships, foliations, lineaments, and xenoliths. The lineament map from satellite image (Fig. 4.11) indicates that structural relationship between the Idanre batholith and the bounding rocks is crisscrossed by several fractures (Anifowose and Kolawole, 2012). The structural attribute and principal stress direction may relate to the orientation of a major discontinuity (Ifewara Fault) that runs along NNE-SSW direction and located towards west of Idanre. The emplacement of the Idanre granite batholith may have affected the structural trajectories entire terrane or reoriented the structural trends of the basement in dominantly N-S direction.

4.2.1 Folds

A fold is a bend or flexure in rocks. Although, folds may occur in igneous and metamorphic rocks, they are more conspicuous in beds of sedimentary rocks. Sediments are originally laid down in horizontal layers so, any set of sedimentary bed that is tilted or show a measurable inclination or deviation from the horizontal must have violated the rule of original horizontality. In the study area, folds are most exhibited by biotite-hornblende gneiss and migmatite gneiss (Figs. 4.10 and 4.10 b). Folds exhibited by rocks in Idanre are of diverse geometric types and shapes. However, folds were not observed on the massive granite outcrops. Geologically, rocks with ductile tendencies are more frequently folded, while those that are brittle readily become fractured jointed or faulted.

Figure 4.10: Structures (folds) in the basement gneisses (a) deformation ripples and folds on a biotite-hornblende gneiss outcrop from the study area, (b) complex folds on a migmatite gneiss outcrop in Idanre area

There are several types of folds with geometry ranging from similar folds, polygonal folds, overturned folds, and recumbent folds in Idanre gneiss complex. Among the fold shapes are open folds, close folds, tight folds, and parallel folds. Usually, folds are generated by compressional forces which results in shortening rather than tensional or extensional forces.

4.2.2 Fractures and Joints

Adekoya, (1977) believed tectonic forces which manifested as discontinuities and joints in an area quantitatively reflects the forces that are in operation and give insight of conceivable stress pattern within a terrain. The entire Idanre granite complex is crisscrossed by fractures that are haphazardly arranged. Satellite image of the granite complex (Fig. 4.11a) and the extrapolated structural map (Fig. 4.11b) (Anifowose and Kolawole, 2012) shows the orientation of these fractures. Fracture is a deformation style that is usually initiated at microstructural levels when a small space or opening (crack) develops in rock in response to tensional stress and later expand to become fractures (Fig. 4.12a and 4.12b). The tendency of granite to be fractured is linked to granite being once beneath the earth before they are relieved of their overburden through continuous erosion or upliftment. In the process, the granitic rocks become highly jointed as it responds to the release of the overburden. Fractures and joints can aid rapid weathering in rocks as the crevices allow water to penetrate deeper parts of the rocks. The presence of such little amount of water could trigger several chemical reactions in rocks especially at elevated temperatures thereby initiating chemical and mechanical breakdown of rocks. This is true because when fractures are created within rocks, they form not only a means of increasing the surface area to allow chemical reactions to take place, but they also reduce the mechanical strength of rocks considerably. Hence, the evaluation and analysis of the size and orientation of these planes of discontinuities may connote how stress are distributed in any terrain.

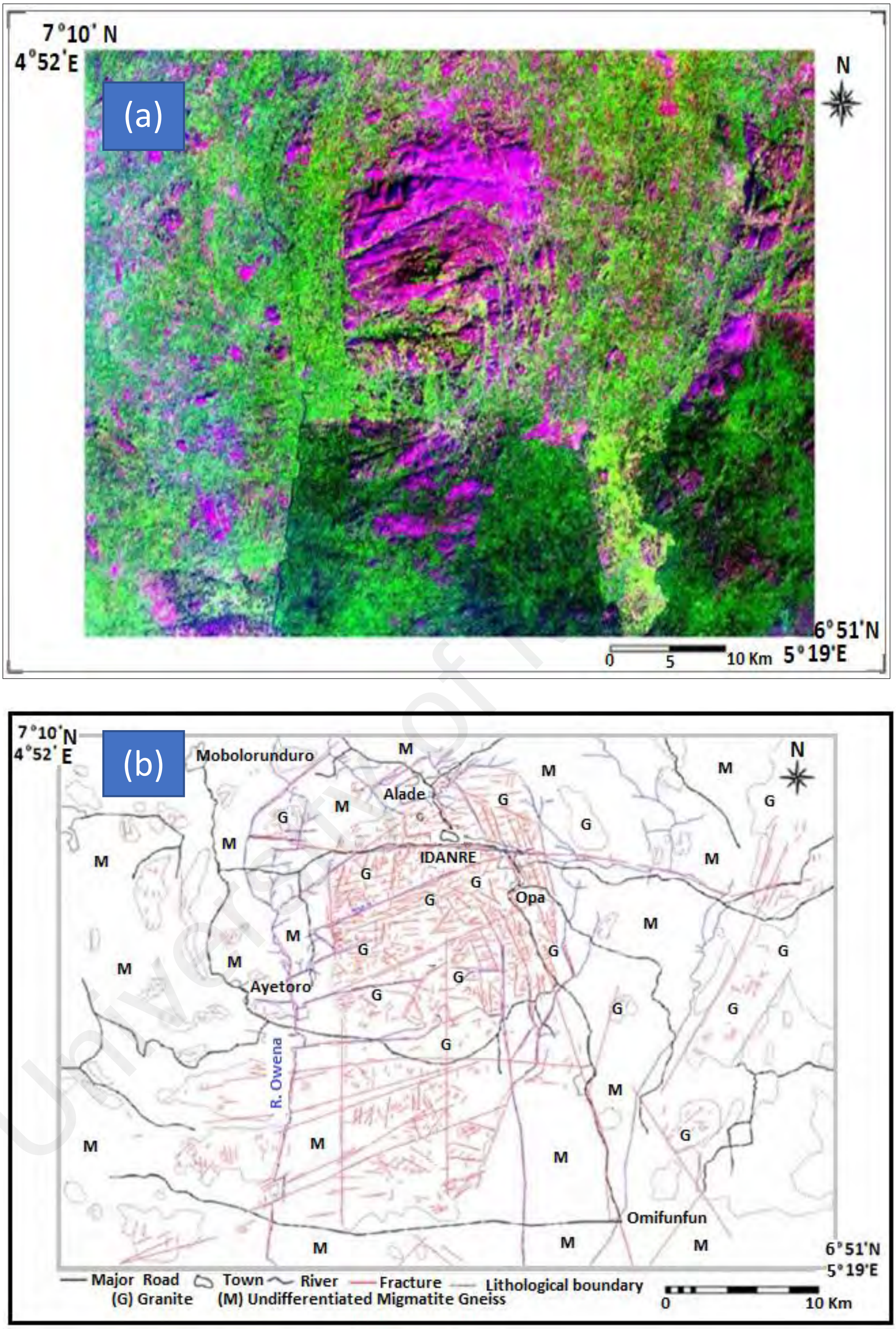

Figure 4.11: Fractures in the Idanre Granite Complex (a) as observed from satellite image, (b) structural map (fractures) of Idanre Granite Complex extrapolated from the Satellite image (after Anifowose and Kolawole, 2012)

Figure 4.12: Fractures in the basement gneisses (a) as observed in a migmatite outcrop (red part of hammer), (b) in a rigorously folded banded gneiss (running parallel to hammer) outcrop

4.2.3 Weathering and Exfoliation

Weathering is the process by which rocks are mechanically disaggregated and chemically decomposed to become lose particles. Exfoliation occurs when a mass of rock is worn off in a spherical manner by agents of denudation. Spheroidal weathering is likened to the way an onion skin peels off in layers. This type of weathering is common in tropical regions where there are alternate dry and wet seasons. As a rock body experiences alternating heating during the day and contraction in the night, they expand and contract until a weak zone is generated. The cohesion force becomes insignificant and the rocks give way. Many boulders of granite display chemical weathering (Fig. 4.13a) with evidence from hollow sound when struck with hammer and softness. Aplitic dykes within the granitic mass show exfoliation (Fig. 4.13b).

4.2.4 Quartz vein intrusions and quartz dykes

Quartz vein intrusions are spectacular and far more abundant structural feature in Idanre. However, most of the structures are too small to be plotted on the present map scale. In the study area, quartz vein intrusions are more common on the gneissic outcrops. However, few quartz veins occur as fracture fillings and quartz fluid injections within the low-lying granitic bodies. On a biotite hornblende gneiss outcrop (Fig. 4.14a), the quartz veins are almost parallel, they are extensive and traceable for several meters. Few of the much bigger quartz intrusions occurs as quartz dykes that show prominent metasomatic alteration at their contact with host rocks (Fig. 4.14b), while in other localities, it varies in size from tiny stringers of few millimetres to centimetres in thickness. Quartz vein intrusions in the study area occur mainly as silica-rich infiltrations which is distinctly recognizable from the enclosing rock bodies owing to discrepancies in physical characteristics such as colour, grainsize or mineral composition. They are dominantly inclined along north-south direction, in few localities however, the orientation is N45^{o}E.

Figure 4.13: Weathering in rocks of Idanre area (a) porphyritic granite with pinkish porphyries chemically altered to whitish colour, (b) exfoliation (spheroidal weathering) shown as rock peeling off in concentric rings in aplite dyke in the study area

Figure 4.14: Felsic veins and dykes in basement gneiss (a) parallel felsic veins (tip of GPS) in biotite-hornblende gneiss in Idanre, (b) a large quartz dyke (left side of geologic hammer) in a migmatite gneiss outcrop showing metasomatized contact (tail of hammer)

In Owomofewa village which lies in south eastern part of the study area, the veins are profusely haphazard with records of irregularity of direction of orientation. Most often, the veins are common in rocks with many fractures, joints or cracks any other plane of discontinuity in the host rocks, so they act as fracture fillings or originate through quartz injections. Quartz vein intrusions are usually planar bodies (even though some are now folded) with sharp borders, and in places where they are abundant, they form infusions of randomly emplaced bodies that crisscross one another (Fig. 4.15). Quartz veins sometimes give indication of their sequence of emplacement as the younger one's crosscut the older. The presence of veins in rock symbolizes channelled fluids mobility in jointed and cracked rocks Although, quartz appears to be the major mineral in the veins, but oftentimes, the aplite veins contain others like feldspar and muscovite. The condition whereby assemblage minerals in veins are similar with their host rock sometimes suggest they are formed at the apex of metamorphic conditions accompanied by metasomatic exchange of materials through fluids into a fracture. In this situation, individual grains extend continuously from the wall-rock into the vein interior. In other veins, the mineral assemblage is inconsistent with the immediate wall rock and transport of dissolved constituents from a distant external source is implied. The conclusion of most petrologists regarding the origin of quartz veins is that plentiful amount of aqueous solutions and fluids plays significant roles in this regard more so that quartz is virtually soluble under varying physiochemical settings and metamorphic conditions. Belousov and Volvovsky, (1988) believed quartz veins are formed when tension cracks in metamorphic rocks get filled with quartz by "sucking in" from enclosing rock, occasioned by sharp pressure drop following the development of the opening.

4.2.5 Pegmatite and aplite dykes

This tabular mass of intrusive rocks is emplaced discordantly within both granite and gneiss host: therefore, dykes are secondary geological structures. In the study area, dykes

Figure 4.15: Diffused aplite dykes and quartz veins in biotite-hornblende gneiss in the study area

occur commonly as pegmatitic bodies (coarse-grained) or as fine-grained aplitic bodies. The dykes show sharp contacts with its hosts and are of variable sizes. Spectacular among the pegmatite and aplite dykes in the study area is the one cross cutting each other on a low-lying granite outcrop around Obatedo at location (N 07º 05′ 53″, E 05º 03′38″) (D 35) (Fig. 4.16a) which is traceable for over 120m. The susceptibility of the fine-grained aplitic rock to weathering is evidenced by obvious exfoliation, a depression or hollow in rock. Pegmatite dykes in Idanre have a coarse texture, bulging appearance, and a lighter colour. The width of some aplite dykes exceeds 50cm (Fig. 4.16b).

4.2.6 Xenoliths

Sometimes the evidence of tectonic activities in an orogen is manifested as blocks of foreign rocks that are completely enclosed by magmatic bodies. Xenolith which represents remnant of country rock that are stranded within the granitic mass varies between 14cm in length and 6cm in width to those that are larger and measuring about 120cm in length to 45cm in width. Although smaller sizes are also encountered, usually

Figure 4.16: Dykes in granite from the study area (a) a pegmatite dyke cutting through an aplitic dyke in coarse-grained granite (Undifferentiated) of Idanre (Loc. D35), (b) a sharp lithologic contact between an aplitic dyke and Idanre porphyritic granite

the large xenoliths are of irregular shapes and occur prominently in porphyritic granite and fine-grained granite. However smaller ones are also encountered as mafic clots within the granite porphyry. The mafic clots are now preserved bulging out on the flat surfaces of the extensive granitic rocks (Fig. 4.17). Large xenoliths with remnant foliation often occur as marginal facies within the fine-grained granite (Fig. 4.18a). Because the xenoliths are variable in size, they are often indication of the magnitude of forces that are in operation in any terrain or tectonic forces that accompany plutonic activities. The angular nature and the well-preserved relict foliation may indicate that the granite emplacement occurred rapidly, while the size of the xenolith may indicate that the emplacement was accompanied by great force. One of the largest xenoliths in Idanre area

Figure 4.17: A bulging xenolith of country rock in Idanre porphyritic granite

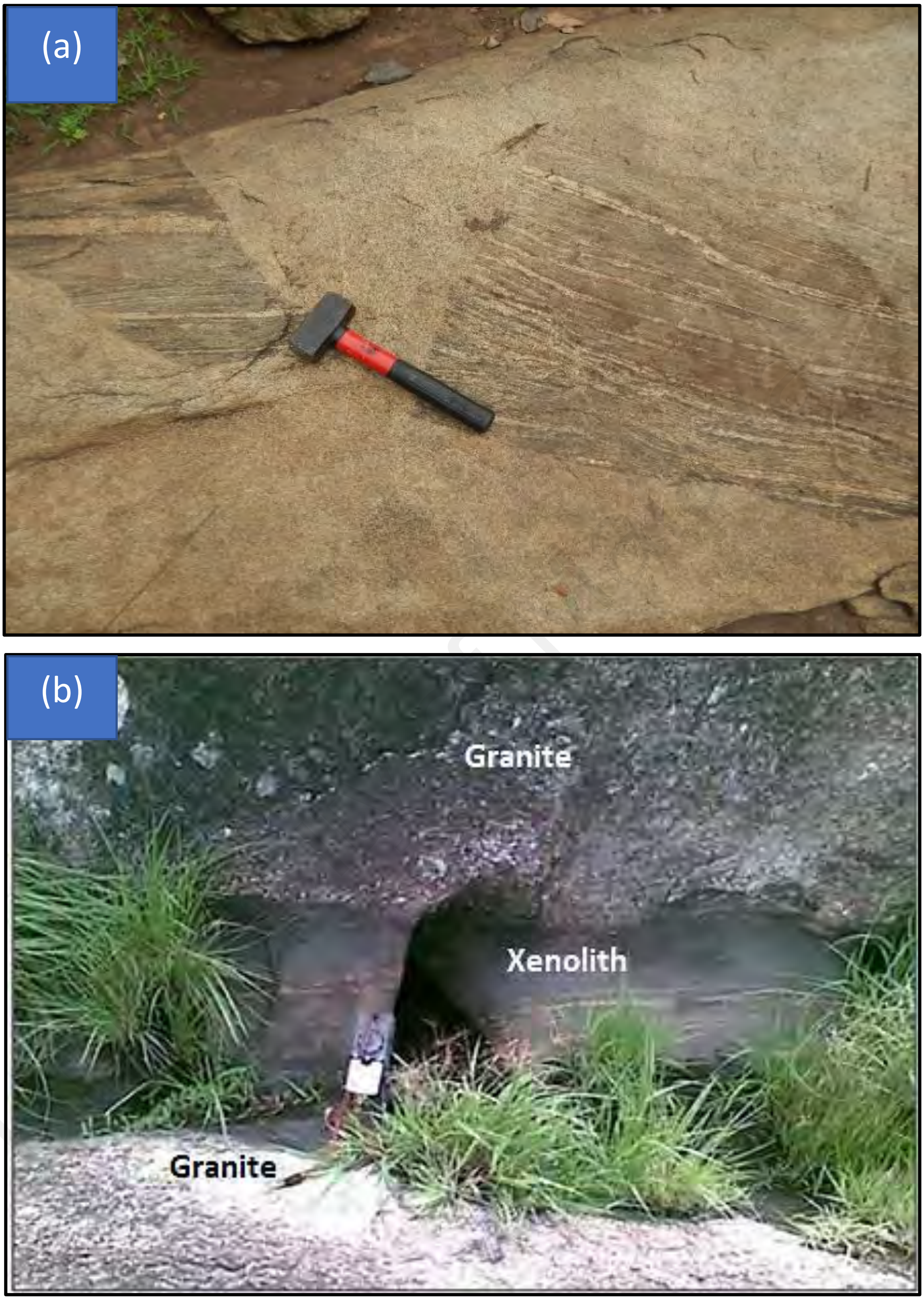

Figure 4.18: Large xenoliths of country rock in Idanre granites (a) preserved in the margin of fine-grained granite pluton (head and tail of hammer), (b) one of the exceedingly large xenoliths embedded within the porphyritic granite around Oke-Idanre (after Anifowose and Kolawole, 2012). The size of these xenoliths clearly indicates the granite was forcefully introduced into the gneissic basement and enormous amount of energy accompanied the granite emplacement

(Fig. 4.18b) occurs within porphyritic granite. This massive xenolith is darker in colour than the host rock and show remnant traces of foliation. It appeared weathered as solution cavities are seen on the xenolith. The orientation of the foreign block indicated that they are incompletely digested by the enclosing granitic magma and are dominantly of metamorphic origin. The differences in structure, texture, mineralogy, and shape symbolizes they are hewed from the country migmatitic rock. The xenolith appears more susceptible to weathering than the enclosing rock because of its mafic nature as their boundaries are marked by sharp depressions.

4.3 Petrography

After the outcrop exposures are studied and their structural elements evaluated in the field, hand specimens were also described. Thin sections of the different lithologic units were prepared, and optical microscopy undertaken using the petrological microscope.

4.3.1 Migmatite (M)

Mineralogical composition of Idanre migmatite as observed under the petrological microscope comprise of quartz, orthoclase, plagioclase, muscovite and ferromagnesian aggregates including biotite, hornblende and opaque mineral like magnetite (Fig. 4.19). This porphyroblastic and weakly-foliated mesocratic unit contains almost equal volume of dark (melanocratic) and leucocratic assemblages. The mafic minerals in Idanre migmatite include biotite, magnetite and hornblende, but biotite is rather dominant being the commonest. The leucocratic components are predominantly quartz and feldspar, on few occasions, muscovite is present. Commonly, the porphyroblasts are euhedral to subangular crystals of feldspars and quartz sandwiched between groundmass of mainly quartz and biotitic phyllosilicates. Small biotite plates and muscovite define the weak

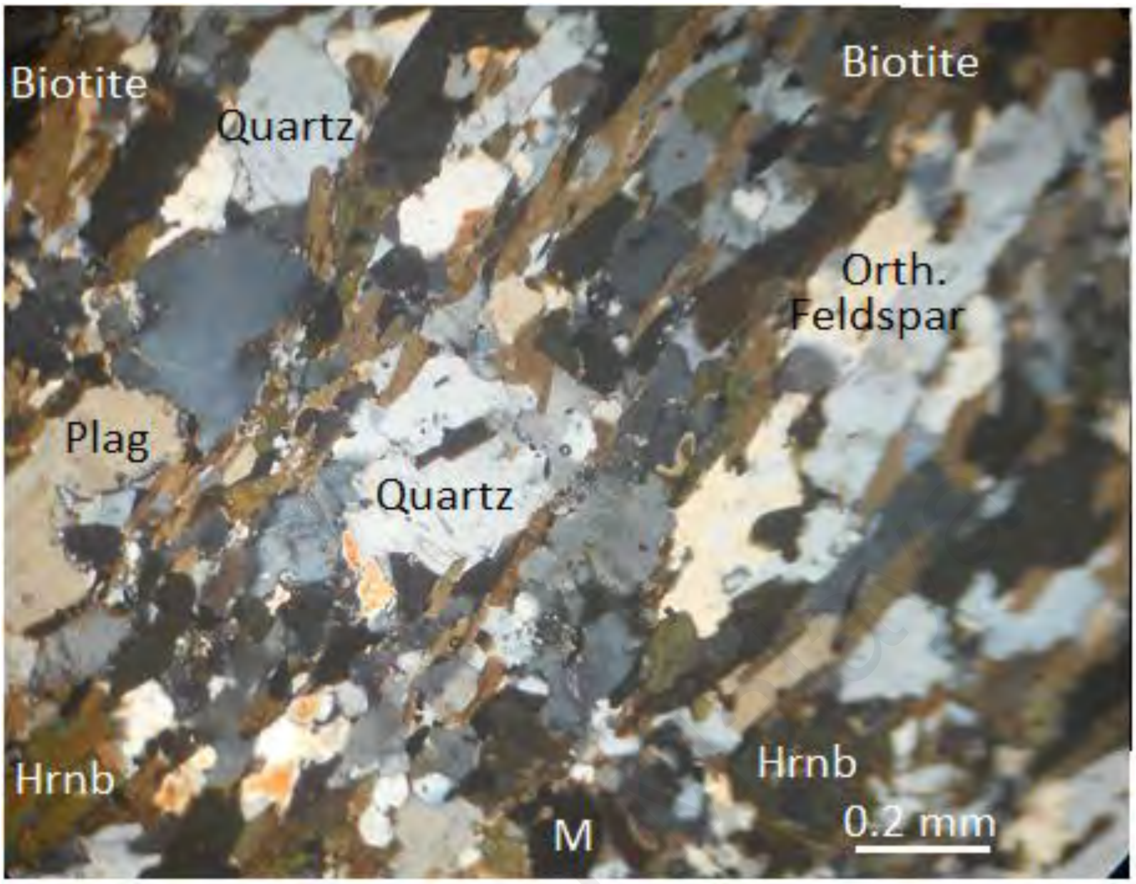

Figure 4.19: Photomicrograph of Idanre Migmatite gneiss in transmitted light (cpl) showing the constituent minerals. Quartz grains are isolated, feldspar (plag) shows faint twinning, biotite plates are aligned and stretched in diagonal direction photograph, hornblende (Hrnb) are scattered, while magnetite (M) occurs in traces.

foliation as they are sub-parallel in orientation (Fig. 4.19). Porphyroblasts and the groundmass commonly show weak alignment in interlocking relationship, but the stretched biotite plates impact a seemingly gneissic foliation. Porphyroblasts of feldspar are approximately 4 to 5 cm long and 1.5 to 2 cm in width, while those of quartz measure between 3 to 2.5 cm long and 1 cm wide. Occasionally, elongate crystals of plagioclase feldspar are aligned along foliated laths of acicular and blades of biotite, but quartz are ubiquitously irregular in shape. Thin section petrography shows dominance of micaceous aggregates arranged in preferred direction to form parallel to sub-parallel alternation of quartz and feldspars. Quartz crystals occur as mosaic of low-birefringent minerals measuring approximately 8 mm in length. Quartz crystals appear colourless and clear, it has no micro-fractures and constitutes approximately 45% of the rock in thin section.

Some of the quartz crystals show straight extinction while fractured and dislocated ones show undulose extinction. Biotite occurs as strongly pleochroic brown lath-like crystals. Some contains inclusions of light-coloured minerals and has perfect one directional cleavage. It has moderate birefringence with reddish to yellowish brown maximum interference colour of the second order. It exhibits parallel to near-parallel extinction. Hornblende is pleochroic with green and brown colours with two directional cleavages. It typically forms aggregates of prismatic grains forming phenocrysts which are six-sided prisms. The feldspars are mainly dominated by orthoclase and plagioclase while microcline is poorly represented. The medium-grained rock exhibits conspicuous mineralogical banding, which implies that the mafic and felsic minerals constituents are segregated into clearly defined parts that alternates.

4.3.2 Biotite-Hornblende Gneiss (BHG)

The fine to medium grained melanocratic rock that show parallel to sub-parallel (preferred) orientation of mineral components which are mainly quartz, hornblende, plagioclase, biotite, and traces of olivine and epidote. Plagioclase has bold albite twin laminae and a maximum extinction angle of 24^{o}. The few olivine crystals have characteristic blue interference colour. Epidote is colourless but sometimes show pale green colour and occurs in granular to columnar aggregates but with high relief and fractures that makes it distinct. Epidote can be seen mantling brown hornblende and surrounded by greenish and brown hornblende. Tiny recrystallized muscovite also appears to be aligned in one direction. The quartzo-feldspartic aggregates are mainly felsic mineral crystals that seem to have been crushed or mylonitized, so that the only very small, anhedral crystals of quartz are recognizable, even in thin section (Fig. 4.20a). It shows weak alignment of dark-coloured minerals. An unidentifiable mineral has been totally crushed and distributed in-between the quartz crystals and occur as abundant groundmass mineral. Under crossed polarized light, some of the mineral looks more like microcline crystals that are showing incipient alteration to sericite. The gneissose foliation is imparted by parallel to sub-parallel alignment of the micas (biotite and muscovite) which are intermingled with the felsic components (quartz and feldspars). The rock occasionally comprises of large porphyroblasts of quartz which are irregularly arranged, while the flaky minerals (muscovite and biotite) cluster in some roughly parallel bands which are in association with fine-grained groundmass aggregates.

4.3.3 Banded Gneiss (BG)

Banded gneiss in Idanre contains essentially of quartz, feldspar, hornblende, biotite, chlorite and opaque minerals as the major identifiable constituents. These principal components account for over 90% of the bulk mineralogical composition. Quartz grains occur mainly as granoblastic aggregates arranged along the diagonal direction (Figs. 4.20b). However, smaller quartz crystals are seen scattered over the entire rock in thin section. Some of the porphyroblasts of quartz occur together with biotite which forms the main platy and stretched minerals exhibiting preferred orientation. The quartz crystals are sometimes segregated into distinguishable plane of characteristic felsic components while others are scattered and stranded among the biotite plates in the form of groundmass minerals. The large crystals of quartz are euhedral to subhedral in shape, while those that are smaller have rounded outlooks.

The modal composition of the basement gneisses and migmatite (Table 4.2a) indicate that the different shades of gneisses have slightly different mineralogical composition. For instance, the average quartz contents vary marginally from 28 volume percent in banded gneiss to average of 22 and 23.3 in biotite hornblende gneiss and migmatite, respectively. In the same order, feldspar (plagioclase + orthoclase) accounts for 34%, 37.3% and 43%. Mafic components (biotite + hornblende) account for approximately 29.3%, 22.7% and 22.3% respectively in the host basement rocks. Gneisses lack microcline because it is only stable under a higher pressure within a plutonic environment.

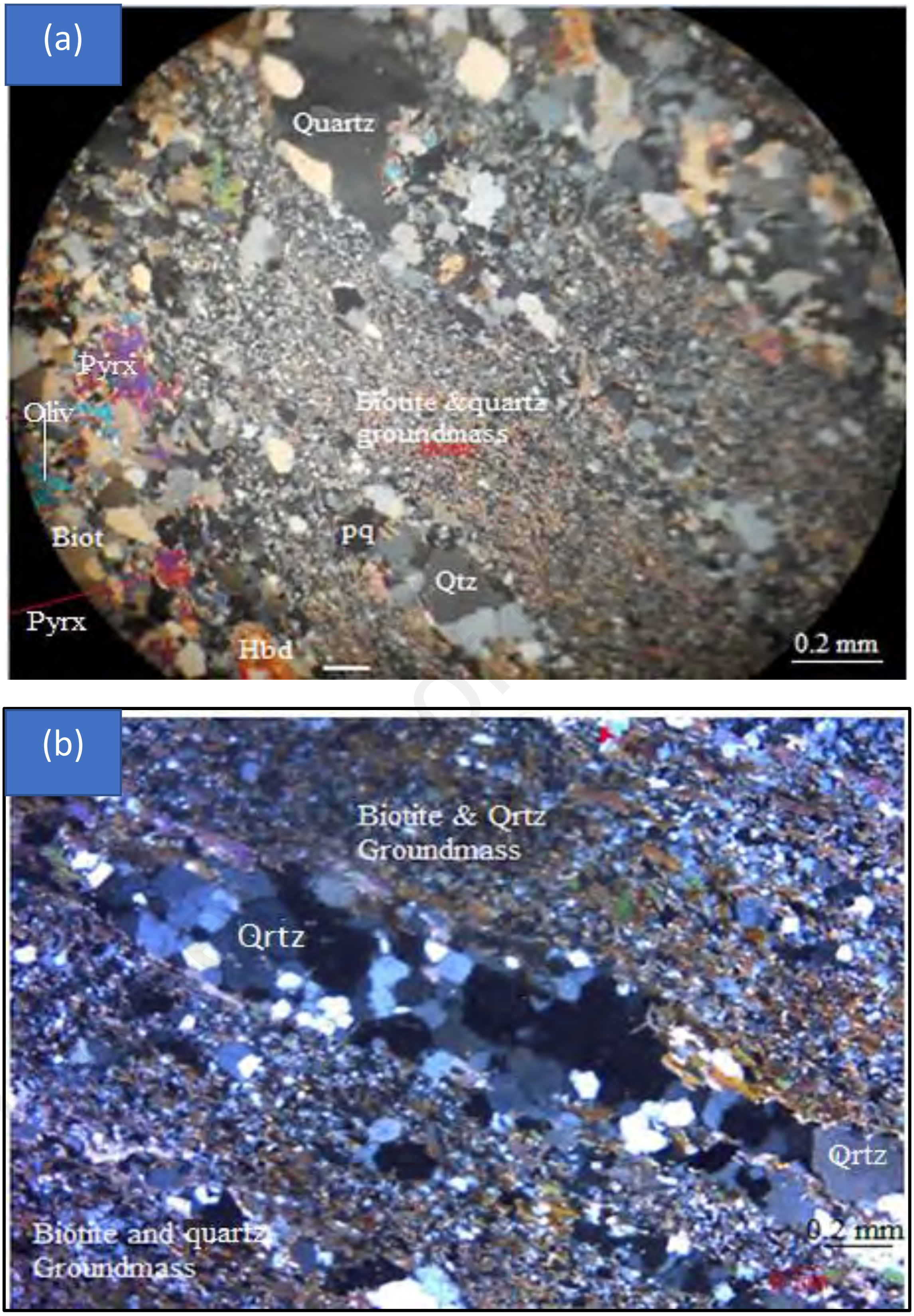

Figure 4.20: Photomicrograph of gneisses from Idanre in transmitted light (cpl) (a) biotite-hornblende-gneiss showing quartz and biotite groundmass arranged along preferred planes in a diagonal direction of photograph. Hornblende (Hbd), pyroxene (Pyrx), and olivine (Oliv) crystals only occur as subordinate minerals, (b) banded gneiss showing the component minerals, grey and white minerals are quartz (Qrtz); brown minerals are biotite

4.3.4 Coarse-grained granite (Undifferentiated) (OGu)

Quartz, feldspar (mainly orthoclase and microcline), biotite and hornblende constitute the mineral component of the rock. (Fig. 4.21a). Quartz grains are heavily interlocked with surrounding biotite and hornblende. Occasionally, the quartz grains occur in clusters. Biotite occurs as dark brown to black coloured minerals with flaky and acicular habits under crossed polarized light. Some of the biotite laths exhibit strong yellowish-brown interference colour and a low relief when the stage of the microscope is lowered. Biotite appears as randomly oriented brown colour mineral with characteristic acicular shape and bird view structure. Microcline occur as greyish mineral with well-developed crosshatched twinning accounting for average of 16.6% (Table 4.2). It occurs as large (1.5cm in length and 0.6cm in width) crystal with low relief. Orthoclase feldspars are large (measuring up to 1cm in length and 0.6cm in width) and blocky, the large grains are mainly pinkish in colour with well-developed twin crystals. Evidence of small fractures are seen on the larger orthoclase crystals (Fig. 4.21b) which account for average of 23% of the minerals in thin section. This crystal show colour variation along the long crystallographic axis parallel to the twin plane. The fractures run obliquely to the twin plane and intersect at the median point within the crystal. Muscovite (average 2.2%) occur sparingly in the rock while quartz form small euhedral aggregated that occur together in clusters. Few larger quartz grains are supported by hornblende. Biotite laths (average of 10.4%) show low relief and their edges are sometimes sutured. Hornblende are small (0.5cm by 0.3cm) dark prismatic minerals with acicular habits. Muscovite occur as silvery white mineral under crossed polarized lights and have sharp borders with brown biotite.

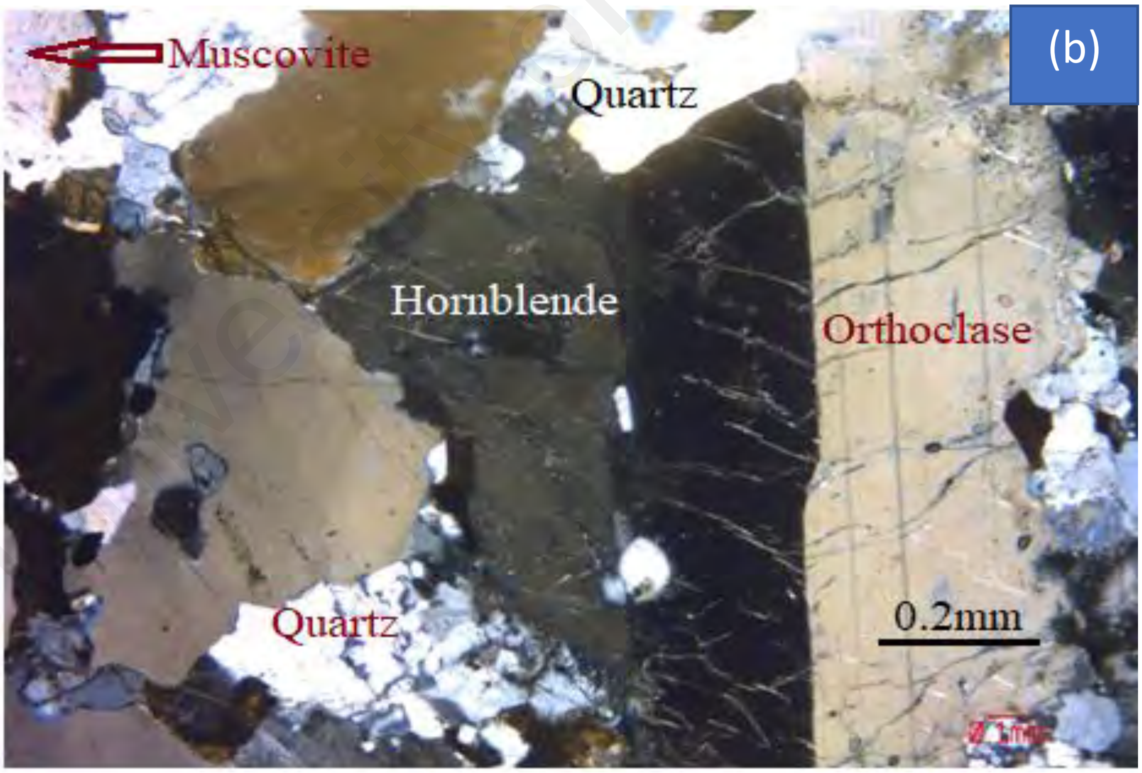

Figure 4.21: Photomicrograph of coarse-grained (undifferentiated) granite from the study area in transmitted light (cpl) showing (a) the constituent minerals as large grains of orthoclase and quartz supported by small blades of biotite, (b) the same rock showing hornblende, orthoclase, muscovite and quartz as the major constituent minerals

4.3.5 Porphyritic Granite (OGp)

As shown, photomicrograph of Idanre porphyritic granite in transmitted light under cross polarized light (cpl) (Fig. 4.22a), the presence of plagioclase, hornblende, biotite, and quartz defines the mineralogy of the rock. Plagioclase is characterized by its twinning according to Carlsbad law in a well-defined albite twinning. The plagioclase is of variable sizes. The larger ones being 2cm in length and 0.8mm in width. Fractures run across the length of the crystal and parallel to the base. Many of the crystals are randomly oriented. Quartz appears as well shaped subangular aggregate. The generally porphyritic textured rock revealed grain boundaries that are well-defined and contact with other minerals are sharp in a chaotic mineral interlock of the constituent minerals. Biotite exhibits brownish colour with striation marking its well-defined cleavage direction. Some of the biotite exhibits acicular habit while some can be described as larger plates. Hornblende is irregular in shape and has green colour under crossed polarized light. Apart from the diagnostic colour, hornblende has more than one cleavage directions and appeared fractured. In (Fig. 4.22b), microcline exhibits a fine grid twinning produced by albite and periclase twins, it is easily identified by its cross-hatched twinning. Myrmekite perthite a symplectitic quartz-feldspar intergrowth is present in the rock. The microcline encircles the quartz grain bearing the myrmekite completely and show some alteration to sericite. Biotite in the porphyritic granite (Fig. 4.23) is distinguished by its deep brown, yellowish-brown and brownish green colour. It is pleochroic with prominent cleavage, birefringence and extinction nearly parallel to (001). In thin section the main mineral commonly associated with biotite is muscovite and quartz. Muscovite differs from biotite by having a silvery white colour. The surface of muscovite is distinct and can be distinguished from quartz by its one cleavage direction, nearly parallel extinction, and a stippled appearance is the extinction position known as bird’s eye texture, which is a characteristic of all mica.

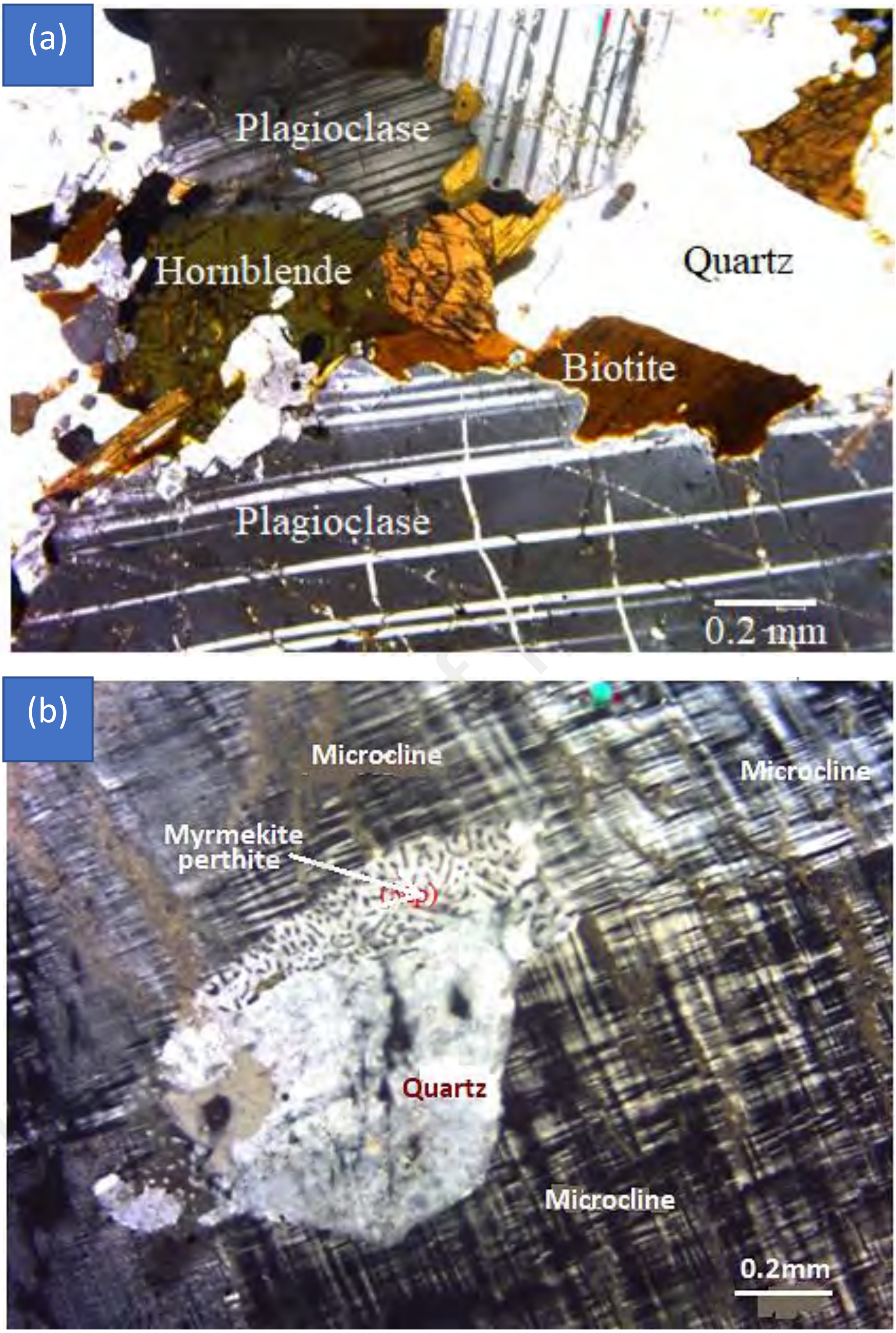

Figure 4.22: Photomicrograph of Idanre porphyritic granite in transmitted light (cross polarized light) showing (a) plagioclase, hornblende, biotite, and quartz (b) the porphyritic granite showing a large crystal of quartz with myrmekite perthite (quartz-feldspar intergrowth) surrounded entirely by a microcline

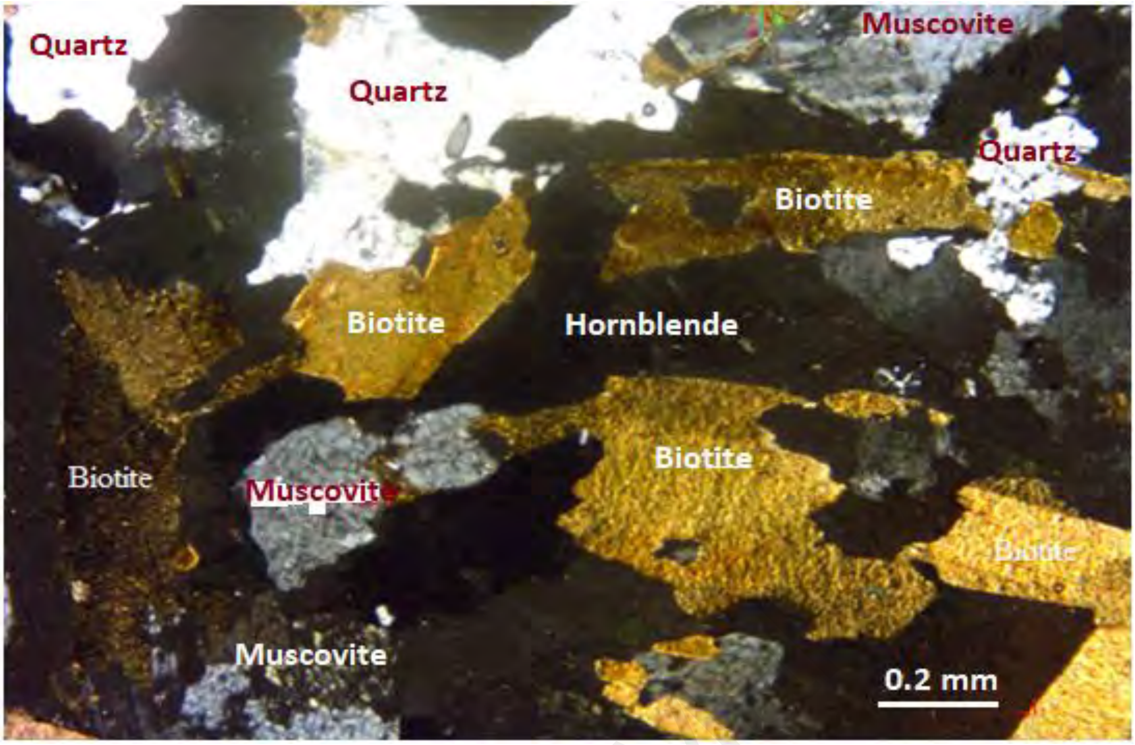

Figure 4.23: Photomicrograph of Idanre porphyritic granite in transmitted light (cpl) showing large randomly arranged laths of biotite supported by crystals of quartz, muscovite, and hornblende

4.3.6 Fine-grained Granite (OGf)

OGf has major mineral constituents which are quartz, orthoclase, biotite, hornblende, and minor amounts of magnetite (Fig. 4.24a). Quartz occurs as irregularly shaped subangular mineral grains with undulose extinction. This type of extinction arises from domain within the crystals having slightly different crystallographic orientations. Even though the rock is fine to medium-grained in hand specimen, orthoclase feldspars grew to sizes ranging from 1cm in length to 0.5cm in width. Biotite has deep brown to light brown colour and are haphazardly arranged. Hornblende occur as stubby grains that are sparingly distributed throughout the rock sections. Accessory magnetite occurs as small dark mineral aggregate. (Fig. 4.24b) show the fine-grained granite as having almost equidimensional quartz grains. The somewhat equigranular to equant texture reflects that the irregularly shaped crystals are firmly interconnected to one another and without spaces between them. Some of the grains show sharp edges with well- defined outlines.

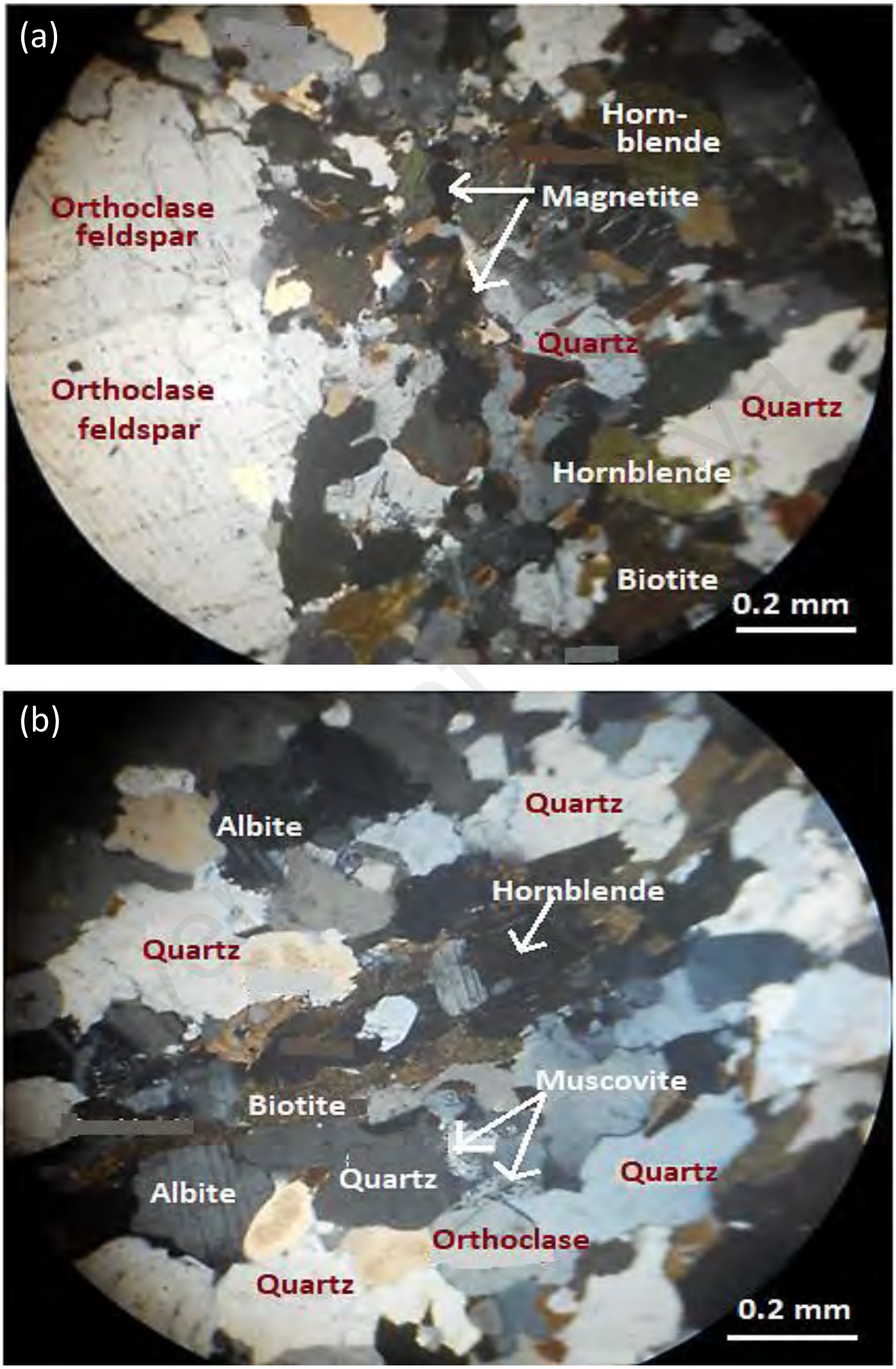

Figure 4.24: Photomicrograph of Idanre fine-grained granite in transmitted light (cpl) showing (a) large grains of orthoclase feldspar heavily interlocked with other constituent minerals, (b) another sample with almost equidimensional grains containing essentially quartz, feldspar (albite) and hornblende

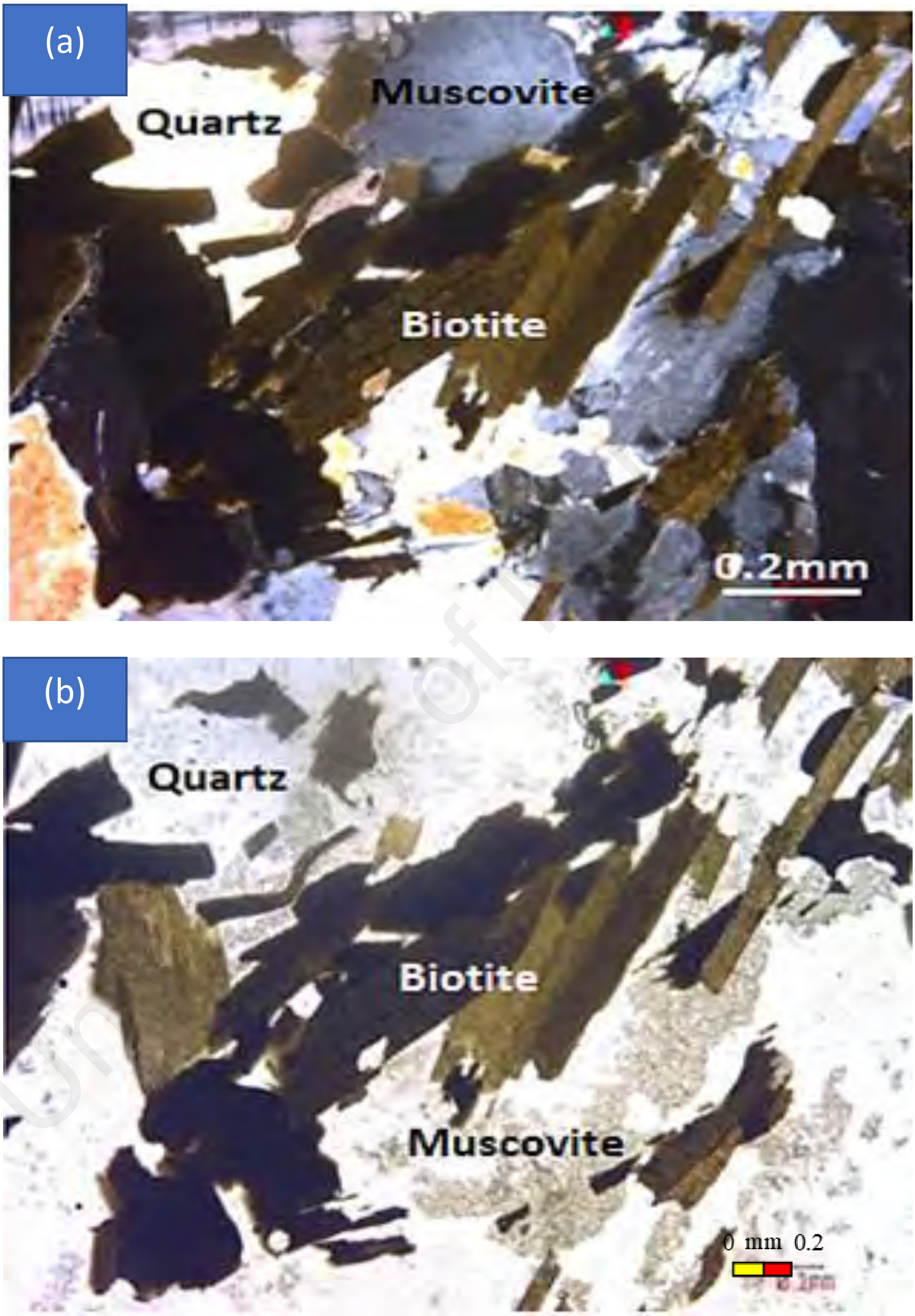

Figure 4.25: Photomicrograph of fine-grained granite showing acicular habits of biotite (a) under cross polarized light, (b) the same slide under plane polarized lights. Other associated minerals are quartz and muscovite

Feldspar occur principally as albite with diagnostic polysynthetic twinning. Hornblende shows brownish to black colour with evident striation. This dark interior is likely inclusion of other minerals. Some of the quartz grains show evidence of strains. Most of the grains appear as clear crystals without fractures or microstructures. Hornblende occurs as deep brown-coloured acicular and prismatic masses forming sharp contacts with other minerals. Biotite occurs as long slender mineral aggregate with characteristic brownish colour and sometimes form in clusters. They have their longer axis aligned fairly in same direction. The fine-grained granite occasionally contains clusters of muscovite and biotite with pronounced acicular habits (Fig. 4.25a and 4.25b).

4.3.7 Charnockite (Ch)

Texturally, Idanre charnockite is fine to medium-grained rock, it contains interlocking aggregates of plagioclase feldspar, quartz, biotite, pyroxene, orthoclase, magnetite, accessory apatite, and zircon. While the first three dominates and account for over 85% of bulk mineralogy, the remaining constitute less than 15% of the rock. Biotite occur as bladed minerals with pinkish to brownish colour (Fig. 4.26a) Plagioclase occurs in form of albite with prominent Carlsbad twinning (Fig. 4.26b). Some of the albite has fracture directions aligned obliquely to the twin plane. Some minerals also contain flame perthite. Biotite occur as yellowish, brownish, pinkish and green coloured mineral. It occurs as large plate aggregates with variable sizes within the rock. Hornblende occur as stubby dark green coloured mineral that makes contacts with plagioclase. Most of the hornblende are of irregular shape. Smaller grains of quartz are well-dispersed around the interstices of biotite and albite crystals. Few grains of quartz are euhedral while some are subhedral and unaltered. Quartz in the rock lack any visible alteration and are all transparently clear. Some sections are abundantly enriched in pyroxene with characteristic mesh texture (Fig. 4.27a). Pyroxene crystal assumed a giant dimension measuring up to 1cm in length and 0.4mm in width. Pyroxene colour varies from pinkish red to purple and deep blue. Quartz

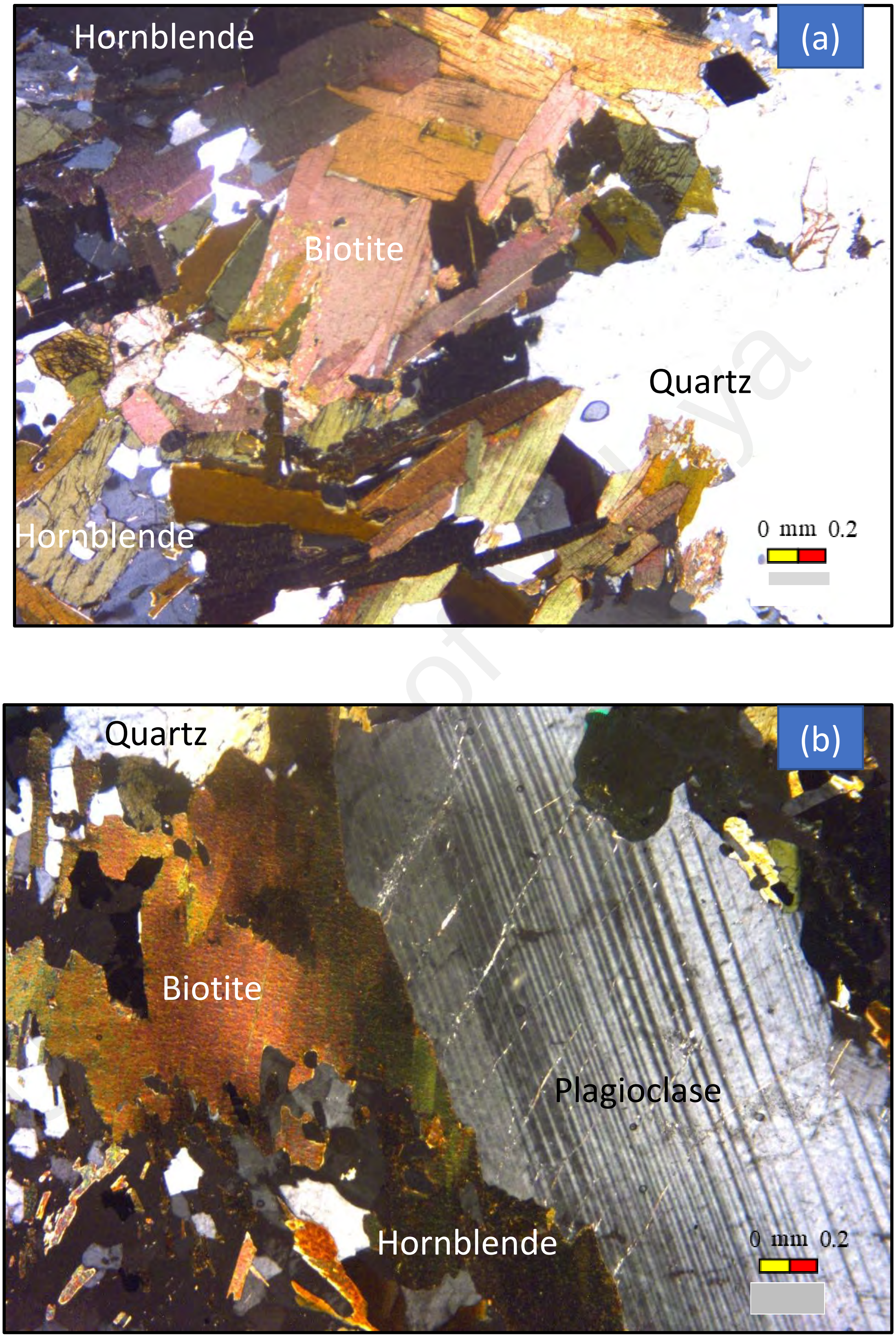

Figure 4.26: Photomicrograph of Idanre charnockite in transmitted light, (cpl) showing interlock of (a) quartz, hornblende, and biotite (b) plagioclase, hornblende, biotite and quartz

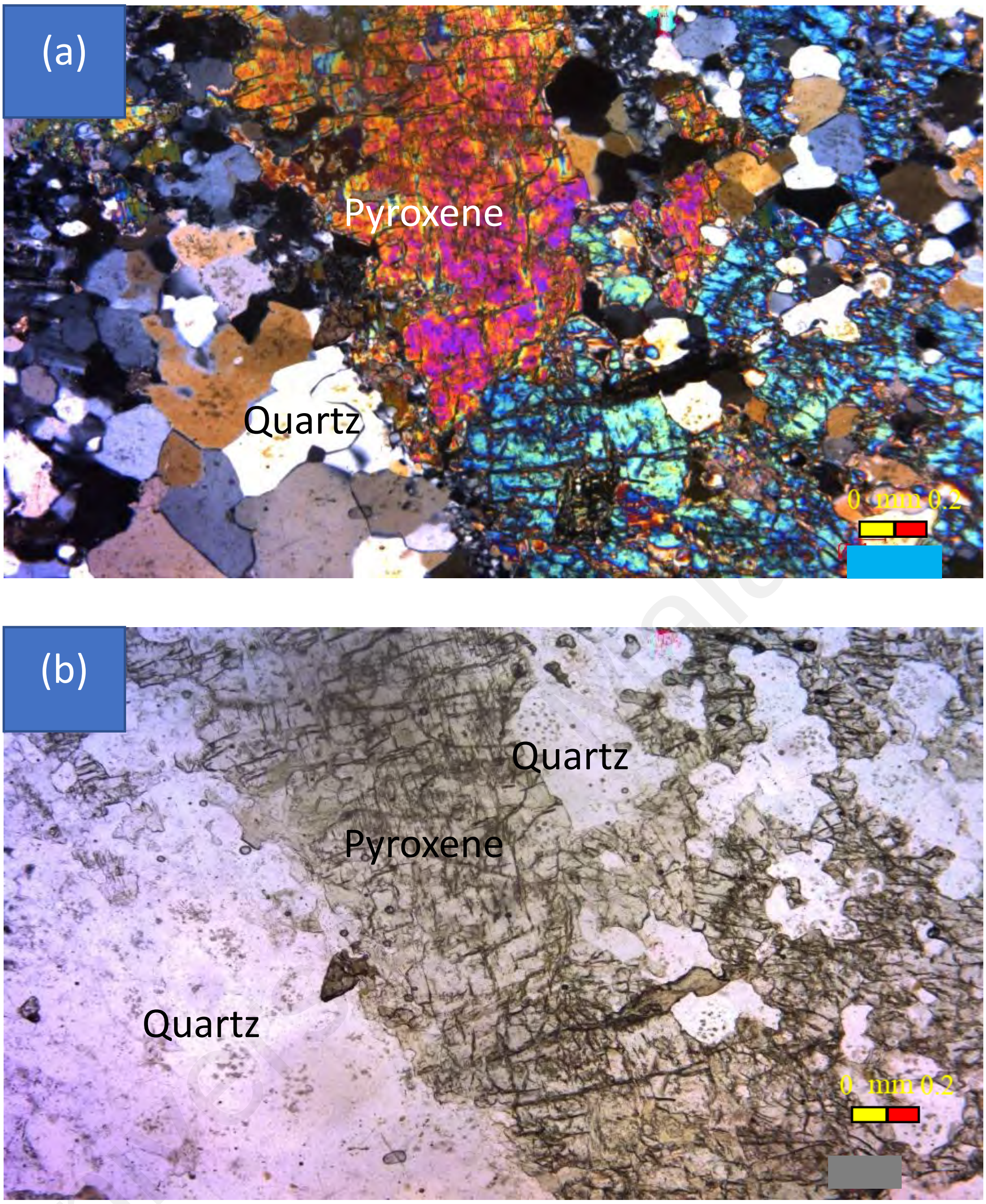

Fig. 4.27: Photomicrograph of charnockite in Idanre area showing pyroxene (hypersthene) and quartz (a) under crossed polarized light, (b) under plane polarized light

grains are variable in size, smaller types measure approximately 0.1 mm by 0.05mm, while the bigger measure 0.3mm by 0.15mm. All the quartz grains have edges that are rounded and have clear outlines with surrounding mineral grain. The plane polarized version (Fig. 4.27b) shows the decussate texture of the pyroxene marked by several intersecting fractures along the length and width of the mineral grain. In the plane polarized version, the quartz boundaries are not so distinct particularly on the left side of the slide owing to the low relief of quartz. Generally, the abundance of these quartz grains gives the rock a characteristic fine to medium-grained texture in hand specimen. The mineralogical feature of the rocks in the study area is shown in the table of modal composition (Tables 4.2).

4.4 Geochemistry

Previous research indicates that Nigeria basement is characterized by different lithologic units each exhibiting unique geochemical traits. Among these (migmatite-gneiss quartzite complex, schistose assemblages located within the schist belts and Older granite) units, the granitoids popularly referred to as Older Granite stand out as representing the youngest rock group. Even though, the geochemistry of granite is generally quite predictable, most granite still exhibits slight differences that allow them to be classified into different petrogenetic groups. Field evidence indicates clearly that these granites are syn-tectonic to late orogenic in origin and are mostly emplaced as granitic addition during concluding phase of the Pan African events.

4.4.1 Major element geochemistry

Geochemical investigation of the rock samples was carried out. For convenience and consistency purposes, the different textural varieties of the granite are tagged as follows: coarse-grained granite (undifferentiated) (OGu); porphyritic granite (OGp) and fine-grained granite (OGf). Analytical result of the main lithologic units in the study area is presented (Table 4.3). Major element (Table 4.3a) and trace elements composition (Table 4.3b) of Idanre granite are presented. Based on petrochemical features, the granitoids in the study area are characterized geochemically and compared to similar rocks in other parts of Nigeria.

Table 4.2: Modal composition (vol. %) of rocks in Idanre area.

Rock type	M	M	M	Mean	BHG	BHG	BHG	Mean	BG	BG	BG	Mean
Minerals	Slide 1	Slide 2	Slide 3		Slide 1	Slide 2	Slide 3		Slide 1	Slide 2	Slide 3	
Quartz	25	21	24	23.3	21	19	26	22	30	25	29	28
Plagioclase	24	25	21	23.3	19	23	21	21	9	9	8	8.7
Orthoclase	21	18	20	19.7	16	18	15	16.3	27	28	21	25.3
Biotite	16	13	19	16.0	15	13	19	15.7	25	24	29	26
Hornblende	6	8	5	6.3	7	9	5	7	4	3	3	3.3
Muscovite	4	7	4	5	2	4	3	3	-	-	1	0.3
Pyroxene	-	1	2	1	5	6	7	4.3	-	-	-	-
Garnet	-	-	-	-	2	1	-	1	-	-	-	-
Magnetite	2	2	-	1.3	-	-	-	-	3	7	3	4.3
Opaque	2	4	5	3.7	4	2	3	3	1	3	2	2
Others	-	1	-	0.3	9	5	1	6	1	1	4	2
	100	100	100	99.9	100	100	100	99.0	100	100	100	99.9

Table 4.2, continued.

Rock type	OGu	OGu	OGu	OGu	OGu	Mean	OGp	OGp	OGp	OGp	OGp	Mean
Minerals.	Slide 1	Slide 2	Slide 3	Slide 4	Slide 5		Slide 1	Slide 2	Slide 3	Slide 4	Slide 5	
Quartz	18	15	21	23	27	20.8	26	25	30	24	19	24.8
Plagioclase	12	12	18	11	10	12.6	15	18	16	16	18	16.6
Orthoclase	29	25	21	21	19	23	24	23	27	22	23	23.8
Microcline	14	17	15	19	18	16.6	18	10	13	15	19	15
Biotite	8	9	13	11	11	10.4	8	14	9	6	7	8.8
Hornblende	12	9	10	7	14	10.4	5	6	5	7	9	6.4
Muscovite	6	-	-	4	1	2.2	4	1	-	5	1	2.2
Garnet	-	-	-	-	-	-	-	-	-	1	-	0.2
Magnetite	-	-	-	-	-	-	-	-	-	-	1	0.2
Opaque	1	3	2	4	-	2	-	3	-	4	3	2
	100	100	100	100	100	98	100	100	100	100	100	100

Table 4.2, continued.

Rock type	OGf	OGf	OGf	OGf	OGf	Mean	Ch	Ch	Ch	Ch	Ch	Mean
Minerals	Slide 1	Slide 2	Slide 3	Slide 4	Slide 5		Slide 1	Slide 2	Slide 3	Slide 4	Slide 5	
Quartz	22	28	31	38	28	29.4	17	24	21	15	19.5	19.3
Plagioclase (Albite)	8	12	11	9	10	10	31	34	28	37	32.5	32.5
Orthoclase	29	21	24	19	22	23.3	-	-	3	-	1	0.8
Microcline	8	-	1	3	3	3	-	-	-	-	-	-
Biotite	12	15	9	9	11.5	11.3	29	24	24	21	24.5	24.5
Hornblende	7	7	4	9	7	6.8	13	13	10	16	13	13
Muscovite	5	5	9	6	6	6.2	-	1	-	-	-	0.2
Pyroxene	1	5	-	-	1.5	1.5	8	3	9	6	6.5	6.5
Garnet	1	-	-	-	0.25	0.25	-	-	-	-	-	-
Magnetite	-	-	1	-	-	0.25	-	-	-	4		1
Opaque	7	7	10	8	10	8	2	1	5	1		2.2
Others	100	100	100	100	99	100	100	100	100	100	100	100

Table 4.3a: Analytical result (%) of the basement rocks in Idanre area.

SID	Rock	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	LOI	Sum
B6	M	65.32	14.98	5.91	1.73	3.8	3.03	3.92	0.6	0.17	0.09	0.2	99.84
C1	M	57.66	16.83	8.47	1.36	3.55	3.58	5.64	1.37	0.34	0.1	0.3	99.55
C5	M	60.85	14.76	8.53	1.41	3.49	3.05	5.25	1.45	0.47	0.12	0.2	99.74
C7	M	65.04	15.1	6.17	1.89	4.17	3.18	3.17	0.64	0.18	0.09	0.1	99.83
C11	M	55.94	17.58	8.59	1.45	3.71	3.81	5.83	1.44	0.33	0.11	0.4	99.51
Avg.		**60.96**	**15.85**	**7.53**	**1.57**	**3.74**	**3.33**	**4.76**	**1.1**	**0.3**	**0.10**	**0.24**	
A1	OGu	66.5	14.27	6.56	0.67	2.26	3.07	4.95	0.78	0.23	0.07	0.3	99.82
B12	OGu	59	20.79	4.08	1.14	5.12	5.85	2.67	0.36	0.12	0.07	0.5	99.8
B14	OGu	64.2	17.89	2.33	0.58	1.95	3.11	8.4	0.19	0.11	0.04	0.7	99.81
B15	OGu	62.97	18.71	2.88	0.65	2.83	4.05	6.51	0.2	0.08	0.04	0.6	99.82
C4	OGu	66.51	14.94	4.53	1.44	2.92	3.28	4.68	0.66	0.22	0.06	0.4	99.79
D3	OGu	72.14	13.68	2.7	0.18	1.18	2.81	6.35	0.3	0.05	0.03	0.3	99.83
D13	OGu	71.95	13.79	3.1	0.29	1.35	3.13	5.52	0.3	0.04	0.03	0.2	99.74
D14	OGu	72.49	13.54	2.91	0.18	1.04	2.73	6.46	0.26	0.03	0.03	0.1	99.83
D24	OGu	64.28	14.25	6.88	1.17	3.47	3.37	4.24	1.04	0.31	0.09	0.5	99.71
D26	OGu	66.6	16.5	2.35	0.26	1.49	3.18	8.44	0.23	0.06	0.03	1.3	99.7
D32	OGu	60.99	19.84	3.13	0.72	4.43	5.37	3.61	0.24	0.09	0.05	0.4	99.79
D33	OGu	63.91	18.36	2.58	0.58	3.21	4.28	5.44	0.18	0.08	0.04	1.3	99.84
D34	OGu	59.38	20.37	4.18	1.17	5.1	5.84	2.44	0.4	0.13	0.07	1	99.85
D35	OGu	61.09	19.82	3.36	0.86	4.22	5.18	4.11	0.29	0.09	0.05	0.6	99.8
D36	OGu	63.78	15.42	5.78	1.94	3.45	3.55	4.07	0.81	0.29	0.07	0.6	99.82
D39	OGu	69.88	13.4	4.57	0.67	2.26	2.69	4.89	0.6	0.16	0.05	0.5	99.77
D40	OGu	72.46	13.3	3.36	0.2	1.17	2.74	6.01	0.27	0.04	0.04	0.2	99.85
Avg.		**65.77**	**16.40**	**3.85**	**0.75**	**2.79**	**3.78**	**5.22**	**0.42**	**0.16**	**0.05**	**0.57**	

Table 4.3a, continued.

SID	Rock	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	LOI	Sum
A15	OGp	73.76	12.68	2.88	0.37	1.42	2.67	5.29	0.36	0.08	0.03	0.2	99.83
B8	OGp	74.52	12.29	2.74	0.22	1.33	2.83	4.87	0.23	0.04	0.03	0.7	99.81
B9	OGp	71.15	13.82	3.2	0.42	1.62	2.95	5.75	0.41	0.1	0.03	0.3	99.83
B11	OGp	59.5	20.68	3.55	0.94	4.83	5.82	3.14	0.34	0.1	0.05	0.7	99.81
B16	OGp	69.61	14.34	3.23	0.41	1.67	2.89	6.53	0.34	0.09	0.04	0.6	99.83
B19	OGp	68.27	14.02	4.83	0.75	2.68	3.19	4.46	0.68	0.19	0.06	0.5	99.75
B20	OGp	60.14	15.58	8.35	1.63	4.17	3.67	3.75	1.31	0.4	0.1	0.4	99.65
B23	OGp	67.92	15.76	2.74	0.32	1.76	3.44	6.54	0.29	0.08	0.03	0.9	99.83
D2	OGp	71.05	13.55	3.63	0.38	1.77	3.12	5.08	0.31	0.07	0.04	0.8	99.84
D11	OGp	68.49	13.53	4.98	0.67	2.28	2.71	5.23	0.66	0.17	0.06	0.9	99.74
D19	OGp	69.46	14.57	3.55	0.39	2.07	3.44	4.99	0.38	0.1	0.04	0.8	99.82
D25	OGp	63.91	14.35	6.41	0.99	2.56	3.05	5.53	1.08	0.25	0.08	1.3	99.70
Avg.		**68.15**	**14.60**	**4.17**	**0.54**	**2.35**	**3.32**	**5.10**	**0.53**	**014**	**0.05**	**0.68**	
B10	OGf	63.6	15.38	6.00	1.08	2.97	3.13	5.74	0.9	0.31	0.07	0.4	99.74
A17	OGf	65.97	14.43	6.32	0.85	3.01	3.55	3.9	0.84	0.27	0.07	0.4	99.68
A10	OGf	67.87	15.09	3.98	0.48	1.93	3.25	6.15	0.49	0.14	0.04	0.3	99.81
Avg.		**65.81**	**14.97**	**5.43**	**0.8**	**2.64**	**3.31**	**5.26**	**0.74**	**0.24**	**0.06**	**0.37**	
D28	Ch	63.53	16.59	5.23	0.52	2.51	3.66	6.41	0.62	0.14	0.09	0.6	99.87
D29	Ch	60.62	16.61	7.15	0.72	2.91	3.72	6.19	0.9	0.21	0.13	0.3	99.77
D30	Ch	63.7	16.88	4.81	0.46	2.4	3.81	6.43	0.52	0.12	0.08	0.4	99.7
Avg.		**62.62**	**16.69**	**5.73**	**0.57**	**2.61**	**3.73**	**6.34**	**0.68**	**0.16**	**0.1**	**0.43**	

Table 4.3b: Trace element composition (ppm) of rocks in the study area.

SID	Rock	Sc	Ba	Be	Co	Cs	Ga	Hf	Nb	Rb	Sn	Sr	Ta
B6	M	10	844	4	12.7	0.6	16	5.2	14.5	151.8	4	348.3	0.9
C1	M	14	3201	4	12.2	0.1	20.8	36.1	61.6	134.8	<1	582.7	19.2
C5	M	12	1567	<1	16.7	0.3	19.7	14.7	48	163.4	3	280.2	21.1
C7	M	10	687	4	14.1	0.5	16.2	6.2	17	140.7	4	338.7	1
C11	M	13	3054	6	13.9	0.1	22.8	42.4	61.5	154.4	1	580.7	15.1
Avg.		**11.8**	**1871**		**13.9**	**0.3**	**19.1**	**20.9**	**40.5**	**149.8**		**426.1**	**11.5**
A1	OGu	9	1402	1	7.5	0.1	21.7	14.3	30.7	145.2	1	229.8	1.3
B12	OGu	15	824	5	8.2	0.1	21.4	5	11.4	80.2	<1	831.9	0.7
B14	OGu	7	3256	4	4.3	0.2	14.4	4.4	26.2	229.2	<1	711.1	20.2
B15	OGu	10	2622	4	4.7	0.3	16.4	4.2	8.8	187.8	<1	735	0.5
C4	OGu	7	1472	2	9.8	0.5	18.9	8.2	26.5	166.4	2	488.6	1.9
D3	OGu	1	1119	2	2.2	0.2	15.2	10.2	30.5	205.1	<1	235.3	23.7
D13	OGu	1	497	2	1.8	0.6	20	11.2	53.4	243.9	<1	93.9	26.8
D14	OGu	3	573	6	1.4	0.5	17.7	7.7	20.1	259.3	1	90	0.9
D24	OGu	12	1242	3	9.8	0.1	18.8	19.1	47.1	167.9	2	323.4	2.4
D26	OGu	9	1479	<1	11.5	0.3	19	17.5	61.2	174.7	1	289.3	0.4
D32	OGu	7	1694	<1	4.4	0.4	20.6	14.6	42.7	133	<1	241.2	0.6
D33	OGu	6	1009	6	5.1	0.1	20.3	4.3	10.1	88.7	<1	683	0.6
D34	OGu	5	1716	2	4.4	0.1	18.2	3.2	20.2	126	<1	651	13.5
D35	OGu	12	676	6	7.7	0.2	20.7	5.5	11.6	71	<1	748.4	0.5
D36	OGu	11	1281	2	6.1	0.2	18.4	4.1	21.8	107.8	<1	750.2	1.3
D39	OGu	7	851	<1	5.6	0.2	16.4	12.4	42.9	166.5	2	247.1	18.8
D40	OGu	3	539	2	2	0.6	19.5	8.5	24.5	252.7	2	90.7	1.1
Avg.		**7.3**	**1309**		**5.7**	**0.3**	**18.7**	**9.1**	**28.8**	**165.0**		**437.6**	**6.8**

Table 4.3b, continued.

SID	Rock	Sc	Ba	Be	Co	Cs	Ga	Hf	Nb	Rb	Sn	Sr	Ta
A15	OGp	4	819	1	3.5	0.1	16.5	8.7	59	164.4	<1	214.6	45.6
B8	OGp	3	391	4	2.9	0.4	16.1	6.9	81.7	230.8	<1	115.3	67.2
B9	OGp	3	1057	1	3.7	0.1	16.9	8.6	14.7	181.5	<1	235.5	0.6
B11	OGp	10	983	3	6.3	0.4	21.7	4.6	39.1	84	<1	770.1	31.1
B16	OGp	4	948	2	3.6	0.1	17.1	9.6	42.5	260.1	<1	204.6	25.2
B19	OGp	6	1288	1	6.6	0.1	17.4	14.6	25.6	142.7	<1	312.6	1.2
B20	OGp	12	1409	4	14.2	0.3	23.1	23.4	78.2	161.2	2	386.1	26.2
B23	OGp	3	915	5	2.8	0.1	19.6	7.9	14.2	257.3	<1	226.3	0.5
D2	OGp	6	857	<1	4.7	0.2	16	10.1	11.9	172	1	223.2	0.6
D11	OGp	8	831	3	5.6	0.1	17.2	14.1	26.9	169.4	2	244.9	1.4
D19	OGp	3	733	3	3.6	0.1	17	10.4	39.5	185	<1	182.8	25.1
D25	OGp	9	1479	<1	11.5	0.3	19	17.5	61.2	174.7	1	289.3	16.5
Avg.		**5.9**	**975.8**		**5.8**	**0.2**	**18.1**	**11.4**	**41.2**	**181.9**		**283.8**	**20.1**
B10	OGf	9	1721	2	10.6	0.3	20	14.4	45.8	185.5	1	365.7	13.2
A17	OGf	9	702	5	8.1	0.2	20.8	17.2	35.2	146.2	1	222.4	1.4
A10	OGf	4	992	4	4.8	0.2	18.7	8.1	36	194.1	<1	252.3	19.2
Avg.		**7.3**	**1138**		**7.83**	**0.23**	**19.8**	**13.2**	**39**	**175.3**		**280.1**	**11.3**
D28	Ch	2	1295	1	2.8	0.2	18.7	5.4	11	302.4	<1	246.4	12.5
D29	Ch	9	1624	2	4.5	0.3	21.6	19	42.4	132.5	<1	238.9	2.1
D30	Ch	12	1525	<1	6	0.4	21.5	26.3	48.5	123.5	<1	227.7	16.6
Avg.		**7.7**	**1481**		**4.4**	**0.3**	**20.6**	**16.9**	**33.9**	**186.1**		**237.7**	**10.4**

Table 4.3b, continued.

ID	Rock	Th	U	V	W	Zr	Y	La	Ce	Pr	Nd	Sm	Eu
B6	M	32.4	1.9	66	<0.5	182.2	31.7	58	108.5	11.38	41.5	7.24	1.45
C1	M	3.5	0.9	31	<0.5	1754.5	48.6	134.5	285.8	33.99	131.2	21.69	4.86
C5	M	17.7	1.6	72	<0.5	616.5	49.5	105	206	22.56	82.2	14.12	3.04
C7	M	36.2	2.1	71	<0.5	217.7	35	59.9	107.3	11.59	43.1	6.94	1.38
C11	M	5.2	1.1	31	<0.5	2025.8	50.3	137.4	285.9	33.03	122.3	19.99	4.45
Avg.		**19**	**1.5**	**54**		**959.3**	**43.0**	**98.9**	**198.7**	**22.5**	**84.1**	**14.0**	**3.04**
A1	OGu	20.5	1.7	18	<0.5	615.1	35.5	61.5	167.3	14.37	52.4	10.24	2.35
B12	OGu	11.3	1	56	<0.5	187.7	22.6	71.2	134.5	13.85	49.2	8.02	1.94
B14	OGu	18.5	1.3	22	<0.5	171.3	17.2	103.2	180.5	16.88	53.4	7.27	2.31
B15	OGu	9.9	0.9	25	<0.5	150.3	21.1	62.7	111	12.6	43.6	7.37	2.34
C4	OGu	19.3	1.6	46	<0.5	332.4	29.1	92	145.7	16.85	56.5	8.87	1.84
D3	OGu	33.4	1.8	12	<0.5	389.7	10.4	142.3	237.7	21.77	62.3	7.25	1.57
D13	OGu	103.2	6.4	<8	<0.5	373.3	25.2	332.9	627.5	59.2	182.6	22	1.36
D14	OGu	64.3	5.9	<8	<0.5	279.9	31	172.6	317.3	32.22	104.7	14.73	1.36
D24	OGu	22.6	1.7	47	<0.5	819.7	54.2	148.2	293.4	31.57	113.4	18.94	2.67
D26	OGu	29.7	1.2	18	<0.5	206.1	13.5	94.5	163.7	15.73	49.5	6.45	1.85
D32	OGu	11	1.2	21	<0.5	166.7	17.8	68.6	121.3	12.35	42.3	6.86	2.1
D33	OGu	12.9	0.8	14	<0.5	120.6	12.6	83	132.6	12.49	41.1	5.25	1.99
D34	OGu	8.3	1.1	61	<0.5	211.9	20.5	72.1	133.2	13.43	47.8	7.78	2.02
D35	OGu	10.7	1.8	42	<0.5	155	18.4	55.2	100.5	10.55	36.5	5.76	1.8
D36	OGu	21.2	2.5	52	<0.5	395.9	25.4	102.8	191.6	18.64	64.4	9.15	1.79
D39	OGu	51.3	1.7	20	<0.5	514.8	36.8	215.4	387.6	38.1	122.5	16.24	2.07
D40	OGu	44.5	4.4	<8	<0.5	300.5	34.3	135.6	251.4	25.32	84.2	13.13	1.36
Avg.		**28.9**	**2.2**			**317.1**	**25.0**	**118.5**	**217.5**	**21.52**	**70.9**	**10.31**	**1.92**

Table 4.3b, continued.

SID	Rock	Th	U	V	W	Zr	Y	La	Ce	Pr	Nd	Sm	Eu
A15	OGp	25.5	1.9	9	<0.5	371.2	18	138	244.1	22.62	71.5	9.29	1.8
B8	OGp	111.5	11.8	10	<0.5	244.6	20	200.9	360.9	33.57	99.3	13.1	1.14
B9	OGp	29.5	1.2	13	<0.5	336.8	18.2	154.8	267	25.07	79.5	9.85	1.89
B11	OGp	10.7	1.5	41	<0.5	166.4	17.9	66.7	121.2	12.29	43.5	6.62	1.95
B16	OGp	30.8	2.1	12	<0.5	343.8	23	111.0	206.1	20.07	66.3	9.39	1.71
B19	OGp	29.1	0.9	23	<0.5	651.2	28.8	177.4	324.9	31.84	104.8	14.15	2.66
B20	OGp	15.2	1.5	53	0.5	1024.5	62.7	136.7	303.4	34.73	135.1	23.72	3.1
B23	OGp	44.7	2	12	<0.5	298.6	19.5	151.7	270.8	25.54	80.9	9.85	1.68
D2	OGp	29.7	1.7	15	<0.5	392.4	20.8	108.2	188.6	18.83	60.8	8.94	1.67
D11	OGp	65.8	1.6	24	<0.5	554.9	42.9	226.3	412	40.72	132	18.19	2.22
D19	OGp	46.2	2.7	14	<0.5	387.8	19.7	150.1	269.9	26.41	82.9	10.68	1.5
D25	OGp	31.3	1.9	37	<0.5	798.7	47.8	188.8	357.7	38.7	136.3	21.5	3.38
Avg.		**39.2**	**2.6**	**21.9**		**464.2**	**28.8**	**150.9**	**277.2**	**27.5**	**91.1**	**12.94**	**2.06**
B10	OGf	18.4	1.4	41	<0.5	619.1	43	141.7	281.8	29.88	105.7	16.72	2.74
A17	OGf	59.5	2	28	<0.5	741.2	49.2	343.8	621.5	59.03	186.5	25.17	2.38
A10	OGf	29.4	1.5	18	<0.5	353.8	22.1	160.5	283.8	75.61	88.5	12.29	2.28
Avg.		**35.8**	**1.6**	**29**		**571.4**	**38.1**	**215.3**	**395.7**	**54.8**	**126.9**	**18.06**	**2.47**
D28	Ch	16.7	2.1	17	<0.5	789.1	29.2	97.7	186.3	19.66	73.5	11.44	3.3
D29	Ch	27.6	2.9	33	<0.5	1159.7	36.1	136.7	266.1	28.23	103.8	15.96	3.24
D30	Ch	20.2	2.3	21	<0.5	629.6	22	124.2	213.8	21.22	75	9.84	3.31
Avg.		**21.5**	**2.4**	**23.7**		**859.5**	**29.1**	**119.5**	**222**	**23.04**	**84.1**	**12.4**	**3.28**

Table 4.3b, continued.

SID	Rock	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	TOT/C (%)	TOT/S (%)
B6	M	6.22	0.91	5.35	1.09	3.4	0.51	3.41	0.5	0.02	<0.02
C1	M	16.37	2.07	11.25	1.88	5.27	0.68	4.4	0.62	0.03	<0.02
C5	M	12.23	1.81	9.75	1.92	5.26	0.73	4.59	0.66	0.05	<0.02
C7	M	6.63	1.01	6.01	1.27	3.69	0.54	3.66	0.6	0.03	<0.02
C11	M	14.79	1.91	10.12	1.82	4.9	0.7	4.53	0.65	0.16	<0.02
Avg.		**11.25**	**1.54**	**8.5**	**1.60**	**4.5**	**0.63**	**4.12**	**0.61**	**0.06**	
A1	OGu	9	1.36	7.24	1.39	3.79	0.53	3.33	0.48	<0.02	<0.02
B12	OGu	6.14	0.85	4.47	0.85	2.16	0.32	2.03	0.29	0.06	<0.02
B14	OGu	5.26	0.68	3.49	0.64	1.76	0.22	1.42	0.22	0.09	<0.02
B15	OGu	5.38	0.78	4.31	0.72	2.14	0.29	1.88	0.24	0.1	<0.02
C4	OGu	7.1	0.98	5.48	0.98	2.89	0.39	2.61	0.39	<0.02	<0.02
D3	OGu	4.1	0.52	2.35	0.35	0.91	0.13	0.83	0.13	0.1	<0.02
D13	OGu	12.48	1.36	5.79	0.89	2.27	0.31	1.87	0.25	0.05	<0.02
D14	OGu	10.2	1.36	7.26	1.26	3.41	0.44	2.68	0.38	0.03	<0.02
D24	OGu	14.45	2.01	11.18	1.98	5.59	0.77	4.67	0.66	0.11	<0.02
D26	OGu	4.46	0.56	3.07	0.53	1.36	0.17	1.14	0.17	0.11	<0.02
D32	OGu	4.87	0.68	3.42	0.62	1.74	0.26	1.42	0.22	0.21	<0.02
D33	OGu	3.79	0.48	2.66	0.51	1.41	0.2	1.2	0.18	0.15	<0.02
D34	OGu	5.54	0.75	4.04	0.71	2.22	0.29	1.82	0.24	0.08	<0.02
D35	OGu	4.46	0.63	3.25	0.63	1.75	0.24	1.63	0.24	0.07	<0.02
D36	OGu	11.7	0.86	4.69	0.91	2.37	0.37	2.37	0.32	0.02	<0.02
D39	OGu	11.8	1.54	8	1.35	3.6	0.46	2.99	0.42	0.12	<0.02
D40	OGu	9.9	1.37	7.36	1.29	3.67	0.5	3.03	0.41	0.04	<0.02
Avg.		**7.68**	**0.99**	**5.34**	**0.92**	**2.57**	**0.35**	**2.17**	**0.31**		

Table 4.3b, continued.

SID	Rock	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	TOT/C (%)	TOT/S (%)
A15	OGp	5.89	0.73	4	0.6	1.61	0.24	1.42	0.22	<0.02	<0.02
B8	OGp	7.52	0.92	4.61	0.74	1.94	0.28	1.71	0.25	0.08	<0.02
B9	OGp	6.56	0.79	3.9	0.66	1.74	0.22	1.4	0.21	<0.02	<0.02
B11	OGp	5.05	0.66	3.91	0.7	1.88	0.24	1.53	0.26	0.11	<0.02
B16	OGp	7.41	0.93	5.02	0.95	2.57	0.3	1.9	0.28	0.11	<0.02
B19	OGp	10.12	1.21	6.37	1.06	2.7	0.39	2.29	0.33	0.09	<0.02
B20	OGp	17.63	2.46	12.91	2.32	6.26	0.84	5.18	0.74	0.05	<0.02
B23	OGp	6.73	0.84	4.03	0.64	2	0.24	1.57	0.21	0.08	<0.02
D2	OGp	6.29	0.85	4.36	0.76	2.15	0.29	1.66	0.25	0.14	0.08
D11	OGp	13.08	1.76	9.28	1.63	4.45	0.6	3.47	0.46	0.12	<0.02
D19	OGp	7.32	0.87	4.13	0.75	2.13	0.27	1.65	0.25	0.11	<0.02
D25	OGp	15.82	2.02	10.81	1.81	5	0.65	4	0.56	0.25	<0.02
Avg.		**9.12**	**1.17**	**6.11**	**1.05**	**2.87**	**0.38**	**2.3**	**0.34**		
B10	OGf	12.5	1.71	9.34	1.61	4.38	0.58	3.45	0.53	0.02	<0.02
A17	OGf	17.09	2.13	10.73	1.92	5.08	0.64	4.04	0.56	0.04	0.02
A10	OGf	8.52	1.05	5.23	0.87	2.44	0.29	1.92	0.26	0.02	<0.02
Avg.		**12.7**	**1.63**	**8.40**	**1.47**	**3.97**	**0.50**	**3.14**	**0.45**		
D28	Ch	9.38	1.14	6.25	1.13	3.1	0.42	2.74	0.45	0.08	<0.02
D29	Ch	12.05	1.57	7.95	1.43	4.04	0.56	3.74	0.58	0.08	<0.02
D30	Ch	7.32	0.86	4.56	0.8	2.23	0.31	2.05	0.36	0.07	<0.02
Avg.		**9.58**	**1.19**	**6.25**	**1.12**	**3.12**	**0.43**	**2.84**	**0.46**		

Table. 4.3c: Abundance of Trace elements in geological materials compared to Idanre Granite (after Taylor, 1962).

Tr. Element.	Zr	Hf	Y	Li	Rb	Cs	Be	B	Sr	V	Cr	Th	U	Nb	Ta	Mo	W	Y	Sc
Chondrite	35	0.2	2	2.7	2.3	0.18	1	5	10	70	2500	0.03	0.01	0.5	0.04	1.5	0.14	2	11
Crust	165	3	30	20	90	3	2.8	10	375	135	100	10	2.7	20	2	1.5	1.5	30	16
Ultra-basic	50	0.5	-	-	-	-	-	5	1	50	2000	0.003	0.001	15	1	0.3	0.5	-	10
Basalt	150	2	25	10	30	1	0.5	5	465	250	200	2.2	0.6	20	0.5	1	1	25	38
Granite	180	4	40	30	150	5	5	15	285	20	4	17	4.8	20	3.5	2	2	40	5
IGC	**450.9**	**11.21**	**30.47**	**nd**	**174**	**nd**	**nd**	**-nd-**	**318.5**	**26.3**	**nd**	**34.63**	**2.13**	**36.34**	**12.72**	**nd**	**<0.5**	**30.47**	**6.84**
Grey- wacke	140	2	10	-	-	-	-	-	-	70	140	10	3	20	2	-	2	10	10
Shale	160	3	25	-	-	-	-	-	-	130	100	12	4	20	2	3	2	25	15

Table. 4.3d: Abundance of REE in geological materials compared to Idanre granite (after Taylor, 1962).

REE	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Chondrite	0.39	1.05	0.15	0.62	0.21	0.072	0.27	0.049	0.32	0.079	0.22	0.037	0.19	0.03
Crust	30	60	8.2	28	6	1.2	5.4	0.9	3	1.2	2.38	0.48	3	0.5
Ultra-basic	3.3	8	1.02	3.4	0.57	0.16	0.65	0.088	0.59	0.14	0.36	0.053	0.43	0.064
Basalt	10.5	35	3.9	17.8	4.2	1.27	4.7	0.63	3	0.64	1.69	0.21	1.11	0.2
Granite	25	46	4.6	18	3	-	2	0.05	0.5	0.07	0.2	-	0.06	1.01
IGC	**161.55**	**296.79**	**34.6**	**96.31**	**13.77**	**2.15**	**9.8**	**1.26**	**6.62**	**1.17**	**3.14**	**0.41**	**2.54**	**0.37**
Grey- wacke														
Shale	20	50	6	24	6	1	6	1	5	1	2	0.2	3	0.5

4.4.1.1 Migmatite

Migmatite gneiss in Idanre area contains average SiO_2 content of 60.96% with values that range between (55.94 – 65.32%) (Table 4.3a). The range of SiO_2 in migmatite-gneiss unit of Idanre area is comparable to gneiss of the Obudu area (53-66%) (Ekwueme and Kröner, 2006) and melanocratic gneissic biotite-hornblende (58.08-59.81%) rocks encountered in southern parts of Ilesha (Elueze, 1982). This value is lower than mean value (68.6%) reported for migmatite from Ekiti area (Talabi, 2013). CaO content which range from 3.49-4.17% with average value of 3.74 in Idanre migmatite is significantly higher than those recorded for Akwanga gneiss (1.48-2.08%) located within the basement area of north central Nigeria (Onyeagocha, 1986). The Idanre migmatite contains alumina content (Al_2O_3) which ranges from 14.76 to 17.58% with average of 15.85%, these values are comparable to garnet sillimanite gneiss reported from Obudu area (Ekwueme and Kröner, 2006), and Ekiti migmatite (15.1%) (Talabi, 2013). The high content of K-feldspar in the modal composition probably was responsible for the high alkali content and this may suggest derivation from protoliths that have alkaline to calc-alkaline signature. Migmatite in Idanre contain high alkali content ($K_2O + Na_2O$) ranging between 6.35 to 9.64 wt. %. This value is comparable to average of 7.92% for Ekiti migmatite. The high alkali content in the Idanre migmatite is reflected in Na_2O+K_2O values that range between 6 and 10. However, the rock generally contains lower TiO_2 (1.1%), MgO (1.57%) and MnO (0.1%). This compositional characteristic is comparable to granitoid rocks. The unprecedented high value of Fe_2O_3 and MgO in migmatite may be attributed to abundance of ferromagnesian minerals and redistribution of ions during metamorphic transformation.

4.4.1.2 Granitoids

Analytical result (Table 4.3a) indicate that each of the granite units in the study area is compositionally unique. Although each member has oxide values that agree to the general chemistry of granitoids in the basement complex terrain of Nigeria, but each has minor variations in their elemental abundances. For instance, all the granites contain SiO_2 contents that exceeds all other oxides.

From literature, Oluyide et al., (1998) indicated the Undifferentiated coarse-grained granite (OGu) unit around Ilorin area is associated with assortment of migmatites, augen gneisses and granitic bodies which individually cannot be presented cartographically but have been collectively designated as undifferentiated Older Granite. This unit is usually coarse-grained and has been reported from different parts of the basement of southwestern Nigeria. These include Ado-Ekiti-Ikere area (Olarewaju and Rahaman, 1982), Ilorin area (Oluyide at al., 1998) and Idanre area among others. Coarse-grained granite from Idanre contains average SiO_2 content of 65.77%. This value is marginally lower than (67.19 wt. %) recorded for similar rocks from Ado-Ikere Ekiti area and 69.94 wt. % for that in Ilorin area. Total alkali content ($K_2O + Na_2O$) in OGu range between 7.58 to 11.62 wt % with an average of 9.00 wt. %. This value is marginally higher than average of 8.42% for Semorika granite in Igarra area and contains lower TiO_2 (0.42%), MgO (0.75%) and MnO (0.05%). Porphyritic granite (OGp) contains average SiO_2 content of 68.15% while average Al_2O_3 is 14.6%. ($K_2O + Na_2O$) value range between 7.42 to 9.98% with average of 8.42%.

Fine-grained granite contains average SiO_2 content of 65.81% and average alumina content of 14.97%. $K_2O + Na_2O$ values range between 7.45 to 8.87 with average value of 8.57%. This compositional characteristic is comparable to granitoid rocks in other parts of the country. For instance, SiO_2 content in undifferentiated Older granite (OGu), porphyritic (OGp), the fine-grained granite (OGf) are all within the upper limit values

(71.90-75.00%) reported from granites in Ekiti (Talabi, 2013); porphyritic granite (74.25-76.52%) and medium-grained granite (73.52%-75.43%) from Ado-Ekiti area (Oyinloye and Obasi, 2006). However, the Idanre granite complex spread across wider range of SiO_2 values. These values are also comparable to the granite from Solli Hills (63.84-75.09%), Rahama amphibole-biotite granite (65.59-67.87%), Monzonite (62.92-67.79%) and Toro amphibole-biotite granite (65.74-69.18%) (Ferré et al., 1998) from the basement complex of northcentral Nigeria.

Harker variation plots of major oxides against SiO_2 (Fig. 4.28) reflect the relative mobility that show distinctive trends for major elements. SiO_2 variation diagrams against TiO_2, Al_2O_3, FeO^t, MgO, CaO, Na_2O and P_2O_5, all show strong negative correlation. However, K_2O versus SiO_2 exhibits wide-spread data scatter but a positive trend. This positive trend may have resulted from K^+ ion mobilization attributable to albitization and weathering (Pearce, 1976), K-metasomatism or plagioclase fractionation. All granitoids in Idanre are generally enriched in alkali (Na_2O+K_2O).

The values of (Na_2O+K_2O) range from 7.58-11.62% for the undifferentiated granite (OGu) (ca. 9.00%), 7.42-9.98% for the porphyritic granite (OGp) (ca. 8.42%), and 7.45-9.40% for the fine-grained granite (OGf) (ca. 8.57%), explicitly, this is shown on K_2O versus SiO_2 binary diagram (Fig. 4.29). In this diagram, the granite type plot within the shoshonite and high-K calcic alkali field. According to Frost et al., (2001), the value of SiO_2 versus Na_2O+K_2O-CaO which divide the fields into alkalic, alkali-calcic, calcic alkali and calcic groups is useful for geochemical characterization of granites (Fig. 4.30), the Idanre granite plots mainly within the alkalic and alkali-calcic field. On Al/NK versus Al/CNK (Fig. 4.31a) plot (Chappell and White, 1974), (Mania and Piccoli, 1989) where Al/NK stands for $Al_2O_3/(Na_2O+K_2O)$ and Al/CNK $Al_2O_3/(CaO+Na_2O+K_2O)$, the plot

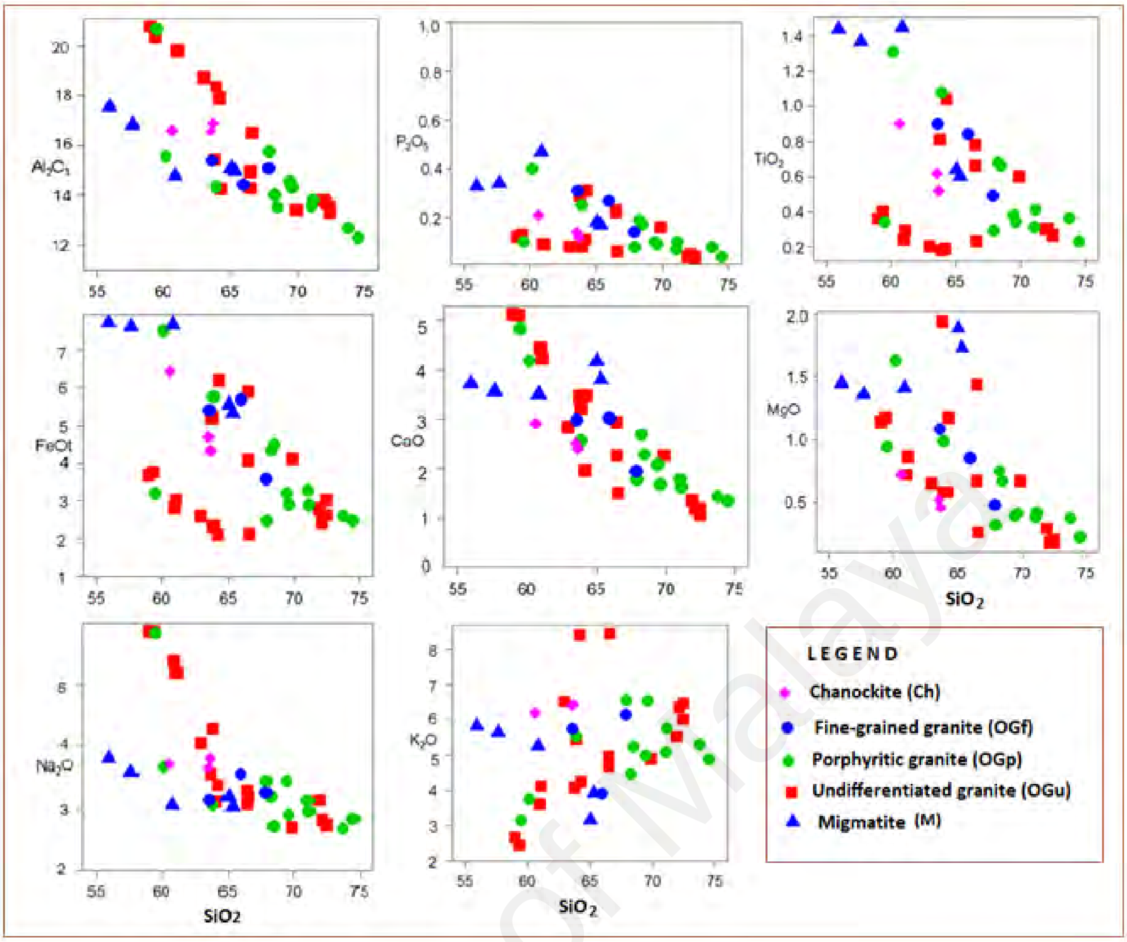

Figure 4.28: Negative trends in Major Element Harker Diagrams of rocks in Idanre area

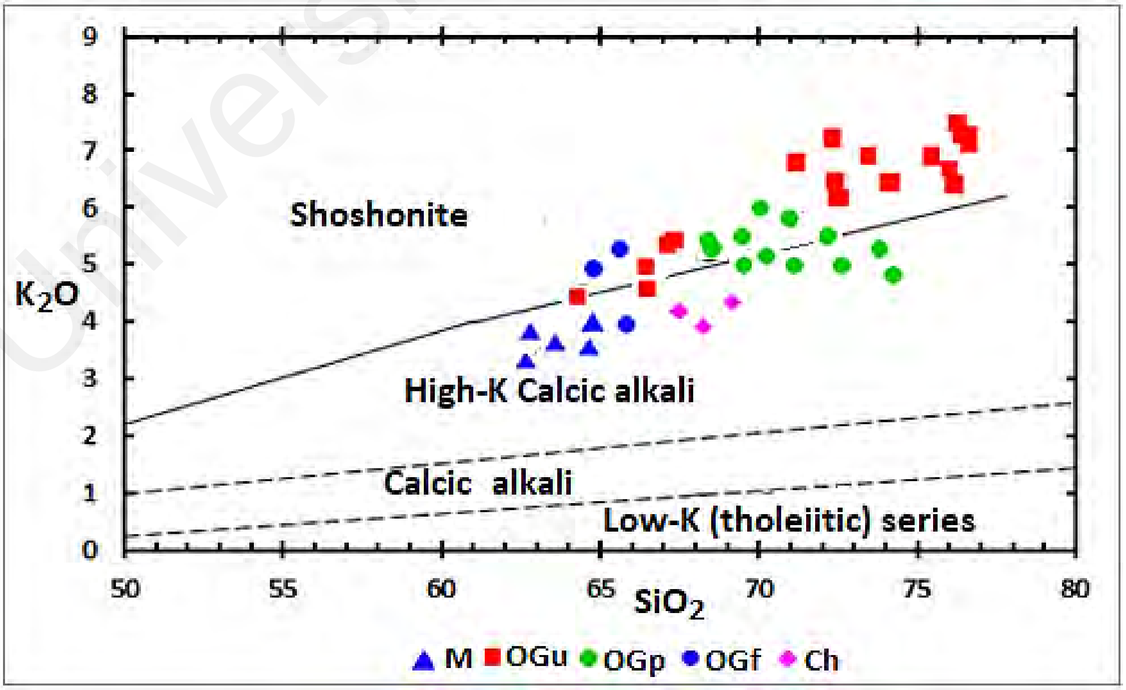

Figure 4.29: K_2O versus SiO_2 binary diagram of rocks in Idanre (after Peccerillo and Taylor, 1976)

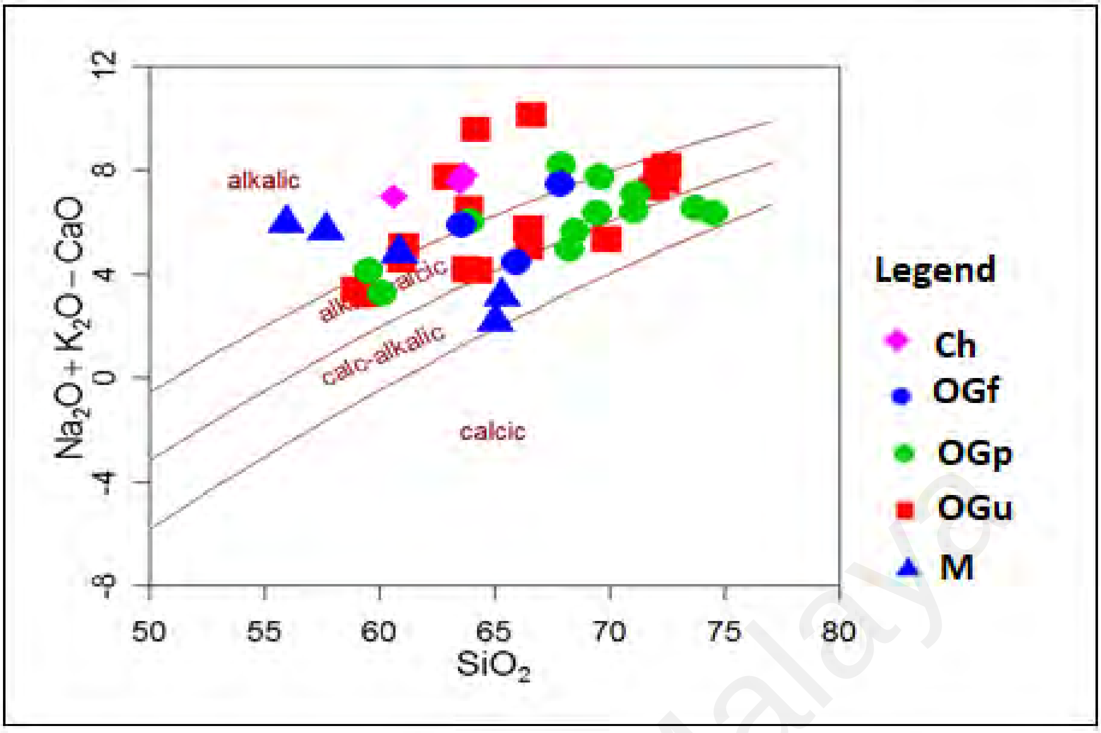

Figure 4.30: (Na_2O+K_2O-CaO) versus SiO_2 diagram for rocks in Idanre (The alkalic, alkali-calcic, calc-alkalic and calcic boundaries are after Frost et al. 2001)

classifies the granite as metaluminous. The geochemical classification of the granitoids into metaluminous group based on relative molecular proportions of Al_2O_3, Na_2O and K_2O as depicted in the plot of A/NK versus ACNK binary diagram (Fig. 4.31a), and ANK versus ASI diagram, where ASI stands for Alumina Saturation Index (Fig 4.31b). In the plot, Al/CNK values are consistently above 1.2 for all the granite samples. The characterization of the granite into I-type and S-types is further established on the K_2O versus Na_2O binary diagram (Fig. 4.32) where granite from the study area plots extensively within the I-type granite field. This imply that both the migmatite gneiss and granites clearly are sourced from anatexis of igneous rocks. The granites do not plot on the boundary line demarcating the two different fields to result in an ambiguous interpretation. The occurrence of mineral like sphene with its characteristic wedge-shaped crystals may further reinforce this igneous origin. The migmatitic gneiss, granites and charnockite all plot in igneous field.

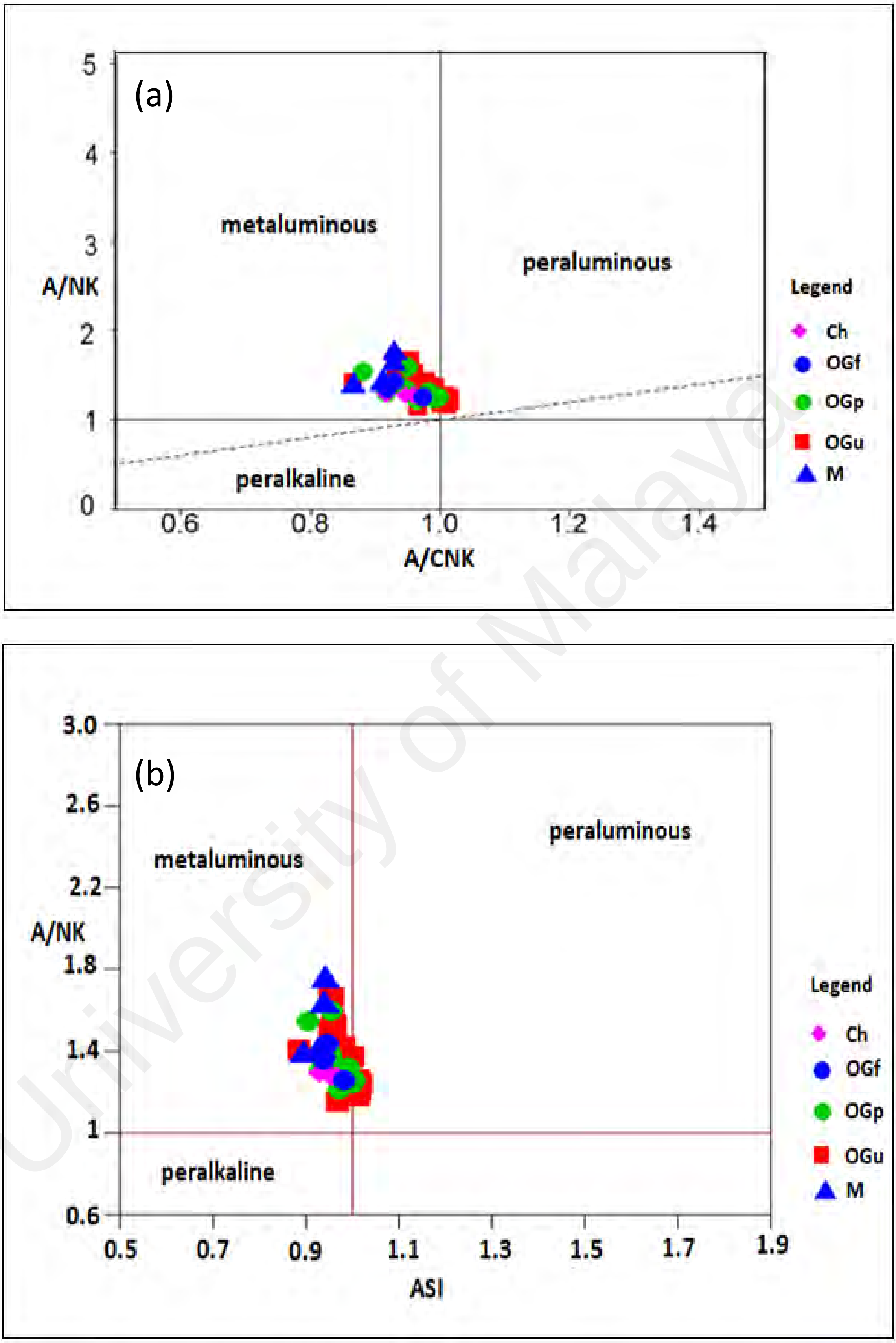

Figure 4.31: (a) Shand's Index Al_2O_3/Na_2O+K_2O versus $Al_2O_3/CaO+Na_2O+K_2O$ (ANK vs ACNK) binary diagram for rocks in Idanre (after Maniar and Piccoli 1989); (b) A/NK versus Alumina Saturation Index (ASI) binary plot for the rocks in Idanre.

which indicate some igneous antecedents for the rocks. This implies that all the rocks have a common igneous ancestry even though the metamorphic transformation that affected the migmatite gneiss had caused recycling and obliterated the original igneous character of the rocks. Classification of granite into I-type and S-types is further established on the K_2O versus Na_2O binary diagram (Fig. 4.32) where granite from the study area plots extensively within the I-type granite field. This imply that both the migmatite gneiss and granites clearly are sourced from anatexis of igneous rocks. The granites do not plot on the boundary line demarcating the two different fields to result in an ambiguous interpretation. The occurrence of mineral like sphene with its characteristic wedge-shaped crystals may further reinforce this igneous origin. The migmatitic gneiss, granites and charnockite all plot in igneous field which indicate igneous antecedents for the rocks. This implies that all the rocks have a common igneous ancestry even though the metamorphic transformation that affected the migmatite gneiss had caused recycling and obliterated the original igneous character of the rocks.

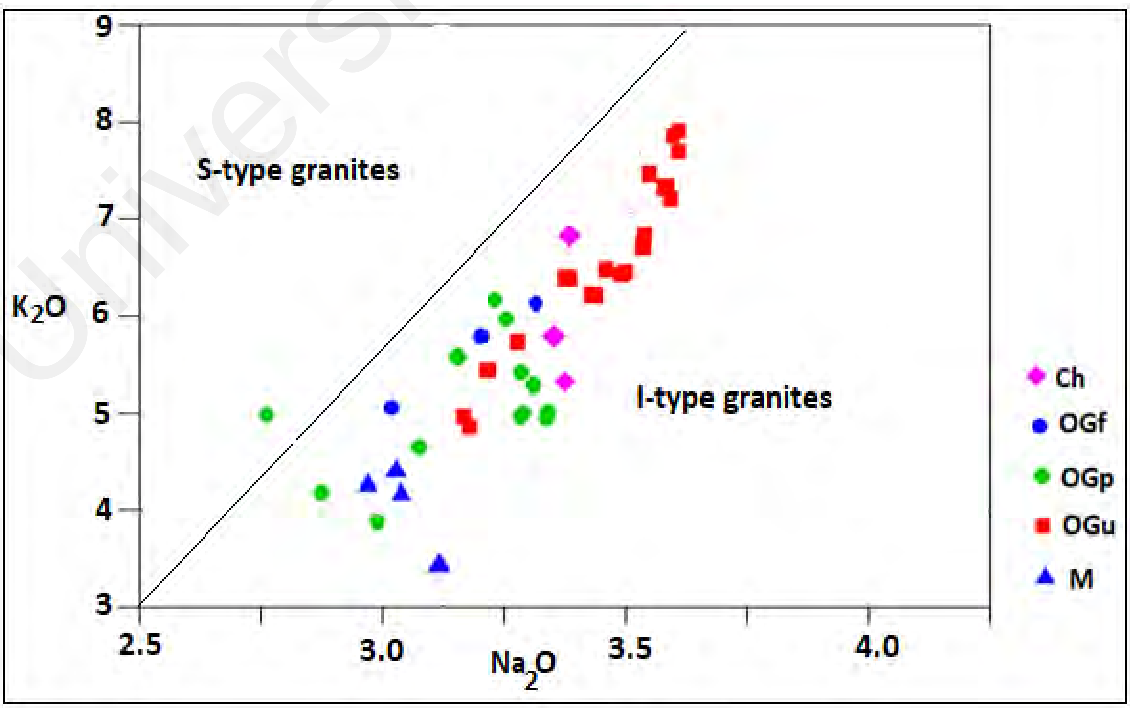

Figure 4.32: K_2O versus Na_2O diagram classifying the granite as I-type

4.4.2 Classification of Idanre rocks by Major elements

Geochemical features of rocks are useful to classify them into groups. On (Na_2O + K_2O) versus SiO_2 binary plot (Fig. 4.33), the rock plotted extensively on granite-syenogranite fields two of the samples of migmatite have high Na_2O and K_2O values, thereby pushing the plot towards Na_2O and K_2O enrichment by falling within syenite field. These samples, due to their low SiO_2 contents which makes them to plot within the syenite class and fall within the intermediate group of rocks. The others plot in the granodiorite class. Essentially, most of the undifferentiated coarse-grained granite, porphyritic granite and fine-grained granite that are characterized by higher silica values plots within the granite class, even though some strayed into the syenogranite and granodiorite fields. The binary diagram SiO_2 versus Nb/Y (Fig. 4.34) which divided the granite fields into granite, granodiorite and alkali granite subdivisions, the granite in the

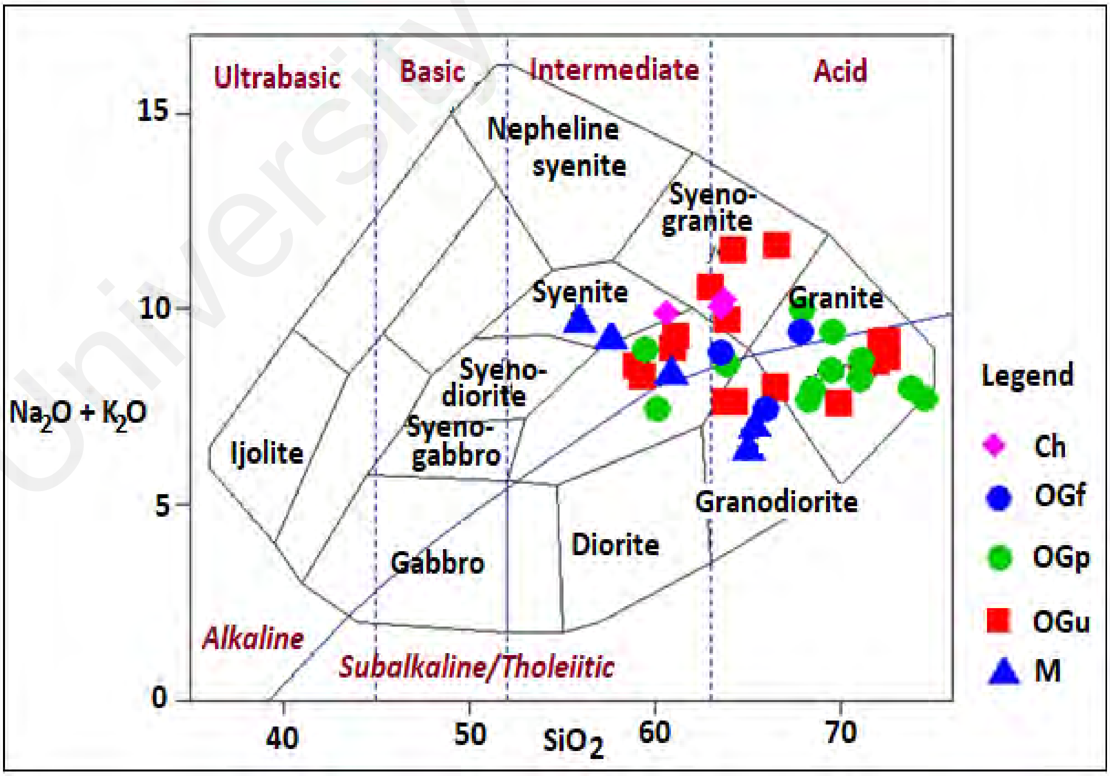

Figure 4.33: Na_2O+K_2O versus SiO_2 binary plot of rocks in Idanre (after Cox et al., 1979)

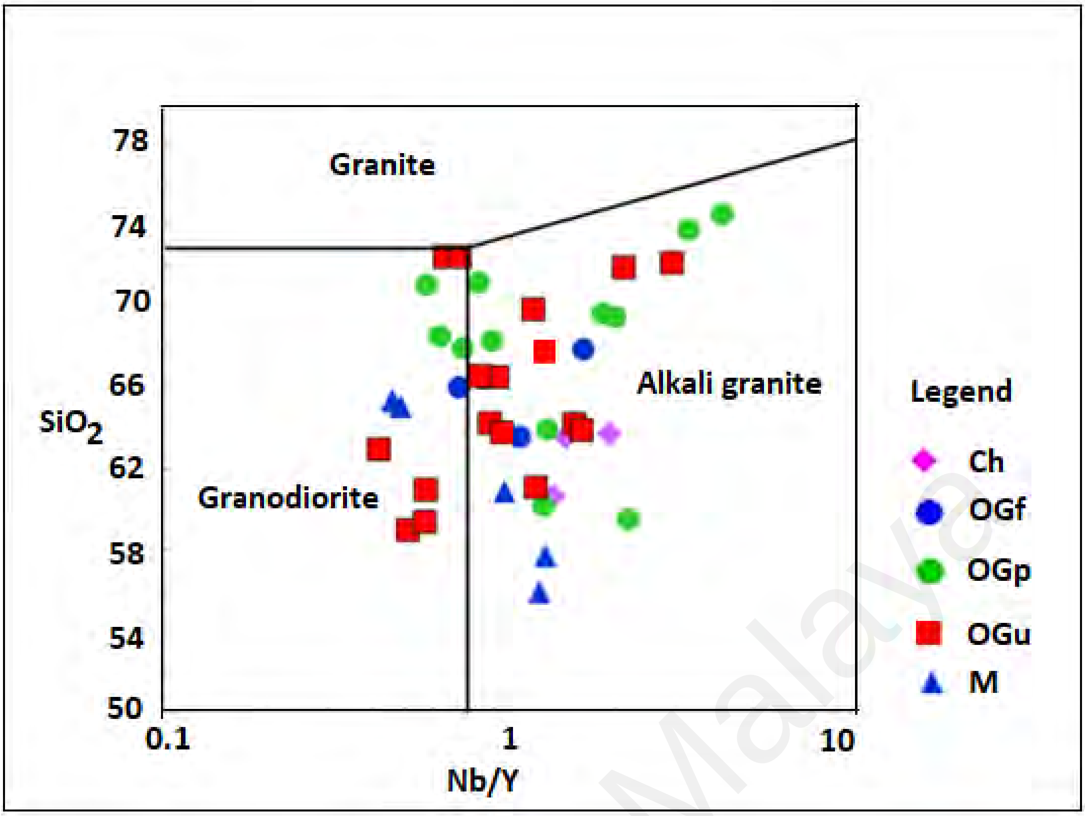

Figure 4.34: SiO_2 versus Nb/Y diagram of Idanre rocks (after Winchester and Floyd, 1977)

study area falls dominantly on alkali granite class, while few samples plotted in granodiorite class thus confirming the (Na_2O + K_2O) versus SiO_2 diagram. Geochemical characterization of granites is based upon the three major parameters which are (Na_2O+K_2O-CaO) known as Modified alkali-lime index (MALI), FeO^t/FeO^t+MgO also known as the Fe number, and Aluminium Saturation Index (ASI) defined by [Al/Ca-1.67P+Na+K], binary plot of $FeO^t/(FeO^t + MgO)$ versus SiO_2 (Fig. 4.35) indicates the rock units plots within the ferroan class. Ferroan granitoids by their higher Fe-number are distinguished from magnesian granitoids which often exhibits lower iron enrichment.

Frost et al., (2001), believed Ferroan-type granites are produced under low H_2O conditions, and by implication low oxygen fugacity (fO2) during anatexis of their source rocks, hence they are crystallized under low-water conditions. Frost and Lindsley, (1991) indicates that magnesian granites are products of relatively hydrous magmas under an

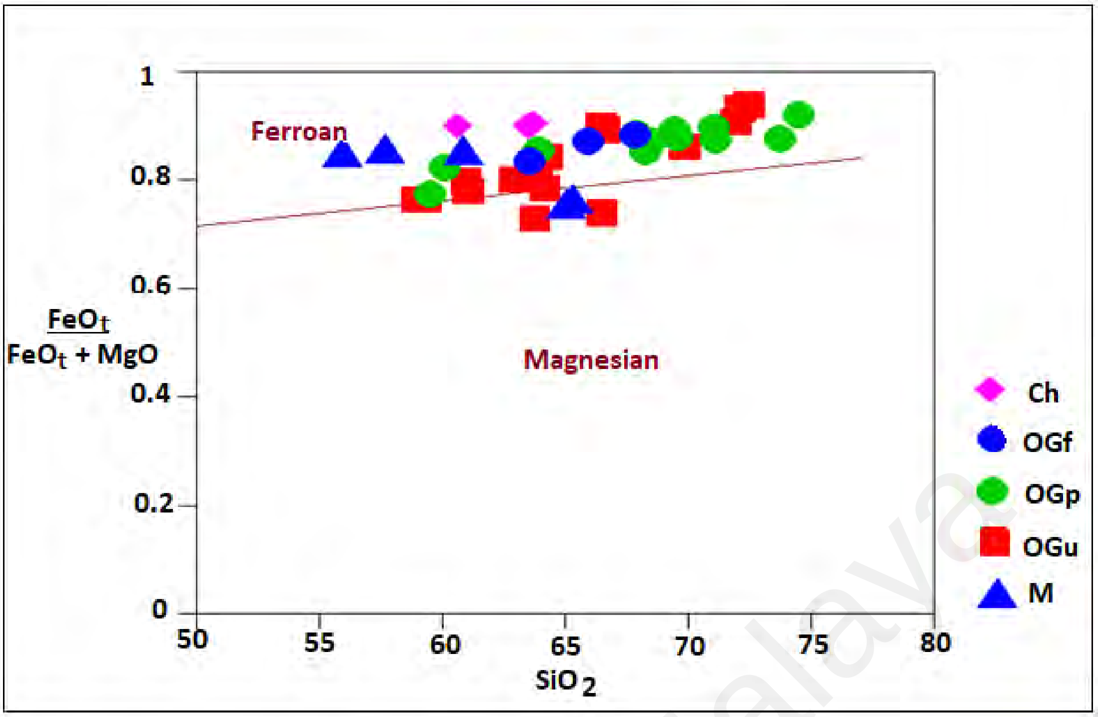

Figure 4.35: FeOt/(FeOt+MgO) versus SiO_2 diagram of rocks in Idanre (after Debon and Le Fort, 1988)

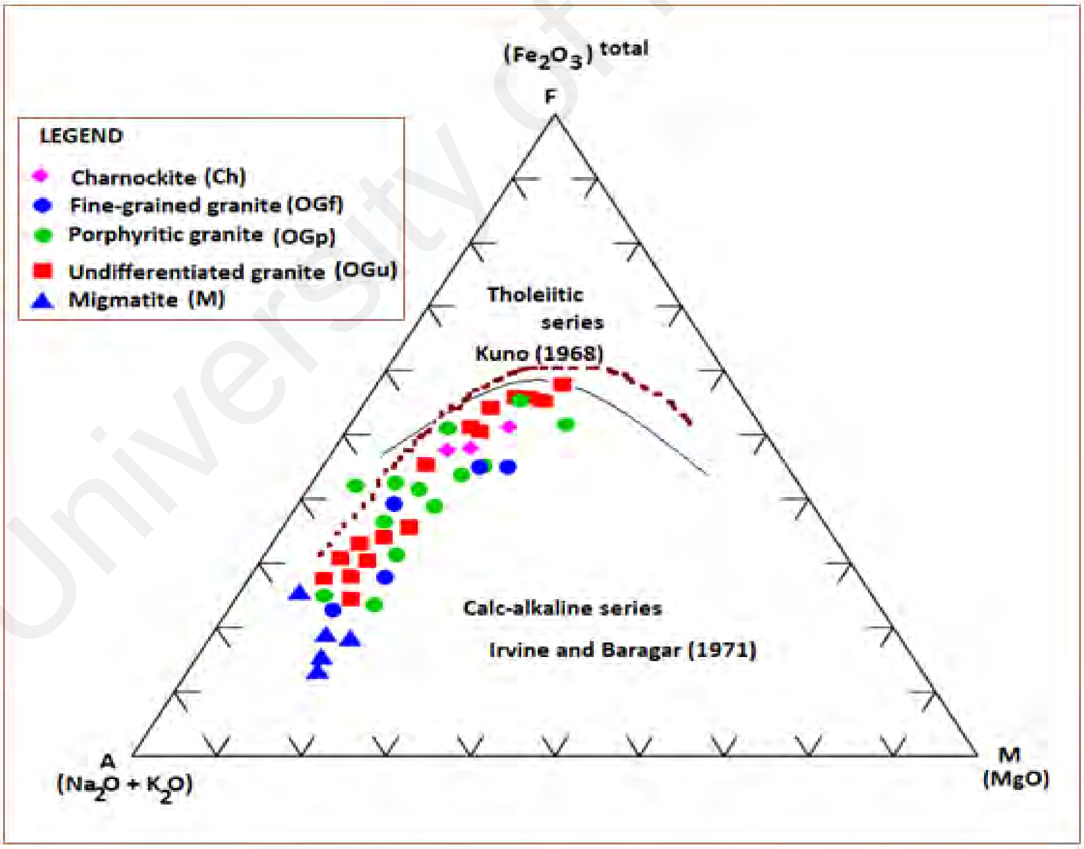

Figure 4.36: (Na_2O+K_2O)-Fe_2O_3(t)-MgO AFM ternary diagram of rocks from Idanre area (Kuno, 1968) and (Irvine and Baragar, 1971)

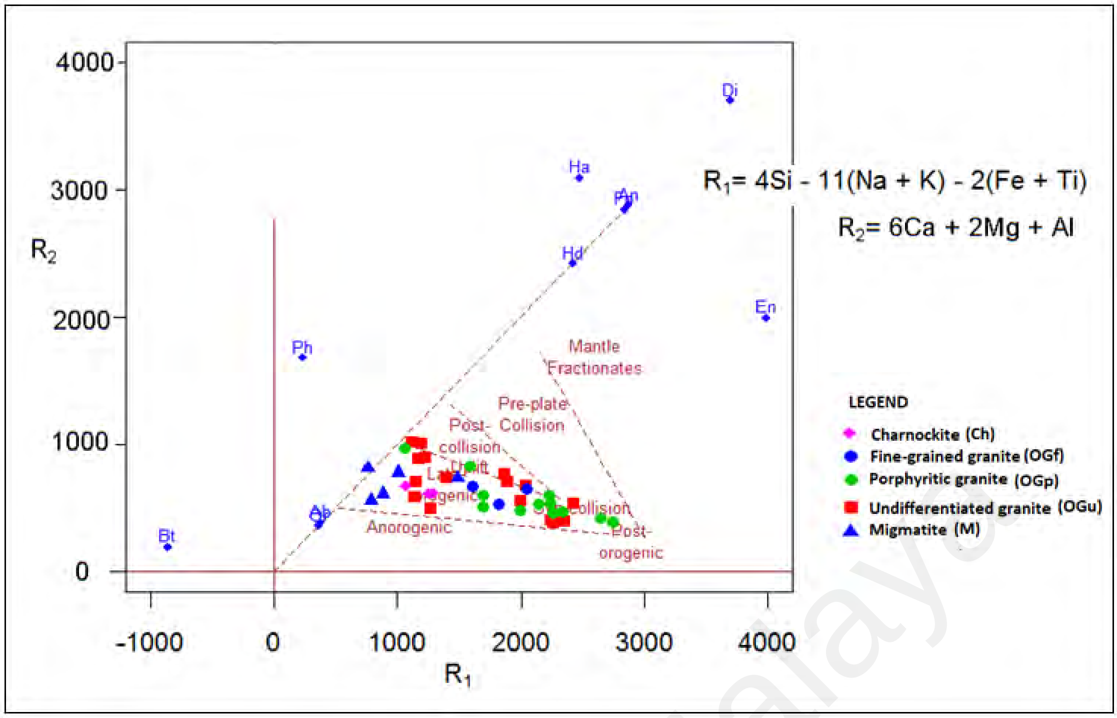

Figure 4.37: Binary plot for classification of Idanre granite using R1 versus R2 parameters of De la Roche et al., (1980), where R_1=[4Si-11(Na+K)-2(Fe+Ti)], R_2= [6Ca+2Mg+Al]

oxidizing conditions. The above suggested that the Idanre granite suites probably evolved under a reducing condition with respect to these parameters. On (Na_2O+K_2O)-Fe_2O_3(t)-MgO AFM Ternary diagram which discriminate between tholeiitic and calc-alkaline suites, rocks in Idanre area follows calc-alkaline trend (Fig. 4.36). Batchelor and Bowden, (1985) distinguished between orogenic and non-orogenic plutons using R1 versus R2 parameters of the De la Roche et al., (1980), where R1=[4Si-11(Na+K)-2(Fe+Ti)], R2= [6Ca+2Mg+Al] (Fig. 4.37) Most of the data points fall within Late orogenic and syn-collision granite field.

4.4.3 Trace Elements Geochemistry

Trace elements distribution in any geochemical system and the quantitative interpretation of data from such depends on adequate knowledge of the essential parameters which govern the behaviour of trace elements. The essential factor that controls this behaviour ultimately have profound effects on their mobility. Among such parameters, ionic size and electrical charge are the most dominant. Similar ionic radius and electrical charge is responsible for inter-element substitution in rock-forming minerals. Statistical summary of trace and rare earth elements in rocks from Idanre (Table 4.3b) is compared with Table 4.3c which has been included to justify trace-elements abundances in other geological materials such as chondrite, crust, ultrabasic rocks, basalt, granite, greywacke and shale.

The distribution of trace elements in rocks within Idanre area indicates that certain trace elements show pronounced enrichment e.g. (Ba, Rb, Sr and Zr) which records values ranging between 100-3200 ppm relative to others e.g. (Hf, Ga, Nb, Ta and Y) whose concentration ranges between 10-100 ppm. While other elements e.g. (U, Be, Sc, Co and Ga) recorded very low values between 1-10 ppm. However, few elements (W, Sn, Cs) fall within those whose concentration are less than 1.0 ppm. The distribution pattern (Table 4.3b) also show that a significant geochemical relationship exists between trace element composition of the migmatite-gneiss host rock and granite. High concentration of Ba, Rb, Sr and Zr is expected in the upper continental crust due to their preference for rock-forming minerals, they have higher affinity for silicates forming lithophile group of elements. Average Ba content in migmatite gneiss (1871 ppm) (range: 687-3201 ppm) is higher than undifferentiated coarse-grained granite (ca. 1308ppm), fine-grained granite (ca. 1132ppm), porphyritic granite (ca. 975.8 ppm), and charnockite (ca. 1481 ppm). Similarly, Zr content in migmatite gneiss (ca. 959.3 ppm) is higher than coarse-grained granite (ca. 317.1 ppm), porphyritic granite (ca. 464.2 ppm), fine-grained granite (571.4 ppm) and charnockite (859.5 ppm). The high abundance of Zr in granite is attributed to the occurrence of Zircon which is a common mineral in the accessory phases. Again, Zr may have replaced some elements with similar chemical properties in ferromagnesian minerals that significantly allow for substitution of these elements in these phases. The resilience of zircon and its ability to survive during crustal anatexis and metamorphic transformations could as well be responsible for this anomalously high concentration.

However, the concentration of Rb follows a reverse trend, Rb value in migmatite gneiss (ca. 149.8 ppm) is lower than the coarse-grained granite (ca. 165 ppm), fine grained granite (175.3ppm), porphyritic granite (ca. 181.9 ppm), and charnockite (186.1 ppm). This trend is expected because Rb as a radioactive element tends to be preferentially concentrated in siliceous rocks or rocks of granitic composition during magma evolution rather than basic rocks which are richer in ferromagnesian minerals. Average Sr contents for migmatite gneiss (426.1ppm) is marginally lower than coarse-grained granite (437.6 ppm), even though the value is evidently higher than porphyritic granite (283.8 ppm), fine-grained granite (280.1ppm) and charnockite (237.7 ppm). All values are still within permissible range for granitoids and average concentration expected for the crust Taylor, (1962) (Table 4.3c). Except for porphyritic granite (OGp) which recorded a mean value of 41.2 ppm, average niobium contents of the granites (OGu 28.8 ppm), (OGf, 39.0 ppm), and charnockite (Ch 33.9 ppm) are lower than migmatite gneiss (40.5 ppm). However, these values are well above the 20-ppm quoted for average silicic rocks like granite by Taylor, (1962) (Table 4.3c). Most often, rocks that are rich in Rb also tend to be enriched in Sr because they are both radioactive and have similar geochemical coherence owing to similarities in their electrical charges and ionic radii. The slightly higher values in migmatite gneiss may have resulted from remobilization during subsequent metamorphic transformation, and the granite due to contamination from anatexis of crustal melts. Th content in Idanre migmatite gneiss (19.0 ppm) is significantly lower than coarse-grained granite (28.9 ppm), porphyritic granite (39.2 ppm), fine-grained granite (35.8 ppm) and charnockite (21.5 ppm). These values are however higher than the average for the crust of the earth but within acceptable limit for granites. Average Ta contents of Idanre granite suite (OGu: 6.8 ppm), (OGp: 20.1 ppm), (OGf: 11.3 ppm) are significantly higher than average 3.5 ppm recorded for granitic rocks (Taylor, 1962). Nb contents in the granite (OGu, ca. 28.8 ppm; OGp, ca. 41.2 ppm; OGf, ca. 39.0 ppm) are also higher than average granite (20 ppm) Taylor, (1962). However, even with these values, the Older granite suites in Nigeria have been designated as having poor Ta-Nb mineralization potentials when compared to their derivative granite-pegmatite counterparts, this shows that the rocks constituting Idanre granite suites are not formed from highly evolved silicate melts. Again, it is also possible that the tantalum and Niobium components do not occur as a separate oxide phase such as TaO_2 or Nb_2O_5 but as substitute for other elements with similar charge and geochemical character. Average Ta and Nb values in Idanre granite suites are generally lower than the albite arfvedsonite granite (Ta 248 ppm; Nb 1568 ppm) which is a member of Younger Granites Tin Belt of Northern Nigeria (Ogunleye et al., 2005). The difference in the Ta-Nb potentials of the two granites types (Older and Younger) may be attributed to differences in structural evolution (mode of formation), petrology, tectonic setting, and age.

4.4.4 Trends in trace elements geochemistry of Idanre rocks

The relationship between the behaviour of certain trace elements with respect to SiO_2 in the basement rocks of Idanre area is shown on Trace element Harker diagrams (Fig. 4.38). The negative correlation between trace elements Ba, Sr, Zr, Th, Rb and Hf versus SiO_2 as depicted from Ba vs SiO_2, Sr vs SiO_2, Zr vs SiO_2, Th vs SiO_2, Rb vs SiO_2 and Hf vs SiO_2 respectively, has significant geochemical, post magmatic and petrogenetic implications. However, the trends of Ta vs SiO_2 and Nb vs SiO_2 is indiscernible. The indiscernible pattern of both Ta versus SiO_2 and Nb versus SiO_2 binary diagrams may have correlation with their similar geochemical behaviour. The two elements act as identical pairs in geochemical systems owing to similarities in their charges and ionic radii Ta^{3+} (72) and Nb^{3+} (71). The similarities in the abundances of Zr and Hf in terrestrial materials such as rocks may also be linked to similarities in geochemical behaviour attributable to comparable ionic radii and charges Zr^{4+} (72), Hf^{4+} (71). This imply that the two elements can substitute extensively for each other under similar geochemical conditions. Even though, Ba^{2+} and Sr^{4+} have unequal charges, however, the radius of Ba (132) and Sr (114) are both large, meaning they could be accommodated into coordination sites in crystal lattices of certain minerals easily but the replacement of Ba^{2+} by Sr^{4+} will have to be accompanied by the exchange of Si^{4+} for Ca^{2+} to preserve the electrical neutrality. The similarities between the scatter pattern on the Trace Elements Harker diagram (Fig. 4.38) may suggest similar mobility which may connote common origin for both migmatite country rock and the granite or that the granite is produced by anatexis of the basement gneiss. On ternary An-Ab-Or diagram (Fig. 4.39) Idanre rocks plot extensively on quartz monzonite and granodiorite fields. However, some of the undifferentiated granite and porphyritic granite samples cross the dividing line between these fields and plot on granite field. On Rb-Ba-Sr ternary diagram (Fig. 4.40), Idanre rocks plot extensively on anomalous granite field with few samples spreading into granodiorite and quartz diorite fields. However, a few undifferentiated granites became stranded within anomalous granite boundary and normal granite fields. These slight variations may be attributed to varying geochemical differentiation during magmatic evolution.

4.4.5 Classification by trace elements on An-Ab-Or and Rb-Ba-Sr Ternary plots

Classification of rocks is crucial to placing them in their appropriate groups to link them together in geochemical and petrogenetic terms. Generally, rocks are classified based on mineralogical composition, texture, or chemistry. Trace elements apart from being useful in geochemical classification of rocks, they also have application in petrogenetic studies. The ternary diagram An-Ab-Or (Fig. 4.39) (after Baker, 1979) classified the rocks as granodiorite, granite, and quartz monzonite. The Rb-Ba-Sr ternary diagram (Fig. 4.40) show the rocks plotting mainly within the anomalous granite, granodiorite, and quartz diorite fields, while four samples of the undifferentiated granite spreads into the normal

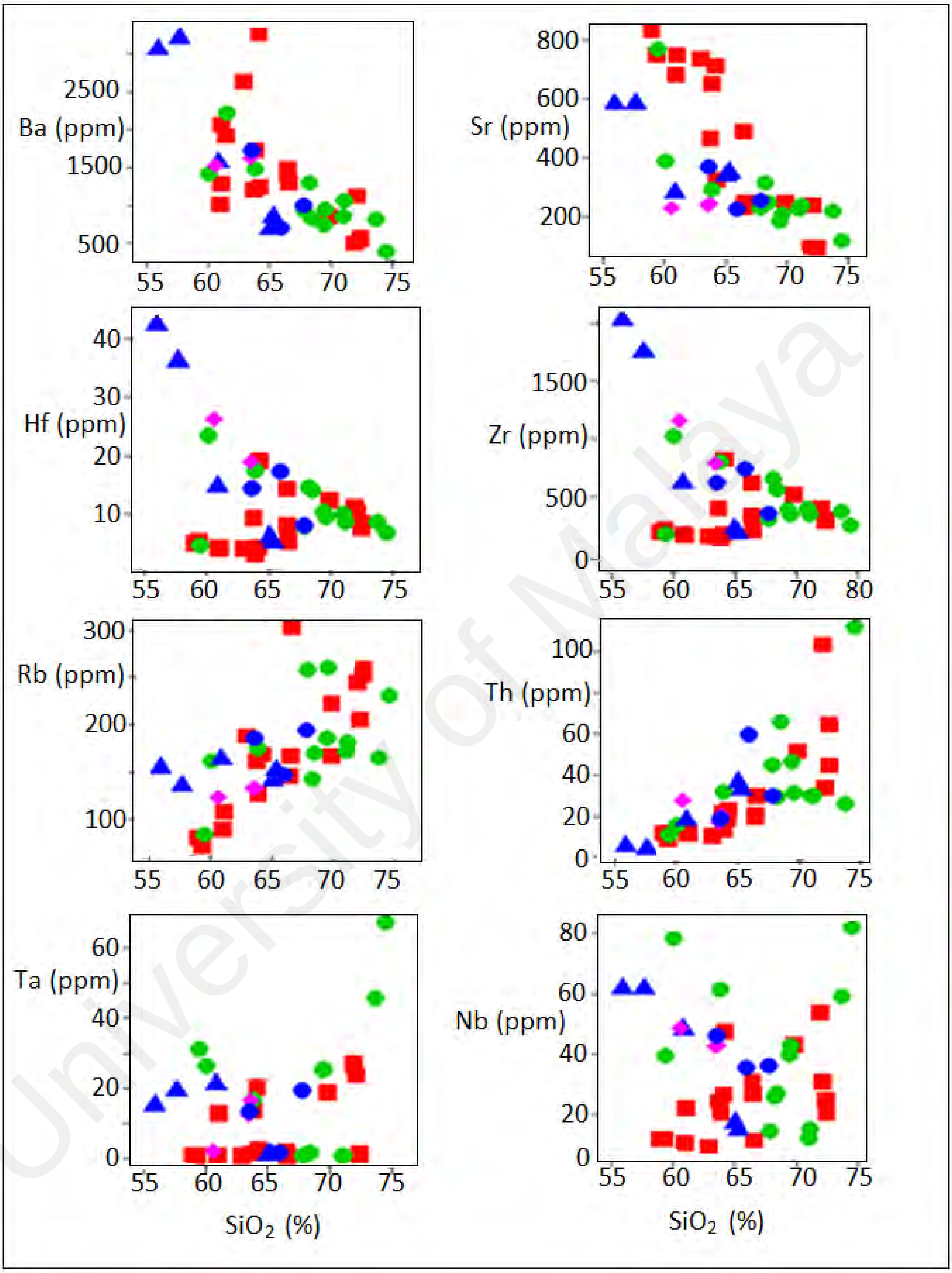

Figure 4.38: Trace elements Harker Diagrams for Idanre rocks (symbols as in Fig. 4.37)

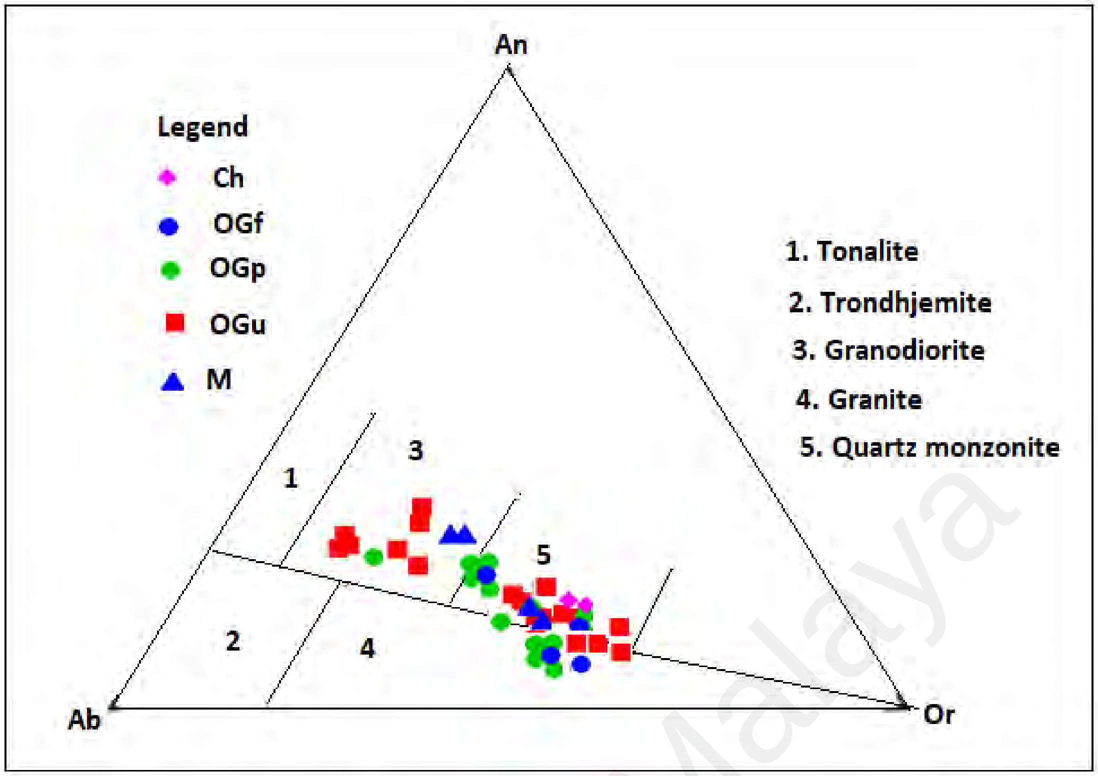

Figure 4.39: An-Ab-Or Ternary diagram of rocks in Idanre (after Baker, 1979)

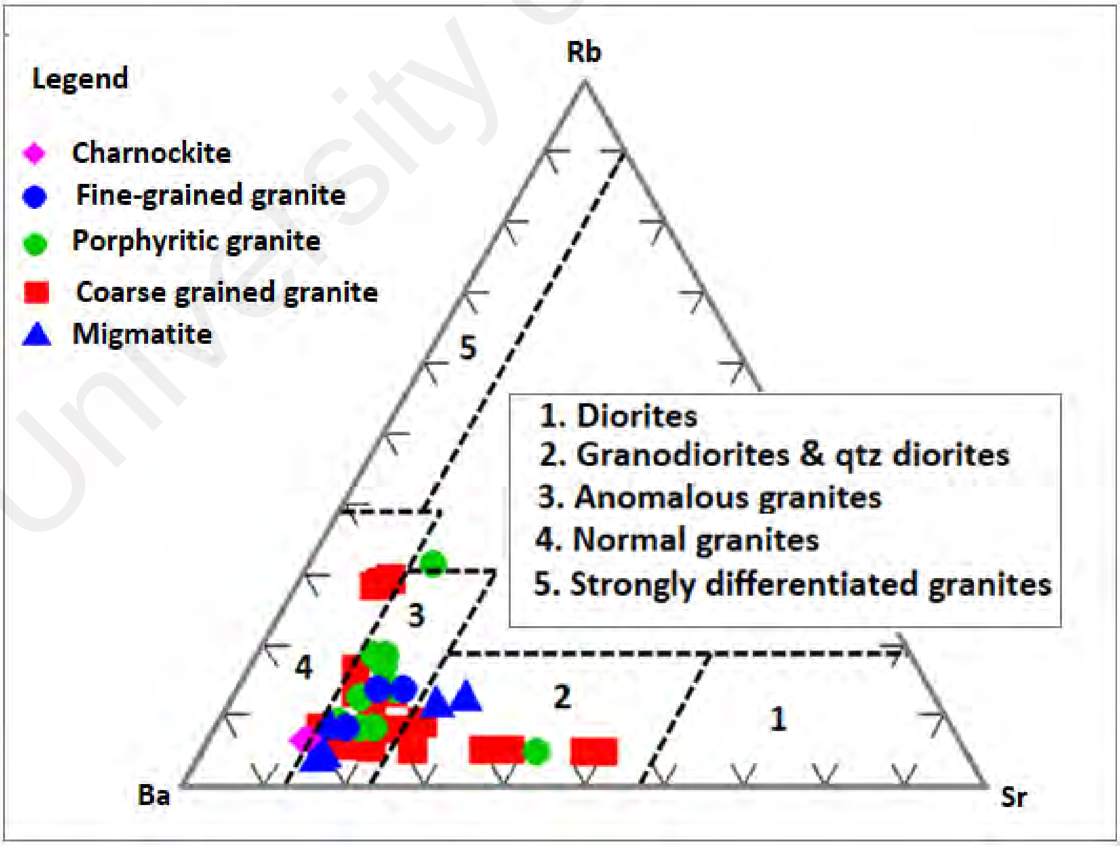

Figure 4.40: Ba-Sr-Rb Ternary diagram of Idanre rocks (after El Bouseily and Sokkary, 1975)

granite field thus confirming the An-Ab-Or classification. Based on binary plot FeO(t)/MgO versus Zr+Nb+Ce+Y (Fig. 4.41) which divide the granite field into three main classes: fractionated granite (FG), OTG, and Anorogenic (A). The Idanre granite complex plots extensively on anorogenic granite field, even though two samples of the undifferentiated granite and migmatite fall on the line dividing OTG and A granite groups. On $(Na_2O+K_2O)/CaO$ versus Zr+Nb+Ce+Y variation plot (Fig. 4.42), the rocks fall dominantly within the anorogenic field thus confirming the FeO(t)/MgO versus Zr+Nb+Ce+Y binary diagram.

Geochemical evaluation of the rocks displays two evolutionary trends as shown in many geochemical diagrams. This can be explained by ascribing each sample to the correct trend and examining where they are exposed. For instance, in the case of OGu, samples B12, B14, B15, D32, D33, D34 and D35 are characterized by high alumina and

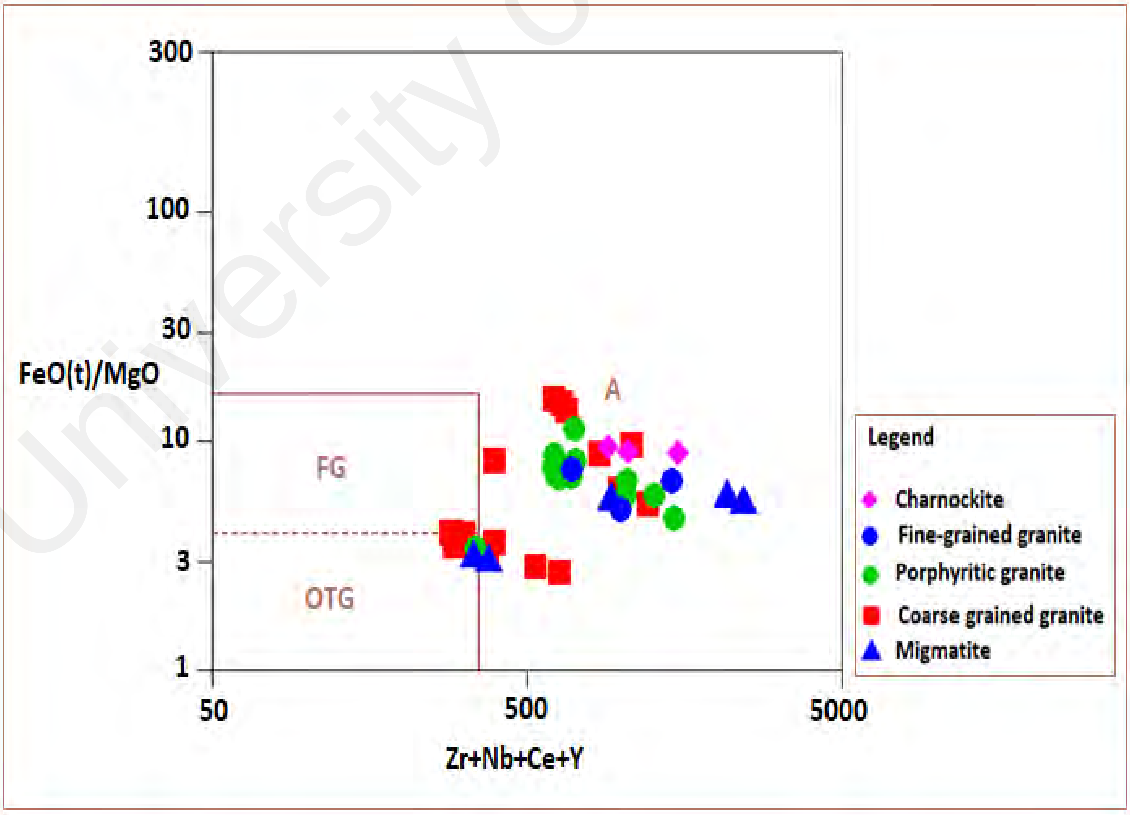

Figure 4.41: Binary diagram of FeO(t)/MgO versus Zr+Nb+Ce+Y of rocks from Idanre

Sr but low Ti, Zr, Hf etc. and corresponds to western corner of the intrusion. Even though these samples do not bear any special recognizable features that distinguishes them from the rest of OGu, nor any contact relationship. Hence these features may symbolize feldspar accumulation.

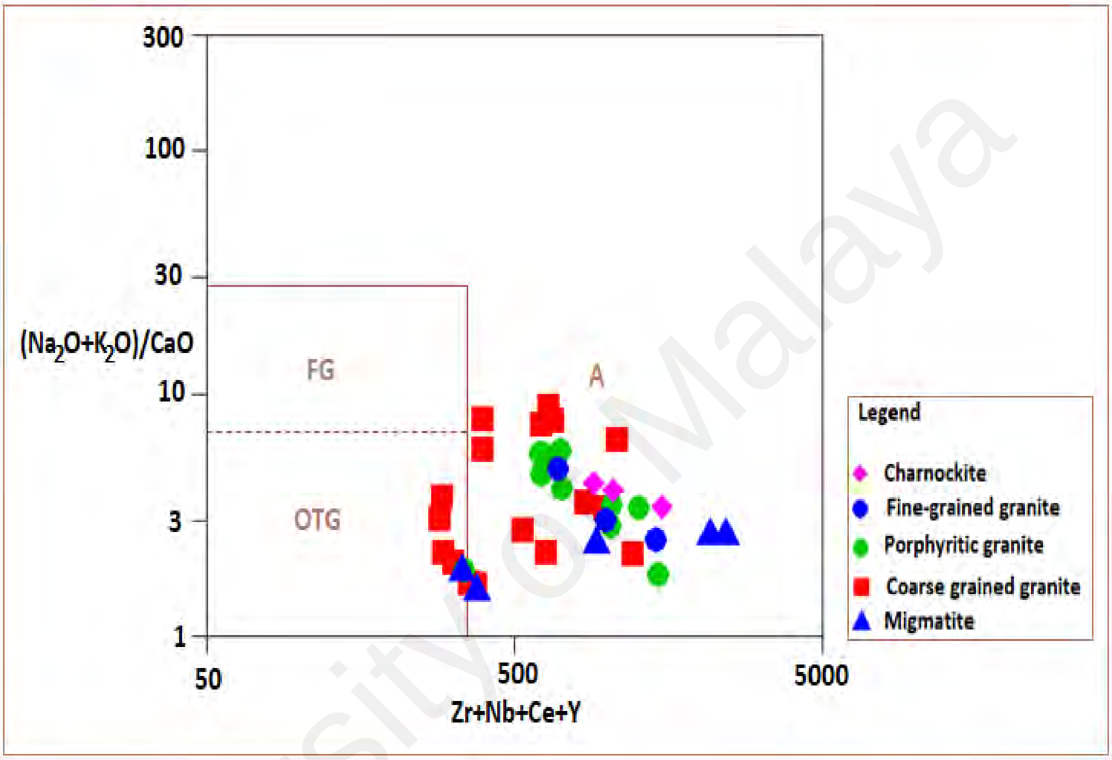

Figure 4.42: Binary diagram of (Na_2O+K_2O)/CaO versus (Zr+Nb+Ce+Y) of rocks from Idanre

CHAPTER 5: GEOCHRONOLOGY AND LU-HF ISOTOPES

5.1 Geochronology

Sampling points for geochronological investigation (Table 5.1, Fig. 5.1) and the images for cathodoluminescence (Fig. 5.2) are shown. The result of Laser Ablation U-Pb zircon analyses of migmatite unit and granite members of the Idanre granite suite are listed (Appendix 1), supplementary data is plotted in the Concordia diagrams (Figs. 5.3, 5.6, 5.9, 5.12, and 5.15).

5.1.1 Coarse-grained granite (Undifferentiated) (OGu)

Zircon grains from this unit exhibits oscillatory zoning (Fig. 5.2a) and vary in dimension from 100 to 250 μ m. The transparently clear grains appear stubby, the ratios of the length versus width range between 1:1 to 3:1. However, few grains (about 25% of the population) contain indistinct or convoluted inner zones. A sum of 23 analyses made on selected grains of zircon indicates that concentration of U in the sample range from 84.185 to 1880.024 ppm, Th ranges from 95.043 to 866.359 ppm. The ratio (Th/U) for the analysis have values which range from 0.461 to 1.476, with mean value (0.894) which suggests derivation from a magmatic source (Zhao et al., 2002a; Belousova et al., 2002; Corfu et al., 2003). The ^{206}Pb/^{207}Pb age which ranges between 576 and 857 Ma has a weighted average of 581.8 ± 5.5 Ma (MSWD = 0.68). This is regarded as crystallization age of Undifferentiated coarse-grained granite in Idanre area. Concordia diagram (Fig. 5.3) for the unit is shown, the mean and age range of Laser Ablation points U-Pb zircon dates for the rocks is shown (Fig. 5.4), while normalized probability plots and histograms is shown as (Fig. 5.5).

5.1.2 Porphyritic Granite

Zircon grains from porphyritic granite in Idanre area are long, prismatic and euhedral in shape, they are generally smooth and devoid of cracks and inclusions. They have sizes that range between100 and 350 μ m while the ratio (length/width) range from 1:1 to 4:1.

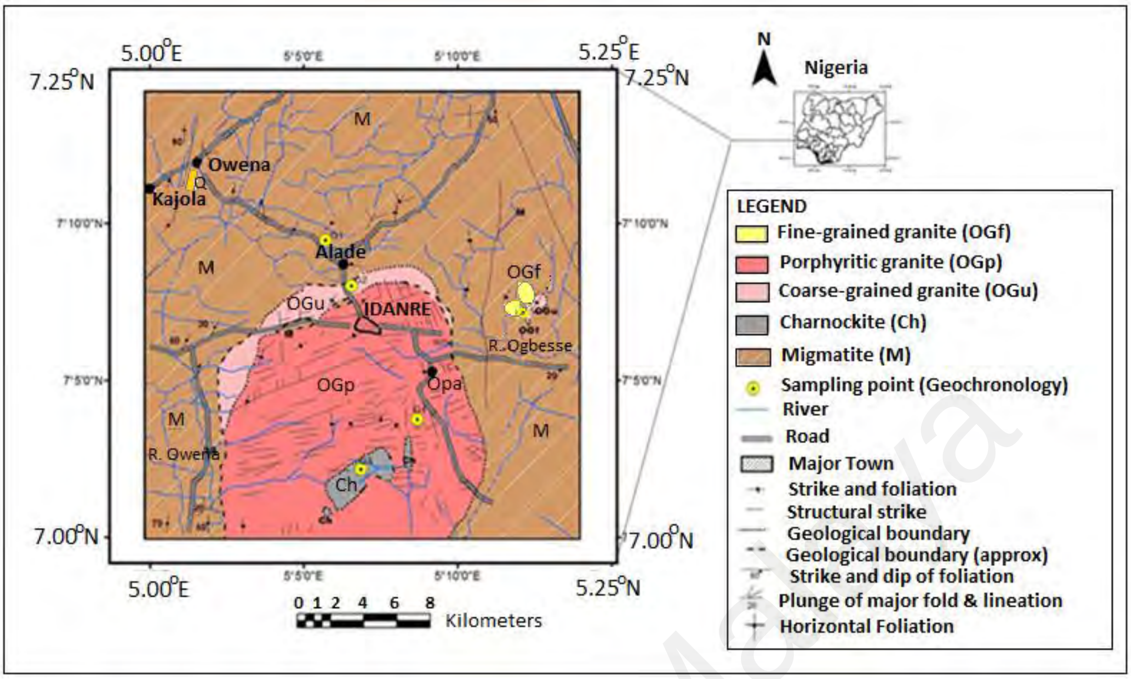

Fig. 5.1: Sampling points for geochronology

Table 5.1: Location and lithology of samples analysed for geochronology

S/N	ID	Rock types	Location	Lithologic description
5	B15	Coarse-grained Granite (OGu)	N07 º 06' 10" E05 º 03' 32"	Coarse to very coarse-grained biotite-hornblende granite, feldspars are mainly greyish in colour.
4	B9	Porphyritic Granite (OGp)	N07 º 02' 52" E05 º 09'33"	Porphyritic granite, feldspars are dominantly grey, but with minor pink coloured plagioclase
3	C5	Fine-grained-Granite (OGf)	N07 º 07' 09" E05 º 13' 10"	Fine-grained biotite-hornblende granite, colour of the feldspars is dominantly pinkish.
2	D29	Charnockite (Ch)	N07 º 01' 42" E05 º 06' 27"	Medium to coarse-grained charnockite with olive-green colour and vitreous lustre
1	A17	Migmatite (M)	N07 º 01' 48" E05 º 01' 50"	Fine to medium-grained, weakly foliated rock, outcrops mainly have low-lying outlook

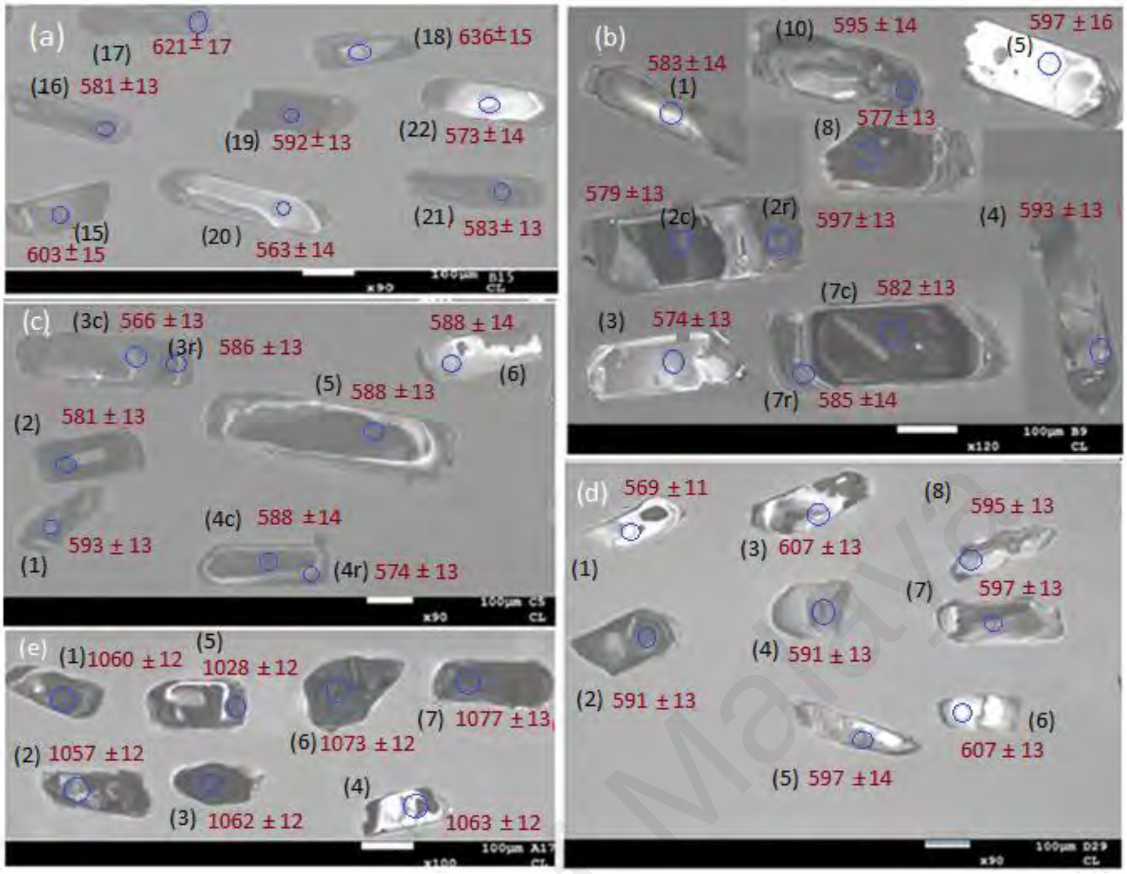

Figure 5.2: Cathodoluminescence images of zircon grains from (a) coarse-grained granite (undifferentiated), (b) porphyritic granite (c) fine-grained granite (d) charonockite (e) migmatite in the study area

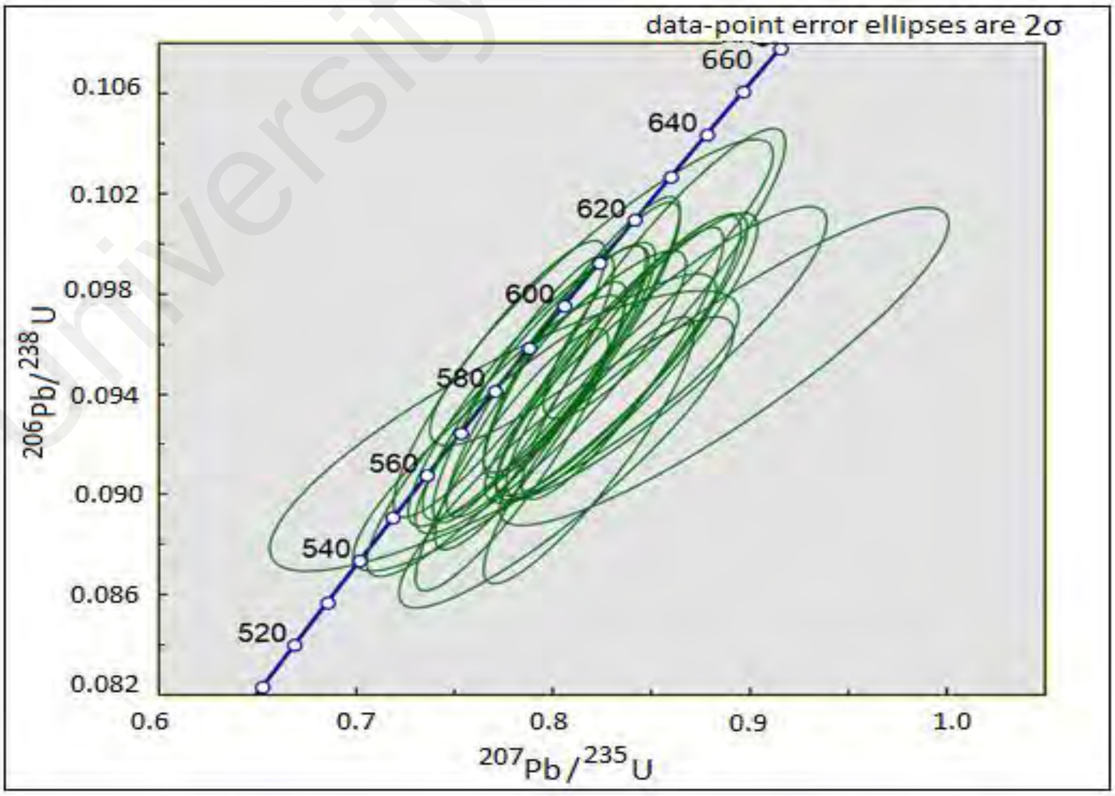

Figure 5.3: Concordia diagram of the U-Pb zircon geochronology of coarse-grained granite (undifferentiated) (OGu) of Idanre area

Cathodoluminescence image indicates that most of zircons show oscillatory zoning (Fig. 5.2(b)). Generally, most of the cathodoluminescence images lack inherited crystals in all the samples. This remarkable observation suggests weak to no contamination by country rock. This assertion is important in terms of source rocks. The complicated oscillatory zoning usually shows darker inner zones and brighter outer zones. Twenty-two (22) grains were analysed from a total of 26 grains. The concentrations of U in the sample range from 85.56 ppm to 1330.31 ppm while the contents vary from 75.06 ppm to 686.99 ppm. Study show that there is a relationship between silica content and Th/U ratios in granites, Kinny et al., (1990) observed that higher Th/U ratio in granites (Th/U >0.44) signify 65-75% SiO_2 and a lesser ratio (Th/U <0.44) imply 70-75% SiO_2. Furthermore, the authors believed that different rock types exhibit different REE element concentration for different range of silica for granites. They found out that Yb < 501 stands for granite <65% SiO_2 and Yb >501 for granite 70-75% SiO_2. In another study, it was stated that a relationship exists between zircon and their source rocks. Belousova et al., (2002) pointed that cores of zircon of most siliceous felsic rocks or metamorphic rocks bear potential information of the original source rock and detrital zircon in sedimentary rocks can be assigned to specific lithologies.

Th/U ratios of zircons in porphyritic granite of Idanre area ranges between 0.303 to 1.669, and a mean of 0.906, showing a magmatic source for the zircons. The $^{207}Pb/^{206}Pb$ yielded ages which range from 569 to 803 Ma with an average of 584.5 ± 5.8 Ma (MSWD = 0.53). This represents the age of emplacement of porphyritic granite member of the Idanre granite suite. The Concordia diagram (Fig. 5.6), mean age and range (Fig. 5.7) and probability plot and histogram (Fig. 5.8) are as displayed.

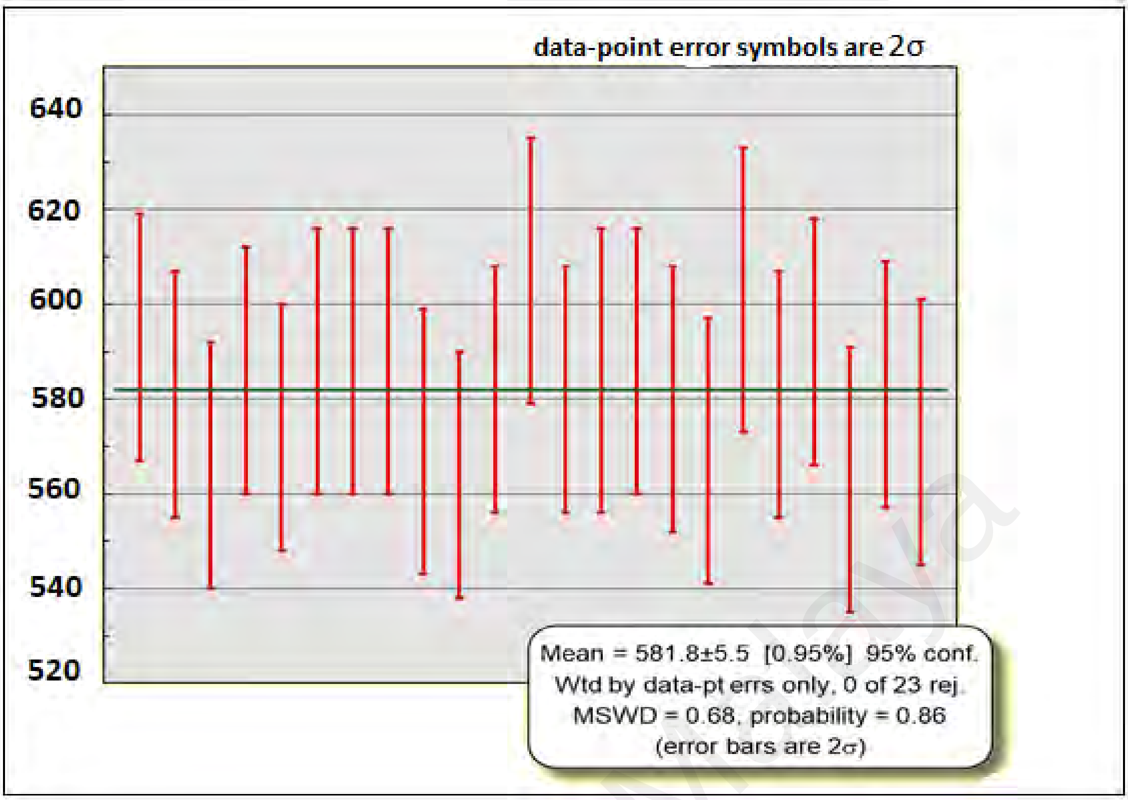

Figure 5.4: Mean and age range of the 23 LA points U-Pb zircon dates for the undifferentiated coarse-grained granite (OGu) of Idanre area

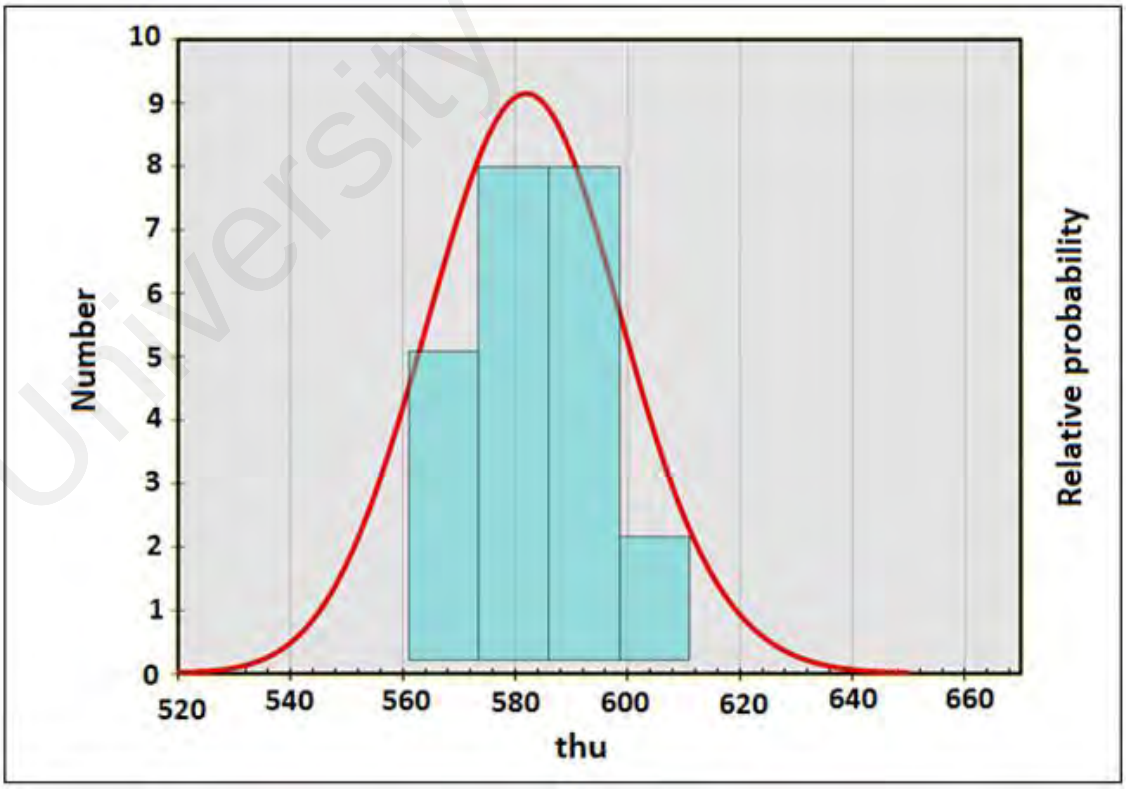

Figure 5.5: Normalized probability plot and histogram for zircon U-Pb ages of Undifferentiated coarse-grained granite (OGu) from Idanre

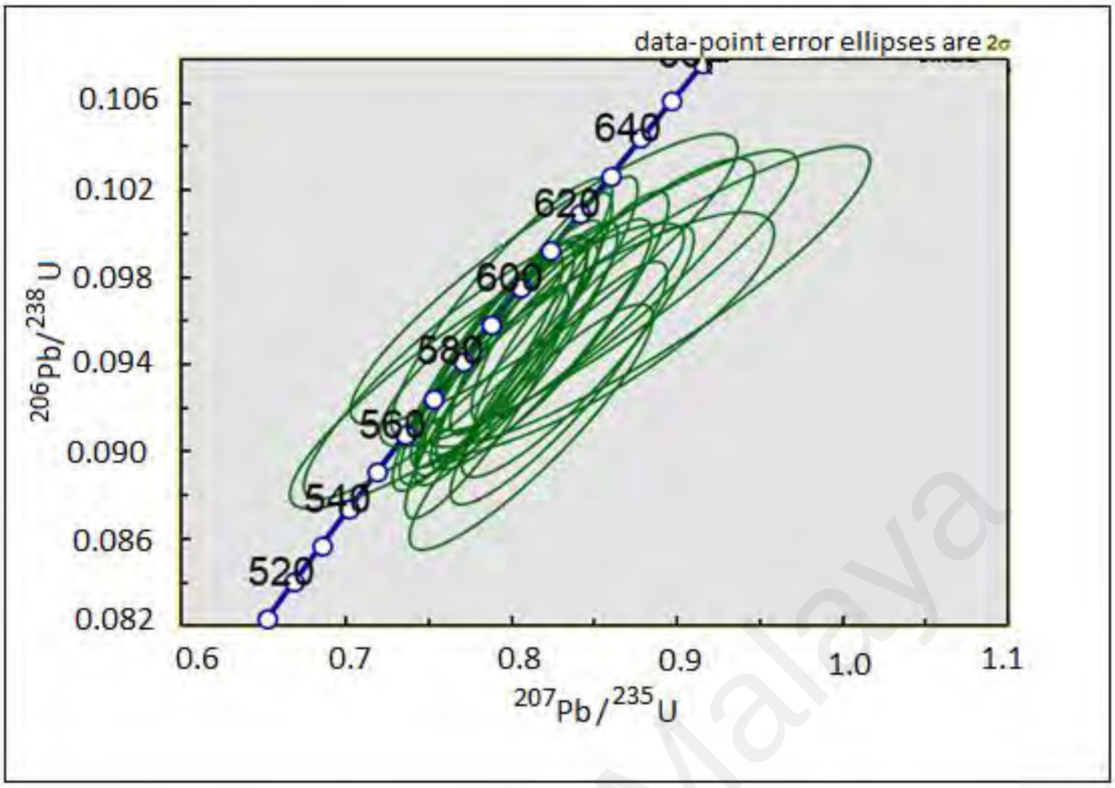

Figure 5.6: Concordia diagram of U-Pb zircon geochronology of porphyritic granite (OGp) of Idanre area

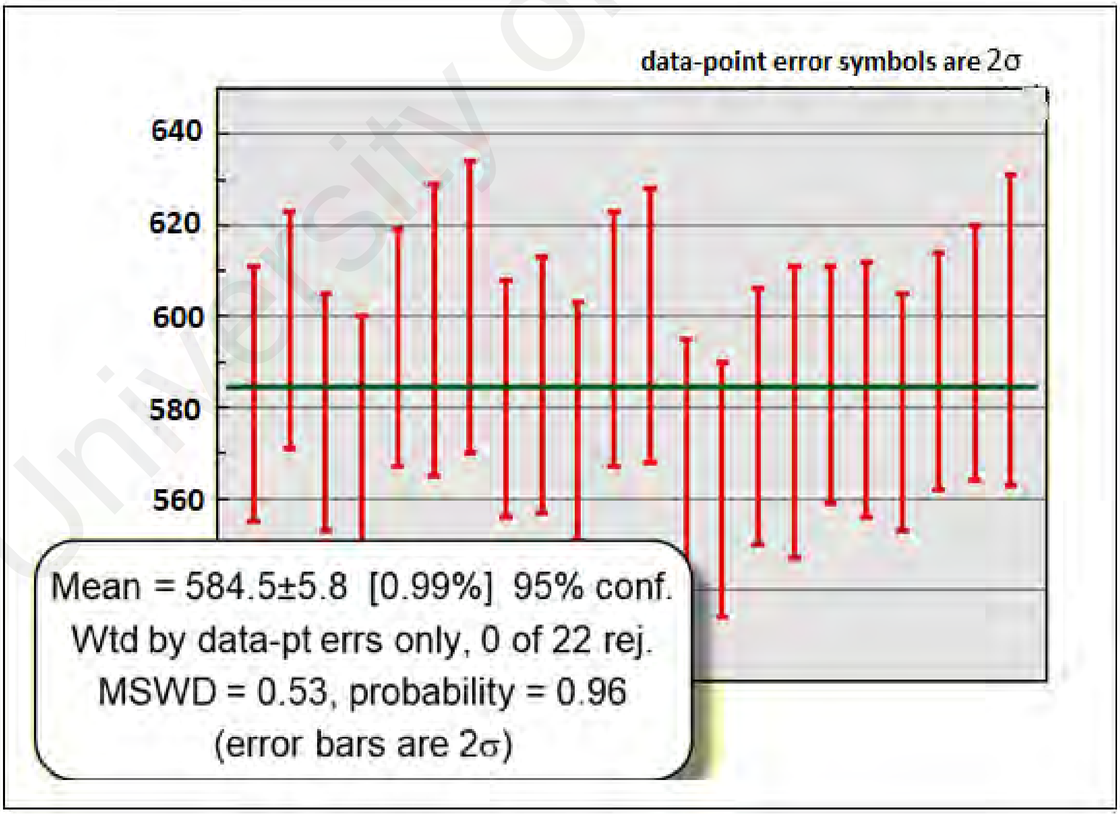

Figure 5.7: Mean and age range of 22 LA-points U-Pb zircon dates for porphyritic granite (OGp) of Idanre area

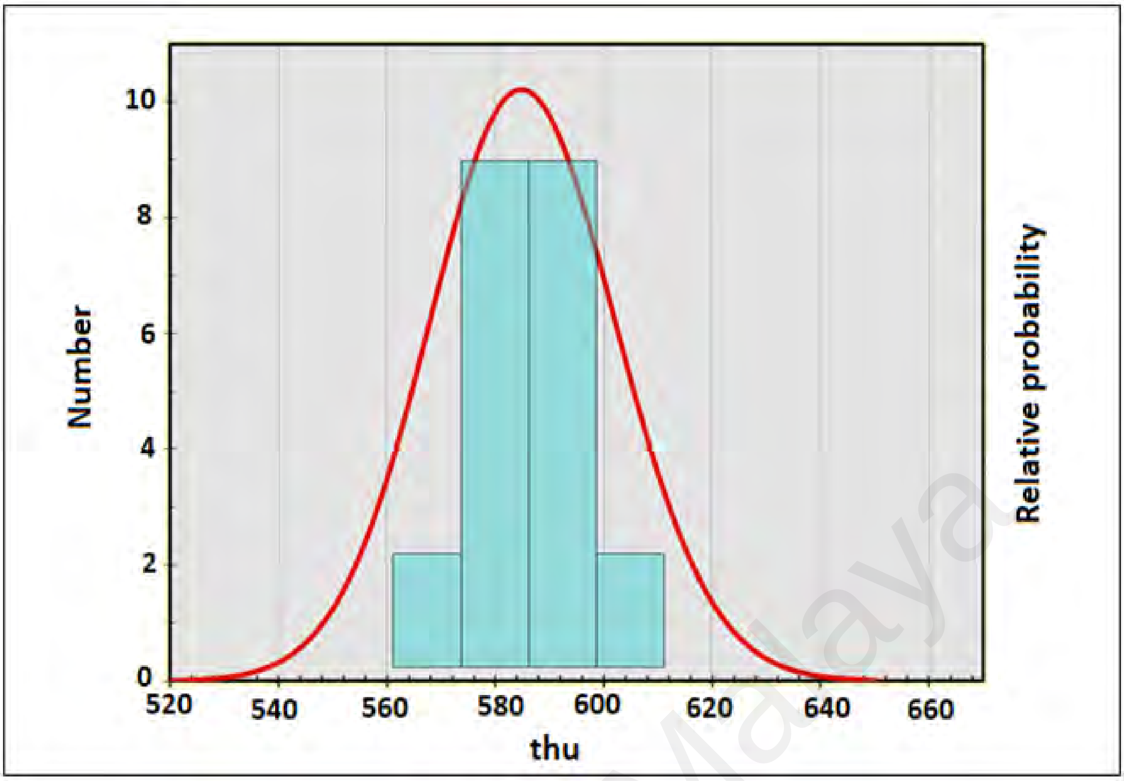

Figure 5.8: Normalized probability plot and histogram for zircon U-Pb ages of the porphyritic granite (OGp) from Idanre

5.1.3 Fine-grained Granite (OGf)

Zircon grains from fine-grained granite is morphologically variable, some are elongate to equant, they are largely unaltered even though few are fragmented. The zircon crystals range in size between 120 and 500 μ m and exhibits noticeable oscillatory zoning (Fig. 5.2c). During evaluation of fine to medium-grained granite in this study, 20 analyses carried out on zircon grains yielded, U values which ranged from 131.232 to 3769.028 ppm, and Th from 91.541 to 964.435 ppm, while Th/U ratios are between 0.189 and 0.878, with an average of 0.549. The inferred ages vary from 576 to 610 Ma and an average age of 588.4 ± 5.5 Ma (MSWD = 0.81), representing age of emplacement of Idanre fine-grained granite. About 50% of the zircon population has age that clustered between 570-590 Ma. The Concordia diagram for the rock (Fig. 5.9), the mean and age range (Fig. 5.10) and normalized probability plot and histogram (Fig. 5.11) for the U-Pb ages of fine-grained granite are shown.

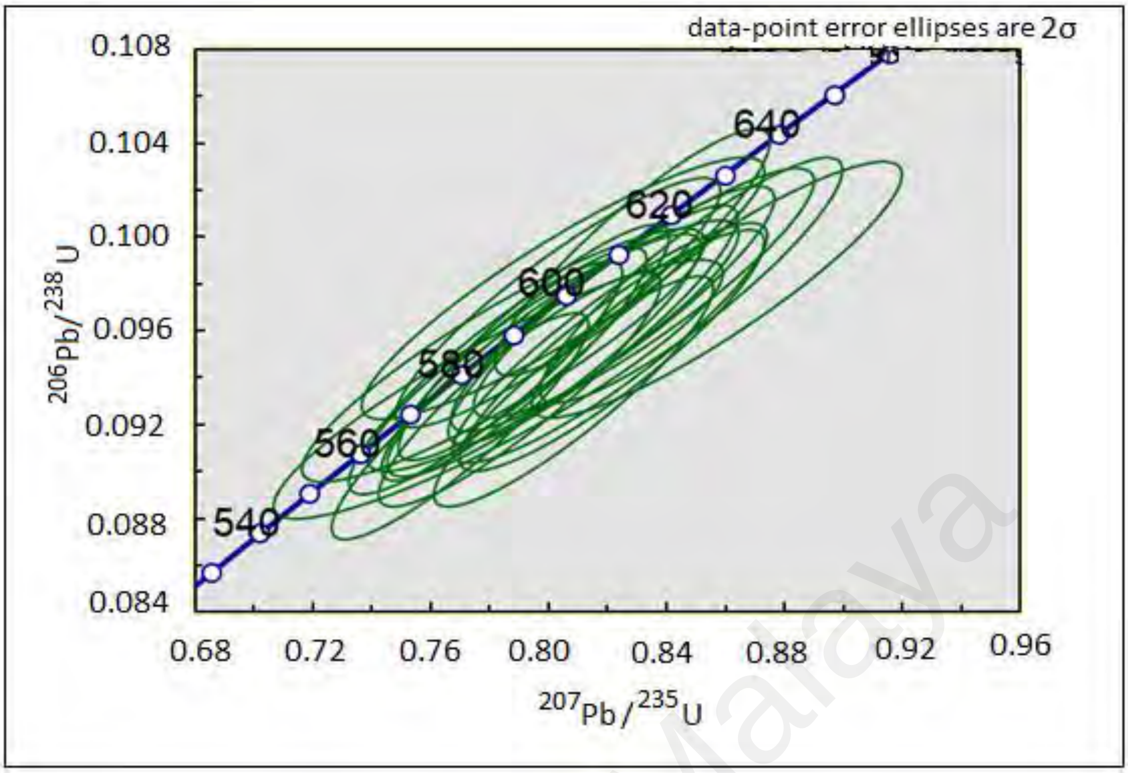

Figure 5.9: Concordia diagram of U-Pb zircon geochronology of fine-grained granite (OGf) of Idanre area

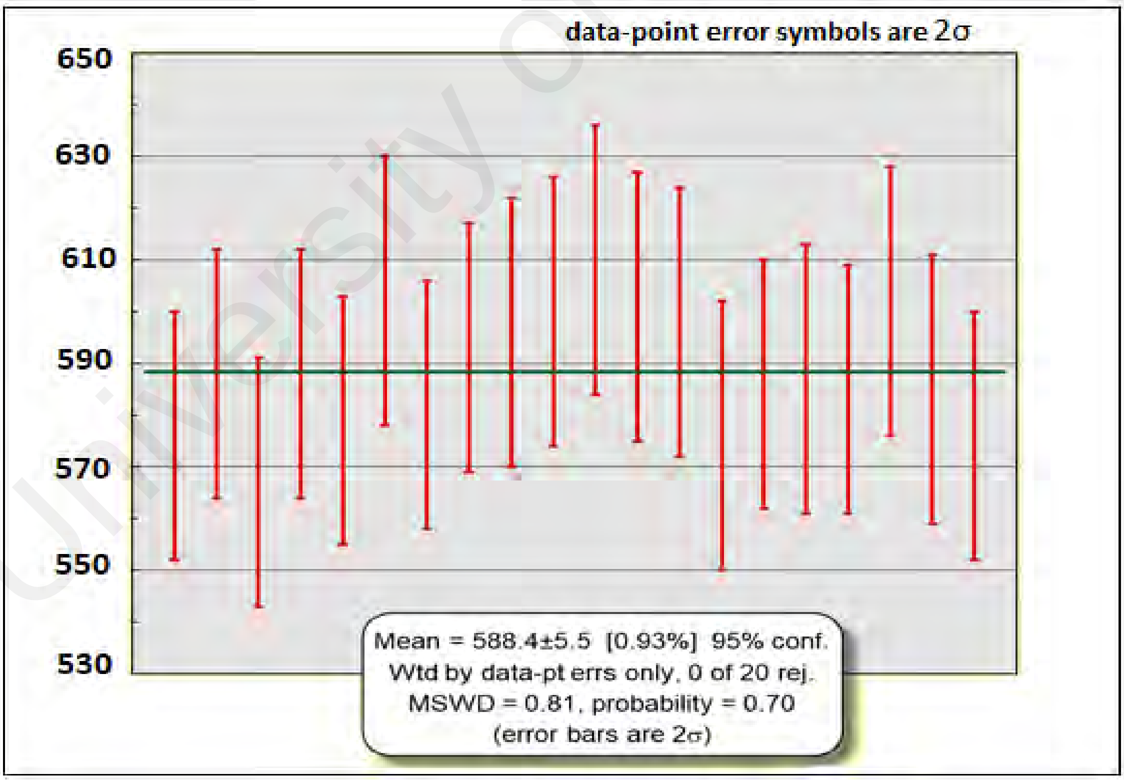

Figure 5.10: Mean and age range of the 20 LA-points U-Pb zircon dates for the fine-grained granite (OGf) of Idanre area

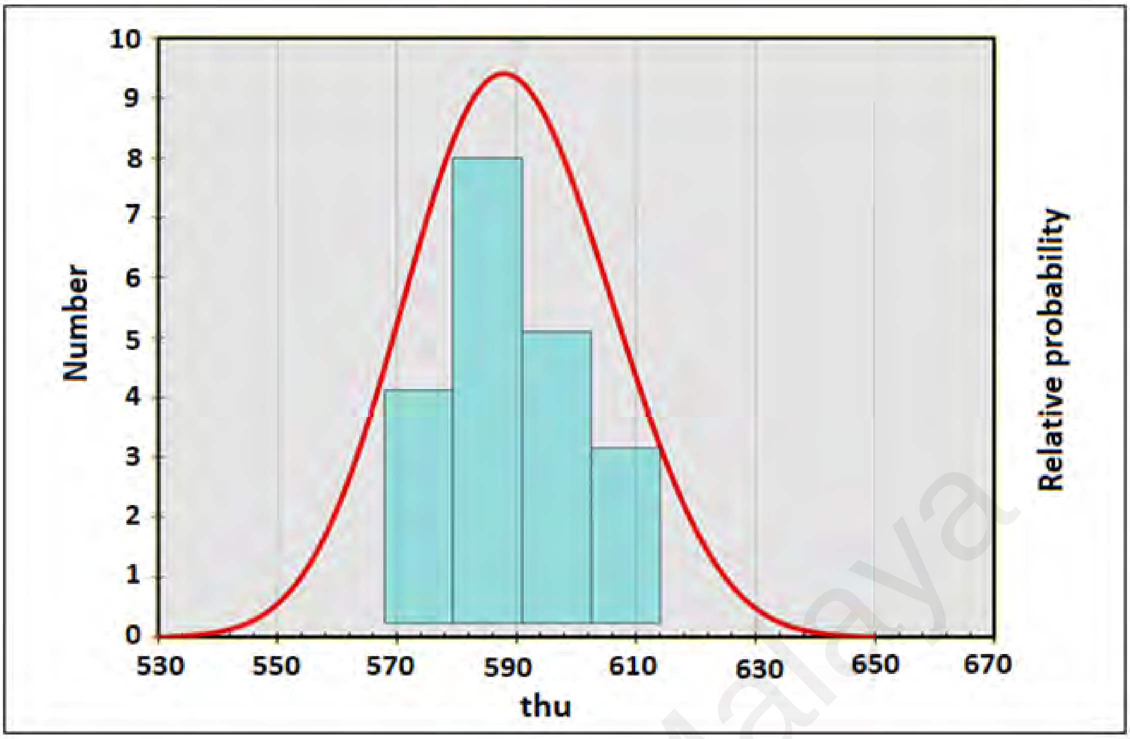

Figure 5.11: Normalized probability plot and histogram for zircon U-Pb ages of fine-grained granite (OGf) from Idanre

5.1.4. Charnockite

Zircon grains from charnockite associated with the granite intrusive in Idanre area vary in size between 100 and 250 μ m. The oscillatory zoning is not as prominent as those in the granite (Fig. 5.2d), in few cases however, the oscillatory zoning is almost indiscernible. The non-apparent metamorphic rims may indicate that crystallization probably occurred during one single magmatic episode. During the geochemical analysis of the zircon grains, 24 evaluation were made in which the U values ranges between 92.858 to 1506.932 ppm while Th show varying concentrations between 61.902 to 476.611 ppm. The ratio Th/U for the zircons have values which range between 0.316 and 0.835. The $^{206}Pb/^{207}Pb$ ages range between 569 to 613 Ma and 7 spot ages concentrated around 585−595 Ma. The ages yielded a mean value 590.3 ± 5.3 Ma (MSWD = 0.82), which symbolized emplacement age of Idanre charnockite. Concordia diagram for the rock (Fig. 5.12) is shown, while the mean and age range (Fig. 5.13) and normalized

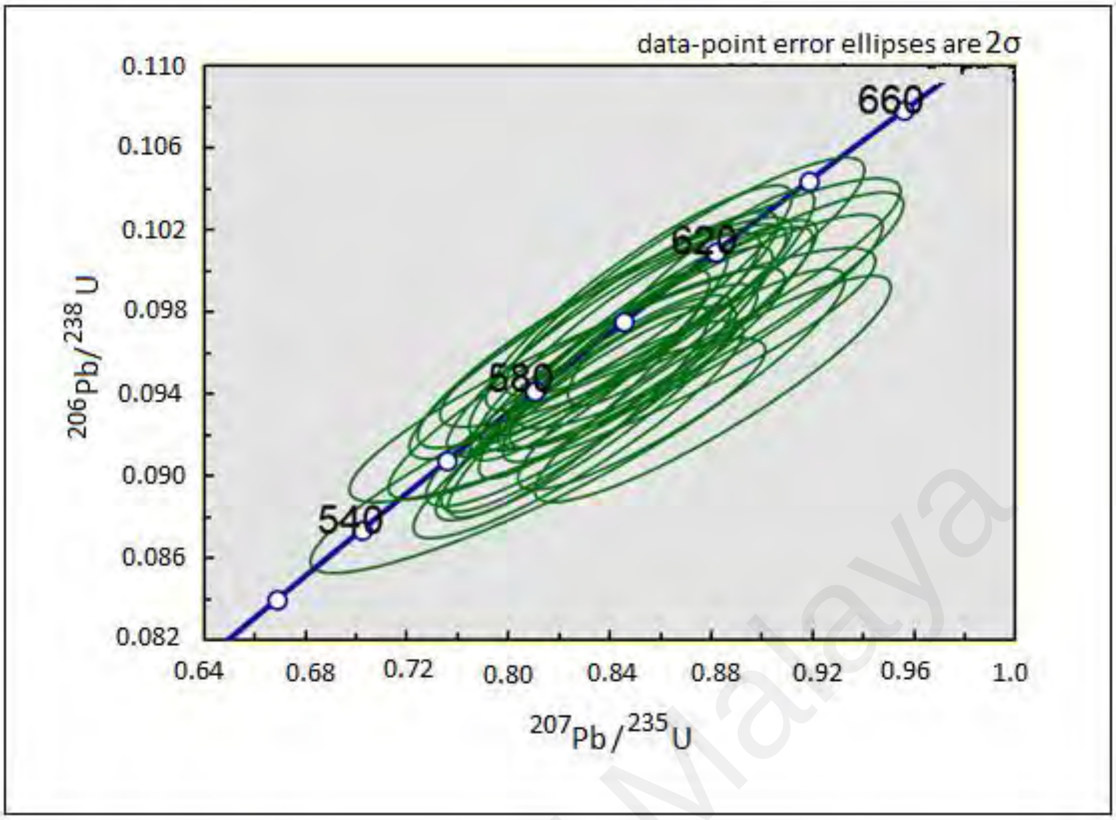

Figure 5.12: Concordia diagram of U-Pb zircon geochronology of charnockite (Ch) from Idanre area

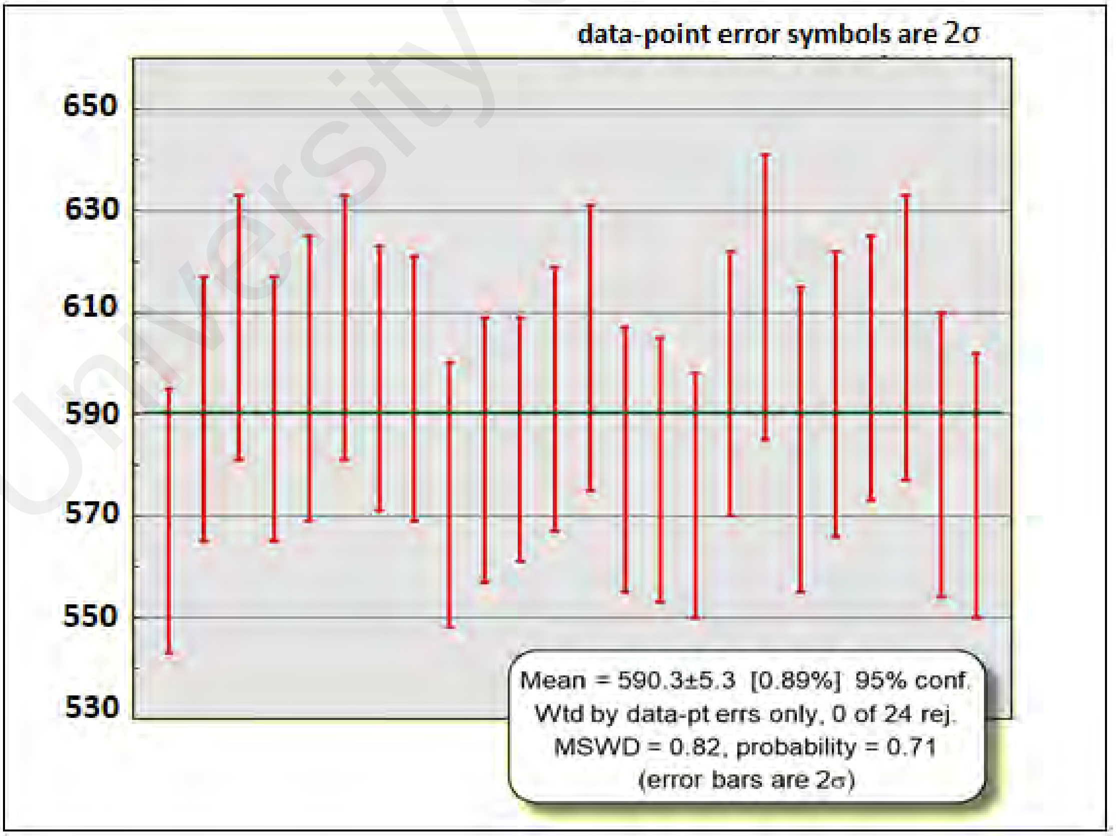

Figure 5.13: Mean and age range of the 24 LA-points U-Pb zircon dates for the charnockite (Ch) of Idanre area

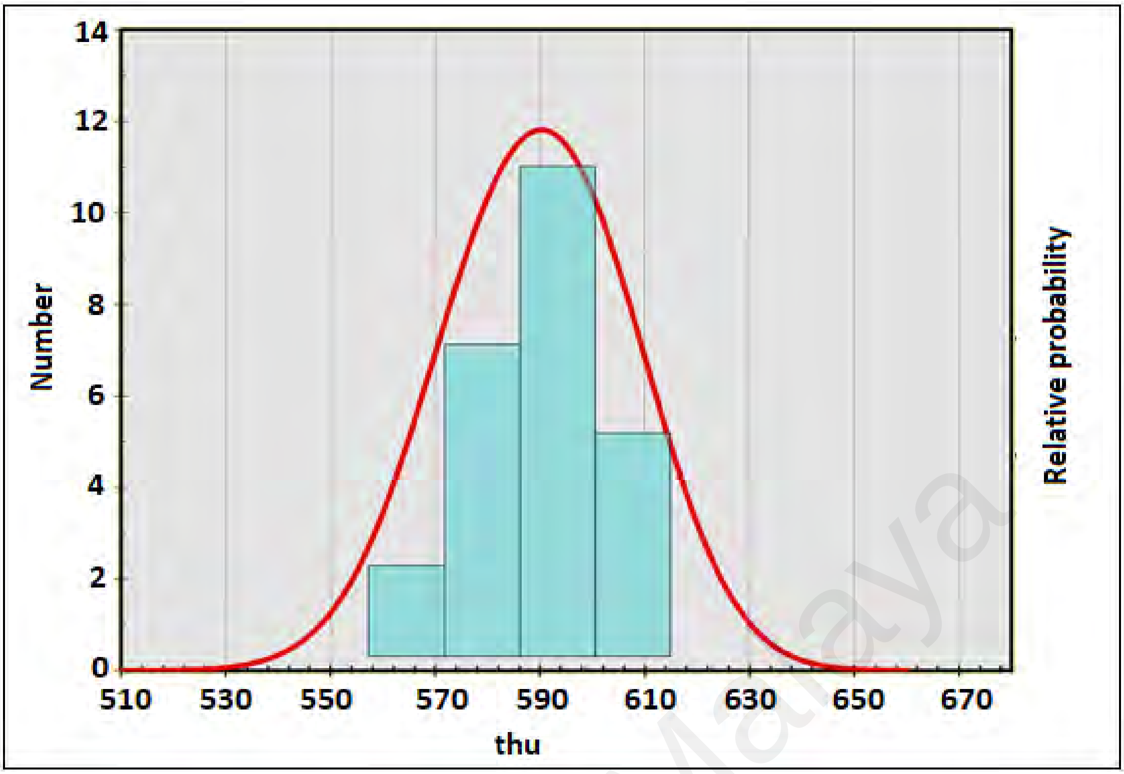

Figure 5.14: Normalized probability plot and histogram for zircon U-Pb ages of charnockite (Ch) associated with granite suites of the basement terrain of Idanre

probability plot and histogram (Fig. 5.14) for the U-Pb ages of the charnockitic rock is shown.

5.1.5. Migmatite Gneiss

Zircon grains in Idanre migmatite have sizes that range between 50 and 200 μ m and are concentrically zoned (Fig. 5.2e). Many of the grains appeared cloudy and fragmented. In another analysis, 25 evaluations on zircon grains were carried out which show that U contents range between 80.838 to 116.736 ppm, Th between 25.647 and 38.227 ppm, while Th/U ratio have values between 0.299 and 0.356. The range of $^{206}Pb/^{207}Pb$ ages is from 1051 to 1082 Ma. A weighted average age 1065.1 ± 7.1 Ma (MSWD = 0.28) represents the estimation of age of the migmatite-gneiss from Idanre area. The Concordia diagram (Fig. 5.15) for the rock is shown, while the mean and age range (Fig. 5.16) and normalized probability plot and histogram (Fig. 5.17) for the migmatite rock is shown.

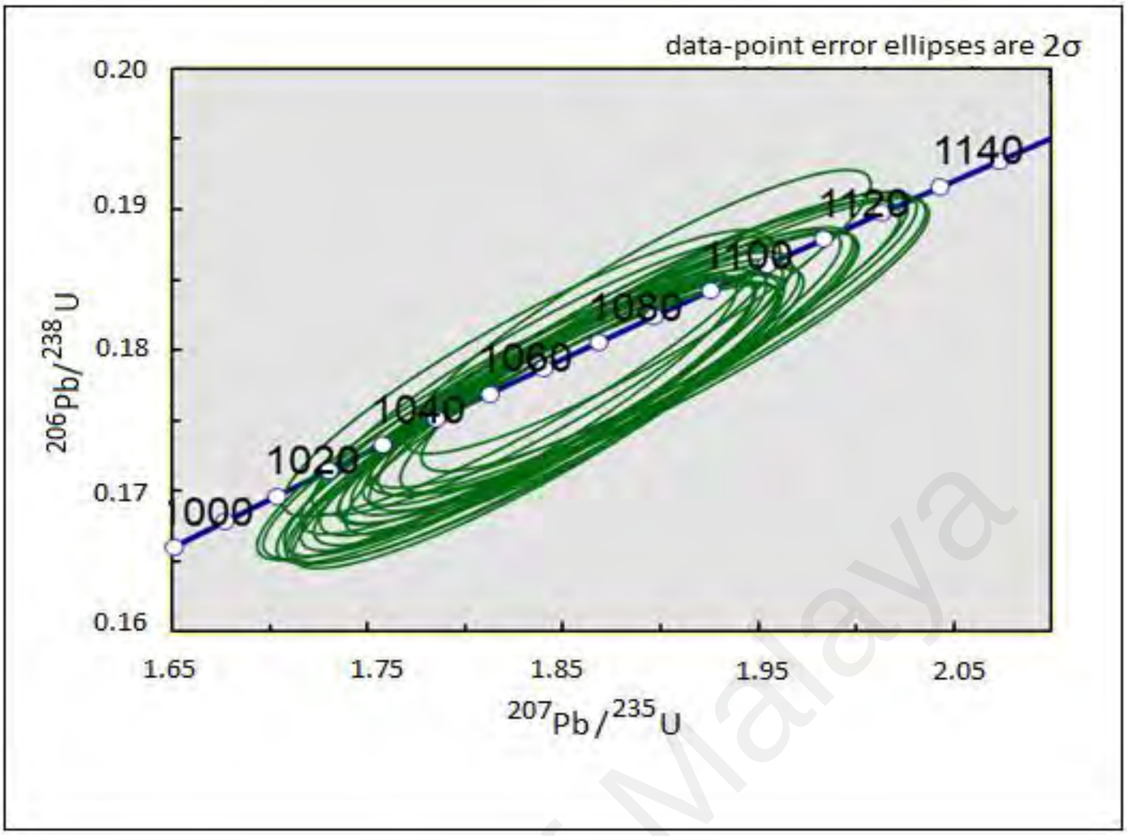

Figure 5.15: Concordia diagram of U-Pb zircon geochronology of migmatite gneiss (M) from Idanre area

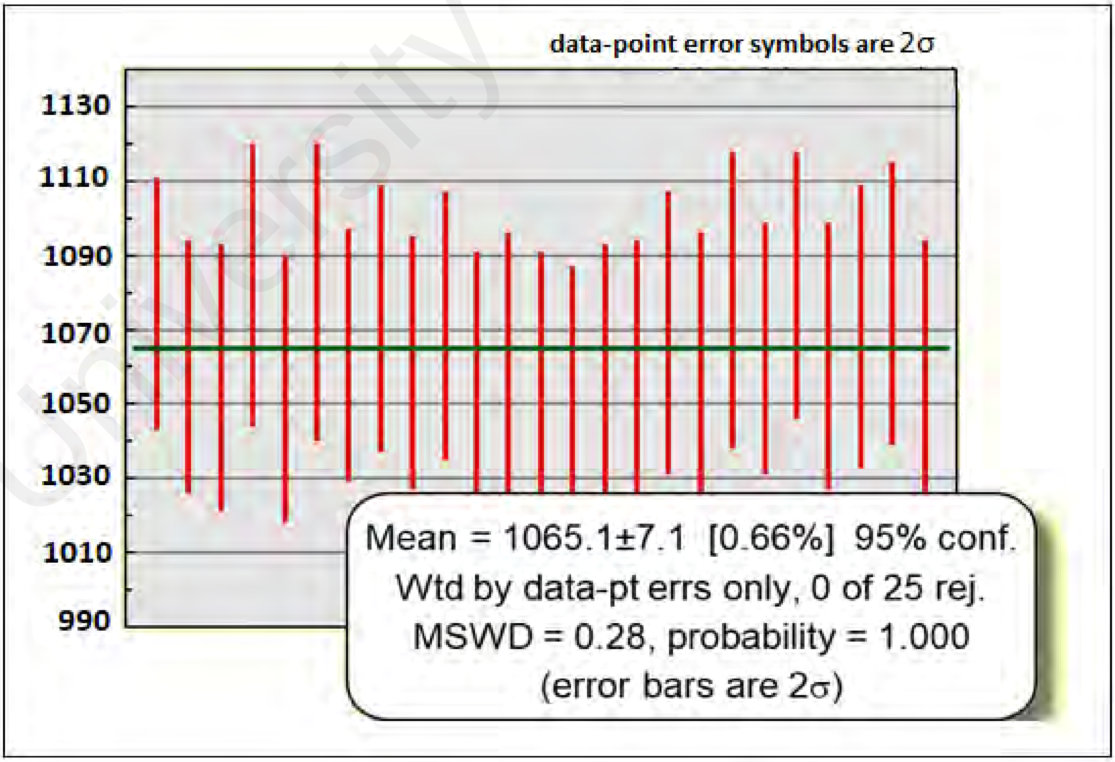

Figure 5.16: Mean and age range of 25 LA-points U-Pb zircon dates for migmatite-gneiss (M) of Idanre area

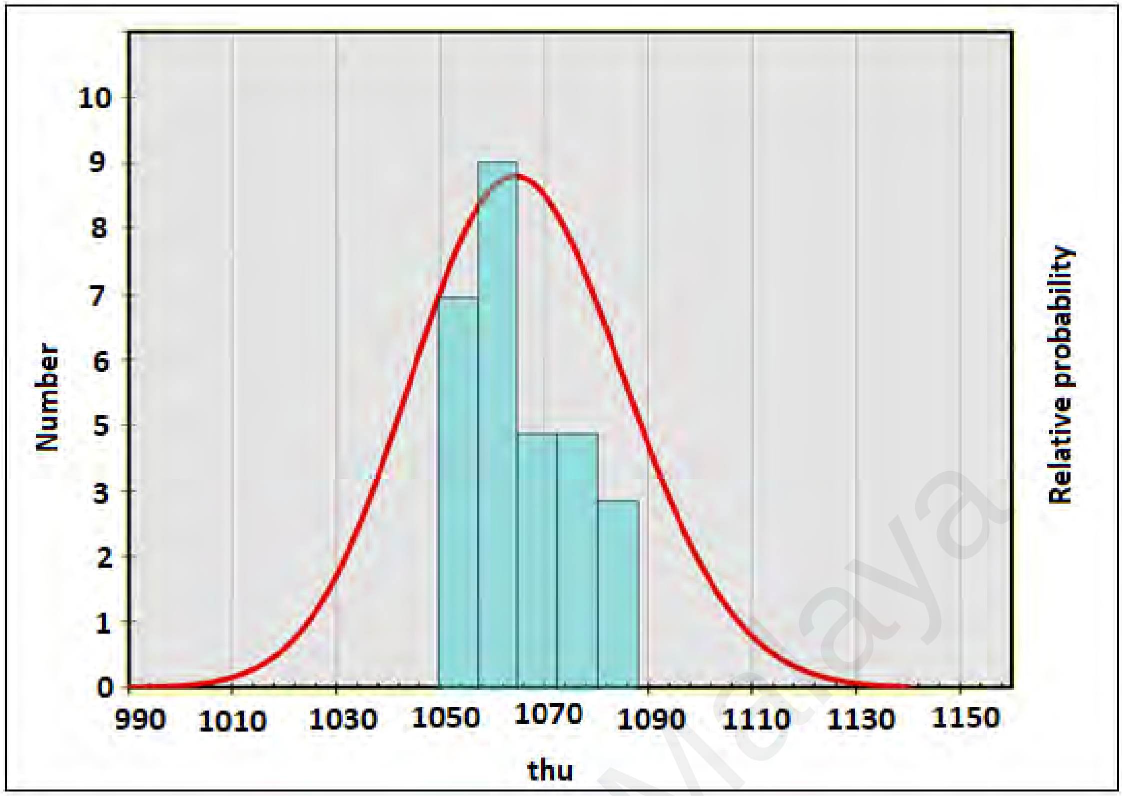

Figure 5.17: Normalized probability plot and histograms for zircon U-Pb ages of migmatite host rock in the basement terrane of Idanre

5.2 Lu–Hf Isotopic Composition

Although, seismic data and geophysical methods were at one time largely depended upon as the only means of imaging the inner parts of the crust. However, structural, and geodynamic evolution of the earth's continental plate has been linked to interplay of multiple geological processes. Consequently, the recent times has witnessed how the ancient and modern state of the lithosphere can be picked by U-Pb-Hf isotopic study of zircon which can act as a paleo-geophysical tool that showcases crust-mantle interaction through time (Hartnady et al., 2018).

Zircon grains extracted from different units of the granite complex and surrounding migmatite country rocks were subjected to Lu-Hf isotopic analyses. For all the analyses, the exact spots within the domains of zircon that were used for U-Pb isotopic composition were adopted. The U-Pb ages which was previously obtained from the samples was also used to compute the Hf isotope ratios initially incorporated into the zircons and crustal model ages. Pictorial representation of εHf(t) values versus age is shown in Figure 5.18a, while the initial hafnium $^{176}Hf/^{177}Hf$ ratios versus ages is plotted on Fig 5.18b and the summary of isotopic composition of analysed points and their data are shown (appendix 2). $^{176}Lu/^{177}Hf$ value of the zircon grains range from 3.02-10.65 x 10^{-4} in fine-grained granite (C5); 4.09-13.04 x 10^{-4} in coarse-grained (undifferentiated) granite (B15); 3.83-13.45x10^{-4} in porphyritic granite (B9); 4.55-9.35x10^{-4} in charnockite (D29) and 3.67-16.69x10^{-4} in migmatite (A17). All ratios which are substantially less than 0.002 indicated that the zircon grains contain low radioactive Hf growth after they are crystallized. Consequently, the isotopic $^{176}Hf/^{177}Hf$ ratio could decipher growth and decay processes in isotopic composition of Hafnium in the system during evolution (Knudsen et al., 2001; Wu et al., 2007).

The coarse-grained (undifferentiated) granite and porphyritic granite have similar Lu-Hf isotopic compositions. For the coarse-grained (undifferentiated) granite, $^{176}Hf/^{177}Hf$ ratios of 15 spots investigated, values vary from 0.281724 to 0.281843. The initial Hf isotope ratios ($^{176}Hf/^{177}Hf$)i calculated from their zircon U-Pb ages is from 0.281715 to 0.281782. Hf isotopic composition fluctuates within wide limits. εHf(t) values which changes from -21.1 to -25.1 are mainly concentrated between -22.2 to -23.5 (Fig. 5.18a). The two-stage model age is tDM_2 = 2827 to 2877, mainly within the range of 2800 to 2990 Ma.

For porphyritic granite, the $^{176}Hf/^{177}Hf$ ratios of 16 spots vary from 0.281692 to 0.281863. The Hf isotope initial ratio ($^{176}Hf/^{177}Hf$)i is from 0.281683 to 0.281848. εHf(t) values also vary widely, changing from -21.2 to -26.1, mainly from -22.5 to -25.5. The two-stage model age is tDM2=2718 to 3070 Ma, mainly within the range of 2850 to 2950.

For fine-grained granite, the evaluated 15 zircon grains yielded $^{176}Lu/^{177}Hf$ isotopic composition which range from 0.000302 to 0.001065. $^{176}Hf/^{177}Hf$ ratio also ranges from 0.281712 to 0.281813. The Hf isotope initial ($^{176}Hf/^{177}Hf$)i from the U-Pb age is from

0.281708 to 0.281802. The Hf isotopic composition vary within narrow limits while εHf(t) changes between -22.4 to -25.7. The two-stage model age tDM_2 = 2880 to 3030, mainly within the range of 2800 to 3000 Ma. For this unit, $^{176}Hf/^{177}Hf$ ratios of 15 measurements vary from 0.281716 to 0.281813. The Hf isotope initial ratio of $^{176}Hf/^{177}Hf$ is from 0.281708 to 0.281802 (Fig. 4.63b). The εHf(t) values vary within limits that are close and changes from -22.4 to -25.7, but most values are concentrated between -23.5 to -24.5. The two-stage model age is tDM2=2829 to 3030 Ma mainly within the range of 2900 to 3000.

For charnockite, 15 grains of zircon yielded $^{176}Lu/^{177}Hf$ isotopic composition with values ranging between 0.000416 to 0.000935. Initial $^{176}Hf/^{177}Hf$ ratios range from 0.281957 to 0.281984. Hf isotope initial $(^{176}Hf/^{177}Hf)_i$ range between 0.281951 to 0.281996. εHf(t) changes between -14.8 to -16.6 (Fig. 5.19a). The two-stage model age tDM2=2395 to 2504, mainly within the range 2400-2500.

For migmatite, the evaluated 15 zircon grains yielded $^{176}Lu/^{177}Hf$ isotopic composition with values within the range 0.00367 to 0.001669 while the $^{176}Hf/^{177}Hf$ ratio range from 0.281955 to 0.282022. The Hf isotope initial $(^{176}Hf/^{177}Hf)_i$ values range between 0.281969 to 0.282005 (Fig. 4.64b). εHf(t) changes between -3.5 to -5.2. The two-stage model age tDM2 = 2080 to 2161, mainly within the range 2080 to 2100 Ma.

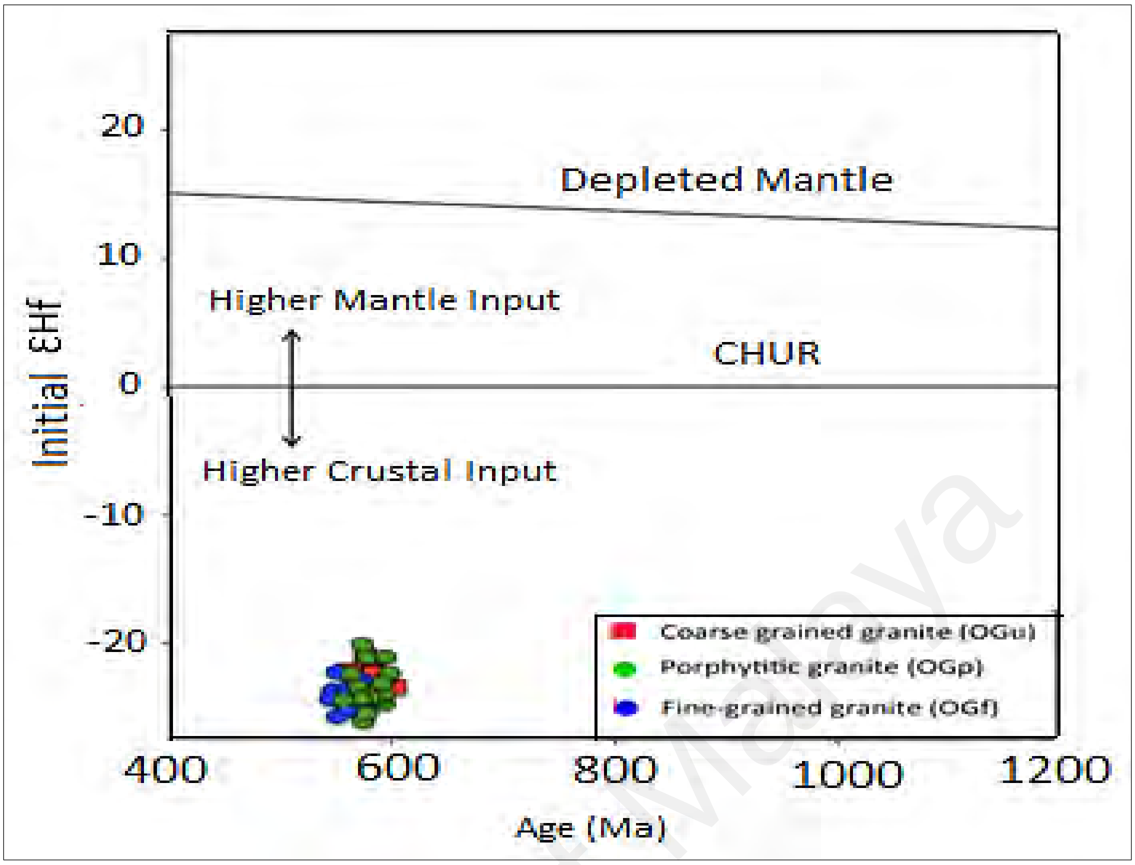

Figure 5.18a: Binary diagram of initial εHf(t)-Age (Ma) of Idanre granite Complex

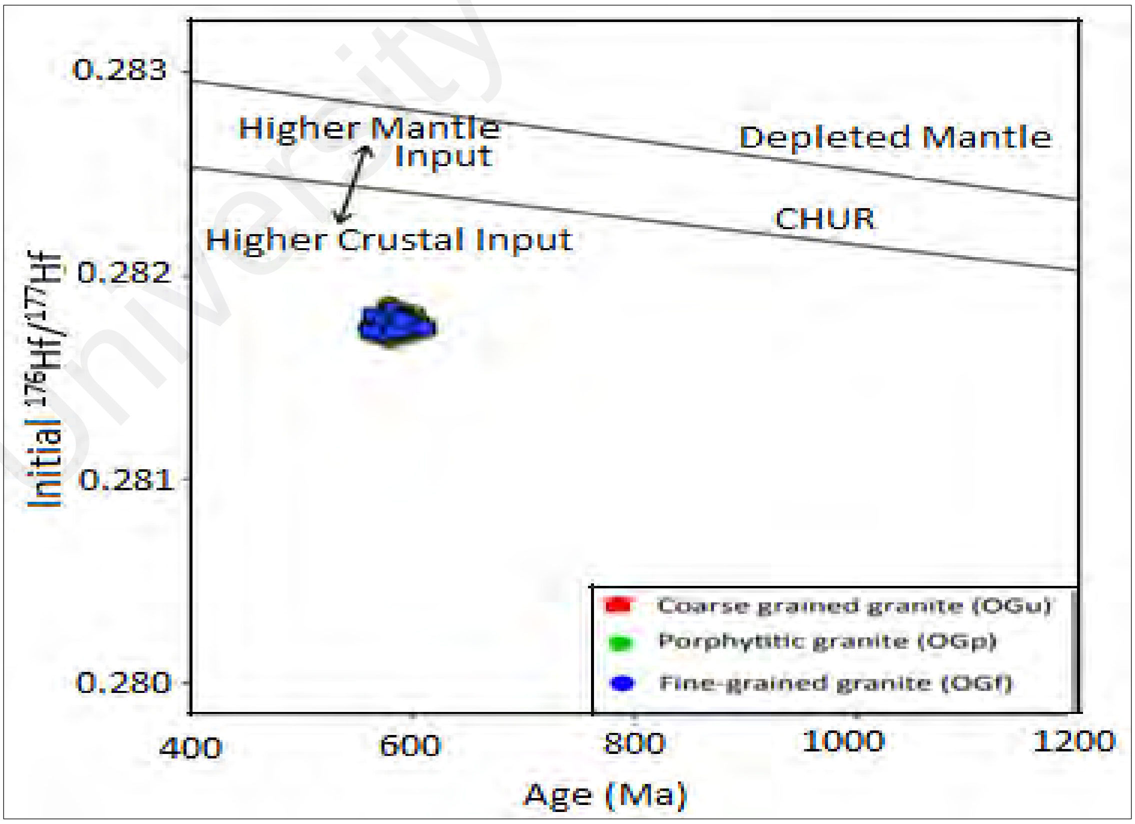

Figure 5.18b: Binary plot of initial $^{176}Hf/^{177}Hf$ isotope versus Age (Ma) of Idanre granite complex

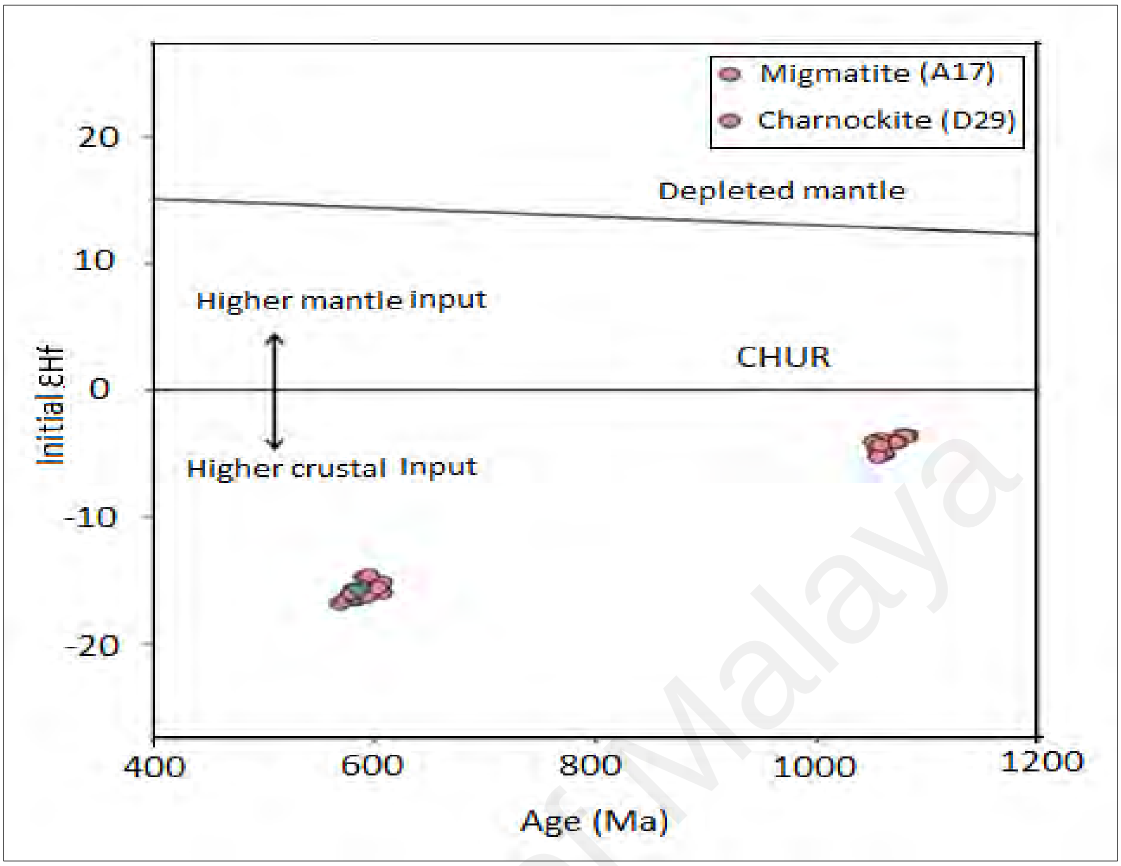

Figure 5.19a: Binary diagram of initial εHf(t) versus Age (Ma) of charnockite and migmatite in the study

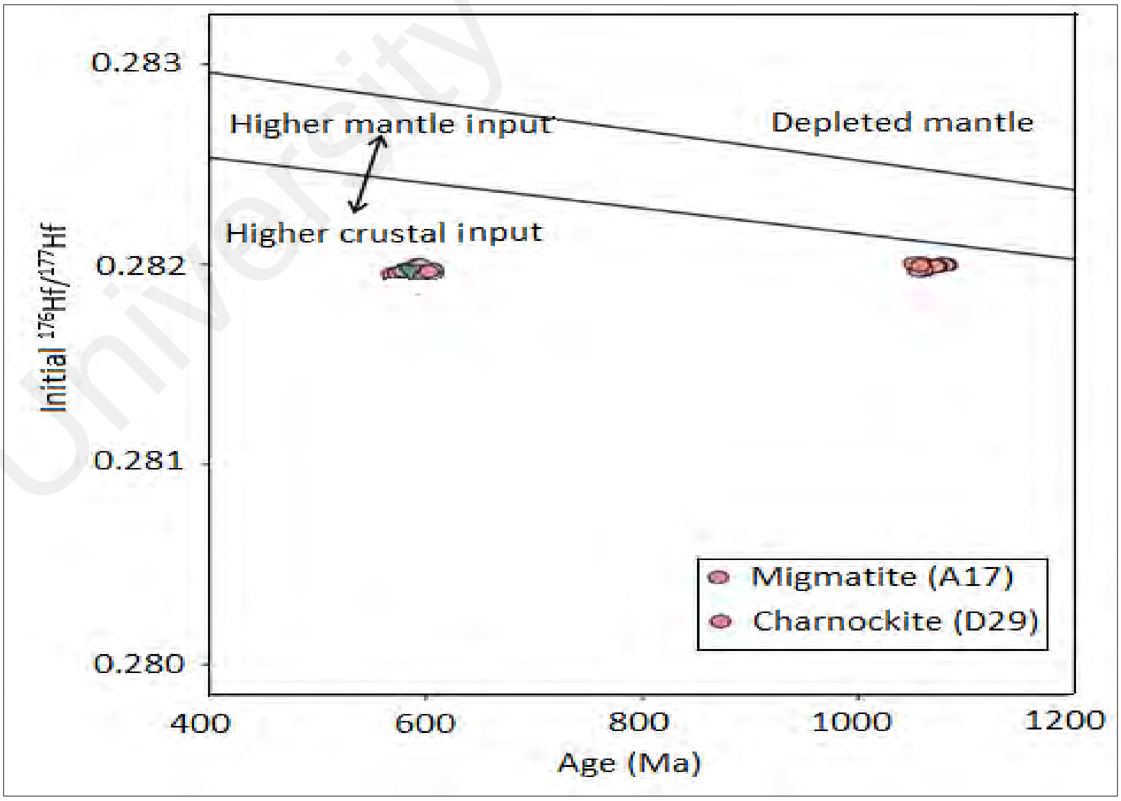

Figure 5.19b: Binary diagram of initial $^{176}Hf/^{177}Hf$ isotope versus Age (Ma) of charnockite and migmatite in the study

CHAPTER 6: DISCUSSION

6.1 Lithologic Relationship

The migmatite-gneiss-granite terrane of Idanre is a typical Precambrian domain characterized by rocks such as migmatite, biotite-hornblende gneiss, banded gneiss, granite and charnockite. Unlike the basement complex of Zungeru and Nasarawa areas in north central Nigeria, or the nearby Ife-Ilesha and Igarra areas all of which falls dominantly on schist belts, Idanre area is unique for not having schistose assemblages dominated by rocks such as garnet schist, mica schist, amphibole schist, staurolite-mica schist or biotite schist. The granitoids which intruded the gneissic basement are members of the Older Granite (Pan-African) suite and forms the prominent topographic feature of the study area. The granites are intruded by series of aplitic dykes, pegmatitic dykes and quartz veins. These tabular bodies occur in varied sizes and orientation. However, in similarity with the basement of Igarra area (Odeyemi, 1990) which lies in eastern flank of basement terrain of southwestern Nigeria, Nasarawa-Keffi area (Ojo, 1994; Maloma, 2004) in northcentral Nigeria, and Iseyin area (Rahaman, 1976), the general foliation trend in Idanre area is dominantly between N4^{o}E to N38^{o}E. Older tectonic structures in the basement were obliterated by younger ones making the Pan-African (~600Ma) orogenic signatures to be the most dominant.

The general petrology, structural and geochemical characteristics of the rocks constituting Nigerian basement complex are reported extensively in earlier works of Russ (1956), Ajibade, (1980), Elueze, (1982), Ogezi, (1988), Rahaman, (1976, 1978, 1988). Others are Annor et al., (1996), Annor, (1998) and Caby, (1989). More recent research works on the basement complex are contained in the works of Okonkwo and Winchester, (2000); Ukaegbu, (2003); Ephraim, (2005); Ekwueme and Kroner, (2006); Obaje, (2009); Goodenough et al., (2014); and Adetunji et al., (2016) among others. All the above authors indicated that the Nigeria basement contains heterogenous units with dominance of migmatite gneisses, schistose assemblages and granitoids and that these different lithologies have unique chemistries. In addition, they also indicated the structural framework of the basement is related to orogenic activities. The results of this research confirm the assertions of these earlier authors.

The lithologic interrelationship in the study area denote the granite intruded the older gneissic basement (Migmatite, biotite-hornblende gneiss and banded gneiss). The intrusive granites, which were once deep-seated plutons are now unmasked after the overburden is removed by prolonged weathering and denudation. The granite occurs in three textural varieties which are: coarse-grained granite (OGu), porphyritic granite (OGp), and fine-grained granite type (OGf). The granitoids form circular intrusive masses that occupies central region of the research location and entirely ringed by older gneissic lithology. Morphologically, the topographic variation of the terrane is controlled by lithologic differences as the low land areas are underlain by migmatite and gneisses while the prominent hills are granitoids occurring as towering inselbergs some of which are of batholithic dimensions.

Aplite and pegmatite dykes which exhibit E-W and NE-SW sense of directions have dominant cross-cutting relationships indicating they belong to terminal phase of Neoproterozoic thermo-tectonic activities. The pegmatite dykes are of simple (quartz, K-feldspar) mineralogy and does not exhibit complex internal structure.

6.2 Petrography

Optical microscopy indicates that all the members of the suite have varying proportions of quartz, feldspar, hornblende, and biotite. Feldspars occur in the granite as aggregates of plagioclase, orthoclase, and microcline. Sphene, pyroxene, zircon and magnetite occur in subordinate amounts. While the basement gneiss in addition to the above major minerals contains traces of some metamorphic minerals like chlorite, cordierite, garnet and staurolite.

6.3 Geochemistry

The chemistry of a rock is significant in its geochemical characterization and rocks having similar chemistry may reflect similar origin of formed from sources that are related. In the case of granitoids, similar chemistry and distribution patterns of some specific immobile elements or their isotopic ratios may reflect comagmatic relationships.

6.3.1 Geochemistry of the granite complex compared to other similar rocks

The geochemistry of Idanre granite Complex showed clearly it is enriched in K_2O. This enrichment is visibly reflected in Na_2O+K_2O versus SiO_2 binary diagram (Middlemost, 1994). (Fig. 6.1) where the granitoids plotted within quartz monzonite and granite fields. However, few samples strayed into the adjacent granodiorite fields and monzonite. This plot adequately supports previous assertions that the Nigeria granite range in composition from granite, granodiorite and quartz monzonite and adamellite (Rahaman et al., 1988).

The geochemical parameter for granite classification based on Al_2O_3/(Na_2O+K_2O) versus Al_2O_3/(Na_2O+K_2O-CaO) (A/NK vs A/CNK) (Fig. 6.2) indicate that the Idanre granite complex is classified as metaluminous granitoids (A/NK>1, A/CNK<1). The Idanre granite complex is geochemically comparable to granite and quartz-monzonites from Eastern Nigeria (Goodenough et al., 2014). However, the rock is significantly different from quartz monzodiorite reported by same authors from eastern side of the country. Great is the diversity of granite that are contained in the Nigeria basement terrain. Albeit these granites sometimes show some geochemical coherence while at some instances, they are petrologically distinct. The high K_2O content in the Idanre granite

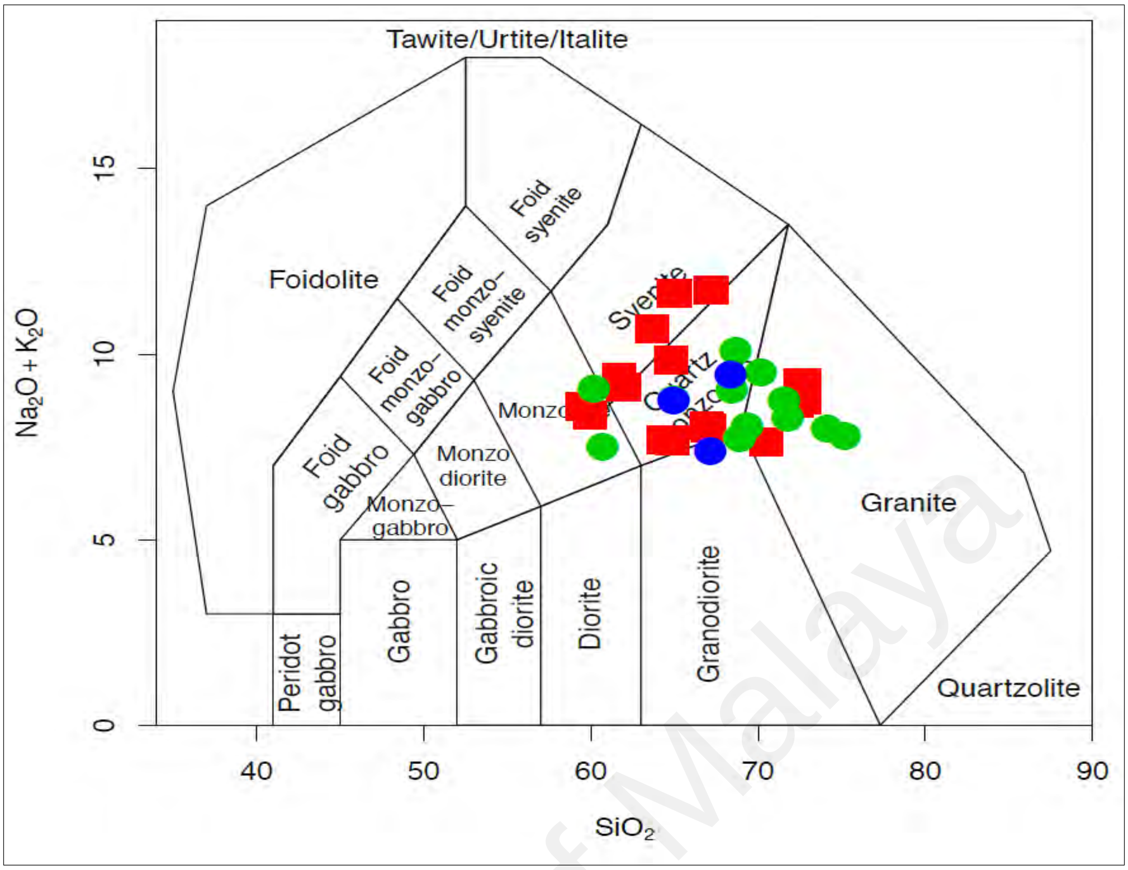

Figure 6.1: (Na_2O+K_2O) versus SiO_2 plot of Idanre granite complex (after Middlemost, 1994)

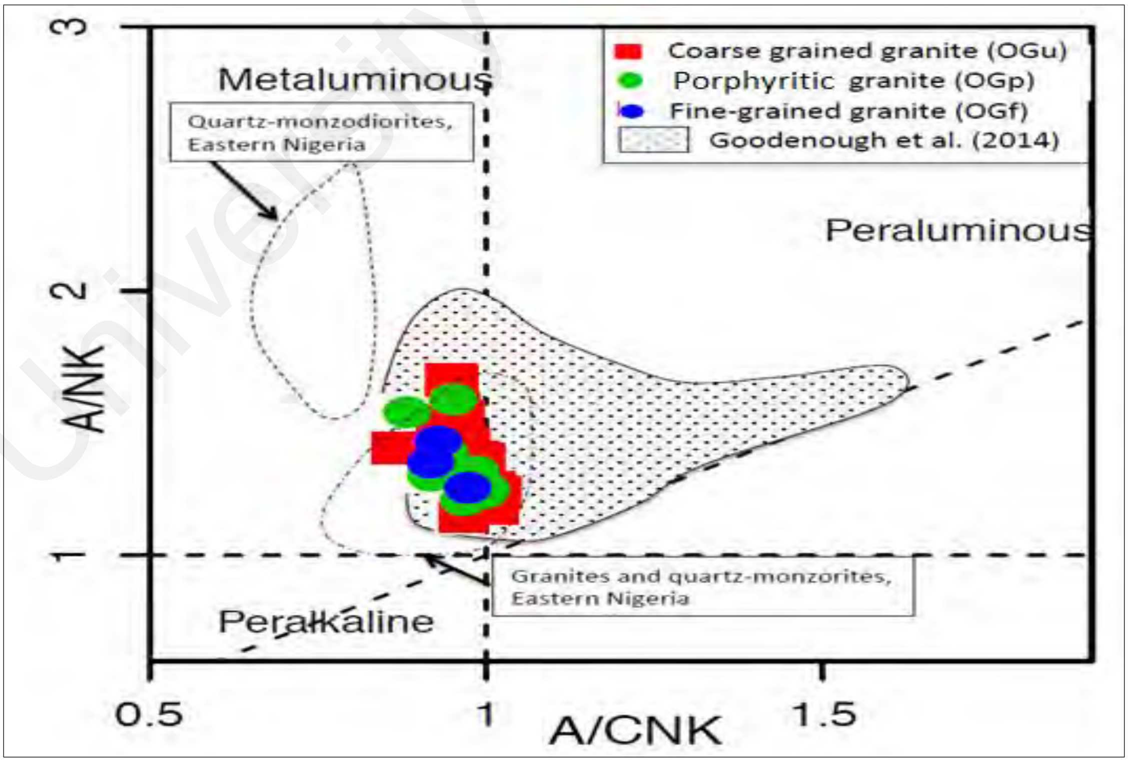

Figure 6.2: $Al_2O_3/(Na_2O+K_2O)$ versus $Al_2O_3/(Na_2O+K_2O-CaO)$ diagram of granite from Idanre compared with granitoids from basement of SE Nigeria (after Shand, 1947)

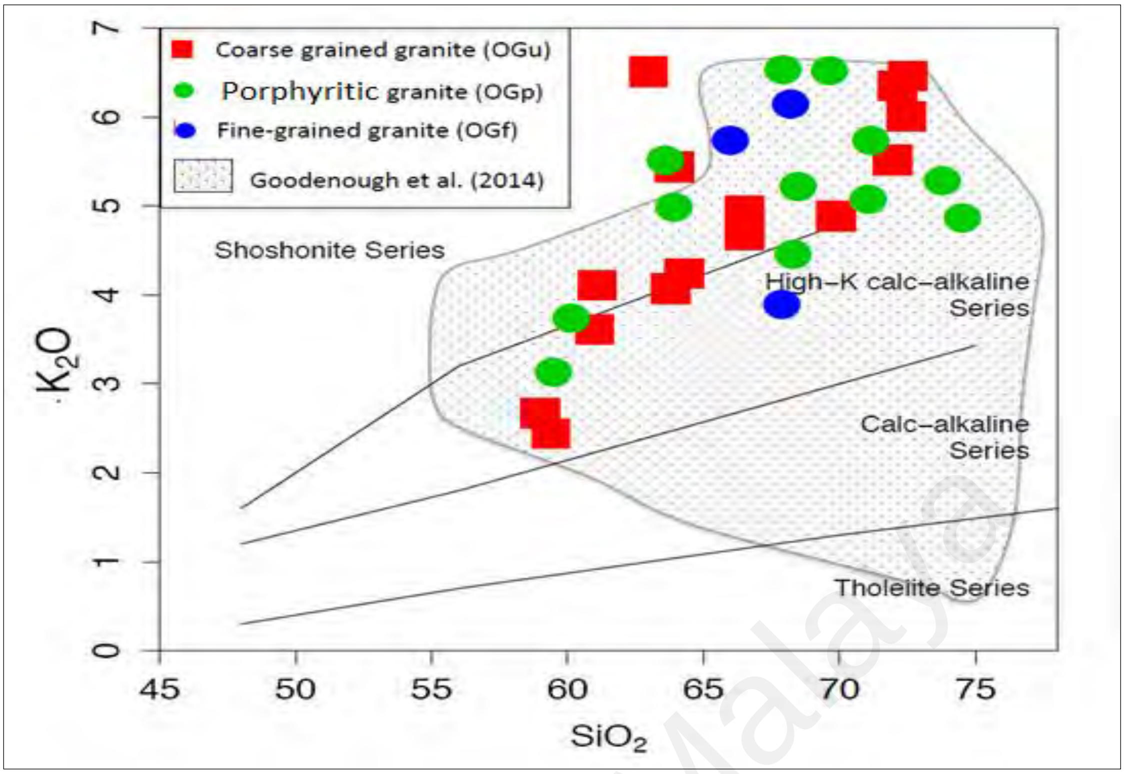

Figure. 6.3: K_2O versus SiO_2 diagram of Idanre granite complex compared with similar rocks from other parts of Nigeria (after Peccerillo and Taylor, 1976)

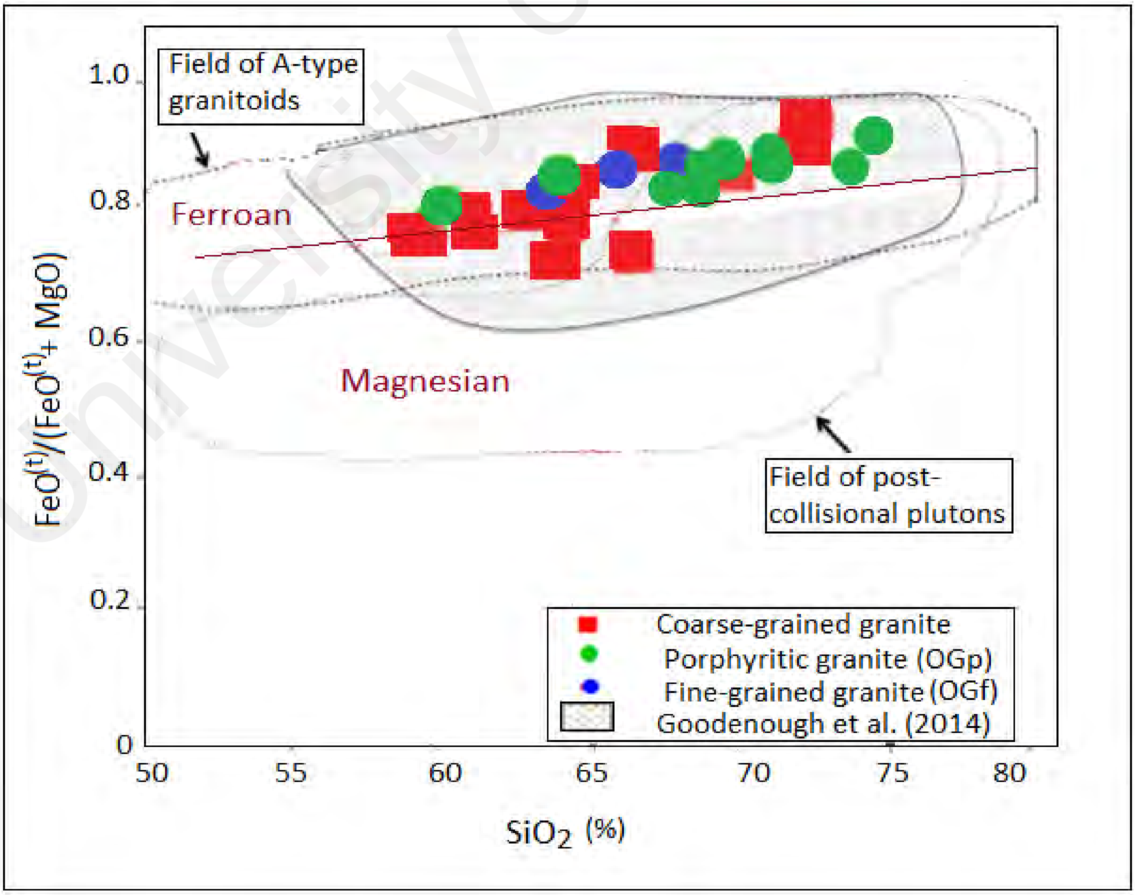

Figure 6.4: FeOt/(FeOt + MgO) versus SiO_2 diagram of Idanre Granite Complex compared with other granitoids in Nigeria, boundaries are drawn after Frost et al., 2001

complex (Fig. 6.3) is comparable to similar rocks reported by Goodenough et al., (2014) from eastern Nigeria.

FeOt/ (FeOt + MgO) versus SiO_2 plot (Fig. 6.4) showed the Idanre granite is ferroan type and falls within the field of A-type granites even though some samples of the suite plots within the field of post-collision granite.

6.3.2 Tectonic Setting

Apart from basalt which has proved useful as tectonic indicators, granite is another group of rock that often reflect their tectonic settings. However, due to the complex petrogenetic pathways granite follows during evolution, it is apparently difficult to establish their tectonic setting solely on field geology for two main reasons. First, granite being a rock intruded into a constantly changing crust, the interval between granite emplacement and its exposure at the surface, if long enough, can make explicit evidence of its tectonic interpretation during intrusive stage to become obscured. This makes it difficult to sample granites of known tectonic setting (Pearce et al., 1984). Secondly, their chemical composition is difficult to interpret due to their complex petrogenetic pathways (Hanson, 1978). Even though geochemical and isotopic information are sometimes characterized by undefined conclusion on these parameters, yet granites types are typically connected to their tectonic settings (Storey et al., 1988). Furthermore, for these reasons, the evaluation of the tectonic setting of granite is based on indirect evidences. It is also noteworthy that the initial S- and I- type subdivisions which are initially genetic are now extended into tectonic indicator. The S- type is considered to originate from continental domains while the I- type are linked to post-orogenic uplift regimes.

The source rock and the processes of melting and crystallization of granitic rocks also reflects their petrogenetic affinities (Storey et at., 1988). As indicated in chapter 2, based on intrusive setting, granites have 4 main groups and types which can be divided in conformity with their tectonic setting and petrological features (Pearce et al., 1984).

Binary diagrams of trace element have been reliable for identifying the tectonic setting of basalts erupted during different geological ages (Pearce and Cann, 1973) are often adopted for granites. Furthermore, the duo indicated that the elements Ti, Zr, Y, Nb, and Sr can possibly characterize volcanic rocks of different tectonic settings. Discrimination borders, even though practically drawn, indicate that modelling of geochemical parameters has a theoretical bases in the history of origin of different granite groups. According to Pearce et al., (1984), post-collision granites appear to be the only type that pose a problem in tectonic classification because it is affected by variation in the size and nature of the crust associated with the collision process and on the exact time and place where magmatism took place. The binary variation diagrams predicated on trace components (Nb and Y) composition as indicated on Nb versus Y binary diagram (Fig. 6.5) shows all samples of rocks from the study area plotting in WPG and VAG + syn-COLG fields. This is further supported by Rb versus Y+Nb binary diagram (Fig. 6.6) where Idanre rocks plot extensively on WPG field and no sample plotted on ORG field. Typically, within-plate granites in continental environment is often characterized by close association with meta-igneous rocks such as amphibolite. Even though, the Idanre area do not bear outcrop exposures of meta-igneous rocks such as amphibolite or rocks of amphibolitic affinity, the prevalence of amphibolite in the nearby Ife-Ilesha schist belt which lies in the western side of Idanre which equally falls within the same basement may support this.

Previously Storey et al., (1988), indicated that granites located in within-plate environment particularly those that are characterized by crust dominated features intruded into normal thick crust or intensely thinned crust features higher concentration of Nb, Rb, Sm, Y, Th and Yb. Trace element geochemical result of Idanre granite (Table 4.3b) shows

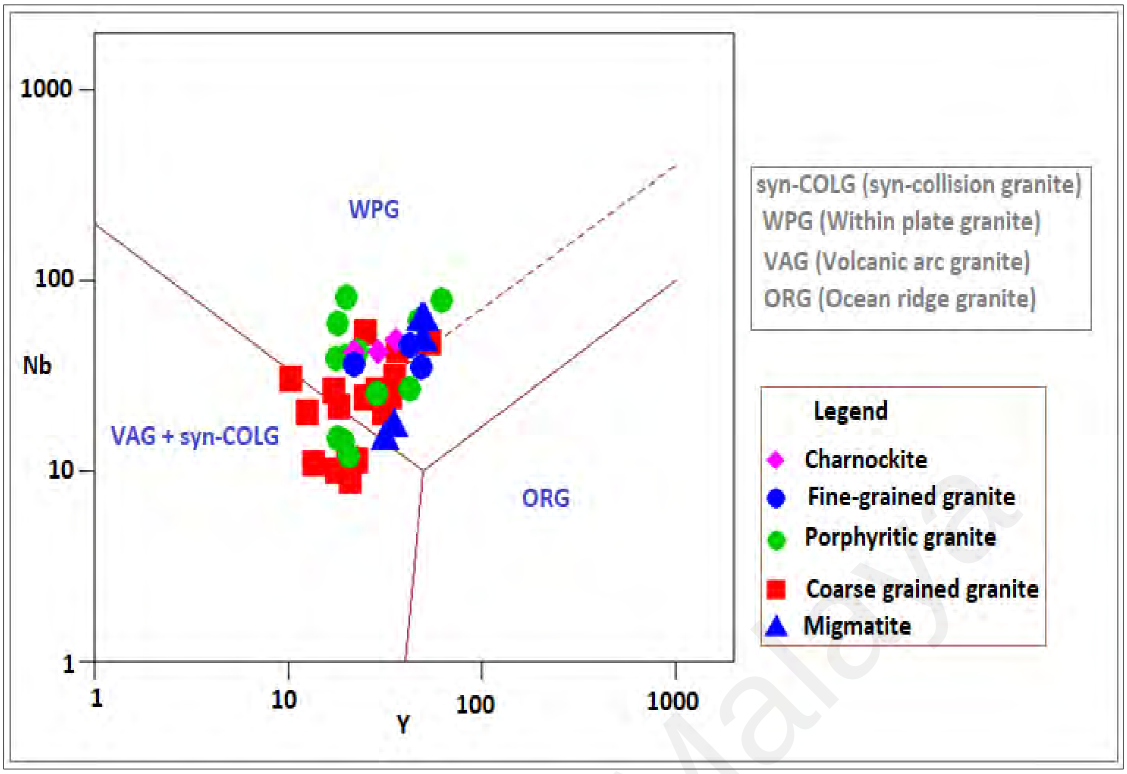

Figure 6.5: Tectonic discrimination diagram Nb versus Y for Idanre rocks (after Pearce et al., 1984)

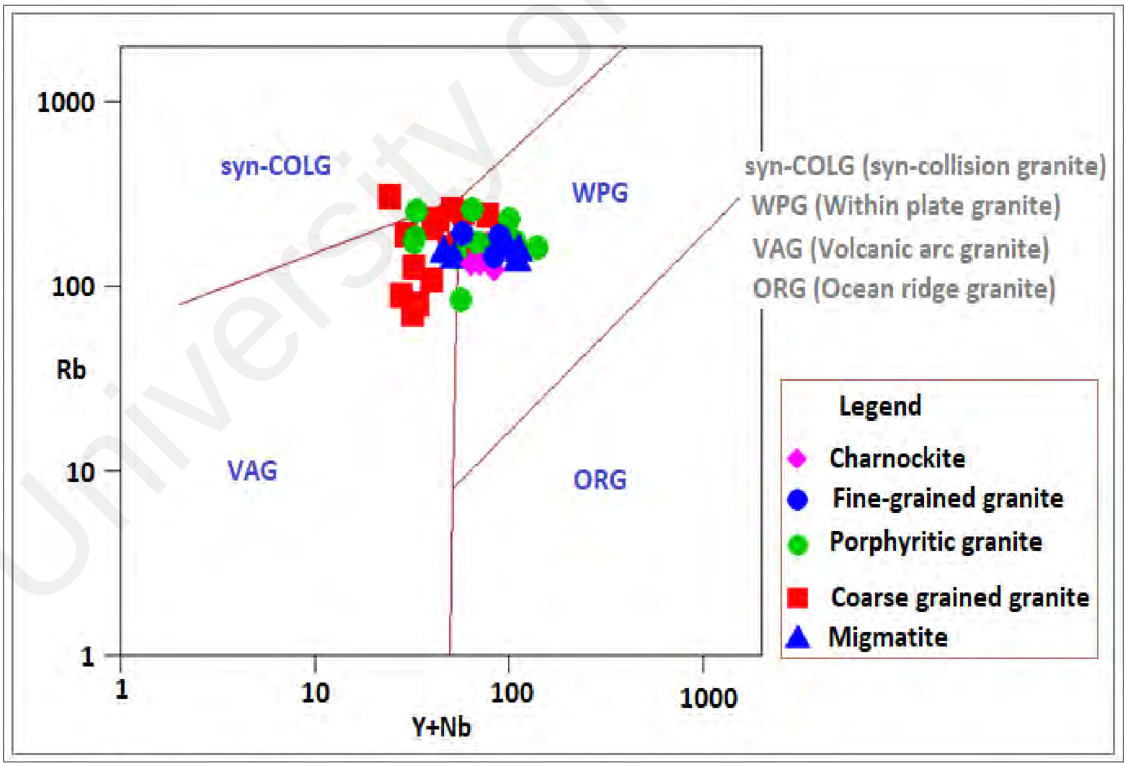

Figure 6.6: Tectonic diagram Rb versus Y+Nb of Idanre rocks (after Pearce et al., 1984)

a compositional feature that follows a similar trend with Nb (8.8-61.2), Rb (71.0-260.1), Sm (5.3-25.2), Y (13.5-62.7), Th (8.3-111.5) and Yb (0.8-4.7) (all in ppm) confirming its within plate environment status.

Previous model reveals that granites in within-plate environment which have formed without crust-contaminated materials like those from Ascension Island originated directly from mantle with evidence of clinopyroxene and plagioclase and magnetite assemblages such that the granites have high Rb, Nb and Y abundances. More so, Pearce et al., (1984) pointed out that, the plagioclase-enriched mineralogy tends to provide flat REE profiles with negative Eu anomalies which are characteristics of crust-free granite of within plate origin. Within-plate granites in Nigeria have incorporated crustal materials to the extent that Rb/Nb and (La/Yb) normalized ratio which are high for various continental rocks gave rise to non-corresponding variations in Rb compared to Nb and Y abundances (Pearce et al., 1984). Bowden and Turner, (1974) have earlier demonstrated that with plate granite in Nigeria to have assimilated crust materials to have enhance the crystallization of abundant amphibole. The manifestation and prevalence of biotite-hornblende granites in the basement complex may further reinforce this.

The Idanre granite is mildly fractionated, it has metaluminous ($Al_2O_3 \approx K_2O+Na_2O$) geochemical feature and high K_2O/Na_2O ratios. Overall, the SiO_2 content of Idanre granites ranges from 61.5-74.56%, the Harker Diagram trends for: MgO, CaO, FeO total, TiO_2, MnO, Al_2O_3 and Na_2O all decrease with respect to increasing SiO_2, whereas K_2O trend increases. The increase in K_2O trends with respect to SiO_2 probably arose from fractionation of amphibole or feldspars during the magmatic stage. High A/CNK and K_2O values, low Ca, variable LIL/HFS, high Rb, Th, U are all features of I-type granitoid. The Nigeria Pan-African granites are generally linked to the orogenic activity of the Upper Precambrian, they are related to continental collision and has been severally referred to as post-collisional granite e.g. (Goodenough et al., 2014).

The tectonic setting of granite reflects in a way it is formed. Granite may be of orogenic origin or anorogenic (non-orogenic). The orogenic granitoids may belong to oceanic Island Arc, Continental Arc with mantle wedge melting or Continental Collision where batch melting and local anatexis is in operation or the granitoid magma is principally produced by underplated mantle melts. It may also be transitional combining Post-Orogenic and Uplift/Collapse where decompression melting aided by hot spot plume takes place (Pitcher 1983). The anorogenic setting may be either from Continental Rifting and Hot Spots or Mid Oceanic Ridge and Ocean Islands. The tectonic setting of Idanre granite according to Nb versus Y binary diagram (Fig. 6.7a) (Pearce et al., 1984) is within plate granites. The tectonic setting of the Idanre granite Complex is like the granite and quartz monzonite of Eastern Nigeria.

Zr vs 10000*Ga/Al binary plot (Fig. 6.7b) which distinguishes A-type granite from those of I, S and M types show the composition of the Idanre granite complex falls within the field of granitoids reported by Goodenough et al., (2014). However, a large population of the granite falls outside the geochemical ring representing granite and quartz monzonite of eastern Nigeria.

6.3.3 Evidence of plagioclase fractionation during evolution of the granite complex

During evolution of magma, evidence of fractionation can be determined using the elements Zr, Rb, Sr, Ba and REE (Jung et al., 1995). Plagioclase fractionation is often reflected in granitoids by presence of a negative Eu anomaly, usually, this can be generated through fractionation or fusion of plagioclase feldspar, garnet, apatite, allanite, magnetite and possibly clinopyroxene and amphibole. The choice of mineral(s) participating in the fractionation process is a function of the partitioning coefficients between crystalizing minerals and the magma. However, the profile of Idanre granite shows a similar distribution pattern for both REE and LREE and all analysed samples

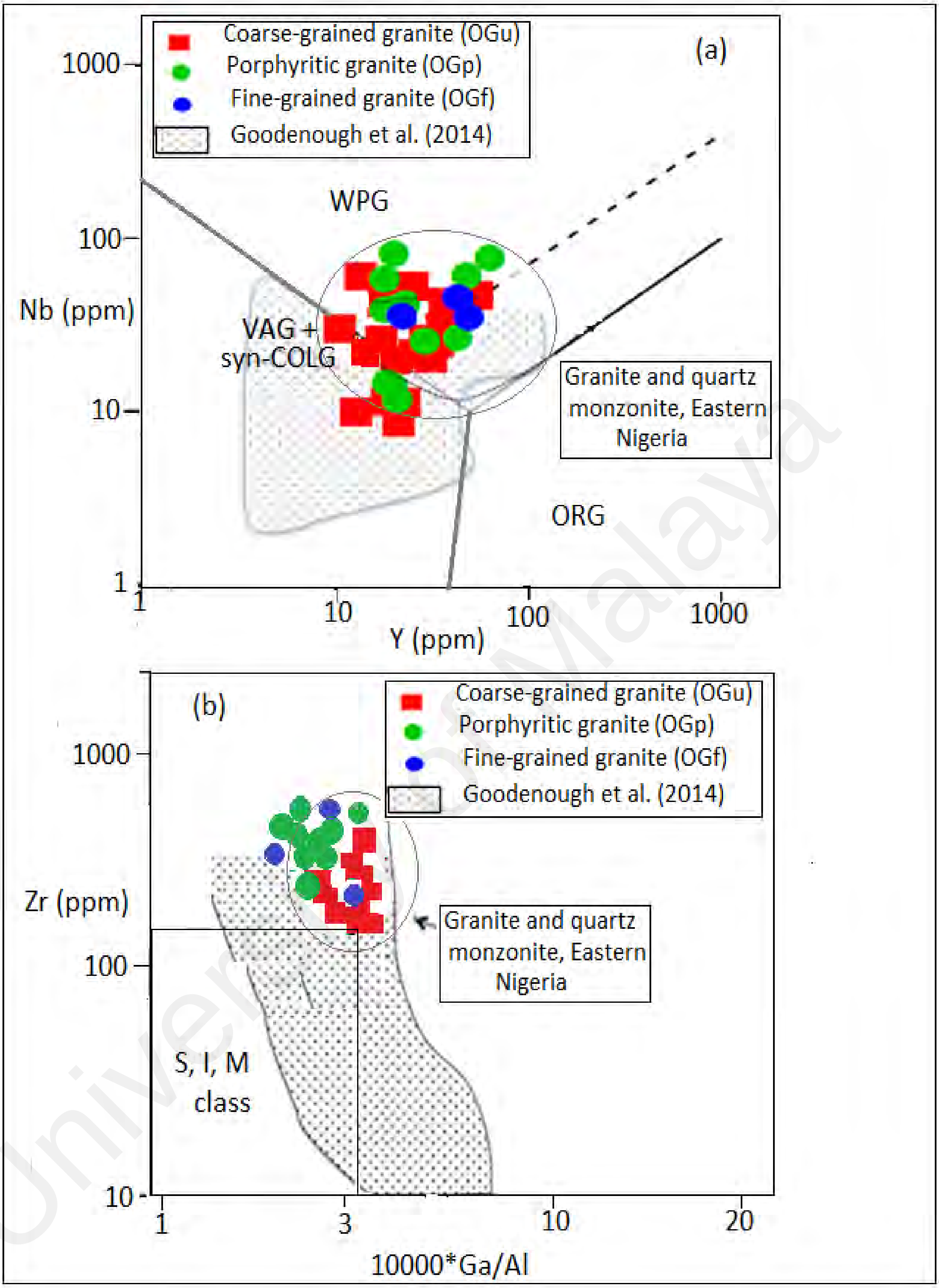

Figure 6.7: Binary diagram (a) Nb versus Y plot of Idanre granite complex compared with other Nigeria granites, (b**)** Zr vs 10000*Ga/Al of Idanre granite compared with granitoids in other parts of Nigeria

display striking uniformity in shape for their REE pattern. The dominance of LREE over HREE as indicated by chondrite normalized REE pattern (Fig. 6.8) and a negative Eu anomaly reflect that plagioclase fractionation may be essential in the development of the Idanre granite suites. Sun and McDonough's (1989) normalized REE profile (Fig. 6.9), indicates that the Idanre granite show enhancement in Rb, Th and Zr, but show Nb, P and Ti depletion. All the rock samples analysed in Idanre area show enhancement in LREE and depleted in HREE. LREE in the granite typically have 180-1100 times chondrite levels, meanwhile, the HREE has 3-35 times chondrite levels, and all samples display a negative Eu anomaly. Further evidence of plagioclase fractionation is shown on Ba vs Rb plot (Fig. 6.10a) and Ba vs Sr binary diagrams (Fig. 6.10b) where all the granite samples plotted on the trend of plagioclase fractionation. La/Yb vs La diagram (Fig. 6.11c) indicate that monazite and allanite may have contributed to the fractionating process in the coarse-grained undifferentiated granite while zircon play a significant role in fractionation process of Idanre Porphyritic granite. On Rb vs Sr binary plot (Fig. 6.11d), indicate dominance of plagioclase fractionation over hornblende and biotite is established. The linear trend given by all the rock samples on Rb/Sr vs Sr binary diagram (Fig. 6.11e) further confirms the fractionation of plagioclase is dominant over the other minerals. The binary diagram of Th vs U (Fig. 6.11f) (Ng et al., 2015) showing all the rocks in Idanre area clustering around the line Th/U=10 signifies poor mineralization potential of the granitoid. Ng et al., (2015) indicates that lower Th/U ratios in granite symbolizes better the mineralization potential. The crystallization process of the granitoids are significantly determined by fractionation of K-feldspar according to Ba/Sr binary diagram (Fig. 6.12). The characteristics related to how REE and HFSEs is apportioned between calcic amphiboles and liquid silicates in more evolved systems in granitoids were highlighted by several previous research at pressures between 0.2-1.0 Gpa and temperature ranging from 800-1050^{o}C (Sisson, 1994; Dalpé and Baker, 2000).

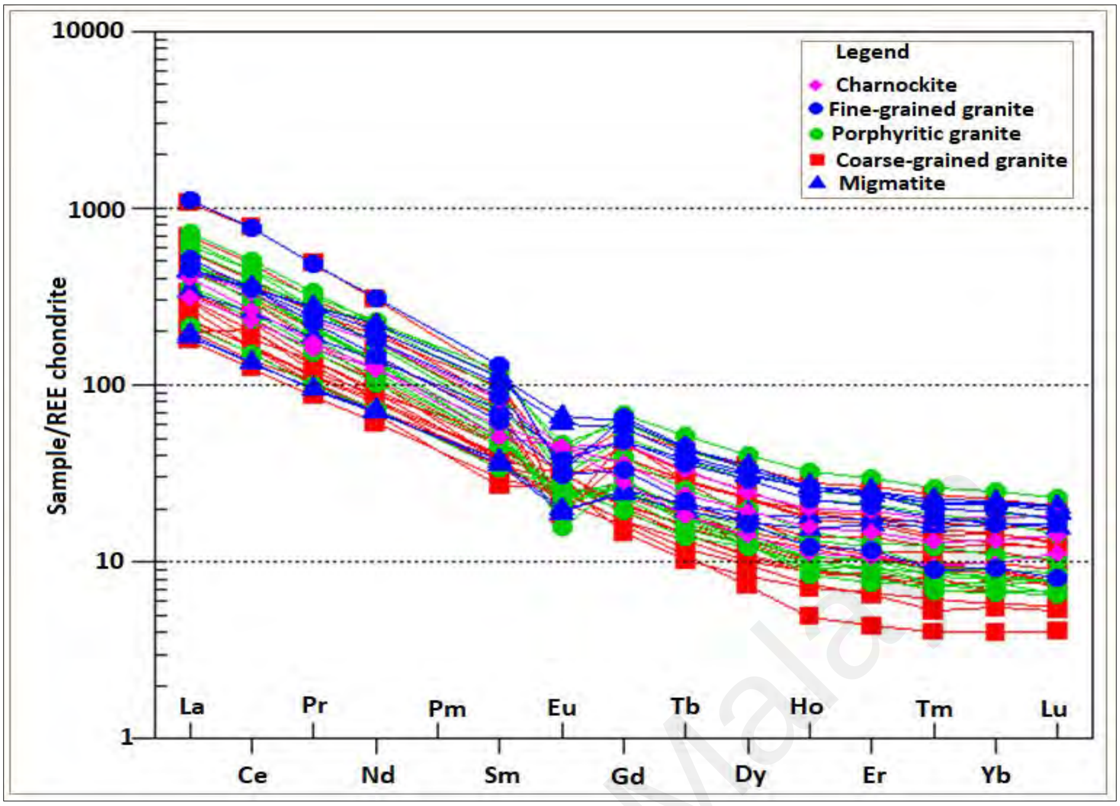

Figure 6.8: Chondrite normalized REE distribution pattern of the rocks in the study area

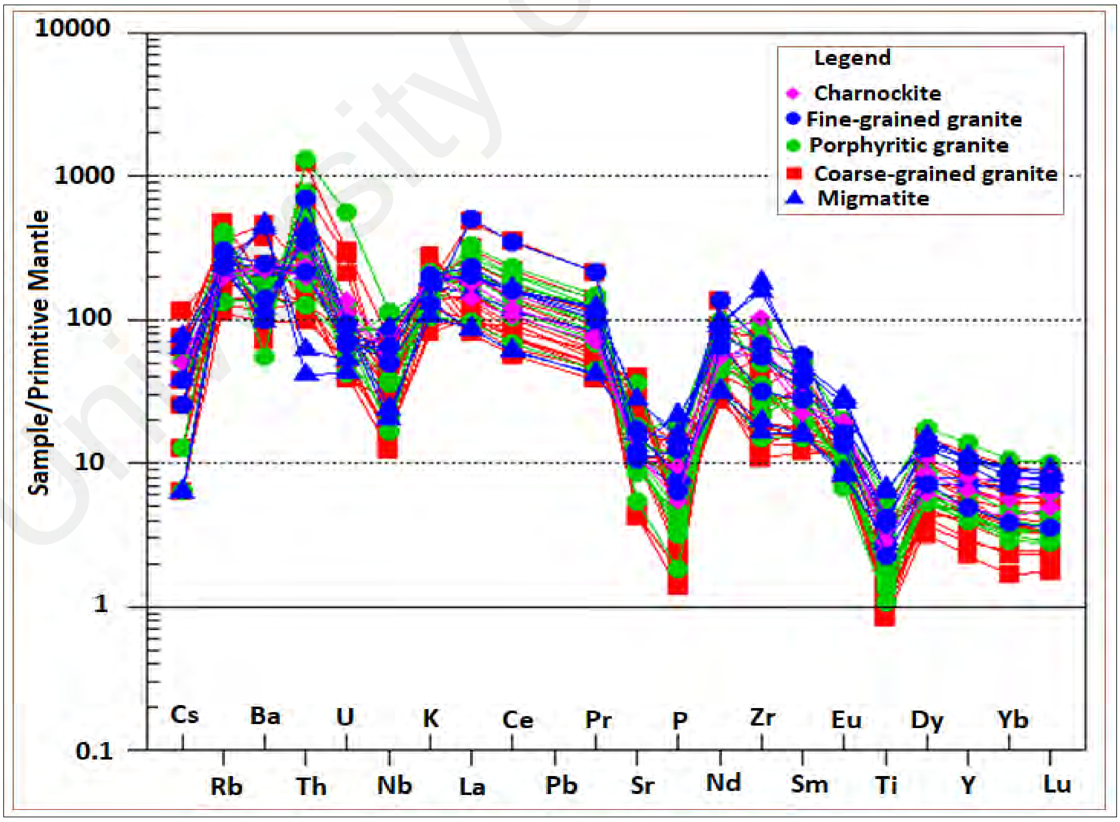

Figure 6.9: Primitive mantle/spider plot of rocks from the study area

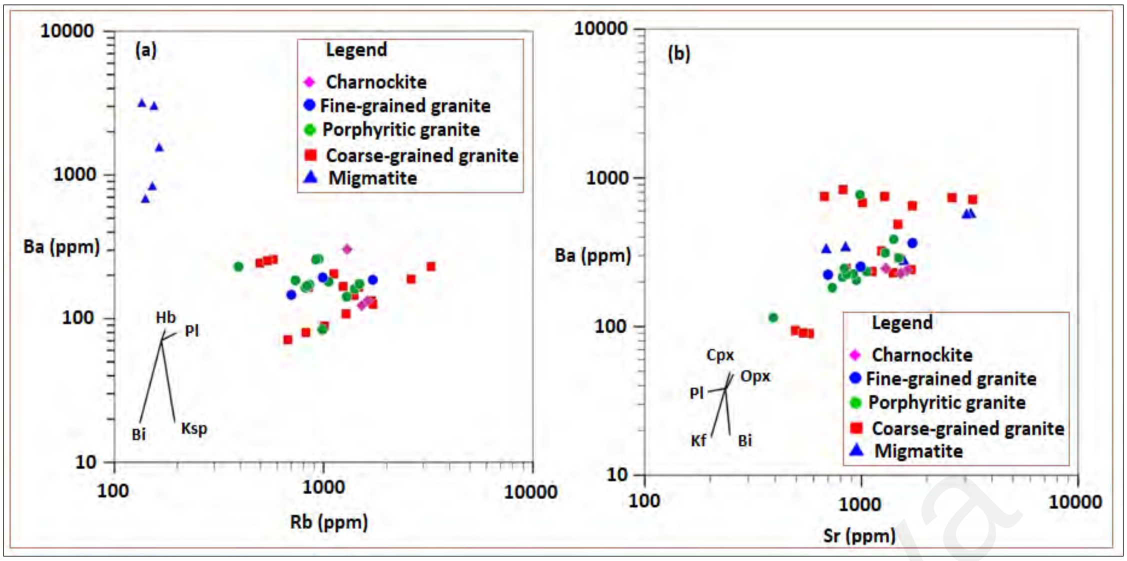

Figure 6.10: Binary diagram of (a) Ba vs Rb, (b) Ba versus Sr for the rocks from Idanre area. Pl (plagioclase); Hb (Hornblende); Bi (Biotite); Cpx (Clinopyroxene); Opx (Orthopyroxene); Kf (K-feldspar)

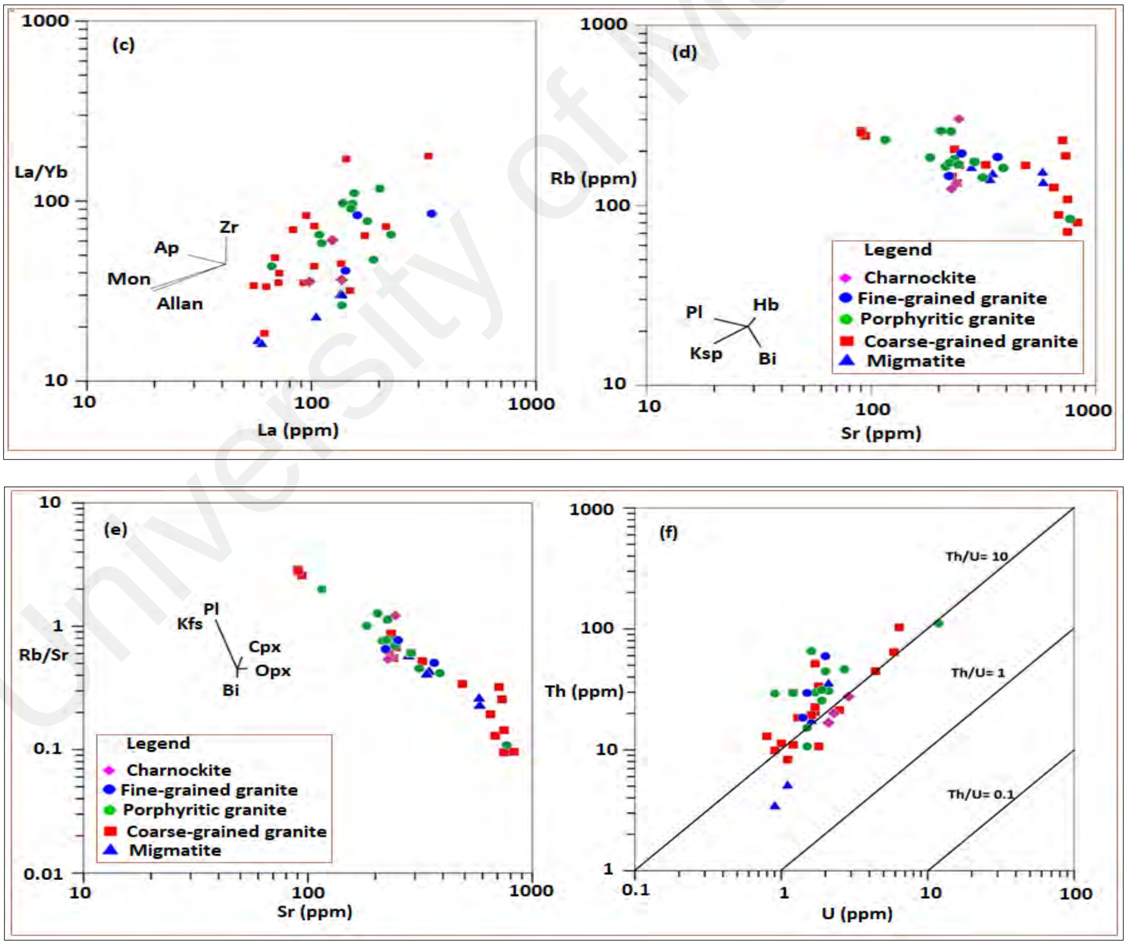

Figure 6.11: Binary diagram of (c) La/Yb vs La plot (d) Rb vs Sr (e) Rb/Sr vs Sr plot, (f) Th vs U plot for rocks in Idanre (Ng et al., 2015). Mon (Monazite); Allan (Allanite); Ap (apatite); Zr (Zircon), Ksp (K-feldspar), Pl (plagioclase); Hb (Hornblende); Bi (Biotite)

However, fractionation of biotite and K-feldspar appear to have contributed significantly to the crystallization process in undifferentiated coarse-grained granite. During the crystallization process, zircon saturation temperature ranges between 740°C-920°C in all the granites (Fig. 6.13) within the Idanre suite, but there seems to be two different patterns exhibited by the relationship between zircon saturation temperature and SiO_2 content. In Undifferentiated Granite (OGu), zircon temperature principally increases with increasing silica content, whereas in the other rocks, an inverse relationship exists between silica and zircon. Variation in degree of fractionation in granitic rock often result from effects of variable temperature, pressure, and composition. These variations control accessory minerals and how (e.g. allanite), and others can be generated by fractional crystallization or fusion of plagioclase feldspar, garnet, apatite, allanite, magnetite and possibly clinopyroxene and amphibole (Clark, 1984).

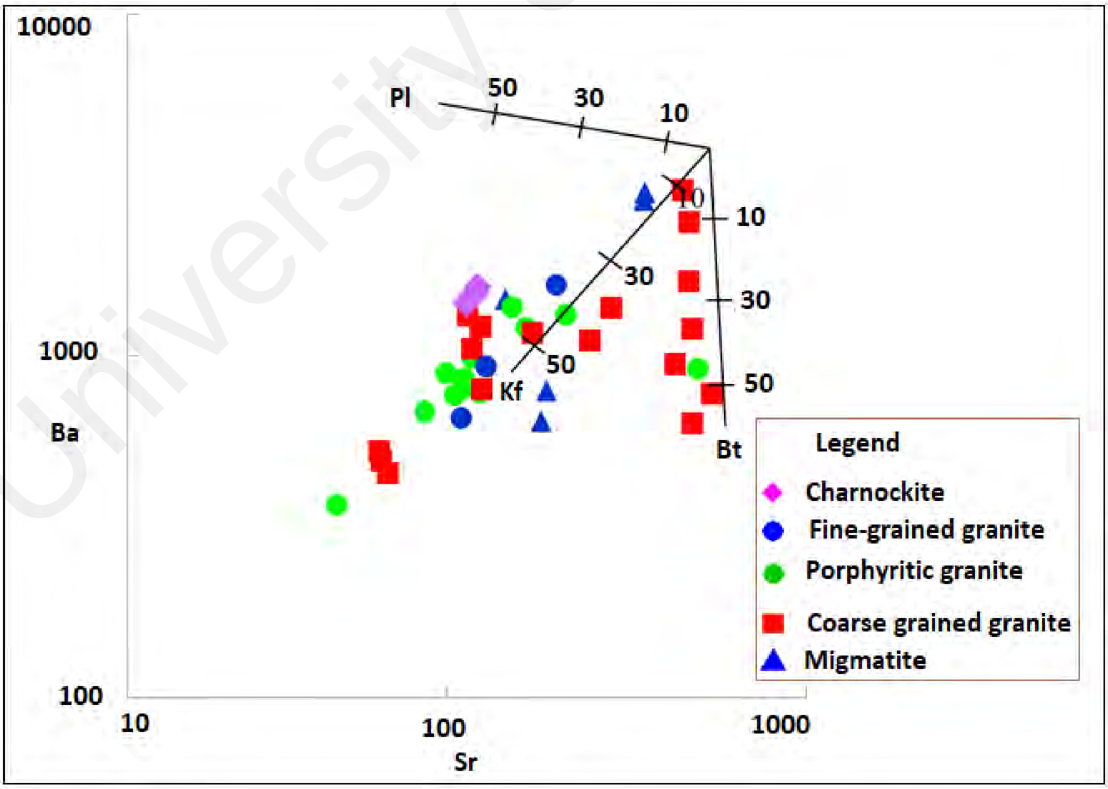

Figure 6.12: Ba versus Sr diagram indicating percentage of mineral fractionation in the rocks

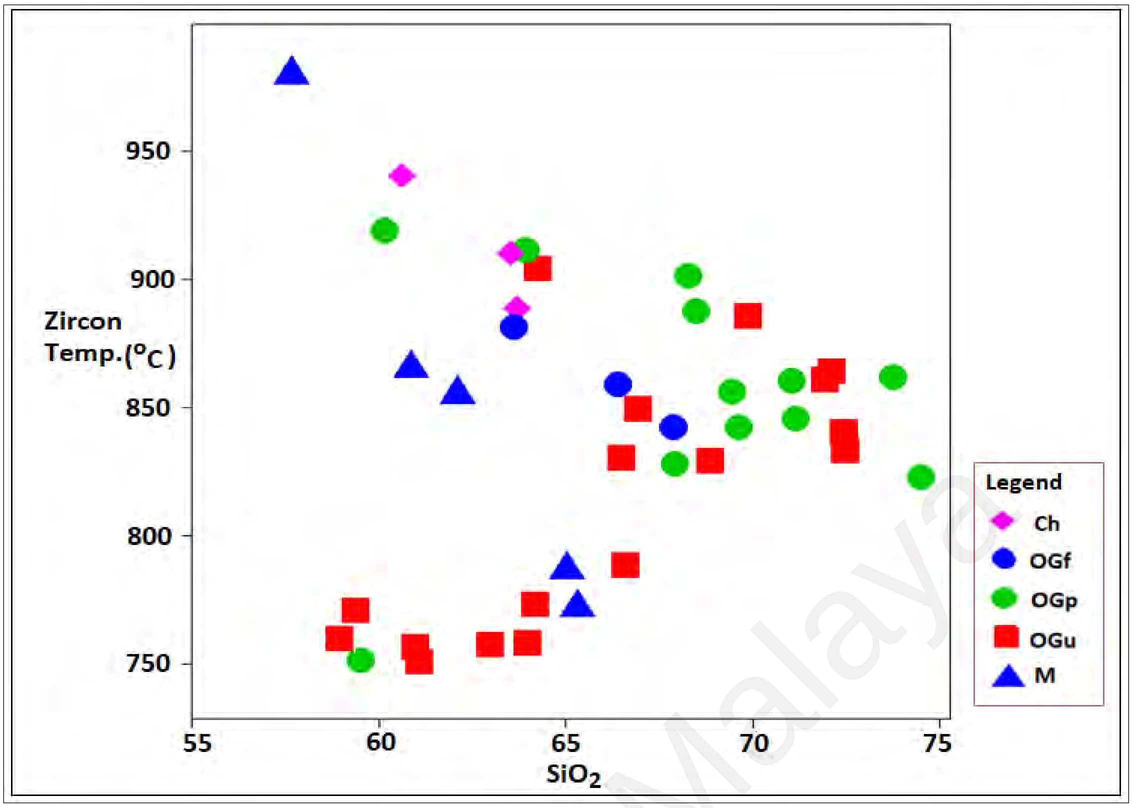

Figure 6.13: Zircon saturation temperature against SiO_2 content in the rocks

6.3.4 Trace Element ratios and Petrogenesis

As demonstrated by Miller (1985), Harris and Inger, (1992), certain elemental ratios can indicate source rocks of granitic magmas. According to Miller, (1985), granites resulting from partial melting of pelitic sources have lower Rb and Ba contents and Rb/Ba ratios >0.25. Harris and Inger, (1992) believes, vapour-absent melting indicated by incongruent melting of biotite is symbolized by elevated Rb/Sr (2-6) and minimal Sr/Ba (0.2-0.7) ratios in the melts. The duo believes that intrusive granites, which have not experienced extensive crystal fractionation have a Rb/Ba ratio around 1.0, Rb/Sr of 2.60-3.14 and Sr/Ba of 0.30-0.40 are therefore products of dehydration melting processes of biotite-bearing pelites in the deeper crust. Many studies have indicated that variation in geochemical behaviour of Sr and Y made the Sr/Y ratio useful in evaluation of depth of partial melting particularly in collisional orogens (Chapman et al., 2015).

As indicated by Lee and Morton, (2015), the higher the degree of fractionation in magma, the lower will be the Sr content; hence decrease of Sr/Y ratios. According to Ganne et al., (2017), assimilation of crustal materials at sallow depth within the crust typically reduces the Sr/Y ratio while the relationship between crustal thickness and Sr/Y ratio is given by Sr/Y=1.49D_M-42.03, (where Sr/Y are integral values, and D_M represents depth to boundary between the crust and mantle). In highly fractionated silicate melts, Rb values are usually high, so the elevated Rb/Sr ratio in Idanre granite may point to its high degree of fractionation. High Sr/Y granitoids are presumed to be sourced from pure crustal melts originating from deeper regions of the crust whereas, low Sr/Y granitoid are produced by magma mixing with low Sr/Y (Ganne et al., 2017). High silica granites containing high Rb/Sr ratio, but low Sr/Y contents result from anatexis of either metasedimentary assemblages at sallow depth or highly fractionated magmas (Dong et al., 2012a; Meng et al., 2013; Yang, 2012a). Hu el at, (2017) indicated that at deeper crustal environment particularly where pressure exceeds 1.0 Mpa, fractionation and differentiation causes Y and Yb to be favourably incorporated into garnet or hornblende while Sr and La goes into magma to cause higher Sr/Y and La/Yb ratios. All the above points to the fact that Idanre granites originates from shallow depth ranging between 32 and 36 kilometres. On the other hand, in shallow crustal environment characterized by pressure lower than 1.0 MPa, Sr will likely be partitioned into plagioclase feldspar, while Y and Yb goes into liquid phase and cause a reduction in Sr/Y and La/ Yb ratios.

Trace element ratios investigated for the Idanre rocks are Rb/Ba, Sr/Ba, Rb/Sr, Zr/Hf, Zr/Nb and Nb/Y. Others are Ta/Yb, Th/U, Ce/Yb and Ta/Nb (Table 4.3d). From the result, Zr/Nb, Th/U, K/Rb and Ce/Yb ratios vary within wide limits for the different rock units, while the other ratios (Rb/Ba, Sr/Ba, Rb/Sr, Zr/Hf, Nb/Y and Ta/Nb) vary within narrow limits. Rb/Ba ratios in migmatite has values which range between 0.04-0.21 recorded a mean value of 0.11. This mean value is lower than coarse-grained undifferentiated granite (0.07-0.49, ca. 0.17), porphyritic granite (0.09-0.59, ca. 0.22) and fine-grained granite (0.11-0.21, ca. 0.17). As Miller (1985), Harris and Inger, (1992) have shown that Rb/Ba, Rb/Sr and Sr/Ba ratios can place constraints on the source rocks of granitic magmas. The average Rb/Sr ratio in all the granite of the suite are comparatively lower than 0.7, which suggested that the granite is probably not produced from melting of pelitic rocks. The absence of metapelites, metasediments or schistose assemblages in the study area may support this assertion. Mean Zr/Nb ratio in migmatite (19.92ppm) is higher than OGu (13.48 ppm), OGp (15.04 ppm) and OGf (14.8 ppm). The strong variation in Zr/Nb ratios between the two species of rock may be attributed to petrographic differences arising from readjustment of the original composition during metamorphic remobilization. The ratio Th/U in migmatite (3.89-17.01; ca. 10.78) (range and average respectively) is significantly lower than OGu (5.94-30.17; ca. 13.64), OGp (7.13-41.13; ca. 18.85) and OGf (13.14-29.75; ca. 20.83). Th and Rb are both radioactive, thus, these elements are preferentially concentrated in siliceous rocks such as granite rather than basic rocks. The lower Th/U ratio in migmatite gneiss may have resulted from low concentration of radioactive Th and U in rocks with higher proportion of mafic assemblages. Ce/Yb ratio in migmatite (29.32-64.95; ca. 46.82) is lower than OGu (50.24-335.56; ca. 113.49) OGp (58.57-211.05; ca.134.97) and OGf (81.68-147.81; ca. 123.58). The remarkable difference between Ce/Yb ratios in migmatite and the granite

Table: 6.1: Trace elements ratios of rocks in Idanre area.

ID	B6	C7	C5	C11	C1		A1	B12	B14	B15	C4	D3	D13	D14	D24	D26	D32	D33
Rock	M	M	(BHG)	(BG)	(BG)	**Mean**	OGu	OGu	OGu	OGu	OGu	OGu	OGu	OGu	OGu	OGu	OGu	OGu
Rb/Ba	0.18	0.21	0.1	0.04	0.04	**0.11**	0.1	0.1	0.07	0.07	0.11	0.18	0.49	0.45	0.14	0.12	0.08	0.09
Sr/Ba	0.41	0.49	0.18	0.19	0.18	**0.29**	0.16	0.14	0.22	0.28	0.33	0.21	0.19	0.16	0.26	0.2	0.14	0.68
Sr/Y	10.98	11.99	5.66	9.68	11.54	**9.91**	6.4	16.81	21.34	14.83	16.79	14.36	3.73	2.9	5.97	11.43	13.55	14.2
Rb/Sr	0.44	0.42	0.58	0.27	0.23	**0.39**	0.63	0.22	0.32	0.26	0.34	0.81	0.47	0.65	0.52	0.6	0.55	0.42
Zr/Hf	35.03	35.11	41.94	47.77	48.6	**41.69**	43.01	37.54	38.93	35.78	40.53	38.21	33.33	36.35	42.92	11.77	11.42	28.05
Zr/Nb	12.56	12.81	12.84	32.93	28.48	**19.92**	20.04	16.46	6.54	17.08	12.54	12.77	6.99	13.92	17.4	13.37	13.9	11.94
Nb/Y	0.46	0.49	0.97	1.22	1.27	**0.88**	0.86	0.5	1.52	0.42	0.91	2.93	2.11	0.65	0.87	4.53	2.39	0.8
Ta/Yb	0.26	0.27	4.59	3.33	4.36	**2.56**	0.39	0.34	14.23	0.27	0.73	28.55	28.55	0.34	0.51	0.35	0.42	0.5
Th/U	17.01	17.23	11.06	4.73	3.89	**10.78**	12.06	11.3	14.23	11	12.06	18.56	16.13	10.9	13.29	24.75	9.17	16.13
Ce/Yb	31.82	29.32	44.88	63.11	64.95	**46.82**	50.24	66.26	127.11	59.04	55.82	286.39	335.56	118.39	62.82	143.59	85.42	110.5
Ta/Nb	0.06	0.06	0.43	0.25	0.31	**0.22**	0.04	0.06	0.78	0.06	0.07	0.78	0.5	0.05	0.05	0.06	0.01	0.06
K/Rb	214.4	347.3	266.7	187	313.4	**265.8**	283	276.4	304.5	287.8	233.5	257	187.9	206.8	229.4	209.7.	225.3	313.2

Table: 6.1, continued.

ID	D34	D35	D36	D39	D40		A15	B8	B9	B11	B16	B19	B20	B23	D2
Rock	OGu	OGu	OGu	OGu	OGu	**Mean**	OGp	OGp	OGp	OGp	OGp	OGp	OGp	OGp	OGp
Rb/Ba	0.07	0.11	0.08	0.2	0.47	**0.17**	0.2	0.59	0.17	0.09	0.27	0.11	0.11	0.28	0.2
Sr/Ba	0.38	0.45	0.53	0.29	0.17	**0.28**	0.26	0.29	0.22	0.27	0.22	0.24	0.27	0.25	0.26
Sr/Y	11.7	10.67	9.54	6.71	2.64	**10.79**	11.92	5.77	12.94	43.02	8.9	10.85	6.16	11.61	10.73
Rb/Sr	0.19	0.29	0.14	0.67	0.58	**0.45**	0.77	0.49	0.77	0.63	0.78	0.46	0.42	0.65	0.77
Zr/Hf	66.22	28.18	96.56	41.52	35.35	**39.16**	42.66	35.44	39.17	36.17	35.81	44.6	43.78	37.79	38.85
Zr/Nb	10.49	13.36	18.16	12	12.26	**13.48**	6.29	2.99	22.9	4.26	8.09	25.4	13.1	21.03	32.9
Nb/Y	0.98	0.63	0.86	1.17	0.71	**1.29**	3.28	4.08	0.81	2.18	1.85	0.89	1.25	0.73	0.57
Ta/Yb	7.42	0.31	0.55	6.29	0.36	**5.33**	32.11	39.3	0.42	20.32	13.26	0.52	5.06	0.32	0.36
Th/U	7.54	5.94	8.48	30.17	10.11	**13.64**	13.42	9.45	24.58	7.13	14.67	32.33	10.13	22.35	17.47
Ce/Yb	73.19	61.66	80.84	129.63	82.97	**113.49**	171.9	211.05	190.71	79.21	108.47	141.87	58.57	172.48	113.61
Ta/Nb	0.67	0.04	0.06	0.44	0.04	**0.22**	0.77	0.82	0.04	0.79	0.6	0.05	0.34	0.03	0.05
K/Rb	160.7	480.5	313.4	243.8	197.4	**271.2**	267.1	175.2	262.9	310.3	208.4	229.7	120.9	315.6	246.9

Table: 6.1, continued.

ID	D11	D19	D25		B10	A17	A10		D28	D29	D30	
Rock	OGp	OGp	OGp	**Mean**	OGf	OGf	OGf	**Mean**	Ch	Ch	Ch	**Mean**
Rb/Ba	0.2	0.25	0.12	**0.22**	0.11	0.21	0.2	**0.17**	0.23	0.08	0.08	**0.13**
Sr/Ba	0.29	0.25	0.2	**0.25**	0.21	0.32	0.25	**0.26**	0.19	0.15	0.15	**0.16**
Sr/Y	5.71	9.28	6.05	**9.85**	8.5	4.52	11.42	**7.35**	8.44	6.62	10.35	**8.17**
Rb/Sr	0.69	0.7	0.6	**0.64**	0.51	0.65	0.77	**0.64**	0.83	0.55	0.54	**0.64**
Zr/Hf	39.35	37.29	45.64	**39.71**	42.99	43.09	43.67	**43.25**	35.01	61.04	23.99	**40.01**
Zr/Nb	20.63	9.82	13.05	**15.04**	13.52	21.06	9.83	**14.8**	71.73	27.35	12.98	**37.35**
Nb/Y	0.63	2	1.28	**1.63**	1.07	0.98	1.63	**1.23**	0.38	1.17	2.2	**1.25**
Ta/Yb	0.4	15.21	4.13	**10.95**	3.83	0.35	10	**4.73**	4.56	0.56	8.1	**4.41**
Th/U	41.13	17.11	16.47	**18.85**	13.14	29.75	19.6	**20.83**	7.95	9.52	8.78	**8.75**
Ce/Yb	118.73	163.58	89.42	**134.97**	81.68	141.25	147.81	**123.58**	67.99	71.15	104.29	**81.14**
Ta/Nb	0.05	0.64	0.27	**0.37**	0.29	0.03	0.53	**0.28**	0.3	0.28	0.34	**0.31**
K/Rb	234.7	223.9	238.1	**236.1**	256.9	221.4	263	**247.1**	176.2	387.8	432.2	**332.1**

series might have resulted from petrological differences and by extension, compositional variations. However, even though the Ce/Yb ratios vary slightly in the three types of granite, they all have values that range between 110 and 135, which of course, is still relatively close. Ce/Yb ratio is essential in constraining the rates of partial melting in rocks, where low partial melting produces high Ce/Yb ratio magmas (Rollinson, 2014). Therefore, higher Ce/Yb ratios in the granite suite (OGu: 113.49; OGp: 134.97; OGf: 123.58) may be an indication of low partial melting in the source rocks. This is equally supported by mean Sr/Ba ratios (OGu: 0.28; OGp: 0.25; OGf: 0.26) which falls outside the narrow limit (Sr/Ba = 0.3-0.4) for intrusive granites produced by extensive crystal fractionation. Mean Sr/Ba ratio in migmatite (0.29) is comparable to OGu (0.28), OGp (0.25) and OGf (0.26). Average Rb/Sr ratio in migmatite (0.39) is marginally lower than OGu (0.45), OGp (0.64), OGf (0.64) and Ch (0.64). In a study carried out on melt fractions by Jung et al., (1995) he observed that Harris and Inger, (1992) indicated "*granitic melts produced by incongruent melting of muscovite are characterized by low Rb/Sr (0.7-1.6) and high Sr/Ba (0.5-1.6) ratios as restite is depleted in feldspar*" (pp. 29) , the low Rb/Sr and Sr/Ba ratios probably indicate the magma is not a product of incongruent melting of muscovite. However, low average Sr/Ba ratio of 0.25, 0.26 and 0.28 in OGp, OGf and OGu respectively falls within the value (0.2-0.7) quoted for fluid absent melting of biotite. This assertion is adequately supported by prominence of orthoclase phenocrysts in the granite and charnockite and of pyroxene crystals in the charnockite which could be indicators of low water content of the source magma. Zr/Hf ratios in migmatite gneiss (35.03-48.69; ca. 41.69) is marginally higher than OGu (11.42-96.56; ca. 39.16), OGp (35.44-45.64; ca. 39.71) but lower than OGf (42.99-43.67; ca. 43.25) and Ch (23.99-61.04; ca. 40.01). Similarity between the Zr/Hf ratios for all the granites may indicate same source or are produced from the same magma. Nb/Y ratio in migmatite (0.46-1.27; ca. 0.88) is marginally lower than OGu (0.42-4.53; ca. 1.29), OGp

(0.57-4.08; ca. 1.63), OGf (0.98-1.63; ca. 1.23) and Ch (0.38-2.20; ca. 1.25). Ta/Nb ratio in migmatite (0.06-0.43; ca. 0.22), OGu (0.04-0.78; ca. 0.22), OGp (0.03-0.82; ca. 0.37), OGf (0.03-0.53; ca. 0.28) and Ch (0.28-0.34; ca. 0.31) is understandably low since the Ta contents in Older granites in Nigeria are generally poor. The similarities between the Ba/Sr, Rb/Sr, Zr/Hf, Nb/Y and Ta/Nb ratios in the rocks may indicate some petrogenetic link with regards to mobility of elements during magma evolution. HFSEs Rb, Ba, Sr, Th and U tend to exhibit similar behaviour, while Zr, Hf, Nb and Ta exhibits similar mobility pattern as indicated by their ratios in the granitic rock.

6.4 Geochronology

6.4.1 Zircon U-Pb Dating

Although earlier studies highlighted that granites in Basement complex of Nigeria was emplaced during Pan-African episode, some of the intrusions such as the Idanre granite suite have not yet been precisely dated. Literature review show that prior to this research work, there was no reliable record of sequence of magmatism in the study area.

The outcome of LA-ICP-MS zircon U-Pb geochronology shows that undifferentiated coarse-grained granite was formed at 581.8 ± 5.5 Ma. This unit is apparently the youngest of three granites members in the suite. The upper and lower limits of the emplacement period are 587.3 Ma and 576.3 Ma. This indicates that the commencement of the intrusive phase to crystallization lasted for about 11 million years. During the period, the crystallization process must have taken enough time for the mineral to be stable. This age agrees with those of U-Pb zircon evaporation age (589 ± 11 Ma) (Dada et al., 1989) for amphibole-biotite granite in Toro, and the (598 ± 11 Ma) (Ferré et al., 1998) biotite-hornblende granite of Solli Hills in south-eastern Nigeria. Different dating methods such as Rb-Sr, K-Ar, U-Pb, and mineral dating using U-Pb evaporation techniques on zircon, and Ar-Ar have been adopted by earlier workers to show the exact period of magma plutonism in Nigeria. K-feldspars in Rukuba biotite-granite (Eastern Nigeria) yielded 510

± 20 Ma (Tougarinov et al., 1968), Rb-Sr method on biotite from biotite granite in Nassarawa Eggon yielded 539 ± 8 Ma (Umeji and Caen-Vachette, 1984). Ar-Ar age of amphibole from biotite granite from Solli Hills also yielded between 559.6 ± 1.6 Ma to 566.5 ± 4.5 Ma (Ferré et al., 1998). While Rahaman granite was emplaced between 555.9 ± 4.5 to 562.7 ± 4.4 Ma (Ferré et al., 1998). All these results indicate that granite plutonism in basement complex of Nigeria generally fall within time frame of the Pan-African orogeny.

The Idanre porphyritic granite has an emplacement age of 584.5 ± 5.8 Ma according to this U-Pb zircon geochronology. By implication, using the upper and lower age limits, the emplacement of this unit span between 590.3 Ma to 578.7 Ma. The plutonic phase lasted 11.6 million years. The upper limit of this intrusive phase overlaps with the emplacement of the fine-grained granite, meaning that the intrusion of the porphyritic granite commenced before the cessation of the plutonic activity of the fine-grained granite which came at 588.4 ± 5.5 Ma forming the oldest granite unit of the suite. The emplacement of fine-grained granite between 593.9 to 582.9 Ma lasted about 11 million years. However, before the cessation of the emplacement of charnockite between c. 595.6 to 585 Ma which lasted about 10.6 million years, the emplacement of the fine-grained granite started. The overlap between the two magmatic episodes was so much as to be regarded as having same age, because they were emplaced simultaneously for about 9million years. Based on the current geochronological study, the three types of granites in Idanre granite suite in order of ages from youngest to oldest is the Undifferentiated coarse-grained granite (OGu), the porphyritic granite (OGp), and the fine-grained granite (OGf). Charnockite in the basement complex of Idanre yielded U-Pb zircon age 590.3 ± 5.3 Ma in the current study. However, (Tubosun, 1981, Tubosun et al., 1984) earlier reported that the gneissic charnockite was formed between 580 ± 12 Ma. Kayode, (1988) investigated the chemical zircon typology of the hornblende-granite-acid charnockite contact intercepted at Ikere-Ekiti (approx. 45 km northeast of Idanre) and concluded that granite and charnockite in the southwestern Nigeria are formed contemporaneously. That these rocks were formed at the same time was well accepted. This was also supported by Snelling, (1966) who investigated mineral dating by K/Ar method to arrive at 535 ± 35 Ma age on hornblende from Bauchi charnockite; U-Pb zircons age of 634 ± 30 Ma from charnockite in Ipinsa (Tubosun, 1981) among others. Thus, by extension, the Idanre granite and charnockite association had been visualized to have same age from this angle. Tubosun, (1981) also reported that the massive charnockite from Ikere-Ekiti has an age of 620 ± 20 Ma.

U-Pb zircon age of 590.3 ± 5.3 Ma in the current study agrees with several other charnockitic rocks from the basement complex in other parts of the country. They are also comparable to those beyond the borders of Nigeria, for example those found in Cameroon. While, in Nigeria, particularly Obudu area, an age of 593.5 ± 26.5 Ma has been recorded during migmatization and formation of granulite, however, zircons from granulite which yields uranium-lead age of 610 ± 2 Ma can be found in Ghana's Akuse Massif area. He also pointed out that U-Pb age of 610 ± 2 Ma is related to the age of metamorphic event of granulite-facies (Ekwueme and Kröner, 2006).

Neoproterozoic age with average age of 612.5 ± 0.8 observed in Togo's enderbite is consistent with peak of granulite facies metamorphism which accompanied continental collision that occurred between the Eastern margin of West African craton and the Tuareg shield during Pan-African episode (Affaton et al., 2000). These ages also correlated well with the Oban Massif charnockite and 574.1 ± 1.0 Ma age of charnockite in Obudu area (Ekwueme and Kröner, 2006). Although, numerous granite intrusions occurred throughout Pan-African domain between the interval 645 to 580 Ma as reported by several authors including (Leigéois et al., 1994) among others. However, the age of crystallization of charnockite associated with this lithology has been regarded as contemporaneous but the structural attributes of some of this charnockite has been virtualized differently by different authors while others believed they are igneous, others believe they are metamorphic. The origin of charnockite has generated much controversy over the years, some authors believed they are igneous, while others e.g. (Hubbard, 1975; Ekwueme and Kroner, 2006) believed widespread occurrence of charnockitic rocks symbolized granulite-facies metamorphism. After following the classification of Streckeisen, (1974), Cooray, (1977), suggested that charnockite found within the Nigerian Basement exhibit several characteristics which denotes they are not sourced from magmatic origin. He insisted that this rock being foliated and carry quantitatively high percentage of pyroxene should be termed hypersthene granulite, gneissose granulite or gneissic charnockite. Apart from controversy that trails the mode of formation, Nigeria charnockite have generated a lot of debate among geologists because of age differences. Hubbard, (1975) interpreted the granulite as rocks formed early in Earth's history during Archaean. Although, a relatively younger age of mid Proterozoic was suggested by Hurley et al., (1966). However, Van Breemen et al., (1977) and Tubosun et al., (1984) opined these rocks are largely formed during the concluding phase of Pan-African thermo tectonic events. The researcher, based on field relationships of some charnockitic/granite association that coexisted in a lithologic intermix in a single outcrop in Ikere Ekiti area of SW Nigeria, indications are high that the rock is formed contemporaneously with the Older granite which have an unequivocal Pan-African in the basement complex.

Migmatite is the oldest lithologic unit around Idanre. This unit yielded an age of 1065.1 ± 7.1 Ma on U-Pb zircon date (Fig. 5.15). Although Archaean to early Proterozoic age has been reported for gneissic units in the Basement of Nigeria, for example, (Okonkwo and Ganev, 2012) study show that a concordant age of 2207 ± 20 Ma has been recorded from Jabba granitic gneiss on U-Pb zircon geochronology.

The relatively younger age reported for this migmatitic rock in the study area may have resulted from metamorphic recrystallization and re-melting during which the geochronologic clock was reset, or that they are probably formed from yet another older migmatite gneiss protoliths through recycling. The disparity between the ages of many of these migmatites may symbolize overwhelming evidence of reworking and migmatization of the basement complex.

However, this age is in conformity with 1070 ± 12 Ma recorded for whole-rock (W.R.) Rb-Sr for migmatite from Kaduna (north-central Nigeria) (Grant et al., 1972), the age is equally comparable to 1174 ± 140 Ma reported on W.R. Rb-Sr from granite gneiss from Ile-Ife by the same author. While the deformed pegmatite (1107 ± 32 Ma), (W.R. Rb-Sr) from Badarawa, Kaduna also fall within the same age range (Ogezi, 1977).

Field pictures reveals migmatite are diatexites whereas gneisses are metatexites (Sawyer, 2008, Atlas of Migmatites). This implies that all metamorphic country rocks are migmatites. However, because most migmatites in other parts of the basement complex especially in Kaduna area Nigeria is Archaean in (Ekwueme and Kroner, 1992; Dada et al., 1993) almost make one to question the efficacy of what 1.06 Ga U-Pb age is. However, while other age reported by Grant et al., 1972 on migmatite around Kaduna yielded 1174± 140 Ma on Rb-Sr method gives comparable ages. The 1.06 Ga age of migmatite formations is unknown in neighbouring parts of the Pan-African belt. It is older than the Bayudan event (~0.92 Ga) recorded in the Bayuda Desert of Sudan (Kuster et al., 2008) and younger than the age determined from the core of zircon grains from the Issia granite (2212–2305 Ma) in southwestern Cˆote d'Ivoire (Kouamelan, 1997a). The geological interpretation of this age which characterizes Meso-Neoproterozoic (Stenian-Tonian) boundary shall be explored further in subsequent research. Consequently, it is possible that part of the country rocks are not migmatite but special rocks that resulted from magma mixing as already described by Gasquet et al. (2003) following Fernandez and Gasquet, (1994) and others who studied the viscous flow of magma mixing under stress.

6.4.2 Zircon Lu–Hf isotopic composition

Although, seismic data and geophysical methods were at one time largely depended upon as means of imaging the inner parts of the crust. However, structural and geodynamic evolution of the earth's continental plate has been linked to interplay of multiple geological processes. Consequently, the recent times has witnessed how the ancient and modern state of the lithosphere can be picked by Lu-Hf isotopic study of zircon which can act as a paleo-geophysical tool that showcases crust-mantle interaction through time (Hartnady et al., 2018).

Zircon grains extracted from different units of the granite complex and surrounding migmatite country rocks were subjected to Lu-Hf isotopic analyses. For all the analyses, the exact spots within the domains of zircon that were used for U-Pb isotopic composition were adopted. The U-Pb ages which was previously obtained from the samples was also used to compute the Hf isotope ratios initially incorporated into the zircons and crustal model ages. Pictorial representation of εHf(t) values versus age is shown in Figure 5.17a, while the initial hafnium $^{176}Hf/^{177}Hf$ ratios versus ages is plotted on Fig 5.17b and the summary of isotopic composition of analysed points and their data are shown (Appendix 2). $^{176}Lu/^{177}Hf$ value of the zircon grains range from 3.02-10.65 x 10^{-4} in fine-grained granite (C5); 4.09-13.04 x 10^{-4} in coarse-grained (undifferentiated) granite (B15); 3.83-13.45 x 10^{-4} in porphyritic granite (B9); 4.55-9.35 x10^{-4} in charnockite (D29) and 3.67-16.69 x 10^{-4} in migmatite (A17). All ratios which are substantially less than 0.002 indicated that the zircon grains contain low radioactive Hf growth after they are crystallized. Consequently, the isotopic $^{176}Hf/^{177}Hf$ ratio could decipher growth and decay processes in isotopic composition of Hafnium in the system during evolution (Knudsen et al., 2001; Wu et al., 2007).

Coarse-grained (undifferentiated) granite and porphyritic granite have similar Lu-Hf isotopic compositions. For the coarse-grained (undifferentiated) granite, $^{176}Hf/^{177}Hf$ ratios of 15 spots investigated, values vary from 0.281724 to 0.281843. The initial Hf isotope ratios ($^{176}Hf/^{177}Hf$)i calculated from their zircon U-Pb ages is from 0.281715 to 0.281782. Hf isotopic composition fluctuates within wide limits. εHf(t) values which changes from -21.1 to -25.1 are mainly concentrated between -22.2 to -23.5. The two-stage model age is tDM_2 = 2827 to 2877, mainly within the range of 2800 to 2990 Ma.

For porphyritic granite, the $^{176}Hf/^{177}Hf$ ratios of 16 spots vary from 0.281692 to 0.281863. The Hf isotope initial ratio ($^{176}Hf/^{177}Hf$)i is from 0.281683 to 0.281848. εHf(t) values also vary widely, changing from -21.2 to -26.1, mainly from -22.5 to -25.5. The two-stage model age is tDM2=2718 to 3070 Ma, mainly within the range of 2850 to 2950.

For fine-grained granite, the evaluated 15 zircon grains yielded $^{176}Lu/^{177}Hf$ isotopic composition which range from 0.000302 to 0.001065. $^{176}Hf/^{177}Hf$ ratio also ranges from 0.281712 to 0.281813. The Hf isotope initial ($^{176}Hf/^{177}Hf$)i from the U-Pb age is from 0.281708 to 0.281802. The Hf isotopic composition vary within narrow limits while εHf(t) changes between -22.4 to -25.7. The two-stage model age tDM_2 = 2880 to 3030, mainly within the range of 2800 to 3000 Ma. For this unit, $^{176}Hf/^{177}Hf$ ratios of 15 measurements vary from 0.281716 to 0.281813. The Hf isotope initial ratio ($^{176}Hf/^{177}Hf$)i is from 0.281708 to 0.281802. The εHf(t) values vary within limits that are close and changes from -22.4 to -25.7, but most values are concentrated between -23.5 to -24.5. The two-stage model age is tDM2=2829 to 3030 Ma mainly within the range of 2900 to 3000.

For charnockite, 15 grains of zircon yielded $^{176}Lu/^{177}Hf$ isotopic composition with values ranging between 0.000416 to 0.000935. $^{176}Hf/^{177}Hf$ ratios range from 0.281957 to 0.281984. The Hf isotope initial ($^{176}Hf/^{177}Hf$)i range between 0.281951 to 0.281996. εHf(t) changes between -14.8 to -16.6. The two-stage model age tDM2=2395 to 2504, mainly within the range 2400-2500.

From geochemical point of view, Idanre granite complex belongs to metaluminous high-K calc-alkaline series. Chondrite normalized REE diagrams reflects light rare earth enrichment and noticeable discrepancy between LREEs and HREEs. The reflection of moderate negative Eu anomaly (δ Eu < 1), large ionic lithophiles such as K, Rb, Ba, Sr, and Th enrichment, and depletion of high field strength elements like Nb, Ti and P are indications that the granite possess evidence of crust-derived materials. Also, Zr/Hf ratio of 39.16 (OGu), 39.71 (OGp), and 43.25 (OGf) which is between average for crustal rocks and the average for mantle-derived source reflects the significant contribution of crustal source materials in the protolith.

6.5 Tectonic Evolution of Idanre Granite Complex

Previous literature described Nigeria granites using ambiguous and confusing terms. These terms, although not explicitly insignificant, but considering the context of evolution of Nigeria granites, they do not specifically define their tectonic settings. Those terms include early phase, main phase, or late phase, syn-kinematic, syn-tectonic, late-kinematic/ inter-tectonic or post-kinematic/post-tectonic (Odeyemi, 1990). The phase-related terminologies were suggested in line with timing of Pan-African orogeny while the latter were applied to convey tectono-structural evolution of these rocks.

Rahaman et al. (1988), in a bid to discuss tectonic evolution of southwestern Nigeria and more importantly, the Ife-Ilesha schist belt, applied trace-elements geochemistry of two types of amphibolite found within the terrain. The result characterized one group as resembling ocean floor tholeiites while the other have chemistry that is close to island arc tholeiites. The authors observed that abundance of incompatible trace elements in these rocks indicated contamination from crustal source. On this note, they suggested a model involving opening and closing of Atlantic-type ocean basin behind the island /volcanic arc (Pharusian) on the continental mass to the east of West African craton. Specifically, the authors indicated Ife-Ilesha schist belt and the Igarra schist belt to the eastern part have a paired eugeosynclinal and miogeosynclinal relationship. This interrelationship was earlier suggested by Olade and Elueze, (1979) who believed the Nigeria schist belt is a Precambrian ensialic (continental) mobile belt and represents upper Proterozoic succession that were deformed during Pan-African thermo-tectonic activities. However, in a later study, Elueze, (1981) came up with a different view, pointing out that Ife-Ilesha schist belt developed in a volcanic trough. Ajayi (1981) and Rahaman et al. (1988) suggested that the schist belts are relevant in any geotectonic study of Precambrian rocks located in west Africa. They stressed further that to establish an account of evolution, such study must be able to provide evidence of this setting.

Geochemical studies are important in the classification of various tectonic environments and have proved useful in tectonic study and evolution of Precambrian terrains (Lambert and Holland, 1976). In this regard, extensive geochemical studies were carried out on the rocks of Ife-Ilesha and adjoining areas. However, original nature of rocks in Idanre like in other Precambrian terrains in Nigeria have been transformed by varying grades by tectono-metamorphic processes so, caution must be taken in the use of geochemical data from such rocks to evaluate tectonic setting of ancient terrains. However, Menzies, (1976) suggested that a group of trace components (Ti, Y, Nb and Zr) are immobile during rock alteration and as such, any petrogenetic evaluation based on these elements may still be valid even for altered rocks (Wood et al. 1979). So, in the investigation of the tectonic setting of the Idanre area, a combination of field geology, REE geochemistry, zircon date and Lu-Hf isotopic studies are combined to pigeonhole their tectonic significance.

Typically, within-plate granites in continental domains are characterized by close association with meta-igneous rocks such as amphibolite. Although, Idanre area do not bear outcrop exposures of amphibolite or rocks of amphibolitic affinities, the prevalence of amphibolite in adjourning Ife-Ilesha schist belt which lies in western side of Idanre equally falls among the ancient basement terrain of southwestern Nigeria may support this.

6.5.1 Evolution model for Idanre Granite Complex

The evolution model for Idanre granite complex and the basement terrain of Idanre area was visualized and conceptualized based on facts from relevant literature on perception of previous researchers and in line with evolution of basement terrain of SW Nigeria. In the current study, field geology, detailed geochemical study, zircon U-Pb geochronology and Lu-Hf isotopic study and petrogenetic concept reveals a six- stage tectonic model (Fig. 6.14). Stage 1: subduction process at west African craton margin on an eastward dipping Benioff zone. The continental crust overriding the asthenosphere was pushed towards the west. Stage 2: Further westward push led to closure of ocean at craton-Pan-African belt boundary and deep fracturing induced by warping took place at Ife-Ilesha sedimentary and igneous belt. Stage 3: rifting and formation of new oceanic crust. Stage 4: subduction process at westward dipping Benioff zone in Ife-Ilesha area. Stage 5: closure of ocean and formation of late K-granites. Stage 6: emplacement of late stage cross cutting granite and pegmatites. An earlier idea of this evolution model was pioneered by Rahaman et al., (1988).

However, the above tectonic model predates a more resent one in which Liegeois et al., (2006) proposed a geodynamic evolution in which mountain building process in regions surrounding the West African craton during Pan-African time falls under a six-stage scenario. The authors believed that the first stage occurred around 890-760 Ma when there was a continental break up. This stage was subsequently followed by 760-700 Ma episode during which a widespread continental convergence led to the building of

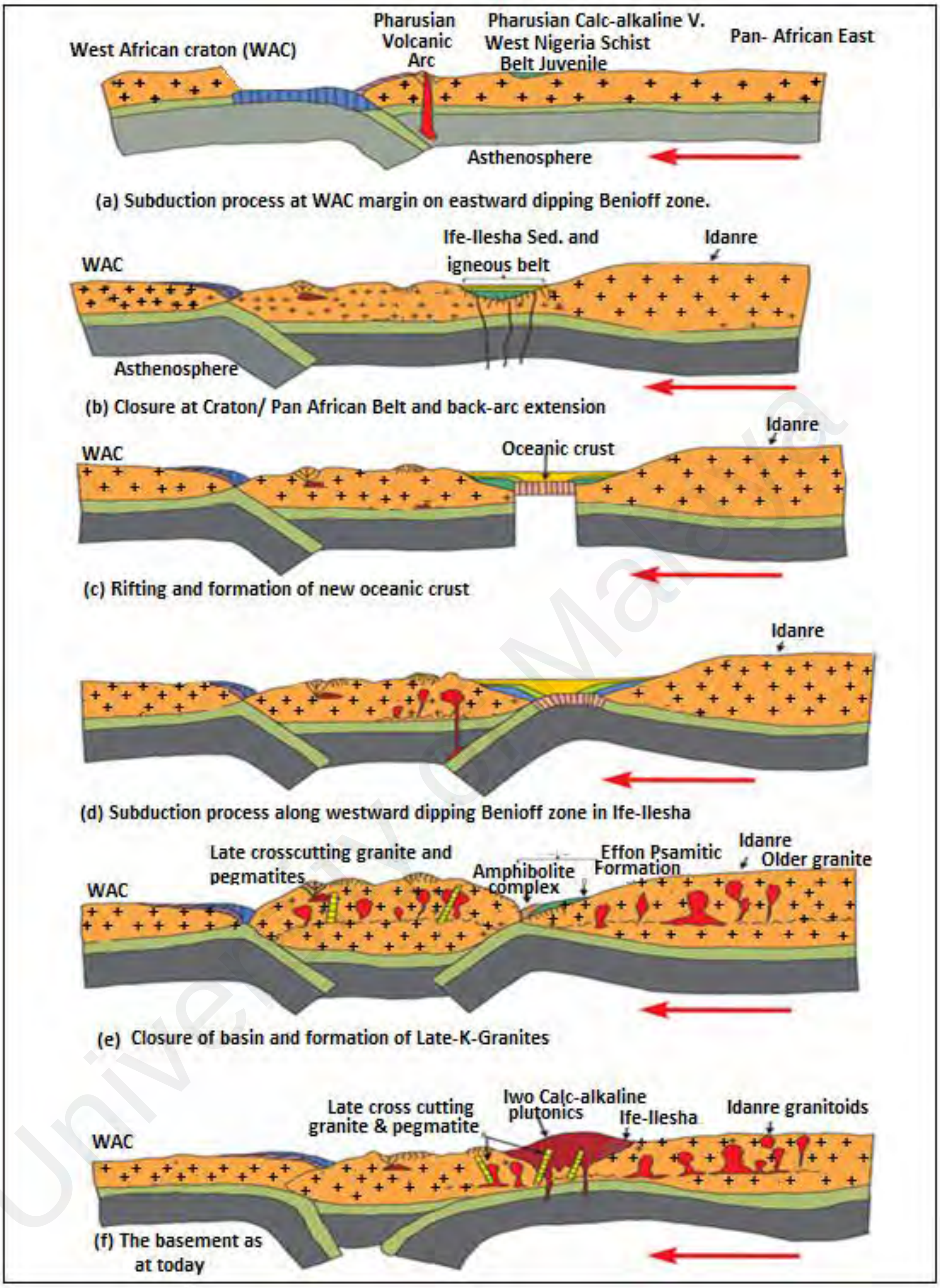

Figure 6.14. Tectonic evolution diagram of basement terrain of SW Nigeria and Idanre granite complex (modified after Rahaman et al. 1988)

Island arc on the eastern side of the West African craton. The third stage at c. 680-650 Ma featured obduction (lateral, sub-horizontal displacement of a lithospheric plate to a continental margin at a destruction plate boundary) and first phase of Pan-African accretion. The fourth stage (650-610 Ma) was characterized by transpressive (combination of both transcurrent strike-slip movement with oblique compression) early metacratonic phase. The fifth stage was 610-580 Ma during which there was translation from transpressive to transtensive (strike-slip movement with oblique extension) magmatism. The last stage occurred between 580-550 Ma which was generally referred to as post-orogenic phase with extensive transtensive plutonism. The Tuareg shield according to Gasquet et al., (2008) represents the preserved remnant of Pan African terrain that collided with West African craton.

CHAPTER 7: CONCLUSIONS AND FUTURE RECOMMENDATION

7.1 Summary

The flat-lying migmatite-gneiss basement forms the most extensive lithologic unit in Idanre area. It is composed of migmatite, biotite-hornblende gneiss and banded gneiss which makes border with granitoid intrusions and extends in all directions into the neighbouring villages. Even though, the migmatite-gneiss basement appears more extensive going by coverage by land mass, however, the granitoids are more prominent owing to their notable heights, thus, they form the main topographic feature of the terrane.

The fine to medium-grained migmatite and gneissic rocks show pervasive tectonic signatures attributable to polymetamorphic Pan-African thermo-tectonic activities. The rocks are characterized by several deformational structures including folds, fractures, and joints. The basement rocks are crisscross by several quartz veins, aplite, and pegmatite dykes. The dykes which are of variable sizes show sharp lithologic boundaries with their host rocks. The extension of some dykes across lithologic boundaries indicate they probably represent the last magmatic activity in the area. The general foliation trends and alignment of fold axes as observed in the migmatite and gneissic rocks coincided with orientation of feldspar porphyries in the granite. The general regional structural trend is inclined dominantly in N-S direction. However, in few localities located around south-eastern part of Idanre, the observed trend is NNE-SSW.

The emplacement scenario of the Idanre Granite Complex based on field geology, particularly, size of the xenoliths (mafic enclaves) which varied significantly in different parts of the granite bodies indicate different segments of the intrusion have experienced inhomogeneous stress distribution at the time of emplacement. Forceful and catastrophic emplacements are usually characterized by heavy damage to the host rock in which massive lumps of the country rocks are forcefully dislodged, hewed, and scattered within the uprising magma as it makes space for itself. The size of enclaves is largest around

Oke-Idanre (Figs. 4.20b and 4.20c) along the western segment of the intrusion indicating the intrusive activity was probably initiated around this area. The orientation of phenocrysts of feldspar which showed mild inclination towards the east direction in a flow structure are evident. Xenoliths with their attendant remnant foliations (Figs. 4.20b and 4.20c) and the parallelism of migrating strands of feldspar phenocrysts arranged along their margins (Fig. 4.20a) may indicate evidence of post-magmatic metasomatism. Traces of several smaller xenoliths that have been dissolved, completely digested, assimilated and homogenized into the granite bodies are compelling evidences that the plutons underwent a relatively slow cooling.

Field observation revealed the migmatite exhibit two component parts, the light portions (palaeosome) and dark parts (melanosome) which are quite distinct. Biotite hornblende gneiss outcrops are overwhelmingly crisscross by quartz vein intrusions. Banded gneiss in Idanre shows fantastic display of alternating bands of mafic and felsic minerals. In the field, different gneissic subunits grade into each other and the gradational lithologic contacts are diffuse. However, structural attributes of the showed the core parts of the three subunits could be distinguished without ambiguity. Generally, the granite outcrops are massive and stands out prominently as towering inselbergs, the three granite members are quite distinguishable because they occupy specific locations and have characteristic textures. The coarse-grained undifferentiated granite occurs towards the north-western part of Idanre town forming spectacular outcrops lining both sides of Alade-Idanre road. The rock has a characteristic greyish colour. The porphyritic granite is distinguished by its pinkish-feldspar and occupies major parts of Idanre town extending into the newly developing sections of the town towards the east. The fine-grained granite form plutons that are restricted in occurrence to the north-eastern part of Idanre.

Petrographic examination revealed that the migmatite-gneiss basement shows dominance of quartz, feldspar, and biotite. Biotite-hornblende gneiss exhibits mylonitic texture with prominence of quartz and hornblende in the groundmass matrix. Banded gneiss shows porphyroblasts of quartz arranged along preferred directions within groundmass of biotite and quartz.

However, porphyroblastic aggregates are euhedral to subhedral crystals of feldspars and quartz set within medium to fine-grained matrix of quartz, feldspars, and biotite. Smaller plates of biotite and muscovite defines weak foliation due to parallel to sub-parallel manner they are arranged (Fig. 4.21). Within the interlocking arrangement, the porphyroblasts and groundmass commonly exhibits weak alignment, but the stretched biotite plates impact a seemingly gneissose texture. Textural characteristics showed the gneisses are products of recrystallization with evidences from quartz grains exhibiting translational fabrics and distorted twinned albite crystals. Porphyroblasts of quartz show textural features comparable to minerals that grew under pressure as they appeared strained and cloudy, some have sutured edges while others appeared stretched. From petrographic point of view, quartz account for 23.3%, 22% and 28%; feldspar 43%, 37.3% and 34% in migmatite, biotite-gneiss and banded gneiss, respectively. On the other hand, in the granite, quartz contributed 20.8% in OGu, 24.8% in OGp, and 29.4% in OGf while feldspars account for 52.2%, 55.4% and 36.3% respectively. This indicates the granite suite is enriched in feldspar than the country rocks. Poikilitic texture is evident in the granitic rocks as smaller grains of early-formed minerals are embedded within larger crystals of late-stage hornblende. The prominence of myrmekite which are normally connected with breakdown of feldspars may be an indication that retrograde metamorphism affects Idanre area.

The occurrence of palaeosome in migmatite, complex tortuous veins, augen structures and prevalence of quartzo-feldspartic veins and dykes suggested that the tectono-thermal activities that affected the gneisses probably resulted in partial melting (anatexis). The mineral assemblage: quartz + biotite + K-feldspar + opaque in migmatite and gneisses represents a medium-grade metamorphic (lower amphibolite facies) condition. The index assemblage represents a temperature of about 550-600^{o}C and a pressure range between 3 to 10 K bar. Nevertheless, the simultaneous occurrence of K-feldspar and plagioclase might indicate a slightly higher metamorphic conditions which does not exceed the upper amphibolite facies metamorphism (670-700^{o}C).

From geochemical point of view, the Idanre granite suite is more saturated with respect to silica than the gneisses. Coarse-grained granite (OGu), porphyritic granite (OGp) and the fine-grained granite (OGf) all show silica saturation. The average SiO_2 in the rocks are respectively 65.77%, 68.15% and 65.81%. However, the average Al_2O_3 content of OGu (16.4%), OGf (14.9%), and OGp (14.6%) is expected for these types of rock and are comparable to similar rocks in basement of other parts of the country. Average K_2O values are 5.22%, 5.26%, and 5.10% for OGu, OGf and OGp respectively. Variation plot of $FeO^t/(FeO^t+MgO)$ versus SiO_2 classifies the rocks as ferroan type, Al_2O_3 versus MgO plot classifies it as orthogneiss, while total alkali (Na_2O+K_2O) versus SiO_2 (TAS) classified the rocks as granite. AFM [(Na_2O+K_2O)-Fe_2O_3-MgO] ternary diagram geochemically classifies the rock as calc-alkaline series, while Ba-Rb-Sr ternary plot classifies the rock anomalous granite. $Al_2O_3+Na_2O+K_2O$ versus Alumina Saturation Index (ANK vs ASI) indicates ASI<1.0 showing the granite is metaluminous.

From Economic geological point of view, the salient differences between the Idanre granite and its Younger Granite equivalent is the poor economic potential in terms of Ta-Nb Sn mineralization. Stavrov et al., (1969) indicated that barren granite/pegmatite contains Rb<500 ppm with K/Rb ratios >100, whereas the mineralized types contain Rb >500 ppm with K/Rb<100. Mean Rb values of OGu (165 ppm), OGp (181.9 ppm), and OGf (175.3 ppm) are critically lower than the recommended threshold value (Rb>500 ppm) for mineralized granites. From K_2O values of OGu (5.22%), OGp (5.10%) and OGf (5.26%), the calculated K/Rb ratios of OGu (262.42), OGp (232.55) and OGf (249.29) all indicate that K/Rb>100, which further confirm that the Idanre granite suite is the barren type. Ng et al. (2015) indicates that the ratio Th/U serves as indicator of degree of mineralization in granites, and that higher ratios indicates poor potentials. The high average Th/U ratio in the Idanre granite (OGu, 13.64; OGp, 18.85; and OGf, 20.23) with all points clustered around Th/U=10 line, indicate low degree of granite evolution and by implication, low magmatic differentiation. Thus, the granite contains poor economic mineralization in relation to rare metals Ta-Nb status.

From post magmatic viewpoint, the similar shape for chondrite normalized REE distribution for both gneiss and granite indicate similar geochemical trends. LREE enrichment, HREE depletion and negative Eu anomaly signified plagioclase fractionation. Since plagioclase is only stable at about 10 K bar pressure which is equivalent to depths less than 40 km, the negative Eu anomaly (Eu/Eu*<1) provides compelling evidence that the granite magma originated at a relatively shallow depth.

U-Pb zircon geochronology indicates that migmatite (1065.1 ± 7.1 Ma) forms the oldest rock in the basement complex of Idanre while Charnockite (590.3±5.3 Ma), fine-grained granite (588.4 ± 5.5 Ma), porphyritic granite (584.5±5.8 Ma) and Coarse-grained (Undifferentiated) granite (581.8 ± 5.5 Ma) are relatively younger. $^{176}Lu/^{177}Hf$ isotope reveals that crustal materials play significant role in the evolution of Idanre granite complex.

Petrogenetic evaluation indicate the granite magma is derived from anatexis of igneous rocks, Ce/Yb ratios indicate the granite units are sourced from low partial melting of igneous protoliths. Assessment of depth of emplacement based on Sr/Y =1.49 D_m - 42.03 (Ganne et al., 2017) indicated the Idanre granite is intruded at a relatively low depth ranging between 32 to 36 km. From geochemical evidences, there exist similarities in elemental distribution and pattern of mobility of certain elemental components between the migmatite-gneisses and granites. This points in the direction that the two rocks are either derived from similar protoliths or that the granite originate from partial melting of the host migmatite.

Tectonic discrimination diagrams indicate Idanre granite is late orogenic granitoid, Nb versus Y, and Rb versus Y+Nb shows the granite were intruded into within-plate environment.

The continuation of granite plutons into three other states along the northern direction and in a manner parallel to the Ifewara Fault indicate the origin of the plutons is related to deep seated regional structural trends within the basement while the shape of the plutons may have been controlled by local tectonic setting.

7.2 Conclusions

Idanre Granite Complex which occur as intrusive bodies within the migmatite-gneissic terrane of Idanre is Pan-African in age. In terms of trace elements distribution pattern, the granite is geochemically related to the country rock and are product of partial melting of igneous protoliths. Structural evaluation indicates that the granite intruded into the host rock in a catastrophic emplacement scenario as heavy lumps of xenoliths are shattered within the margins of the granite plutons. The granitic suite which occur in three different textural forms all show evidence of plagioclase fractionation. Petrographic investigation indicated that the undifferentiated granite contains several large crystals of hornblende which exhibits poikilitic textures and the porphyritic granite contained myrmekite perthite. The magma which crystallized as the Idanre granite complex originated from a depth of 32-36 km within the crust. The granite complex has poor mineralization index in terms of Ta-Nb-Sn.

7.3 Limitation of the study Recommendations and Future works.

Unlike many other notable granite complexes in other parts of the world which have been investigated and reported by several authors, the Idanre granite complex is presented here for the first time. The samples for this study were carefully selected so that it accurately represents each part of the geographical spread. Although, some samples were collected at intervals close to 50 meters particularly in areas where there are noticeable mineralogical, structural or textural changes, but the rugged topography and high gradients in some locations did not allow regular sampling interval to be maintained throughout the study area. However, considering the size of the area, the collected outcrop samples was assumed insufficient to adequately establish mineralogical, structural, and compositional variations within the entire study area particularly along any vertical profile. Even though, the report showcased and discussed the granite's geological, structural, geochemical, and geochronological attributes, the depth to the root of granite intrusions could not be established, hence a three-dimensional (3-D) pictorial representation of the granite complex is not included in the study. Geophysical evaluation of the granite complex was also not included in the present study and has not been undertaken in any previous research. No seismic refraction investigation or data was available for the complex as at the time of this investigation. As such, it is recommended that subsequent research complement the present research by investigating and reporting the three dimensional (3-D) image of the granite complex to further enhance the understanding of its size and geometric shape and other parameters that may be related to knowing its extent, volume and geodynamics of its evolution.

Melt inclusion study of the granite complex is recommended to evaluate in detail the paleo-environmental condition under which it evolved and to examine the possibility of any mineralizing fluid during the rock petrogenesis.

Finally, the current research is limited to the southern map limit of Akure sheet produced by the Geological Survey 1966. However, the northern extension of the granite complex towards Ekiti and Omu-Aran in Kwara State need to be investigated to see the possibility of any link with the Ifewara Fault System which lies on western side of the extensive granite chain. Also, the economic implication of the granite complex has not been evaluated. Many granite and granite pegmatites around the world have been a source of economic mineralization in copper and other specialty metals like tantalum, niobium, and tin. It is recommended that the Idanre granite complex is evaluated for possible economic benefits.

REFERENCES

Adekoya, J. A. (1977). A note on jointing in the basement complex of the Ibadan area, Oyo State, Nigeria. *Journal of Mining and Geology*, *14*, 48-52.

Adetunji, A., Olarewaju, V. O., Ocan, O. O., Ganev, V. Y., & Macheva, L. (2016). Geochemistry and U-Pb zircon geochronology of the pegmatites in Ede area, southwestern Nigeria: A newly discovered oldest Pan African rock in southwestern Nigeria. *Journal of African Earth Science, 115*, 177-190.

Affaton, P., Kröner, A., & Seddoh, K. F. (2000). Pan-African granulite formation in the Kabye Massif of northern Togo (West Africa): Pb–Pb zircon ages. *Geologische Rundschau, 88*, 778-790.

Afolagboye, L. O., Talabi, A. O., & Akinola, O. O. (2015). "Evaluation of selected basement complex rocks from Ado-Ekiti, SW Nigeria, as source of road construction aggregates" *Bulletin of Engineering Geology and Environment, 75*(2), 853-865.

Aicard, P. (1957). Le Precambrien du Togo et du Nord-Ouest du Dahomey. Gouvernement general de l'Afrique occidendale francaise. *Bulletin of the Federal Ministry of Geological Affairs,* Dakar 23.

Ajayi T. R. (1981). On the geochemistry and origin of the amphibolite in Ife-Ilesha area, Southwestern Nigeria. *Journal of Mining and Geology*, *17*(2), 179-195.

Ajibade, A. C. (1976). Provisional classification and correlation of the schist belts in Northwest Nigeria. In C. A. Kogbe, (Ed.), *Geology of Nigeria.* Elizabethan Publishing Company, (pp. 85-90), Surulere, Lagos, Nigeria.

Ajibade, A. C. (1980). Geotectonic evolution of the Zungeru region, Nigeria (Doctoral dissertation, University College, Wales.

Ajibade A. C., Fitches W. R., & Wright J. B. (1979). The Zungeru Mylonites, Nigeria. The recognition of a major tectonic unit, *Review of Dynamic Geology and Physical Geography, Paris, 21*(5), 359-363.

Ajibade A. C., Woakes, M. R., & Rahaman, M. A. (1988). Proterozoic crustal development in the Pan-African regime of Nigeria. In Precambrian Geology of Nigeria, Geological Survey of Nigeria (pp. 72-81), Esho Publishers. Kaduna.

Ajibade, A. C., & Fitches, W. R. (1988). The Nigerian Precambrian and the Pan-African Orogeny. *Precambrian Geology of Nigeria, 3,* 45-53.

Ajibade, A. C., & Wright, J. B. (1989). The Togo-Benin-Nigeria Shield: evidence of crustal aggregation in the Pan-African belt. *Tectonophysics, 165*(1-4), 125-129.

Ajibade, A. C., Woakes, M., & Rahaman, M. A. (1987). Proterozoic crustal development in the Pan-African Regime of Nigeria. *Proterozoic Lithospheric Evolution*, *17*, 259-271.

Akoh, J. U., & Ogunleye, P. O. (2014). Mineralogical and geochemical evolution of muscovite in the pegmatite group of the Angwan Doka area, Kokoona district: a clue to petrogenesis and tourmaline mineralization potential. *Journal of Geochemical Exploration, 146*, 89-104.

Anifowose, A. Y. B., & Kolawole, F. (2012). Emplacement Tectonics of Idanre Batholith, West Africa. *Geological Communication, 99*(2), 13-18.

Anike, L. O., Umeji, A. C., & Onyeagocha, A. C. (1990). Geology and geochemistry of the Muro banded-iron formation, SW Plateau State, Nigeria. *Journal of Mining and Geology*, *26*, 21-26.

Annor A. E., Olobaniyi, S. B., & Mucke, A. (1996). A note on the geology of Isanlu areas in the Egbe-Isanlu schist belt, S.W Nigeria. *Mining Geology, 32*(1), 47-52.

Annor, A. E. (1998). Structural and chronological relationship between the low-grade Igarra schist and its adjoining Okene migmatite-gneiss terrain in the Precambrian exposure of southwestern Nigeria. *Journal of Mining and Geology, 34*(2), 187-196.

Badejoko, T. A. (1986). The petrogenesis of the Younger Granite of Nigeria. *Journal of African Earth Sciences*, *5*(3), 233-242.

Bafor, B. E. (1988). Some geochemical considerations in the evolution of the Nigerian basement in the Egbe area of southwestern Nigeria. *Precambrian Geology of Nigeria. Geological Survey Nigeria Special Publication*, 277-288.

Baker, F. (1979). Trondhjemites: definition, environment and hypothesis of origin. In: Barker F. (ed.), Trondhjemites, Dacites and Related Rocks. Elsevier, 1-12.

Batchelor, R. A., & Bowden, P. (1985). Petrogenetic interpretation of granitoid rock series using multicationic parameters. *Chemical Geology, 48*, 43-55.

Belousova, E. A., Griffin, W. L., O'Reilly, S. Y., & Fisher, N. I. (2002). Igneous zircon: trace element composition as an indicator of source rock type. *Contribution to Mineralogy and Petrology, 143*, 602-622.

Belousov, V. V., & Volvovsky, B. S. (1988). Structure and evolution of the Earth's crust and upper mantle of the Black Sea. *Bulletin of Theory and Application of Geophysics*, *30*(117-118), 109-196.

Bertrand, J. M. L., & Davison, I. (1981). Pan Africa granitoid emplacement in the Adrar des Iforas mobile belt (Mali); A Rb/Sr. Isotope study. *Precambrian Research, 14*, 333-361.

Black, R., Caby, R., Moussine- Pouchkine, A., Bayer, R., Betrand, J. M., Boullier, M. M., …& Resquer, A. (1979). Evidence for late Precambrian plate tectonics in West Africa. *Nature*, *278*(5701), 223-227.

Black, R. (1980). Precambrian of West Africa. *Episodes*, 4, 3-8

Boissonnas, J., Borsi, S., Ferrata, G., Fabries, J., & Gravelle, M. (1969). On the Early Cambrian age of two late orogenic granites from West-central Ahaggar (Algerian Sahara). *Canadian Journal of Earth Science. 6,* 25-37.

Boissonnas, J., Leutwein, F., & Sonet, J. (1970). Age du granite hyperalcalin de la Gara Adjemamaye (Ahaggar du Sub-Est. Sahara Algerien). *Geological Society of France, 7,* 251-252.

Bowden, P., & Turner, D. C. (1974). Peralkaline and associated ring complexes in the Nigeria-Niger Province. West Africa. In: *the alkaline rocks.,* H. Sorensen (Ed.), John Wiley and Sons, London.

Burke, K. C., & Durotoye, B. (1970). Boulder Slide on an Inselberg in the Nigerian Rain Forest, *Journal of Geology*, *78*(6), 733-735.

Burke, K. C., Freeth, S. T., & Grant, N. K. (1976). The structure and sequence of geological events in the basement complex of Ibadan area, Western Nigeria. *Precambrian Research, 3*, 537-545.

Caby, R. (1989). Precambrian terranes of Benin-Nigeria and Northeast Brazil and the late proterozoic south Atlantic fit. *Geological Society of America*, *Special Paper 230*, 145 – 158.

Caen-Vachette, M., & Ekwueme, B. N. (1988). Rb-Sr ages of schists in the metasedimentary belts in southeast Lokoja and their implications for the Precambrian evolution of central Nigeria. *Journal of Africa Earth Science, 7*, 127-131.

Cahen, L., Snelling, N. J., Delhal, J., Vail, J. R., Bonhomme, M., & Ledent, D. (1984). The geochronology and evolution of Africa. Clarendon Press.

Casas, A. M., Cortes, A. L., Maestro, A., Soriano, M. A., Riaguas, A., & Bernal, J. (2000). A program for lineament length and density analysis. *Computers and Geosciences*, *26* (9-10), 1011-1022.

Chapman, J. B., Ducea, M. N., DeCelles, P. G., & Profeta, L. (2015). Tracking changes in crustal thickness during orogenic evolution with Sr/Y: An example from the North American Cordillera. *Geology*, *43*(10), 919-922.

Chappell, B. W., & White, A. J. R. (1974). Two contrasting granite types. *Pacific Geology*, *8*, 173–174.

Clark, A. M., (1984). Mineralogy of the rare earth elements. In Rare Earth Geochemistry. *Developments in Geochemistry* 2, Henderson, P. (ed.). Elsevier, Amsterdam, 33-62.

Corfu, F., Hanchar, J. M., Hoskin, P. W., & Kinny, P. (2003). Atlas of zircon textures. *Reviews in Mineralogy and Geochemistry*, *53*(1), 469-500.

Cooray, P. G. (1977). Classification of charnockite rocks of Nigeria. *Journal of Mining and Geology, 14*, 1–6.

Cox, K. G., Bell, J. D., & Pankhurst, R. J. (1979). The Interpretation of Igneous rocks. George Allen and Unwin, London.

Dada, S. S. (1989). Evolution de la croute continentale au Nord Nigeria: apport de la géochimie de la géochronologique U-Pb et des traceurs isotopiques Sr, Nd et Pb. (*Doctorate Thesis.*): *University Science Technologie. Languedoc,* Montpellier. 194 p.

Dada, S. S., Lancelot, J. R., & Briqueu, L. (1989). Age and origin of the annular charnockitic complex at Toro, Northern Nigeria: U-Pb and Rb-Sr evidence, *Journal of African Earth Sciences, 9*, 227-234.

Dada, S. S., Tubosun, I. A., Lancelot, J. R., & Lar, A. U. (1993). Late Archaean U-Pb age for the reactivated basement of North-eastern Nigeria. *Journal of African Earth Sciences (and the Middle East)*, *16*(4), 405-412.

Dada, S. S. (2006). Proterozoic Evolution of Nigeria. In O. Oshin, (Ed.), The Basement Complex of Nigeria and its Mineral Resources. Petrochemical. Services Ltd. Ibadan, Nigeria. 29 - 45.

Dada, S. S. (2008). Proterozoic evolution of the Nigeria-Boborema province. In R. J. Pankhurst, R. A. J. Trouw, B. B. Brito Neves, M. J. de Wit (Eds.), *Geological Society of London, Special Publication*, *294*, 121-136.

Dalpé, C., & Baker, D. R., (2000). Experimental investigation of large-ion-lithophile-element, high-field-strength-element- and rare-earth-element-partitioning between calcic amphibole and basaltic melt: the effects of pressure and oxygen fugacity. *Contribution to Mineralogy and Petrology, 140*, 233-250.

Debon, F., & Le Fort, P. (1988). A cationic classification of common plutonic rocks and their magmatic associations: principles, method, applications. *Bulletin of Mineralogy*, *111*(5), 493-510.

De la Roche, H., Leterrier, J., Grandclaude, P., & Marchal, M. (1980). A classification of volcanic and plutonic rocks using R1, R2- diagrams and major element analysis- its relationships with current nomenclature. *Chemical Geology 29*, 183-210.

Didier, J. (1973). Granites and their enclaves: Elsevier Scientific Publishing Company, Amsterdam, 393 pp.

Dong, Y. P., Liu, X. M., Zhang, G. W., Chen, Q., Zhang, X. N., Li, W., & Yang, C. (2012a). Triassic diorites and granitoids in the Foping area: constraints on the conversion from subduction to collision in the Qinling orogen, China. *Journal of Asian Earth Sciences, 47*, 123–142.

Durotoye, B. (1976). The Geomorphic Regions of Southwestern Nigeria, *ASEQUA Bulletin*, *47*, 78-83.

Egbuniwe, I. G. (1982). Geotetonic Evolution of the Maru belt, north-western Nigeria (Doctoral dissertation, Ph.D. thesis, University of Wales, Aberystwyth, UK).

Ekwueme, B. N. (1990). Rb-Sr ages and petrologic features of Precambrian rocks from the Oban Massif, south-eastern Nigeria. *Precambrian Research*, *47*(3-4), 271-286.

Ekwueme, B. N. (2003). *The Precambrian geology and evolution of the South-eastern Nigerian basement complex*. University of Calabar press.

Ekwueme, B. N., & Kröner, A. (2006). Single zircon ages of migmatitic gneisses and granulite in the Obudu Plateau: Timing of granulite-facies metamorphism in south-eastern Nigeria. *Journal of African Earth Sciences*, *44*(4-5), 459-469.

Ekwueme, B. N., & Kröner, A., (1992). Preliminary zircon evaporation ages from migmatitic gneisses in Kaduna, northern Nigeria: evidence for an early Archaean (Pre-Leonian) event in the Nigerian basement complex. In: IGCP 280 International Conference, Salvador, Brazil, 46-53.

El Bouseily, A. M., & El Sokkary, A. A. (1975). The relation between Rb, Ba and Sr in granitic rocks. *Chemical Geology*, *16*(3), 207-219.

Elueze, A. A. (1981). Geochemistry and petrotectonic setting of metasedimentary rocks of the schist belt of Ilesha area, Southwest Nigeria*, Journal of Mining and Geology, 18*(1), 167-169.

Elueze, A. A. (1982). Petrochemistry of Precambrian gneisses and migmatites in the western part of Nigeria. *Brazilian Journal of Geology*, *12*(1-2-3), 301-306.

Elueze, A. A. (1982). Geochemistry of the Ilesha granite gneiss in the basement complex of southwestern Nigeria. *Precambrian Research,* 19, 167-177.

Elueze, A. A. (2000). Compositional appraisal and petrotectonic significance of the Imelu banded ferruginous rock in the Ilesha schist belt, southwestern Nigeria, *Journal of Mining and Geology, 36*(1), 9-18.

Elueze, A. A. (2002). Compositional character: Veritable tool in the appraisal of Geomaterials. *An inaugural lecture*. University of Ibadan.

Ephraim, B. E. (2005). Petrology and geochemistry of basement rocks in northeast Obudu area, Bamenda Massif, south-eastern Nigeria. *Unpublished PhD thesis, University of Calabar*.

Fabre, J. (2005). Geologie du Sahara occidental et central Tervuren. *Africain Geoscience Colloquia. 108,* Geological Article # 572.

Falconer, J. D. (1911). The Geology and geography of Nigeria MacMillian, London.

Fernandez, A. N., & Gasquet, D. R. (1994). Relative rheological evolution of chemically contrasted coeval magmas: example of the Tichka plutonic complex (Morocco). *Contributions to Mineralogy and Petrology*, *116*(3), 316-326.

Ferré, E. C., Caby, R., Peucat, J. J., Capdevila, R., & Monie, P. (1998). Pan-African, post-collisional, ferro-potassic granite and quartz-monzonite plutons of Eastern Nigeria. *Lithos, 45*, 225-279.

Fitches, W. R., Ajibade, A. C., Egbuniwe, I. G., Holt, R. W. & Wright, J. B., (1985). Late Proterozoic schist belts and plutonism in NW Nigeria. *Journal of Geological Society, London 142*, 319-337.

Frost, B. R., Lindsley, D. H., (1991). The occurrence of Fe-Ti oxides in igneous rocks. In: D. H. Lindsley (ed.), Oxide Minerals: Petrologic and magnetic significance, Mineralogical Society of America*, Reviews in Mineralogy*, *25*, 433-486.

Frost, B. R., Barnes, C. G., Collins, W. J., Arculus, R. J., Ellis, D. J., & Frost, C. D. (2001). A geochemical classification for granitic rocks. *Journal of Petrology, 42*(11), 2033-2048.

Ganne, J., Schellart, W. P., Rosenbaum, G., Feng, X., & De Andrade, V. (2017). Probing crustal thickness evolution and geodynamic processes in the past from magma records: An integrated approach. *Geological Society of America Special Papers*, *526*, 1-25.

Mackenzie, F. T., & Garrels, R. M. (1971). *Evolution of sedimentary rocks*. New York: Norton.

Gasquet, D., Ennih, N., Liégeois, J. P., Soulaimani, A., & Michard, A. (2008). The pan-african belt. In *Continental evolution: the geology of Morocco* (pp. 33-64). Springer, Berlin, Heidelberg.

Gasquet, D., Barbey, P., Adoua, M., and Paquette, J. L., (2003). Structure, Sr–Nd isotope geochemistry and zircon U–Pb geochronology of the granitoids of the Dabakala area (Cˆote d'Ivoire): evidence for a 2.3 Ga crustal growth event in the Paleoproterozoic of West Africa? *Precambrian Research, 127*, 329-354.

Goodenough, K. M., Lusty, P. A. J., Roberts, N. M. W., Key, R. M., & Garba, A. (2014). Post-collisional Pan-African granitoids and rare metal pegmatites in western Nigeria: Age, petrogenesis, and the 'pegmatite conundrum'. *Lithos*, *200*, 22-34.

Grant, N. K., (1970). Geochronology of Precambrian basement rocks from Ibadan, southwestern Nigeria. *Earth and Planetary Science Letters, 10*, 29-38.

Grant, N. K., Hickmann, M., Burkholder, F. R., & Powell, J. L. (1972). Kibaran metamorphic belt in Pan-Africa domain of West Africa. *Nature physical. Science, 238*, 90-91.

Grant, N. K. (1978). Structural distinction between a metasedimentary cover and an underlying basement in the 600my. Old Pan-African domain of northern Nigeria, West Africa. *Geological Society of America Bulletin, 89*, 50-58.

Hanson, G. N. (1978). The application of trace elements to the petrogenesis of igneous rocks of granitic composition. *Ibid.* 26-43.

Härme, M. (1965). On the Potassium Migmatites of Southern Finland: With 31 Figures and 7 Tables in Text and One Map. Geologinen tutkimuslaitos. *Bulletin of Geology, Finland, 219*, 1-43.

Harris, N. B. W., & Inger, S. (1992). Trace-element modelling of pelite-derived granites. *Contributions to Mineralogy and Petrology*, *110*, 46–56.

Haruna, I. V. (2014). Petrology and geochemistry of granitoids of the Northern part of Adamawa Massif, N.E Nigeria. *Journal of Geology and Geosciences, 3*(177), 1-9.

Hartnady, M. I. H., Kirkland, C. L., Dutch, R. A., Bodorkos, S., & Jagodzinski, E. A. (2018). Zircon Hf isotopic signatures of the Coompana Province in South Australia. In *Coompana Drilling and Geochemistry Workshop 2018 extended abstracts, Report Book, 19*, 132-144.

Hatch, F. H., Wells, A. K., & Wells, M. K. (1972). Petrology of the Igneous Rocks. Thomas Murby and Company, London.

Hockey, R. D., Sacchi, R., De Graff, W. P. F. H. & Muotoh, E. O. G. (1986). The geology of Lokoja-Auchi area. *Geological Survey of Nigeria Bulletin, 39*, 71-85.

Holt, R. W. (1982). *The Geotectonic evolution of the Anka Belt in the Precambrian Basement Complex of Northwestern Nigeria. Unpublished* (Doctoral dissertation, Ph. D. Thesis, The Open University, Milton Keynes, England.

Hu, F., Liu, S., Ducea, M. N., Zhang, W., & Deng, Z. (2017). The geochemical evolution of the granitoid rocks in the South Qinling Belt: Insights from the Dongjiangkou and Zhashui intrusions, central China. *Lithos*, *278*, 195-214.

Hubbard, F. H. (1975). Precambrian crustal development in western Nigeria: Indications from the Iwo region. *Geological Society of America Bulletin, 86*, 548-554.

Hurley, P. M., Fairbairn, H. W., & Pirson, W. H. (1966). Continental drift investigations. Massachusetts Institute of Technology. U. S. A. 14th Annual Progress Report., UASEC, *1381*(14), 3-15.

Ige, O. A., Okrusch, M., Schussler, U., Schmadicke, E., & Cook, N. J. (1998). The metamorphosed mafic-ultramafic complex of Mokuro, Ilesha Schist belt, southwestern Nigeria. *Journal of African Earth Sciences, 26*(4), 593-618.

Ige, O., Adeyemi, C., Ogunfolakan, A., Ayansola, A., Olayemi, A., Taiwo, Y., …. & Oyelade, J. (2011). An inventory of the geological, biological and cultural resources on Ufe-Oke Hill, Idanre, southwestern Nigeria. *Natural Resources, 2*, 180-190.

Irvine, T. N., and Baragar, W. R. A. (1971). A guide to chemical classification of the common volcanic rocks. *Canadian Journal of Science, 8*, 523-548.

Jacobson, R. E. E., Macleoed, W. N., & Black, R. (1958). Ring-Complexes in the Younger Granite Province of Northern Nigeria. *Memoir of Geological Society London*, 1, 1-72.

Jeje, L. K. (1974). “Effects of Rock Composition and Structure on Landform Development: The example of Idanre Hills of Western Nigeria,” *Journal of Tropical Geography*, *39*, 43-53.

Jeje, L. K. (1979). “Debris Flow on a Ridge near Ile-Ife, Western Nigeria,” *Journal of Mining and Geology*, *16*(1), 9-16.

Jelsma, H. A., & Dirks, P. H. (2002). Neoarchean tectonic evolution of the Zimbabwe Craton. *Geological Society, London, Special Publications*, *199*(1), 183-211.

Jones, H. A., & Hockey, R. D. (1964). The Geology of parts of Southwestern Nigeria. Explanation of 1:250,000 Sheets 59 and 68 Authority of the Federal Government of Nigeria. *Geological Survey of Nigeria Bulletin, 31*, 101-124.

Jung, S., Hoffer, E., Masberg, P., & Hoernes, S. (1995). Geochemistry of granitic in-situ low-melt fractions: an example from the central Damara Orogen. *Communications of the Geological Survey of Namibia*, *10*, 21-31.

Kayode, A. A. (1976). On the genesis of the small and large-feldspar porphyritic Older Granites in the Igbo-Ora Complex, southwestern Nigeria In C. A. Kogbe (Ed.), *Geology of Nigeria,* 75-84.

Kayode, A. A. (1988). Chemical zircon typology and two pyroxene investigation of the Hornblende granite-acid charnockite contact in Ikere-Ekiti, southwestern Nigeria, *Precambrian Geology of Nigeria,* (1), 144-145.

Key, R. M., Johnson, C. C., Horstwood, M. S., Lapworth, D. J., Knights, K. V., Kemp, S. J., ... & Arisekola, T. (2012). Investigating high zircon concentrations in the fine fraction of stream sediments draining the Pan-African Dahomeyan Terrane in Nigeria. *Applied Geochemistry*, *27*(8), 1525-1539.

Kinny, P. D., Wijbrans, J. R., Froude, D. O., Williams, I. S., & Compston, W. (1990). Age constraints on the geological evolution of the Narryer Gneiss Complex, Western Australia. *Australian Journal of Earth Sciences*, *37*(1), 51-69.

Klemm, D. D., Schneider, W., & Wegner, B. (1984). The Precambrian metavolcano-sedimentary sequence East of Ife and Ilesha, southwestern Nigeria. A Nigerian Greenstone Belt. *Journal of African Earth Sciences, 2*, 161-176.

Knudsen, T. L., Griffin, W. L., Hartz, E. H., Andresen, A. & Jackson, S. (2001). In-situ hafnium and lead isotope analyses of detrital zircons from the Devonian sedimentary basin of NE Greenland: A record of repeated crustal reworking. *Contributions to Mineralogy and Petrology, 141*, 83–94.

Kolawole, F., & Anifowose, A. Y. B. (2011). Talus Caves: Geotourist attractions formed by spheroidal and exfoliation weathering on Akure-Ado Inselbergs, Southwestern Nigeria. *Ethiopian Journal of Environmental Studies and Management, 4*(3), 1-6.

Kouamelan, A. N., Delor, C., & Peucat, J. J. (1997a). Geochronological evidence for reworking of Archean terrains during the early Proterozoic (2.1 Ga) in the western Cˆote d'Ivoire (Man Rise- West African Craton). *Precambrian Research, 86*, 177–199.

Kröner, A., & Stern, R. J. (2005). Pan-African Orogeny. *Encyclopaedia of Geology*, *1* (A-E), 1-12.

Kuno, H. (1968). Differentiation of basalt magmas. *The Poldervaart treatise on rocks of basaltic composition*, *2*, 623-688.

Küster, D., Liégeois, J. P., Matukov, D., Sergeev, S., & Lucassen, F. (2008). Zircon geochronology and Sr, Nd, Pb isotope geochemistry of granitoids from Bayuda Desert and Sabaloka (Sudan): evidence for a Bayudian event (920–900 Ma) preceding the Pan-African orogenic cycle (860–590 Ma) at the eastern boundary of the Saharan Metacraton. *Precambrian Research*, *164*(1-2), 16-39.

Lambert, R. S. J., Chamberlain, V. E., & Holland, J. G. (1976). Amistoq gneiss geochemistry: preliminary observations. In: *The Early History of the Earth.* Wiley, London.

Leake, B. E., Brown, G. C., & Halliday, A. N. (1980). The origin of granitic magmas: a discussion. *Journal of Geological Society, 137*, 93-98.

Lee, C. T. A., & Morton, D. M. (2015). High silica granites: Terminal porosity and crystal settling in shallow magma chambers. *Earth and Planetary Science Letters*, *409*, 23-31.

Liégeois, J. P., Fekkak, A., Bruguier, O., Errami, E., & Ennih, N. (2006). The Lower Ediacaran (630–610 Ma) Saghro group: an orogenic transpressive basin development during the early metacratonic evolution of the Anti-Atlas (Morocco). In: *International Geological Conference, 4th meeting, Algiers*.

Liégeois, J.-P., Benhallou, A., Azzouni-Sekkal, A., Yahiaoni, R. & Bonin, B. (2005). The Hoggar swell and volcanism: Reactivation of the Precambrian Tuareg shield during Alpine convergence and West African Cenozoic volcanism. *Geological Society of America, 388*, 379-400.

Liégeois, J. P., Black, R., Navez, J., & Latouche, L. (1994). Early and late Pan-African orogenies in the Air assembly of terranes (Tuareg Shield, Niger). *Precambrian Research*, *67*(1-2), 59-88.

Malomo, S. (2004). Geological Map of Nigeria. Geological Survey of Nigeria.

Maniar, P. D. & Piccoli, P. M. (1989). Tectonic discrimination of granitoids. *Geological Society of America Bulletin 101*, 635–643.

Marc, D. (1992). Granites and rhyolites from the north-western USA: temporal variation in magmatic processes and relations to tectonic setting. Transactions of the Royal Society of Edinburgh. *Earth Sciences, 83*, 51-64.

McCurry, P. (1976). The Geology of the Precambrian to Lower Paleozoic rocks of northern Nigeria - a review of Geology of Nigeria, C.A. Kogbe (Ed.), Elizabethan Publishing Company, (pp 15-39). Lagos.

Meng, F., Zhang, J., & Cui, M. (2013). Discovery of Early Palaeozoic eclogite from the East Kunlun, Western China, and its tectonic significance. *Gondwana Research*, *23*(2), 825-836.

Menzies, M. (1976). Rare earth geochemistry of fused ophiolitic and alpine lherzolites-I. Othris, Lanzo and Troodos. *Geochimica et Cosmochimica Acta*, *40*(6), 645-656.

Middlemost, E. A. (1994). Naming materials in the magma/igneous rock system. *Earth Science Reviews*, *37*(3-4), 215-224.

Miller, C. F. (1985). Are strongly peraluminous magmas derived from pelitic sedimentary sources?. *Journal of Geology, 93*, 673-689.

Muotoh, E. O. G., Oluyide, P. O., Okoro, A. U., & Muogbo, O. E. (1988). The Muro hills banded iron formation. In P.O. Oluyide, W. C Mbonu, A. E. Ogezi I. G. Egbuniwe, A. C. Ajibade, & A. C. Umeji (Eds.), Precambrian Geology of Nigeria (pp. 219-227). Geological Survey of Nigeria, Kaduna.

Wai-Pan Ng, S., Chung, S. L., Robb, L. J., Searle, M. P., Ghani, A. A., Whitehouse, M. J., ... & Roselee, M. H. (2015). Petrogenesis of Malaysian granitoids in the Southeast Asian tin belt: Part 1. Geochemical and Sr-Nd isotopic characteristics. *Bulletin*, *127*(9-10), 1209-1237.

Obaje, N. G. (2009). Geology and mineral resources of Nigeria. Lecture notes in Earth Sciences, 120, Springer – Verlag Berlin Heidelberg.

Obiadi, I. I. (2012). “Determining Subsurface Fracture Characteristics from the Azimuthal Square Array Resistivity Survey at Igarra, Nigeria.” *Pure and Applied Geophysics, 170*(5), 907-916.

Obiora, S. C. (2008). Geology and Mineral Resources of the Precambrian Basement Complex of Nigeria. A talk presented at the National Geophysical Research Institute, Hyderabad, India on 25th November 2008 as a CSIR- TWAS Postdoctoral Fellow.

Obiora, S. C. (2005). Field descriptions of hard rocks, with examples from the Nigerian Basement Complex. 1st Edition. Snap Press (Nigeria) Ltd. Enugu.

Odeyemi, I. B. (1977). The Basement rocks of Bendel state of Nigeria. *Unpublished Ph.D. Thesis. University of Ibadan*.

Odeyemi, I. B., Anifowose, A. Y. B. & Asiwaju-Bello, Y. A. (1999). Multitechnique Graphical Analysis of Fractures from Remote Sensing Images of Basement Regions of Nigeria. *Journal of Mining and Geology*, *35*(1), 9-21.

Odeyemi, I. B. (1990). The petrology of a Pan-African pluton in Igarra area, Southwestern, Nigeria. *Nigeria Journal of Science*, *24*(142), 181-193.

Odeyemi, I. B. (1981). A review of the orogenic events in the Precambrian basement of Nigeria, West Africa. *Geologische Rundschau*, *70*(3), 897-909.

Ogezi, A. E. O. (1977). Geochemistry and geochronology of basement rocks from northwestern Nigeria. *Unpublished Ph. D. Thesis, University of Leeds*.

Ogezi, A. E. O. (1988). Geochemistry and origin of Ensialic Alpines - type serpentine Associations from Mallam Tanko (Shemi) and Ribah Northern Nigeria. In Precambrian Geology of Nigeria, GSN, Esho Publications, Kaduna.

Ogunleye, P. O., Ike, E. C., & Garba, I. (2005). Geochemical characteristics of the niobium-rich arfvedsonite granites, Younger Granites province of Nigeria. *Chemie Der Erde, 65*, 279-296.

Ogunmola, J. K., Gajere, E. N., Ayolabi, E. A, Olobaniyi, S. B., Jeb, D. N & Agene, I. J. (2015). "Structural study of Wamba and Environs, north-central Nigeria using aeromagnetic data and Nigeria Sat-X image" *Journal of African. Earth Sciences, 111*, 307-321.

Ojo, O. M. (1994). Geological Map of Nigeria. Geological Survey of Nigeria.

Okonkwo, C. T., & Ganev, V. Y. (2012). U-Pb zircon geochronology of the Jebba granitic gneiss and implications for the Paleoproterozoic evolution of Jebba area, southwestern Nigeria. *International Journal of Geosciences, 3*, 1065-1073.

Okonkwo, C. T., & Winchester, J. A. (2000). Petrochemistry and petrogenesis of migmatitic gneisses and metagreywackes in Jebba area, southwestern Nigeria. *Journal of Mining and Geology 36*, 1–8.

Okunlola, O. A. (2001). Geological and compositional investigation of Precambrian marble bodies and associated rocks in the Burum and Jakura areas, Nigeria. *Unpublished Ph. D thesis, University of Ibadan*.

Olade, M. A., & Elueze, A. A. (1979). Petrochemistry of the Ilesha amphibolite and Precambrian crustal evolution in the Pan-African domain, SW Nigeria. *Precambrian Research*, *8*, 303-318.

Olarewaju, V. O. (1981). *Geochemistry of the charnockitic and granitic rocks of the basement complex around Ado Ekiti-Akure, SW Nigeria* (Doctoral dissertation).

Olarewaju, V. O., & Rahaman, M. A. (1982). Petrology and geochemistry of older granites from some parts of northern Nigeria. *Journal of Mining and Geology*, *18*, 16-28.

Olarewaju, V. O. (1999). Fluid inclusion studies of coarse grained charnockitic and the hybrid rocks in Ukpilla area, southwestern Nigeria, *Journal of Mining and Geology, 35*(1), 1-18.

Oluyide, P. O., Nwajide, C. S., & Oni, A. O., (1998). The geology of the Ilorin area. Explanation of the 1:250000 sheet 50 (Ilorin). Ministry of solid mineral development, *Geological Survey of Nigeria, Bulletin,* No. 42.

Onyeagocha, A. C. (1986). Geochemistry of basement granitic rocks from north-central Nigeria. *Journal of African Earth Science, 5*, 637–651.

Orajaka, S. (1964). Geology of the Obudu area, Ogoja Province, Eastern Nigeria. *Le Naturaliste Canadian*, *140*(3), 72-86.

Oversby, V. N. (1975). Lead isotope study of Aplites the Precambrian basement rocks near Ibadan, southwestern Nigeria. *Earth and Planetary Science Letters, 27*, 177-180.

Oyawoye, M. O. (1964). The Geology of the Nigerian Basement complex. *Journal of Mining and Geology, 1*, 87-102.

Oyawoye, M. O. (1972). The basement complex of Nigeria. *African Geology*, 67-99.

Oyinloye, A. O. (1992). Genesis of the Iperindo gold deposit, Ilesha schist belt, southwestern Nigeria. *Unpublished thesis of University of Wales*.

Oyinloye, A. O. (2002). Geochemical Characteristics of some granite Gneisses in Ilesha area: Implication on the Ilesha Schist Belt, southwestern Nigeria. *Trends in Geochemistry,* 2, 59-71.

Oyinloye, A. O. (2006). Metallogenesis of the Lode Gold deposit in Ilesha area of Southwestern Nigeria: Inference from Lead Isotope systematic. *Pakistan Journal of Scientific and Industrial Research, 49*(1), 1-11.

Oyinloye, A. O., & Obasi, R. A. (2006). Geology, geochemistry and geotectonic setting of the Pan- African Granites and Charnockites around Ado-Ekiti, SW Nigeria, *Pakistan Journal of Scientific and Industrial Research, 40*(5), 200-208.

Oyinloye, A. O. (2007). Geology and Geochemistry of some crystalline rocks in Ilesha, southwestern Nigeria; implications on provenance and evolution. *Pakistan Journal of Scientific and Industrial Research, 50*(4), 223-231.

Pearce, P. A., Harris, N. B. W., & Tindle, A. G. (1984). Trace element discrimination diagrams for the tectonic interpretation of granitic rocks: *Journal of Petrology*, *25*, 956-983.

Pearce, J. A., & Cann, J. R. (1973). Tectonic setting of basic volcanic rocks determined using trace element analyses. *Earth and Planetary Science, Letters*, *19*(2), 290-300.

Pearce, J. A. (1976). Statistical analysis of major element patterns in basalts. *Journal of Petrology, 17*, 15-43.

Peccerillo, A., & Taylor, S. R. (1976). Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamona area, northern Turkey. *Contribution to Mineralogy and Petrology, 58*, 63-81.

Pitcher, W. S. (1979). The nature, ascent and emplacement of granitic magmas, *Journal of the Geological Society, London, 136*, 627-662.

Pitcher, W. S. (1983). Granite: typology, geological environment and melting relationships. In M. P. Atherton, & C. D. Gribble (Eds.), *Migmatites, Melting and Metamorphism.* Nantwich: Shiva Publications, 2, 77-87.

Rahaman, M. A. (1976). Review of the Basement geology of southwestern Nigeria. In: *Geology of Nigeria*. Kogbe, C. A (Ed.) Elizabethan Publishing Company, Lagos, Nigeria.

Rahaman, M. A., Tubosun, I. A., & Ocan, O. O. (1981). Preliminary U-Pb ages on charnockitic rocks from Akure-Ado Ekiti area. In *Abstract for 22nd Annual Conference of Science Association, Jos Nigeria*.

Rahaman, M. A., Van Breemen, O., Bowden, P., & Bennett, J. N. (1984). Age migrations of anorogenic ring complexes in Northern Nigeria. *Journal of Geology*, *92*(2), 173-184.

Rahaman, M. A. (1978). Geochemistry of some gneisses from parts of southern Nigeria. *Journal of Mining and Geology, 15*(1), 38-48.

Rahaman, M. A., Ajayi, T. R., Oshin, I. O., & Asubiojo, F. O. (1988). Trace elements Geochemistry and geotectonic setting of Ife-Ilesha schist belts. *Precambrian Geology of Nigeria*. *1,* 241-256.

Rahaman, M. A., & Lancelot, J. R. (1989). Continental crust evolution in southwestern Nigeria: constraints from U/Pb dating of pre-Pan-African gneisses. *Earth Planetary Science Letters, 125*(1-4), 89-96.

Rahaman, M. A. (1988). Recent advances in the study of the basement complex of Nigeria. In (P. O. Oluyide, W. C. Mbonu, A. E. Ogezi, I. G. Egbuniwe, A. C. Ajibade, & A. C. Umeji,) (Eds.), Precambrian Geology of Nigeria, (pp 11-41). *A publication of Geological Survey of Nigeria.* Elizabethan Publishing Company, Lagos.

Rollinson, H. R. (2014). Using geochemical data: *evaluation, presentation, interpretation*. Routledge.

Russ, W. (1957). The geology of Northern parts of Nigeria, Zaria and Sokoto Provinces, with special reference to the occurrence of gold. *Geological Survey of Nigeria Bulletin, 1*, 27-42.

Ray, R. G. (1960). *Aerial photographs in geologic interpretation and mapping* United States Government Print Off. *Professional Paper* (No. 373).

Sawyer, E. W. (2008). Atlas of migmatites, *The Canadian Mineralogist*, Special Publication 9. NRC Research press, Ottawa, Ontario, Canada.

Schlüter, T. (2008). Geological Atlas of Africa: with notes on stratigraphy, tectonics, economic geology, geohazards, geosites and geoscientific education of each country. Springer Science and Business Media.

Shand, S. J. (1947). *Eruptive rocks: their genesis, composition, classification, and their relation to ore-deposits, with a chapter on meteorites*. Thomas Murby.

Sisson, T. W., (1994). Hornblende-melt trace element partitioning measured by ion microprobe. *Chemical Geology, 117*, 331-344.

Snelling, N. J. (1966). Geochronology. In Overseas Geological Survey Annual Report. HMSO, London.

Storey, B. C., Hole, M. J., Pankhurst, R. J., Millar, I. L., & Vennum, W. (1988). Middle Jurassic within-plate granites in West Antarctica and their bearing on the break-up of Gondwanaland. *Journal of the Geological Society, London, 145*, 999-1007.

Streckeisen, A. (1974). How should charnockitic rocks be named? Centenaire Societe Geologique de Belgique, *Geologie des Domaines Cristallins, 2,* 349-360.

Sun, S. S., & McDonough, W. F. (1989). Chemical and isotopic systematics of ocean basalts: implications for mantle composition and processes, In A. D. Saunders, & M. J. Norry, (Eds.), Magmatism in the Ocean Basins. *Geological Society of London, 42*, 313-345.

Suzen, M. L., & Toprak, V. (1998). Filtering of satellite images in geological lineament analyses: an application to a fault zone in Central Turkey. *International Journal of Remote Sensing*, *19*(6), 1101-1114.

Talabi, A. O. (2013). Mineralogical and chemical characterization of major basement rocks in Ekiti State, SW Nigeria. *RMZ-Materials and Geoenvironment 60*, 73-86.

Taylor, S.R., (1962). Meteoritic and Terrestrial Rare Earth Abundance Patterns. *Geochim Cosmochim. Acta. 26*, 685-722.

Tugarinov, A. I., Knorre, K. G., Shanin, L. L., & Prokofieva, L. N. (1968). The Geochronology of some Precambrian rocks of southern West Africa. *Canadian Journal of Earth Science, 5*, 639-642.

Truswell, J. F. (1960). A contribution to the study of Older granites in the Nigerian Precambrian, with special reference to the Tegina Granites, *Unpublished Ph.D. Thesis,* University of Cape Town.

Truswell, J. F., & Cope, R. N. (1963). The geology of parts of Niger and Zaria provinces, Northern Nigeria: *Geological Survey of Nigeria Bulletin, 29*, 52- 59.

Tubosun, I. A., Lancelot, J. R., Rahaman, M. A., & Ocan, O. O. (1984). "U-Pb Pan-African Ages of Two Charnochite-Granite Associations from SW Nigeria," *Contributions to Mineralogy and Petrology*, *88*(1-2), 188-195.

Tubosun, I. A. (1981). Chronologie U/Pb évènements magmatiques du socle Precambrien du sud-ouest du Nigeria. *Unpublished D.E.A Dissertation,* 1-17.

Turner, D. G. (1976). Structure and petrology of the Younger Granite Ring complexes. In C. A. Kogbe (Ed.), Geology of Nigeria, (pp. 143-158) Elizabethan Publishing Company, Lagos.

Turner, D. G. (1983). Upper Proterozoic Schist Belts in the Nigerian Sector of the Pan-African Province of West Africa*, Precambrian Research, 21*, 55-79.

Udensi, E. E., Ojo, S. B., & Ajakaiye, D. E. (1986). A three-dimensional interpretation of the bouguer anomalies over the Minna batholith in central Nigeria. *Precambrian Research*, *32*(1), 1-15.

Ugwuonah, E. N., Tsunogae, T., & Obiora, S. C. (2017). Metamorphic P–T evolution of garnet-staurolite-biotite pelitic schist and amphibolite from Keffi, north-central Nigeria: Geothermobarometry, mineral equilibrium modeling and PT path. *Journal of African Earth Science*, *129*, 1-16.

Ukaegbu, V. U. (2003). The petrology and geochemistry of parts of Obudu Plateau, Bamenda Massif, south-eastern Nigeria. *Unpublished Ph.D. Thesis*, University of Port Harcourt.

Umeji, A. C., & Caen-Vachette, M. (1984). Geochronology of Pan-African Nassarawa-Eggon and Mkar-Gboko Granites, Southeast Nigeria. *Precambrian Research, 23*, 317-324.

Van Breemen, O., Pidgeon, R. T., & Bowden, P. (1977). Age and Isotopic Studies of Some Pan-African Granites from North-Central Nigeria. *Precambrian Research, 4*, 319-407.

Winchester, J. A., & Floyd, P. A., (1977). Geochemical discrimination of different magma series and their differentiation products using immobile elements. *Chemical Geology, 20*, 325-343.

Wood, D. A., Joron, J.-L., & Treuil, M., 1979. A re-appraisal of the use of trace elements to classify and discriminate between magma series erupted in different tectonic settings. *Earth planetary Science Letters. 45*, 326-36.

Wu, F. Y., Li, X. H., Yang, J. H., Gao, S., & Zheng, Y. F. (2007). Discussions on the petrogenesis of granites. *Acta Petrology Sinica, 23*, 1217–1238.

Yang, D., Xue, Z., & Mathias, S. A. (2012a). Analysis of momentum transfer in a lid-driven cavity containing a Brinkman–Forchheimer medium. *Transport in Porous Media*, *92*(1), 101-118.

Zhao, G., Wilde, S. A., Cawood, P. A., & Sun, M. (2002a). SHRIMP U–Pb zircon ages of the Fuping Complex: implications for late Archaean to Paleoproterozoic accretion and assembly of the North China Craton. *American Journal of Science*, *302*(3), 191-226.