ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

SCHOOL OF EARTH SCIENCES

PETROGENESIS OF PLUTONIC ROCKS FROM SOUTHWEST OF GIMBI (HOMA AREA), WESTERN ETHIOPIA

BY

FEYE ABULE YADA

ID. No: GSR/0433/08

ADVISOR: Prof. DEREJE AYALEW

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of requirements for the degree of Master of Science in Earth Sciences (Geochemistry)

Addis Ababa University

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Approval board:

Dr. Balemwal Atnafu	________________	_______________
(Head, School of Earth Sciences)	Signature	Date
Prof. Dereje Ayalew	________________	_______________
(Advisor)	Signature	Date
1) Prof. Asfawossen Asrat	________________	______________
(Examiner)	Signature	Date
2) Dr. Mulugeta A.	_______________	_____________
(Examiner)	Signature	Date

Addis Ababa University

May 2017

Declaration of Originality

I hereby declare that this thesis is my own original master 's degree work under the supervision of Prof. Dereje Ayalew, School of Earth Sciences, Addis Ababa University during academic year 2017. In addition, I announce this research work has not been submitted to any other University or Organization/institution for the award of any Degree or Diploma. Besides, all referenced materials and sources that used for this work have been punctually acknowledged.

Student:

Feye Abule Yada ______________ ________________

Signature Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Advisor:

Prof. Dereje Ayalew ______________ ________________

Signature Date

Acknowledgment

This research work is done by contribution of different organizations and individuals. Firstly, I would like to give my deepest gratitude reaches to my advisor Prof. Dereje Ayalew for his follow up, constructive comment, valuable suggestion, encouragement and tireless support. My second great gratitude also extends to the former and current School of Earth Sciences chairman Dr. Balemwal Atnafu and all academic staff of the School.

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List of Acronyms

ANS	Arabian-Nubian Shield
DEM	Digital Elevation Model
EAO	East African Orogeny
GPS	Global Positioning System
HREE	Heavy Rare Earth Element
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy
GSE	Geological Survey of Ethiopia
LREE	Light Rare Earth Element
MB	Mozambique Belt
MREE	Middle Rare Earth Element
PPL	Plane Polarized Light
ppm	parts per million
REE	Rare Earth Element
TAS	Total Alkali Silica
UTM	Universal Transverse Mercator
Wt%	Weight percent
XPL	Cross Polarized Light
Mcl	Microcline
Bt	Biotite
Qtz	Quartz
Ms	Muscovite
Plg	Plagioclase
K-fs	K-feldspar
Ep	Epidote
Opq	Opaque (Fe-Ti oxides)

Abstract

Southwest of Gimbi is located within the Western Ethiopian Precambrian shield that emplaced in between the low-grade volcanic and volcano-sedimentary rock assemblages and the high-grade gneiss and migmatites assemblages. The area is situated approximately about 508 km far from Addis Ababa. The main objective of the thesis is to characterize the petrology and geochemistry of plutonic rocks from Southwest of Gimbi area. To achieve the general and specific objectives of the research and come up with the expected result, starting from the beginning to the end different methods have been applied. Southwest of Gimbi Homa area is characterized by the plutonic rocks which have emplaced pre-, syn/late-to post-tectonic with associated to the major deformational events. Modally, plutonic rocks of Homa area range from rare diorite/gabbro through dominant granodiorite and monzogranite to alkali feldspar granite. Petrographic study shows that, Southwest of Gimbi Homa area granite rocks has medium to coarse grains and dominantly consist of K- feldspar phenocrysts, plagioclase, quartz and less biotite. All analyzed granite rocks from Southwest of Gimbi provide geochemical features of sub-alkaline series, high-K calc alkaline series, high silica concentration and high total alkali concentration. These granite rocks show enrichment in large ion lithophile elements and highly depleted in heavy rare earth elements. Southwest of Gimbi (Homa) granite rocks show enrichment in most incompatible elements (Rb and Pb) and depleted in compatible elements (Ba, Sr and Ti) reflecting the crustal source involvement in the rock genesis. Besides, the REE patterns of these granite rocks have subparallel and show pronounced negative Eu anomalies with increasing total REEs, typical of a feldspar fractionation trend. The considerable depletion in Nb, Ta and Ti and enrichment in large ion lithophile elements (Rb and Pb) on multi-element diagram indicates there is a subduction/volcanic arc related origin of granite rocks from Southwest of Gimbi. Southwest of Gimbi Homa granite rocks were genetically formed by small degree partial melting of crustal materials and by fractional crystallization of mantle derived mafic magma.

Key words: *Anomalies, Fractional crystallization, partial melting and ANS and MB.*

Chapter One

1. Introduction

1.1. Background

Late tectonic, post-collisional granite suites are a feature of many parts of the late Neoproterozoic to Cambrian of East African Orogeny (EAO). They were generally attributed to late extensional collapse of the orogeny. This was followed by high heat flow and asthenospheric up rise (Küster and Harms, 1998). The Pan-African Orogeny consist two types of major Belts (terranes). The Arabian-Nubian Shield (ANS) and Mozambique Belts (MB). These two terranes are the key to understand about the geodynamic of East African Orogeny. They are believed to be more prominent outcrop in Ethiopia than in any other country in the Horn of Africa (Kazmin, 1972; Berhe, 1990; Asfawossen Asrat and Pierre Barbey, 2003 and references therein). The Precambrian terrain in Ethiopia occupies a unique position of African continent. It situated between the predominantly gneissic rocks of the Mozambique Belt, to the southeastern and southern Africa, and the volcano-sedimentary-plutonic complexes along a strike to the north bordering of the Red Sea. Geologically, the lithology distribution (rocks) belonging to these belts are only exposed in few areas which have not been affected by rifting processes and Cenozoic volcanic activities. But, it is the place from where the Phanerozoic rocks have been eroded away by external geological processes (Tefera et al., 1996).

The tectonic development of the Precambrian shield of Ethiopian, associated with tectonic processes. Such as: subduction-accretion processes that occur between arc terranes of the Arabian-Nubian Shield and gneissic terranes of the Mozambique Belt. This is a result of collisional amalgamation of lithotectonic terranes across sutures. It is related to a plate tectonic cycle spanning a time-period of 350 Ma, beginning by about 900 Ma with rifting process and continental break-up. This tectonic cycle was ending by about 550 Ma subsequent to a continental-continental convergence between East and West Gondwana

(Vail, 1985; Berhe, 1990; Abdelsalam and Stern, 1996). It consists of two recognizable lithotectonic terranes which show contrasting lithological association, internal structures and grade of metamorphism (Yibas, 2000; Yibas et al., 2000a).

According to the above authors, these terrains consists of: (1) The granite-gneiss terrane, consisting of high-grade para- and ortho-gneisses, deformed and metamorphosed granitoids and (2) The ophiolitic fold and thrust belts, consisting of low-grade, mafic–ultramafic and sedimentary assemblages. These two terranes types separate by major fault and/or shear zones displaying multiple deformation features. Besides, the gneissic rocks of the MB are exposed to the east and west of a relatively narrow zone, but northward-widening zone of low-grade volcano-sedimentary-plutonic sequences of the Arabian-Nubian Shield (ANS) are exposed (Figure 1.1).

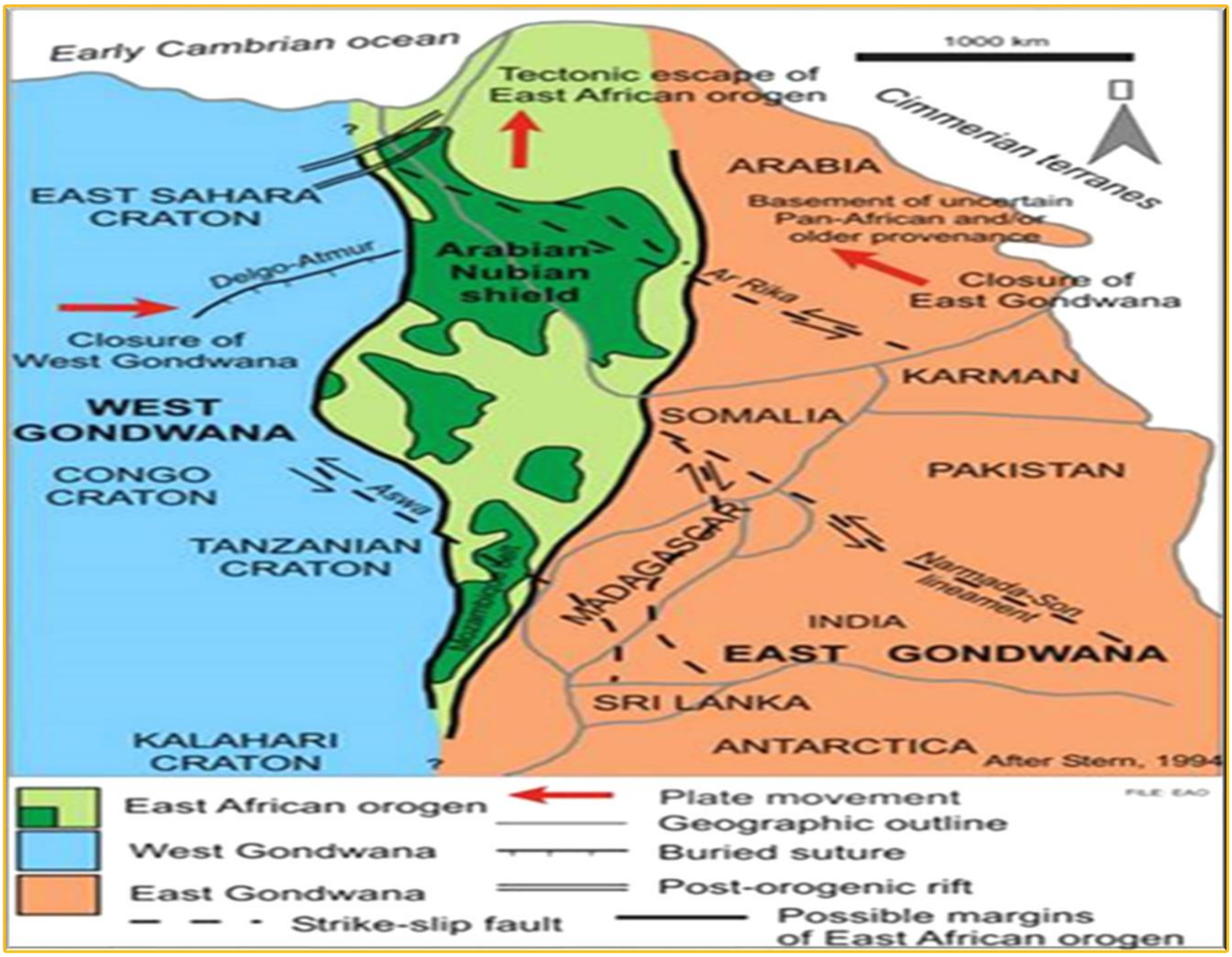


Figure 1.1: Map of East African Orogeny showing the location of the Arabian-Nubian Shield relative to the Mozambique Belt and adjacent cratonic margins referenced from previous work (adopted after Stern, 1994).

On the other hands, intrusive rocks of variable composition and different age interval were intruded the basement rocks of Western Ethiopia (Particularly, the low-grade volcano-sedimentary sequences). A number of studies were done in previous on the pre- syn- and post tectonic suites replaced the basement and dominated by granites and granodiorites, Kebede et al., 1999 and references therein, Major Lithotectonic blocks that comprise high-grade gneissic migmatitic associated and low-grade meta-volcano sedimentary sequences. These blocks were intruded by syn-to late-tectonic granodioritic and granitic plutons are exposed throughout western Ethiopia as discussed by (Kazmin, 1972; Tefera, 1987; Tefera et al., 1996). Geological Survey of Ethiopia (GSE) studied the Precambrian geology of western Ethiopia at different scales as discussed by (de Wit, 1977b; Kazmin, 1978; Kazmin et al., 1979; Berhe, 1987; Ayalew and Moore, 1989, Tadesse and Tsegaye, 2000). According to the above authors the Precambrian terrane of Western Ethiopia consists of: (i) high grade gneiss and migmatites, (ii) low-grade metavolcano-sedimentary rocks and associated intrusive rocks and, (iii) metavolcano-sediments and associated mafic-ultramafic rocks of probable ophiolitic origin.

1.2. Geographic Setting of the Study Area

1.2.1. Location and Accessibility

This research project is conducted in Western Ethiopia in which the research area lies on the Inango sheet with sheet number 0935-D3 according to topographic map distribution of Ethiopian Mapping Agency (EMA). Southwest of Gimbi can be reached via two direction roads from Addis Ababa. The first and the shortest route are from Addis Ababa through Nekemte to Gimbi. The second route is from Addis Ababa through Jimma, Gambella, and Dembi Dolo to Gimbi. The study area is located about 508 km far from Addis Ababa and 70km from the center of Gimbi Town (i.e. the largest city of West Wollega Zone) in the southwest direction. Geographically it is located between 35̊ 40' to 35̊ 45' E and 9̊ 00 to 9̊ 10 N or between UTM (Universal Transverse Mercator) the area is bounded by a grid of Easting from 795000 to 801000m and Northing of 1001000 to 1008000m (figure 1.2). The study area has coverage of approximately 86 sqkm. It can be reached through the all Gimbi town and Inango all-dry weathered roads. Further to the North, South, East and West of the study area, there are foot trails developed by the local peoples for their day to day activity. This foot trails help to access the portion of the study area that is located far away from the main dry weathered road. In addition to the foot trails some gravel roads are constructed for raw material transportation from quarries of granite and different wood products. This makes the area more accessible. But the other difficulty to access the area is, due to the area highly covered by thick soil and denser forests. Due to this no complete sequence of different lithology was found any place except some uplift and some quarry sites. So, the location map of the area is as follows (figure1.2).

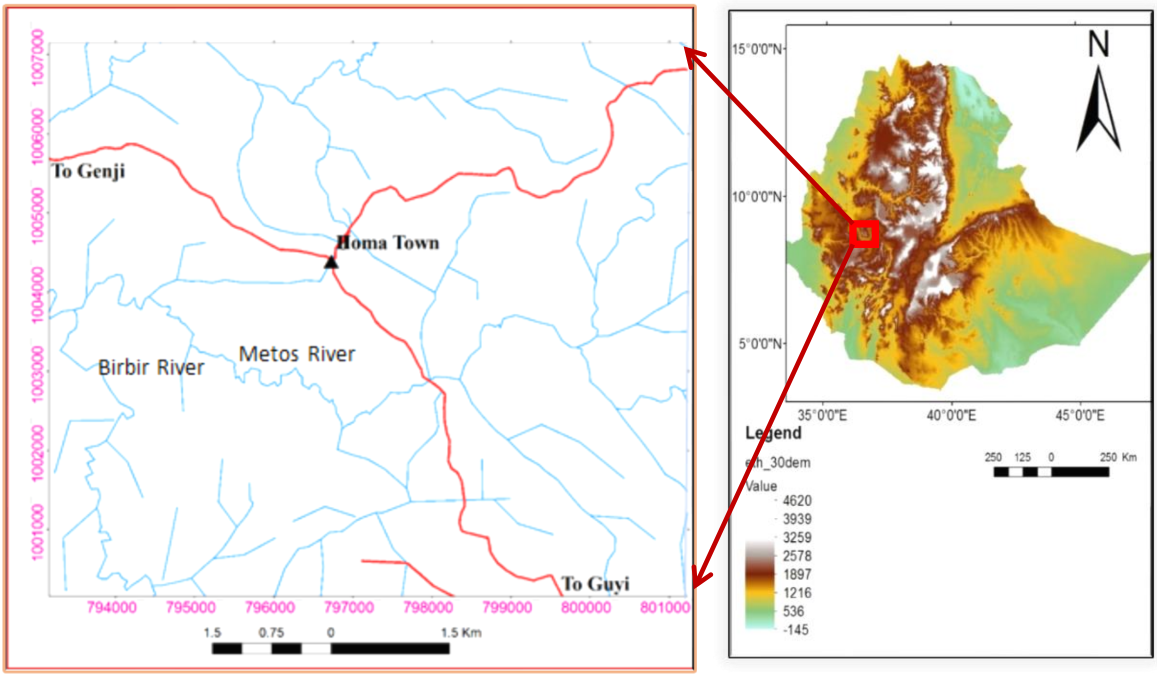


Figure 1.2: Location Map of the Study Area

1.2.2. Physiography and Drainage

The studied area is located in the Western Ethiopian basement rocks (metamorphic terrain). The altitude difference or topography has a big effect on the climatic, drainage and physiographic conditions. Especially, in the study area topographic or altitude shows areas of different climatic conditions that greatly affect the type and density of vegetation, distribution of flora, fauna and population.

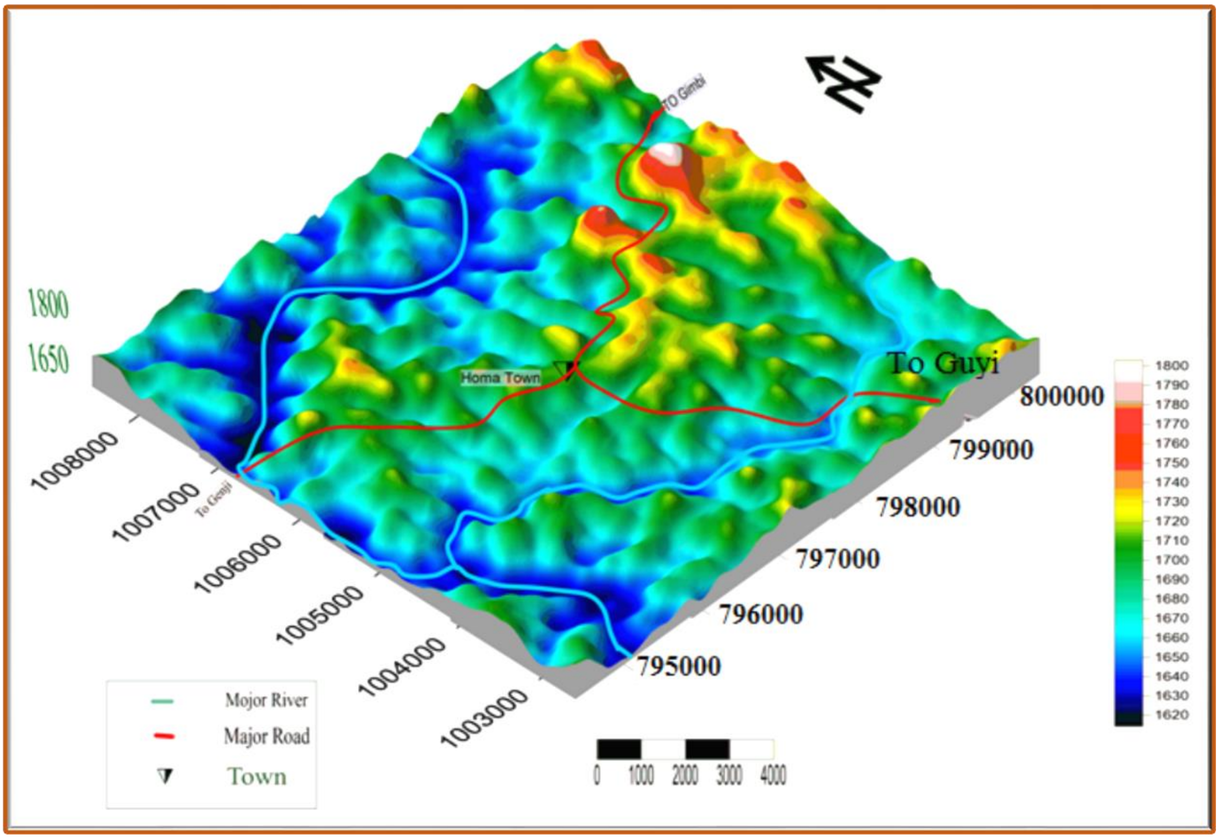


Figure 1.3: Physiographic Map of the Study Area.

On the base of difference in elevation, climatic, vegetation, population and geologic features, the Southwest Gimbi area is subdivided into five major physiographic regions. Those are:(1) the Dabus catchment basin, (2) the Sirkloe catchment, (3) the Central Highland, (4) the Abay-Didesa catchment basin and (5) the Birbir catchment. Generally, all of these physiographic regions are elongated in NW-SE direction according to Tadesse Alemu and Tsegaye Abebe (2000). The catchment basins of Dabus and Abay-Didesa is divided diagonally by central highland, whereas the Birbir and Dabus catchments have opposite drainage directions, and are treated as separate regions. From the above five major physiographic regions, the Birbir catchment is situated at the southwestern end of the Central Highland (within my study area).
It represents the initial catchment area of Birbir River that flows first towards northwest and then forming a big "U" type bend, flows to the southeast. Birbir catchment is one of the most powerful tributaries of Geba River. It is the major tributary of Baro, drains towards south unlike the other drainage systems that flow towards Abay in northwestwards. Generally, the area is covered by thick soil and dense vegetation. Exposure of the bedrock is rarely found in the streambeds, along river beds, uplifts and at quarry sites. The Birbir catchment area is

located in the southeastern part of Gimbi area (particularly, it occupies the Inango subsheet and partly the Guliso subsheet). The Birbir River forms an inverted, open towards south. In similar fashion the watershed of Birbir catchment forms inverted "U"shape and it almost follows the main road Gimbi-Meke-Nejo-Guliso-Ayra. All affluent streams of Birbir, such as Metos, Hersena, Wenjo, Meti, Kobena and Kote flow southwards. Only few others and less important streams are flow from east to west and from south towards north.

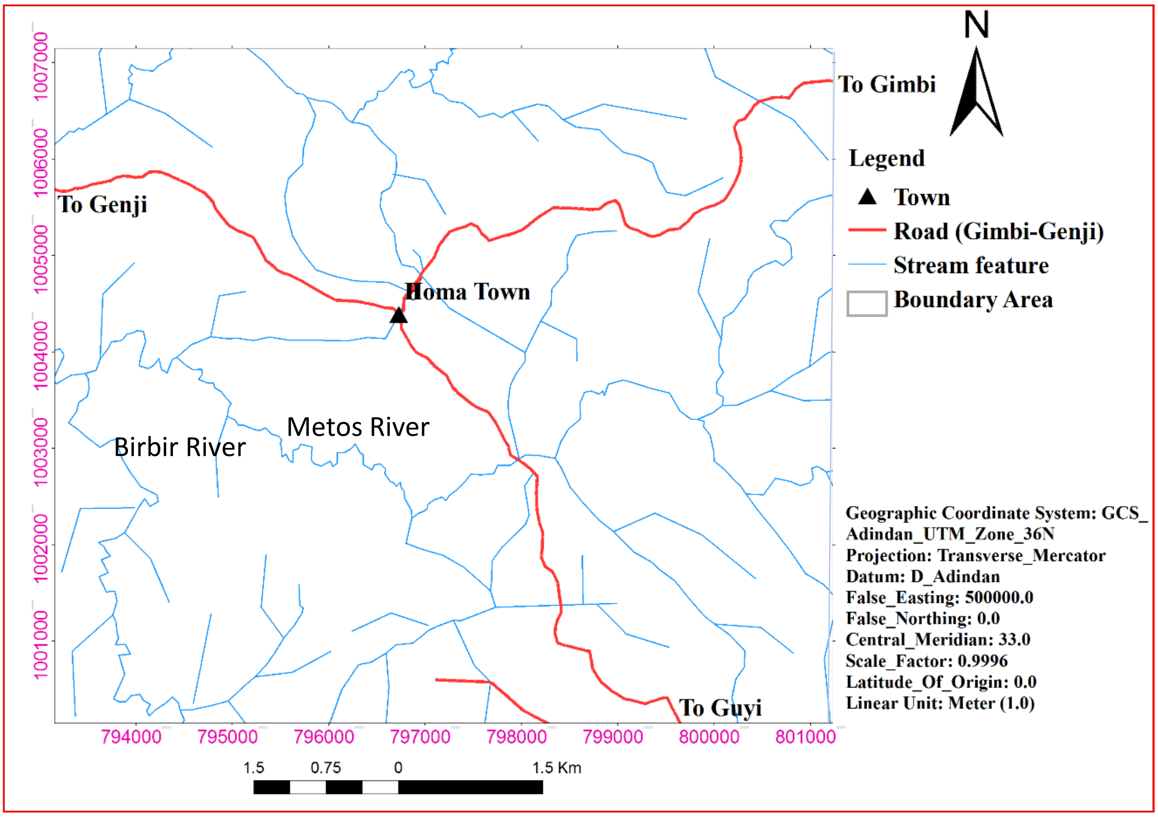


Figure1.2: Drainage pattern map of the Southwest of Gimbi (Study area).

1.2.3. Climatic condition and Vegetation

The climate condition in Gimbi area is warm and temperate. The summer season here have a good amount of rainfall, while the winter season has very little. The average annual temperature is 14.7 °C in Gimbi area and about 1,294 mm of precipitation falls annually.

The driest month is December, with 13mm of rain while the most precipitation here in August, averaging 269mm. On the other hands, March is the warmest month of the year with temperature averages 16.1°C. August is the coldest month, with temperatures averaging13.6°C. There is a difference of 256mm of precipitation between the driest and wettest month. Throughout the year, temperatures vary by 2.5°C. Generally, the climatic condition around the study area is very hot during the day time and become slightly unpleasantly cold and no wind during the evening.

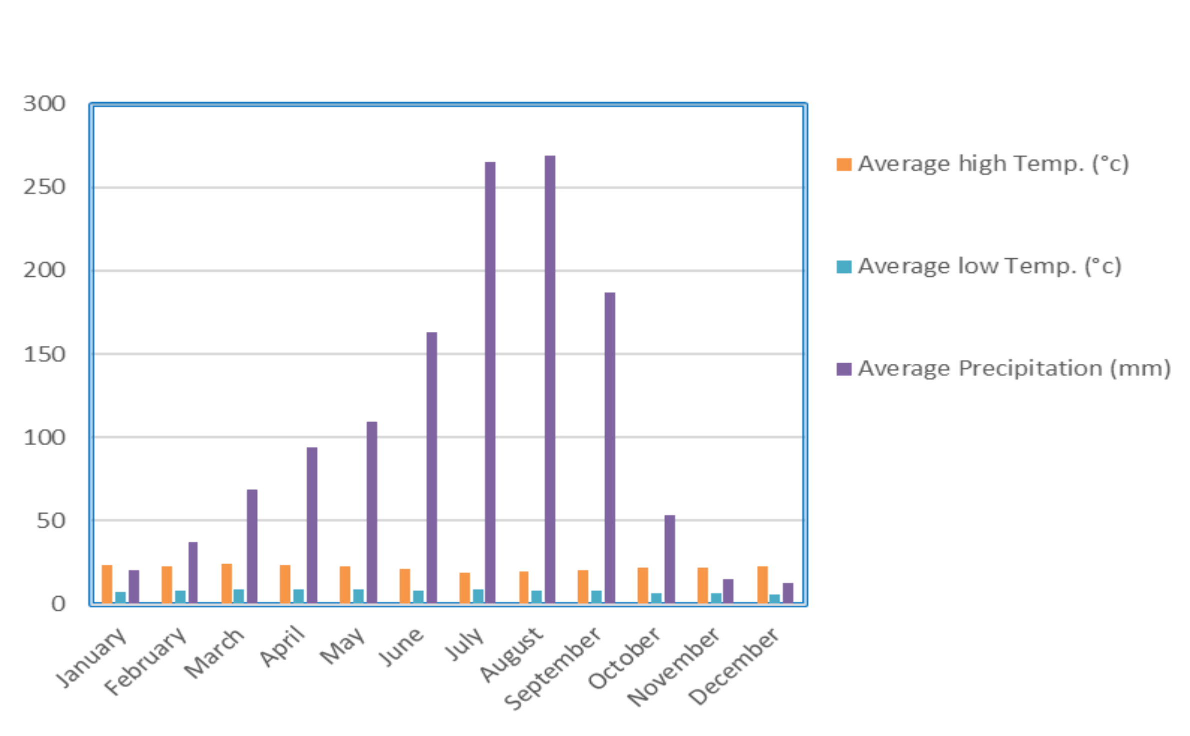


Figure 1.5: A bar chart that shows climatic condition of Gimbi area. Sourced from Climate-data.org in *http://en.climate-data.org/location/780463/.*

Type, density and distribution of Vegetation in the Southwest of Gimbi area are strongly influenced by the altitudinal or physiographic variations. It directly influences the climatic conditions of the area and the area is covered by thicker forest and grass. The reason that there exists dense population with dense vegetation is because of the coffee plantations that need to be a shadow. Therefore, the local people do not cut the natural trees that are used as protection for their coffee plants and soil erosion. For this reason, all the streams and creeks of the highlands are covered by forest and usually there is seepage of water even in the dry seasons. As explained on the above paragraph, the climate is characterized as warm and temperature. On this type of climate vegetation is densely and many types of vegetation are present. The typical example that occurred in the area is olive, oak, eucalyptus, papyrus, Pine, Eucalyptus and Acacia.

Sometimes there are some plains covered by short grass and rarely elephant grass. Eucalyptus (Bahirzaf) is grown by the local people for the purpose of construction and soil conservation program that is mainly applied in the Western Ethiopia. The common types of crops cultivated in the area are, Sorghum and Maize as well as they cultivating Coffee. The harvesting season is between October and December at which the rainfall becomes lower in amount.

1.2.4. Population and Settlement

The population density in the area is medium. The closest big town to the study area is Gimbi Town and the smallest town is Homa Town. On the other hands, there are small villages like Tulu Macha, Bondewo Dengil, Tulu Sawwa and Homa Birbir Villages etc. that are found within the study area. Those small Town that are found in the center of the study area have small number of population relative to Gimbi town. Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), West Wollega Zone has a total population of 1,350,415, of whom 671,538 are men and 678,877 are women; with an area of 10,833.19 square kilometers with a population density of 124.66. From the above explanation, 146,672 or 7.39% are urban inhabitants, a further 2,578 or 0.19% are pastoralists (a sheep or cattle farmer). A total of 266,773 households were counted in this Zone, which results in an average of 5.06 persons to a household, and 250,473 housing units. The three largest ethnic groups reported in West Wollega were the Oromo (96.72%), the Mao (1.45%), and the Amhara (1.2%); all other ethnic groups made up 0.63% of the population. Afaan Oromoo (Oromiffa) was spoken as a first language by 97.06%, 1.36% spoke Mao, and 1.15% Amharic; the remaining 0.43% spoke all other primary languages reported.

The majority of the inhabitants professed Protestantism, with 59.55% of the population having reported they practiced that belief, while 20.19% of the population practiced Ethiopian Orthodox Christianity and 19.66% were Muslims.

1.3. Problem Statement

Western Ethiopian Precambrian Shield is an area where metamorphic evolution, petrogenesis and tectonic setting are studied by different authors, in different time. But, there is a number of scientific problems remain satisfactorily unsolved, particularly about plutonic rocks of Homa area. The intrusive rocks in the belt are represented by more than eight separate plutons. Such as: Borchicha, Dega Bor, Genji, Giranche, Homa, Sayi Meti, Shimelakono, Ujjuka, Suqqii-Wagga etc. All the above plutons were studied regional wise in previous work that focused on petrogenesis and geochemistry, Nd and Sr isotopic compositions provinces and U/Pb and Pb/Pb Zircon ages from granitoids rocks of Western Ethiopia generally. As discussed by Tesfaye Kebede and Christian Koeberl (2003) intrusive rocks of Western Ethiopia were originated by melting of an original igneous type source formed at active subduction zone.

However, the present study uses both petrographical and geochemical data, to discuss by which mechanisms the plutonic rocks from Southwest of Gimbi Homa area was formed. Determine and analysis of these plutonic rocks by providing the source of origin, characterize the geochemical signatures, description and systematic classifications of rocks, describe their textures, geological processes and tectonic setting. Also, the present study is going to add new idea to the pre-existing one or going to proof the previous idea.

1.4. Objectives

1.4.1. General Objective

The main objective of this study is to characterize the petrology and geochemistry of plutonic rocks from Southwest of Gimbi area, Western Ethiopia.

4.1.2. Specific Objectives

Specific objectives include:

- To describe and classify the rocks based on the petrographic and geochemical analysis
- To constrain the origin of the rocks
- To place constraints on the paleotectonic setting of the rocks

1.5. Methodology

1.5.1. Introduction

To achieve the general and specific objective of the project and come up with the expected result, the research is mainly divided into three phases: pre-field work, field work and post-field work. In the pre-field work the assessment on literatures about the methods that would be applied and about the study area accessibility extent are done. During these stages, a detail work plan is made, collection of secondary data that are relevant for literature review, topographic map, geologic map and aerial photographs. These methods will be used extensively to identify and locate major outcrops, geological structures, lithology and lithological contacts. Also delineation of project area and tracing traverse line from topo-map will be done before field work.

Through field work and post-field work different procedure was applied. Such as: collecting, analyzing, synthesizing, presenting and interpreting of data were done. For this work two types of data were collected (secondary and primary data). Primary data were collected during the field work. For example, hand specimen characteristics of rocks, geologic structure and collection of representative samples from variety of lithologies. After collecting data, the next step is to analyze those relevant data. Most of the analyses were done in the laboratory. The samples collected from the field work were prepared for two purposes. The first purpose is for petrographic analysis and second is for the geochemical analysis. The process of data synthesis involves collecting and combining (integrating) of different data sets into consistent information for interpretation. Generally, all data including both those from literature and collected through the field work were been analyzed, interpreted and presented together. The presented data is being put into a regional context by comparing relevant literature on nearby or similar plutonic rocks and Granitoids of the area.

Finally, all collected data and a discussion of interpretation is being written up in a final thesis report. During different phases a variety of materials are used. These material including: topographic maps and geological maps at a scale of 1: 50,000, standard field sampling and measuring tools, ArcGIS, Google earth, Global mapper, Petrography beta, Golden software (surfer 10), WinRockV8 and GCDkit 3.00 rock analysis software packages were used. In the following sections the main methods that applied in the research work is discussed.

1.5.2. Field work and sample collection processes

In addition to the secondary data that collected from different sources which existed before this research, the primary data are used. The main methods of collecting the primary data are through field work. The field work had two phases. The first phase of the field work is undertaken between October 16 to 20/2016. The main purpose of this field work is to know the distribution of the lithologies, accessibility and geology of the area as much as possible. The second phase of the field work was done in between December 3 to December 17/2016. The main aim of this phase is to take representative samples for laboratory analysis (especially for petrographic and geochemical analysis) based on visible outcrops. During this work, the measurement is undertaken by following preplanned GPS points and systematic sampling method.

1.5.3. Laboratory and Data analysis

A) Petrographic Analysis

For petrographic analysis, ten granite rock samples were collected for thin-section preparation. Thin-section were prepared in Geological Survey of Ethiopia, thin-section and sample examination room. The selection of samples that used for thin-section is based on the variety of the lithologies, their importance and their difficulty to identify during in the field work. The main output results of the thin-section analysis are: the average grain shape of those existed minerals, modal proportion of minerals and grain to grain relationship of the phenocrysts. These processes will help mainly in the rock classification, textures, mineral contents, and understanding the tectonic evolution.

B) Geochemical Data Analysis

The samples for geochemical analysis were collected in the second phase of the field work which is discussed in section 1.5.2. The sample preparation was done in Geological Survey of Ethiopia Mill Room. The sample preparation for geochemical analysis includes making a rock powder after removing the weathered part from the surface of the rock. To do these the step that followed is:
The first step is removing the weathered part from the surface of the rock sample and breaks it into desirable sizes. The second step is to crush the broken fresh sample in a jaw crusher and finally, the crushed sample will be milled down to micron size particles in an agate ball automatic milling machine after it stay for 24 hour in temperature of 100č.

To minimize cross contamination of samples after crushing and milling every single rock sample, the Jaw crusher and the ball mills are blown by an air compressor. This is helping us to wash out to remove any possible contaminant, continue with the second sample. The powdered rock samples are seven in number. These samples are sent to ALS SERVICES PLC. Geoanalytical laboratory for determinations of major and trace element concentrations of each sample. The composition of each element of each rock samples was determined by the helping Inductively Coupled Plasma Absorption Emission Spectroscopy (ICP-AES) and Inductively Coupled Plasma Mass Spectroscopy (ICP-MS). For the accuracy the website http/www.alsglobal.com, can help us.

1.5.4. Expected outcome and Research Relevance

As discussed in the problem of the statement Southwest of Gimbi has not been studied in the aspect of petrology and geochemistry of plutonic rocks in detail. This will be the first detail study on its petro-chemical characteristics of plutonic rocks of this area. The main expected research outputs will be as follows:

An interpretation and analysis based on the geochemical and petrographic analysis of plutonic rocks exposure in the study area is done: to determine by what mechanism the rock was formed, their occurrences and origin, characterize the geochemical signatures, discriminating tectonic setting of the studied rocks.

The research study is mainly done for the partial fulfillment of my Master's degree in Geochemistry. In addition to this, it has relevance to the scientific community by providing some information listed on the above statement. It provides more important information about the plutonic rocks in the Western Ethiopia, particularly in Southwest of Gimbi around Homa Town.

1.6. Review of Previous Works

Gimbi area is situated in Oromia Regional States, Western Ethiopia. It is underlain by crystalline basement rocks of Precambrian-Paleozoic age, comprised of various types of gneisses, metamorphosed volcanic, volcano-clastic and sedimentary succession with associated mafic-ultramafic and granitoids intrusive which make up about 60% of the area.

Paleozoic sedimentary rocks and Tertiary volcanic rocks, which make up about 40% of the area, are found overlying the basement rocks (Tadesse Alemu and Tsegaye Abebe, 2000). Concerning the present project (i.e. Western Ethiopia) a number of reports have been done regional wise for the last decades. According to Kebede et al. (1999) the plutonic rocks of variable composition and age intruded the basement rocks, particularly the low-grade volcano-sedimentary sequences. This work reports that, pre-, syn- and post tectonic suites constitute the basement and are dominated by granites and granodiorite. There is some understand from the above statement, the Precambrian rocks in western Ethiopia highly consist of high- and low-grade terranes which intruded by granitoids with a wide compositional spectrum.

Among the numerous plutonic rocks, there are some previous works done on the field relationships and petrography, geochemistry and petrogenesis of these granitoids. As Kebede et al. (1999, 2000 and reference therein) argued that, field relationships and petrography, geochemistry and petrogenesis of these granitoids intruded into the high-grade gneisses and low-grade metasedimentary and meta-volcanic rocks. According to the above statements, the Precambrian terrane is overlain in the East and West by tertiary volcanic sequences. The occurrences of intrusive bodies of a wide compositional spectrum-gabbro to granite characterize the volcano-sedimentary assemblage. Granitoids intrusion into the high-grade terrane, however restricted both compositionally (diorite/granodiorite to granite) and geographically, they occur in few areas/ locations.

There is a numerous type of plutonic rocks on which some previous works were done. Such as: Geology, Petrogenesis and geochemistry of Ujjuka granite, Dhagaa Booqa granite and Guttin K- feldspar Megacrystic granites discussed by Tesfaye Kebede, Christian Koeberl and Friedrick Koller (1999). U/Pb and Pb/Pb zircon ages from granitoids rocks of Ujjuka granite and granodiorite, the anatectic orogenic Genji monzogranites (Tesfaye Kebede, U.S. Kloetzli and C. Koeberl, 2000). U/Pb and Pb/Pb zircon ages from granitoids rocks of Wollega area: constraints on magmatic and tectonic evolution of Precambrian rocks of western Ethiopia (i.e. Ganjii monzogranite, Homa granite and Tuppii granites) as discussed by Tesfaye Kebede and Christian Koeberl (2003).

From different studies by different authors, the Western Ethiopian Precambrian rocks are highly affected by two types of Pan-African terranes (belts). These belts are the upper crustal Arabian-Nubian Shield and the lower crustal Mozambique Belts. They are not fundamentally different but constitute different crustal levels of collisional and/or accretional systems (Kazmin et al., 1979 and references therein).

According to (Kazmin, 1972; Tefera, 1987; Tefera et al., 1996) major lithotectonic blocks of the terrane are comprises high-grade gneissic-migmatitic associations and low-grade meta-volcano sedimentary sequences. This terrane is intruded by syn-to late-tectonic granodioritic and granitic plutons that exposed throughout western Ethiopia. The gneissic rocks of the MB are exposed to the east and west of a relatively narrow, but northward-widening zone of low-grade volcano sedimentary- plutonic sequences of the Arabian-Nubian Shield (ANS).

In case of Western Ethiopian Precambrian shields the ANS is distinguished from the Mozambique Belt by its dominantly juvenile nature, relatively low-grade of metamorphism and ophiolites. MB terrane essentially consists of medium to high-grade gneisses, migmatites and voluminous granitoids.

Besides, different previous works were done on the intrusive rocks of Gimbi area, Western Ethiopia. They explained their formation and emplacement, from which types of parent material (protoliths) these rocks came. According to Kebede et al. (2001) have been explained the Western Ethiopian Precambrian rocks are characterized by emplacement of several granitoids rock bodies during the Neoproterozoic. Furthermore, granites were originated by different processes and from different sources. Such as: i) Melting of a pre-exiting metasedimentary or sedimentary source rock as a result of continental-continental collision, ii) Melting of an original igneous type source and formed at active subduction zone, iii) Formed either intruded into greenschist facies of volcano-sedimentary sequence or emplaced at the contact between low and high grade terranes which considered as an orogenic granite. As Tesfaye Kebede and Christian Koeberl (2003) discussed, A-type granitoids, either intruded into facies volcano-sedimentary sequence or emplaced at the contact between low and high grade terranes. These granitoids constitute a significant proportion of the granitoids rocks in the Precambrian of western Ethiopia. They argued that, in case of Western Ethiopia the granitoids intrusions were formed either intruded into greenschist facies volcano-sedimentary sequence or emplaced at the contact between low and high grade terranes and considered an orogenic granite.

In additional to these, Tadesse Alemu and Tsegaye Abebe (2000, 2002) discussed, the low-grade metavolcano sedimentary rocks and associated intrusive outcrop is remarkably persistent and can be traced for the entire length of the Precambrian of western Ethiopia. The assemblage varies in width along strike that is wider in the north and narrower in the south. Further south, the assemblage pinches out and truncates by NW-trending Surma shear zone.

Their contact with the high-grade gneiss and migmatites is not exposed, nor has it been mapped in detail. Usually the contact is tectonic represented by tightly folded and strike-slip shear zones. Part of the contact is also marked by SE-dipping and NW verging thrust faults and folds.

There is a shortage of knowledge exists in the petrology and geochemistry about the plutonic rocks of Gimbi area, Western Ethiopia.

The work done by Tesfaye Kebede and Christian Koeberl (2003), general outlined by Kebede et al. (1999) and Tadesse Alemu and Tsegaye Abebe (2000) are the work done in this area that sketch a geological map of the Precambrian of Western Ethiopia block (modified after Tefera et al., 1996). These works give some information on the distribution, stratigraphy, petrography and geochemical property of plutonic rocks of Gimbi area in large scale. They did a geological map at a scale of 1: 50,000 that reveal the lithologies and structures distribution of this area. The age relationships among the granites emplaced into the same terrane or between granite populations intruding contrasting terranes are still not well understood. Particularly, the systematic geochronological studies are lacking for the western Ethiopian Precambrian areas. However, the work done by Tesfaye Kebede and Christian Koeberl, (2003) who reported Nd and Sr isotopic compositions of A-type granitoids. Also, Tesfaye Kebede, U. S. Kloetzli and C. Koeberl (2001) who reported U/Pb and Pb/Pb zircon ages from granitoids rocks of Wollega area: constraints on magmatic and tectonic evolution of Precambrian rocks of western Ethiopia.

CHAPTER TWO

2. Regional Geological Setting

2.1. East African Orogeny

The term Pan-African Orogeny is used to describe tectonic, magmatic, and metamorphic activities of Neoproterozoic to earliest Paleozoic age. Especially for crust that was once part of Gondwana. According to different authors, in different time reports, East African Orogeny has long been considered as the best exposed bowels of former mountain building. This is due to the result of continent-continent collision and the combine together of many oceanic arcs and remnants of oceanic lithosphere that once separated the cratons. It is come along through the final collision between East and West Gondwana. The collision was followed the closure of the Mozambique Ocean forming the East African Orogeny. The East African Orogeny enclosed both Arabian–Nubian Shield in the north and the Mozambique Belt in the south. These and several other orogenic belts are commonly referred to as Pan-African belts. A number of distinct belts in Africa and other continents with deformation, metamorphism and magmatic activity were spanning the period of 800–450 Ma. Pan-African tectonothermal activity in the Mozambique Belt was broadly contemporaneous with magmatism, metamorphism and deformation in the Arabian–Nubian Shield. There is a difference in lithology and metamorphic grade between these two belts. This has been attributed to the difference in the level of exposure, with the Mozambican rocks interpreted as lower crustal equivalents of the juvenile rocks in the Arabian–Nubian Shield. As recently geochronological data indicates the presence of two major Pan-African tectonic events in East Africa. The East African Orogeny has an age interval from 800a–650 Ma (Stern, 1994). It represents a distinct series of events within the Pan-African of central Gondwana that responsible for the assembly of greater Gondwana.

Relatively, the low-grade rocks of western and Southern Ethiopia are considered to be the part of Arabian-Nubian Shield and the high-grade gneissic rocks that adjacent to these rock assemblages were considered as older/Achaean to Neoproterozoic basement (Kazmin, 1971). However, recent zircon dating has demonstrated that, there are no Archaean to Mesoproterozoic (Yibas et al., 2001) rocks in western and southern Ethiopia. Their ages range from-900 to 580 Ma for pre- and syn-tectonic, arc and collisional, granitoids gneisses, followed by -550-530 Ma post-orogenic granites. This age range is similar to that observed in the ANS of Arabia and Sudan as well as to high-grade granitoids rocks in Tanzania and Madagascar.

Although, it strongly favors the interpretation of the Neoproterozoic high grade rocks are lower crustal equivalents of the arc/ophiolite assemblages in the ANS as discussed in in introduction part (figure 1.1).

2.2. Precambrian rocks of Western Ethiopia

The Precambrian basement and related intrusive igneous rocks make up 25% of the country’s land mass. The distributions of the Precambrian metamorphic rocks are exposed in the Western, Eastern, Northern and Southern parts of the country. These rocks have a fundamental important tectonic setting. They occupy the interface between the Arabia-Nubian Shield in the north and the Mozambique Belts to the South (Stern, 1994). Precambrian rock of Western Ethiopia is the largest Precambrian block in the country (i.e. it extends north wards from 60̊ N for about 650Km). The area is largely covered by Precambrian basement rocks. There are some plutonic rocks which is important to study the Petrogenesis, tectonic evolution, history of deformation, metamorphism etc. of the Precambrian metamorphic and associated intrusive igneous rocks. These plutonic rocks were intruded in the belts. But, still now the problem of plutonic rocks of Western Ethiopia is unsolved. These Precambrian basement rocks forms the western and wider branch of the low-grade volcano-sedimentary terrane of the ANS Northward-widening zone and bounded both to the east and to the west by the gneissic terrain of the MB studied by Tadesse Alemu and Tsegaye Abebe (2007).

Similar to the other Precambrian terrain in Ethiopia, western Ethiopia Precambrian terrain have relationships with Pan-African belts. These two terranes are not fundamentally different. But, they constitute different crustal levels of collisional and/or accretional systems (Kazmin et al., 1979). According to the above authors, these belts are the upper crustal Arabian Nubian Shields and the lower crustal Mozambique Belt. ANS is distinguished from the MB by its dominantly juvenile nature, relatively low-grade of metamorphism and ophiolites. But, MB belt essentially consists of medium to high-grade gneisses and voluminous granitoids.

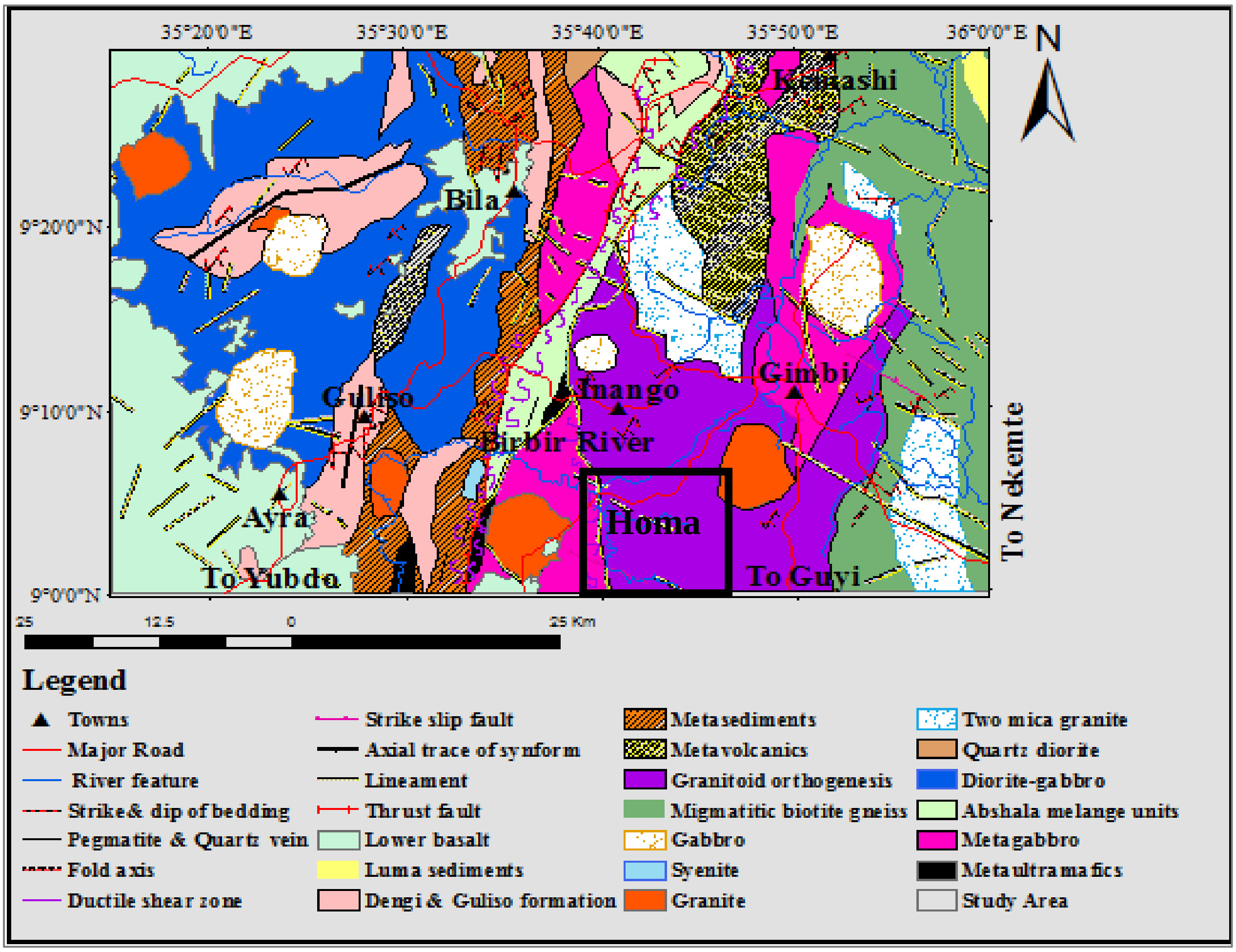


Figure 2.1: Geological Map of Gimbi Area digitized from previous map (after GSE)

2.2.1. Litho-stratigraphy

The Western Ethiopia Precambrian terrain is containing lithological components common to both the Arabian-Nubian Shield in the north and the Mozambique Belt in the south (Kazmin et al., 1978, 1979). This terrane can be broadly subdivided into two contrasting groups depend on the lithological succession. Namely: the high-grade gneissic terrane and the low-grade volcano-sedimentary terrane.

In other case, the geology of the area classified into five tectonic zones from east to west as discussed by Tadesse Alemu and Tsegaye Abebe, 2000. Such as: 1) An eastern block of high-grade pre-pan-Africa rocks, 2) An ophiolite belts, 3) A zone of dioritic/granodioritic batholiths and associated intermediate volcanics, 4) A meta-volcano sedimentary belt and 5) A western block of high-grade pre-pan-African basement.

The lithological boundary between central low-grade volcano-sedimentary assemblage and the high-grade gneisses to the west and east is tectonic as marked by shear zones and mylonitic rocks (Abraham, 1989).

Based on different previous works Western Ethiopian shield is classified into four different domains (Tadesse Alemu and Tsegaye Abebe, 2000): Katta domain, Chochi domain, Aba Sina domain and Afa domain.

2.2.1.1. Katta domain

This domain enclosed Dengi formation with metamorphosed sandstone and conglomerate with subordinate sericite/muscovite schists, phyllites and metatuff. Also, Gulisoo formation with comprises interlayered psamites and pelites with variation facies. Stratigraphically, it is coarser at the base and finer at the top. Another unit is Daleti formation also included under this domain which show medium-grained calcite marble which is cut by dolerite dike. The other formation is metasediments and metavolcanics. Metasediments contains: graphite-quartz-mica-schist/phyllite, graphite schist, quartzite, metasandstone and chlorite-quartz schist. The metavolcanics are mainly basic and associated with chlorite schist and amphibolite. They are intruded by voluminous pre-tectonic gabbroic to granite intrusions.

2.2.1.2. Chochi domain

Chochi domain consists of upper greenschist to mid-amphibolite facies pelitic and psammo-pelitic schist and gneisses, amphibolite and marble. There are two marbile units: i) pelitic and psammo-pelitic schist and ii) biotite and biotite-hornblende gneiss. They are intruded by syn- to late tectonic granitoids.

2.2.1.3. Aba Sina Domain

This domain contains sayi chenga group and Gneissic associations which related with metavolcanics mainly basic and metasediments. This includes quartzite and graphite, semi pelitic schists and phyllites and marble. Generally, this domain is characterized by mid to upper greenschist facies metamorphism. Also, there is migmatitic biotite gneiss, biotie-hornblende gneiss and granitoids orthogenesis with minor intercalations of metasediments and amphibolite facies metamorphism.

2.2.1.4. Afa domain

Metavolcano-sedimentary rocks and associated mafic-ultramafic rocks dominated within this domain. Green schists are characterized by the associations of chlorite, chlorite-actinolite and talc-tremolite schists gneiss consists of biotite-hornblende gneiss with subordinate calc-silicate. They are varying from upper greenschist to mid-amphibolite facies metamorphism.

The high-grade gneiss and migmatite is referred as lower complex that considered as the northern continuation of the pan-African Mozambique Belt. They are not juvenile pan-Africa terrane and consist of Mesoproterozoic crust that was reworked in the East African Orogeny. The low-grade metavolcano-sedimentary is referred as upper complex which have been considered as the southern continuation of the pan-African Arabian-Nubian Shield (Kazmin, 1972).

Geochronological investigations from plutonic rocks suggest that, the age of the low-grade rocks range from ~830 to ~540 Ma (Ayalew et al., 1990). Based on field observation, lithologic units, geochemical and geochronological evidence, the low-grade rocks of the Western Ethiopia were correlating to the Juvenile pan-African assemblage northern Ethiopia, Eritrea and the Southeastern Sudan.

CHAPTER THREE

3. Geology, Lithology and Petrography Descriptions

3.1: Geology overview of Gimbi Area

Southwest of Gimbi is located within western Ethiopia Precambrian terrain that is emplaced in between the low-grade, volcanic and volcano-sedimentary rock assemblages and high-grade gneissic and migmatite assemblages. This exposures shield is positioned within the juvenile Neoproterozoic crust of the Arabian-Nubian Shield and the older predominately gneissic Mozambique Belt (Woldemicael et al., 2010 and reference). The plutonic rocks in the belt are represented by circular, sub-circular and elliptical in shape. They have been emplaced pre-, syn/late-to post-tectonically with respect to the major deformational events. Modally, the intrusive rocks range from rare diorite/gabbro through dominant granodiorite and monzogranite (Kebede et al., 1999, 2000).

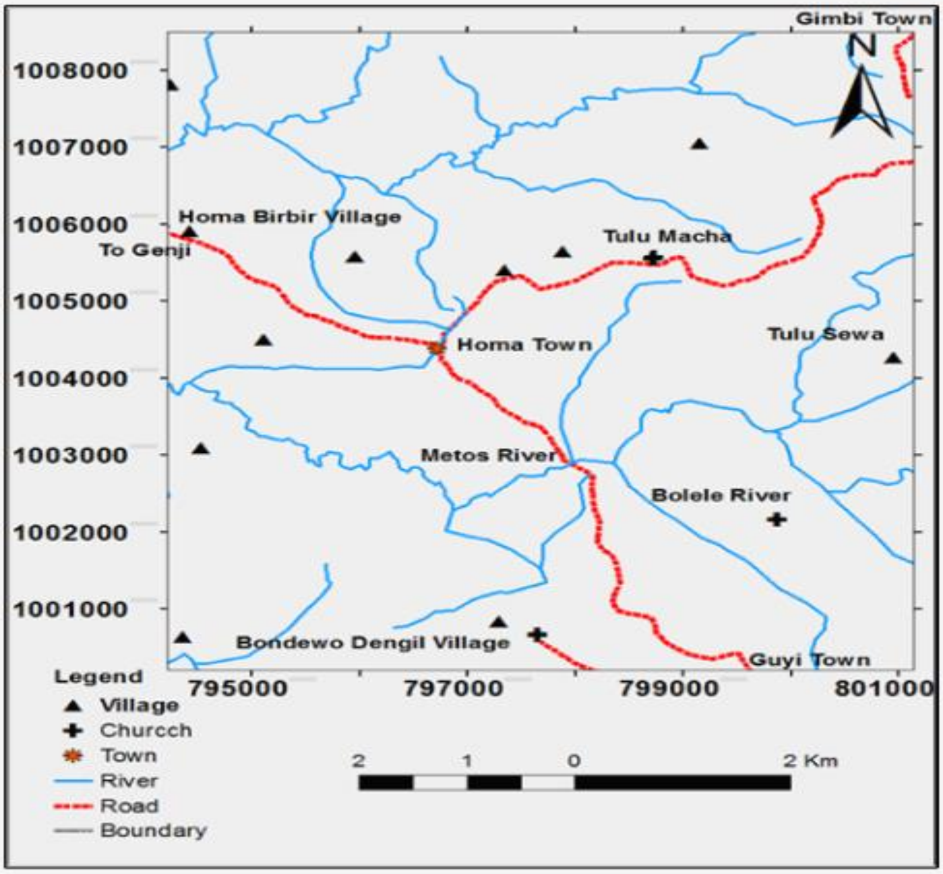


Figure3.1. Sample location map of the study area (black triangles represent the location from where the samples were collected)

3.2. Lithology Descriptions

AS explained in previous section (section 3.1), the Southwest of Gimbi Homa area was highly covered by granite rocks rather than other plutonic rocks which show narrow variation in texture from medium to coarse grained and all most have similar mineral assemblages. For instance, the granite rock units in this area show the field characteristics of hard, compact and medium grained. Their color varies from pale pinkish to pink and some of them show pink to light grey. Mineralogically, these rocks are composed of quartz, alkali feldspar and less biotite. Besides, from this area ten representative granite rock samples were collected for thin-sections preparation. This is used for a detailed petrographic investigation including: identification of the constituent mineral phases, textural characteristics and determination of modal mineralogical composition through visual estimation.

These granite rock outcrops are represented by well-rounded boulders and in some places, vary in shape from elliptical to surround and with parallel arrays of elongated exposures. Some field relationships, petrographic and mineral phase of the granitic rocks are also given in field photographs, photomicrographs and the individual granites details descriptions are given below. These rocks are massive rocks and except some fractured structure on the rock body no other structure are visible in hand specimen. The physical characteristics of the above granitic rock units are presented by field photographs as follows (figure 3.2).

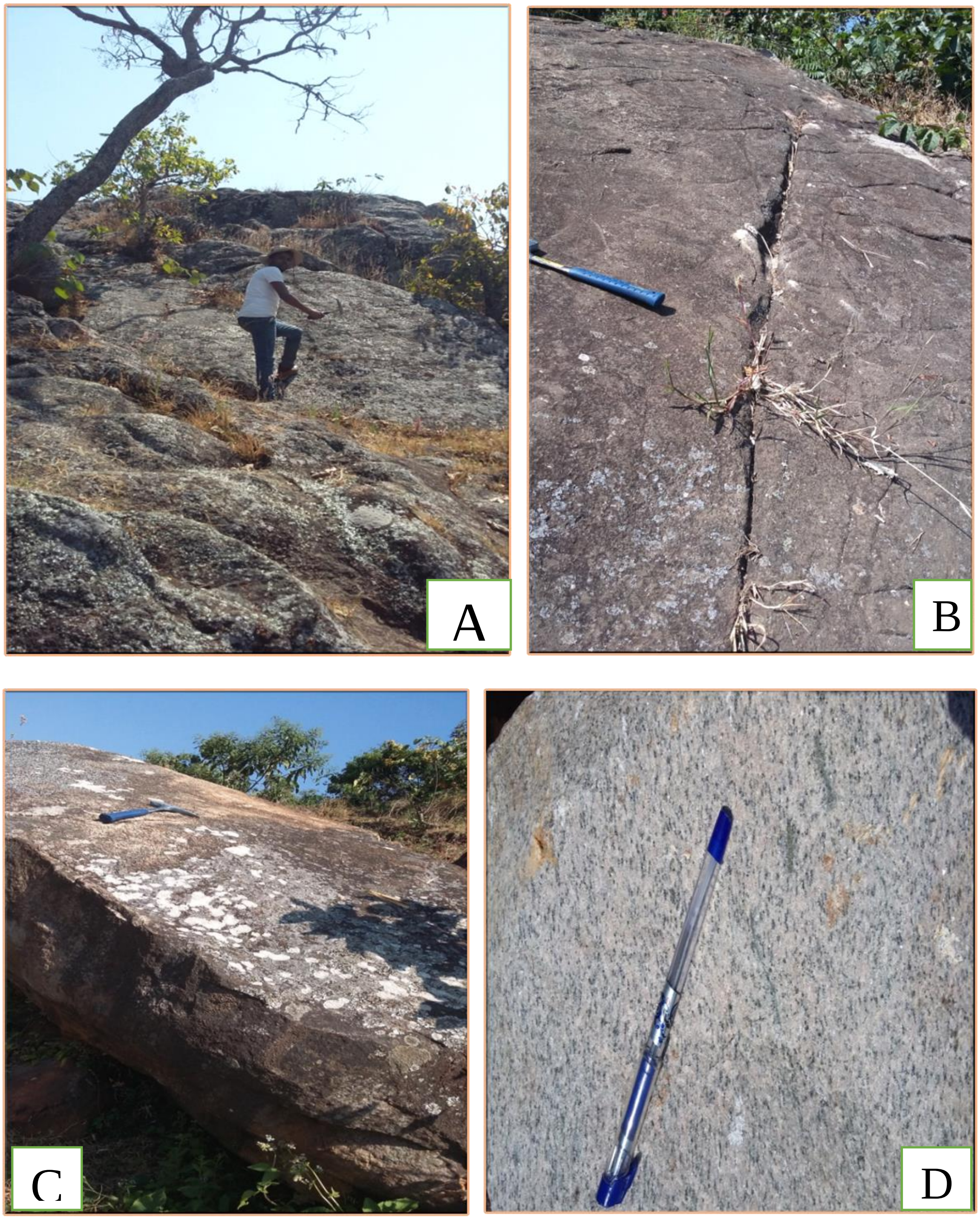


Figure 3.2: A) Massive granite rocks outcrop as batholith in the study area

B) Granite rock outcrop that have a fracture on its body

C) Elliptical in shape granite rocks from the study area

D) Fresh part of massive granite from Southwest of Gimbi.

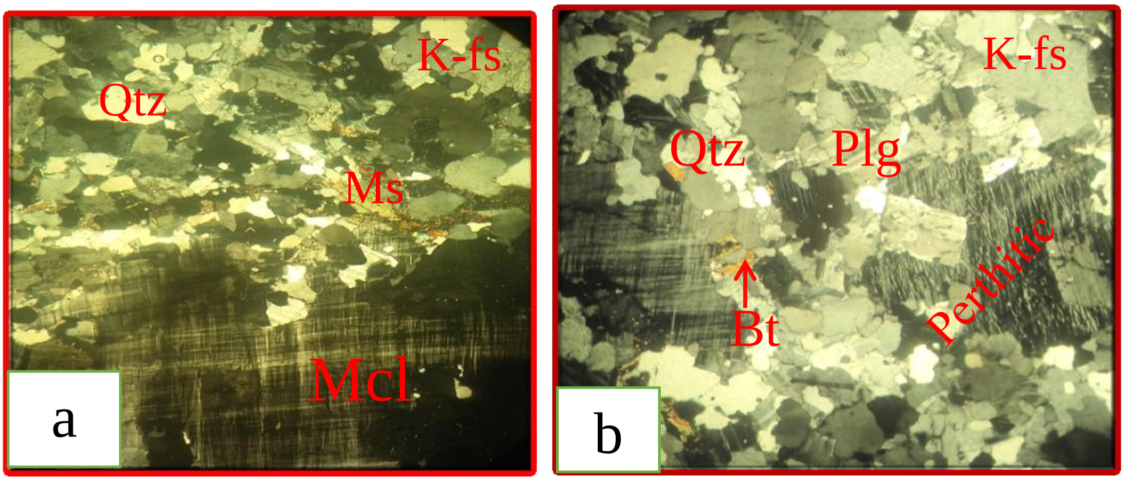
3.3. Petrography Descriptions

The granite rocks from Southwest of Gimbi are represented dominantly by pale pinkish to grey and pink with grey spot as discussed earlier in the previous sections. The most common mineral assemblage of these rocks of the study area is mainly composed of alkali-feldspar from (39%-54%), quartz from (23%-34%), plagioclase from (3%-10%), biotite (<11%), as major components. Epidote (<9%), muscovite (sericite) with (<9%) and opaque (Fe-Ti oxide) with (<6%) as minor components and sphene with (<3%) and hornblende with (<2%) as accessory minerals. Zircon and apatite are present as trace amount components in these rocks. There is an alteration features are common and represented by sericitization of plagioclase and alkali-feldspar was apparent.

Granite rock units Southwest of Gimbi dominated mainly by quartz, plagioclase and two K-feldspars (microcline and orthoclase) under petrographic microscope (representative sample in figure 3.3). Quartz is recognized in the PPL view by the absence of alteration. Except biotite and some opaque minerals the other minerals show colourless in PPL. Quartz is xenomorphic and appears as small crystals (0.60 mm) scattered in the rock and occurs as rounded to sub-hedral crystals or appears as clusters between the feldspars and granophyric intergrowth of quartz and feldspar were also observed. In this field of view, some plagioclase crystals exhibit a simple twinned crystal with very dark grey interference colours. The plagioclase is mostly subhedral-euhedral and zoned with laths. The euhedral to subhedral phenocrysts of plagioclase are common. Sometimes plagioclase appears with zircon inclusions and biotite occurrence. The other minerals that presented in this field of view are: biotite and muscovite crystal. Biotite and muscovite exhibit platy and Tiny-platy texture respectively. Biotite occurs in anhedral flakes occupying interstices between plagioclase crystals. The presence of hydrous mineral muscovite, chlorite and biotite may indicate a retrograde metamorphism phase caused by fluids. K-feldspars are dominated by microcline, orthoclase, and microcline-perthite and occur as subhedral to anhedral grains. In the perthite, the exsolved plagioclase component occurs within the host microcline as microscopic lamellae. In thin-section of these granite rocks, microcline is clearly identified by the typical cross-hatched twinning. Also, there is a sign of perthitic and microperthitic texture which Caused by un-mixing, exsolution or separation of Na^+ and K^+ as the feldspar cools may indicate stages of granite magmatism. The micro perthitic to perthitic intergrowth were also observed in the twin lamellae of K-feldspar and plagioclase may be due to deformation. This crystal is represented here by small crystals of microcline (~from 0.54mm to 2mm).

Generally, from the below microphotographs and thin-section analysis some grains of K-feldspar (microcline) and plagioclase lose twin lamella due to deformation. In addition to this, K-feldspar (microcline and orthoclase) altered to sericite and biotite replaced by muscovite. Also, K-feldspar (microcline and orthoclase) and plagioclase show curved twin lamella due to deformation. Biotite and muscovite show sub-parallel alignment. Furthermore, there are common textures that observed in these granite rock thin-sections. Such as: i) antiperthite intergrowth which occur when plagioclase encloses potash feldspar, perthite intergrowth on feldspar formed due to un-mixing, exsolution or separation of Na+ and K+ as the feldspar cools.

Myrmekites also develop at the level of alkaline feldspars-plagioclase contact. It is an intergrowth of dendritic quartz and plagioclase at K-feldspar/plagioclase interface. It related to a deuteric (late magmatic) effect, or related to deformational recrystallization in some cases. Some Sphene grains are rimmed by Opaque minerals. Secondary minerals are represented by Epidote, sericite and Myrmekites crystallizing according to the primary phases. Epidote, allanite, etc. are secondary minerals issued from the transformation of plagioclases and biotite. Accessories minerals include zircon, apatite and oxides. The leucocratic gneissic granite of Homa is generally fine grained and composed of Plagioclase, alkali-feldspars, quartz, and biotite, with accessory white mica, Fe–Ti oxides of small size (<0.1mm), apatite, zircon, monazite, and rutile. Microcline is poikilitic, with inclusions of Plagioclase, Biotite, and Quartz (Tesfaye Kebede and Christian Koeberl, 2000).



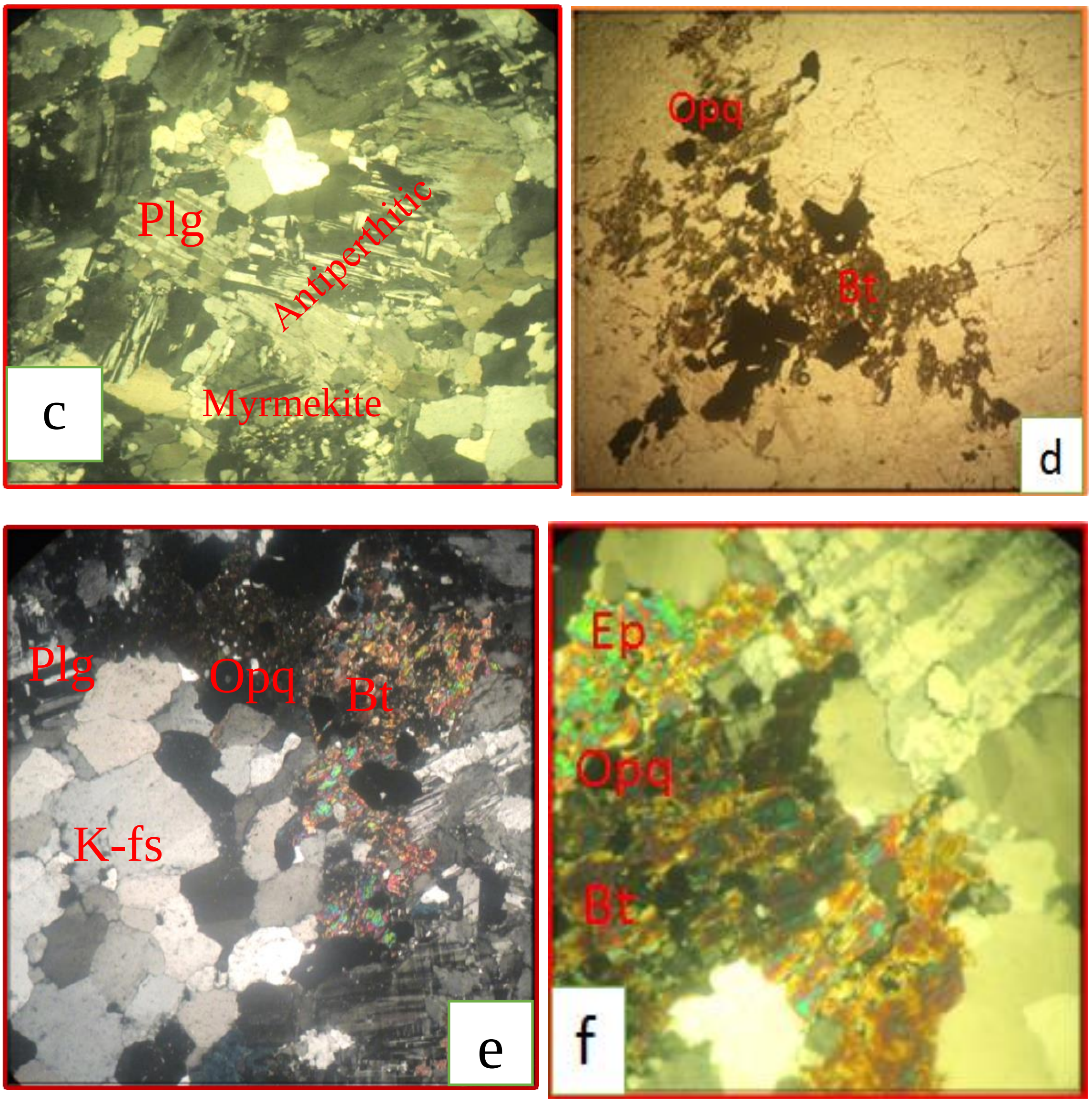


Figure 3.3: **a**) Microphotography which show microcline and muscovite minerals.

b) Microphotography indicate the nature of perthitic texture of granite rocks

c) Microphotography show that the occurrence of antiperthitic and myrmekite texture and plagioclase of granite rocks

d) Granites rocks thin-section under PPL view.

(e, f) Microphotography show the presence of K-feldspar and epidote minerals

3.3.1. Petrographical Classification of the Studied Rocks

Ten representative rock thin sections were used for a detailed petrographic investigation including structural/textural characteristics, identification of the constituent mineral phases and determination of modal mineralogical composition through visual estimation. From (figure 3.3), most of the studied sample located in the position of K-feldspar granite and other presented in field of syenogranite position. Based on these details, the studied rocks and their characteristics are listed in tables as follows.

Table3.1: Show modal percentage of each samples from the study area after multiplied by hundred (normalized to hundred).

Modal percentage of each sample after individual major mineral multiplied by hundred (x100) and divided by sum of major mineral in a sample.			
Sample#	Q	K-fs	Plg
HM-01	35.36	59.76	4.88
HM-02	30.95	60.71	8.34
HM-03	31.03	62.07	6.90
HM-04	33.34	59.72	6.94
HM-05	36.58	53.66	9.76
HM-06	33.73	62.79	3.49
HM-07	36.96	57.61	5.43
HM-08	34.62	57.69	7.69
HM-09	30.34	58.43	11.23
HM-10	33.34	56.52	10.14

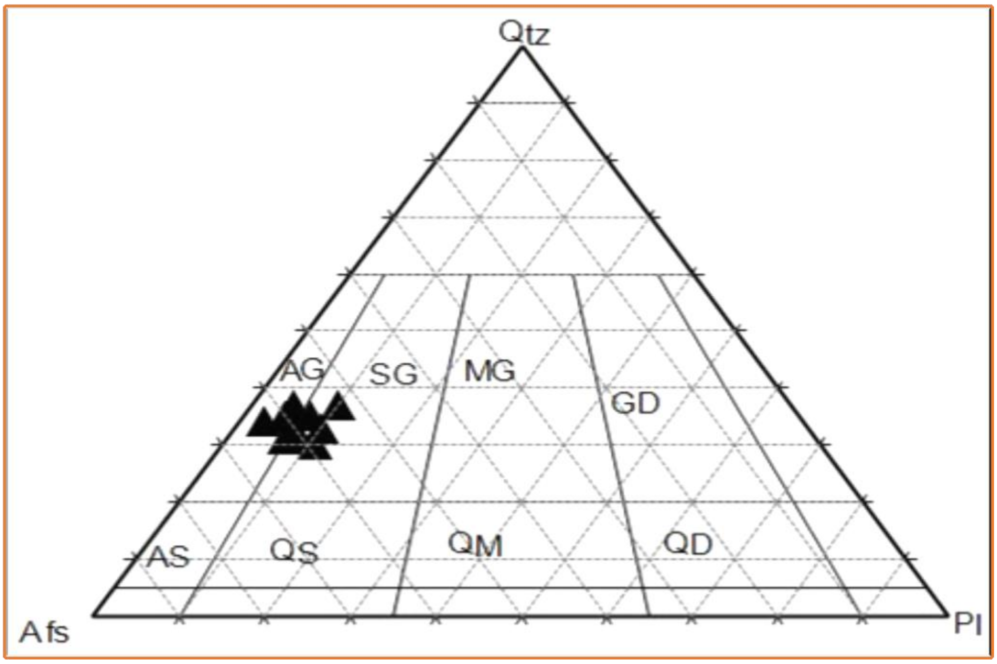


Figure 3.4: Modal classification of the granites, Where:

AG: alkali-feldspar granite; AS: alkali-feldspar syenite; SG, Syenogranite; QS: quartz syenite; MG: Monzogranite, QM: quartz monzonite; GD, Granodiorite; QD: quartz monzodiorite. Fields and nomenclature after Streckeisen (1976)

CHAPTER FOUR

4. Geochemistry

4.1. Introduction

Geochemistry is common method that used to study the magmatic evolution, Petrogenesis and tectonic setting of any plutonic rocks. The geochemical characteristics of various granite rocks from southwest of Gimbi was done to characterize their chemical composition, geochemical and petrographical classification, chemical affinity, constrain the origin of the rocks and to place constraints on the paleotectonic setting of the rocks. This method mainly depends on the characteristics of the elemental composition which can be used to identify geological processes. Generally, geochemical data are categorized into four main classes: the major elements, trace elements, radiogenic isotopes and stable isotopes according to Rollinson (1993). From the above four categories of geochemical data, the present study is used only two of them (major and trace). Furthermore, the collected samples were carefully prepared in powder form in Geological Survey of Ethiopia, Mineralogy and Geotechnical Laboratory Milling room. The powdered sample is analyzed by analytical method of Inductively Coupled Plasma Absorption Emission Spectroscopy (ICP-AES) whole rock package for major element analysis result and Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) lithium borate fusion for trace element. By combining a number of methods into one cost effective package, a complete sample characterization is obtained. This package combines the whole rock package ME-ICP06 and to quantify the major elements in sample analyzed by ICP-AES methods and trace elements including the full rare earth element suites are reported from three digestions with either ICP-AES or ICP-MS. Lithium borate fusion for the resistive elements (ME-MS81) methods.

Totally, seven samples were collected for the purpose of geochemical analysis from the study area. The sample location and geochemical result is presented on Table 4.1, Table 4.2 and Table 4.3 as follows:

Table 4.1: Major Elements Oxides in (wt %)

	HM-09 Granite	HM-05 Granite	HM-07 Granite	HM-10 Granite	HM-06 Granite	HM-08 Granite	HM-03 Granite
E(m)	**0802620**	**0797397**	**0797670**	**0804524**	**0794352**	**0795014**	**0798145**
N(m)	**1004551**	**1005766**	**0998082**	**1004654**	**1006650**	**0998783**	**1005817**
DESCRIPTION	wt%	wt%	wt%	wt%	wt%	wt%	wt%
SiO2	74.7	75.2	75.8	75.8	76.4	79.3	79.8
TiO2	0.18	0.17	0.17	0.17	0.09	0.11	0.07
Al2O3	13.1	13.85	12.25	12.35	12.15	11.3	11.75
Fe2O3	2.94	2.3	3.12	2.78	2.88	2.68	1.83
MnO	0.06	0.02	0.03	0.03	0.07	0.01	0.02
MgO	0.06	0.11	0.1	0.09	0.03	0.01	0.03
CaO	0.37	0.35	0.07	0.2	0.48	0.03	0.31
Na2O	3.93	3.92	4.24	4.61	4.29	4.02	3.28
K2O	5.36	5.02	4.4	4.31	4.44	4.14	4.68
P2O5	0.01	0.02	0.03	0.03	<0.01	0.01	<0.01
C	0.01	0.04	0.01	<0.01	0.07	0.01	0.03
S	0.01	0.02	<0.01	<0.01	0.23	<0.01	<0.01
LOl	0.29	0.42	0.15	0.2	0.98	0.04	0.18
Total	101	101.38	100.36	100.57	101.82	101.65	101.96
Cao/Na2O	0.094	0.098	0.016	0.043	0.11	0.007	0.094
Na2O/K2O	0.733	0.781	0.964	1.069	0.966	0.971	0.701
Na2O+K2O	9.29	8.94	8.64	8.92	8.73	8.16	7.96
K2O/ Na2O	1.364	1.281	1.037	0.935	1.035	1.029	1.427
Fe2O3/MgO	49	20.9	31.2	30.89	96	268	61

Table 4.2: Trace elements in (ppm)

	HM-09 Granite	HM-05 Granite	HM-07 Granite	HM-10 Granite	HM-06 Granite	HM-08 Granite	HM-03 Granite
E(m)	**0802620**	**0797397**	**0797670**	**0804524**	**0794352**	**0795014**	**0798145**
N(m)	**1004551**	**1005766**	**0998082**	**1004654**	**1006650**	**0998783**	**1005817**
Description	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**Ppm**	**ppm**
Li	<10	10	20	10	<10	<10	<10
Ti	0.02	0.07	0.03	0.03	0.02	0.04	0.03
V	<5	5	<5	<5	<5	<5	<5
Cr	10	10	<10	20	20	10	10
Co	<1	1	<1	<1	<1	<1	<1
Ni	9	6	6	7	7	2	8
Zn	93	36	74	24	77	29	23
Ga	22.1	23.6	27.1	24.7	27.8	27	21.5
Ge	<5	<5	<5	<5	<5	<5	<5
Se	1.2	1	1.5	1.2	0.3	0.2	0.5
Rb	60.3	106.5	110.5	105	65.4	69.9	82.5
Sr	26.9	68.9	13.5	6.2	18	0.9	6.3
Y	37.3	36.6	51	28.6	11.9	5.1	20.3
Zr	490	271	526	389	70	36	122
Nb	13.2	16.9	18.8	15	3.4	3.7	7.6
Cs	0.12	0.32	0.34	0.34	0.09	0.09	0.14
Ba	227	627	115	39.2	47.5	38.7	34.3
Hf	10.6	8	10.9	8.7	1.5	0.8	4.8
Ta	0.7	1.4	1.6	1.3	0.8	0.8	7.7
Re	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Pb	7	13	4	4	4	<2	13
Th	6.44	5.29	10.2	5.26	1.27	1.19	6.04
U	0.91	1.35	3.01	1.68	0.31	0.31	1.32
Rb/Sr	2.24	1.54	8.18	16.93	3.63	77.67	13.1

Ba/Sr	8.44	9.10	8.52	6.32	2.64	43	5.45
Rb/Ba	0.26	0.17	0.96	2.68	1.38	1.81	2.4
Ba/Rb	3.76	5.89	1.04	037	0.73	0.55	0.41
Y/Nb	2.82	2.16	2.71	1.91	3.5	1.38	2.67

Table 2.3: REEs (Rare Earth Elements) in (ppm)

E(m) **N**(m)	HM-09 Granite **0802620** **1004551**	HM-05 Granite **0797397** **1005766**	HM-07 Granite **0797670** **0998082**	HM-10 Granite **0804524** **1004654**	HM-06 Granite **0794352** **1006650**	HM-08 Granite **0795014** **0998783**	HM-03 Granite **0798145** **1005817**
Description	ppm	ppm	ppm	ppm	Ppm	ppm	Ppm
La	119	45.1	91.1	72.5	10.7	8.3	18.2
Ce	265	89.1	169.5	90.7	24	21	45.4
Pr	27.7	11.45	20.5	20	3.1	2.78	5.14
Nd	94.8	41.5	70.6	65.9	12.6	11.6	18.4
Sm	17.5	8.8	13.3	13.25	2.66	2.43	4.27
Eu	0.73	1.07	0.44	0.5	0.17	0.12	0.09
Gd	12	7.91	11.45	8.83	2.47	1.77	3.73
Tb	1.73	1.29	1.81	1.41	0.43	0.26	0.69
Dy	8.97	7.01	9.88	7.32	2.44	1.28	4.2
Ho	1.62	1.48	2.02	1.24	0.47	0.25	0.87
Er	4.03	3.7	5.45	3.14	1.28	0.63	2.43
Tm	0.58	0.57	0.84	0.52	0.18	0.07	0.37
Yb	3.61	3.21	4.93	3.06	1.24	0.58	2.07
Lu	0.57	0.46	0.73	0.46	0.21	0.1	0.32
(Ce/Yb) N	16.68	6.31	7.81	6.74	4.39	8.23	4.98
(La/Sm) N	3.73	2.81	3.76	3.0	2.21	1.89	2.34
(La/Yb) N	19.99	8.51	11.12	14.36	5.23	8.67	5.33
(Gd/Yb) N	2.67	1.98	1.86	2.32	1.6	2.45	1.45
(Ce/Sm) N	3.1	2.08	2.62	1.41	1.86	1.78	2.19
(La/Lu) N	21.52	10.1	12.86	16.24	5.24	8.55	5.86

EU/Eu*	0.15	0.39	0.11	0.14	0.20	0.18	0.07

4.2. Major Element Geochemistry

The major elements are those elements which predominate in any rock analysis include; Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P and others in which their concentrations are expressed as a weight percent (wt%) of the oxide. In this report the uses of major element data for three principles: i) in rock classification, ii) in the constructive of variation diagrams and iii) for means of comparison with experimentally determined rock compositions those conditions of formation are well known regard to the study area. In order to overcome the principles, major element oxides selected were plotted against SiO2 concentrations in Harker variation diagrams. Most of the rock samples are characterized by high silica contents (74.7 to 79.8 wt. %); average 77.25%, high contents of Al2O3 (11.3 - 13.85 wt. %); average 12.57%, Fe2O3 (1.83 to 3.12 wt%); average 2.47%, Na2O (3.28 to 4.61wt%); average 3.94%, K2O (4.14 to 5.36 wt%); average 4.75%, low contents of CaO (0.03 to 0.48 wt%); average 0.25%, MgO (0.03 to 0.11 wt%); average 0.07%, TiO2 (0.07 to 0.18 wt%); average 0.12%, MnO (0.01 to 0.07 wt%); average 0.04%, very low P2O5 (0.01 to 0.03 wt%); average 0.02%.

These granite rock samples from Southwest of Gimbi area show higher SiO2, Al2O3, K2O, Na2O and Fe2O3 relative to the other major oxides, but lower TiO2, MgO, CaO and very low P2O5 (Table 4.1). Based on the geochemical data**,** geochemical classification and magmatic affinity of the studied granite rock units from Southwest of Gimbi distributed mainly in the granite field. For instance, in total alkali-silica; SiO2 (wt %) versus Na2O + K2O in (wt %) diagram (Middlemost, 1985) as drawn on (figure 4.1), most rock unit samples are positioned mainly in the granite field. Although, on SiO2 (wt %) Vs K2O (wt%) diagram (Peccerillo and Taylor, 1976), all the granite rock unit samples occupying the high-K calc alkaline series with exception of one sample (sample HM-09) that lies close to shoshonitic series as clustered on (figure 4.2). On the other hands, the Ab-An-Or classification diagram of (O'Connor, (1965) can be applied to felsic rocks with more than 10 % normative quartz.

From this triangular diagram, almost all studied granite rocks are occupied in the fields of granite as shown on (figure 4.3) and this prove the major element classification of those granite rocks from Southwest of Gimbi.

Generally, the studied granite rock samples from Southwest of Gimbi show a general trend of decreasing Al2O3, TiO2, Fe2O3, MgO and CaO with increasing SiO2 as shown on (figure

4.4). On this Harker variation diagrams, Al2O3, Fe2O3, TiO2 and MgO show good negative correlation with SiO2 content. CaO and P2O5 show poor negative correlation with SiO2 content even if the data is scattered. K2O contents show negative correlation with increasing SiO2 and Na2O shows poor positive correlation with increasing SiO2 even if there is a wider scattered and irregular distribution patterns of data. The irregular trends may indicate the effects of crystals during fractional crystallization processes. The scattered trend is probably due to alteration effect because the area is affected by metamorphism.

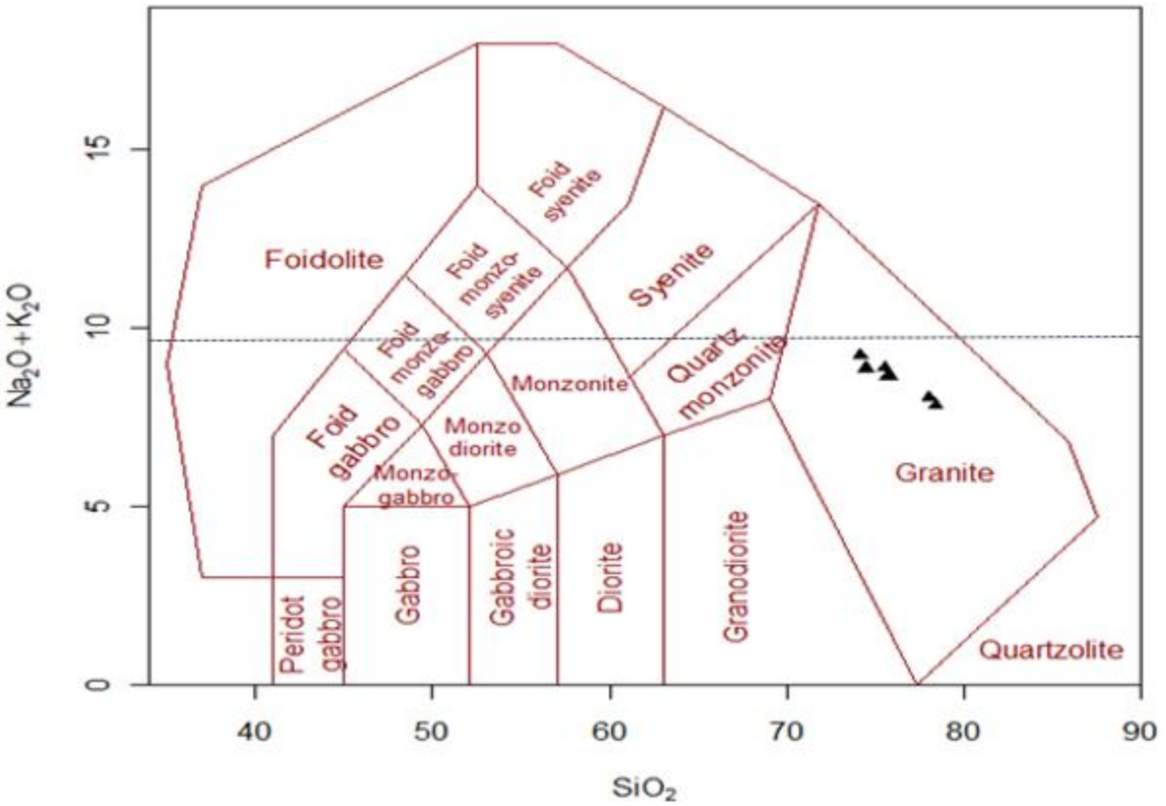


Figure 4.1: Chemical classification diagrams for the granite rocks of TAS, SiO2 (wt %) **versus** (Na2O + K2O) in wt% of (Middlemost, 1985).

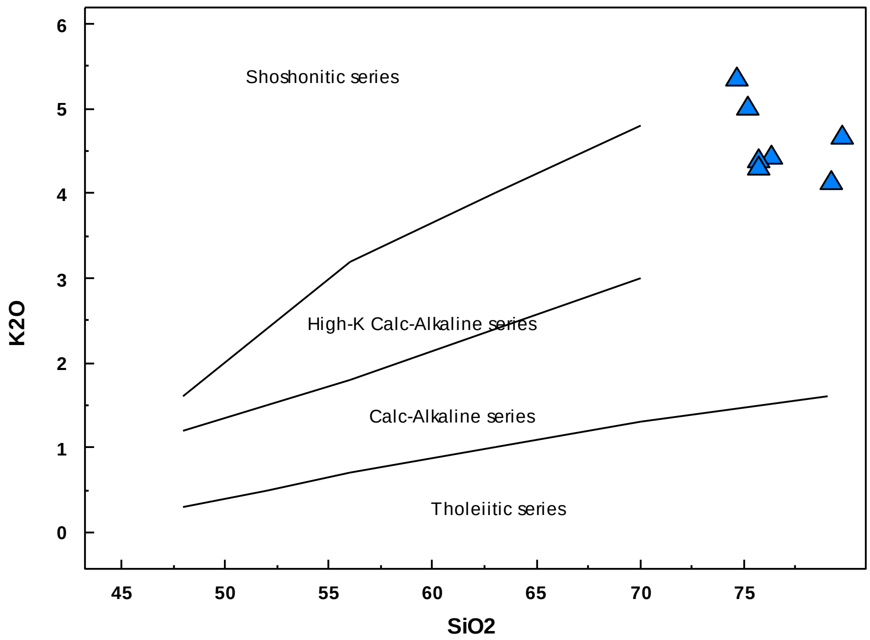


Figure 4.2: The K2O (wt. % **versus** SiO2 (wt. %) plot showing High-K nature and slight shoshonitic series (Peccerillo and Taylor, 1976) of the granites rock from Southwest of Gimbi area.

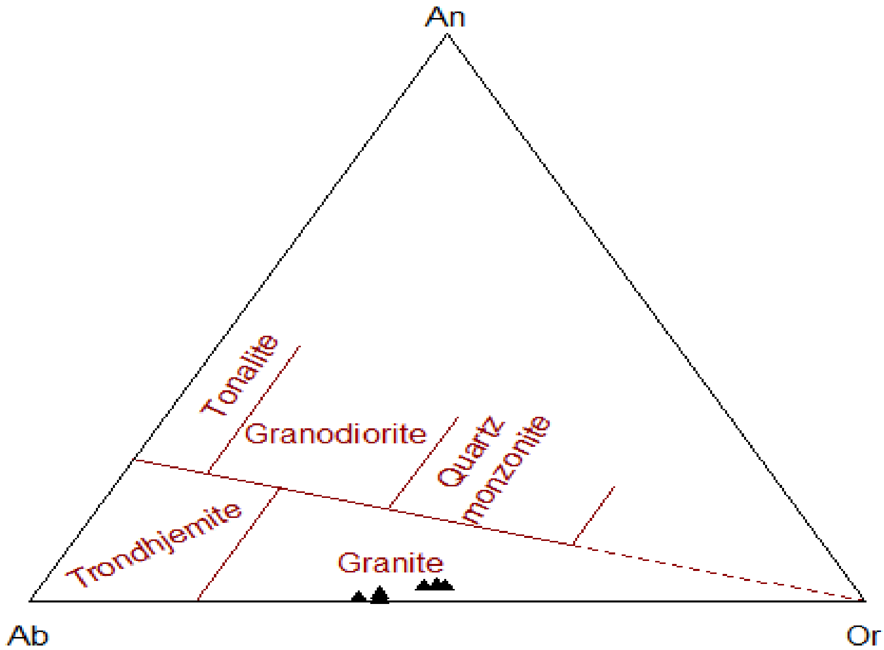
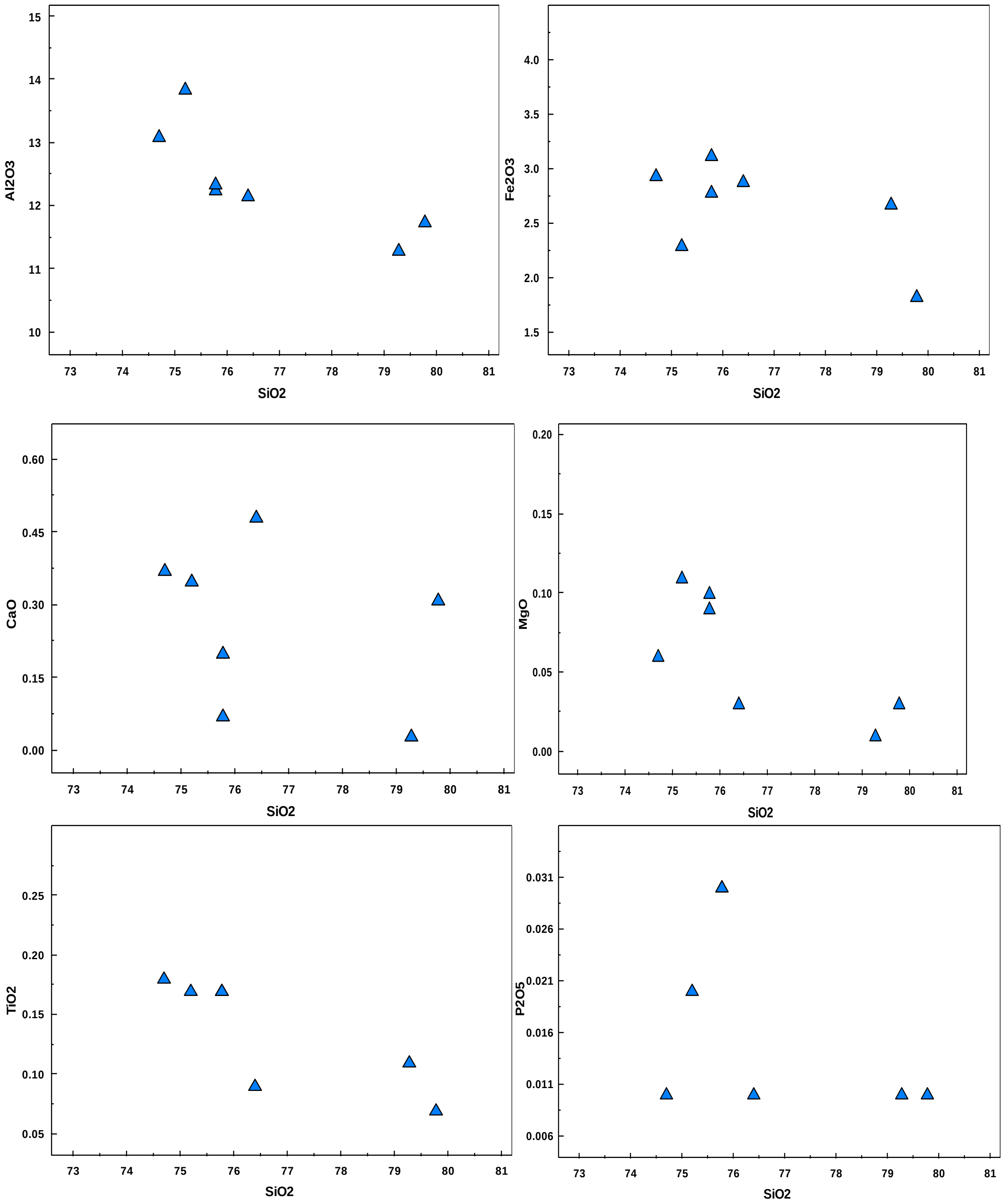


Figure 4.3: The classification of Granitic rocks according to their molecular normative An-Ab- Or composition after Barker (1979). Original fields of feldspar triangle (O 'Connor, 1965).


Al2O3
15
14
13
12
11
10
73 74 75 76 77 78 79 80 81
SiO2
Fe2O3
4.0
3.5
3.0
2.5
2.0
1.5
73 74 75 76 77 78 79 80 81
SiO2
CaO
0.60
0.45
0.30
0.15
0.00
73 74 75 76 77 78 79 80 81
SiO2
MgO
0.20
0.15
0.10
0.05
0.00
73 74 75 76 77 78 79 80 81
SiO2
TiO2
0.25
0.20
0.15
0.10
0.05
73 74 75 76 77 78 79 80 81
SiO2
P2O5
0.031
0.026
0.021
0.016
0.011
0.006
73 74 75 76 77 78 79 80 81
SiO2

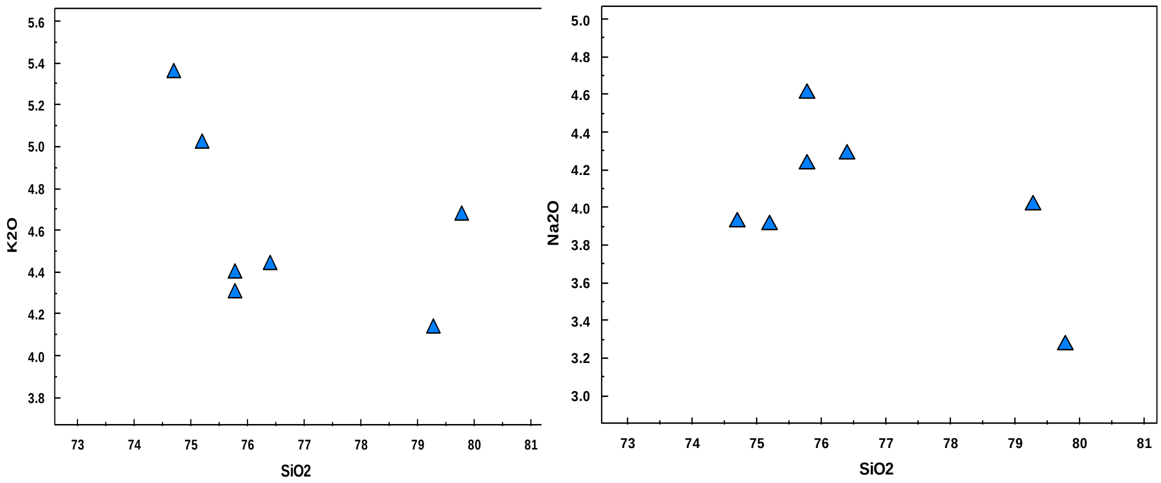


Figure 4.4: Harker variation diagrams: Silica (SiO_2 wt. %) plotted against a range of major oxides (wt. %) showing the behavior of major elements against SiO_2 for granite rocks from Southwest of Gimbi area.

4.3. Trace Element Geochemistry

Trace elements are an element which is present in a rock in concentrations of less than 0.1wt%, that is less than 1000 parts per million (ppm). In fact, most commonly trace elements substitute for major elements in the rock forming minerals but, sometimes they form their own mineral species in their own normal state/condition (Rollinson, 1993). Trace elements concentrations of the rocks from the studied area are listed in table 4.2.

The selected trace elements are plotted against SiO_2 as presented on (figure 4.5). The granite rock units samples from Southwest of Gimbi (Homa area) are characterized by medium to high concentration of Rb (60.3 to 106.5 ppm; av. 83.4 ppm), high Ba (34.3 to 627 ppm; av. 330.65 ppm), high Zr (36 to 526 ppm; av. 281 ppm) and low concentration of Sr (0.9 to 68.9 ppm; av. 34.9 ppm) and other presented Table 4.2.

On the variation diagram of silica plotted against selected compatible and incompatible trace elements (in ppm) for the granite rocks from this area, the Rb concentration increase with increasing of SiO_2 whereas the concentration of Zr, Sr and Ba decrease with increasing of SiO_2 (figure 4.5).

On the other hands, a primordial mantle-normalized multi-element variation diagram of the granite rocks from Southwest of Gimbi (McDonough and Sun,1995) as presented in (figure 4.6), all granite rock samples are characterized by depletion in Nb, Sr, and Ti and slightly depletion of Ta and Ba. In contrast to this Rb, K and Pb show peak (enrichment). All the studied granite rock samples are characterized by enrichment of large ion lithophile elements

(Rb, K and Pb) and high field strength elements (U and Th) while Eu was slightly depleted. Side by side, the high field strength element Y, Yb and Lu were relatively flat. Ti was slightly depleted and Sr is strongly depleted. As displayed on diagram (figure 4.6), there is an enrichment in more incompatible elements (Rb, K and Pb) relative to the less incompatible/compatible elements with an important depletion in Ba, Nb, Sr and Ti. From the above explanations, the depletion of Ba, Sr, Nb, Ta and Ti in the more evolved rocks is an indicative of alkali feldspar, plagioclase, rutile, and sphene and ilmenite/magnetite fractionation. The enriched in K, Rb and Pb mobile elements and poor in Nb, Ta and Ti immobile elements indicates, there is an arc volcanism processes behind the formation of those rocks.

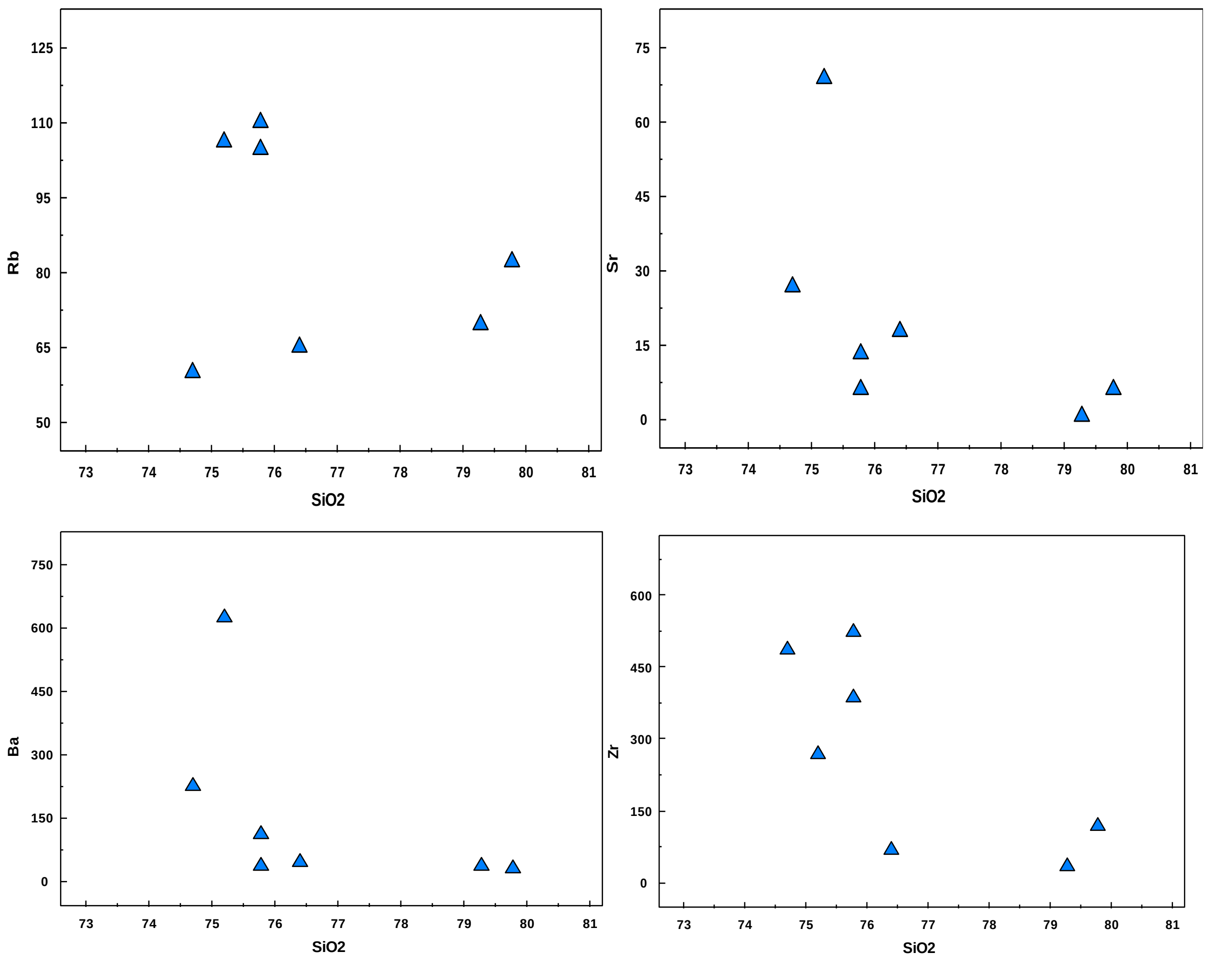


Figure 4.5: Harker variation diagrams, Silica (SiO2 in wt %) plotted against selected compatible and incompatible trace elements (in ppm) for the granite rocks from Southwest of Gimbi.

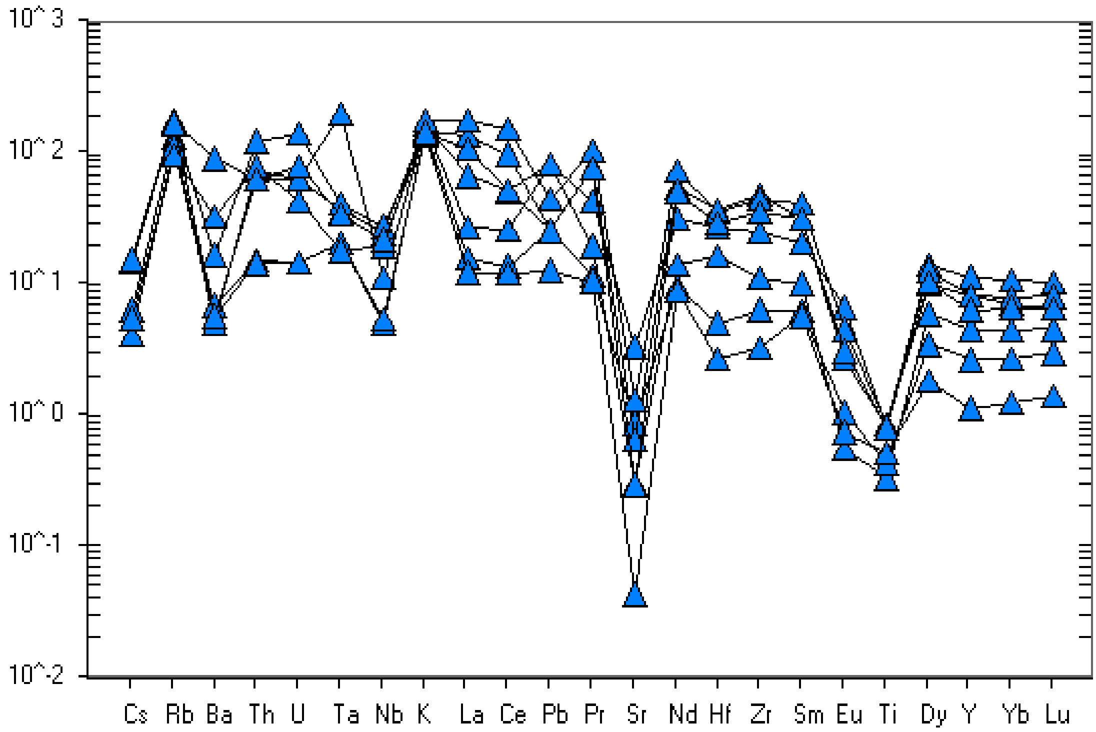


Figure 4.6: Primordial Mantle –normalized multi-element diagram of granites rock from Southwest of Gimbi (McDonough and Sun, 1995).

4.4. Rare earth elements Geochemistry

Rare Earth elements concentrations of the studied granite rock samples from Southwest of Gimbi were given in table 4.3. Typically, the low atomic number members of the series are known as the light rare earths elements (LREE) and those with the higher atomic number members termed as the heavy rare earth elements (HREE), (Rollinson, 1993). However, in geochemistry they classified into two main groups: the large ion lithophile (LIL) elements (K, Rb, Cs, Ba, Pb, Sr, and Eu) are generally considered to be more mobile, particularly if a fluid phase is involved. Also, the high field strength (HFS) elements include the REE, (Th, U, Ce, Pb, Zr, Hf, Ti, Nb, and Ta) are generally conceived as less mobile elements, if a fluid phase involved. The concentration of La ranges (8.3 -119 ppm, ave. 63.65ppm), Sm (2.66-17.5 ppm, ave. 10.08ppm), Eu (0.09-1.07ppm, ave. 0.58 or <2 ppm), Gd (1.77-12 ppm, ave. 6.88ppm), a very low Lu (0.07-0.73ppm, ave. 0.4ppm or <2 ppm) and other presented in Table 4.3.

The Chonderite –normalized Rare Earth Elements (REEs) diagrams (Boynton, 1984) show that, the overall patterns characterized by enrichment in light rare earth elements and relative to flat in heavy rare earth elements as presented on (figure 4.7). The enrichment in LREEs and a flat pattern in HREEs is an indicative of acidic properties of the studied rocks. They have a fractionated spectrum showing a very pronounced negative anomaly in Europium (Eu) when samples are normalized with respect to the primitive mantle. Europium anomalies may be quantified by comparing the measured concentration (Eu) with an expected concentration obtained by interpolating between the normalized values of Sm and Gd= (Eu*). Thus, the ratio Eu/Eu* is a measure of the Europium anomaly and a value of greater than 1.0 indicates a positive anomaly. Whereas, a value of less than 1.0 is a negative anomaly (Taylor and McLennan (1985) recommend using the geometric mean; in this case Eu/ Eu* =EuN/ √ [(Sm N)*(GdN)]. This anomaly shows that, the fractionation is revealed by the ratio Eu/Eu* whose values are range from 0.07 to 0.39 for granite rock samples from Southwest of Gimbi (Homa) area. Almost all granite rock samples from this area have similar Rare-Earth Elements (REE) distribution patterns. The REE patterns of these granite rocks are subparallel and show pronounced negative Eu anomalies with increasing total REEs, typical of a feldspar fractionation trend. Europium anomalies are highly controlled by feldspars, particularly in felsic magmas. Thus, the removal of feldspar from a felsic melt by crystal fractionation or the partial melting of rocks in which feldspar is retained in the source will give rise to a negative Eu anomaly in the melt. The presence of accessory phase such as: sphene, apatite and zircon in felsic liquids may strongly influence REE pattern (even if they may be present in only small quantities, often much less than 1% of the rock). Because of they have very high partition coefficients; mean that they have a disproportionate influence on the REE pattern.

Generally, as displayed on figure 4.7 the negative Eu anomaly indicates that, there is crystal fractionation or the partial melting in which the feldspar removed from felsic magma.

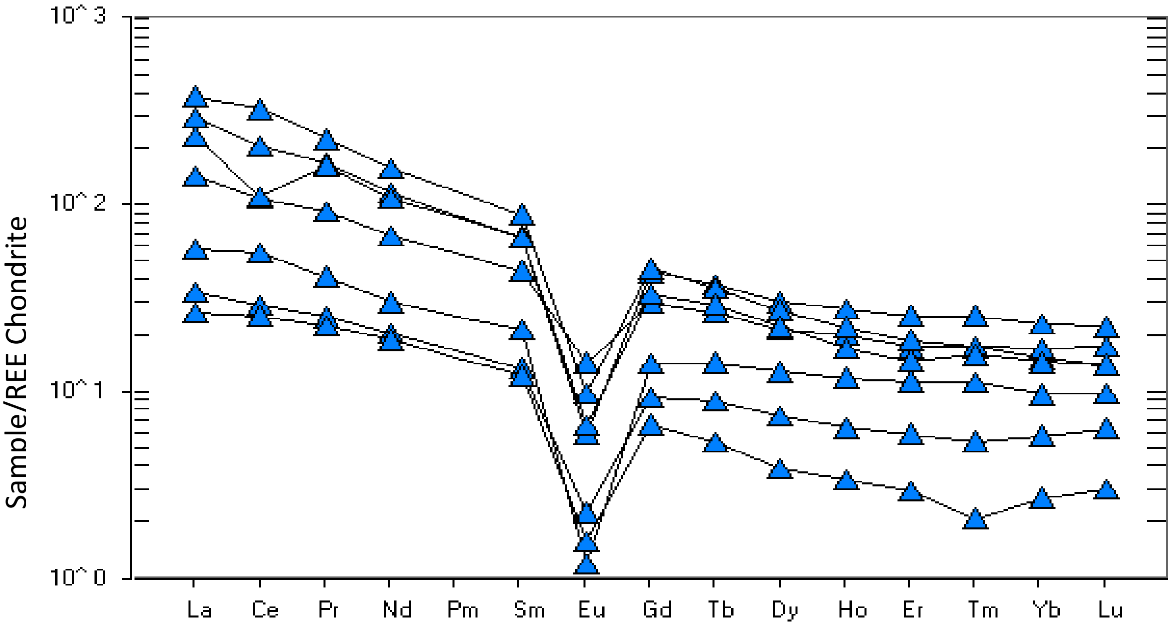


Figure 4.7: Chonderite-normalized REE patterns granites rocks from Southwest of Gimbi area (Boynton, 1984).

4.5. Tectonic setting

Based on the geochemical data, the tectono-magmatic discriminant diagrams, geochemical variation diagrams on which magmas produced in different tectonic setting may be distinguished one from another depend on their chemistry. For instance, in the discriminating diagrams, Rb Vs (Y + Nb) and Rb Vs (Ta+Yb), most of the granite rocks samples stands in the field of volcanic-arc granitoids (VAG) except one sample which positioned in the field of within plate granite (WPG), as display on figure 4.8 a and b. According to Brown et al. (1984), with increasing arc maturity, volcanic-arc granites are enriched in the elements Rb, Th, U, Nb, Hf and Y and depleted in the elements Ba, Sr, Ta, Zr and Ti. Therefore, a bivariate plot of the ratio Rb/Zr against either Nb or Y shows a positive correlation in which values increase with increasing arc maturity (Rollinson, 1993).

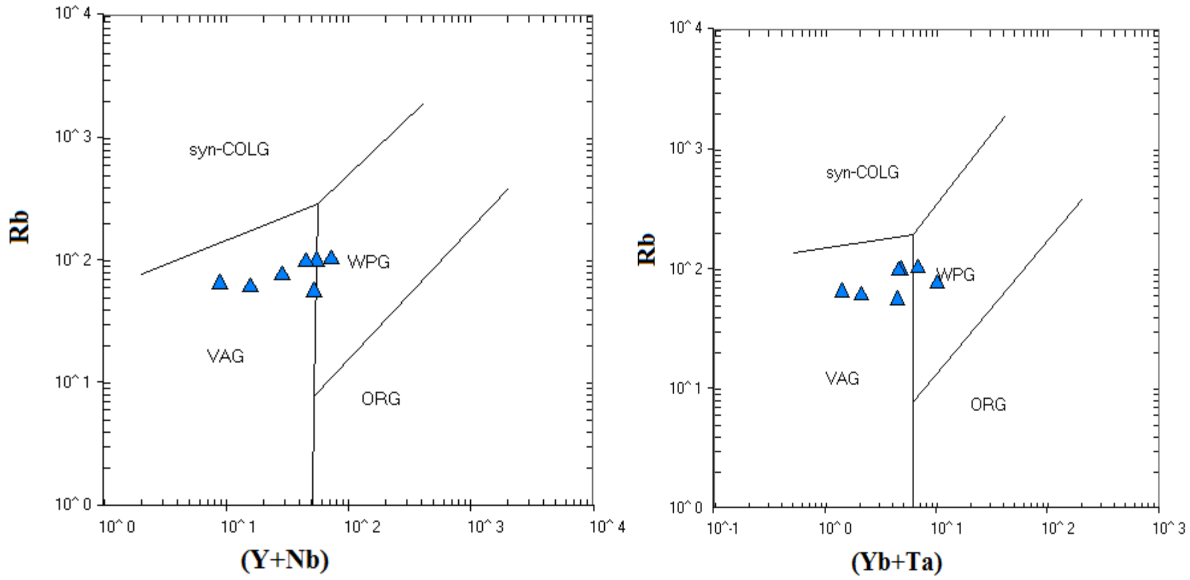


Figure 4.8: Tectonic discrimination diagram for the granitic rocks of the Southwest of Gimbi (Homa area). (Y + Nb) Versus Rb and (Ta+ Yb) Versus Rb with discriminative field after and Pearce et al. (1984): WPG = within plate granites; VAG = volcanic arc granites; syn-COLG = syn-collisional granites; ORG: oceanic ridge granite.

Therefore, from the above tectonic setting discussion including (figure 4.8), the studied granite rocks from Southwest of Gimbi are strongly associated with volcanic-arc granite and marginally, associated with late to post-collision granite in tectonic setting origin. These features, together with their high-K calc-alkaline, strongly potassic character and the presence of pronounced negative anomalies in Nb, Ta and Ti are related with subduction geodynamic environment in which the crust was formed originally. However, these chemical features are often retained during crustal reprocessing and can also be occurring in collisional-type granitoids. Likewise, shoshonitic to calc-alkaline high potassic chemical attraction are general characteristics of syn- to post-collisional granitoids in the continental collision context.

CHAPTER FIVE

5. Discussion

5.1. Petrogenetic Implication

The data and results presented in the previous section will be discussed as follows.

To provide the geochemical and petrographical data (major, trace, rare elements and petrographic properties of the granite rocks), numerous diagrams and plots are used. Such as: Harker variation diagrams, Primordial Mantle–normalized multi-element diagram, Chonderite-normalized REE patterns, primitive multi-element diagram, tectonic discrimination diagram, Triangular plot for modal classification, graphical plots and field photographs and microphotographs have been prepared and used to represent the results obtained from the different analytical methods (geochemical and petrographical analysis).

5.1.1. Petrography

The study area is situated within the Western Ethiopian Precambrian shield terrain. This terrane represents wider branch of the low-grade volcano-sedimentary terrain of the ANS of a northward-widening zone and bounded both to east and to the west by the gneissic terrain of MB of a relatively narrow zone as discussed by Tadesse Alemu and Tsegaye Abebe (2007). The granite rocks in Southwest of Gimbi (Homa area) are characterized by textural variations and inter- and intra-unit compositional, which reflect their petrogenetic evolution. Granite rocks from this area show medium to coarse grained in texture and all most have similar mineral assemblages.

Petrographically, the Southwest of Gimbi (Homa area) granite rocks are represented dominantly by pale pinkish to grey and pink with grey spot in color. From the petrographic analysis, most field of view mainly occupied by fairly phenocrysts of K-feldspars and quartz (figure 3.3) with the other minor minerals like: biotite, epidote and muscovite. Accessory minerals phases including zircon, apatite, sphene and others as trace amount. Generally, from the petrographic description and from microphotographs recognized some of the K-feldspar (microcline) and plagioclase loose twin lamella due to deformation. Although, some grains of K-feldspar (microcline and orthoclase), quartz and plagioclase are recrystallized. Feldspar alteration is common because of the area is affected by metamorphism (i.e. feldspar altered to sericite and epidote). This alteration indicates that, there is a replacement of igneous minerals by metamorphic minerals.

Based on the modal percentage of the mineral phases, most of the studied granite rocks from Southwest of Gimbi are clustered in field of granite (i.e. alkali feldspar granite and syenogranite as presented on figure 3.4).

5.1.2. Major Element Compositions

The analysis of major element data shows a limited range in major element composition with regarding to P as trace element with high concentration of silica (74.7 to 79.8). According to the Harker variation diagrams plotted on the base of geochemical data of granite rocks from Southwest of Gimbi (figure 4.4), plutonic rocks define trends that explain the genetic relationships among each sample from this area. Both fractional crystallization and partial melting hypothesis were tested to identify constraint on the petrogenetic relationships of these rocks. Next to this, based on the major element variation diagram (major oxide against silica concentration diagrams in wt%) as display on (figure 4.4), the studied granite rock units from this area more or less well defined clusters and well defined trends even if the data is more scatter. Al2O3, Fe2O3, MgO and TiO2 concentration decreases with increasing SiO2. This implies that, the beginning of plagioclase fractionation or magmatic differentiation trends. Whereas, the concentration of Na2O increase with increasing SiO2 and K2O decrease with increasing SiO2 content. The granitic rocks of this area highly characterized by sub-alkaline because (Na2O + K2O < 10 wt% and Si2O > 74 wt%) as represented by dash type line on (figure 4.1) and related to high k-calc-alkaline series as display on (figure 4.2). The variation diagrams for major elements of the studied granite rocks indicate a magmatic differentiation by fractional crystallization of mafic magma. Indeed, it show a progressive enrichment in silica and decrease in Al2O3, Fe2O3, TiO2 and MgO indicate that, the possibility of fractional crystallization related to the fractionation of mineral phases observed in these rocks. The total alkali concentrations are similar (close each other) within each granite rock sample (i.e.7.97 to 9.29 wt %). Besides, the decreasing of Al2O3 with increasing silica concentration indicates fractionation of aluminum-rich phases (plagioclase). So, the fractionations of plagioclase (decreasing of CaO contents), magnetite and ilmenite (decreasing of TiO2, Fe2O3 contents) in these granitic rocks are recognize. A very low concentration of P2O5 is related with decreasing solubility of Phosphorous in siliceous melts or removal of apatite with relatively high sodium (Na_2O greater than 3.2%) in felsic varieties. The high SiO_2, (Na_2O + K_2O), and Al_2O_3, low MgO, Fe_2O_3, and CaO concentration imply that, the primary magma was derived from partial melting of the lower crust.

5.1.3. Trace and Rare Element composition

In contrast to the major element composition, the trace and rare earth element concentration can vary widely in felsic rocks. Those trace elements that occur in feldspar (i.e. Rb, Sr, and Ba) and those that are major components of accessory minerals (i.e. P, Zr, Nb, Y, Ce, Sn, Th, U) may vary widely in these rock suites. Those trace elements that occur in feldspar and accessory minerals which may as a result of abundances that vary with and reflect the degree of fractional crystallization of such minerals from a felsic melt. Depending on the trace element data and the Primordial mantle-normalized multi-element plot (McDonough and Sun, 1995), granite rocks from Southwest of Gimbi are more enriched in light rare earth elements (Rb, Pb, and K) and highly depleted in heavy rare earth elements (Nb, Ta P and Ti). Besides, the silica contents of those rocks are higher than (74%) with the abundance of trace elements such as; Rb, Pb, Th and K and low abundance in Sr, Nb, Ti and P starts to decrease with fractional crystallization. This suggest that, the granite rocks from Southwest of Gimbi were established by highly fractional crystallization of mantle derived mafic magma and by small degree of partial melting from lower crust materials. In other case, as displayed on REE spectrums of granite rocks from Southwest of Gimbi are strongly fractionated and characterized by significant negative anomaly in Eu, showing a differentiation controlled by fractionation of plagioclase feldspar (figure 4.7).

On the other hands, primordial mantle-normalized trace element spider diagrams (figure 4.6) for granite rocks from Southwest of Gimbi shows a depletion in Ti, Nb and Sr. This is processes related to fractionation of (Fe-Ti -magnetite) and plagioclase feldspars respectively. Those granite rocks show enrichment in most incompatible elements as well as significant positive anomalies in Rb and Pb and depleted in less incompatible (compatible) elements Nb, Ba, Sr and Ti reflecting the crustal sources involvement in the rock genesis. Therefore, trace and rare earth elements display characteristics features usually attributed magmatic arc calc-alkaline granitoids. Enrichment in large ion lithophile elements and depletion in high field strength elements imply, a significant amount of crustal material was involved in the Southwest of Gimbi granite rock genesis, most probably as a result of arc-related magmatism/subduction-related (Pearce et al., 1984) and fractional crystallization of mantle derived mafic magma.

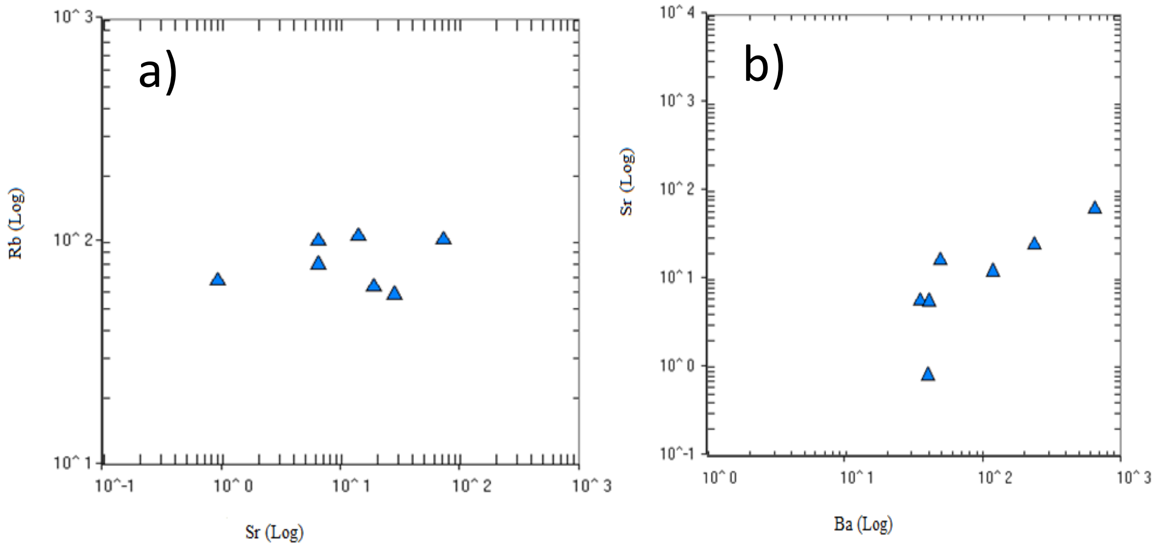


Figure 5.1: Binary diagrams; a) incompatible Trace element versus compatible Trace element {i.e., Log (Rb) Versus Log (Sr) in ppm and b) Log (Sr) versus Log (Ba) in ppm}

Based on the above diagram Log (Sr) Versus Log (Rb) as presented on (figure 5.1. a), highly incompatible element concentration is not varying in fractional crystallization and will vary little during partial melting. Compatible trace elements concentrations change dramatically in igneous liquid (fluids) during fractional crystallization. So, from this statement the southwest of Gimbi granite rocks were formed by small degree of partial melting from crustal materials followed by fractional crystallization of mantle derived mafic magma. Because, when the trace element concentration in the wall rock is less than in the melt, compatible elements are strongly depleted (figure 4.6). However, during partial melting highly compatible elements are buffered by solid phase with respect to solid-melt equilibria during partial melting. But, on diagram Log (Ba) Versus Log (Sr), both Sr and Ba concentration are varying and this implies that both elements have similar behavior in the melt as shown on (figure 5.1. b). This indicates that, the granite rocks from Southwest of Gimbi were formed by fractional crystallization. The Rb, Ba, K and Pb are concentrated in felsic melts being derived from the partial melting of alkali feldspar (Thompson et al., 1983). Besides, the high concentration of Ba in the granite rock samples from Southwest of Gimbi show a partial melting take place above the subduction zones of volcanic arc tectonics. The concentration of Zr controlled by zircon, P by apatite, Sr by plagioclase and the concentration of Nb, Ti, and Ta by rutile, ilmenite/sphene. The negative Nb and Ta anomalies and the higher Y/Nb ratios are related with the characteristic of the continental crust and also an indicator of crustal involvement in petrogenesis processes of the rocks. More mobile LIL element concentration may be controlled by aqueous fluids but those elements are concentrated in the continental crust and can also be used as an indicator of crustal contamination of magmas. Geochemical characteristics of the studied granite rocks from Southwest of Gimbi are also comparable to those of many syn-to late tectonic Pan-African granitoids studied in the past. For instance, geochemical characteristics of the studied granite rocks are also comparable to those of many syn- to late-tectonic Pan-African granitoids studied in the Central North Cameroon: Implications for their sources and geological setting (Tchameni, R., Pouclet, A., Penaye, J., Ganwa, A.A. and Toteu, S.F., 2006). The constructed tectonic-setting discrimination diagram (Pearce et al., 1984) displays that, most of the granite rocks Southwest of Gimbi are strongly associated with subduction zones (volcanic arc) and within plate granites tectonic environments.

CHAPTER SIX

6. Conclusion and Recommendation

6.1. Conclusions

Depend on the integration of geochemical data, petrographic data and geological data of the granite rocks from Southwest of Gimbi, Western Ethiopia; the following conclusions can be overcome:

1. The present study is located within the Western Ethiopian Precambrian shield terrain which represents the gneissic rocks of the MB and low-grade volcano-sedimentary-plutonic sequences of the ANS. This study provides to understand the tectonic setting and related geological processes responsible for the origin and evolution of the rock in the region. The studied area is covered by granitic rocks and the main aim of the present study focus on plutonic rocks, major lithologic units have been identified in this area is granite suites. These granite suites are dominantly composed of K-feldspar, quartz, and biotite etc. It represented by pale pinkish and grey color and characterized by medium to coarse textures.
2. Petrographically, the studied granite rock from Southwest of Gimbi is mainly composed of K-feldspars (i.e. contain perthitic, microcline, myrmekitic), quartz, plagioclase, biotite as major, muscovite, apatite (Ilmenite and magnetite/Fe-Ti oxides) as minor and sphene, hornblende and zircon as trace amount. From petrographic analysis there is a sign of deformation recognized because of some grains feldspar (microcline) and plagioclase lose twin lamella. Similarly, some grains of feldspar (microcline and orthoclase), quartz and plagioclase are recrystallized. Alteration of feldspar to epidote and sericite is common in these granite rocks. This suggests that, the replacement of igneous minerals by metamorphic minerals. Modally, the petrographic classification of plutonic rocks from Southwest of Gimbi is clustered in field of granite (especially in alkali feldspar granite and syenogranite).
3. Geochemical analyzed data of granite rocks from Southwest of Gimbi (Homa) show the compositional trends of these granite rocks decreases in $Al2O3$, $Fe2O3$, CaO, $TiO2$ and MgO with increasing $Si2O$, which might because of fractionation of plagioclase/biotite. Decreasing in the concentration of $P2O5$ with increasing $SiO2$ and the low values of $P2O5$, which is consistent with decreasing solubility of Phosphorous

in siliceous melts is related to the removal of apatite from the melt. The above statement indicates that, the granite rocks from Southwest of Gimbi (Homa) the high Si2O, (Na2O+ K2O), and Al2O3, low Fe2O3, CaO and MgO concentrations suggest that the primary magma was derived from partial melting in which the lower crust was involved. Also, this implies there is a possibility involvement of crustal materials (particularly, metasedimentary rocks) in magmatic process. The scattered trend of Harker variation diagram the granite rocks from Southwest of Gimbi is more or less affected by metamorphism.

4. According to, the Primordial Mantle-normalized multi-element, total alkali concentration and geochemical characteristics of high K-calc-alkaline affinity, the granite rocks from Southwest of Gimbi enriched in light rare earth elements (Rb, Pb, and K) and depletion in heavy rare earth elements (Nb, Ta and Ti). This implies that, the tectonic setting of granite rocks from Southwest of Gimbi typical characterized with volcanic arc magmatism/subduction related granites. On the other hands, the high concentration of Ba in the rocks from this area shows that, there is a partial melting above subduction zones of volcanic arc tectonic. The REE spectrums of granite rocks of this area are strongly fractionated and characterized by a significant negative anomaly in Eu which suggests that, the granite rocks from Southwest of Gimbi were further established due to the evolution of mafic magma. The enrichment in most incompatible elements as well as significant positive anomalies in Rb, Th, U, and depletion in Ba, Nb, Ta, Sr, P and Ti reflecting a significant crustal source involvement in their genesis. The depletion in Ba, Ti, Ta, Nb, P and Sr is related to the fractionation of biotite, opaque minerals such as Ti magnetite, apatite, and plagioclase feldspars respectively. The constructed tectonic-setting discrimination diagram indicates that, the tectonic setting of those granite rocks is associated with subduction zones (volcanic arc) tectonic environments.
5. Available evidence suggests that, the western Ethiopia Precambrian rocks were affected strongly by arc-magmatism that resulted in the intrusion of plutons, of which plutonic rocks constitute a major part of the terrane.

Finally, the combination of petrographical and geochemical analysis indicate that, the granite rocks from Southwest of Gimbi(Homa) were genetically formed by small degree of partial melting in which crustal material significantly involved in their genesis and by fractional crystallization of mantle derived mafic magma.

6.2. Recommendation

The present study is located within the Western Ethiopian Precambrian shield terrain which represents the gneissic rocks of the MB and low-grade volcano-sedimentary- plutonic sequences of the ANS. Thus identification of the geneses of intrusive igneous rocks based on the petrographic and geochemical analysis may face ambiguity on the exact source materials for the plutonic rocks. So, the intrusive (plutonic) rocks of western Ethiopia are until now poorly understood. The future research opportunity in Southwest of Gimbi includes detail work on isotope analysis the strong tool to understand magma evolution and petrogenesis of granitoids of western Ethiopia. Therefore, isotope geochemistry is suggested for further support of the source and petrogenesis of the subalkaline rocks.

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Appendix I

Petrographic Analysis

Sample code HM-01					
Minerals Phases	Modal Proportion (%)	Phenocryst average grain shape	Geographic-al location	Elevation	Rock name
Alkali-feldspar	49%	Subhedral	0797397 E 1005766 N	1682m	Metagranite
Quartz	29%	Subhedral-Anhedral			
Biotite	10%	Anhedral			
plagioclase	4%	Subhedral			
Muscovite	4%	Anhedral			
(Fe-Ti oxide)	2%	Anhedral			
Sphene	2%	Anhedral			
Zircon	As trace element	Anhedral			
Apatite	As trace amount	Anhedral			
Sample HM-02					
Minerals Phases	Modal Proportion (%)	Phenocrysts average grain shape	Geographic-al location	Elevation	Rock name
Alkali-feldspar	51%	Anhedral-Subhedral	0798145 E 1005817 N	1663m	Metagranite
Quartz	26%	Anhedral			
plagioclase	7%	subhedral			
Biotite	9%	Anhedral			
(Fe-Ti oxide)	4%	Anhedral			
Epidote	2%	Anhedral			
Sphene	1%	Subhedral			
Apatite	As trace	Anhedral			

	amount				

Sample HM-03					
Minerals Phases	Modal Proportion (%)	Phenocrysts Average grain shape	Geographical location	Elevation	Rock name
Alkali-feldspar	54%	Subhedral	0798145 E 1005817 N	1663m	Metagranite
Quartz	27%	Anhedral			
plagioclase	6%	Subhedral			
Muscovite	6%	Anhedral			
(Fe-Ti oxide)	4%	Anhedral			
Biotite	2%	Anhedral			
Sphene	1%	Subhedral			
Zircon	As trace amount	Anhedral			

Sample HM-04					
Minerals Phases	Modal Proportion (%)	Phenocrysts average grain shape	Geographic-al location	Elevation	Rock name
Alkali-feldspar	43%	Anhedral	0798061 E 1005899 N	1663m	Metagranite
Quartz	24%	Anhedral			
plagioclase	5%	Subhedral			
Muscovite	9%	Anhedral			
Biotite	7%	Anhedral			
Epidote	5%	Anhedral			
(Fe-Ti Oxide)	5%	Anhedral			
Sphene	2%	Subhedral			
Zircon	As trace amount	Anhedral			

Apatite	As trace amount	Anhedral			

Sample HM-05					
Minerals Phases	Modal Proportion (%)	Phenocrysts average grain shape	Geographical location	Elevation	Rock name
Alkali-feldspar	44%	Subhedral	0797397 E 1005766 N	1682m	Metagranite
Quartz	30%	Anhedral			
plagioclase	8%	Subhedral			
Biotite	7%	Anhedral			
Epidote	4%	Anhedral			
(Fe-Ti Oxide)	4%	Anhedral			
Muscovite	3%	Anhedral			
Zircon	As trace amount	Anhedral			
Apatite	As trace amount	Anhedral			
Sample HM-06					
Minerals Phases	Modal Proportion (%)	Phenocrysts average grain shape	Geographic-al location	Elevation	Rock name
Alkali-feldspar	54%	Anhedral	0794352 E 1006650 N	1645m	Metagranite
Quartz	29%	Anhedral			
plagioclase	3%	Anhedral			
Sphene	5%	Anhedral			
(Fe-Ti Oxide)	6%	Anhedral			
Hornblende	3%	Anhedral			
Sample HM-07					
Minerals Phases	Modal Proportion (%)	Phenocrysts average grain	Geographic-al location	Elevation	Rock name

		shape			
Alkali-feldspar	53%	Subhedral	0797670 E 0998082 N	1681m	Metagranite
Quartz	34%	Anhedral			
epidote	8%	Anhedral			
plagioclase	5%	Subhedral			
(Fe-Ti Oxide)	As trace amount	Anhedral			

Sample HM-08					
Minerals Phases	Modal Proportion (%)	Phenocrysts average grain shape	Geographic-al location	Elevation	Rock name
Alkali-feldspar	45%	Subhedral	0795014 E 0998783 N	1707m	Metagranite
Quartz	27%	Anhedral			
Epidote	9%	Anhedral			
Biotite	6%	Anhedral			
plagioclase	6%	Subhedral			
(Fe-Ti Oxide)	5%	Anhedral			
Sphene	2%	Subhedral			
Sample HM-09					
Minerals Phases	Modal Proportion (%)	Phenocrysts average grain shape	Geographic-al location	Elevation	Rock name
Alkali-feldspar	52%	Subhedral	0802620 E 1004551 N	1715m	Metagranite
Quartz	27%	Anhedral			
plagioclase	10%	Subhedral			
Epidote	3%	Anhedral			
(Fe-Ti Oxide)	3%	Anhedral			
Hornblende	3%	Anhedral			
Biotite	2%	Anhedral			
Sphene	As trace	Subhedral			

	amount				
Zircon	As trace amount	Anhedral			
Sample HM-10					
Minerals Phases	Modal Proportion (%)	Phenocrysts average grain shape	Geographic-al location	Elevation	Rock name
Alkali-feldspar	39%	Anhedral	0804524 E 1004654 N	1720m	Metagranite
Quartz	23%	Anhedral			
plagioclase	7%	Anhedral			
Epidote	8%	Anhedral			
Biotite	10%	Anhedral			
Muscovite	8%	Anhedral			
(Fe-Ti Oxide)	5%	Anhedral			
Sphene	As trace amount	Subhedral			
Zircon	As trace amount	Anhedral			

Appendix II

Geochemistry Data

Trace element ratios and Trace Elements in ppm

Sample#	(Sm/Gd)N	Rb/Sr	Ba/Y	Ti/Zr	Eu/Eu*	Y/Nb	Rb/Nb	Rb/Zr	Ce/Pb	La/Nb	Th/Ta
HM-03	1.57	13.1	1.69	0.004	0.07	2.67	10.85	0.68	3.49	2.39	0.78
HM-05	1.53	1.54	17.13	0.001	0.39	2.16	6.30	0.39	6.85	2.67	3.78
HM-06	1.48	3.63	3.99	0.003	0.20	3.5	19.23	0.93	6	3.15	1.59
HM-07	1.59	8.18	2.25	0.005	0.11	2.71	5.88	0.21	42.37	4.84	6.37
HM-08	1.88	77.67	7.59	0.02	0.18	1.38	18.89	1.94	10.5	2.24	1.49
HM-09	2.01	2.24	6.08	0.003	0.15	2.82	4.57	0.12	37.86	9.01	9.2
HM-10	2.06	16.93	1.37	0.004	0.14	1.91	7	0.27	22.67	4.83	4.05

Trace Elements in ppm

	HM-09 Granite	HM-05 Granite	HM-07 Granite	HM-10 Granite	HM-06 Granite	HM-08 Granite	HM-03 Granite
E(m)	**0802620**	**0797397**	**0797670**	**0804524**	**0794352**	**0795014**	**0798145**
N(m)	**1004551**	**1005766**	**0998082**	**1004654**	**1006650**	**0998783**	**1005817**
Description	wt%	wt%	wt%	wt%	wt%	wt%	wt%
Sc	1	2	1	1	<1	<1	<1
Cu	8	12	6	12	24	19	9
As	0.9	1	1	1.3	1	0.8	0.8
Mo	4	6	1	4	2	1	2

Ag	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cd	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
In	0.08	0.014	0.062	0.018	0.047	0.04	0.01
Sn	1	2	4	3	1	1	2
Sb	0.2	0.19	0.2	0.21	0.19	0.22	0.23
Te	0.01	0.01	0.01	0.01	0.01	0.01	<0.01
W	<1	1	1	1	<1	<1	<1
Hg	<0.005	<0.005	0.005	<0.005	<0.005	<0.005	<0.005
Bi	0.01	0.01	0.07	0.06	0.01	0.04	0.01

Appendix III

Molecular CIPW norm of the samples (in wt%)

Sample#	HM-03	HM-05	HM-06	HM-07	HM-08	HM-09	HM-10
Q	42.129	32.328	33.740	34.083	40.021	30.472	32.124
C	0.749	1.379	-	0.457	0.175	0.184	-
Or	27.657	29.667	26.239	26.003	24.466	31.676	25.471
Ab	27.754	33.170	36.301	35.878	34.016	33.255	39.009
An	1.473	1.606	0.782	0.151	0.084	1.770	0.275
Di	-	-	0.161	-	-	-	0.003
Wo	-	-	0.423	-	-	-	-
Hy	0.075	0.274	-	0.249	0.025	0.149	0.223
Il	0.019	-	-	0.041	-	0.105	0.041
Hm	1.830	2.300	2.880	3.120	2.680	2.940	2.780
Ru	0.060	0.170	-	0.149	0.110	0.125	-
Ap	0.024	0.047	0.024	0.071	0.024	0.024	0.071
Sum	101.788	100.975	100.889	100.219	101.617	100.719	100.379
ASI	**1.42**	**1.49**	**1.32**	**1.41**	**1.38**	**1.36**	**1.35**