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PETROGENESIS OF GRANITOIDS OF GABA SANBATA AREA, EASTERN GIMBI, WESTERN ETHIOPIA

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GRADUATE STUDIES OFFICE

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A Thesis submitted to the School of Earth Sciences, Bahir Dar University in partial Fulfillment of the Degree of Master of Sciences in Petrology

By: Degefa Temesgen Bacha

August, 2020
Bahir Dar, Ethiopia

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Advisor: Minyahl Teferi (PhD)

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Approval of Dissertation/thesis for defense

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Minyahl Teferi (PhD)	_______________	____________
Advisor's name	Signature	Date

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Approval of Dissertation/thesis for defense result

We hereby certify that we have examined this dissertation/thesis entitled "**Petrogenesis of granitoids from Gaba Sanbata area, Eastern Gimbi, Western Ethiopia**" by Degefa Temesgen. We recommend this thesis is approved for the degree of "Masters in petrology"

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Declaration of Originality

I hereby declare that this thesis is my original master's degree entitled "petrogenesis of granitoids from Gaba Sanbata area, Eastern Gimbi, Western Ethiopia ''was prepared by me, with the supervision of Dr. Minyahl Teferi, school of Earth Science, Bahir Dar University during the year 2019/2020.This thesis is my original work and has not been presented for a degree or diploma in any other university and all sources of materials used for thesis have been duly acknowledged.

Degefa Temesgen ______________ ________________

Signature Date

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Abstract

The study area is situated within Eastern Gimbi, western Ethiopian Precambrian basement terrain which can be classified into Didesa Domain group. It covers about 170 km^2. This study generally considered the petrogenesis of granitoids of Gaba Sanbata area, Eastern Gimbi, Western Ethiopia. Field investigation, petrographic interpretation and geochemical data analyses have been applied to meet the objectives. The study area is dominated by migmatites gneiss, gabbro, quartz vein and granitoids. On the basis of modal analysis the studied samples are classified as syenogranite and alkali-feldspar granite. The petrographic interpretation suggested that the studied samples are characterized by phaneritic texture with dominance of K- feldspars, quartz, polysynthetic twining plagioclase and minor amount of biotite and opaque.

Petrography and geochemical compositions of granitoids indicates that they are shoshonitic to high-K calc-alkaline affinities and characterized by high SiO_2, high total alkali (Na2O+k2O) concentrations (8.42–10.32 wt. %). The negative correlation between SiO_2 with other oxide such as Al_2O_3, MgO, CaO, Fe_2O_{3total}, TiO_2 and P_2O_5 and positive correlation with other alkali K_2O and Na_2O indicate fractional crystallization process controls the evolution of magma. The enrichment of large ion lithophile elements (LILE), depletion of high field strength elements (HFSE) indicates a partial melting and crustal contamination of magma and were formed in the post-collisional tectonic setting. The negative Eu anomaly and depletion in Sr, Nb, Ba, and Ti are imply that fractionation of plagioclase. The studied samples are A-type, metaluminous granitoids and display slightly enriched in light rare earth elements relative to heavy rare earth elements. Thus, we concluded that the granitoids rocks are A-type and likely derived from mantle–crust (magma mixing) source of juvenile crust. The negative anomalies of Nb, Ti and P might indicate a source and contamination origin. Therefore, studied samples of A-type granitoids were formed by assisted of fractional crystallization from a crustal contamination of mantle derived magmas and partial melting of crustal materials within plate granite tectonic setting.

Key words: Granitoids, petrogenesis, partial melting, fractionational crystallizations, crustal contamination, and tectonic setting

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Acronyms

ANS	Arabian-Nubian Shield
Bt	Biotite
EAO	East African Orogeny
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
HREE	Heavy Rare Earth Element
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
K-fs	K-feldspar
LREE	Light Rare Earth Element
MB	Mozambique Belt
Ms	Muscovite
Mcl	Microcline
Qtz	Quartz
Plg	Plagioclase
Opq	Opaque (Fe-Ti oxides)
Ppm	Parts per million
REE	Rare Earth Element
TAS	Total Alkali Silica
Wt%	Weight percent

CHAPTER ONE

1. INTRODUCTION

1.1. Background

East African Orogeny is the place where a complex history of magmatic, intra-oceanic and continental margin, metamorphic activity and tectonic thermal events are highly taken place. Tectonism and orogenic processes are often suggested the emplacement of syn- and post tectonic granitoid intrusions (Stern, 1994).The formation of orogenesis was interpreted by which is the result of collision between two Neoproterozoic continental masses, East Gondwana and West Gondwana (Stern, 1994; Kröner and Stern, 2005).It origins an interface between the lower crustal rocks found in the south EAO known as the Mozambique belt and upper crustal rocks of the northern Arabian-Nubian Shield (Blade et al., 2015). The MB and ANS terrains hold distinctive litho tectonics, which shows different lithological association, internal structure and grade of metamorphism activities(Blade et al., 2015). These are (1) granite-gneiss terrain, which contains both the high grade para and orthogenesis and deformed and metamorphosed granitoids and (2) the ophiolite fold and thrust belt, which comprise on the low-grade, mafic ultramafic and volcano-sedimentary assemblages (Allen and Tadesse, 2003).

MB and ANS in western Ethiopia and southern part and southeastern part of Sudan and northwestern Kenya, are not only possess the most southerly exposures of the ANS, yet it contains high-grade gneisses of possible MB affinities (Allen and Tadesse, 2003). The ANS is suggested to be a crust that was generated during the origin of smaller terrains of arc and back arc crust within and around the margins of a large oceanic tract show as the Mozambique Ocean, which formed in related with the breakup of Rodina during ~800–900 Ma (Stern, 1994). The formation of the ANS witnessed the emplacement of post tectonic A-type granites, sediments and bimodal volcanic and it identify strong extension caused by orogenic collapse at the end of the Neoprotozoic (Kröner and Stern, 2005).All granites are in a sense, fractionated rocks, high-temperature because they genesis are originally from a magma that was completely or largely molten intrusion of quartz-monzonite and monzogranite afterwards, extrusive volcanic were erupted and A-type granite was intruded (King et al., 2001)

The oldest rocks formed in the country belong to Precambrian era and they are formed before about 600–300 million years and include various lithological types more or less intensively affected by metamorphism: i.e. gneisses, phyllite, quartzite, schists, and granitoids, mafic and ultramafic in dikes, bodies or complexes of variable size (Getaneh et al., 1981). In Ethiopia, the Precambrian rocks comprise both the ANS in the north and the gneissic rocks of MB in the south (Ayalew, 1997).

The western Ethiopia shield have been contains high grade gneisses and migmatites, ophiolitic rocks and also consist of low to moderate grade of meta-sedimentary and meta-volcanic rocks that are intruded by deformed and undeformed ultramafic rocks (Asrat et.al. 2001). Granitoid rocks considered as pre-,syn- and post tectonic and accompanied by pegmatite ,aplite, quartz porphyry dikes and quartz veins are mostly exposed in the metamorphic terrains (Asrat et.al., 2001).The granitoids suites have variable composition, textures and structures and ages ranging from about 885Ma to 426 Ma(Asratetal.,2001;Lissan et.al.,2010).

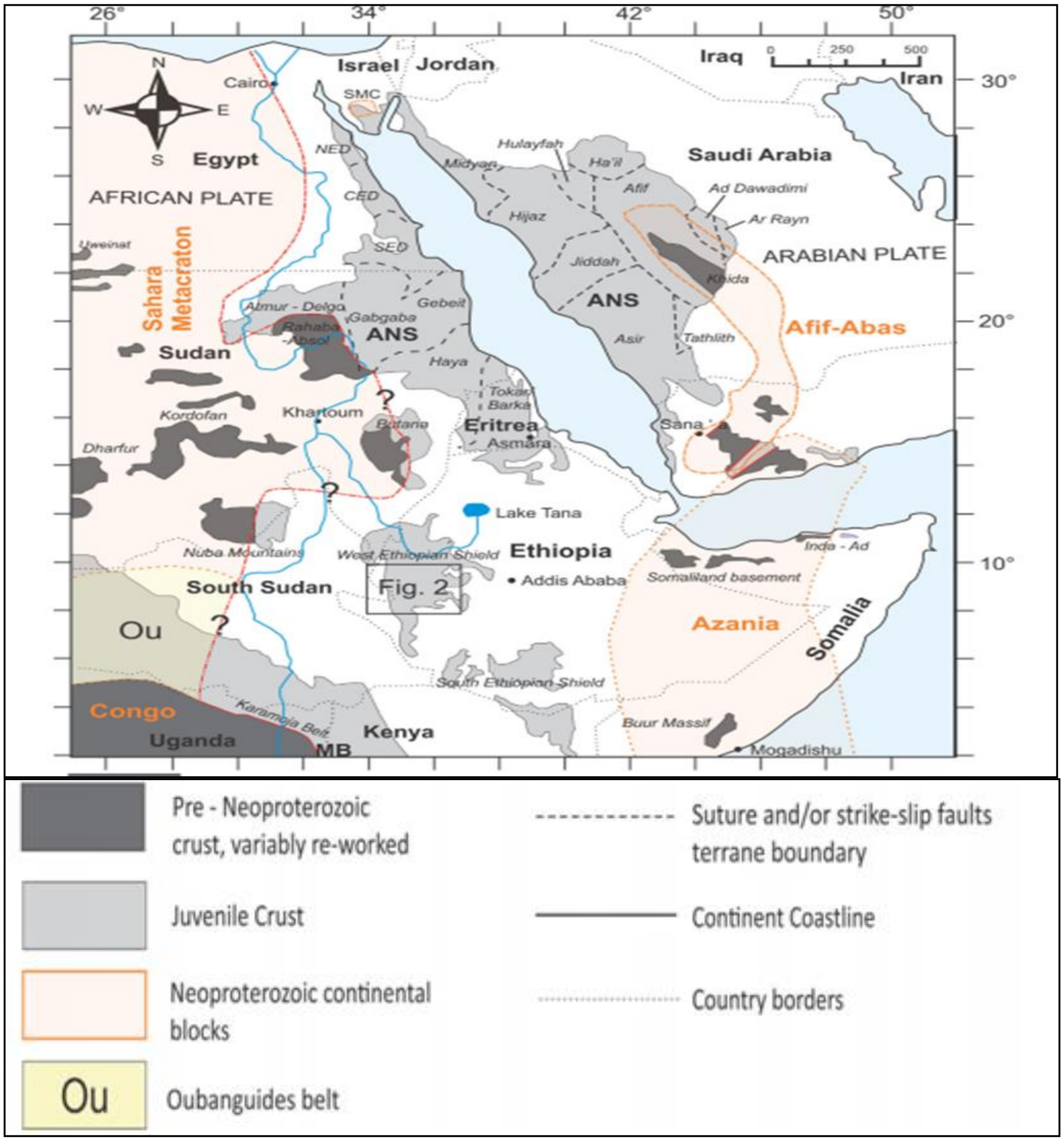

Figure 1.1 Map of East African Orogeny; SM, Sahara Met Craton; ANS, Arabian Nubian Shield. MB, Mozambique Belt, Sa'al Metamorphic complex; SMC. Adapted from Blades, et al., (2015) reference there in.

The crystalline basement shield in western Ethiopia contains two major rock types' high-grade gneisses which are more intensely migmatites units and meta-volcano-sedimentary green schist assemblages with associated linear belts of Yubdo-Dalatii-Tullu Dimtu ultramafic rocks (Kebede et al., 1999. Different models were suggested for the origin of granitoids, the first one is re-melting of previously melted granulite source rock which contained quartz, plagioclase alkali feldspar. This indicated that, partial melting of tonalitic to granodiorite crust to form A-type granite melts. The second model is Partial melting of dehydrate, which forms residue from the earlier I-type of magma by temperatures greater than $900C^0$ subduction-related tectonic setting. The others are by metasomatic origin and Differentiation from the mantle-derived basaltic magma during fractionation (Whalen et al. 1987, Kebede and Koeberl, 2003). The geochemical and mineralogical data for Homa gneissic granite, Ganji monzogranite, Tuppii granite, and Tullu Kapii quartz syenite of the western Ethiopian Precambrian terrain indicate that they represent within-plate granite (Kebede and Koeberl, 2003).Structural and metamorphic characteristic imply that the syn-kinematic Homa gneissic granite predates the emplacement of the Ganji, Tuppii, and Tullu Kapii granitoids (Kebede and Koeberl, 2003)

The petrology and geochemistry of the western part of Ethiopian shield specifically Gaba Sanbata area is not well studied. The current thesis present, detail analysis of these granitoids by providing the source of origin, characterize the geochemical signatures, description and systematic classifications of rocks, describe their textures, geological processes and tectonic setting is going to add new idea which is found in in Didesa domain (Allen and Tadesse, 2003). Therefore, in this study the geochemical and petrographic analyses of the granitoid rocks integrated with field observations are provide in all attempt to determine the petrogenesis and tectonic significance.

1.2 Geographic setting of the study area

1.2.1 Location and Accessibility

The selected study area, Gaba Sanbata, Eastern Gimbi is located in Oromia National Regional State in Gimbi woreda (Fig. 1.2). It is located at about 441 km from the capital, Addis Ababa and it is 508 from Bahir Dar town and can be accessed via the main road that joins Addis Ababa and West Wollega through Addis Ababa-Ambo-Nekemte-Gimbi. The site is located at about 30 Km to East of Gimbi and geographically bounded by 9° 00’ to 9°20’ latitude and 35°10’ to 35°60’longitude. It covers 170km^2 area.

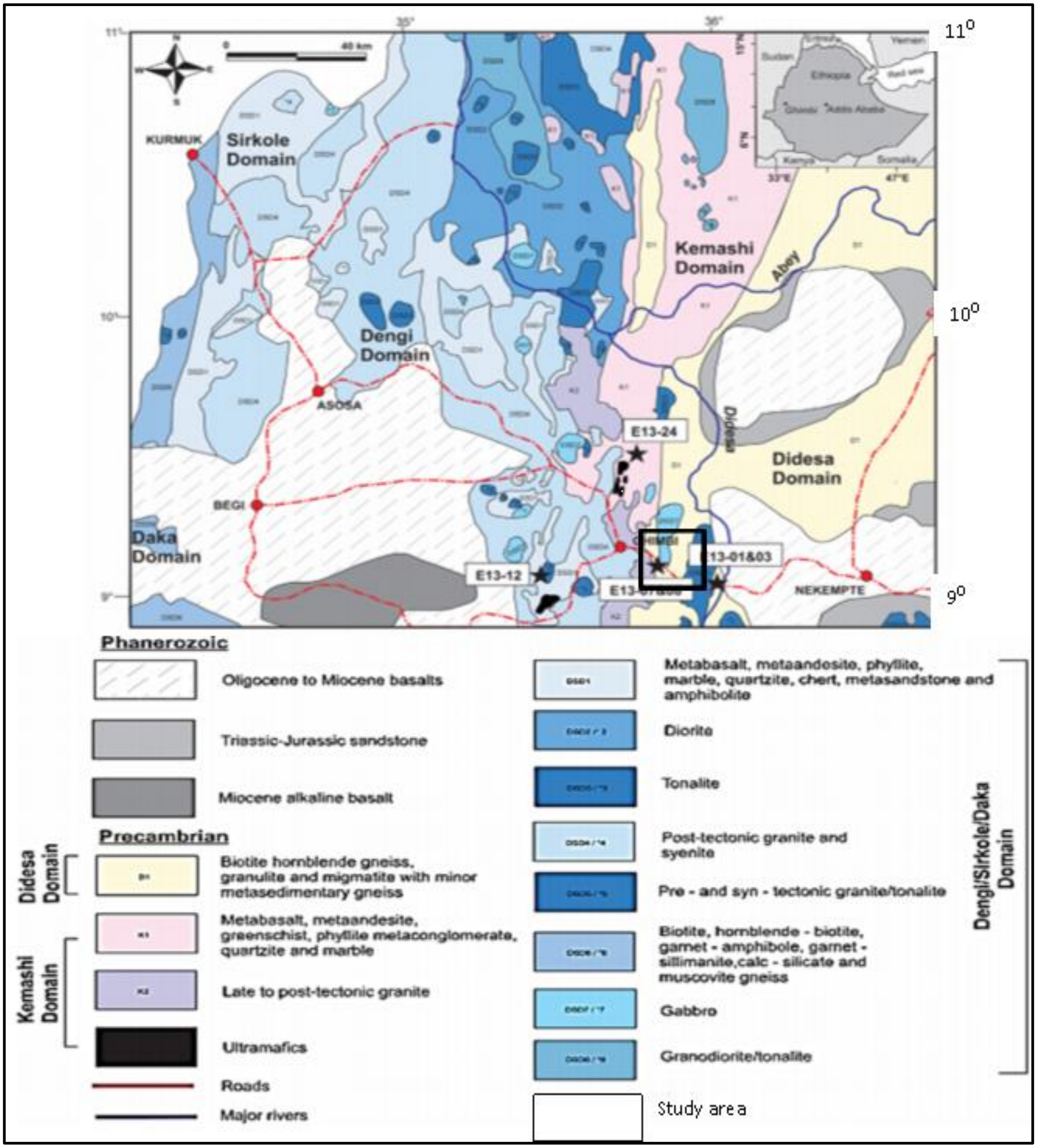

Figure 1.2 Simplified geological map of western Ethiopia (adopted from Teferra et al., 1996). The study area also located in western Ethiopia (2nd edition),scale 1:2,000,000, The Dengi,Sirkole and Daka domains are separated either by tectonic contact or are isolated by phanerizic cover (Blade et al.2015).The inset rectangule show the location of the study area.

1.2.2. Physiography

The physiography of study area is characterized by hill topographic terrains in the North Western and northern parts and some slightly flat topography at the central part of a cross the road. The granitoids and gabbro occupy of at mountainous elevation and the migmatites gneiss ,quartz vein rocks occupy the flat land areas. The western and north western parts of the study area are dominated by mountainous ranges, which consists of Precambrian metamorphic rocks such as meta-sedimentary and meta-volcanic rocks. The eastern parts of the study area have gentle and undulating topographic features.

1.2.3 Climate and vegetation

The climate condition of the study area is characterized by moderately humid to semi-arid with average annual temperature of 22.4^{o} C and annual rainfall of 1400 mm. The area gets high rainfall from June to September. The climatic data was gained from Gimbi Meteorological station, located in Gimbi woreda (2018/2019 GC). The study area is covered by grasses and different moderately vegetated and different types of grass and forests trees. The area is covered by short trees such as Savanna grass, scarce grasses, and long trees with small bushes cover and bamboo forest, and deciduous trees all parts. The geologic exposure of the area is found along the hill.

1.3 Research problem

The Western Ethiopian Precambrian shield comprises a low-grade volcano sedimentary assemblage and high grade Orth-and para-gneisses and forms the southern extension of the Arabian–Nubian Shield (ANS) that forms the northern-half of the East African Orogeny (Stern 1994). The western basement shield High grade gneisses and migmatites, ophiolitic rocks and low to moderate grade meta-sedimentary and Meta-volcanic rocks intruded by deformed and undeformed ultramafic, mafic, intermediate and felsic igneous bodies (Allene and Tadesse, 2003; Alemu and Abebe, 2000).Accordingly, geotectonic of evolution Western Ethiopia Shield has been interpreted in terms of early rifting and related sedimentation, followed by subduction and island-arc origins, arc-accretion and at the end of geotectonic, continent-continent collision and granitoids composition and different texture that the majority formations are tonalitic or granodiorite orthogenesis(Allen and Tadesse, 2003). As discussed by Kebede and Koeberl (2003) the metaluminous-per aluminous Homa and Tuppii granites have display chemical characteristics related to volcanic arc granites and within plate granite. A-type granitoid rocks of volcanic arc granitoids (VAG) and syn-collisional leucocratic granites are also studied from the western Ethiopia such as Guttin K-feldspar, Dhaga Boqa granite and Ujjukka granitoids (Kebede , 1999).

Due to this, the geology of any particular section of the western Ethiopia makes it difficult to correlate despite of the existing high quality geochemical data because the Wallagga granitoids are vary by tectonic setting and compositionally from place to place. In the current thesis, detail petrographic descriptions and geochemical analysis have been done to decipher geological processes, sources and tectonic setting of the granitoids.

1.5 Objectives

1.5.1 General Objective

The general objective of this research is to determine the petrogenesis of granitoid rocks around Gaba Sanbata area.

1.5.2 Specific Objectives

- To produce the geological map of the study area at the scale of 1:50,000
- To determine and interpret the petrographic and geochemistry of the granitoid rocks
- To evaluate the possible source of the granitoid rocks of the area
- To determine the tectonic setting of the granitoid rocks of the area.

2. Methodology and Materials

2.1 Methodology

In order to achieve the objectives, different methods and techniques have been applied. Field observation, analytical methods such as petrographic, geochemical and detail field mapping by delineating the study area. During this work digital image processing techniques and GIS software have been used to produce geological map of study area.

2.1.1 Petrography description

After the field work, lithological units collected from the field have been done in the Geological Survey of Ethiopia .Twelve representative fresh rock samples collected from different lithological units were sent to GSE central laboratory for thin section making. The samples have been selected based on the different lithological and sample spatial variation. The fresh parts of the samples cut with a diamond saw before preparation and ground optically flat. It mounted on a glass slide and the put ground smooth using progressively finer abrasive grit until the sample is 0.03 mm thickness. Modal analysis the common procedure to estimate the composition of minerals. Detail petrographic or thin section description was under taken by transmitted light microscope for mineral identification, estimate modal proportion, textural descriptions carried out. These petrographic data have been used to provide petrological conclusions such as textures, mineral assemblages and cooling history of magma and time of cooling

2.1.2 Geochemical analysis

Eight representative samples were analyzed abroad for major and trace element geochemical determination by ICP-AES and ICP-MS methods respectively based on the lithological variation and sample distribution. To minimize and remove 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 and washed out to clean and remove any possible contaminant for each sample powdering. The sample preparation for geochemical analysis includes making a rock powder after removing moisture content of rock through heating of crushed rock sample (100°C). During preparation rock sample for geochemical analysis the procedures followed are; first crushing the broken fresh sample in a jaw crusher, after that removing the moisture content from crushed rocks at 100°C for 24 hours, and finally the crushed sample milled down to micron size particles in an agate ball automatic milling machine to size of less than 75µm . Concentration of major and selected trace elements in samples were determined by combined of methods of Inductively Coupled Plasma-Mass Spectrometry (ME-MS81) and Atomic Emission Spectrometry (ME-ICP06), base metals such as Ni and Pb by four-acid digestion (code: ME-4ACD8) Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). This done to ALS services PLC laboratory in Ireland for determinations of major and trace element concentration. The powdered sample (0.65Kg) was added to lithium metaborate/lithium tetraborate flux (0.90 g) to analyze whole rock chemistry. Reproducibility and accuracy of the study samples are analyzed results were checked by using blank, AMIS0304, OREAS 102a duplicated sample. Finally, the data are presented in the form of Text, Tables, Figures, graphs, maps and reports.

2.2 Materials.

Different materials and software needed to analysis the geochemistry and identify study area. The software such as Arc GIS 10.3, R- software, GCD kit 4.1(petrography beta ex), google earth and different plotting software used to prepare geological map and to plot the geochemical and petrographic data of the analyzed sample.

2.3 Significances of the research work

- To give petrographic description and the major element and trace element with geochemical signature of the rocks in Gaba Sanbata area.
- It contributes some input to the future study of research and project and evolution history on Western Ethiopia plutonic rocks.
- Now a day's, plutonic rocks are quite increasingly required by companies, Public interest groups and private sectors for purpose of working dimensional stone and crushed specially granitoids rocks for infrastructural developments. Therefore, this work can be an input for them.

CHAPTER-TWO

2. REGIONAL OF GEOLOGICAL SETTING

2.1. THE EAST AFRICAN OROGEN

EAO developed due to the collision of East and West Gondwanaland during the late Proterozoic, which finally formed the Gondwanaland Supercontinent (De Wit and Chewaka, 1981; Stern, 1994; Stern, 2005). The terrains that north lies the broadly juvenile ANS combined upper crustal and the south part is the MB which are lower crustal (Yibas et al.,2003 ,Woldemichael et al., 2010 ; Johnson et al., 2011;Blades et .al.,2015). ANS shield is crustal back bone of northern Ethiopia (Asrat et al., 2001). The crust largest tract of the juvenile continental crust originated during Neoproterozoic age and affected by the Pan -African orogenic cycle (Kröner and Stern, 2005, Tadesse and Allen, 2005). ANS is Northern half of the EAO and stretches from southern Israel and Jordan as far as Ethiopia and Yemen, which it makes transition to the MB (Yibas et. al.2003; Kröner & Stern, 2005; Blades et. al.,2015).

In the south it comprising more pre Neoproterozoic crust with a Neoproterozoic– early Cambrian dominate (Johnson et al., 2011, Blade et.al 2015). In the EAO southern part is contains medium to high grade gneiss and granitoids (Kröner and Stern, 2005). Generally, the well-established Precambrian outcrops in this part of the MB include Precambrian basement rocks of Southern Kenya, Southern Ethiopia, Eastern Ethiopia, Northern Somalia, Western Ethiopia and to small amount of Northern Ethiopia (Kazmin et al.,1978, Alemu and Abebe, 2007).Plate tectonic cycle spanning, beginning by about 900 Ma with rifting and continental break-up and ending by about 550 Ma subsequent to a continental convergence between East and West Gondwana (Abdelsalam and Stern, 1996; Blade et.al., 2015). The Pan-African domains, composed of two broad types of mobile belts. One of the orogenic types consists predominantly of Neoproterozoic supra crustal and magmatic assemblages, many of mantles derived origin, with different structural and deformation histories that are similar to those in Phanerozoic collision. These orogenic or belts expose upper to middle crustal levels and contain diagnostic features such as ophiolites, subduction or collision-related within granitoids, island-arc evolution in Phanerozoic style plate tectonic (Blade et.al 2015).

Depending on the tectonic evolution of the EAO, the area contains (fig 2.1) : 1) Rodina rifting that are formed by the evolution and break-up at approximately 900-850 Ma; (2) seafloor spreading, arc and back-arc basin originations and terrane accretion starting from 870 until 690 Ma; (3) continent-continent collision begin from 630 to 600 Ma, and (4) more crustal shortening, orogenic collapse and extension leading to the break-up of Gondwana during the age of 600 to 540 Ma (de Wit and Chewaka 1981; Stern 1994,Abdelsalam and Stern, 1996). Crustal and lithospheric reworking; continued shortening, deposition and magmatism escape tectonics and orogenic collapse 600-650 Ma (Kröner and Stern, 2005)

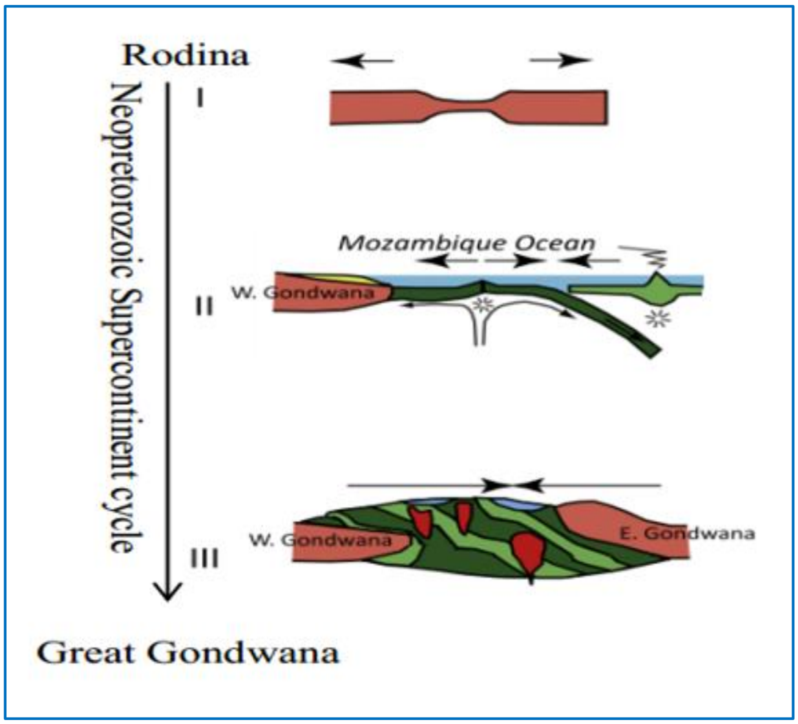

Figure 2.1 Tectonic Evolution of the Arabian-Nubian Shield (Kröner and Stern, 2005)

2.2 Geology of the Ethiopian basement rocks

The Ethiopian basement rocks are exposed in western, northern, eastern, and southern parts of the country (Alene et al., 2000, 2006, Asrat et al., 2001). Neoproterozoic crystalline basement terrain ranging in age from 880 to 550 Ma and exposed in the southern and western and to a less extent, in the northern part of Ethiopia Alene et al., 2000, 2006).

The Ethiopian basement rocks are exposed in areas not intensively affected by Cenozoic volcanism and rifting and when the Phanerozoic cover rocks have been eroded away (Tefera et al. 1996). In northern part of Ethiopia the Nubian portion of the Shield is prevail highly dominantly low-grade meta-volcano sedimentary rocks. The age of Ethiopian basement rocks have been studied by several authors (Kazmin, 1971, 1975; Beyth, 1972; Kazmin et al., 1978; de Wit and Chewaka, 1981; Ayalew et al., 1990; Tadesse, 1996;Tadesse et al., 1997; Alemu, 1998; Teklay et al.,1998; Alene et al., 2000, 2006; Asrat et al., 2001 Yibas et al., 2002,2000; Avigad et al.,2007; Blade et al.,2019). According to Kazmin (1971, 1975) the basement rocks of Ethiopia are subdivided into Lower, Middle, and Upper Complexes depending on compositional, deformational and metamorphic grade variations. But recently, the subdivision of basement shield has been studied based on the geochronological and isotopic data (Ayalew et al., 1990; Teklay et al., 1998;Gerra, 2000). The two litho tectonic terranes classification which show contrasting lithological association, internal structures and grade of metamorphism (Yibas et al., 2000;Yibas, 2003), as (1) the granite-gneiss terrane which are contains of high-grade, para- and ortho-gneisses and deformed and metamorphosed and granitoids; includes, Lower and Middle Complex of (Kazmin,1971, 1975) old classification and (2) the ophiolitic fold and thrust belts are contains low-grade, mafic–ultramafic and sedimentary assemblage

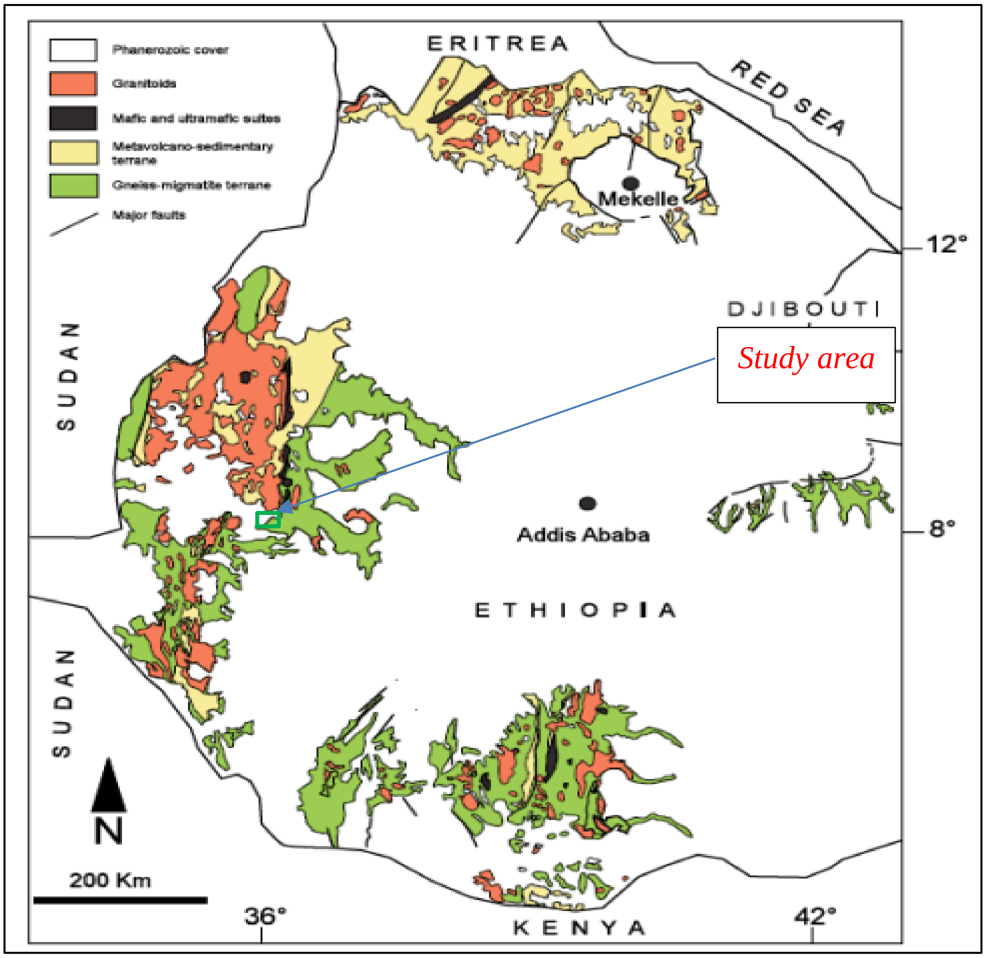

Figure 2.2 Distribution of Ethiopian Precambrian basement rocks (adapted from Asrat, 2001)

2.3 Lithology and tectonics of western Ethiopia basement rocks

2.3.1 Didesa Domains

The Didesa domain extends from East of Didesa River in area covering about 90km up to about 25km East of Gimbi town. The lithology of this domain are high grade of para-gneisses which consist of interlayered highly biotite amphibole gneiss, quartzo feldspathic gneiss, garnet-biotite gneiss and Orth-gneisses which consist banded mafic gneiss and quartz vein (Allen and Tadesse, 2003,Alemu and Abebe (2002)). According to Allen and Tadesse, (2003) banded mafic gneisses in ortho gneisses of the Didesa domain contain an ultramafic bands derived from a layered mafic intrusive rock body and very coarse grained granitoid gneiss and intruded by Neoproterozoic intrusive rocks such as gabbro.

2.3.2 Birbir Domain

The Birbir domain consists meta-sedimentary and meta-volcanics rock including mafic to felsic intrusive and extrusive rock. The metasedimentary rock contains metagraywacke, pelite, and volcanoclastic and carbonate rocks (Ayalew et al, 1990; Allen and Tadesse 2003). The foliation feature of the Birbir domain were the result of syn-tectonic recrystallization during the early stage shearing and folding episodes (Ayalew, 1997). According to Ayalew (1997) the structural features (such as foliation) of Birbir domain display the strike orientation of north-south and dip to west.

2.3.3 Kemashi Domain

Kemashi domain is located to the western of Didesa domain in the West Ethiopian shield basement. The Kemashi domain is forms a narrow N-S strip that is 10–15 km wide paralleling the trend of Tulu Dimtu belt (Blade et. al., 2015). It contains different lithological units and is characterized by a sequence of metasedimentary rocks, interlayered with abundant mafic to ultramafic rocks (Blade et al., 2015).Low grade metasedimentary rocks like marine origin which are highly pelitic to psammatic schist, intercalated with chert, graphitic phyllite and marble, and ultramafic–mafic, Metavolcanic rocks (Allen and Tadesse, 2003).

2.3.4. Dengi Domain

The Dengi domain contains different lithological units, which are characterizing deformed ,undeformed, metamorphism and volcano sedimentary sequence, a coarse-grained para- and ortho-gneissic unit and mafic to felsic intrusive bodies intruding to the later. The west of the Kemashi Domain indicate two pulses of magmatism at 850–840 Ma and 780–760 Ma in similar way to Didesa domain (Blades et al, 2015). The low-grade metasedimentary rocks, mafic to felsic metavolcanics rocks and moderate grade gneisses intruded by deformed and undeformed gabbroic to granitoid bodies are also highly dominate (Allen and Tadesse, 2003). The gneissic assemblage consists of biotite hornblende paragneisses and pelitic gneiss, together with mafic and garnet ferrous granitoid ortho gneiss. The domain gneisses are locally migmatised, and the assemblage as a whole is intensely folded and veined (Allen and Tadesse, 2003)

2.3.5 Sirkole domains

The Sirkole Domain is extending into Sudan and consists of different N–S elongated blocks which have only a small km widths. It consists of either medium grade gneisses or metavolcanics rocks intruded which are foliated and massive granitoids. It is different lithological units. Those units are alternating sequences of moderate grade polydeformed, low- to moderate-grade metasedimentary rocks metamorphosed gneisses, mafic to felsic metavolcanic rocks intruded by deformed and undeformed granitoid plutons rocks (Allen and Tadesse, 2003). The second lithology unit is Yangu Granitoid, large homogeneous anatectic granite gneiss originated by partial melting of the Tosho Gneiss (Allen and Tadesse, 2003). The volcano-sedimentary succession encompasses a thick sequence of mafic metavolcanic and interbedded metasedimentary rocks subjected to folding and strong cleavage. The volcano-sedimentary succession is folded and strongly cleaved with an N–S striking, easterly dipping schistosity and stretching lineation plunging gently eastwards (Allen and Tadesse 2003).

2.3.6 Daka domain

Daka domain are predominantly gneissic and they are extends in to Sudan. They are known by three lithological units which are correlated by with two gneissic group (Allen and Tadesse, 2003). According to (Allen and Tadesse, 2003), the two rock units with the two gneissic units of the Sirkole Domain, i.e. the Tosho Gneiss, and the Yangu Granitoid Gneiss correlated. The lithological unit of relationships is more clearly delineated in this domain. The Tosho gneiss which are belongs to amphibolite facies and grades from east to west into the granitoid gneiss through a zone of increasing metamorphic grade and migmatisation. The increment in grade of metamorphism of Tosho gneiss towards the west is interpreted to represent origin of Yangu granitoids by anatectic partial melting of the Tosho Gneisses. Daka Domain's another gneissic unit is a banded orthopyroxene-bearing granulite facies unit termed Daka Gneiss (Allen and Tadesse, 2003).

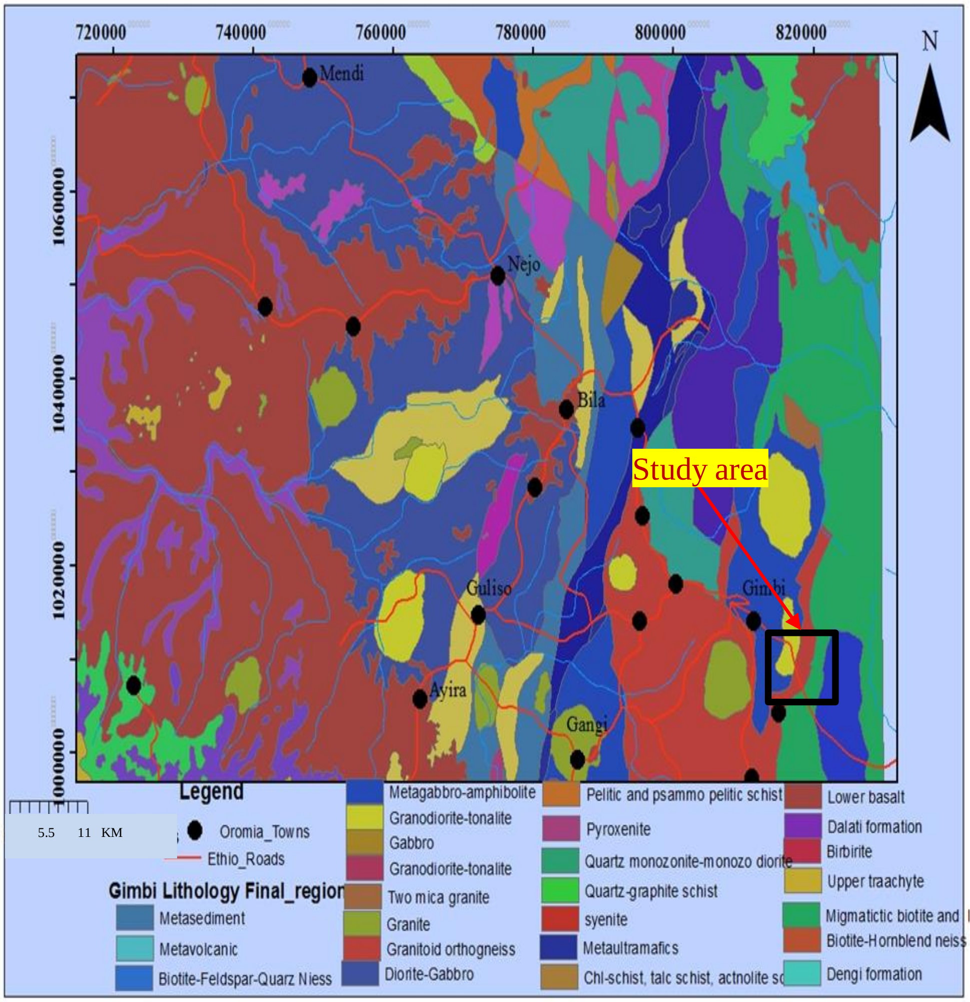

Figure 2.3 Geological Map of Gimbi Area at scale of 1:250,000(adapted from Alemu and Abebe, 2000). Inset rectangle indicates the location of the study area.

CHAPTER-THREE

3. GEOLOGY AND PETROGRAPHY OF THE STUDY AREA

The study area is located in the western part of Ethiopia and covered wider range of granitoids units . The area is composed of Post-Pan-African plutons (granitoids). It consists of mainly quartz vein and quartzite, high grade metamorphic rocks, intrusive rocks such as gabbro and granitoids. The main lithological units are intruded by post tectonic magmatism. Granitoids of the study area covers approximately 80% of outcrop.

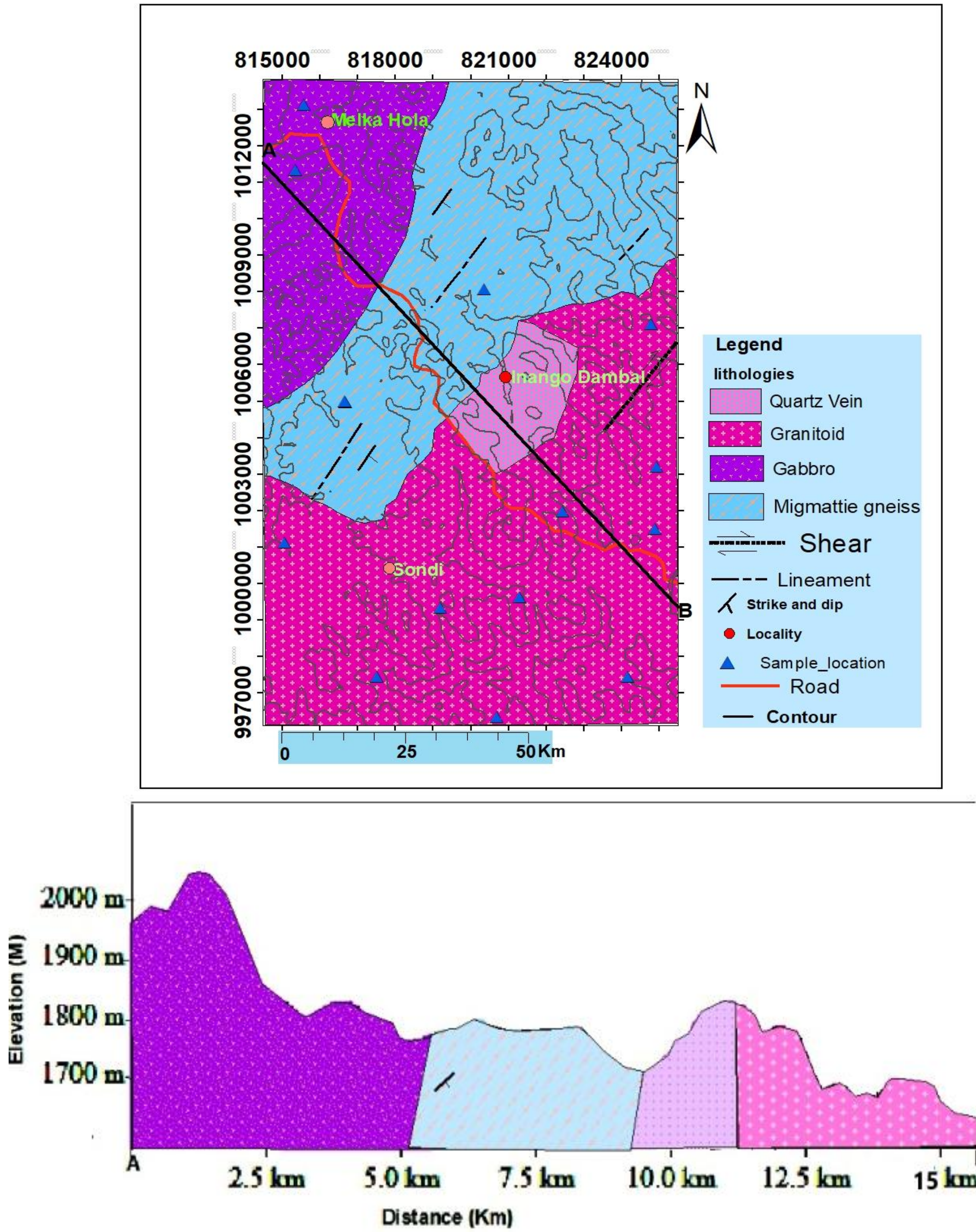

Figure 3.1 Geological map and cross section of the study area at scale of 1:50,000.

3.1 Intrusive bodies of the study area

3.1.1 Granitoids

Gaba Sanbata area granitoids are characterized by massive, light grey to dark grey, pinkish to white in color, covers an approximated area of ~ 90 km ^{2}. The granitoids in the study area outcropped in the hill side and flat lands (figure 3.2 a) and the outcrops display sub-circular, circular and elliptical shapes. The dominant lithologic unit in the study area is alkali rich granite. These alkali-feldspar granite rock appear to light to pinkish grey in color, coarse grained and forming small hill (figure 3.2 a). They are mainly composed of quartz, K-feldspar, microcline and mica group minerals such as biotite and muscovite (Figure 3.2 d).The Gudare and Sondi granitoids are the highly fractured and weathered features. Texturally, most of granitoids of study area ranges from equigranular, porphyritic, medium grained to phaneritic (figure 3.2 c and d). The alkali-feldspars which have been equigranular, very coarse grained, granular texture are (figure 3.4 c) highly observed.

Figure 3.2 Field photographs of granitoids rocks a) granitoid rocks of area from hill/ridge, blocky and patterns with irregular shape of granitoids which are describe in figure D b) fracture which have orientation like mud crack patterns with irregular surface of the granitoids c) very coarse grained, pegmatite textures which contains both pinkish and white color of granite which are due to form at low temperature d) fine grained textures and light color of granitoids and major mineral constitutes of alkali granite rocks of the area

Figure 3.3 Field photographs of granitoids units characteristics through my the study area a) very massive light to dark of mica rich granitoids c) Ductile deformation that form fold in the granitoids d) joint aperture which are 3cm in measurement

3.1.2 Gabbro

The subordinate gabbroic rocks in the study area are spatially associated with migmatites gneiss and some exposed in localities near Melka Hola. South Eastern part of (fig 3.4b) study area gabbro rock unit is not well exposed to the surface due to the overlaying thick which are 3m thickness soil coverage but the Melka Hola and west North of the study area of gabbro units are exposed (Fig. 3.4a).Texturally, it varies from medium to coarse grained and the color ranges from light gray to dark. This massive gabbro typically consists of variable crystals such as plagioclase, pyroxene, and hornblende. They are contains elliptical to sub elliptical shape.

Figure 3.4 Field photographs of gabbroic exposure a) an elliptical gabbro units, (b) gabbro which are not expose due to thickness of soil

3.2 Quartz vein

The quartz vein are distributed throughout the study area, especially it related with the quartzite rocks unit , migmatites gneiss and granitoid rocks. They are antitaxial veins; formed when the vein material (quartz) have different composition to that of host rocks. The quartz vein outcrops are exposed around Inanago Danbali area with the intercalations of small amount monomineralic quartz. The color of quartzite ranges from white to pink due to the presence of feldspar minerals (fig 3.2 a and b). The field investigation show different geological structurals such as slightly fractured and have been discordant to the host rock. The outcrops of the rock unit are characterized by fine grained, weakly weathered, reddish to white.

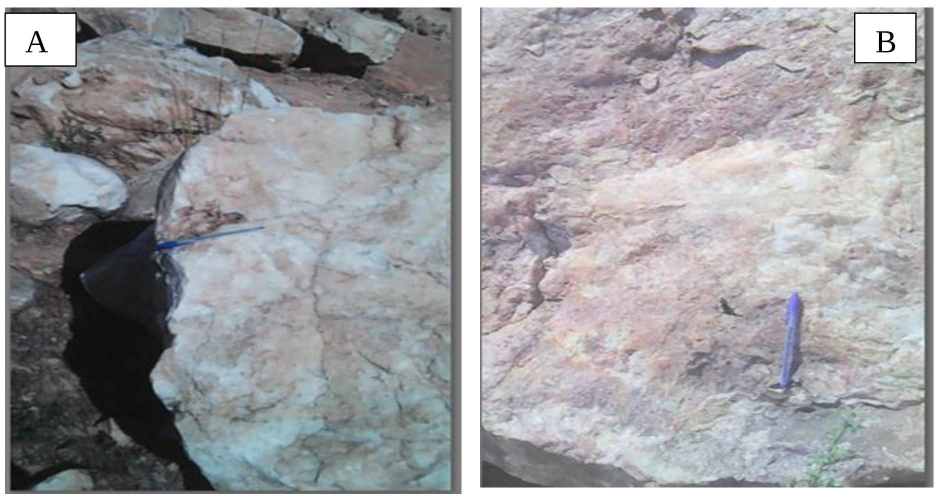

Figure 3.5 Field photo characteristics of quartz vein. (a) Massive and veins of quartz (b) Massive and pinkish color of feldspar rich of quartzite

3.3 Petrographic descriptions

Modal analysis is one of the common procedure to study the petrographic feature of granitoids. Petrographically, the studied granitoids are classified based on the Qtz-Kfs-Pl (Streckeisen, 1976). The studied samples are classified into alkali feldspar granite and syenogranite based on the modal analysis. For petrographic study representative twelve (12) samples have been selected (i.e. MD2, MD5, MD8, MD9, MD10, MD12, MD13, MD21, MD22, MD25, MD31and MD 34). Petrographic study of representative samples of granitoids rock indicate that the rock is highly dominated by quartz and feldspars. The dominant minerals are k-feldspar (~30 to 45%), quartz (~30%), plagioclase (~ 20 - 30 %), mica (biotite and muscovite) (~<15 %) and opaque (~3%). Moreover, accessory minerals such as illeminte, titanite and apatite minerals are also observed. Undeformed rocks of granitoids display hypidiomorphic, coarse grained, equigranular and inquigranular textures.

Table 3.1 Average modal estimation of the Gaba Sanbata granitoids (values in wt %)

S/No	Sample code	Mineral assemblages							
		Qtz	Kfs	Pl	Bt	OP	Tit	Ap	Total
1	MD2	26.84	38.30	25.56	8.34	2.53	+	+	101.57
2	MD5	30.32	38.54	28.00	3.00	0.25	-	+	100.11
3	MD8	25.40	54.00	19.23	1.50	-	+	+	99.13
4	MD9	29.00	44.50	21.23	2.30	1.5	+	-	98.53
5	MD10	35.13	42.35	17.32	3.00	2.14	+	+	99.94
6	MD12	29.54	39.00	25.25	4.25	+	+	+	98.04
7	MD13	31.25	43.50	21.76	2.00	+	+	+	98.51
8	MD21	32.12	41.40	23.60	3.75	-	+	+	100.87

Quartz crystals commonly display anhedral shape. The plagioclase crystals show subhedral to euhedral shape and sometimes display zoning features. The large grain size which ae 1.5mm-3mm assemblage of mineral is feldspars groups of grain of K-rich and sodium rich feldspars which have dark gray. Generally, the overall texture of the studied samples varies from medium to course grained (1-3mm in crystal size). Sometimes the quartz crystals appear as xenomorphic in the studied samples. In addition, granophyric intergrowth of quartz and feldspar were also observed. opaque mineral grain shows subhedral in which the developments of crystal face are medium. Sometimes the plagioclase crystals display polysynthetic twinning. Therefore thin section observation and description the rock sample of an area is mainly dominated by alkali feldspar, quartz and plagioclase minerals in addition to these minerals that incorporation like muscovite, opaque minerals area involved.

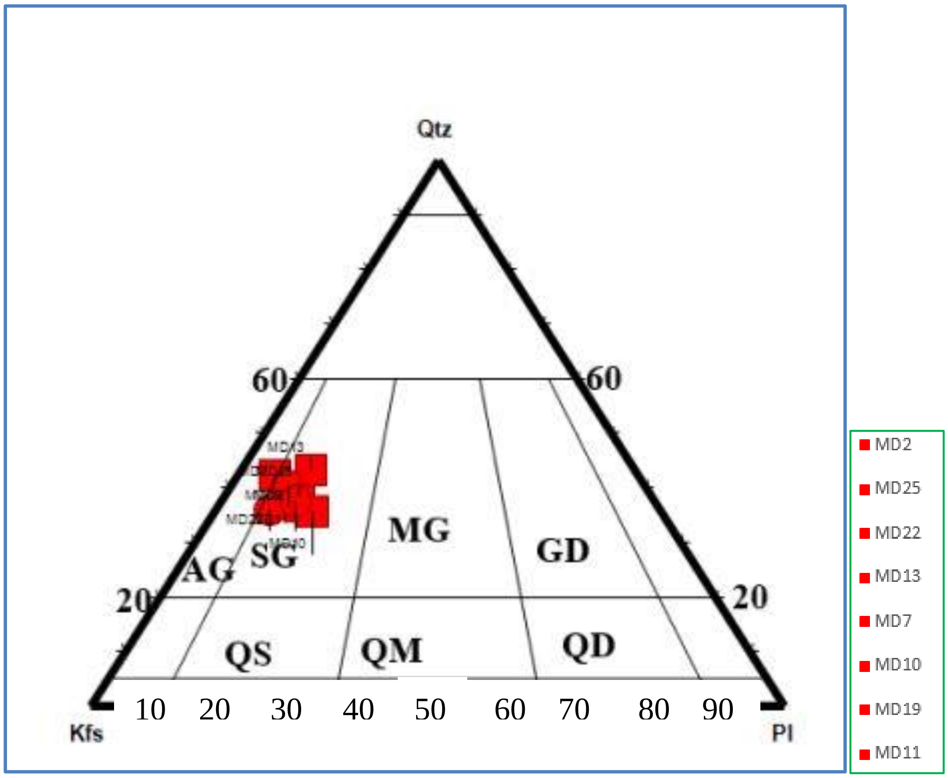

Figure 3.6 Modal classification based on quartz (Qtz), K-feldspar (Kfs), plagioclase (Pl) ternary diagram for Gaba Sanbata granitoids, where SG: Syenogranite, AG: alkali-feldspar Granite; MG: monzogranite and GD: granodiorite; QS: quartz syenite; QM: Quartz monzogranite; QD: Quartz monzodiorite; Fields and nomenclature after Streckeisen (1976) and mineral Abbreviations taken from Kretz (1983)

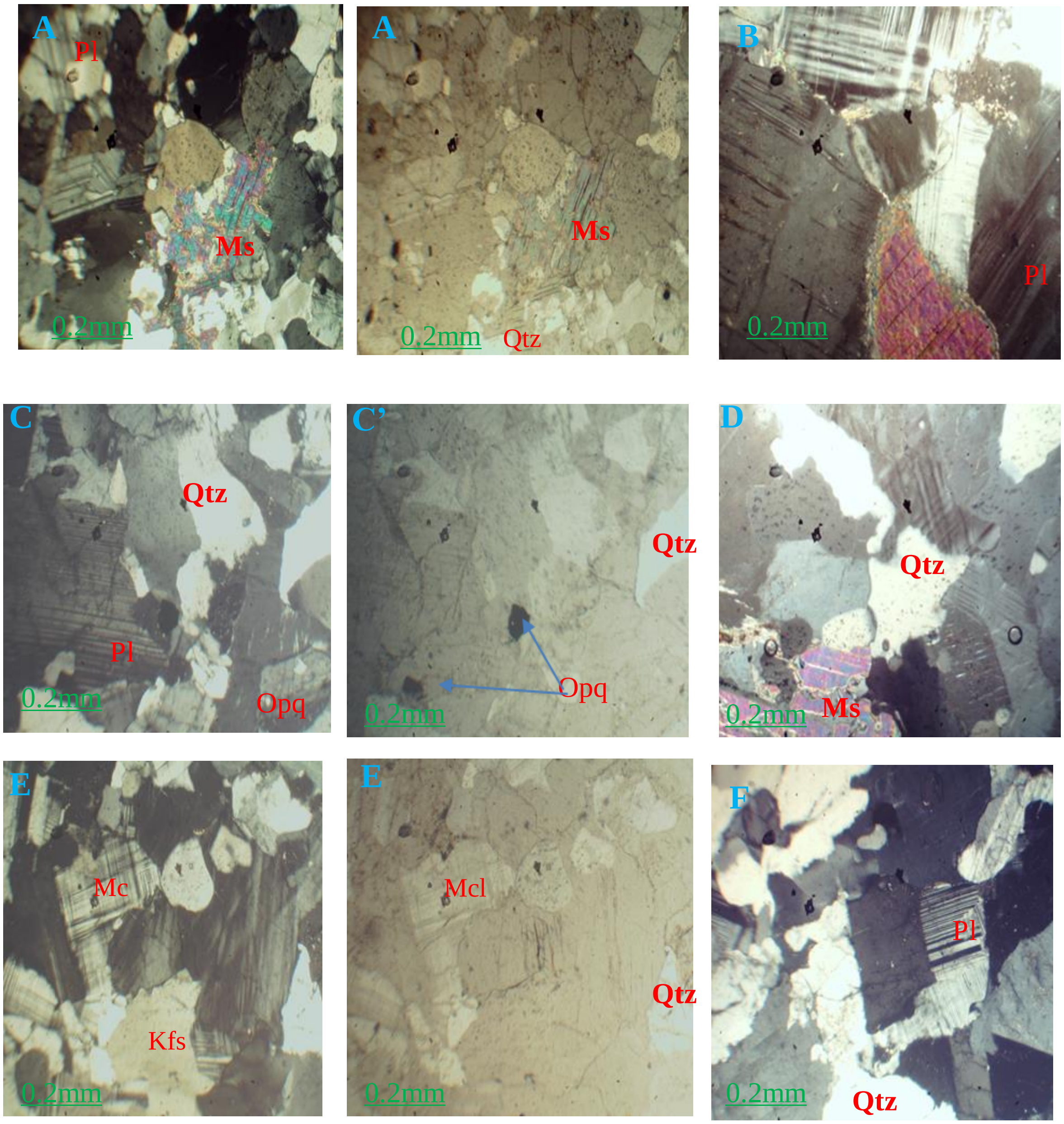

Figure 3.7 Microscopic images of Gaba Sanbata granitoids under XPL (A, B, C, D, E, and F) and PPL (A' C' and E'). at the magnification of 10x (A) granite rocks of microcline with cross hatch twinning and Pl minerals with some Ms and muscovite show elongate shape B)large crystal of microcline with other minerals of plagioclase in opaque units C) elongate shape of plagioclase with opaque D)large crystal size of Kfs ,Qtz and Pl with irregular crystal shape of quartz

CHAPTER-FOUR

4. Whole-rock Geochemistry

This thesis presented the geochemical characteristics of granitoids from Gaba Sanbata area. The chemical composition variation in various geological activities (environments) of the magma is due to partial melting ,fractional crystallization, magma mixing, contamination or mixing processes (Rollinson, 1993).The major elements mainly have been used to classify igneous rocks and study the chemical evolution of magma during the fractional crystallization or melting (Rollinson, 1993), while the concentration and distribution of trace element can be used to constrain magma sources and discriminate tectonic setting between some magmatic evolution processes. The concentration of trace elements are mainly controlled by the minor phase change, mixed source, volatile interaction, variable partial melting and restite accumulation in the magmatic evolution (Feininger, 2001). According to (Rollinson, 1993; Feininger, 2001) the errors and all elements and minerals found in the rocks are not analyzed, due to this total of analyzed sample lies between 98.8 wt % and 100.8 wt %, it is considered to be acceptable. All of the analyzed sample in the study area lies between 98.8 wt % and 101.06 wt % and the loss on ignition (LOI) of samples ranges from 0.25 to 0.43 wt. %. Therefore, it is considered to be acceptable and all samples collected are free from alteration and fresh samples. The major oxides, trace and rare earth elements reports are given in table 4.1 below.

Sample In wt%	Granitoids							
	MD2	MD25	MD22	MD13	MD7	MD10	MD19	MD11
SiO_2	74.40	72.30	75.10	74.90	73.40	73.90	75.10	76.50
Al_2O_3	13.35	14.50	13.95	14.15	14.15	13.65	13.60	13.30
Fe_2O_3	1.00	1.29	0.96	0.84	0 .89	1.04	1.00	0.75
$Fe_2O_{3(T)}$	0.89	1.16	0.86	0.76	0.80	0.94	0.89	0.67
CaO	1.12	0.87	0.94	0.88	0.83	0.63	0.88	0.73
MgO	0.07	0.13	0.05	0.05	0.07	0.04	0.04	0.04
Na_2O	5.03	4.08	5.69	5.67	4.81	4.45	4.76	4.77
K_2O	3.39	6.24	3.66	3.56	4.97	5.04	4.52	4.59
TiO_2	0.05	0.09	0.03	0.04	0.05	0.04	0.03	0.04
MnO	0.02	0.02	0.06	0.03	0.01	0.09	0.04	0.04
P_2O_5	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01
LOI	0.37	0.25	0.31	0.38	0.30	0.25	0.43	0.29
Total	98.82	99.8	100.76	100.52	99.49	99.14	100.41	101.06
Trace element (ppm)								
Ba	50.20	49.90	1.90	1.90	4.80	1.20	8.60	6.10
Rb	4.30	3.30	3.10	3.70	1.90	5.70	2. 80	3.60
Cr	30.00	30.00	40.00	30.00	30.00	40.00	30.00	30.00
Ho	4.10	4.00	2.10	1.80	3.40	3.50	2.20	2.30
Nb	17.70	18.80	45.40	50.80	14.40	54.30	14.60	56.10
Nd	4.10	3.80	3.40	4.30	1.50	7.40	3.00	3.80
Sr	32.6	45.90	3.30	3.10	14.60	3.30	10.50	9.30
Ta	3.50	2.10	3.70	3.10	2.10	5.40	2.00	4.40
Th	23.60	16.30	5.76	6.55	16.35	11.20	12.75	10.00
U	12.05	5.63	18.05	17.35	18.2	27.5	6.62	50.4
W	4 .00	<1.00	1 .00	1.00	1.00	2.00	1.00	3.00
Y	18.80	14.60	32.10	33.00	18.10	47.80	28.20	23.50
Yb	2.66	1.85	3.91	3.09	1.92	6.11	2.45	3.49
Zr	71.00	73.00	21.00	17.00	49.00	32.00	29.00	23.00
Cu	9.00	4.00	2.00	1.00	<1.00	1.00	1.00	2.00

Li	30.00	60.00	30.00	40.00	40.00	30.00	40.00	40.00
Pb	34.00	34.00	38.00	35.00	38.00	41.00	35.00	44.00
Sc	2.00	3.00	3.00	7.00	2.00	7.00	2.00	2.00
Zn	32.00	59.00	31.00	17.00	44.00	23.00	25.00	29.00
REE(Ppm)								
Ce								
CS	6.00	6.30	5.50	6.60	3.10	11.40	4.80	6.30
Dy	2.19	4.47	2.17	1.7 0	3.05	4.39	1.83	2.60
Er	2.19	2.16	5.96	6.59	2.57	8.21	3.94	4.30
Eu	2.02	1.57	3.72	3.54	1.68	5.68	2.34	3.10
Ga	0.28	0.40	0.15	0.11	0.26	0.13	0.19	0.15
Gd	20.70	22.60	25.50	27.80	24.10	28.30	23.6	21.70
La	1.84	1.77	3.83	4.36	1.59	4.53	2.87	2.32
Lu	4.30	3.30	3.10	3.70	1.90	5.70	2.80	3.60
Pr	0.42	0.26	0.52	0.43	0.29	0.88	0.31	0.47
Sm	1.03	0.87	0.72	0.92	0.40	1.60	0.63	0.81
Sn	1.43	1.16	2.05	2.22	0.67	2.95	1.55	1.45
Tb	2.00	3.00	2.00	5.00	2.00	5.00	2.00	2.00
Tm	0.41	0.30	0.83	0.90	0.33	1.10	0.60	0.57
(Eu/Eu*)N	0.37	0.25	0.54	0.49	0.31	0.97	0.36	0.49
LaN/YbN	0.53	0.85	0.16	0.11	0.77	0.11	0.28	0.25
Rb/Sr	1.16	1.28	0.56	0.85	0.71	0.67	0.82	0.74
Rb/Zr	5.49	6.10	69.09	73.87	19.65	93.03	22.28	30.96
Rb/Ba	2.52	3.83	10.85	13.47	5.85	9.59	8.06	12.52
	3.56	5.66	120	120.5	59.79	255.83	27.20	47.21

Table 4 1 Major, trace elements and REE element analytical results of the granitoids rocks collected from the Gaba Sanbata area. FeOt=Fe2O3* 0.9 + Fe_2O_3 (Rollinson, 1993), Eu/Eu*=Eu/EuN/√SmN*xGdN (Rollinson, 1993), and normalized Sun and McDonough, 1989

4.1 Major element

Gaba Sanbata granitoid rocks are classified as granite (figure 4. 1). On the AFM plot (Irvine and Baragar, 1971), (Fig.4.5) to discriminate between calc-alkaline and tholeiitic suites, all studied samples occupy the calc-alkaline affinity indicating their (Na_2O+K_2O) rich nature. All studied sample are occupying the high-K calc alkaline Series with exception of one sample from shoshonitic series (Fig 4.6). From the (figure 4.7) diagram Gaba Sanbata granite show that the studied samples are metaluminous. The A/CNK and A/NK ratios for the majority of the samples are less than 1 (figure 4.7).

Major element oxides selected such as Al_2O_3,CaO,MgO, Na_2O ,K_2O,TiO_2, $Fe_2O_{3(T)}$ plotted against SiO_2 concentrations in (Figure 4.4). All of the granite samples are characterized by high silica contents which are (72 to 76.5wt. %, ave.74.5 wt %).The granite rocks indicate higher SiO_2, Na_2O and K_2O, Al_2O_3 but lower TiO_2, Fe_2O_{3T}, CaO, MgO and P_2O_5 (Table 4.1).Overall, from major element of (Fig. 4.3) the studied samples indicate a general variation of decreasing Al_2O_3,TiO_2, Fe_2O_{3T}, MgO, CaO and P_2O_5 with increasing trend SiO_2. The K_2O and Na_2O contents show an increase with increasing of SiO_2 even if K_2O shows scattered distribution. By major elements (figure 4.3) Al_2O_3, Fe_2O_{3T}, CaO, P_2O_5 and MgO show poor correlation with SiO_2 content. The TiO2 is negatively correlated with SiO_2. The entire analyzed samples from Gaba Sanbata area are plotted on the TAS diagrams of (Middlemost, 1994**)** for classification purpose and studied samples fall on the granite (figure 4.1)

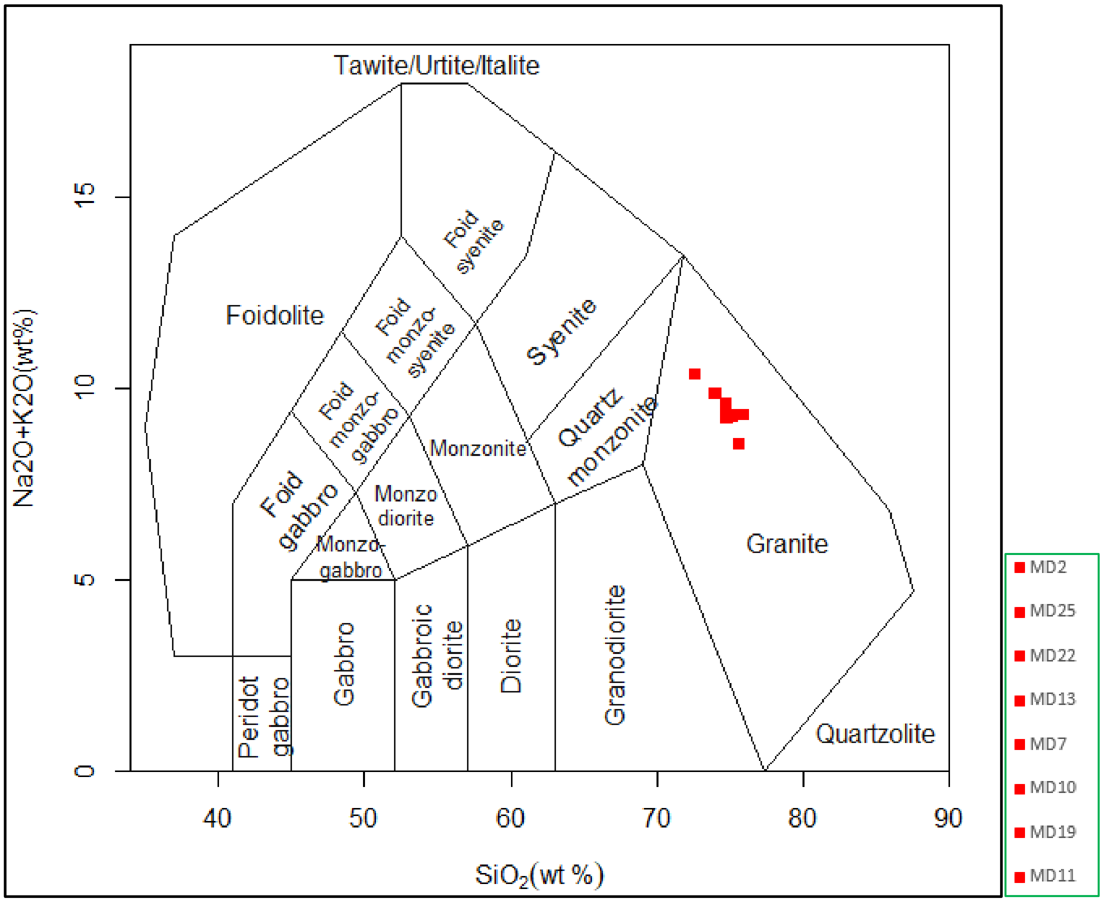

Figure 4.1 Total alkali versus silica diagram for the granitoids rocks of Gaba Sanbata area (a) classification diagrams for the granitoid rocks and based on TAS Middlemost, (1994

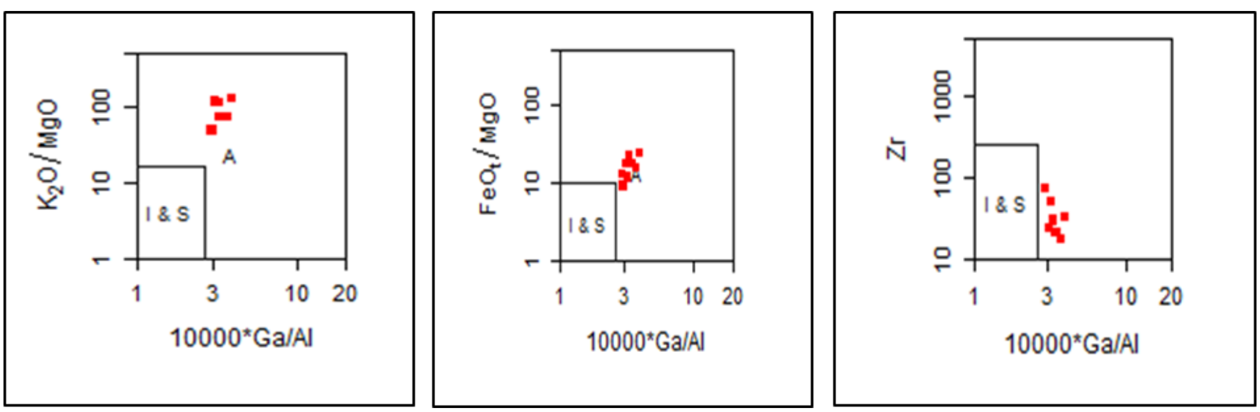

Fig 4.2 Geochemical discrimination diagrams after Whalen et al. (1987) Gaba Sanbata area

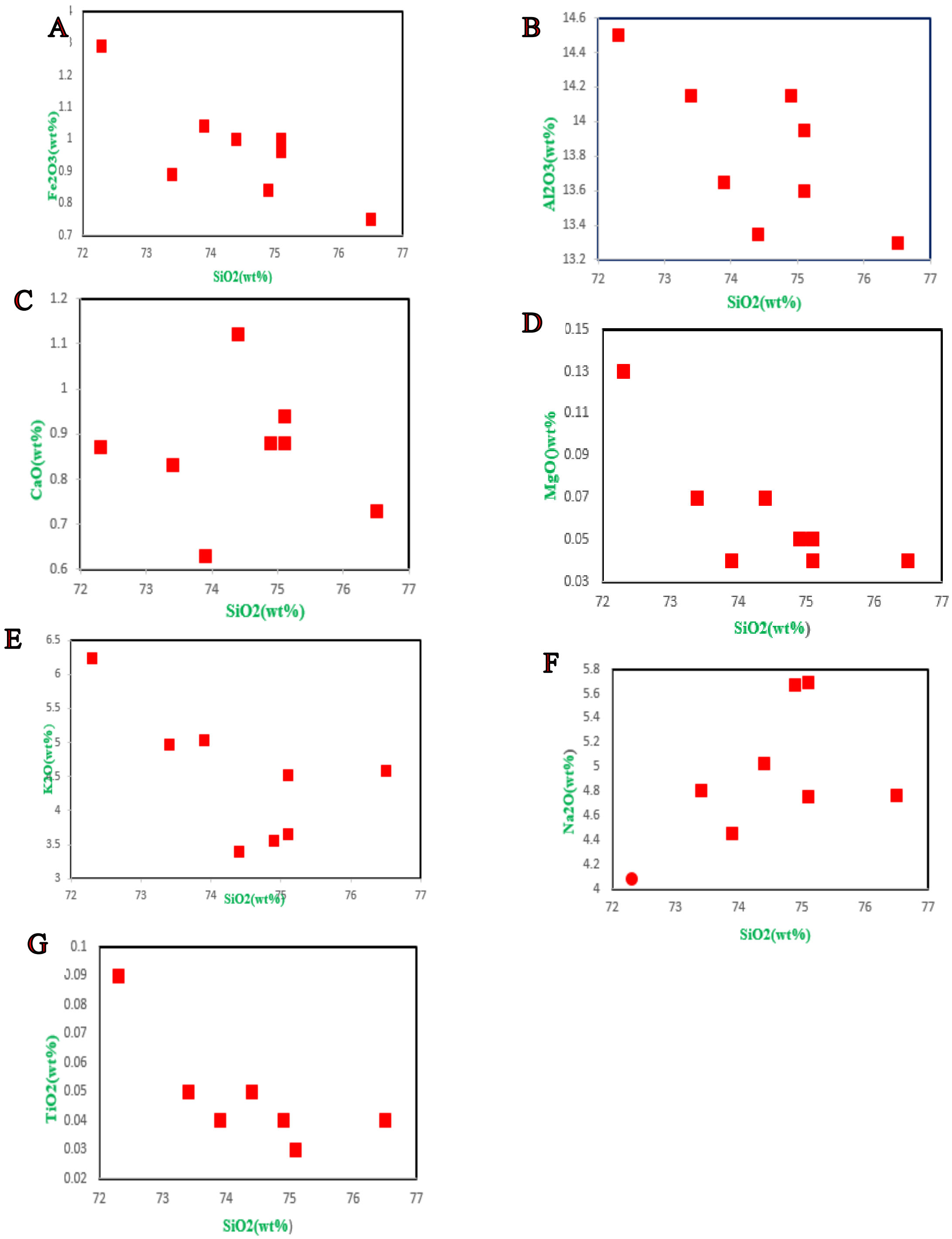

Figure 4.3 Harker variation diagrams of silica oxide (SiO_2 wt. %) versus range of with selected major oxides (wt. %) from the Gaba Sanbata area.

4.2 Trace element

The Trace element concentrations for representative samples are listed in Table 4.1. The selected trace elements are plotted against SiO_2 (Fig. 4.4). Rb and Nb positively correlated with SiO2 and Y and Sr negatively correlated with SiO_2. The studied samples are characterized by high concentration of Rb (288 to 179 ppm; av. 233.5 ppm) and low concentration of Sr (45.9 to 3.1 ppm; av.24.5 ppm).

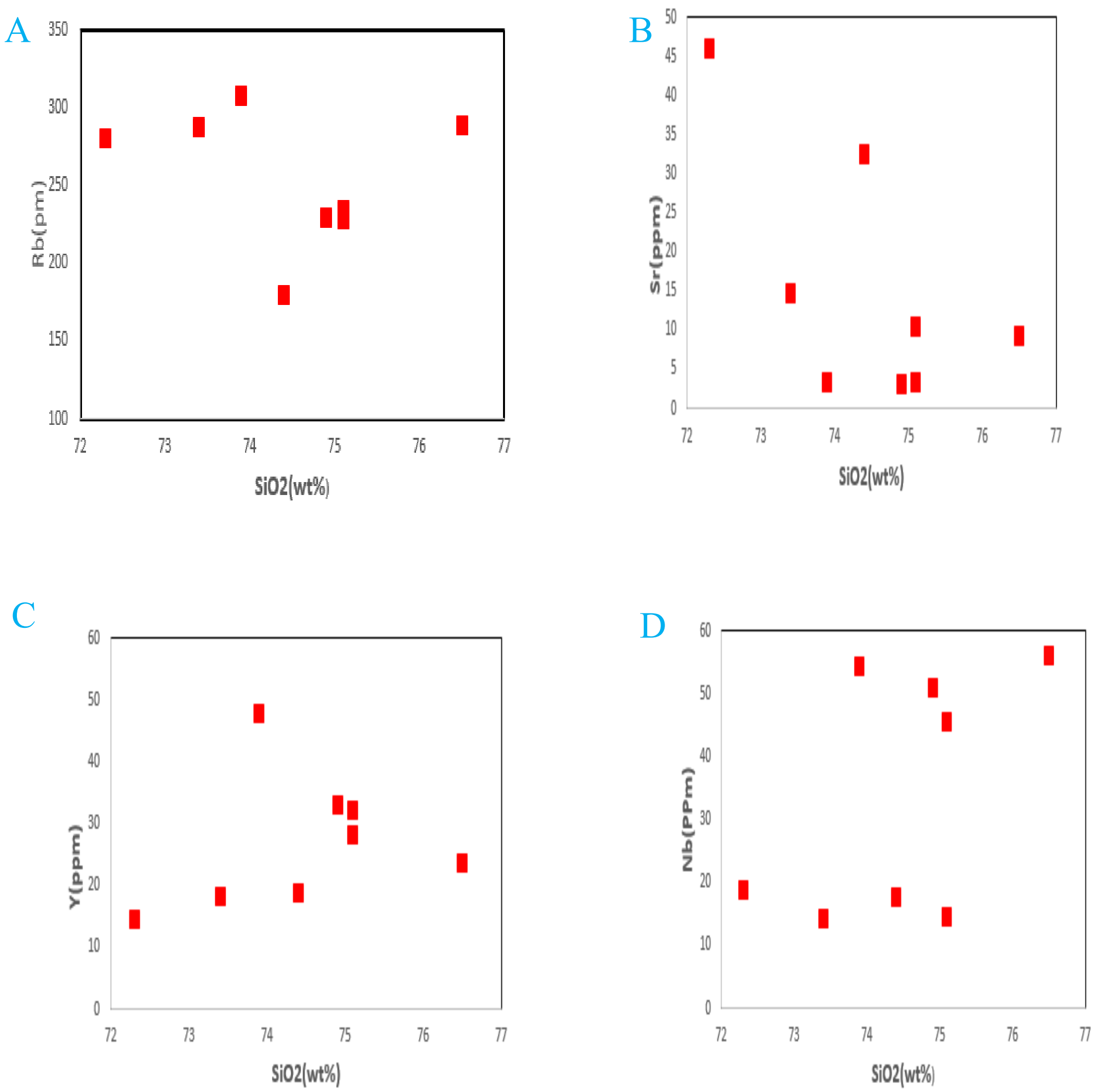

Figure 4.4 Harker variation diagrams of silica oxide (SiO_2 in wt. %) plotted versus selected trace elements (in ppm) for the granitoid rocks from the studied area.

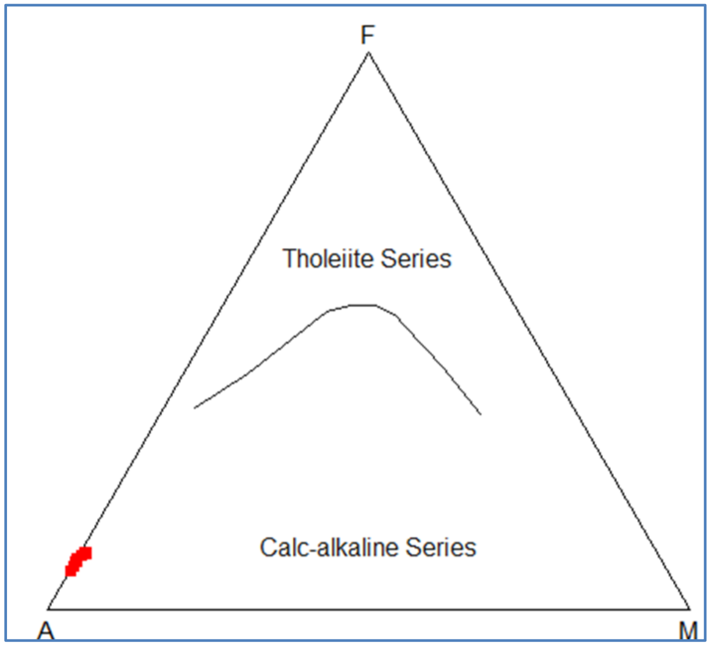

Figure 4.5 AFM ternary diagram of the granitoid Gaba Sanbata area (Irvine &Baragar, 1976)

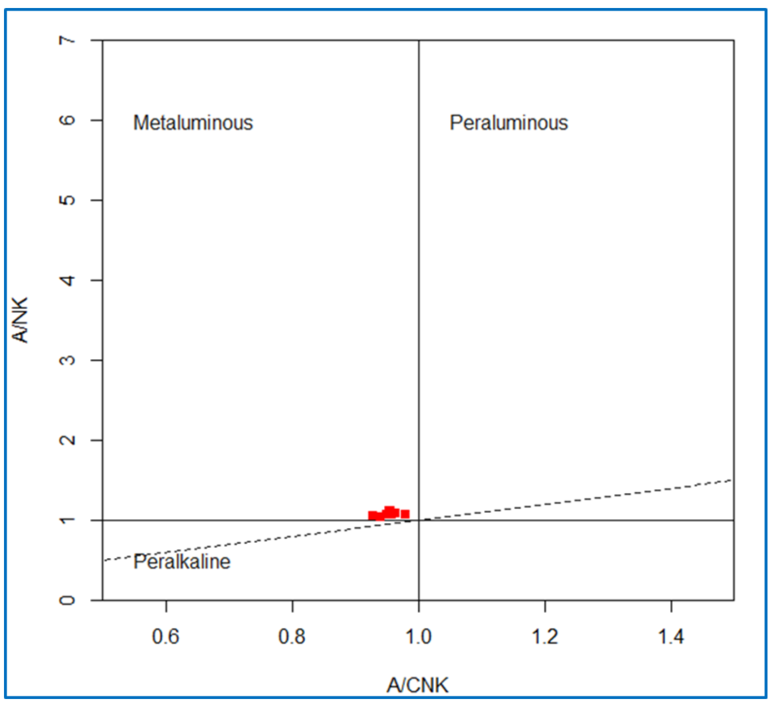

Figure 4.6 A/CNK (Al_2O_3/ ($CaO+Na_2O+K_2O$) vs A/NK ($Al_2O_3/NaO+K_2O$) plot (Shand, 1943) discriminating metaluminous, per aluminous and peralkaline composition of granitoids.

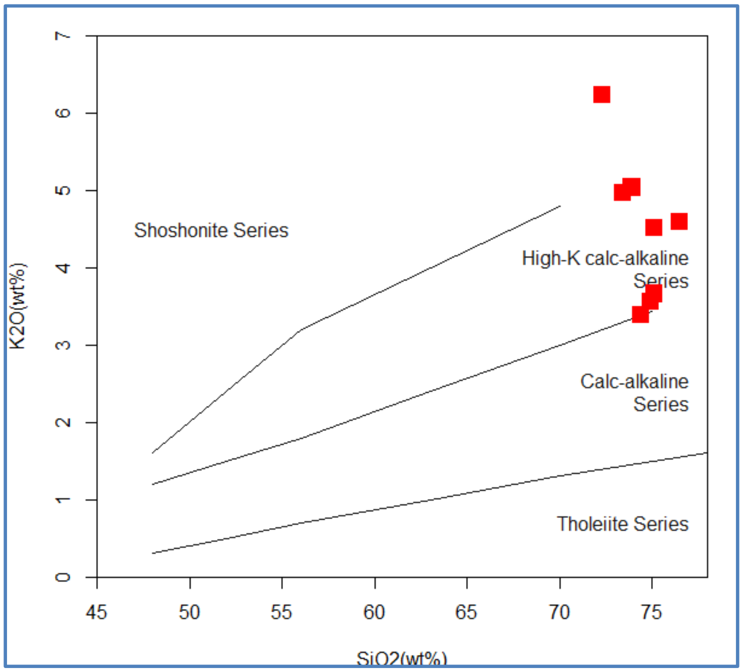

Figure 4.7 K_2O-SiO_2 plot imply high–K and shoshonitic series (Peccerillo and Taylor, 1976) of the granitoids from the study area.

Both Primitive mantle normalized, multi-element variation diagram and chondrite normalized rare earth element (REE) patterns of granite rocks are plotted (Fig.4.8 and 4.9 respectively).The chondrite normalized (Boynton, 1984) rare earth element (REE) patterns of the granite rocks is presented in Figure 4.9. The ratios of La/Yb in the analyzed samples range from 0.56 to 1.28. This indicates that REE patterns of studied sample are sub-parallel at Heavy rear earth elements (HREE). From this diagram it can be observed that all the studied samples show marked negative Eu anomalies (Eu/EU*=0.11 to 0.85) and the LREE slightly depleted and HREE nearly flat.

In the primitive mantle normalized (Sun and McDonough, 1989) multi-elements diagram the studied granite show enrichment and deplete in incompatible elements. The studied samples display pronounced negative anomalies of Ba, Sr, Nb and Ti. Moreover the studied samples show enrichment of large ion lithophile elements such as Cs, K, and Rb and high field strength elements (Pb, U and Th). High field strength element Yb, Y, Lu was approximately flat Nb, and Ce was slightly depleted and Ba, Ti and Sr are show strongly depletion. Generally, Gaba Sanbata granites show within plate granite patterns with enrichment to depleted in incompatible trace elements

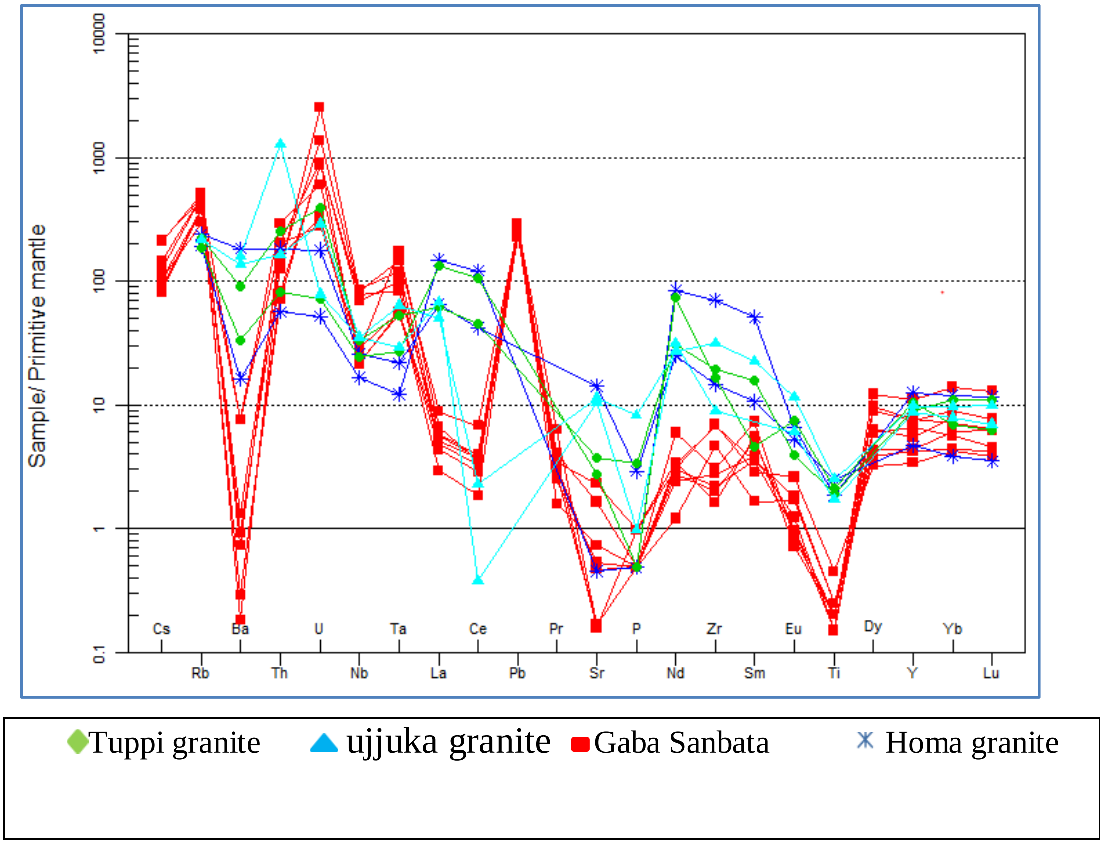

Figure 4.8 The Primitive Mantle –normalized multi-element diagram (Sun and McDonough, 1989) of granitoids of the study area, for compression Tuppi granite, Homa granite and Ujjukka granite also plotted (Kebede and Koeberl, 2003, Kebede et.al., 1999)

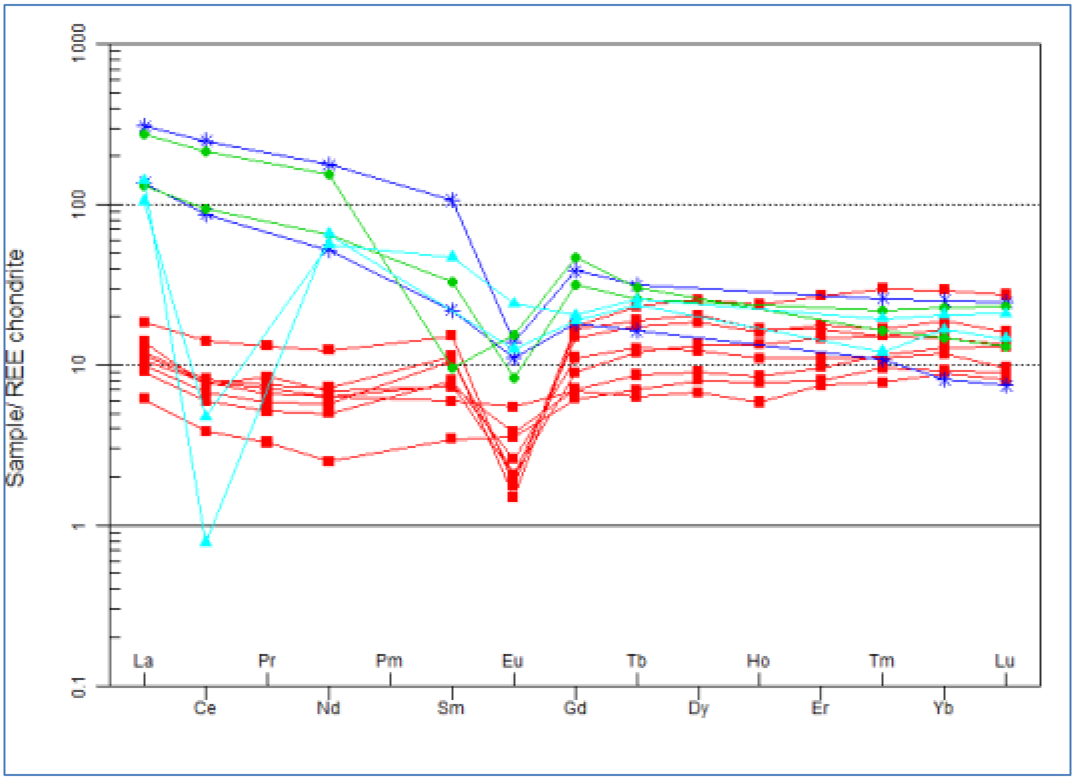

Figure 4.9 chondrite normalized REE patterns (Boynton.1984) of granitoids of Gaba Sanbata area for compression Tuppi granite, Homa granite and Ujjukka granite also plotted (, Kebede and Koeberl, 2003, Kebede, 1999), symbols same as figure 4.9

CHAPTER-FIVE

5. DISCUSSION

To illustrate the major, trace and rare earth elements, several graphical representation have been plotted and used to discuss the petrogenesis and tectonic settings of granitoid rocks. The study area is occurred within western Ethiopian Precambrian shield basements rock, which represents the extension of the MB and ANS. The western Ethiopian Precambrian shield basements largely of belt of high grade gneiss and low-grade assemblages of Neo-Proterozoic meta-volcanic, mafic-ultramafic, meta-sedimentary such as schist ,slate and phyllite, intrusive rocks such as gabbro and granitoids, and contains many remnants of oceanic crust (ophiolites) (Allen and Tadesse ,2003; Kebede and Koeber,2003). Petrographically, most of the granite rocks show different textures from the western shield (Kebede and Koeberl, 2003). The studied samples are area mainly comprises of quartz vein, mafic, migmatites gneiss and granitoids. Granite from this study area exhibit coarse to medium grained textures. The studied samples of area characterized by a quartz, feldspar and sodic rich that are white, colorless to pinkish color. This quartz and feldspar rich the pegmatite vein occur in the study area. In addition, phaneritic textures of granites rock with variable grain sizes that correspond to cooling rate of a crystal. According to Scaillet and Macdonald (2001) major and trace element variations during magma evolution is a function of phases fractionating which are indicating physical conditions of magma cooling and crystallization.

5.1 Petrogenesis

Geochemical data of the study area (i.e. CaO and K_2O) (fig 4.3, fig 4.4 fig 4.8 and fig 4.9) show considerable different trend and compositional variations, may be due to the presence of different plutonic centers with variable chemical compositions or may magma contamination by crustal rocks during ascent of magma to generate of the granites body (Kebede and Koeberl, 2003; Keshaverzi et al., 2014; Nazemi et. al., 2015). The trace element and rare earth can be used to indicate source of magma and to evaluating the composition of magma sources may from the mantle and/or lower crust, the can determine behaviors of each trace elements magmatic evolution and tectonic setting of the granite rocks. According to Whalen, (1987) samples fallen in the A-type granite field in 10,000×Ga/Al vs Na_2O+K_2O, (Na_2O+K_2O)/CaO and K_2O/MgO diagrams (Figure 4.2) and the show the transition of Metaluminous to peralkaline. The diagrams above (figure. 4.2) agree with the previous work done that A-type granites have been identified in Wollega area such as Homa gneissic granite and Tuppii granite (Kebede and Koeberl, 2003). According to Whalen et al. (1987) the sample suggested fractional crystallizations and partial melting processes are responsible for compositional variations in A-type granites. Petrogenesis of Gaba Sanbata granites are discuss detail in terms of fractional crystallization, partial melting and source characteristics.

5.1.1 Fractional Crystallization

The study area show high alkaline contents (Na_2O+K_2O) and all granitoid rocks are lie within the granite field (Fig. 4.1). Role of fractional crystallization in the formation of rocks can be identify from a plot of major oxides versus SiO_2 and trace elements. Figure 4.5 show a negative trends of oxides versus SiO_2 including Y and Sr except major elements of i.e. Na_2O, K_2O and incompatible elements Rb and Nb that show positive trend for rocks values. The K_2O and CaO, the different trend define may be due to variable of chemical composition and/or magma contamination. Al_2O_3, MgO ,CaO, $Fe_2O_{3(T)}$, TiO_2, and P_2O_5 concentrations decrease negatively correlated with increasing SiO_2 that are indicating the characteristic of mineral fractionation or magmatic differentiation trends in the early crystalizing phase (Clarke et al .,2005; Nazemi et.al., 2015).

During magmatic evolution the early forming rocks can be fractionation of early formed minerals phases like such as amphiboles, apatite, biotite, illeminte and decrease in those of the late phase of mineral forming rocks. This it indicates that Gaba Sanbata granites are formed by fractional crystallization and it can formed from remelting of previously melted (Nazemi et. al 2015; Negue, 2015).

A-types of granites have relatively high sodium, Na_2O greater than 4.08 %, and K_2O greater than 3.39 in felsic rocks of granite that show enrichment of alkaline (table 4.1).

The concentration of Na_2O and K_2O increases with increasing SiO_2 characteristic of mineral fractionation because they are not enter in the early forming crystalizing. The content (13.3-14.5) of Al_2O_3 in A-type granitoid rocks of the area is characterized by due to the enrichment of mineral phase like plagioclase and biotite. Variation of CaO contents with SiO_2 decrease and trends not well define in granites. The decrease of CaO with SiO_2

is suggested partial fractional crystallization of plagioclase through magma differentiation and an increase in the sodicity of plagioclase. The concentration of P_2O_5 in A-type granites was descending with increasing SiO_2 (Figure 4.3) that is showing reducing solubility of Phosphorous in siliceous melts or it imply removal of apatite by fractional crystallization (Rollinson ,1993; Chappell, 1999; Sha and Chappell, 1999 Nazmi et al., 2015). The small amount of P_2O_5 (0.08-0.13%) in the studied samples imply that apatite are strongly fractionated in the samples of A-type granites (Rollinson, 1993; Nazemi et .al, 2015).

The trace element variation diagrams of the Sr, Y, Nb and Rb versus SiO_2 reflect different positive and negative trends (Fig. 4.4). The variations of trace elements give additional information about the major processes and sources that controlled the formation. The variation of Nb vs of SiO_2 is show the contamination of the magma or source characteristics of the granitoids (figure 4.4 d). The negative anomalies of Sr with SiO_2 together with the strong negative Eu anomalies (fig 4.9) in the samples indicate either fractionation of plagioclase or magma contamination (Nazemi et. al., 2015). The decreasing of Sr suggested that trace element support the fractional crystallization during differentiation and magma evolution. The increasing in Rb with increasing SiO_2 indicates the movement of Rb with the liquid where Rb is accommodated in the feldspar fractionation (figure 4.4). The Rare earth element patterns (Figure 4.9) show Negative Eu anomaly (Eu/Eu*=0.11 to 0.85) which indicate fractionation of plagioclase. In the studied rocks, negative anomalies of Eu occur along with Sr, which refers to the plagioclase fractionation played significant role in their genesis .Depletion of P may imply a fractionation of apatite.

From binary plot (figure 5.1) trace elements are identify for the process of fractional crystallization, partial melting and magma mixing in the magmas. According to Keshaverzi et al., 2014 if the trend is straight and almost vertical line, partial melting is the effective process in the evolution of magma. Depending on the (figure 5.1) the trace elements are identify for the process of fractional crystallization in magmatic process of granitoids rock. In addition to this, the trends indicate they are originated from a partial melting (Keshaverzi et al., 2014). The strong linear correlations for pairs of elements (figure 4.4) on variation diagrams for granites are not uncommon. The evidence for magma mixing (Chappell et al., 1987) can alternatively be used as evidence supporting the restite indicators. According to Whalen et al. (1987) stated that mixing is the classic cause of linear variation in major and trace element Harker diagrams (figure 4.3).

Generally, the major and trace element model shows formation of the A-type of Gaba Sanbata granitoids have been formed by crystal fractionation (figure 4.8) at the most probably from partial melting of crustal materials and magma mixing.

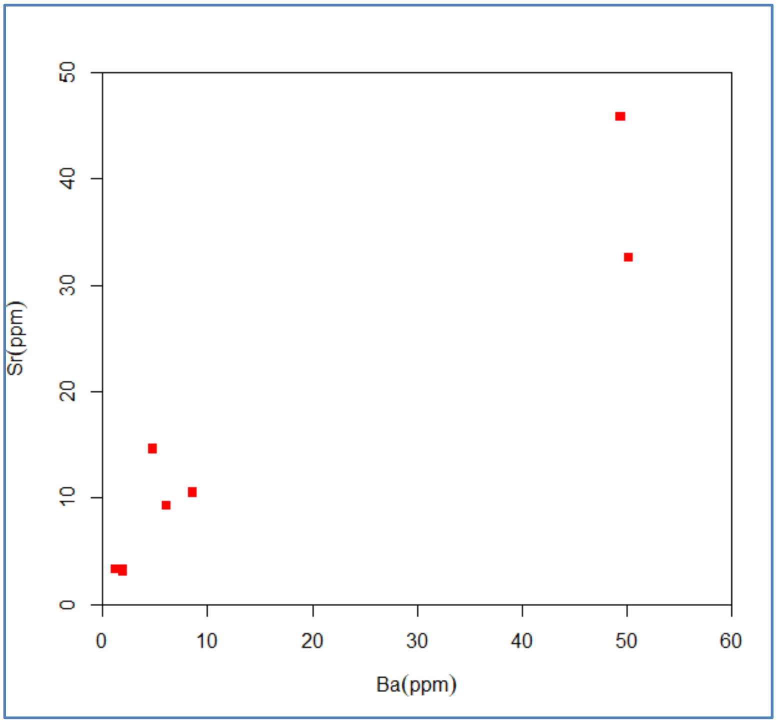

Figure 5.1 Discrimination diagrams Ba vs Sr showing the fractional crystallization trend.

5.1.2 Crustal contamination

The irregular different trends K_2O and CaO indicate a variable of chemical composition or magma contamination (figure 4.3) by crustal rocks during magma evolution (Keshaverzi et al. 2014). According to Rollinson, (1993) and winter, (2001) magma evolution have been the possibility of crustal assimilation and it can be impact upon incompatible trace element composition.

In addition to fractionation mineral phases, primitive mantle-normalized diagram illustrate (McDonough and Sun, 1995 and Sun and McDonough, 1989) for rock groups show a strong negative Nb, P and Ti anomalies (Figure 4.7) suggesting a crustal contamination of the magma with the hosting granite or with other crustal material prior to mixing with the granitic magma during evolution (Tetsopgang, 2003; Chebeu.et al, 2011; Tosanloo, 2017). In addition to this, (Nazimi et. al.2015) concluded that the up and down pattern (zigzag pattern) of primitive pattern (figure 4.8) of these diagrams indicate the crustal contamination of the granites. According to (Tosanloo, 2017) the LILE especially Th enrichment implying the role of large contribution of crustal for genesis of granite rocks of the area and/or other primary magma contamination in the magma processes.

5.1.3 Source characteristics and Tectonic setting

The primitive mantle-normalized diagrams (Figure 4.8) the studied samples are enriched in LILE (i.e., Cs and Rb) and flat in HFSE (i.e. Dy, Y, Yb, and Lu) extremely depleted to (i.e., Ba, Ce Sr Nb, Ta and Ti).The depletion of LREE are show that the magma evolution is imply high partial melting (figure 4.9). The granitoid samples show highly fractionation with steep patterns in the Light Rare Earth Elements. According to (Sun and McDonough, 1989; Kershaverzi et al.,2014) the negative anomalies of Nb and Ti are determined by titanium bearing minerals phases such as rutile, titanite, ilmenite and it related with crustal fraction (figure 4.8). This negative anomaly of cerium is occurred in the Gaba Sanbata granite (figure 4.8) indicate that small amount oxygen fugacity in the source. This show that Gaba Sanbata granite are formed at the depleted mantle or at the crustal involvements. The total concentrations of alkali are varies within each sample from (Na_2O+K_2O) (8.42 – 10.32 wt. %). The concentration major elements of SiO_2, (Na_2O + K_2O) and Al_2O_3, low MgO, Fe_2O_{3T}, and CaO concentrations are suggested that the primary magma was derived from partial melting (Nazemi et.al .,2015).

Most continental crust evolved with shoshonitic and high-K calc alkaline because they are not enter in the early forming mineral phase. The one of the sample which are contains shoshonitic indicate the high concentration of the highly potassium in the sample. The value of Cr varies from (30-40 ppm) in study area. Highly compatible elements are crystalized in early forming such as spinel and clinopyroxene (winter, 2001).due to this very small to rarely amount of chromium is occurred in the sample.

The samples show slightly flat in Light Rare-Earth Element and Heavy Rare-Earth Elements and have fractionated Rare Earth element patterns (La/Yb) N =0.56-1.28) (where N-denotes the normalized to the chondrite in sample).

According to (Irvine and Baragar, 1971) the AFM plot from (fig 4.5) all data are show in the calc-alkaline field suggesting their enrichment in alkali (Na_2O+K_2O) oxides.

SiO2-K2O diagram (Figure 4.6) of (Paccerillo and Taylor, 1976) shows that most of the samples fall within high potash calc-alkaline series and only one sample in shoshonitic series. Accordingly the result obtained in this study area imply that the samples are aluminum saturation index (Al_2O_3/ (Na_2O+K_2O+CaO)) ratio of less than 1 and it suggesting metaluminous and have been formed by partial melting of mixed-origin(mantle and crust) granitoids (Shand,1943; Tosanloo,2017) (A/CNK>0.17) (Fig 4.6).

Metaluminous A-type granitoids are may be indicate the fractional crystallization (Cawthorn et al., 1976; Cawthorn and Brown, 1976) and by partial melting of juvenile crust or from depleted mantle source rocks. The sample in the figure (4.6) occur in the transition between metaluminous and peralkaline this also indicate the A- type granite of Gaba Sanbata area. Therefore, the compositional variation occurred in the granitoids samples is suggest fractional crystallization and partial melting with crustal contamination of magma within plate granite. In addition to this, Batchelor and Bowden (1985) is indicate that the granite of study area is post-orogenic (figure 5.2) and suggested that the granites of this area is located in the continental crust involved with depleted mantle and does not show deformation and metamorphic history. Post-collision calc-alkaline intrusions which probably derived from mantle source yet undergo extensive crustal contamination during magma evolution (Batchelor and Bowden, 1985)

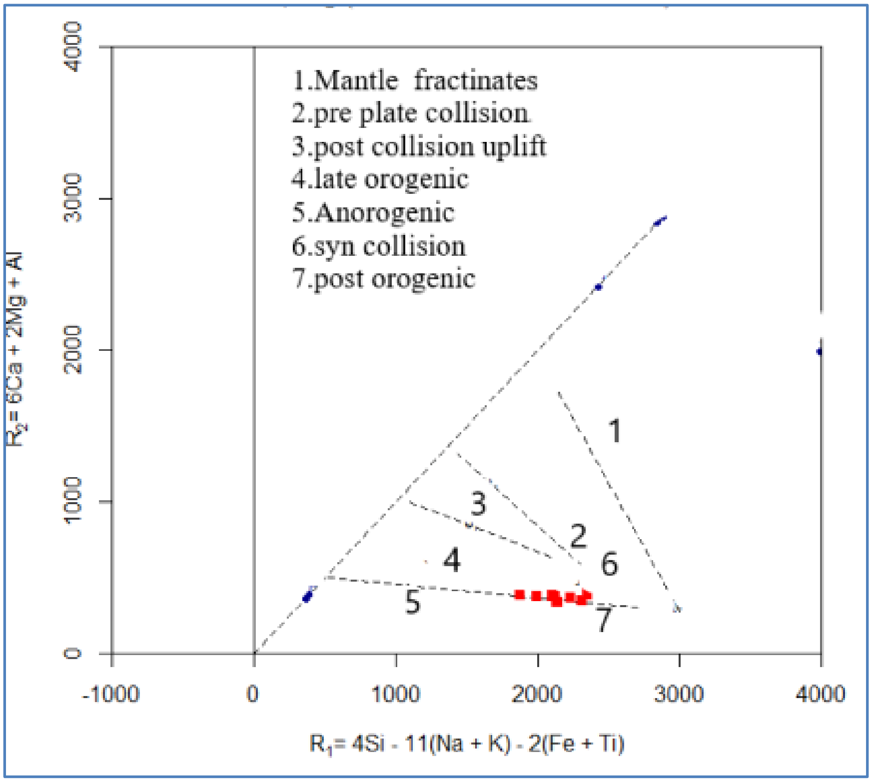

Figure 5.2 R1 Versus R2 multicationic diagram for the granite (Batchelor and Bowden 1985)

Ganji monzogranite, Homa gneissic granite and some of the Tuppii granite show within-plate granite (Kebede and Koeberl (2003) and Ujjukka granitoids and Dhaga Boqa granites are suggested as Volcanic Arc Granite (VAG) and is related to subduction volcanism (Kebede et al. 1999).The origin of granitic liquid can be directly or indirectly related to tectonic activity (Tosanloo,2017) .

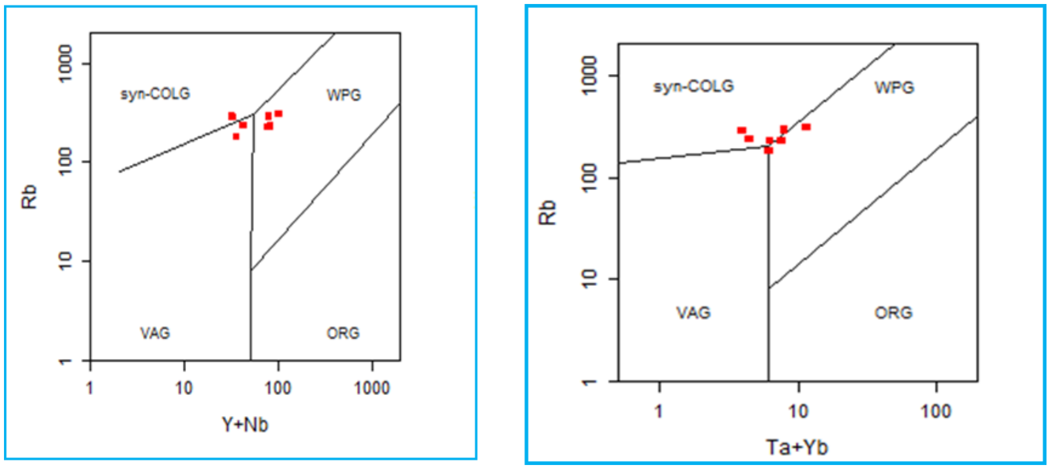

Fig 5.3Tectonic discriminant diagram samples of the Gaba Sanbata area (after Pearce et al., 1984).

Tectonic discrimination diagrams reveal that the granitoids samples consistently plot in the within-plate granite fields. The Rb versus Y+Nb and Nb versus Y, diagrams show the same relationship (Figure5.3) (Pearce et al., 1984). According to (Pearce et al., 1984) the studied samples are plotted in the within plate granite, syn-COLG and volcanic arc granite (Figure 5.3). Some of the samples fall in the field of subduction related (Figure 5.3) these features may be indicate the variation of fractional crystallization or such different tectonic setting within-pluton variations may be attributed to fractionation processes and/or varying contributions of different sources Kebede and Koeberl, (2003).

In the Gaba Sanbata area, the granitoids show depletion features in Sr, Nb, Ba, and Ti, and enrichment in most incompatible elements such as K, Rb, U, Pb and Th compared to highly charged elements are due to in magmatic fractionation and crustal contamination.

The geochemical data show the enrichment in large ion lithophile elements and depletion in high field strength elements (i.e. Ta, Nb, and Ti) that suggest a significant amount of crust material was involved (Pearce et al., 1984). In the studied samples Positive anomalies in K, Pb and Rb attributed to metasomatism of mantle wedge or/and contamination with continental crust Kamber et.al. , (2002) Generally, the result of this study which related with field relationship, petrography description and geochemical data show that the granitoids in the studied area are A-type granitoids which have been formed by the involvement of significant partial melting of crustal material in their petrogenesis assisted by fractional crystallization and magma mixing (juvenile crust). Therefore Gaba Sanbata granite may be formed by partial melting or mantle-derived source magma by extreme fractional crystallization of crustal involvement and magma mixing.

5.2 Comparison of granitoids rocks of the study area with other granitoid rocks of western Ethiopia

The western Ethiopian Precambrian shield of intrusion rocks have been discussed over various times (Kebede, 1999; Kebede and Koeberl, 2003). The A-type or within plate granite of the Gaba Sanbata area are compared with the other granites of the western Ethiopian Precambrian shield such as Tuppi granite, Homa granite and Ujjukka granite, identifying a change of magmatic process from calc-alkaline arc related to within-plate granite (Kebede and Koeberl, 2003). On discussions of this study on the samples which are collected from the Gaba Sanbata area are used for comparison of petrogenesis and tectonic setting. According to (Kebede, 1999) some of the Wallagga intrusive rocks are covered with the volcanic arc granite (VAG). Trace elements which compatible in alkali feldspar, such as Ba, Sr and Eu, are variable, concentrations in the Wallagga area. These values are an indication for fractional crystallization in crustal magma chambers, which probably causes crustal contamination (Kebede, 1999; Kebede and Koeberl, 2003 and references therein

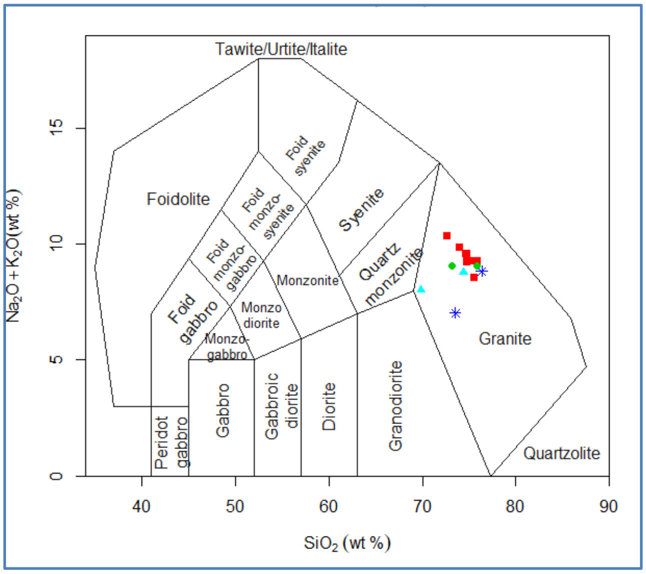

Figure 5.4 comparison of chemical classification diagrams for the granitoids rocks and based on TAS wt%, SiO2 vs (Na2O+K2O) (Middlemost; 1994) symbol the same as figure 4.8

The primitive mantle normalized multi-element patterns of granitoids from the study area are plotted in (Figure 4.8) and show emplacement in continental rift environments. The granitoids from the study area have relatively high concentrations of highly-incompatible trace elements as compared with the Tuppi granite, Homa granite and Ujjukka granite (Kebede, 1999, Kebede and Koeberl, 2003).

In Chondrite-normalized REE patterns in the different Wallagga plutonic rocks show enrichments a LREE high LREE/HREE ration (Figure 4.9). The study area show depleted of the LILE and enrichments of the HFSE, this indicate that Gaba Sanbata granitoids are formed at the high degree of the partial melting than others Wallagga granite rocks.

All phases of Wallagga plutonic indicate negative anomalies Eu while sample from the Ujjukka granitoids show some positive anomaly in Eu (Figure 4.9). The Negative anomalies in Eu are suggested to the feldspar fractionation during magma crystallization or remaining of feldspar at the source.

The negative anomalies are associated with in Sr fractional crystallization of plagioclase responsible for these anomalies (Fig 4.8). Positive anomaly in Eu from the Ujjukka granitoids is indicative for the absence of plagioclase fractionation during the magma crystallization and high concentration of this mineral in these rocks (Boynton, 1984). In the study area, highly negative anomalies of Eu are indicate more fractionation of plagioclase. Due to this Chondrite-normalized patterns of calculated REE concentrations of Wallagga area are different to that of the studied granite sample (Fig. 4.9). The concentrations of compatible trace elements of Tuppi granite, Homa granite and Ujjukka granite and studied samples are flat (Boynton, 1984).

Primitive mantle normalized incompatible trace element patterns for granitoid rocks (Figure 4.8) have similar trends as Tuppi granite and Homa granite after (Sun and McDonough, 1989). From trends diagrams of the Tuppi granite and Homa granite depleted in the Sr shows that plagioclase fractionation is small relative to studied samples. According to (Salem et al., 2001; Papangelakis and Moldoveanu, 2014), the cerium negative anomaly is probably due to high oxygen fugacity at the source of the magma. This strong negative anomaly of cerium is occurred in the Ujjukka granite of Wallagga area suggested that high oxygen fugacity in the source (figure 4.8 and 4.9). Therefore, Ujjukka granite is formed at depth of the enrichment of mantle. The primitive mantle normalized multi-element shows that the fractional crystallization and partial melting is the different.

The granitoid rocks of studied area Sr, Nb and Ba highly depletion in incompatible trace elements than the Tuppi and Homa granite (Sun and McDonough, 1989). The study of granite shows highly depletion at Sr and Ti due to the strong fractionation of plagioclase and Fe-Ti oxides, than the other western region. The highly depletion of the trace elements are show the high degree of partial melting in the granite of Gaba Sanbata granite and the Sr, Nb and Ba of Tuppi granite, Homa and Ujjukka granite are show low degree of partial melting.

Therefore, Gaba Sanbata granitoids are different from the others by degree of partial melting, fractional crystallization which are indicate within plate magmatism as with the suggested western Ethiopia Precambrian rocks such as Tuppi granite and Homa granite. According to (Kebede, 1999) intrusive rocks of western Ethiopia such Ujjukka granite and granodiorite and granites were formed pre- to syn- tectonics employment and the sequence of events were suggested from subduction related. Particularly, discussions of this study on the samples which are collected from the Gaba Sanbata area showed similarities for classification to the earlier works and it described as granite magma series (Fig. 5.4).

CHAPTER-SIX

6 CONCLUSIONS AND RECOMMENDATION

6.1 CONCUISION

Depending on the field observation, petrographic data , geochemical data and geological data of the granitoid rocks of Gaba Sanbata area, western Ethiopia, the following conclusions can be drawn:

- During field observation the studied area is dominated by granitoids, quartz vein, migmatites gneiss and gabbro.
- Gaba Sanbata granitoids are composed mainly of K-feldspar, quartz, plagioclase and biotite and modal data of petrography analyses of granitoid samples are alkali-feldspar granite and syenogranite. From the analyses of samples to identify the mineral composition and texture to suggested the fractional crystal of petrogenesis
- Gaba Sanbata granitoids are A-type granitoids similar to Homa, Tuppii and Ganji granitoids.
- The major, trace, REE and multi element variation diagram indicate that granitoid rocks are originate by fractional crystallization process with crustal contamination and at the most probably from partial melting of crustal materials and magma mixing.
- The geochemical data show calc-alkaline affinity, shoshonitic to high k-calc-alkaline and high SiO_2, (Na_2O + K_2O) and Al_2O_3, low MgO, CaO and Fe_2O_3 concentrations suggest that the primary magma was derived by partial melting that involves crust.
- The Harker variation diagram indicate a decreasing in Al_2O_3, Fe_2O_3, MgO, CaO, TiO_2, P_2O_5, with increasing SiO_2, and depletion of Ba, Sr, and strongly negative anomalies Eu indicate the fractionation of plagioclase and other mineral fractionation or crustal contamination of magmas during magmatic evolution .
- The tectonic setting of the Gaba Sanbata granitoids are Within Plate Granite (WPG) to syn-Collisional Granite (syn-COLG) suites.
- The genesis of granitoids are probably from the involvement of significant partial melting of crustal material in their genesis, most probably by assisted

of fractional crystallization and magma mixing (juvenile crust) which are identify from trace element indication and magma mixing is the classic cause of linear variation in major and trace element Harker diagrams .

6.2 RECCOMMENDATIONS

Even if the present work is considered as enough according to the objectives, further studies had better to recommend in next works such as isotope geochemistry works, age determinations, additional whole rock and mineral chemistry studies are more recommended to get enough information on the magma source characteristics, petrological and geochemical processes involved to produce the rock suites.

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