ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL SCIENCES

SCHOOL OF EARTH SCIENCES

PETROGENESIS OF BASALTS OF GHIBE RIVER GORGE, SOUTH-WESTERN, ETHIOPIA.

A THESIS SUBMITTED TO THE SCHOOL OF EARTH SCIENCES, IN ADDIS ABABA UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR DEGREE OF MASTER OF SCIENCE IN EARTH SCIENCES (PETROLOGY).

BY

FIRAWALIN DESSALE TAFA

June, 2015

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Abstract

Ghibe River gorge is located in Southwestern Ethiopia, in the central part of Omo-Ghibe River Basin. The main objective of this study was to constrain the petrogenesis of Ghibe River gorge basalts using the geochemical signature of major and trace elements and thereby to fill the gap of geochemical data and geochemical process that control the Ghibe River gorge basalts evolution. The ICP-OES and ICP-MS geochemical methods were used for major and trace element analysis, respectively. The study area generally comprises of dominantly basalt, and some trachyte and tuff, with aphyric to sparsely porphyritic texture. Classification of the basalts on TAS variation diagram of LeBas et al., (1986) Ghibe River gorge samples fall in the basalt field and considered to be alkaline in composition. The Ghibe gorge basalts have low content of MgO (3.35-6.00 wt %) and compatible trace elements (Ni, Cr and Co), and positive correlations of Al2O3 and CaO with MgO, suggest that fractionation of olivine, plagioclase and pyroxene. Given that the high ratio of incompatible elements (Ce/Pb, Nb/U), which are not affected by fractional crystallization and low ratio of Nb/Pb and Nb/U, Ghibe River gorge basalts are not affected by crustal contamination, rather they indicate their derivation from lithospheric mantle.

The positive anomaly of Ba in the primitive mantle normalized multi-element variation diagram shows the presence of amphibole which is stable in lithospheric mantle. Therefore, this signifies their derivation from lithospheric mantle. The flat HREE pattern together with (Gd/Y)n = 1.02-1.14 suggests that Ghibe River gorge basalts were derived from spinel peridotite, with no significant contamination by crustal rocks.

Acknowledgment

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Lists of Acronyms

CRPG = Centre de Recherché Petrographique et Geologique

GIS = Geographical Information System

GPS = Global Positioning System

GSE = Geological Survey of Ethiopia

ICP-MS = Inductively Coupled Plasma Mass Spectrometry

ICP-OES = Inductively Coupled Plasma optical Emission Spectrometry

LC = Liquid Chromatography

LOI = Loss on Ignition

MER = Main Ethiopian Rift

PPL = Plane Polarized Light

REE = Rare Earth Element

HREE = Heavy Rare Earth Element

TAS = Total Alkali Silica

WPB = Within Plate Basalt

XPL = Cross polarized Light

CHAPTER ONE

1. Introduction

1.1. Background Notes

The Ethiopian Cenozoic volcanic province constitutes one of the largest continental magmatic provinces, where resulted from the emanation of gigantic amounts of flood basalt and ignimbrite (Gezahegn Yirgu, 1997). Accordingly the erupted magma displays compositional variations on the bases of time and space, which are understood to reflect principally the contributions of different mantle sources beneath the regions of magmatic activity (Hart et al., 1989; Deniel et al., 1994).

The present study area is located in southwestern Ethiopia. The area is specifically located in the central part of Omo- Ghibe River Basin, along the road that takes from Addis Ababa to Jimma about 188 km from Addis Ababa. Previously Ghibe gorge basalts were not studied. But some studies like GSE have done geological map of Akaki basaka including the area. Bonin et al., (2005) also reported on geology and geochronology of Guraghe rift margin and Dereje Ayalew et al., (1999) described the age of geology of Southwestern Ethiopia. Although, they have proposed regionally, the geochemical process and origin, as well as geochemical data of my present study were not assessed.

This study encompasses on the petrogenesis of basalts of Ghibe gorge, for the aim of determining the evolution, origin, composition, and textures etc. of basalts by means of geochemical signatures. Therefore, the major and trace element data presented for basalts from the proposed study area. The datas were used to investigate the geochemical characteristics of the basalts, constrained the possible evolutionary processes, source compositions and produced petrographic characteristics of basalts in the proposed study area.

1.2. Review of Previous Works

This review is largely depends on the regionally written papers, mostly concerning on the present study. As an example:

Ukstins et al., (2002) proposed that the Ethiopian basaltic flood volcanism could have begun significantly earlier than 30.9 Ma, based on $^{40}Ar/^{39}Ar$ dating. The volcanism started with the eruption of flood basalts during Eocene- late Oligocene with relation to the impingement of one or two mantle plume under Afar or Afar-Northern Kenya (e.g., Ebinger and Sleep, 1998; George et al., 1998; Rogers et al., 2000). Ethiopian plateaus formed from flood basalts which is erupted in short time interval (< 5 Ma) with the greatest eruption rate taking place from 31 to 28 Ma (Hofmann et al., 1997; Pik et al., 1998; Ukstins et al., 2002). According to Ingrid et al., (2002) "volcano-stratigraphic profiles and dating indicate that along the rift margin in north central part of Ethiopia volcanism might have been initiated significantly earlier, potentially as early as 32Ma, with the greatest eruption rates and volume occurring from ~ 31 to 28 Ma". Due to the impingements of Afar mantle plume beneath the Ethiopian lithosphere, the Ethiopian flood basalt province date ~ 30 Ma was formed, which includes major sequences of rhyolitic ignimbrites found on the top of flood basalt sequence (Dereje Ayalew et al., 2002). As Mengesha Tefera et al., (1996) these rocks are distributed in different parts of the country including the present study area. These basalts are characterized by having various volcanic rocks, thickness, and chronological ages.

Davidson and Rex (1980) believed that, the earliest volcanism is restricted to SW Ethiopia, where the Akobo basalts gives age as old as 49.4 Ma, and in NW Ethiopia where the Ashange basalts underlie the Aiba basalt which are dated as 34 to 30Ma. As they have been emphasized these two volcanic centers show lithological and geochemical differences, and can be related to two separated rift Zones north of lake Turkana and further north in the Tana graben. They have also reported Eocene basalts in SW Ethiopia.
The Ethiopian flood basalts cover an area of about 600,000 km^2, total volume of about ~ 3.5×10^5 km^3 (Mohr, 1983; Mohr and Zanettin, 1988) with a layer of basaltic and felsic volcanic rocks and comparatively uniform in mineralogical and chemical composition (Kiefer et al., 2004). Most of this basalt erupted since 30 Myr ago, during short 1Myr period, to form a wide volcanic plateau, and are a good example of the youngest major continental volcanic plateau. Texturally it is, mostly aphyric to sparsely phyric and

contain phenocrysts of plagioclase and clinopyroxene with or without olivine. Most have tholeiitic to transitional compositions (Mohr, 1983a, Mohr & Zanettin, 1988; Pik et al., 1998).

Dereje et al., (2002) have demonstrated that, basalt and ignimbrites form a typical plateau topography that is expansively eroded and dissected by deep gorges. Moreover, they have dealt the thickness of the unit; the maximum thickness of the plateau ignimbrite is variable, ranging from 500m in Wegel Tena area to 700m in Jima area and as low as 30m in the Debre Birhan area, close to the rift margin. Commonly Oligocene ignimbrites of the western plateau cover an area of 7 x 10^4 km^2 with an estimate volume of ~4.3 x 10^4 km^3. McDougall et al., (1975) estimate that 10^5 km^3 of rocks were removed from the western part of Ethiopian plateau. The initial volume of the Oligocene ignimbrites of the western plateau was probably at least 6.3 x 10^4 km^3 (Dereje et al., 2002). Accordingly, three distinct Oligocene rhyolites units are: (1) the Lima Limo rhyolites in the northwest plateau forming several beds capping low- Ti basalt flows, (2) the Wegel Tena rhyolite in the east corresponding to very thick ignimbrites overlaying high-Ti flood basalts, and (3) the Jima rhyolites located in the southwestern plateau overlaying high-Ti flood basalts.

Bonini et al., (2005) recognized the overview of Guraghe rift margin, the age spans from Oligocene up to late Pliocene, by K/Ar age of 29 Ma, permitting to cover both the pre-rift and the syn-rift volcanic activity, and the rock successions of basalts, trachybasalts, trachytes and acidic pyroclastic deposits.

Furman et al., (2006) and others cited therein, recognized that, from three volcanism occurred in Turkana Depression, the one which had been taken place in the second more voluminous phase took place roughly between 26 and 16 Ma of eruption (magmatic and tectonic episode) apparently propagated northward from Kenya to Southern Ethiopia, where it is reflected in a volcanic pulse between 20 and 11Ma.

Dereje et al., (1999) have presented major and trace element and Sr, Nd, and Pb isotope data for volcanic rocks of Southwestern Ethiopia. As discussed in their paper, "on the basis of previous K- Ar age determinations, the volcanic rocks of southwestern Ethiopia are subdivided into: Omo basalts (40 to 25 Myr), Jimma basalts (37 to 11 Myr) and Wollega basalts (15 to 7Myr) (Merla et al., 1979; Berhe et al., 1987; Tsegaye, 1997)". They corrected the age of the three formations by using isotopic ratio measurements for in situ radioactive decay recognized an average age of 32 Myr for Omo basalts, 24 Myr for Jima volcanic basalts, and 11Myr for Wollega basalts which were poorly constrained previously.

Like that of northern Ethiopia, Southwestern Ethiopia is also covered by volcanics that belong to the Ethiopian volcanic province and its volcanic rocks range compositionally from mafic rock, which have porphyritic to sparsely porphyritic textures with phenocrysts of plagioclase dominating over olivine, and its minerals are altered, Clinopyroxene and opaque minerals are abundant in the matrix, to felsic rock, which are trachytic textures with laths of alkali feldspar (Dereje et al., 1999). By using major element variation diagrams, they have been recognized, that the scattered trend on the major element variation diagram could be as a result of the accumulations and/or fractionation of heterogeneous phenocrysts or source heterogeneity, and the variation observed in ratios of highly incompatible elements might reflect the heterogeneity in the source. Davidson and Rex (1980), also emphasized three units: (1) the Main sequence (49.4 to 30.5Ma), (2) the Makonen basalts (32.8 to 21.2 Ma), and (3) a post-rift sequence (13.0 Ma to the present day). After that, Davidson (1983) subdivided the Main sequence into: the (1) Akobo basalts (49.4 to 46.0 Ma), which is the earliest basalt in SW Ethiopia (Davidson and Rex, 1980), and (2) the rest of the sequence (40.4 to 30.5 Ma). Actually the oldest rocks described in SW Ethiopia are of Eocene-Oligocene age (Davdson and Rex, 1980) where as the basal vocanics in W Ethiopia are much younger suggests that there is a separate Eocene- Oligocene volcanic field centered in Akobo area.

Ebinger et al., (1993), and George et al., (1998) have proposed that small volume of basalts as old as 45Ma or as young as 27 Ma are found in southwestern Ethiopia (SWE). According to Dereje et al., (1999), the volcanic products in Southwestern Ethiopia are different from that of Northern Ethiopian plateau (Merla et al., 1979; Davison and Rex, 1980; Berhe et al., 1987). SWE is characterized by, scarce flat lying thick piles of basalts (traps), uncommon large volcanic edifies (shield volcanoes), abundant phonolitic lavas in the shield volcanoes, the oldest age volcanic products, and the Cenozoic volcanic rest directly on the crystalline basement of Pan-African age. But, NW Ethiopian plateau is characterized by presence of:

(1) Higher proportion of silicic volcanics within the flood basalts (Merla et al., 1979).

(2) Frequent occurrence of major volcanic edificies overlying the flood basalts some of which reach as much as 100km in diameter (Danielli, 1943; Abbate and Sagri, 1980).

(3) Presence of large volcanic centers which is rare in SW plateau, and the few that exist such as Tulu Wollel, are aligned with the Ambo or Addis Ababa-Nekemt lineament, which controls the existence of Omo and Jima volcanics (Merla et al., 1979).

(4) Presence of few phonolitic types of lava in shield volcano of NW and Central Ethiopia than SW Plateau.

(5) The presence of the Mesozoic sediments between basement and volcanic rocks which is absent in between SW Ethiopian plateau.

In terms of structural control, Berhe (1986) suggested that, Ambo fault separates the NW Ethiopian flood basalt from that of SW Ethiopia. Any more important structure is the Bonga- Goba line (Merla et al., 1979) or the Tepi Fault Belt (Davidson, 1983) which is associated with normal faulting and with a throw to the north. It delimits variously tilted blocks of the Jima volcanics to the north from the horizontal flows to the south, and has controlled recent volcanism in the Jima area (Abbate and Sagri, 1980). It is also offsets the major Ethiopian fault scarps on either side of the rift. The most common other structures that affected the flood basalts are NNE and NW faults. The NW faults are very well developed in SE Ethiopia where they influenced the development of a Mesozoic sedimentary basin in that region (Purcell, 1976). More than that, these fault also controlled the evolution of the rift escarpments and variations in the thickness of lava successions (Arno et al., 1981; Berhe, 1986).

Berhe et al., (1987) noted that, the flood basalts of NW and SW Ethiopia are affected by two major rifts. The Tana Rift in NW, and Turkana Rift system in southwest Ethiopia. The Tana Rift is a 60-70 km wide asymmetric graben trending NNE across the NW Ethiopian plateau and it has a strongly warped, block faulted and tilted western margin. The eastern margin is more weakly faulted and is cut by NW-trending faults.

As Engdawork et al., (2009), and other cited therein, emphasize that, Omo- Ghibe river Basin, comprises of Precambrian crystalline basement, Eocene to Miocene volcanic rocks, Quaternary lacustrine deposits, alluvial sediments and volcanic flows. South of Woliso to Welkite- Hosaina- Sodo Selam Ber and the adjacent plateau west of Omo river is underlain by a sequence of trachyte, rhyolite, ignimbrite and tuff with minor intercalated basalt flows and lacustrine sediments (Engdawork et al., 2009).

Kieffer et al., (2004) emphasized that alkali basalts with higher concentrations of incompatible elements and more fractionated REE patterns, called “high-Ti ” basalts (HT1 and HT2) with HT2 basalt is slightly more magnesian than HT1, are found to south and east. They recognized as, they have higher concentrations of incompatible elements and show extreme fractionation of the REE.

Pik et al., (1998), gave recognitions on the classifications of northwestern Ethiopian plateau using major and trace element data into three magma types (high-Ti groups HT1 and HT2 and low-Ti group LT) (Table 1.1).

Table 1.1: Summaries of types of Titanium content of northwestern Ethiopian flood basalt (Pik et al., 1998).

Group	Contents	compositional ranges	parental magmas	Type	Emplacement time	Occurrence
Transitional to tholeiitic LT suite	Low TiO_2	(1–2.6%),	controlled by the removal of a shallow level gabbroic (Pl + Ol + Cpx)	Transitional to tholeiitic	thick continental flood lava pile was emplaced in short time interval about(1–2Ma)	northwest of the Ethiopian plateau
	Low Fe_2O_3	(10.5-14.8%)				
	Low CaO /Al_2O_3	(0.4–0.75%)				
	Low Nb/La	(0.55–0.85%)				
	high SiO_2	(47–51%)				
HT_2 suite	high TiO2	(2.6–5%)	controlled by the removal of a deeper Ol + Cpx fractionation	Alkaline		Out cropped in the east of Ethiopian plateau
	high Fe_2O_3	(13.1–14.7%)				
	high CaO/Al $_2O_3$	(0.9–1.43)				
	high Nb/La	1.1–1.4)				
	and low SiO_2	(44–48.3%)				
HT_1 suite	TiO2	intermediate between the LT and HT2 groups in compositions	controlled by the removal of a shallow level gabbroic (Pl + Ol + Cpx)	Alkaline or intermediate between LT and HT1.		outcrop in the east of Ethiopian plateau
	Fe_2O_3					
	CaO/Al $_2O_3$					
	Nb/La					
	SiO_2					

1.3. Statement of the problem

Igneous rocks are formed from solidification/crystallization of magma outpoured as continental and oceanic flood-basalts, which have been widely attributed to melting associated with the sub-lithospheric impacts of upwelling plumes of anomalously hot mantle, generally known as Large Igneous Provinces (Dereje et al., 2009). Hence, the determinations and analysis of this flood basalt provides the source region, chemical compositions, geochemical processes, tectonic setting and whether the magma is derivative or primary magma using geochemical signatures of isotopes, major and trace elements data, although the present study uses the major and trace elements data only. Some previous work has been focused on volcanic provinces of southwestern Ethiopia generally, but there were limitations of geochemical data and a specific feature of the Ghibe gorge area is not known. Therefore, the present study was aimed to determine the detail geochemical studies of basalts by using petrographic study, major and trace element data.

The present research study has been identified from previous researches, and interested to understand the geological processes that control basalts and its chemical compositions, rock textures, and evolutionary processes. The aimed objective of this study have been filled the gap that found in the area, therefore different institutions and organizations could use as a ground base, if they want to deal more in different studies.

1.4. Research Objectives

1.4.1. General Objective

The general objective of this study was to constrain the genesis/evolution of basalts in Ghibe River gorge, and understand geochemical signature of the source region.

1.4.2. Specific Objectives

The specific objectives of this study are:-

- ✓ To establish the volcanic stratigraphy of the Ghibe River gorge.
- ✓ To describe the textures, and mineral content of rock.
- ✓ To characterize the geochemistry of Ghibe River gorge basalts.
- ✓ To compare and contrast the petrography and geochemical signatures of basalts.
- ✓ To determine the possible source regions of basaltic magmas.
- ✓ To infer the geochemical processes on a major and trace element variation diagram.
- ✓ To determine whether the magma is primary or derivative magma.

1.5. Methods and approaches

Generally three methods and approaches have been used to achieve the results of the current work.

Desk study

For any research data is the crucial and play a great role, as well in this paper primary (field data) and secondary data (different literatures for review) were greatly used to do detail petrogenesis of basalts. In this stage a books, journals, published and unpublished papers and reports were used. Not only had these, also the preparations of different maps using Arc GIS software of 9.3, Modeling of varies graphs of major and trace elements concentrations using PetroGraph2beta software, as well as interpretations of these models on the bases of the geochemical signatures of major and trace elements, Litho-stratigraphic log and geologic cross section were done by using surfer software 8. This desk study was performed during both pre- and post field work. Lastly the compilations of the whole report were undertaken in this desk study.

Field work

Field work was conducted for the collection of representative samples and to prepare the Geologic map of the study area. For preparation of the geologic map, observations of the area to select the exposure were done. While field mapping, the place where good exposure found was selected and in selected area sampling were performed. The sampling area, were selected where clear exposure is found and easily accessible, and because of the other area is covered by forest and hard to sample across, even to take clear photographs, these upper and lower part were selected. Along these selected outcrops: rock sampling, photographing, stratigraphical logging and observations of structure on the rock, descriptions of samples based on colors, textures, and thickness of the outcrop in each preferred area undertaken.

Therefore from the field about 14 rock samples were taken for petrographical and geochemical analysis with their field descriptions. These representative samples were collected randomly in the selected area. All samples were well labeled with its GPS readings to distinguish each sample from one another easily in the field, as well as in the laboratory. Finally, based on the lithologic difference obtained, litho-stratigraphic log (Figure 3.9), which has various thicknesses produced in the field.

Laboratory work

To characterize Ghibe gorge basalts of the collected samples two general methods were used in the laboratory stage. The first is petrography and the second one is geochemical analysis. For these purposes the collected samples were cut into two, i.e. for petrographical study and for geochemical analysis of major and trace elements.

Petrography

For the petrographical studies, thirteen samples were submitted to AAU Earth Sciences laboratory to prepare thin sections. Thirteen thin sections were prepared from these samples by cutting by diamond saw, ground by diamond abrasives to a flat surface, mounted, and ground and lapped to the final thickness, and covered by cover glass. Totally 13 thin sections prepared and received from the laboratory, and petrographical descriptions were undertaken by using transmitted light microscope in the mineralogy and petrology laboratory of AAU School of Earth Sciences. Farther more; using petrographical description results, the classifications of the rock depending on the phenocrysts of minerals available in ground mass, textures of the rock, grain size, and modal mineralogy of the rock were determined (Appendix 1 and 3).

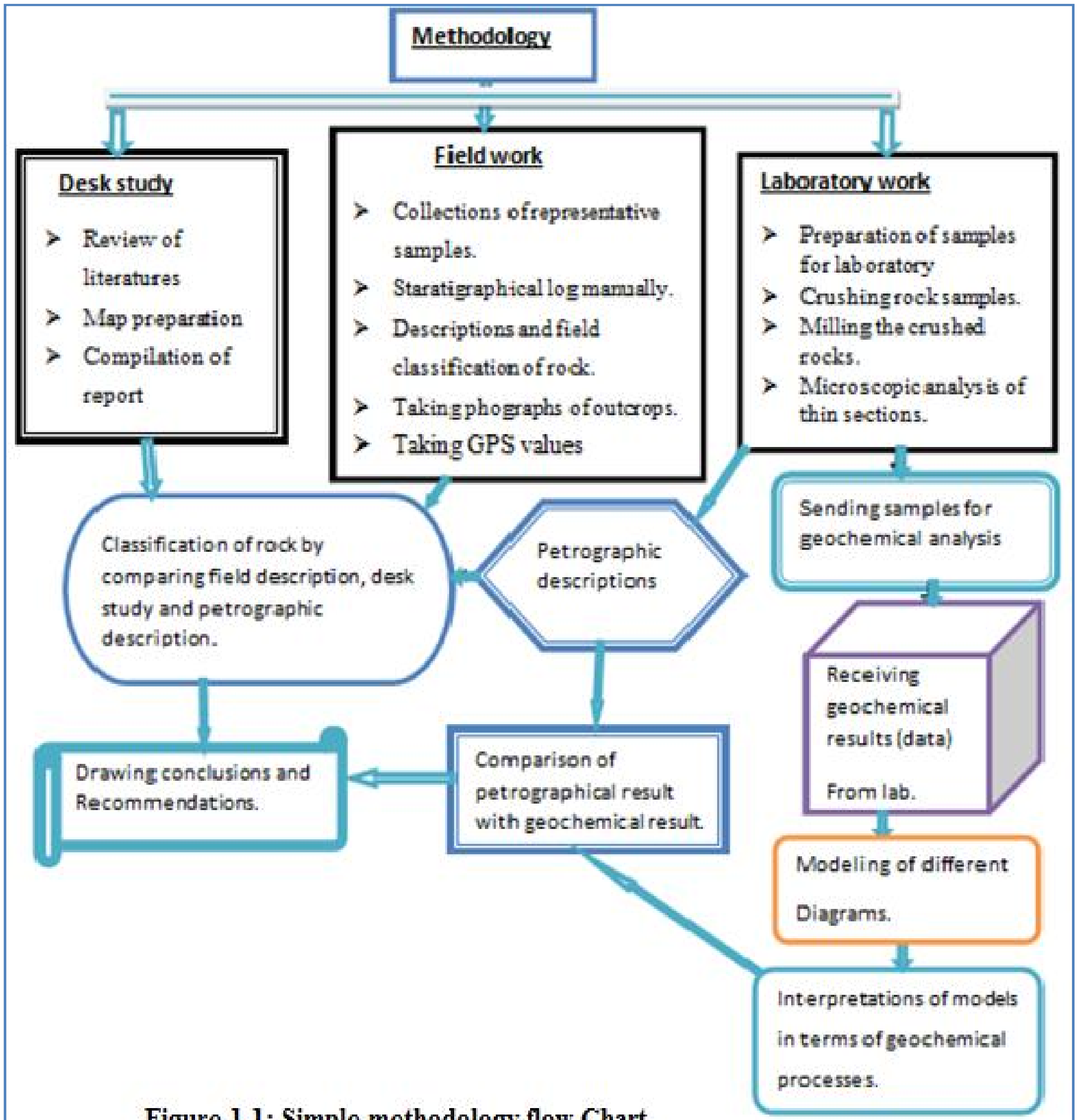


Figure 1.1: Simple methodology flow Chart.

Geochemical analysis

For Geochemical analysis thirteen samples were cut, crushed and milled to about less than 200mesh sieve analysis size in the Addis Ababa University School of Earth Sciences laboratory. These thirteen samples have been sent to Centre de Recherché Petrographiques et Geochimiques Nancy France for determinations of major and trace element concentration of the samples. The elemental composition of each rock samples were determined using ICP-OES and ICP-MS in CRPG in Nancy France more described in next (Chapter 4).

1.6. Significance of the study

This study is dealt with the petrogenesis of basalts of Ghibe River gorge of the central parts of Omo-Ghibe River Basin which provided the geochemical and petrographical data. Essentially the output of the proposed research will provides the basic geological and geochemical information about the area, which can serve as background information.

1.7. Limitations

During undertaking this thesis there were some limitations those inhibits to do the study in detail. These limitations were data and location of the study area. The rough topography and the coverage's of the area by forest and difficult to cross across all areas, and difficult to map geologic structure that may be found in the area as well as needed. Another limitation was lack of structural data, from what have been done previously in regional works.

1.8. Overview of the Study Area

1.8.1. Location and Accessibility

The study area which is just found southwest Addis Ababa is located in southwestern Ethiopia, about 188 km from Addis Ababa along the main(asphalt) road that takes from Addis Ababa to Jimma, which is tried to define on the bellow location map of study area, around central part of Omo- Gibe River Basin (Figure. 1.2). The area found West of Welkite Town of Guraghe zone and covers three kebeles such as: Ghibe Bare, Boketena serite, and Ghibe Yemengist Ersha in Abeshege Wereda. Tawula town is the nearest one among the others. By relative location, the study area is bounded by oromia regional state zones in, West, and South direction, while, in North and East direction by state of

Southern, Nation, Nationalities and Peoples regional state zone. The study area is found between 34^{0}2’00”E, latitude and 91^{0}5’00’’N, longitude. The map is presented only to show the accessibility and the location of the area (Figure 1.2). The colored area in the map shows the present study area.

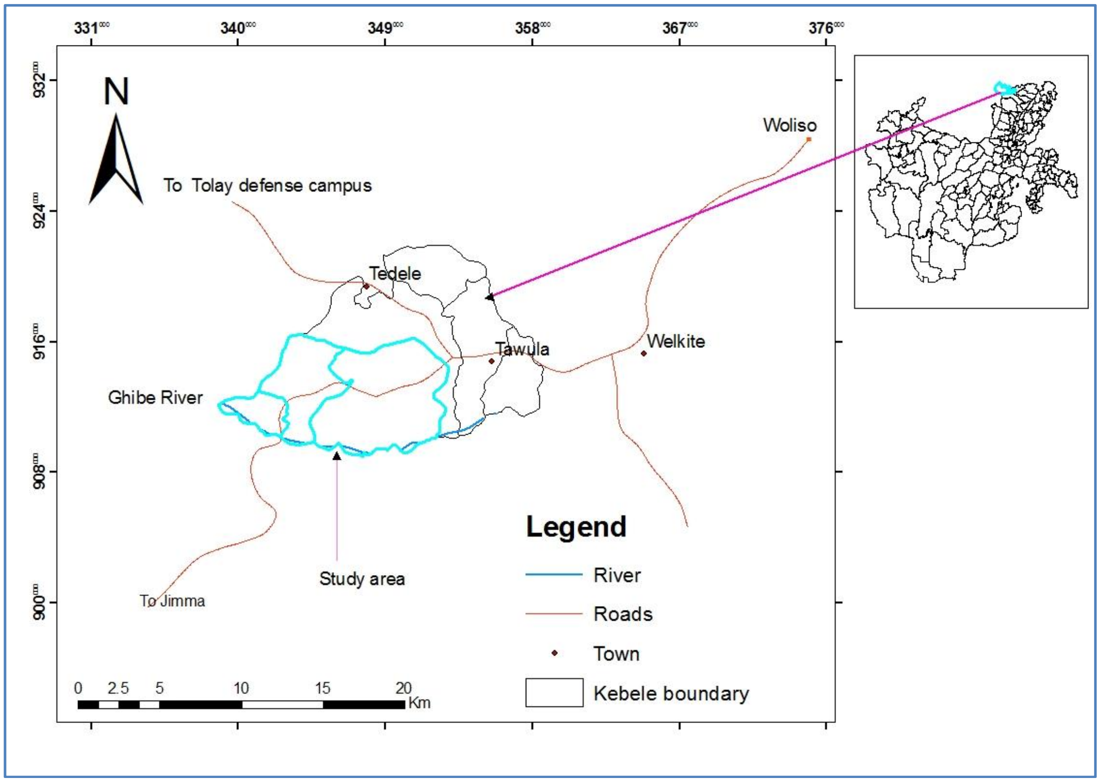


Figure 1.2: Location and Accessibility Map

1.8.2. Physiography and Drainage

As Ethiopian Meteorological Authority (1981) report physiographically, the study area is located partly in the Western Highland Plateaus and in Omo basin. The study area is characterized by varied topography ranging from slightly gentle slope to slightly rugged cliffs, volcanic domes and little valleys (Figure 1.3). In the southwestern and southern part the area is bounded by Ghibe River which flows from northwest and divert to the south around the study area, where it is tributed by Wabe River that flows from East west before joining with Ghibe River at the south east of study area, and originate from Mountain Guraghe. Ghibe River is tribute by many small streams in the study during summer. This Ghibe River with its tributaries Wabe River flows into Lake Turkana to the south. It comprises small rolling ridges and deeply dissected gorge-like valleys bounded to the east by Guraghe and to the west by Jimma scarps.

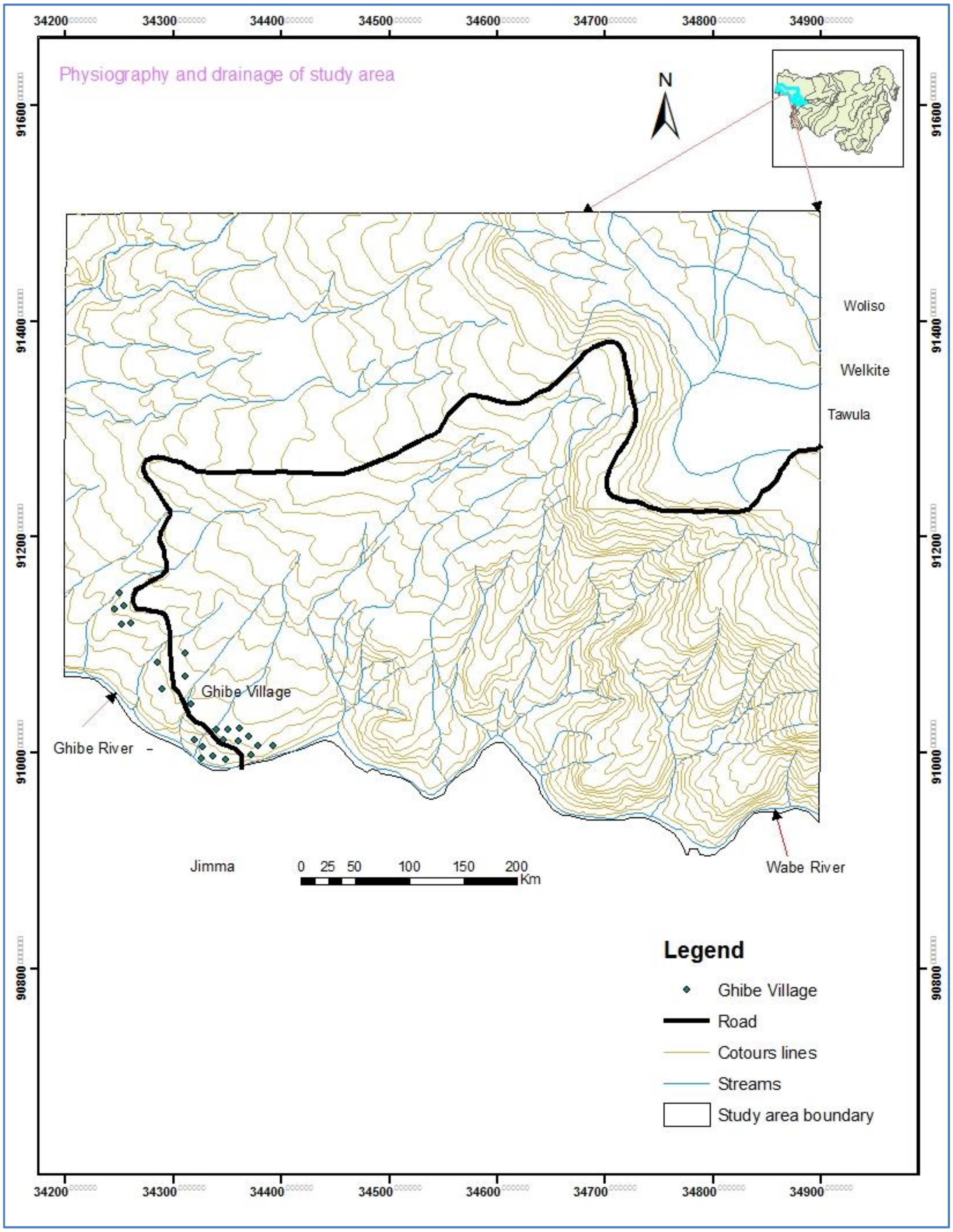


Figure: 1.3: Location map showing the Physiography, and drainage of the study area.

1.8.3. Climate, Vegetation and Socio-economic activities

Climate

Climatologically the study area, lie in a tropical climate, classified as wet, humid region with a mean annual rainfall of 1000-1400 mm per year (Ethiopian Meteorological Agency, 1981). The area is characterized by two seasons of rainfall. The first season spans from late May to late September and the second is from mid March to mid of April. The warmest month is February to May, whereas the coldest month is July and August.

Vegetation

Concerning the study area, the vegetations covered are mostly natural, and few about less than 5% is cultural or manmade are found. Therefore the area is covered by different types of dry savanna grass, bamboo, forest, deciduous Woodland and other varieties (Ethiopian Meteorological Agency, 1981). Geologically the vegetations play a greater role for weathering of the rock unit, next to climate and organisms. There are a number of trees those grown on the outcrop and breaks it into different smaller pieces of rock fragments in the area and it is susceptible to erosion later on.

Socio-economic activities

In the study area the populations are sparsely populated, only in Ghibe village little bit densely populated. It is dominated by Guraghe, Amhara and Oromo people, as well as other Southern Nations and nationalities peoples. The life existence of these peoples mostly depends on farming. Their crops are mostly corn. Facilities such as drinking water, school, clinic, transportation, market and etc. are not sufficient and they go to walkite town, which is east of the project area, about 38km from Ghibe village to Welkite Town. The most common problem of the peoples in this area is the drinking water. They use Ghibe River for both drinking and washing their closes as well their body, which is difficult for the healthy of these peoples.

CHAPTER TWO

2. Regional Geological Setting

2.1. Geology of Omo-Ghibe Basin

The Omo-Gibe Basin lies in the southwestern part of Ethiopia and extends from about 150 km west of Addis Ababa south-west to Ethiopia's boundary with Sudan and Kenya. The Basin encompasses parts of the Southern Ethiopia People's Administrative Region and the Oromiya Administrative Region. It is bounded to the west by the Baro-Akobo River Basin, to the north by the Abay River basin, to the east by the Awash River Basin and the Ethiopian and Chew Bahir rift valleys, and to the south by the Kenya and Sudan borders.

Kazmin (1971, 1972, 1975a, 1975b, 1978, 1979) reported the first stratigraphic subdivision and tectonic synthesis of the Pre-Cambrian rocks of Ethiopia and interpreted the geology of western and south-western Ethiopia on the basis of plate tectonic concepts. The geology of Omo-Ghibe Basin divided into four major groups of rocks according to their age relationships shown on Figure 2.1.

2.1.1. Precambrian crystalline Basement Rocks

In this Basin the Pre-Cambrian basement rock is subdivided into three 'domains' based on a combination of lithology and metamorphic grade, stratigraphic and tectonic relationships and lithological units. These are: Hamer, Akobo, and Surma Domains. The five major Pre-Cambrian lithological units that occur in the Omo-Gibe Basin, those highly deformed and re-crystallized are high grade rock such as: mafic (hornblende) gneiss, biotite-hornblende gneiss, meta-sedimentary gneiss, quartz-feldspar gneiss, and muscovite-biotite granitoid gneiss (Figure 2.1).

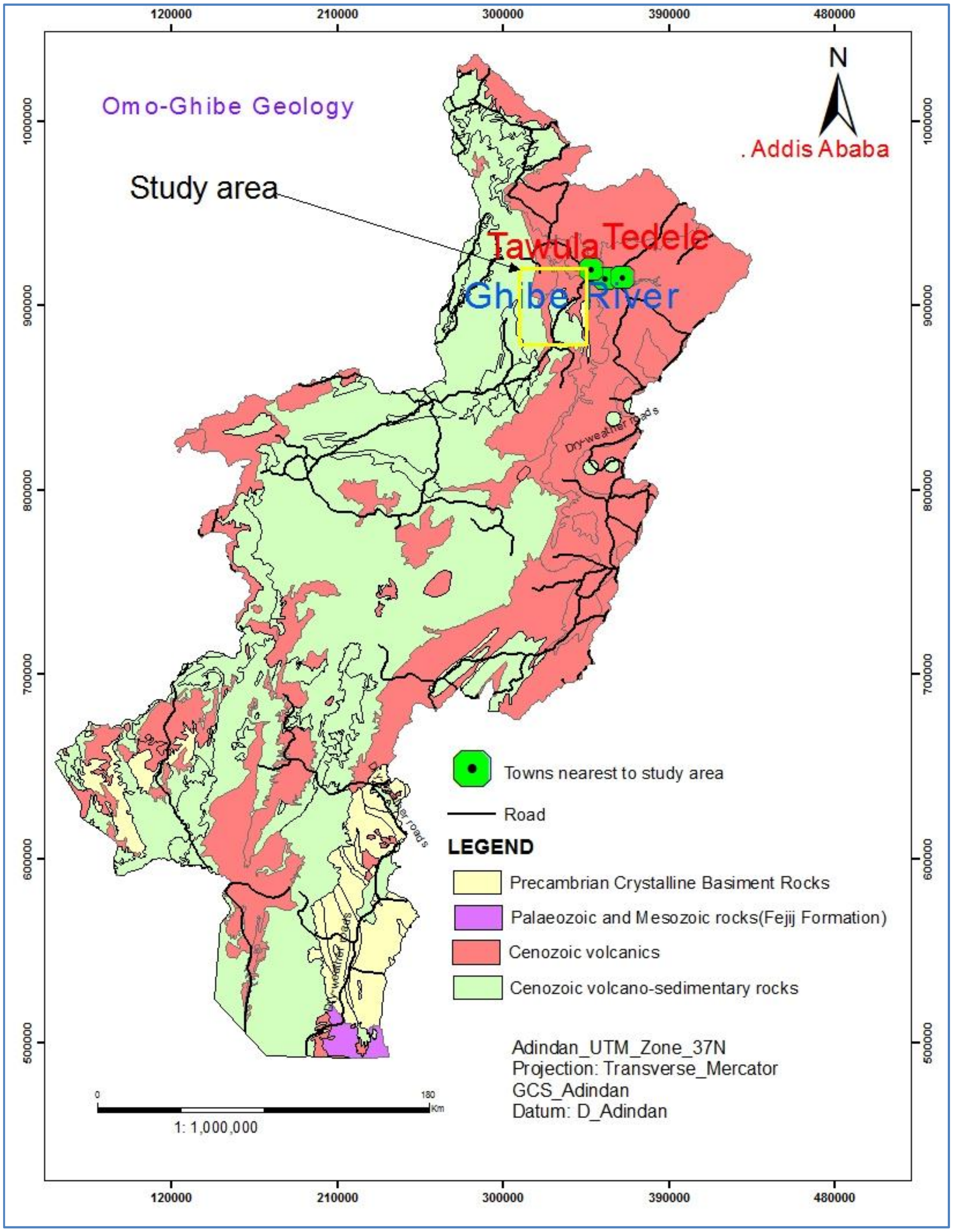


Figure 2.1: Geological map of Omo-Ghibe River Basin modfied from Richard Woodroofe and Associates (1996).

2.1.2. Palaeozoic and Mesozoic rocks

The Omo-Ghibe Basin area was a continental land mass during Palaeozoic and Mesozoic times (Figure 2.1). Pre-cambrian rocks were eroded into a low-lying peneplane and subjected to deep lateritic weathering, with the development of pisolitic ironstone capping in places (e. g the upper Kibbish River area).

In the far south of the Basin, the Fejij basalts in the east and the Surma basalt in the west are underlain by discontinuous light buff sands and gravels up to 20 m thick containing petrified wood, which may be an equivalent of the lateritic sandstones and conglomerates.

2.1.3. Cenozoic volcanics

The Cenozoic geology of the Omo-Gibe Basin is sub-divided into four major groups of rocks, based on their ages relative to the formation of the Rift Valley System:

i) The early 'Flood Basalts' of late Eocene to early Miocene age.

ii) A transitional series of intercalated basaltic and felsic volcanics of late Oligocene to early Miocene age.

iii) A series of felsic volcanics ranging from early Miocene ('Pre-rift') to late Miocene ('Post-rift') in age.

iv) The 'Post-rift' sedimentary succession of Pliocene to Holocene age.

2.1.4. Cenozoic volcano-sedimentary rocks

For the last 3-4 million years of the Plio-Pleistocene periods, major volcanic activity was more and more confined to the Ethiopian Rift (Davidson, 1983). At that time, geological activity in the Omo-Gibe Basin was mostly restricted to deposition of alluvial sediments in the lower parts of the Lake Turkana-Lower Omo Basin along with the activity of young volcanoes along the border of the Ethiopian Rift. The lower Omo Basin contains a huge thickness of fluvial and lacustrine sediments that fill the rift valley (Davidson, 1983); the central of the Omo-Ghibe Basin consists of limited basaltic volcanism flows and tuffs of: The Nakwa Formation (oldest), Wumba Hayk basalt, and the Weliso basalt (youngest).

CHAPTER THREE

3. Geology of the Study area

3.1. Introduction

The present study area, Gibe River gorge is very fascinating area, where volcanic rocks are exposed extensively. To map the geology of the area, observations were done to select good outcrops. After selection of those exposures, the field work was completed. Basaltic rocks which have been distributed in the areas with different thickness from small thickness to about greater than 110m, and as well as those fluctuate in color, from black, dark-grey, to light gray-greenish and enriched by a range of minerals were sampled. The area is dominantly covered by basalt, some trachyte and unwelded tuffs are less common. But the last two are not discussed more; little it is used for classification, since it is out of the objective of the study.

3.1.1. Lithology and petrography

Ghibe gorge is found in the western parts of Ethiopian plateaus at western of Guraghe rift margin, which is separated by Main Ethiopian Rift Valley from eastern Ethiopian plateaus. This area is one of volcanic provinces of Ethiopian high land that is situated in western highland at a distance about 75km west of MER. The litho-stratigraphy of this area is comprises of most dominantly basalts, and less trachyte and tuff are cropped out in some area.

1. **Basalt**

The basaltic unit is classified into lower and upper basalt. There are about three flows in the study area. The thickness of these lava flows varies from one flow to the other flow. In the eastern part of the study area the basalt has continuity from lower to upper basalt (Figure 3.10). The middle and western of the study area is covered by forest and thick surface soil, but there is basalt cropped out along the streams and some areas on the surface. The outcrops in the streams indicate the continuity of the second flow. But, it is taken as the contact between the second and third lava flow, and mapped as middle basaltic unit on litho-stratigraphy (Figure 3.9) and geologic map (Figure 3. 10).

Lower basalt

This is massive basalt, cropped out at lower (southwestern and Southeastern) of the study area overlying unexposed unit. It is classified into first and second lava flow. The contact between the first lava flow and the second lava flow is marked by thin paleo-soil. Hence they are mapped together on the geologic map (Figure 3. 10) and litho-stratigraphy (Figure 3.9) as lower basalt.

The first lava flow is from 1070m to 1099m elevation and thickness is about 29m (Figure 3.1). The morphology of this flow is steep cliff at the bunk of Ghibe River and form gentle slope on the top part. In this flow four samples: GIB-1, GIB-2, GIB-12 and GIB-13 were collected, due to difference in their color and visible mineral phenocrysts of the outcrop (Appendix 2) were collected. Out of these four samples: the one GIB-13 has metallic sound when hammered by geologic hammer. Texturally the basalt of this flow is porhyritic with phenocrysts of feldspars (mainly plagioclase), olivine and pyroxene minerals. In some area of this flow, olivine phenocrysts are more visible. In other area olivine, feldspars and pyroxenes are clearly observable (Appendix 2).

Figure **3.1: Lower basaltic flows cropped out at western and southwestern of Ghibe village (the first flow).**

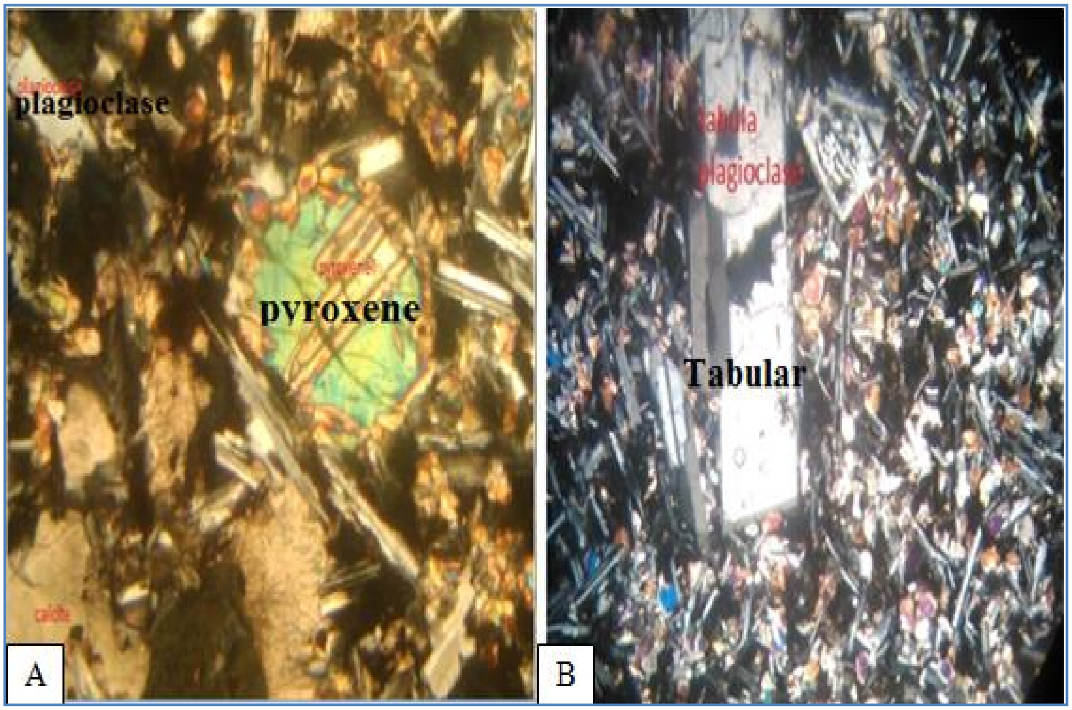


Plate 3.1: Phenocrysts of pyroxene and tabular plagioclase in (plate A, GIB-13 and plate B GIB-4 (10X under XPL).

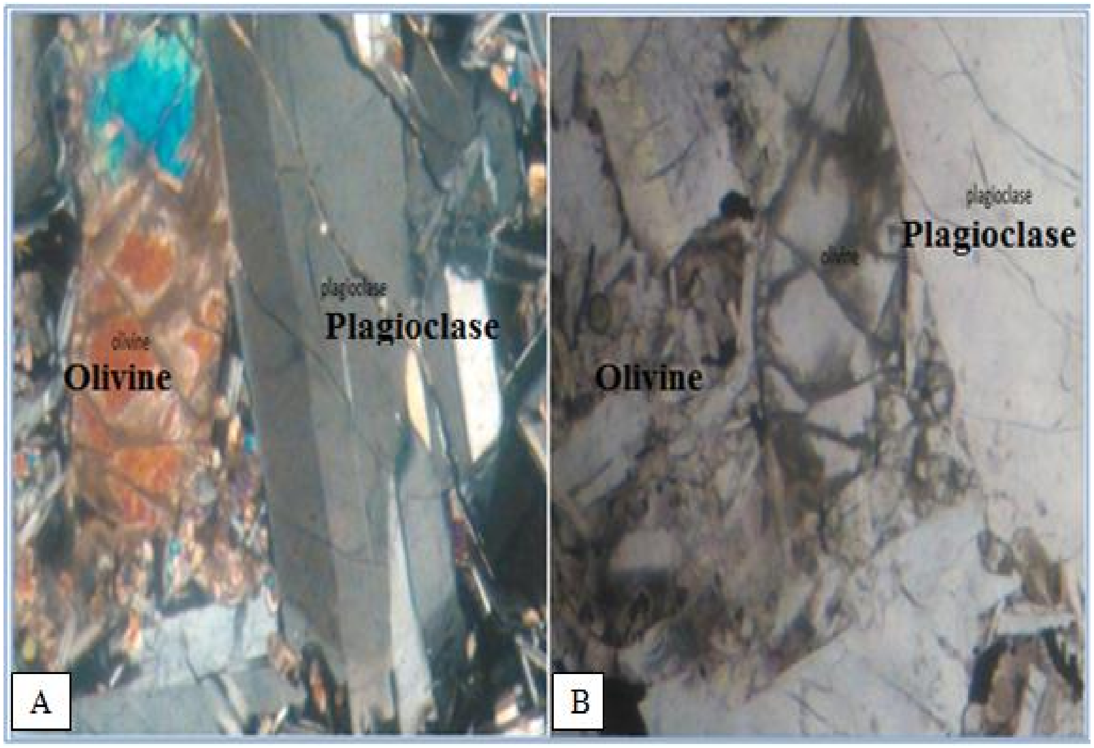


Plate 3.2: Phenocrysts of olivine and plagioclase (10x the left one under XPL and the right one under PPL)

The **second lava flow** starts at elevation of about 1099 -1200m elevation. The thickness of this flow is 101m. The morphology this flow form gentle slope and in some area form steep slope. This unit is characterized by black color and aphyric texture in hand specimen scale (Figure 3.2).

The **contact** between this flow (second flow) and the third flow (upper basalt or northern of study area) is marked by thick surface soil and some basaltic outcrop along streams. In this contact area, also fragments of different sized basaltic unit that falls from cliff forming basalt (the third lava flow) are widely distributed. It covers large area including forest area in the center, western, northern, and northwest of the study area mapped as middle basalt (Figure 3.10).

Figure 3.2: Closely taken photo of lava flows, showing flow banding, taken from second lava flow.

Upper basalt

This upper basalt is the third lava flow, which cropped out at the north and northeastern of study area. It forms a scarp which extend more than 20km at the upper part from northern to southeastern (Figure 3.10) of the study area. The thickness of this flow is about 150m and the morphology form cliff and in some area it form gentle slope. This lava is composed of aphyric and porhyritic texture. The unit is very fine, so in hand specimen scale it is difficult to determine its mineral composition by our necked eye, however, by using hand lens some mineral phenocrysts can be identified. Thus greenish olivine phenocryst is clearly identified. The color of this outcrop is light gray to dark and has shiny fine grained feldspar minerals.

This unit (third flow) is characterized by columnar joint, vesicles, and fault.

The columnarly jointed basalt: is formed as a consequence of contraction and shrinking of lava during cooling, due to this a sets of vertical joints develop on this rock unit (Figure 3.3). The color of this unit is black- dark grey and aphanitic in texture.

Figure: 3.3: Closely taken photo of columnar jointed basalt cropped out at northern of Ghibe Genet forestry and agricultural PLC head office to Serete Village.

Vesicular basalt: vesicle is also the determining feature of the surface morphology of the basaltic rock in this upper basalt. These vesicles are formed when lavas heavily charged with gases and other volatiles are erupted on the surface, the gaseous constituent's escapes from the magma as there is a decrease in the pressure. Thus near the top of flows, empty cavities of variable dimensions are formed.

These vesicles thus are subsequently filled in with some low- temperature secondary minerals. This structure was observed on the basaltic unit cropped out in this area (Figure

3.4). Petrographically, some samples shows the vesicles which filled by secondary minerals calcite or chalcedony. Vein filled by calcite minerals were recognized by petrographical studies of thin section (GIB-10) Plate 3.12.

Figure 3.4: Photo of vesicular basalt cropped out at northern of Ghibe Genet forestry and Agricultural PLC Head Office.

Faulted basalt: As illustrated by the Figure 3.5, the normal fault which shows the movement of similar rock type and placed at different elevation on outcropped rock unit of this flow, portrayed on the basaltic cliff (upper basalt). This faulting corresponds to the brittle failure of an undeformed basalt or alternatively, involves frictional sliding on a pre-existing fault plane is affects the outcrop. Normally this types of faulting, occurs when the maximum differential stress exceeds the shear strength of an intact rock formation, or the frictional strength of a pre-existing fault. This normal fault stepping from lower to upper inferred from the movement of hanging wall down ward relative to the foot wall as illustrated on Figure 3.5.

Figure 3.5: Photo illustrate normal fault, which affect the basaltic unit. HF = Hanging wall, FW = Foot Wall.

From the petrographical studies of thin sections, Ghibe River gorge basalts which reflect the chemical compositions and cooling history were deduced. In this the fabrics indicates the rapid cooling of near liquidus temperature as magma extruded. The grain sizes are variable from glassy to larger phenocrysts minerals. Almost all except one sample (GIB-6), which is aphanitic others, are porphyritic basalts (Appendix 3). The most commonly observed phenocrysts are Plagioclase, olivine and pyroxenes.

As tried to discuss above, this basalt was sampled at lower (first and second flow) and upper section (3rd flow) of the study area. From these flows 11 samples are classified as mafic lava. Mafic lava varies from aphyric to porphyritic with phenocrysts of plagioclase, olivine and pyroxene. The groundmass of mafic lava composed of minerals such as plagioclase, pyroxene, olivine, secondary minerals (calcite or zeolite), opaque may be (Fe-Ti oxide or ilmenite) minerals and interstitial volcanic glass.

Except GIB-6 which has aphyric texture others show phyric texture with phenocrysts of plagioclase, pyroxene, and olivine minerals. Some of them are tabular, some others are bladed, columnar, acicular, zoned, sieve and lath like crystal habit of Plagioclase phenocrysts are dominant. They show the porhyritic texture of bulk rock with the phenocrysts of plagioclase, olivine and pyroxene. The ground mass constitutes of pyroxene, olivine, numerous acicular to lath like crystals of plagioclase, interstitial volcanic glass, opaque minerals and secondary minerals. The phenocrysts are bunched or clustered, in agreggate or clots called glomerocrysts and known as glomeroporphyritic texture (Plate 3.3). The following Plates show the series of photomicrographs illustrating the petrographic variability of basalts. In most cases the phenocryst minerals appear highly embayed and are clearly out of equilibrium with the host magma. Normally, plagioclase is the dominant phenocryst phase, accompanied by olivine and pyroxene minerals. Amphiboles are generally absent and the bulk rock compositions were dominated by plagioclase, olivine, pyroxene and secondary minerals. The phenocrysts are indication of fractionation of early grown minerals in the differentiation process of magma.

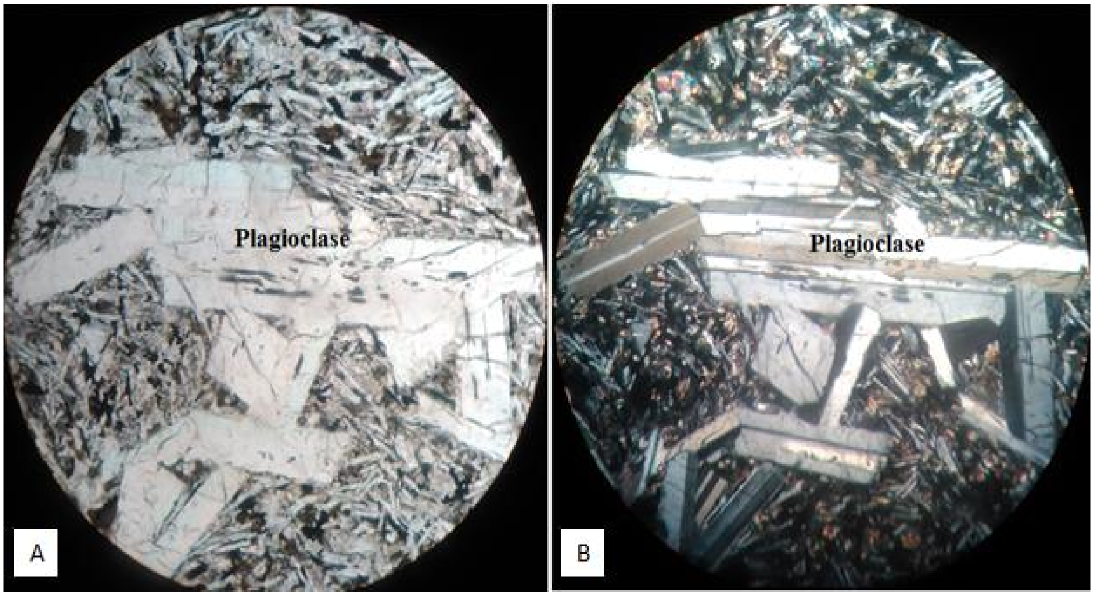


Plate 3.3: Phenocrysts of plagioclase which show glomeroporphyritic texture, in GIB-8 (4X A under PPL and B under XPL).

2. Trachyte

This unit is cropped out at southeast of study area, forming dome like morphology with many ups and downs (Figure 3.6). Two samples, GIB-14 and GIB- 3 are classified as a Trachyte unit.

GIB-14 is a pyroclastic trachyte; light colored, and mainly composed of Quartz, alkali feldspar, rock fragment, some opaque minerals and volcanic glass. Quartz and alkali feldspar crystals are euhedral to sub-hedral in shape. It is porhyritic with 5% phenocrysts of alkali feldspar and Quartz set in fine grained groundmass of 10% Quartz and alkali feldspar, 10% rock fragment, 1% opaque and 74% volcanic glass. It consists of numerous pieces of glassy material, and fine-grained tuff in groundmass. It composed of continuous welded materials caused by strong compaction and welding of original fine materials (Plate 3.4A). The texture is vitrophyric from large crystal phenocryst minerals set in fine materials.

Figure 3.6: Trachyte unit cropped out at the southeast of the study area.

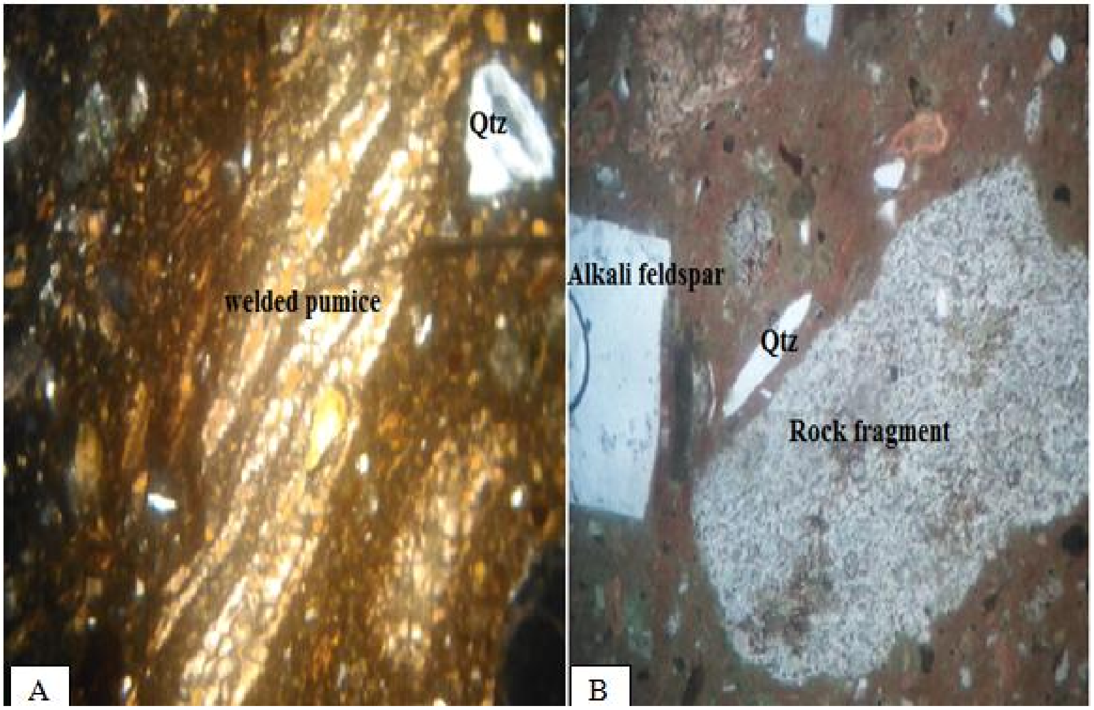


Plate 3.4: Photos shows vitrophyric texture, in GIB-14 (10X plate A, under PPL and plate B, under XPL).

In GIB-3 the mineral composition is mostly plagioclase minerals, and some pyroxene and opaque minerals. It includes: some tabular, few bladed and columnar like grains of plagioclase phenocrysts and acicular, flow like ground mass of plagioclase. From petrographical studies, it is porhyritic with 10% plagioclase and 1% pyroxene phenocryst minerals set in a fine grained ground mass of about 80% plagioclase, 3% pyroxene, 5%, opaque, and 1% interstitial volcanic glass. The common phenocrysts of plagioclase are euhedral to anhedral in grain shape. Texturally it displays trachytic texture, where acicular to tabular plagioclase phenocrysts align in one direction, suggestive of flow prior to cooling (Plate 3. 5). Pyroxene minerals have elongated crystal habit. In this sample most minerals were aligned to one direction giving the trachytic alignment of the rock.

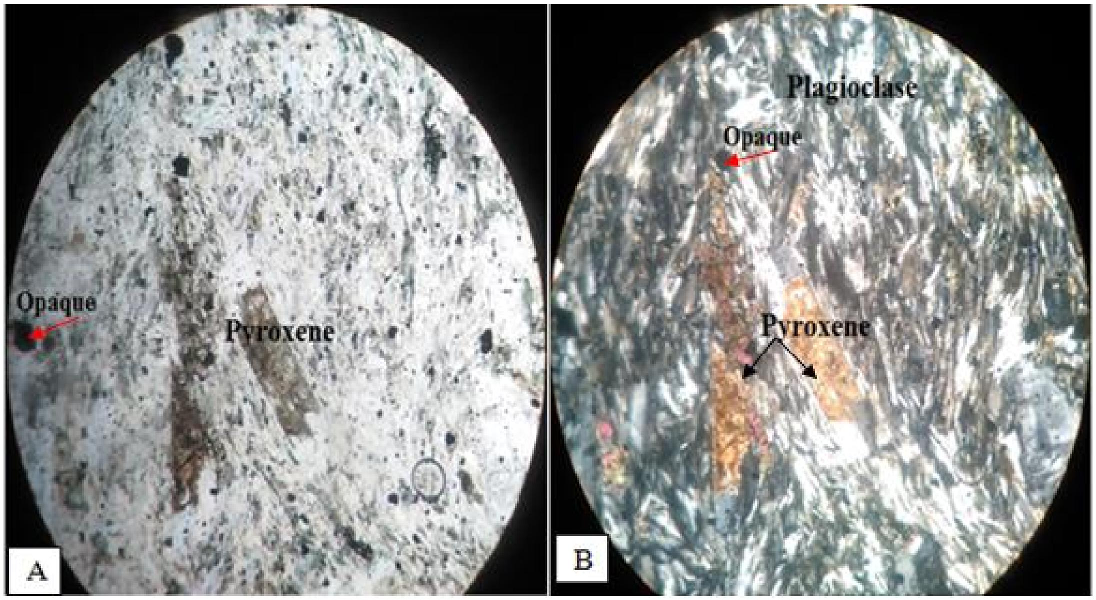


Plate 3. 5: Phenocrysts of clinopyroxene and plagioclase, shows flow like trachytic alignment, in GIB-3 (in 10x, Plate A under PPL, plate B under XPL).

3. Unwelded tuff

This unit is outcropped above upper basalt at 1611m elevation, and thick greater than ~ 6m. It is characterized by dark- greenish and brownish-white color (Figure. 3.7) and cover flat land at northern to northeastern of Study area (Figure. 3.10).

Figure 3.7: Photo of unwelded tuff taken bellow Serete village at NE of the area.

Mineral phenocryst phases

Plagioclase: Plagioclase minerals are found in two generations. They commonly occur as, phenocryst and groundmass phases. It is dominant in GIB-3 sample in which, it is 10% as phenocrysts and 80% as groundmass minerals. Its alteration in this case is commonly appeared dark dirty along grain boundary and looks like zoned crystals in some rocks (Plate 3.7). The plagioclase phenocrysts found in the form of tabular, euhedral to anhedral crystal habit, Carlsbad twinned (Plate 3.8), zoned and some of them have sieve like textures (Plate 3.7). The groundmass of plagioclase has numerous acicular and lath like crystal habits. The sieve like texture of plagioclase is intergrown with some pyroxene, olivine, volcanic glass and other secondary minerals.

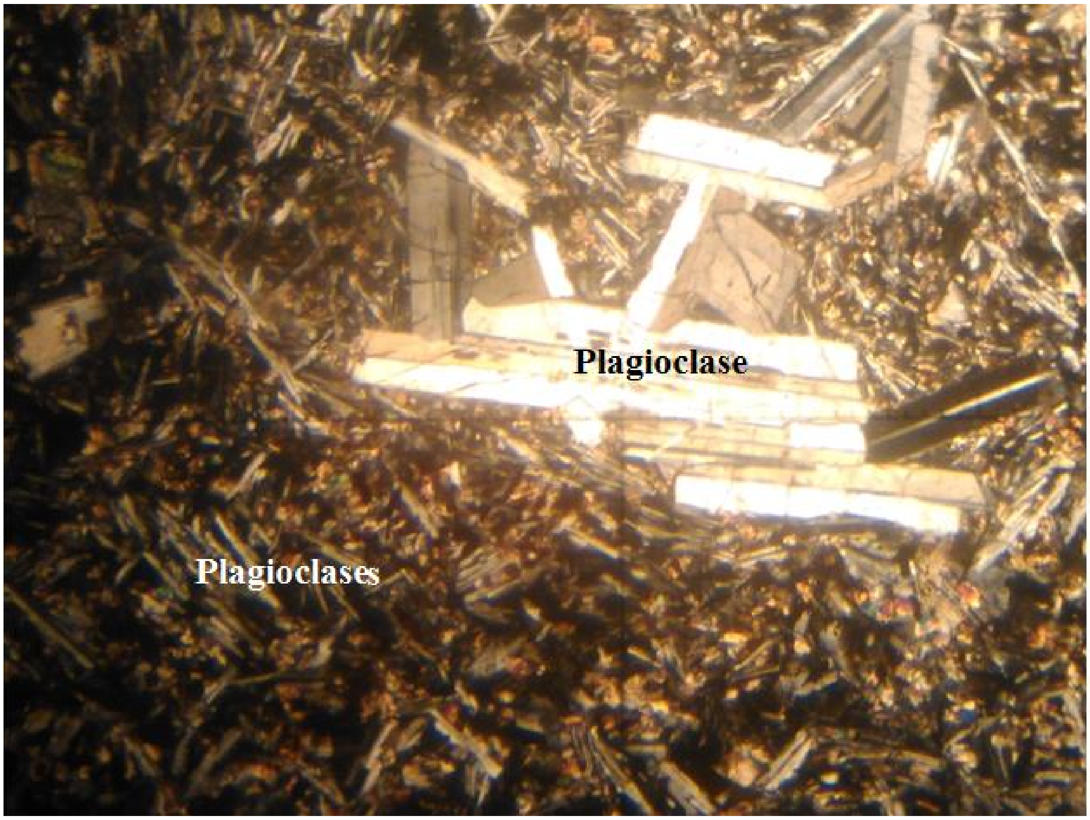


Plate **3.6: Columnar and lath like crystals of plagioclase phenocrysts in GIB-08 (4x XPL)**

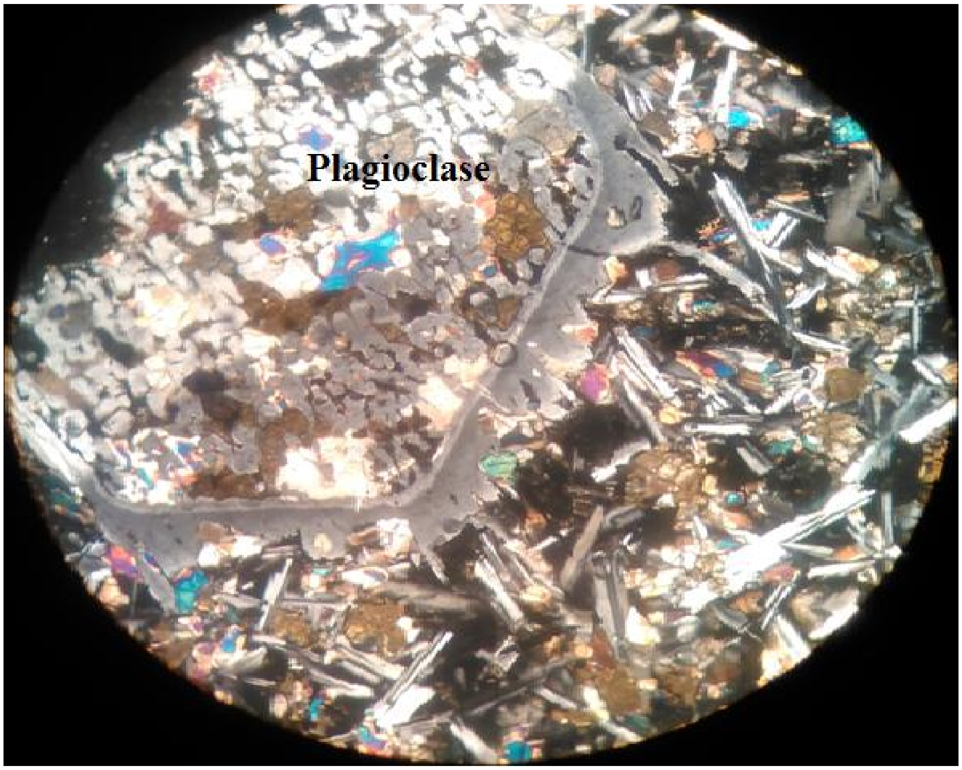


Plate 3.7: Sieve like or poikilitic texture and zoned crystal of plagioclase in GIB-12, (10x under XPL)

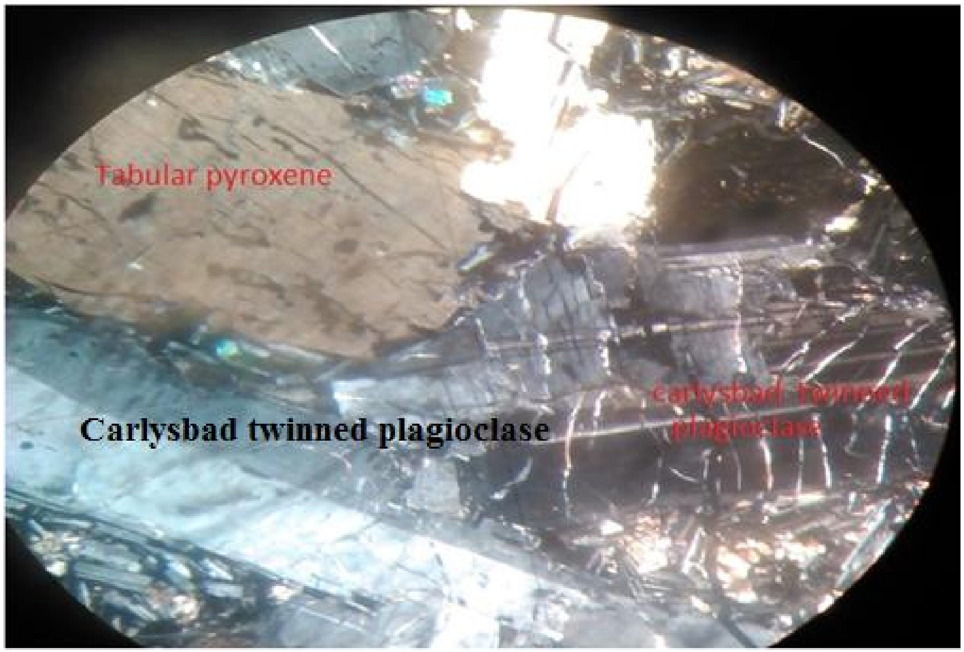


Plate 3.8: Carlsbad twinned plagioclase and tabular pyroxene in GIB-7, (10x XPL).

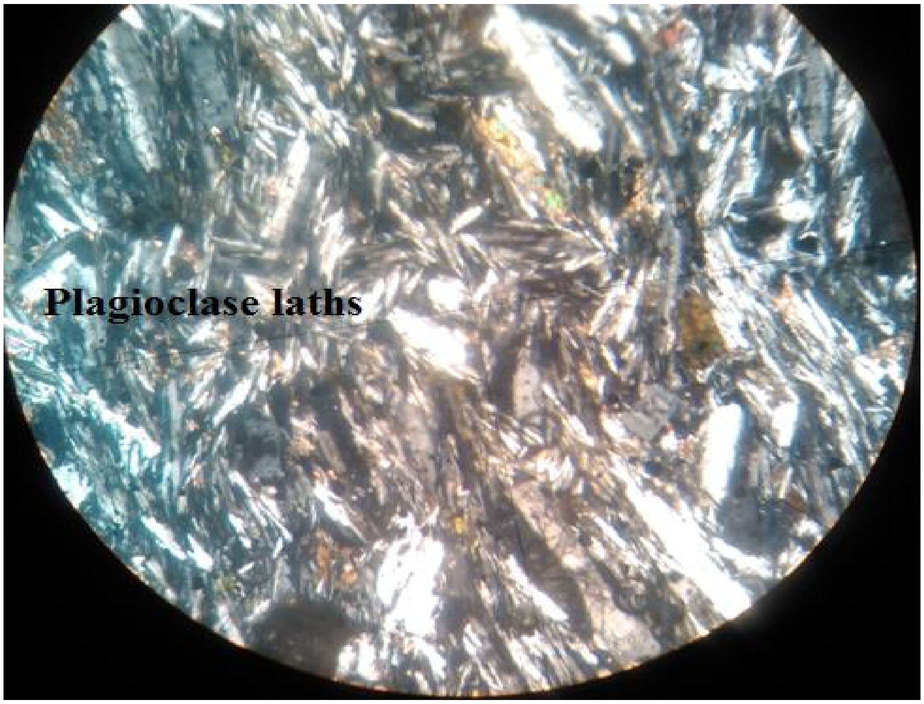


Plate 3.9: Photos of laths of plagioclases in GIB-3 and GIB-4 (4x XPL).

Olivine: olivine mineral is less dominantly found. They are highly fractured and altered since it is very susceptible to alteration. Therefore, bright green olivine losses its appearance rapidly in weathering environment. In some samples olivine minerals are altered to iddingsite (Plate 3.10) largely within the grain, and along grain boundary. It is also occurred in two size ranges, sparsely as phenocrysts and ground mass phases. Sometimes it occurs as inclusions in plagioclase minerals (Plate 3.7). On the (Plate 3.10) olivine is light yellowish - dark gray under XPL, and dark yellow along unaltered grain boundary and white along grain boundary were alteration is high under PPL. The large crystal of olivine is filled by interstitial volcanic glass which is dark under XPL and white or colorless under PPL.

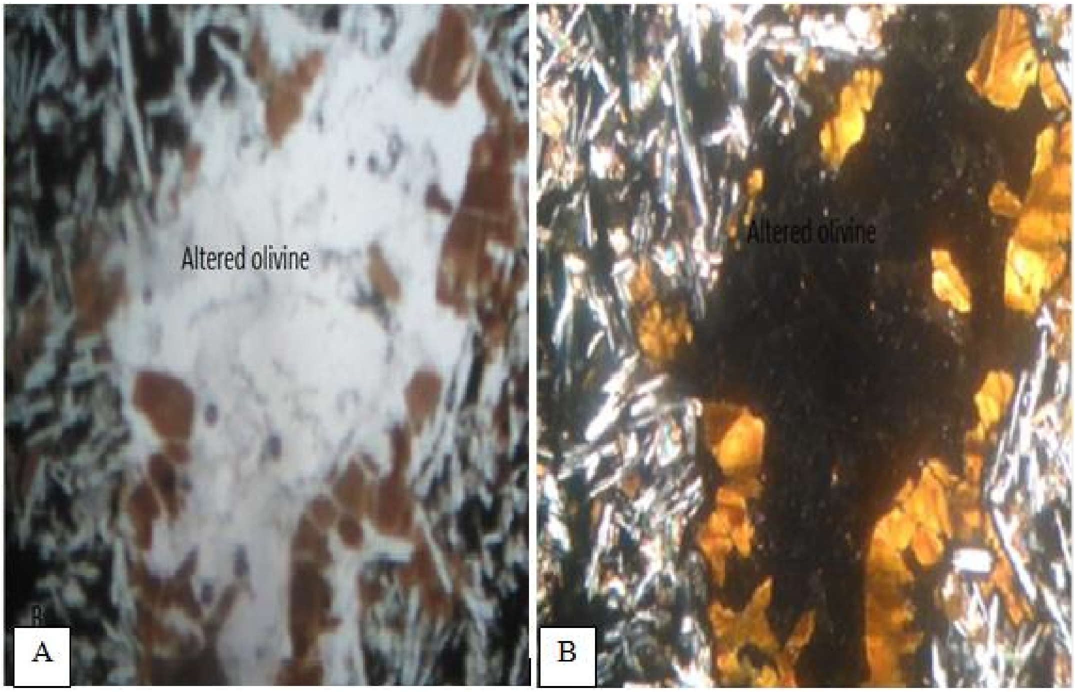


Plate 3.10: Phenocryst of olivine altered to iddingsite in GIB- 2, (10x plate (A) in PPL, plate (B) in XPL).

Pyroxene: pyroxene (mainly clinopyroxene) occurs sparsely as phenocrysts and also as a ground mass. Commonly it forms euhedral to anhedral crystal habit and aggregated with crystals of plagioclase phenocrysts. From (Plate 3.11) it has yellowish interference color XPL and colors less under PPL. Pyroxene is always appears as fresh minerals, which not show us any alteration.

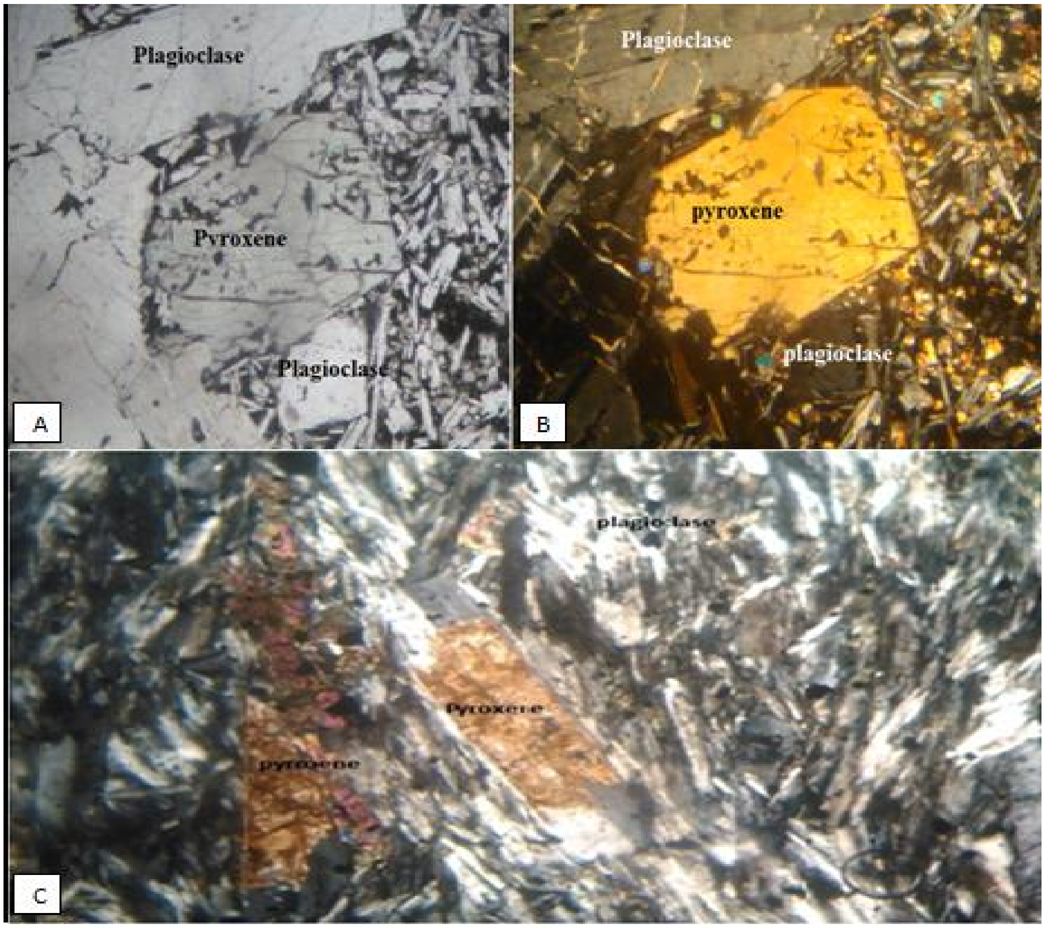


Plate 3. 11: Phenocryst of pyroxene aggregated with plagioclase (10x Plate A, under PPL, plate B, and C, under XPL.

Alterations: Some samples show alteration. Olivine mineral is altered to iddingsite mostly in GIB-2 (Plate 3.10), within the grain and along grain boundaries. It shows fracture without any cleavage and the internal part is filled with interstitial volcanic glass. Almost in all samples, except in GIB-14 and GIB-2 plagioclase shows dark dirty appearance, commonly some of phenocrysts have poikilitic (sieve) texture which is intergrown with fine minerals of pyroxene, olivine, volcanic glass and calcite (Plate 3.7). The alteration of plagioclase to calcite is common. The vesicles are filled with secondary minerals like calcite. Some of filled vesicles have rounded to sub-rounded shape (e.g. GIB-5, GIB-8, and GIB-10). Predominately GIB-10 has a vein filled by calcite minerals. This vein is two in this sample and it is sub-parallel to parallel with the second vein (Plate 3.12). Generally altered minerals include: Olivine and plagioclase (Plate 3.10 and 3.7 respectively).

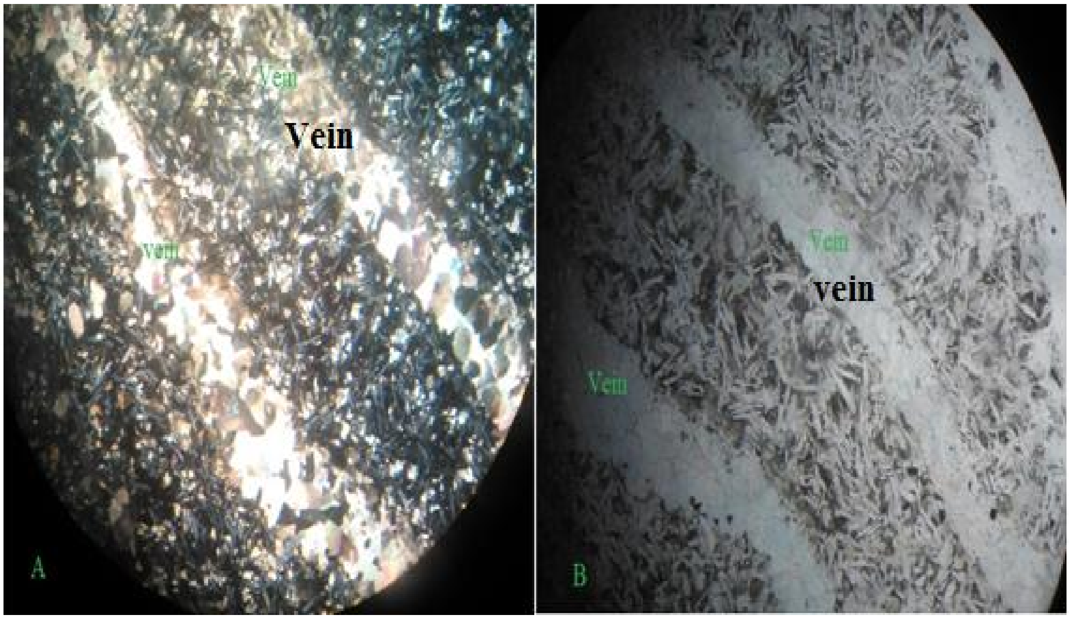


Plate 3.12: Photos of veins filled with secondary minerals (calcite) in GIB-10 (in 4x, plate A under XPL and plate B under PPL).

K/Ar radiometric dating of Ghibe basalt was determined by Bonini et al., (2005). Accordingly the Ghibe basalts were classified into lower and upper those dated as 11.54 Ma and 10.35 Ma respectively. The first and the second lava flows of the present study are in the lower section and the third flow is in the upper section of Ghibe River basalt of Bonini et al., (2005). 7 samples of the present study are from the lower section, whereas other 7 samples are from upper section. As plotted on the (Figure 3.8B) taken from Bonini et al., (2005), GIB-1, GIB-2, GIB-3, GIB-4, GIB-12, GIB-13, and GIB-14 are correlated with lower (11.54 Ma) and GIB-5, GIB-6, GIB-7, GIB-8, GIB-9, GIB-10, and GIB-11 are correlated with the upper section (10.35 Ma).

On the basis of monoclinal attitude of the MER shoulder and rock petrochemistry and ages, the rocks cropping out at Ghibe are correlated to the Guraghe-Anchar basalts exposed at the Guraghe Rift margin (Figures 3.8) Bonini et al., (2005). This interpretation, implying the existence of an upper Miocene plateau-like event, is consistent with the occurrence of widespread time-correlative basaltic units both in western (Wollega, Fursa and Lake Tana basalts, 11–9 Ma) and in the eastern (Upper Trap and Anchar basalts, 10.5–9 Ma) plateaus. Ghibe basalt of (10.35 Ma) and Guraghe-Anchar basalt of (10.25Ma) of Bonini et al., (2005) is concomitant with alkali basalt of (10.76 Ma) of Guna shield volcano of Kieffer et al., (2004).

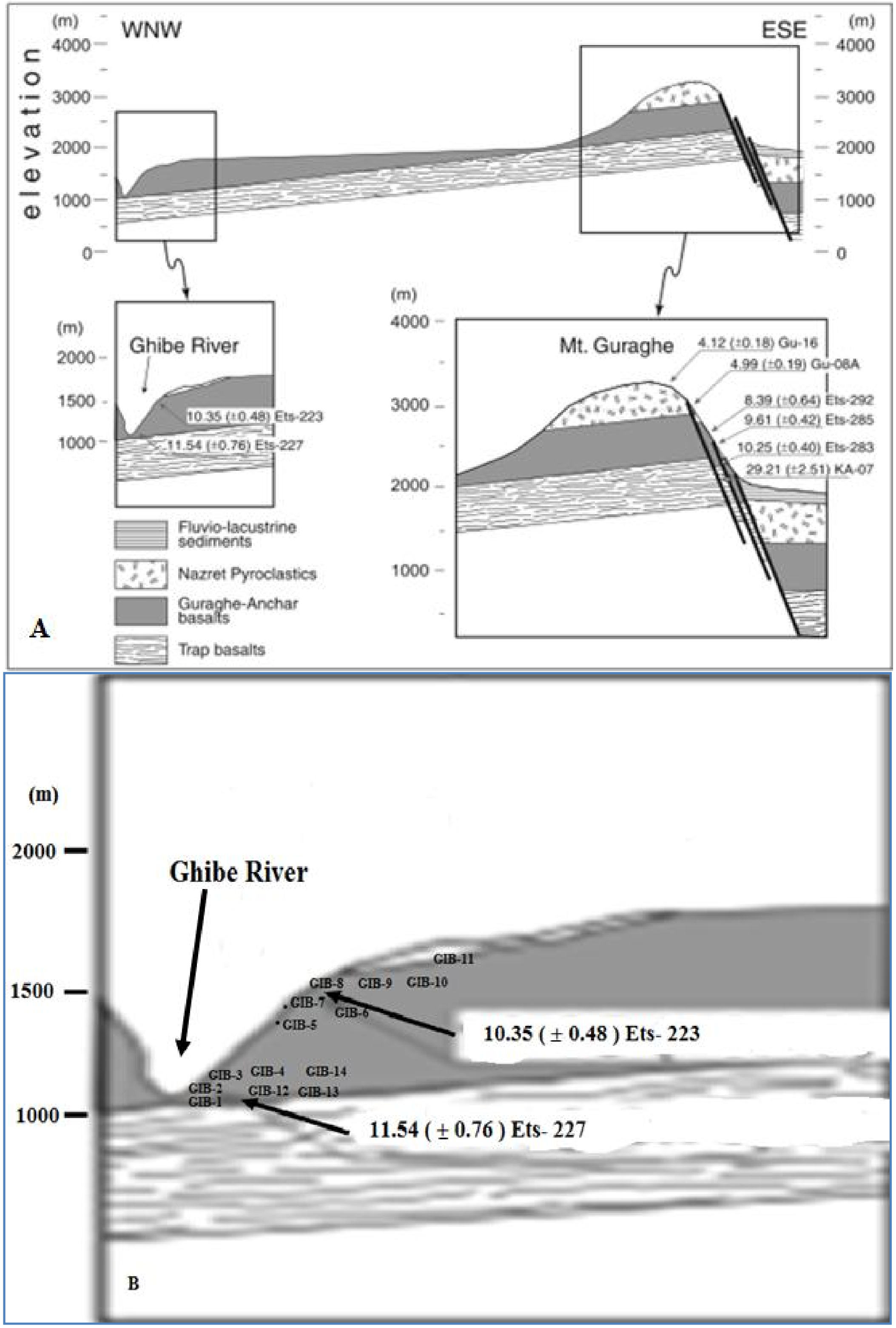
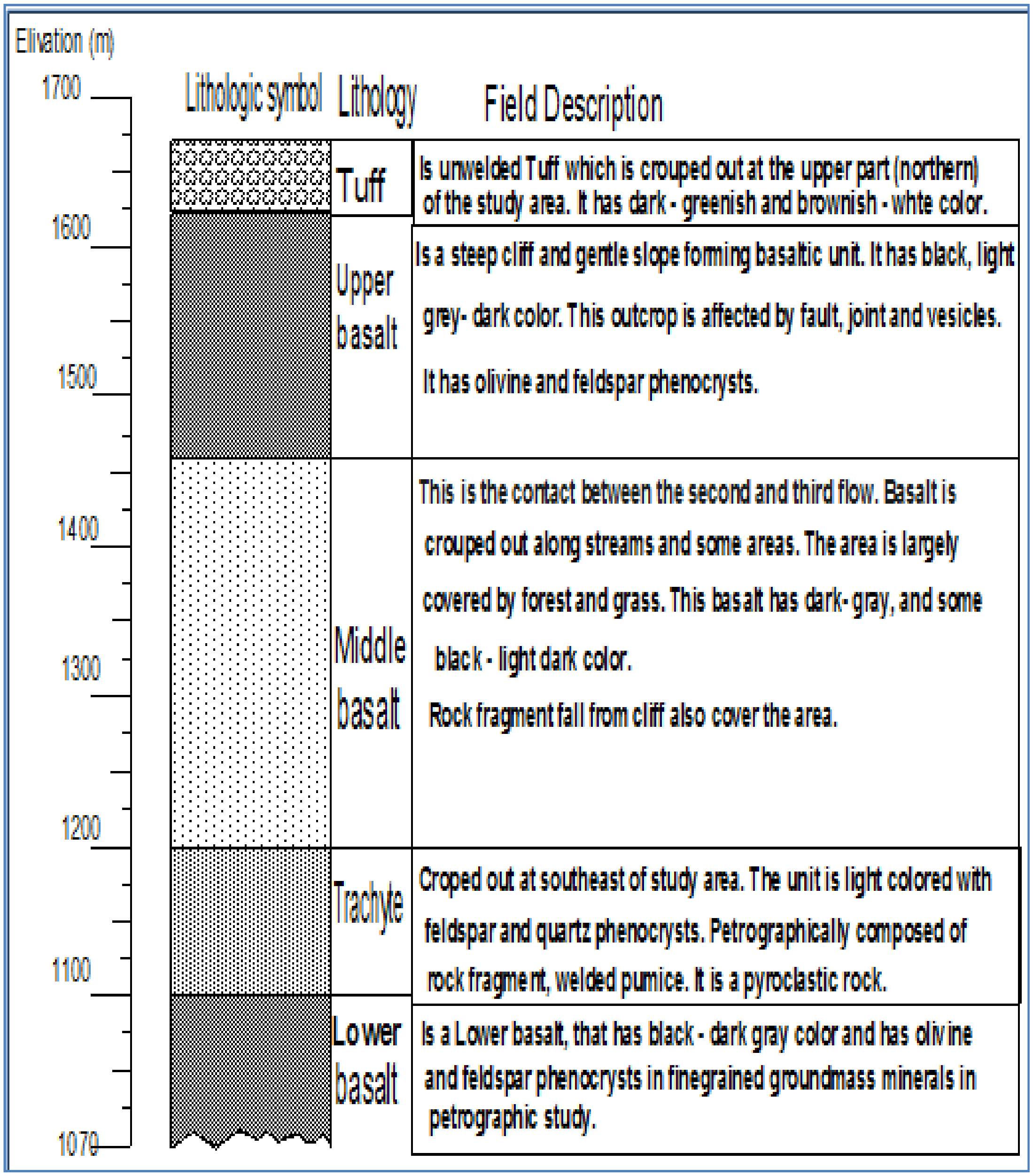


Figure 3.8: Schematic cross section across the Guraghe margin-Ghibe river locally showing the geochronology and sample locations (from Bonini et al., 2005). B is an enlarged version of top left corner in A.



Lithology	Field Description
Tuff	Is unwelded Tuff which is crouped out at the upper part (northern) of the study area. It has dark - greenish and brownish - whte color.
Upper basalt	Is a steep cliff and gentle slope forming basaltic unit. It has black, light grey- dark color. This outcrop is affected by fault, joint and vesicles. It has olivine and feldspar phenocrysts.
Middle basalt	This is the contact between the second and third flow. Basalt is crouped out along streams and some areas. The area is largely covered by forest and grass. This basalt has dark- gray, and some black - light dark color. Rock fragment fall from cliff also cover the area.
Trachyte	Croped out at southeast of study area. The unit is light colored with feldspar and quartz phenocrysts. Petrographically composed of rock fragment, welded pumice. It is a pyroclastic rock.
Lower basalt	Is a Lower basalt, that has black - dark gray color and has olivine and feldspar phenocrysts in finegrained groundmass minerals in petrographic study.

Figure 3.9: Litho-Stratigraphy of Ghibe River gorge.

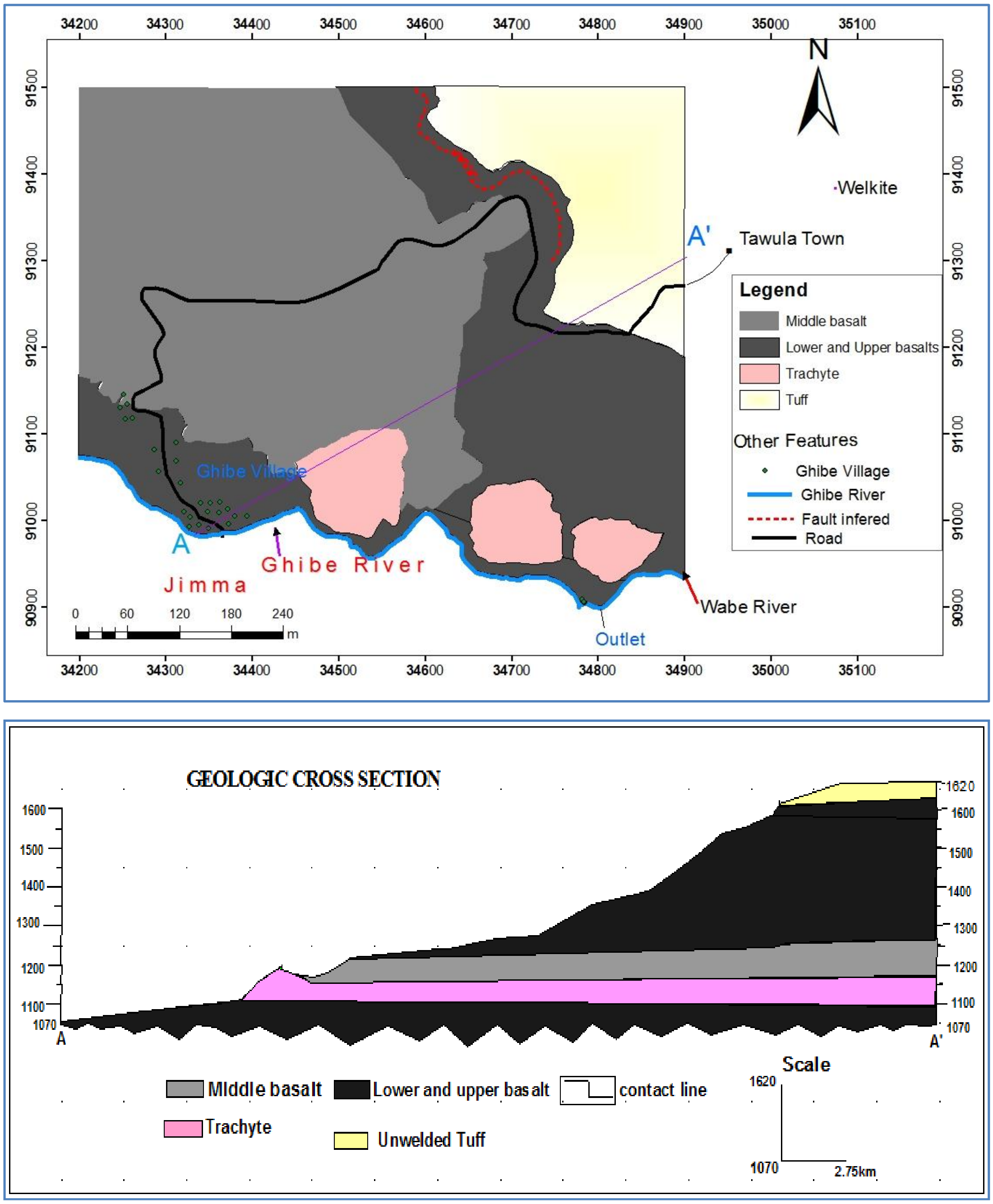


Figure 3. 10: Geological Map and Geologic cross section of the study area.

CHAPTER FOUR

4. Geochemistry

4.1. Analytical Techniques

Representative fresh samples of basalts were collected from a section at Ghibe gorge (of study area) (Figure 3:8). These samples were used for thin section preparation and for geochemical analysis. Thirteen (13) samples were, crushed manually using hammer into gravel sized grains and powdered using a hardened steel mortar. To protect samples from contamination, during crushing and grinding the instruments were cleaned carefully by clean cloth. By coining and quartering method crushed samples were ground to 84 to 88 μm size using an agate ball miller. Later on, after coining and quartering method all samples were sieved to different size fractions and unpowdered grains repeatedly milled at School of Earth Sciences of Addis Ababa University. Finally the milled samples were sent to CRPG (Centre de Recherché Petrographique et Geologique) Nancy, France for Major and trace element analysis.

Major elements were determined by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), whereas trace elements were determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at CRPG.

4.1.1. Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)

Major elements were analyzed using ICP-OES. Firstly, Samples were crushed, powdered to 300 mg of sample was then fused in Pt crucibles along with 900 mg of ultra-pure of LiBO2 at 980 ^{0}c in an automatic tunnel oven. Samples passed through oven on a trial over a period of about 60 minutes at a constant speed, which ensures that all samples encountered the same thermal gradients. After cooling to room temperature, the fused glass was dissolved in a HNO3 (1mol l^{-1}) – H2O2 (~ 0.5 % v/v) - glycerol (~ 10 % v/v) mixture in order to obtain a dilution factor of 333 relative to the mount of sample fused. Water used for the dilution of acids was distilled and de- ionized. Hydrogen peroxide helped to stabilize in solution elements such as titaninium and other HFSE. The sample mist reaching the plasma is quirkily dried, vaporized, and energized through coalitional excitation at high temperature. In this case, the atomic emission emanating from the plasma is viewed in either a radial or axial configuration, collected with a lens or mirror, and imaged onto the entrance slit of a wavelength selection device. By these techniques major elements (Table 4.1) were analyzed.

4.1.2. Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Trace element concentrations of Ghibe basalts were determined at CRPG by ICP-MS of (a Sciex Perkin ELAN 500a) using a one point “linear through zero” calibration. The calibration solution was a multi-element doped solution of BR. A 200 µl calibrated loop mounted on an electro-valve was filled with the sample solution while distilled water was introduced into the ICP-MS. The liquid is aspirated, the electro-valve was locate at 15-20cm from the nebulizer, when the loop filled, the electro- valve switched position so that the distilled water (carrier) passed through the loop and pushed the sample into the mass spectrometer. The loop was cleaned with 1mol l^{-1} HNO3 between each sample. The BIR-1 geochemical references materials used and all rocks were decomposed using alkali fusion. Analysis was done by flow injection ICP-MS and by on-line low pressure liquid chromatography (LC)-ICP-MS for sample containing very low REE, U and Th concentrations. Matrix extraction prior to the analysis of trace elements in geochemical materials were used to: remove possible isobaric interference, eliminate signal suppression in the plasma, makes possible for preconcentrations of elements.

4.2. Alteration

Before discussing about petrogenetic processes that lead to the generation and evolution of the samples, it is essential to assess if they were altered or not. Macroscopically, most sampled rock appears to be unaltered. During microscopic examinations only GIB-10 and GIB- 2 shows substantial alteration. Even though they show alteration petrographically, they do not show alteration geochemically, when considered their LOI. E.g the LOI value of GIB-2 is 0.94.

During petrographical studies some samples were altered differently and some of them appear to be unaltered. In some thin sections of Ghibe basalts most mineral aggregates seem fresh, few of them seem altered and secondary minerals are common. As previously defined (Chapter 3) olivine is altered, few plagioclases show alterations and most plagioclase minerals don’t reveal any sign of alteration and pyroxene always appear fresh. In GIB-10 fine-grained secondary minerals aggregate were filled in the vesicles. As Ghibe basalts geochemical results shows, LOI (Loss on Ignition) of most samples is greater than one (LOI > 1) for most samples except GIB-2(0.94), GIB-3(0.56), GIB-6(0.74), and GIB-9(0.93) measured show significant alterations. Low temperature alteration leads to decrease in the concentration of alkali and alkaline earth metals like Na, K, Rb and Ba, as well as LREE and U are considered as mobile in fluids. But, Ni, Cr, middle and HREE and as well Th and Ti and other HFSE (High Field Strength Elements) are immobile during alteration (Ludden et al.,1982, Staudingel et al.,1996). If mobile and immobile elements with the same partition coefficients are fractionated within the sample series, so it can be concluded that there is alterations (Staudigel et al., 1996). From Ghibe basaltic data the variation diagram (Figure 4.1) indicate good correlation between U and Th concentrations don't show any alterations. On the plots of Na2O, Rb against LOI, show decreasing trend with increasing of LOI, with little scattering. Even though, some samples have high values of LOI, strongly from U vs Th correlation high values of LOI has no effect on the data. In addition to this the mobile element (Na2O, Rb vs LOI) plots shows, they are always mobile and the trend shows fractionation rather than alteration.

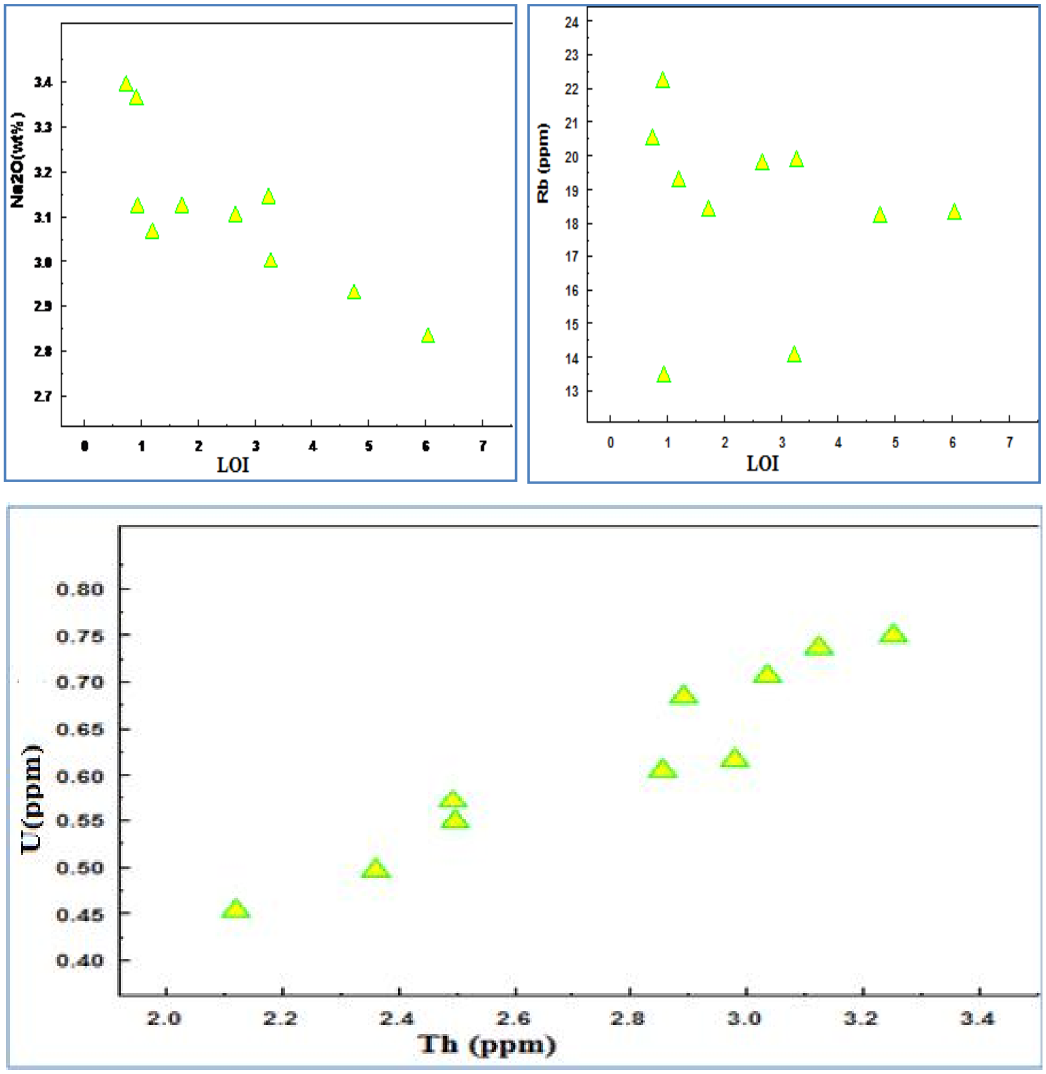


Figure 4.1: Variation diagram of Na2O, Rb, vs LOI and U vs Th for indication of alteration.

4.3. Geochemical results

4.3.1. Major Elements

Table 4: 1: Bulk geochemical analysis of Ghibe River gorge basalts

Sample Code	GIB-10	GIB-1	GIB-8	GIB-13	GIB-7	GIB-2	GIB-6	GIB-5	GIB-12	GIB-9	GIB-4	GIB-3	GIB-14
Rock name	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Trachyte	Trachyte
Wt% by ICP-OES													
SiO2	46.42	48.49	48.71	48.85	49.33	49.66	49.70	49.74	49.90	50.50	50.66	59.85	65.56
TiO2	2.50	2.82	2.44	1.63	2.21	2.19	2.80	1.66	1.65	2.57	1.57	0.41	0.68
Al2O3	13.27	14.12	13.34	14.46	14.77	15.38	13.30	14.59	14.67	14.27	14.98	17.50	12.88
Fe2O3	13.30	13.41	12.91	10.12	13.00	13.07	14.22	10.16	10.44	14.14	10.48	6.59	6.95
MnO	0.22	0.22	0.21	0.18	0.21	0.20	0.24	0.18	0.18	0.24	0.18	0.23	0.15
MgO	3.35	4.53	4.29	5.18	4.95	5.60	4.19	5.05	5.28	4.14	6.00	0.42	0.34
CaO	9.14	9.14	9.00	9.95	9.14	9.51	8.07	9.85	9.81	8.10	9.52	1.85	0.46
Na2O	2.84	3.14	3.15	2.93	3.12	3.12	3.40	3.00	3.10	3.37	3.07	6.85	4.93
K2O	1.02	0.98	0.87	0.96	1.01	0.73	1.26	1.11	0.94	1.32	0.98	4.34	5.44
P2O5	0.60	0.72	0.57	0.25	0.57	0.47	0.87	0.26	0.26	0.88	0.24	0.18	0.11
LOI	6.04	2.81	3.24	4.74	1.73	0.94	0.74	3.28	2.66	0.93	1.20	0.56	1.57
Total	98.71	100.37	98.72	99.24	100.05	100.88	98.78	98.87	98.90	100.45	98.87	98.77	99.07
Mg#	33.51	40.34	39.90	50.58	43.23	46.13	37.08	49.82	50.29	36.95	53.37	11.18	8.82

Mg# = ((MgO%/MgO Mol wt) *((MgO%/ MgO Mol wt) + (Fe2O3%/ Fe2O3 Mol wt))*100), where Mol wt = Molecular weight

4.3.2. Trace element results.

Table 4.2: Bulk geochemical analysis of Ghibe River gorge basalts.

Sample Code	GIB-1	GIB-2	GIB-4	GIB-5	GIB-6	GIB-7	GIB-8	GIB-9	GIB-10	GIB-12	GIB-13	GIB-3	GIB-14
Rock name	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Trachyte	Trachyte
ICP-MS (ppm)													
Be	1.25	1.075	1.225	1.356	1.344	1.127	1.23	1.377	1.234	1.362	1.193	3.818	5.224
Sc	35.01	35.46	30.09	31.16	34.39	34.12	33.86	33.31	33.83	31.24	30.64	3.75	8.02
V	299.5	273.3	220.2	224.1	230.8	240.6	278.1	208.5	283	231.8	223.3	b.d.l	6.487
Cr	32.56	158.4	165.5	147.7	57.89	142.8	34.19	69.43	30.39	149.4	140.4	9.624	6.949
Co	36.41	37.83	35.91	34.2	31.28	35.32	35.68	30.37	35.13	35.93	34.35	1.224	0.643
Ni	25.88	42.75	34.69	30.54	17.23	36.44	28.02	19.51	27.16	34.2	31.56	b.d.l	b.d.l
Cu	30.07	40.46	32.79	32.95	32.73	42.18	38.42	33.86	37.25	33.86	32.06	6.305	b.d.l
Zn	139.1	119.8	102.3	104.2	141.8	121.2	126.5	134.1	126.6	105.7	101.8	108.9	202.1
Ga	20.99	21.18	20.27	20.2	21.44	20.32	19.56	21.26	19.9	20.58	19.44	20.71	31.79
Ge	1.718	1.783	1.617	1.523	1.733	1.716	1.533	1.671	1.673	1.769	1.783	1.656	2.321
Rb	17.86	13.47	19.3	19.92	20.56	18.45	14.08	22.25	18.34	19.79	18.24	118.5	149.1
Sr	440.7	381.9	360.1	345.5	380	376.2	394.9	372.3	415.5	364.5	362.8	271.7	38.73
Y	38.18	33.09	28.47	29.96	42.49	34.46	33.89	42.01	35.02	30.37	28.95	30.52	61.76
Zr	182.4	160.6	187.3	196.8	202.4	169.8	174	200.6	179.2	197.5	189.6	390.3	724
Nb	24.21	16.62	24.63	26.02	22.2	17.82	22.35	21.79	22.64	26.24	24.9	121.5	121.1
Mo	1.336	1.202	1.609	1.658	1.64	1.388	1.172	1.515	1.219	1.713	1.61	1.328	1.338
Cd	0.273	0.22	0.29	0.39	0.238	0.18	0.215	0.205	0.276	0.252	0.212	0.457	0.69
In	0.095	0.095	0.08	0.085	0.122	0.103	0.109	0.124	0.12	0.092	0.091	b.d.l	0.156

Sn	2.194	2.017	3.508	1.962	2.342	2.111	2.178	2.133	2.401	2.182	2.273	3.983	5.992
Cs	0.168	0.155	0.203	0.208	0.241	0.216	0.137	0.285	0.193	0.171	0.173	1.565	0.563
Ba	344.8	338.8	276.6	302.6	586.8	419	330.2	596.3	450	297.8	302	1695	625.4
La	27.37	19.89	21.68	23.1	27.88	21.98	24.97	28.16	25.32	23.18	22.01	82.25	113
Ce	60.04	44.46	45.56	48.32	62.44	49.38	54.09	63.17	55.84	49.14	46.78	139.7	211.7
Pr	7.988	6.014	5.734	6.108	8.402	6.503	7.003	8.447	7.282	6.048	5.807	14.23	23.45
Nd	34.47	26.3	23.41	24.93	37.23	28.96	30.47	37.47	31.61	25.03	23.78	46.58	83.15
Sm	8.002	6.362	5.43	5.694	8.731	6.856	7.157	8.784	7.429	5.772	5.598	7.489	15.28
Eu	2.549	2.168	1.748	1.765	3.064	2.321	2.262	3.092	2.319	1.797	1.734	2.199	3.353
Gd	7.579	6.131	5.174	5.442	8.508	6.615	6.816	8.441	6.998	5.48	5.268	5.848	12.42
Tb	1.194	0.984	0.84	0.882	1.312	1.031	1.058	1.301	1.083	0.889	0.85	0.896	1.96
Dy	7.152	6.084	5.303	5.535	7.992	6.37	6.473	7.956	6.658	5.537	5.308	5.422	11.82
Ho	1.503	1.295	1.106	1.178	1.655	1.344	1.331	1.648	1.36	1.169	1.127	1.163	2.414
Er	3.807	3.331	2.929	3.063	4.279	3.47	3.418	4.27	3.536	3.099	2.97	3.281	6.461
Tm	0.518	0.475	0.415	0.439	0.613	0.502	0.487	0.607	0.487	0.444	0.427	0.507	0.933
Yb	3.396	3.094	2.77	2.932	3.965	3.243	3.118	3.901	3.202	2.974	2.83	3.685	6.341
Lu	0.514	0.471	0.426	0.45	0.6	0.492	0.474	0.586	0.479	0.449	0.429	0.598	0.966
Hf	4.579	4.084	4.619	4.822	5.02	4.288	4.356	4.982	4.532	4.823	4.618	8.285	16.06
Ta	1.881	1.263	1.825	1.926	1.681	1.354	1.744	1.677	1.766	1.948	1.82	8.241	8.623
W	0.531	0.444	0.59	0.583	0.592	0.519	0.487	0.54	0.537	0.614	0.594	0.293	1.316
Pb	3.4714	2.898	5.733	3.3058	3.8789	3.3637	3.2297	3.87	3.2843	3.4134	3.1715	10.8547	16.5043
Th	2.624	2.12	2.894	3.127	2.859	2.363	2.497	2.983	2.494	3.255	3.039	12.53	18.71
U	0.584	0.456	0.685	0.739	0.607	0.499	0.551	0.619	0.573	0.751	0.709	2.467	3.874

CHAPTER FIVE

5. Petrogenesis

5.1. Major element Geochemistry

Bulk geochemical analysis of Ghibe samples are reported in (Table 4.1). Classification of samples on Total Alkali vs Silica classification diagram (TAS, **LeBas et al. 1986, Figure 5.1**), the Ghibe lavas fall in the field of basalt, except two samples (GIB-3 and GIB-14) which are plotted in the field of trachyte. The Ghibe Samples show bimodal composition with dominantly basalt, and few trachytes. This study only focuses on basaltic samples and the trachytes are omitted in the forth coming discussion. Given the high contents of LOI (Loss on Ignition) which mobilize Na2O (Figure 4.1), and on TAS variation diagram classification, the Ghibe basalts are alkaline in composition. Ghibe basalts have low MgO wt% contents (3.35-6.00 wt %) indicating that they are not primary magma and hence have experienced fractional crystallization process.

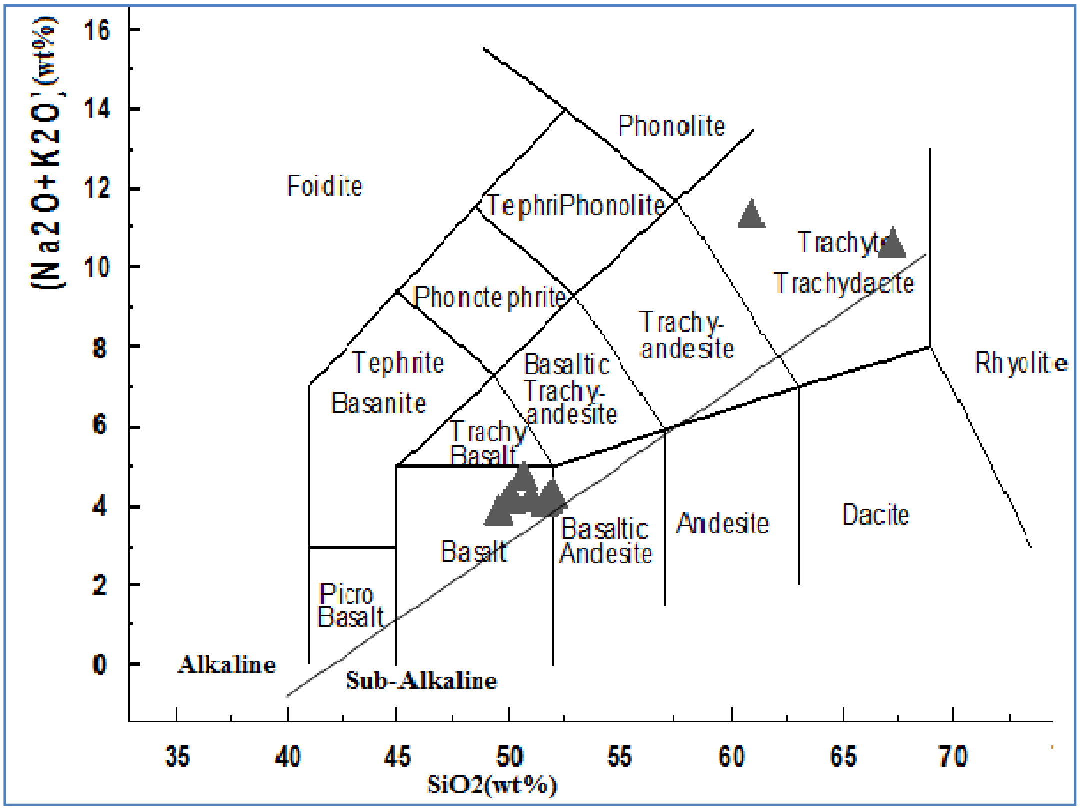


Figure 5.1: Classification of Ghibe basalts using TAS variation diagram (Na2O + K2O vs SiO2) (After LeBas et al., 1986) major elements are normalized on volatile free bases, Alkali- sub alkaline dividing line is from Miyashiro (1978).

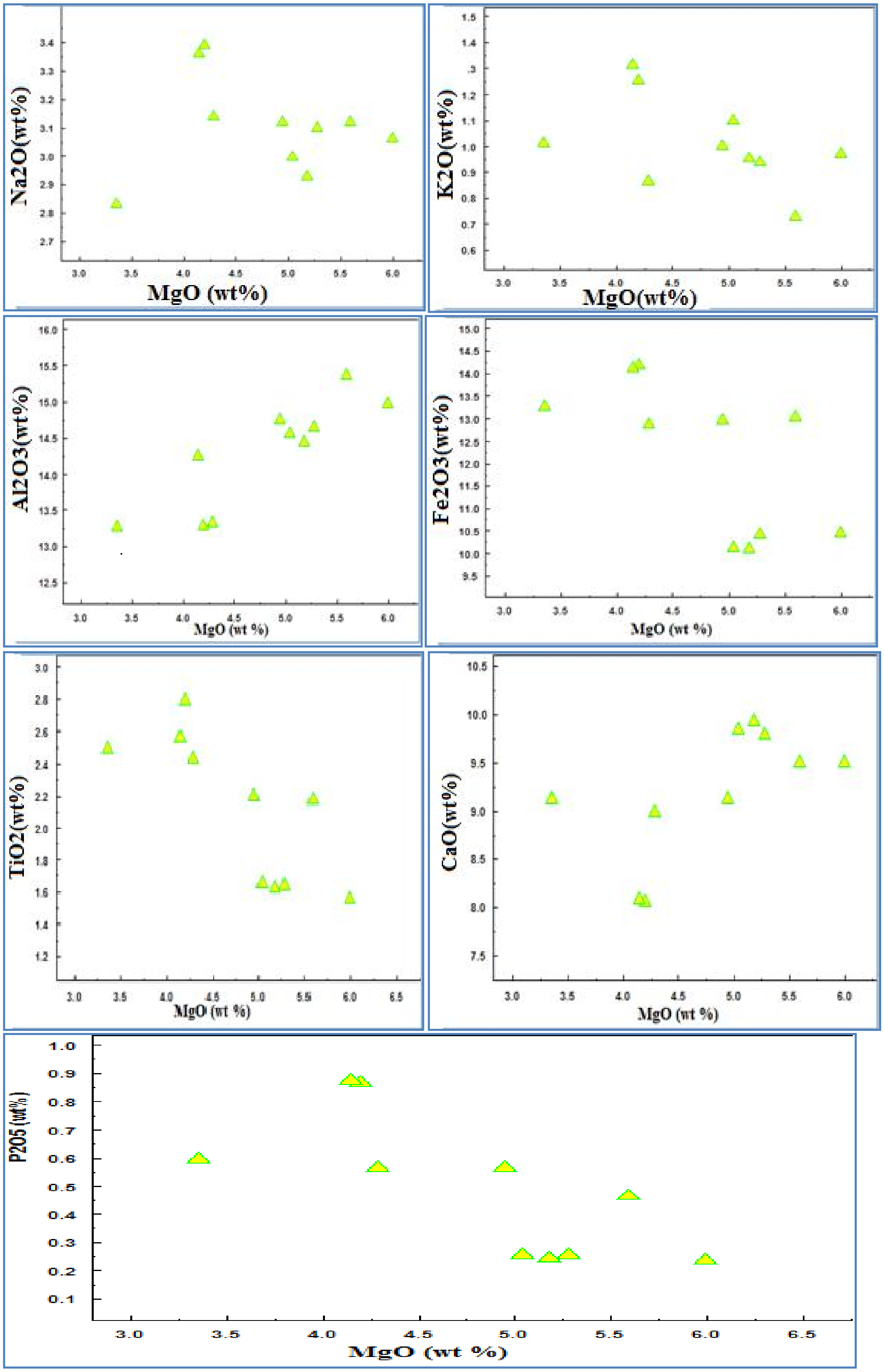


Figure 5.2: Major element against (MgO) for Ghibe basalts.

A geochemical data of Ghibe gorge basalts in (Table 4.1) shows chemical variation in concentration. Major element variations as a function of MgO wt % are illustrated in Figure 5.2 and are positively correlated with MgO. All lavas have low numbers (Mg# < 53.4) indicating the fractionated mafic phases in the early evolutions. The Ghibe basalts have very low MgO content in the range of 3.35- 6.00 wt%. The low content of MgO implies fractionation of olivine. Al2O3 and CaO show positive correlation with MgO suggesting fractional crystallization of Plagioclase and pyroxene respectively, whereas Fe2O3, TiO2, P2O5, K2O, and Na2O are negatively correlated, suggesting their incompatibility during fractional crystallization.

The scattering observed on the diagram may be as the results of accumulation of some phases or fractionation of heterogeneous phenocrysts or source heterogeneity or alteration.

5.2. Trace element Geochemistry

Trace element concentration of basalts gives appending in the source, the composition of original magma and as well the geochemical processes that controls the magma product. The trace elements are classified into compatible and incompatible. The depletions of compatible elements signify that there is the fractional crystallization during en route of magma to the surface, whereas the enrichments of incompatible elements show the partial melting and partitioning of incompatible elements into the melt or residual with decreasing differentiation index (MgO). Ghibe Basalts are highly enriched in incompatible elements like Ba (276.6- 596.3ppm), Sr (345.5-440.7ppm), whereas depleted in compatible elements relative to incompatible. E.g., V 220.2-299.5ppm, Ni 17.23-42.75ppm, Co (30.37-36.41ppm, and Cr 30.39-165.5ppm. Therefore, Ghibe gorge basalts are largely enriched by incompatible elements (data from Table 4.2).

Trace element variation against MgO has shown in figure 5.3 indicate good correlations of compatible and incompatible elements against MgO. Compatible elements Ni and Cr show positive correlations signifying olivine and pyroxene fractionation respectively. Incompatible elements like: Zr, Nb, Sr, La, Ba, and Rb are negatively correlated with MgO being they are incompatible elements (Figure 5.3) and showing their affinity for liquid phase during fractionation.

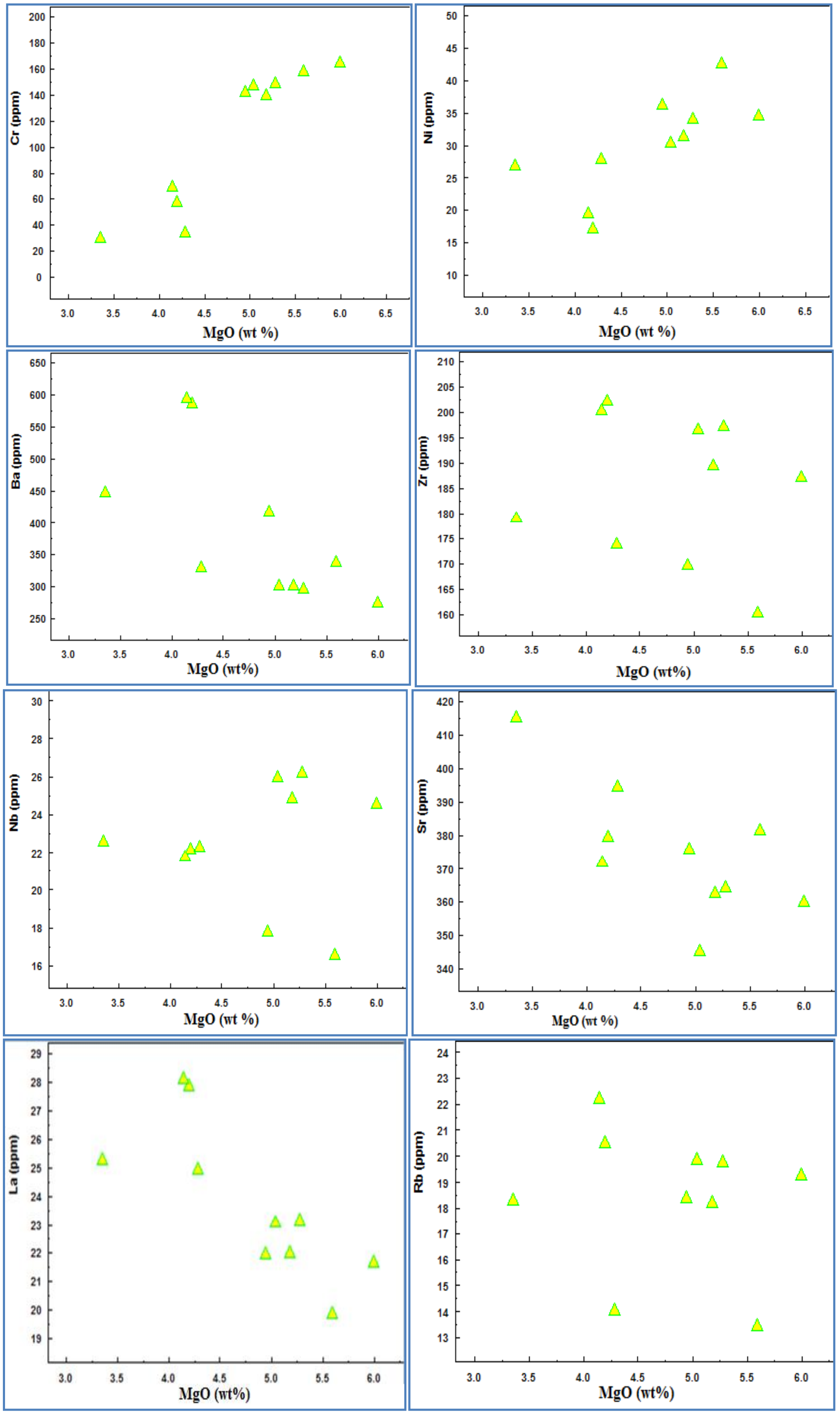


Figure 5.3: Trace element variation against MgO for Ghibe basalts.

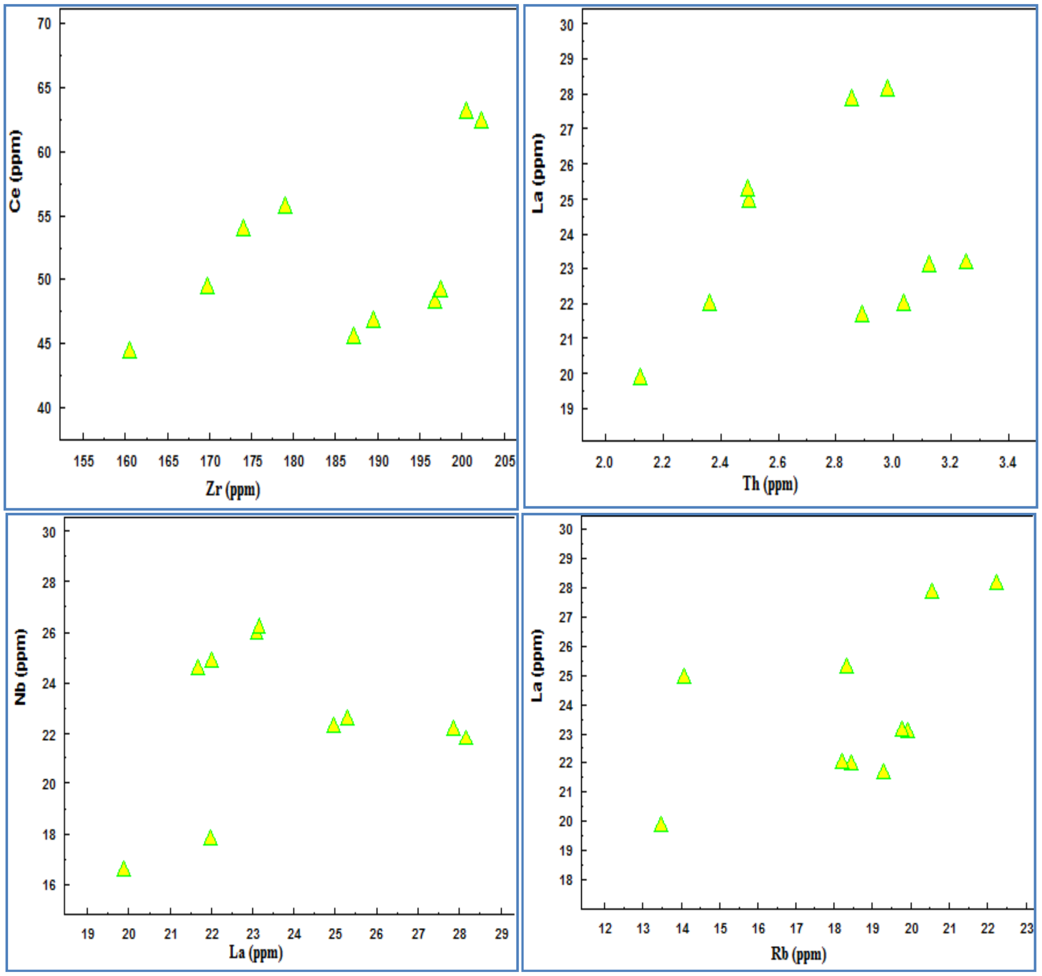


Figure 5.4: Variation diagrams of Ce vs Zr, La vs Th, Nb vs La, and Th vs Rb, showing the cogenesis of Ghibe gorge basalts.

The trace element variation diagram shown on (Figure 5.4) indicate significant variation between basaltic rocks, they show two linear trends (Ce vs Zr, La vs Th, Nb vs La, and La vs Rb) with some scattering, indicating, they may be related genetically either through fractional crystallization or partial melting. The scattering showm may be due to porphyritic nature of the rock. The plots of these elements show positive correlation with each other, which define the basalts, were from the same source and their relationship is from fractional crystallization.

Chodrite- normalized rare earth element (REE) patterns of Ghibe gorge basalts have higher LREE (Figure 5.5). They have relatively steep sloping of LREE and flat HREE with (La/Sm) n = 1.96- 2.54 and (Gd/Yb) n = 1.48-1.8, without any indication of negative or positive anomalies of elements. The steep sloping patterns of LREE shows the concentrations of LREE are higher than that of HREE. Anomalies of Eu is absent in this pattern signifying feldspars are not fractionating phase. Eventhough, the trough of Sr

(Figure 5.6) suggesting that feldspar fractionation may have taken place at high Oxygen fugacity (fO2) (Dereje, A., et al., 1999).

Primitive mantle normalized multi-element variation diagrams (Figure5.6) shows minor trough of Cs, and Sr, indicating pyroxene and plagioclase fractionation respectively.

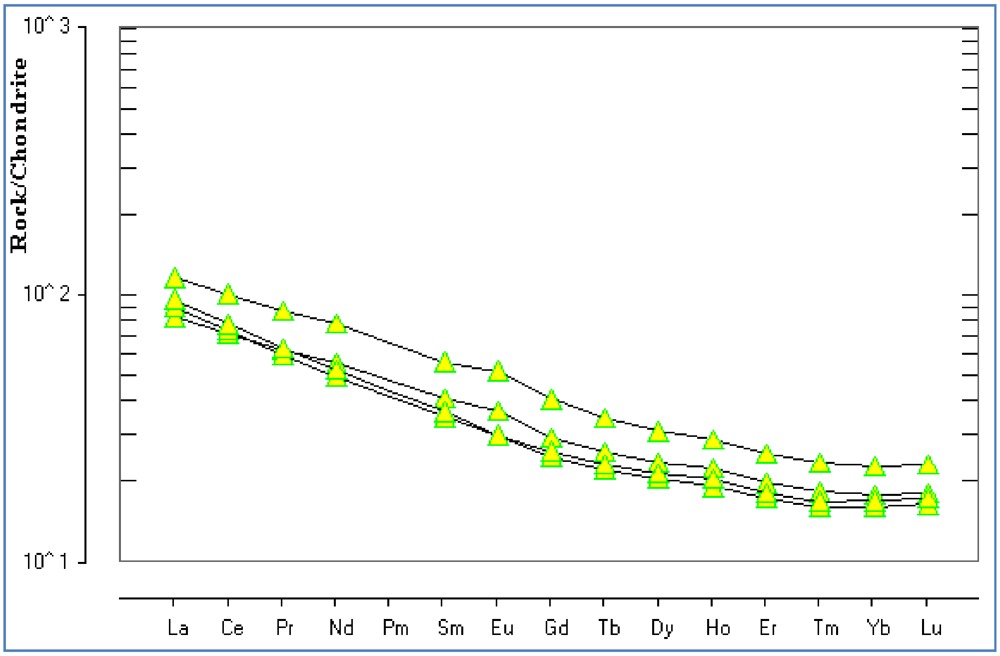


Figure 5. 5: Chondrite normalized rare earth element (REE) patterns for Ghibe gorge basalts. Normalized values are from Sun & McDonough (1989).

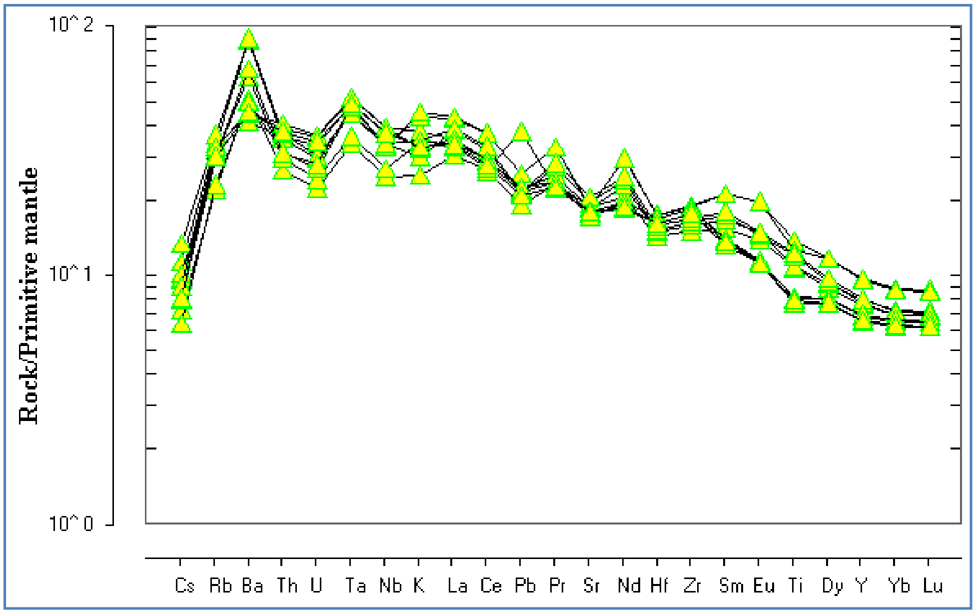


Figure 5.6: Primitive mantle normalized multi-element variation diagram of Ghibe basalts. Normalized values are from McDonough and Sun (1995).

5. 3. Fractional crystallization

As discussed in the previous sections all Ghibe gorge alkali basalts are characterized by low concentrations of MgO, Ni, Cr, and Co, together with the decreasing in CaO contents with MgO requiring co-fractionation of olivine and pyroxene. Figure 5.3, shows a positive correlation of Ni and Cr with MgO, since Ni is a sensitive indicator of olivine fractionation from basaltic magma because of its large mineral/melt partition coefficient, as well as Cr correlation to MgO Possibly due to the concurrent crystallization of olivine and Cr-rich spinel phase. Al2O3 contents decrease with decreasing of MgO, suggesting that plagioclase fractionation from the melt (Figure 5.2). As well Ti2O and P2O5 decrease with increasing of MgO appears to be incompatible element, demonstrating that Fe- Ti oxides and apatites were not significant fractionating phase respectively. Na2O, K2O, and Fe2O3 also decrease, since they are mobile elements. The major and trace element variations of Ghibe gorge lavas are mainly explained by fractionations of olivine, pyroxene and plagioclase, which is consistent with observed phenocryst phases from microscopic studies. It is concluded that Ghibe basalts are largely affected by fractional crystallization process and a derivative magma.

As discussed above Ghibe gorge basalts are not derived from primary magma rather than the melt are evolved magma. Primary magma has high Ni-values (>300 ppm) indicate that a magma could have been in equilibrium with mantle mineralogy commonly containing about 2000 ppm Ni, depending on the MgO content of the partial melt (Hart and Davis, 1978). Frey, Green and Roy (1978) use Co, Sc, as well as Ni concentrations with inferred primary compositions exceeding 300 ppm Ni. Additionally Wilson, W., (1989) proposed that, the estimated Ni contents are relatively insensitive to the degree of partial melting and range between 400 and 500ppm, depending upon the assumption made about mantle mineralogy and Ni content, and the concentrations of Cr > 1000ppm, signify the primary magma.

Ghibe gorge basalts show the characteristics of evolved magma. Because, all Ghibe lavas have Ni contents, in the range of 17.23-42.75 ppm, Cr content 30.39-165.5 ppm, the MgO 3.35 - 6.00 wt %, that is too low than that of primary magma compositions. Since all Ghibe gorge samples of basaltic rocks have low concentrations of these elements, they are considered as evolved magma.

5. 4. Crustal contamination

Ghibe gorge basalts are evolved by a fractionation of Cr, Ni, Co, and MgO. The analyzed samples of basalts are characterized by strong enrichments in LREE and in highly incompatible elements. The enrichment in LREE and in highly incompatible elements may be consequences of crustal contamination or derivation from enriched mantle source (Dereje A., et al., 1999 and others cited therein). Additionally Nb negative anomaly shown on multi-element variation diagram (Figure 5.6) and La/Nb ratios indicate contamination of magma if its ratio is (La/Nb > 1). The evidence for this is shown by some of Ghibe basalt samples having La/Nb ratios > 1, as well as the ratios of Th/Nb ~ 0.12 or 0.13 and/or less such as GIB-1, GIB-2, GIB-6, GIB-7, GIB-8, GIB-9, and GIB-10 indicating may be crustal contamination. The slope of HREE does not change, as a result of the Gd/Yb ratio of the contaminated basalt is similar with that of crustal contaminant (Kieffer et al., 2004), but there is minor change in the Ghibe River gorge basalts (Figure 5.5). According to Wilson, M. (1989) the ratio of La/Nb in continental flood basalts (CFB) ranges 0.5-7, in which Ghibe basalt fall in the range. This suggests that, there may be minimal degrees of contamination in Ghibe gorge basalts as well. Ratios of incompatible trace elements such as Ce/Pb and Nb/U, that are not commonly fractionated during mantle melting and thus reflect the composition of the Earth's mantle, are well constrained in the oceanic basalts (Ce/Pb=25 ± 5 and Nb/U= 47 ± 10, Hofmann et al., 1996) (Figure 5.7). As shown on (Figure 5.7) the Ce/Pb vs Nb/U variation diagram two samples of Ghibe River gorge fall in the boundary of mantle derived basalts, but others are fall in the field of less than the mantle composition constrained by Hofmann (1988). Ce/Pb- NB/U values of the two Ghibe River gorge lavas have low Ce/Pb ratios (7-95-18.1) but their Nb/U ratios resemble those of oceanic basalts. Except three samples(those have in the range of mantle derived basalts (39.5, 40.6, and 41.5)), evolved lavas from Ghibe river gorge have slightly lower Nb/U ratios (34.94 – 36.6) that are close to the lower limit of the range of mantle derived basalts, indicating limited role of crustal contamination. This field (the lower left where most sample plotted in Ce/Pb vs Nb/U) indicates the source is either lithospheric mantle or crustal contamination. But, from the negative correlations of Ce/Pb vs MgO (Figure 5.7) plot of Ghibe basalts does not indicate the crustal contamination. Since Ce and Pb are mobile elements they fractionate to the melt during fractionation of magma as MgO increase.

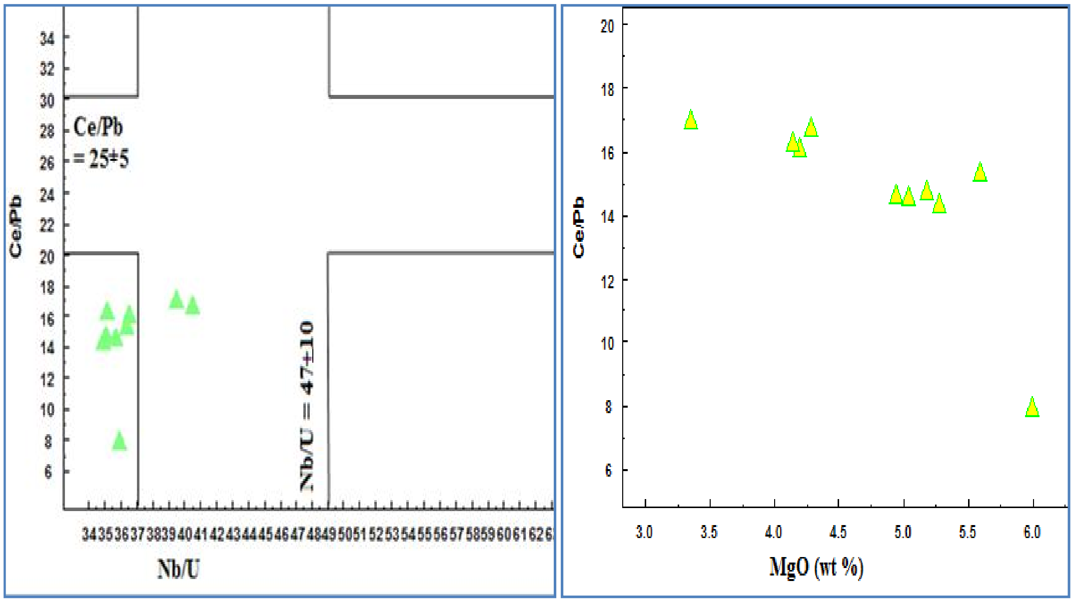


Figure 5.7: Variation diagram of Ce/Pb vs Nb/U and MgO within the Ghibe basalts.

5. 5. Mantle Source

Nearly all basalts of Ghibe gorge are evolved, so it is very difficult to address the issues of mantle source region. For this reason it is good to use the ratio of highly incompatible elements not affected by fractional crystallization, to elucidate the ratio of (such as Ce/Pb = 7.95-17.30, Nb/U = 34.94-41.46) considered as trace of mantle source. The evolved lava from Ghibe gorge is slightly reflect lower Nb/U ratios that are close to the lower limit of the range of mantle derived basalts indicating some degrees of role of crustal contamination.

The Ce/Pb ratios display negative correlation with MgO precluding crustal contamination (Figure 5.7). The low content Nb/Pb values obtained in Ghibe basalts are not the consequences of crustal contaminations, instead they indicates their derivation from lithospheric mantle.

The most prominent features of Ghibe basalt is the existences of positive Ba, Rb,Ta, K and negative Sr, anomalies in their primitive mantle-normalized multi-element variation diagrams (Figure 5.6). The high positive of Ba, HREE >10x chondrite values and the $CaO/Al_2O_3 < 0.69$ are attributed to the presence of amphiboles in the mantle source (Class and Goldstein, 1997). These geochemical features resulted from melting of amphiboles bearing sources. Amphibole is only stable in the lithospheric mantle source (Class and Goldstein, 1997). Ghibe basalts are therefore, interpreted as derived from lithospheric mantle, rather than their contamination by crustal rocks. Thus it inherits a lithospheric trace element signature.

Ghibe gorge basalts are also characterized by flat HREE patterns with ((Gd/Y) n = 1.02-1.14) which signify their derivation from spinel peridotite. Thus Ghibe basalts were originated from spinel peridotite that contains small proportions of amphibole.

From petrographic study Ghibe basalt has abundant in plagioclase feldspars, this constrains their depth of crystallization to less than about 30km, as plagioclase does not readily crystallize from basic melt at greater depths (Powell, 1978).

CHAPTER SIX

6. Conclusion and Recommendations

6.1. Conclusion

The study of Ghibe basalt has been conducted effectively on the bases of field work, petrographic descriptions, and interpretations of geochemical signatures from petrogenetic models. The main lithologic unit that predominantly characterizes the area is basalt. From the petrograhical studies, it is concluded that, Ghibe basalts are aphyric-moderately porphyritic with Plagioclase, pyroxene, and olivine phenocrysts set in the fine grained groundmass of feldspar, olivine, pyroxene, opaque minerals, and some secondary minerals. From available geochemical data on the evolution of Ghibe gorge basalts, varies petrogenetic models have been drawn, and interpretation of these models were made. Based on the variation diagram of major elements, some compatible and incompatible elements against MgO such as Al2O3, CaO, Cr, and Ni are positively correlated with MgO, defining the fractionations of plagioclase, Pyroxene and Olivine were constrained. Again from low contents of MgO, Ni and Cr the Ghiibe gorge basalts are considered derivative, rather than primary magma. It is shown that the fractionation of Ni, Cr, Co and MgO it is concluded that, Ghibe gorge basalts were largely controlled by fractional crystallizations during the evolution of magma. On primitive mantle normalized multi-element variation diagram (Figure 5.6) the high Ba positive anomaly, indicate the presence of amphiboles in the mantle source. Because of amphiboles are only stable in the lithospheric mantle, Ghibe basalts were originated from spinel peridotite that contains small proportions of amphiboles.

6.2. Recommendations

Major and trace element geochemistry were used to constrain the possible evolution of Ghibe gorge basalts, but for further understanding, the mineralogy of phenocrysts is recommended.

As well, on the bases of major and trace element signature it is not so much enough to constrain the geochemical process, which is possibly involved in producing Ghibe gorge basalts; therefore the isotope geochemistry is recommended for further understanding of the age, the source, and the process that undertake this large volume of volcanism.

References

Abbate, E. and Sagri, M. (1980). Volcanites of the Ethiopian and Somali plateaus and major tectonic lines. In: Geodynamic Evolution of the Afro Arabian Rift Sysem. Accademia Nazionale dei Lincei, 47, 219-27.

Abebe, T. (1997). The Yerer Tulu-Wellel volcano tectonic lineament (central Ethiopia): structural, petrologic and geochronologic studies. In: abstracts, international symposium flood basalts, rifting and paleoclimates in the Ethiopian Rift and Afar depression, 43-44.

Arno, V., Dipaola, G.M. and Berhe, S. M. (1981). The Kella horst: its origin and significance in crustal attenuation and magmatic process in Ethiopian Rift valley. Proceedings of the 1st International Symposium on crustal movements in Africa. UNEC. Afr. Addis Ababa.

Bellahsen. N., Faccenna, C., Funiciello, F., Daniel, J. M. and Joliyet, L. (2003). Why did Arabia separate from Africa?: Insights from 3-D laboratory experiments, Earth Planet. Sci. Lett., 216, 365-381.

Berhe, S. M. (1986). Geologic and Geochronologic constraints in the evolution of the Red Sea, Gulf of Aden and Afar Depression. J. Afr. Earth Sci., 5,101-17.

Berhe, S. M., Desta, B., Nicoletti, M. and Tefera, M. (1987). Geology, geochronology and geodynamic implications of the Cenozoic magmatic province in W and SE Ethiopia. J. Geol. Soc. Lond. 144, 213-226.

Bevins, R. E., Kokelaar, B. P. and Dunkley, P. N. (1984). Petrology and geochemistry for lower to middle Ordovician igneous rocks in Wales: a volcanic arc to marginal basin transition. Proc. Geol. Ass. , 95, 337-347.

Bonini, Corti, G., Innocenti, Manetti, P., Mazzarini, F., Abebe, T. and Pecskay, Z. (2005). Evolution of the Main Ethiopian Rift in the Afar and Kenya Rifts Propagation. Tect. , 24, 1-21.

Brown, F. H. and Carmichael I. S.E. (1969). Quaternary Volcanics of the Lake Rudolf Region. The Korath Range, Lithos., 2, 239-260.

Class, C. and Goldstein, S. (1997). Plume lithosphere interactionin the ocean basins: conistrains from source mineralogy, Earth and planet. Sci. Lett. 150, 245-260.

Davidson, A. and Rex, D.C. (1980). Age of volcanism and rifting in southwestern Ethiopia. Nat. 283, 657-658.

Davidson, A. (1983). *The Omo River Project, Reconnaissance Geology and Geochemistry of parts of Illubabor, Kefa, Gamu Gofa and Sidamo*. Bull. 2, EIGS, Ministry of Mines and Energy, Addis Ababa.

Dainelli, G. (1943). Geologia dell' Africa Orientale. Accademia Italiana Centrostudi A.O.L.

Deniel, C., Vidal, P., Coulon, C., Vellutini, P. J. and Piguet, P. (1994). Temporal evolution of mantle sources during continental rifting: the volcanism of Djibuti (Afar). J. Geoph. Res. 99: 2853-2869.

Dereje, A. and Sally, A. G. (2009). Head- to- tail transition of the Afar mantle plume: Geochemical evidence from a Miocene bimodal basalt-rhyolite succession in the Ethiopian Large Igneous Province. Lithos, 112, 461-476.

Dereje, A., Gezahagn, Y. and Pik, R. (1999). Geochemical and isotopic (Sr, Nd, Pb) characteristics of volcanic rocks from southwestern Ethiopia. J. Afr. Earth Sci. 29 (2), 381-391.

Dereje, A., Pierre Barbey, Bernand Marty, Laurie Reisberg, Gezahegn, Y. and Pik, R. (2002). Source, genesis, and timing of giant ignimbrite deposits associated with Ethiopian continental flood basalts. Geoch. et Cosm. Acta 66(8), 1429-1448.

Ebinger, C. J., Yemane, T., Woldegabriel, G., Aronson, J. L. and Walter R. C. (1993). Late Eocene - Recent volcanism and rifting in the southern main Ethiopian rift. J. Geol. Soc. London, 150, 99–108.

Ebinger, C. and Sleep, N. H. (1998). Cenozoic magmatism in central and east Africa resulting from impact of one large plume, Nat. 395, 788 – 791.

Ebinger, C. J., Yemane, T., Harding, D. J., Tesfaye, S., Kelley, S. and Rex, D. C. (2000). Rift deflection, migration, and propagation: Linkage of the Ethiopian and Eastern rifts, Africa, Geol. Soc. Am. Bull., 112, 163-176.

Engdawork Mulatu, Tarun Kumar Raghuvanshi and Bekele, A. (2009). Land slide hazard zonation around Gilgel Ghibe-II hydroelectric project, southwestern Ethiopia. Ethiop. J. Sci. 32, 9–20.

Ethiopian Meteorological Agency (1981). National Atlas of Ethiopia.

Frey, F.A.,Green,D.H. and Roy.S.D.(1978). Integrated model of basalt petrogenesis: a study of quartz tholeiites to olivine milililites from south eastern Australia utilizing geochemical and experimental petrological data. J. pet.,19, 463-513.

Furman, T., Knight, K. M., Bryce, J. G. and Baryy, B. H. (2006). Tertiary mafic lavas of Turkana, Kenya: constraints on East African Plume structure and the occurrence of HIMU volcanism in Africa. J. Petro. 47, 6, 1221-1244.

Gezahegn, Y. (1997). Magma-crust intraction during emplacement of Cenozoic volcanism in Ethiopia: Geochemical evidence from Sheno-Megezez area, Central Ethiopia. SINET: Ethiop. J. Sci., 20(1): 49-72.

George, R., Rogers, N. and Kelley, S. (1998). Earliest magmatism in Ethiopia: Evidence for two mantle plumes in one flood basalt province, Geol., 26, 923 – 926.

Ghebreab, W. (1998). Tectonics of the red sea region reassessed, Earth Sci. Rev., 45, 1-44.

Gouin, P. and Mohr, P. (1964). Gravity Traverses in Ethiopian (Interim Report), Bull. Geophy. Obs. Addis Ababa, 7, 185-239.

Hart,S.R. and Davis, K..E.(1978). Nickel partitioning between olivine and silicate melt: Eath Planetary Sci. Let. 40, 203-219.

Hart, W. K., Woldegabriel, G., Walte, R. C. and Mertzman, S. A. (1989). Basaltic magmatism in Ethiopia: Constraints on continental rifting and mantle interactions. J. Geophys. 94:7731-7748.

Hofmann, A. (1988).Chemical differentiation of the Earth: the relationship between mantle, continental crust, and oceanic crust Earth and Plan. Sci. Lett. 90, 297-314.

Hofmann, C., Courtillot, V., Fe´raud, G., Rochette, P., Gezahagn, Y,., Ketefo, E. and Pik, R. (1997). Timing of the Ethiopian flood basalts event and implications for plume birth and global change, Nature, 389, 838 – 841.

Kazmin, V. (1971). The Pre-cambrian of Ethiopia, Nat. Phys. Soc. 230, 177-197.

Kazmin, V. (1972a). The Geology of Ethiopia. Unpublished Report, EIGS, AA, Ethiopia.

Kazmin, V. (1975a). Explanation of the Geological Map of Ethiopia, Bulletin No. 1, EIGS, Ministry of Mines, AA.

Kazmin, V. (1975b). The Pre-cambrian of Ethiopia and some Aspects of the Geology of the Mozambique Belt, Bull. Geophys. Obs, AAU., 15, 27-43.

Kazmin, V. (1979a). Stratigraphy and Correlation of Volcanic Rocks in Ethiopia. EIGS, Unpubiished. 106, AA, Ethiopia.

Kazmin,V., Berhe, S. M. and Walsh, J. (1980). *Geological Map of the Ethiopian Rift Valley, 1:500 000 scale,* Unpub. repor., EIGS, AA.

Kazmin, V., Shiferaw, A. and Balcha, T. (1978). The Ethiopian Basement: Stratigraphy and Possible Manner of Evolution Geol. Rudsch. 67, pp 531-546.

Kieffer , Nicholas Arndt, Henriette Lapierre, Florence Bastien, Delphine Bosch, Arnaud Pecher, Gezahegn Yirgu, Dereje Ayalew, Dominique Weis, Dougal A.Jerram, Francine Keller and Claudine Meugniot (2004). Flood and Shield Basalts from Ethiopia: Magmas from African Superswell. J. petr. 45(4), 793-834.

Le Bas, M. J., Le Maitre, R.W., Streickesein, A. and Zanettin, B. (1986). A chemical classification of volcanic rock based on the TAS diagram. J. Petrol., 27, 745-750.

Levitte, D., Columba, J. and Mohr, P. A. (1974). Reconaissance geology of the Amaro horst, southern Ethiopian Rift. Geol. Soc. Am. Bull., Washington, 85, 417-22.

Lippard, S. J. (1973). The petrology of phonolites from the Kenyan Rift. Lithos 6, 217-234.

Ludden, J., Geliens, L. and Trudel,P.(1982). Archean metavolcanics from the Rouyin-Noranda district, Abitibi greenstone belt, Quebec, Canadian J. of Earth Sci. 19, 2276-2287.

MC Donough, W.F. and Sun, S.S. (1995). The composition of the earth. Chem. Geol., 120, 223-253.

Mengesha Tefera, Tadiwos Chernet and Warkineh Haro (1996). Explanation of the Geological map of Ethiop.1:2,000,000 Scale. EIGS, 2nd edd.

Merla, G., Abbate, E., Canuti, P., Sagri, M. and Tacconi, P. (1973). Geological Map of Ethiopian and Somalia 1:2,000.000 Scale. CNR. Italy.

Merla, G., Abate, E., Canuti, P., Sagri, M. and Tacconi, P. (1979). Geological map of Ethiopia and Somalia and comment. Cons. Naz. Delle Ric. Italy.

Middle most, E.A. K. (1975). The basalt clan. Earth Sci. Rev., 11, 337-364.

Miyashiro, A. (1978). Nature of alkalic volcanic rock series. Contrib. Mineral. Petrol. 66, 91- 104.

Mohr, P.A. (1962). The Geology of Ethiopia. University. Coll. AA Press. (reprinted in 1971 at the Haile Selassie I University Press), Asmara, Ethiopia, 268.

Mohr, P. A. (1971). The Geology of Ethiopia. AAU Press.

Mohr, P. (1983a). Ethiopian flood basalt province. Nat. 303, 177-584.

Mohr, P. and Zanettin, B. (1988). The Ethiopian flood basalt province. In: MacDougall, J. D. CFB. Dordrecht: Kluwer Acad., 63-110.

Morton, W. H., Rex, D. C., Mitchell, J. G. and Mohr, P. (1979). Riftward younging of volcanic units in the Adds Ababa Region, Ethiopian Rift Valley. Nat., 280, 284-88.

Morley, C. K., Wescott, W. A., Stone, D. M., Harper, R. M., Wigger, S. T. and Karnja, F. M. (1992).Tectonic evolutions of the northern Kenyan Rift, J. Geol. Soc. London, 149, 333-348.

O'Hara, M. J. (1968b). Are ocean floor basalts primary magmas?. Nature.220, 683-686.

Pik, R., Daniel, C., Coulon, C., Gezahagn, Y., Hoffmann, C. and Dereje, A. (1998). The northwestern Ethiopian Plateau flood basalts: classification and spatial distribution of magma types. J. Volca. and Geoth. Res. 81, 91-111.

Powell, M. (1978). Crystallization conditions of Low - pressure cumulate nodules from the Lesser Antilles icland arc. Earth planet. Sci. lett. 39, 162-172.

Purcell, P. G. (1976). The Marda Fault Zone, Ethiopia. Nat., 261, 569-71.

Richard Woodroofe and Associates (1996). Ministry of water resources, Ethiopian Omo Ghibe River Basin Development Master plan study. By 1:1,000,000 scale.

Rogers, N., Macdonald, R., Fitton, J. G., George, R., Smith, M. and B. Barreiro (2000). Two mantle plumes beneath the East African Rift system: Sr, Nd and Pb isotope evidence from Kenya Rift basalts, Earth Planet. Sci. Lett., 176, 387 – 400.

Rollinson, R. (1993). Using Geochemical Data: Evolution, Presentation, Interpretations. longman, England.

Sun, S.S. and McDonough, W. F. (1989). Chemical and isotopic systematic of ocean basalts: implications for mantle composition and processes. In: Saunders A. D. and Norry, M. J. (eds), Magmatism in ocean basin. Geol. Soc. London. Spec. Pub. 42, 313-345.

Staudigel, H., Plank,T., White,B. and Schmincke, H.(1996).Geochemical fluxes during seafloor alteration of the basaltic upper oceanic crust: DSDP sites 417 and 418, Geophysical Monograph 96, 19- 38.

Ukstins, I. A., Renne, P. R., Wolfenden, E., Baker, J., Dereje, A. and Menzies, M. (2002). Matching conjugate volcanic rifted margins: ^{40}Ar/^{39}Ar chrono-stratigraphy of pre- and syn - rift bimodal flood volcanism in Ethiopia and Yemen, Earth Planet. Sci. Lett., 198, 289 – 306.

Wilson, M. (1989). Igneous petrogenesis. Unwin Hyman, London, 1st edd, 1-421.

Wood, M. (1980). The application of a Th- Hf-Ta diagram to problems of tecnomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary volcanic province. Earth and Planet. Sci.Lett., 50, 11-30.

Zanettin, B. and Justin- Visentin, E. (1974). The volcanic succession in Central Ethiopia, the volcanics of the Western Afar and Ethipian Rift Margins. Memoriedegli Istih and di Geologia e Mineralogia dell Universita di padova. 31, 1-19.

Zanettin, B., Gregnanin, A., Justin- Visentin., Mezzacasa, G. and Piccirillo,E. M. (1974a). Petrochemistry of the volcanic series of the central eastern Ethiopian Plateau and relationships between tectonics and magmatology. Memorie degli Istim'di Geologia e Mineralogia and U' Universita di padova, 31, 1-34.

Zanettin, B., Gregnanin, A., Justin-Visentin, Mezzacasa, G. and Piccirillo, E. M. (1976). New chemical analysis of Tertiary volcanics from the central Eastern Ethiopian plateau. Consiglio Nazionale dele Richercha, padova, 1-43.

Appendices

Appendix 1: Microscopic description of samples

Sample code	Texture	Mineralogy				Rock name based on phenocryst available
		% of phenocrysts	% of groundmass	Altered mineral	Grain size (mm) by 4x.	
GIB-1	Porphyritic	Plagioclase 2%	50%	Altered plagioclase	0.01-60	plagioclase phyric basalt
		opaque	20%		0.01-21	
		Secondary minerals	5%		0.01-50	
		pyroxene	5%		0.01-3	
		olivine	8%		0.01-5	
		interstitial volcanic glass	10%			
GIB-2	Porphyritic	Plagioclase	52%		1.01-16	Olivine phyric basalt
		opaque	20%		0.01-20	
		pyroxene	10%		0.01-10	
		olivine 1%	14%	altered to iddingisite	0.05-50	
		interstitial volcanic glass	3%			

Appendix 1: is continued

Sample code	Texture	Mineralogy				Rock name based on phenocryst available
		% of phenocrysts	% of groundmass	Altered mineral	Grain size (mm) by 4x.	
GIB-3	porphyritic	Plagioclase 10%	80%		0.01-27	Trachyte
		opaque(Oxides)	5%		0.1-16	
		Pyroxene 1%	3%		1-20	
		interstitial volcanic glass	1%			
GIB-4	porphyritic	Plagioclase 3%	54%	altered or sieve like texture	0.1-40	plagioclase phyric basalt
		opaque(Oxides)	10%		0.01-16	
		Secondary minerals	3%		1-10	
		pyroxene	20%		0.09-19	
		olivine	5%		0.1-12	
		interstitial volcanic glass	5%			

Appendix 1: is continued

Sample code	Texture	Mineralogy				Rock name based on phenocryst available
		% of phenocrysts	% of groundmass	Altered mineral	Grain size (mm) by 4x.	
GIB-5	porphyritic	Plagioclase 20%	30%	Dirty like altered	1-58	Plagioclase-pyroxene-olivine phyric basalt
		opaque	5%		0.5-25	
		Secondary minerals	25%		1-25	
		pyroxene 3%	7%		1-17	
		olivine 1%	4%		1-10	
		interstitial volcanic glass	5%			
GIB-6	Aphynitic	Plagioclase	55%	altered or sieve like texture	0.01-7	Plagioclase-pyroxene-olivine aphyric basalt
		opaque(Oxides)	25%		0.01-7	
		Secondary minerals	5%		0.01-13	
		pyroxene	10%		0.01-3.5	
		olivine	3%		0.01-7.5	
		interstitial volcanic glass	2%			

Appendix 1: is continued

Sample code	Texture	Mineralogy				Rock name based on phenocryst available
		% of phenocrysts	% of phenocrysts	Altered mineral	Grain size (mm) by 4x.	
GIB-7	porphyritic	Plagioclase 3%	54%		1-50	Plagioclase -pyroxine phyric basalt
		opaque(Oxides)	20%		0.01-12	
		Secondary minerals	6%		1-12	
		pyroxene 1%	4%	has plagioclase overgrowth	1-27	
		olivine	5%	altered to iddingisite	1-10	
		interstitial volcanic glass	7%			
GIB-8	porphyritic	Plagioclase 5%	40%		0.5-63	Plagioclase phyric basalt
		opaque	20%		0.5-20	
		Secondary minerals	10%		0.5-18	
		pyroxene	10%		0.01-4	
		olivine	10%	altered to iddingisite	0.5-0.22	
		interstitial volcanic glass	5%			

Appendix 1: is continued

Sample code	Texture	Mineralogy				Rock name based on phenocryst available
		% of phenocrysts	% of phenocrysts	Altered mineral	Grain size (mm) by 4x.	
GIB-9	porphyritic	Plagioclase	15%	Altered plagioclase	1-9	Olivine phyric basalt
		opaque	35%		0.01-9	
		Secondary minerals	4%		0.01-7	
		pyroxene	10%		0.01-6	
		olivine 2%	30%	altered to iddingisite	1-52	
		interstitial volcanic glass	6%			
GIB-10	Porphyritic	Plagioclase 5%	40%	Altered plagioclase	0.5-	Plagioclase-pyroxine phyric basalt
		opaque	25%		0.5-7	
		Secondary minerals	15%		0.5-7	
		pyroxene 1%	3%		0.5-8	
		olivine	3%	altered to iddingisite	0.01-2	
		interstitial volcanic glass	8%			

Appendix 1: is continued

Sample code	Texture	Mineralogy				Rock name based on phenocryst available
		% of phenocrysts	% of phenocrysts	Altered mineral	Grain size (mm) by 4x.	
GIB-12	Porphyritic	Plagioclase 10%	50%	Altered plagioclase	0.5-36	Plagioclaase-olivine phyric basalt
		opaque(Oxides)	10%		0.5-11	
		Secondary minerals	5%		0.5-15	
		pyroxene	5%		0.5-10	
		olivine 3%	12%		0.5-19	
		interstitial volcanic glass	5%			
GIB-13	porphyritic	Plagioclase 8%	44%		0.5-26	Plagioclase phyric basalt
		opaque	10%		0.01-8	
		Secondary minerals	10%		0.5-20	
		pyroxene	10%		0.5-5	
		olivine	6%		0.5-2	
		interstitial volcanic glass	12%			
GIB-14	Vitrophyric	Crystal(plagioclase, and quartz) 5%	10%		1-35	**Trachyte**
		rock fragment	10%			
		volcanic glass	75			
		opaque(Oxides)	1%			

Appendix 2: Field descriptions of lithologic units.

Sample code.	Elevation(m)	GPS readings (UTM)	Types of Lithology	Hand specimen descriptions
GIB-1	1072	0910081N, 0343282E	Basalt	It is dark-grayish in color, porphyritic rock with alkali feldspar phenocrysts. With black to dark appearance due to weathering.
GIB-2	1086	0910131N, 0343369E	Basalt	Dark – grey in color, with highly altered olivine phenocrysts.
GIB-3	1099	0910307N, 0343406E	Trachyte	Light to dark grey in color with abundant phenocrysts of alkali feldspar minerals. Light colored feldspars and dark colored pyroxene minerals are visible.
GIB-4	1160	0911401N, 0342756E	Basalt	Black-dark colored and aphanitic in hand specimen scale with no minerals observed.
GIB-5	1417	0913788N, 0345897E	Basalt	Dark - Gray greenish and pyroxene phyric basalt.
GIB-6	1440	0914053N, 0346306E	Basalt	It is aphanitic rock which has not any observable minerals and black –light dark.
GIB-7	1500	0914487N, 0346487E	Basalt	Aphanitic in texture and black- dark gray in color.
GIB-8	1484	0913800N, 0347226E	Basalt	It is gray- dark greenish in color, phyric basalt with phenocrysts of pyroxene and feldspars.
GIB-10	1516	0913219N, 0347354E	Basalt	Light gray –dark greenish in color and with feldspar phenocrysts and secondary minerals filling vein.
GIB-11	1611	0912430N, 0348368E	Tuff	Brownish-white light and dark-greenish colored tuff.
GIB-12	1086	0910024N, 0343422E	Basalt	Pyroxene phyric basalt and black-dark greenish.
GIB-13	1081	0910336N, 0344627E	Basalt	Is alkali feldspar phyric basalt, gray – dark greenish in color, and has metal sound while hammering.
GIB-14	1078	0909981N, 0344989E	Trachyte	Light in color contains crystals of quartz, and feldspars minerals.

Appendix 3: Petrographic descriptions of thin sections.

Code	Rock Type	whole rock texture	Petrographic descriptions
GIB-1	Basalt	porphyritic	Porphyritic textured rock with phenocrysts of 2% plagioclase set in fine-grained ground mass composed of 50% plagioclase, 20% opaque minerals, 5%pyroxene, 5% secondary minerals, 8% olivine, and 10% interstitial volcanic glass. The plagioclase minerals have acicular–lathlike crystal habit and few of them have poikilitic texture and as well as zoned and dark-dirty like alterations to calcite along the grian boundary. Olivine crystals altered to iddingsite and has an irregular out line seen clearly by 10X magnification objective. Pyroxenes have euhedral crystal habit and are always fresh.
GIB-2	Basalt	Porphyritic	It is porphyritic texture with ~ 1% olivine phenocrysts set in fine-grained ground mass composed of: 50% plagioclase, 16% olivine, 20% opaque minerals, 3% interstitial volcanic glass, and 10% pyroxenes minerals. Acicular and lath-like crystals of plagioclase in groundmass and anhedral crystals of olivine phenocrysts highly altered to iddingsite. The entire perimeter of large olivine crystals has irregular out line with no planar face. Its entire rim is changed to iddingsite which is formed by hydration and oxidation of olivine. Pyroxenes have elongated euhedral crystal habit and are fresh without any alteration. Plagioclase alterations look like dirty.
GIB-3	Trachyte	porphyritic	Porphyritic texture with phenocryst of 10% plagioclase, and 1% pyroxene set in a fine-grained groundmass consists of 80% plagioclase, 3%pyroxine minerals (may be orthopyroxine from parallel extinction), 5% opaque minerals and 1% interstitial volcanic

			glass. Tabular, columnar, and Flow like crystals of plagioclase phenocrysts. Tabular and elongated crystals of pyroxene phenocrysts usually appear as fresh crystal is clustered in plagioclase minerals.
GIB-4	Basalt	porphyritic	Is a porphyritic texture with phenocrysts of 3% plagioclase set in a fine-grained groundmass of 54% plagioclase, 10% opaque minerals, 5% olivine, 5% interstitial volcanic glass, and 20% pyroxenes mineral. Plagioclase phenocrysts have tabular- bladed and euhedral- anhedral crystal habit. Some plagioclase phenocrsts are sieve like textures of some phenocrysts and has Carlsbad twinning. Plagioclase has dirty like alteration and the phenocrtysts are clustered together. Olivines have anhedral crystal shape, fractured and altered to iddingsite. The pyroxene minerals have euhedral - subhedral crystal habit.
GIB-5	Basalt	Porphyritic	This rock has a Porphyritic texture with phenocrysts of 20% plagioclase, 3%pyroxene, and 1% olivine set in the fine-grained groundmass composed of 30% plagioclase, 7% pyroxene, 4% olivine, 5% opaque minerals, 5% volcanic glass and 25% secondary minerals like calcite. It is characterized by lathlike, tabular, elongate, few poikilitic textured and dark dirty like alteration and the phenocrysts are aggregated together. Olivine minerals are altered and have anhedral crystal habit. Pyroxenes have euhedral- subhedral crystal face.
GIB-6	Basalt	aphynitic	Aphyric textured rock with microcrystalline minerals of 55% plagioclase, 10%pyroxene, 3% olivine, 25%opaque minerlas, 2% volcanic glass, and 5%secondary minerals, in ground mass of the bulk rock. Plagioclase has elongated or acicular like crystal habit.
GIB-7	basalt	Porphyritic	Porphyritic texture with phenocrysts of 3% plagioclase and 1% pyroxene set in a fine-grained ground mass of 54% plagioclase, 20% opaque minerals, 7% volcanic glass, 3% olivine, and 6% pyroxene minerals. The Carlsbad twinning and Acicular – lathlike crystals of

			plagioclase is common. Altered olivine are little bit observed in fine-grained groundmass. Pyroxene and plagioclase phenocrysts form a clot or aggregated.
GIB-8	Basalt	Porphyritic	Porphyritic texture with phenocrysts of 5% plagioclase set in a fine-grained ground mass composed of 40% plagioclase, 5% volcanic glass, 20% opaque minerals, 10%olivine, 10%pyroxene, and 10% secondary minerals. Plagioclase is elongated in grain size, and some plagioclase phenocrysts have poikilitic texture. Olivine crystals are altered to iddingsite and overgrown by plagioclase crystals. Pyroxenes are found as inclusion in plagioclase.
GIB-9	Basalt	Porphyritic	Porphyritic texture with phenocrysts of 2% olivine set in a fine-grained groundmass consists of 15% plagioclase, 35% opaque minerals, 10% pyroxene, and 6% volcanic glass and 30% olivine minerals. The plagioclase minerals have flow – lathlike, and aciular crystal, and equigranural in grain size. Olivines are highly altered to iddingsite and have dark and anhedral crystal habit. Pyroxenes have euhedral – subhedral in crystal habit.
GIB-10	basalt	Porphyritic	Porphyritic texture with phenocrysts of 5% plagioclase, and 1% pyroxene set in a fin-grained ground mass composed of 40% plagioclase, 3% pyroxene, 13%olivine, 15% secondary minerals, 15% opaque minerals, and 8% volcanic glass. Tabular and lathlike crystals, as well as poikilitic textures of plagioclase phenocrysts are common. Plagioclase is alteration shows dark dirty appearance and under PPL it like empty space. This rock is characterized by two veins filled by secondary minerals may be calcite from cleavage. Pyroxenes have clear unaltered appearance and intergrowth as inclusion in some phenocrysts of plagioclase.
GIB-12	basalt	Porphyritic	It has porphyritic texture with phenocrysts of 10% plagioclase, and 3% olivine set in a fine-grained groundmass composed of 40% plagioclase, 10% olivine, 10% opaque minerals, 7%pyroxene, 3% volcanic glass and 17% secondary minerals. Some Plagioclase phenocrysts

			has poikilitic or sieve like texture which show alteration to calcite, pyroxene, some secondary minerals and olivine minerals intergrown in large crystals. Other crystal of plagioclase has tabular and lathlike crystal habit. In this rock the secondary minerals usually calcite easily distinguished by its two directional cleavages over grown by plagioclase crystals. Alteration of olivine is common. Pyroxenes have euhedral crystal shape.
GIB-13	Basalt	Porphyritic	It is a porphyritic textured rock with phenocrysts of 5% plagioclase set in a fine-grained groundmass composed of 44% plagioclase, 10%opaques minerals, 7% volcanic glass, 6% olivine, 10% pyroxenes and 15% secondary minerals. Some plagioclase phenocrysts have Lathlike, poikilitic textures, tabular crystals, Carlsbad twinned dark dirty like alteration and euhedral crystal habit.
GIB-14	Trachyte/ pyroclatic	Vitrophyric	This rock is characterized by porphyritic texture with, 10% alkali feldspars, 5% rock fragment and 7%quartz phenocrysts set in a fine-grained groundmass of glassy matrix Composed of about 35%volcanic glass (rhyolite/pumice redish in color), 10% feldspars, 20% quartz, 7% rock fragment, and 1% opaque. It has the ignimbrite texture, but compositionally it is Trachyte.