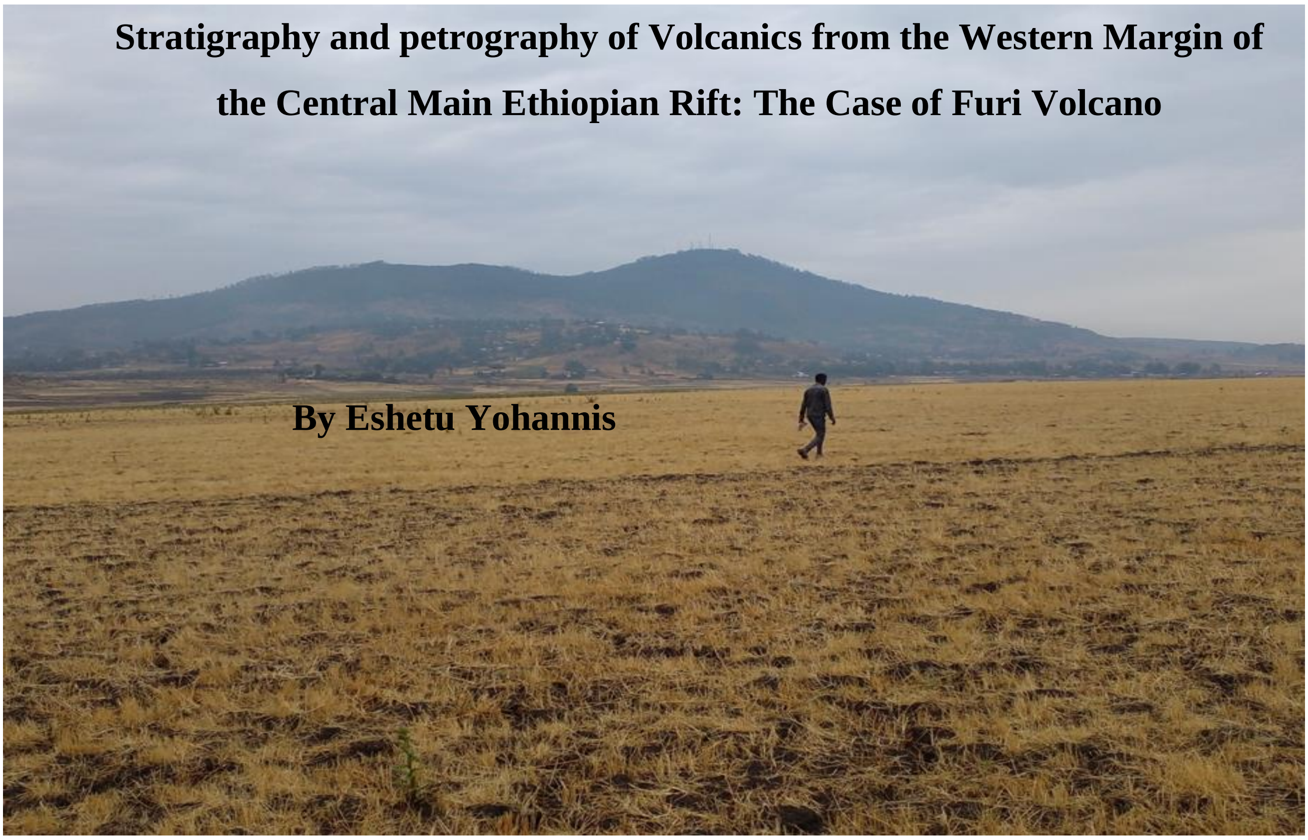
ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCE

SCHOOL OF EARTH SCIENCES

Stratigraphy and petrography of Volcanics from the Western Margin of the Central Main Ethiopian Rift: The Case of Furi Volcano



By Eshetu Yohannis

A THESIS SUBMITTED TO THE ADDIS ABABA UNIVERSITY SCHOOL OF EARTH SCIENCES GRADUATE PROGRAM IN PARTIAL COMPLETION OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN GEOLOGICAL SCIENCES (PETROLOGY)

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Declaration of originality

I declare the thesis is entitled **‘’Stratigraphy and petrography of Volcanics from the Western Margin of the Central Main Ethiopian Rift: The Case of Furi Volcano’’** has been carried out by me under supervision of Prof. Dereje Ayalew and Prof. Gezahegn Yirgu school of Earth science, Addis Ababa University during of 2023 as part of Master of Science in Petrology. I further declare that this work has not been presented or submitted to any other university or institution for the award of any degree or diploma. All sources and materials used for the thesis have been well referenced and duly acknowledged.

Eshetu Yohannis ____________________ ____________________

Signature Date

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

Prof. Dereje Ayalew (Advisor) ____________________ ____________________

Signature Date

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Signature Date

Abstract

Furi Volcano is located near the Western Margin of the Central Main Ethiopian Rift. The location of the area is 26_Km southwest of Addis Ababa. The study's primary goal is to establish volcanic stratigraphy and petrography of Furi Volcano and Escarpment. Various techniques were used to achieve the research objectives, including observation in field, remote sensing, petrographic analysis, and sampling from the study area. Additionally, the study attempts to integrate these data in order to relate them to regional studies investigations on geochronological and magma emplacement behaviour about the Main Ethiopian Rift. The main lithological units exposed in the research area from bottom to top are; partially welded rhyolitic tuff, welded rhyolitic tuff, rhyolite, aphyric basalt, scoria, trachytic basalt, andesite, welded andesitic tuff, welded trachyte tuff, massive to porphyritic trachyte lava. These volcanic rocks are petrographically diverse, with a wide range of mineral compositions and textures; their heterogeneity indicates that magma flux into the lithosphere and depth of fractionation has varied. Total of 25 petrographic samples are studied under the petrographic microscope. The rhyolites and ignimbrite (Welded Rhyolitic Tuff) samples are made of alkali feldspar, quartz, and plagioclase feldspars and are moderately to very porphyritic with up to 10–35% phenocrysts. The felsic units' predominance of alkali feldspar phenocrysts indicates a lower rate of magma flux. The presence of plagioclase, cpx and olivine in basalt reveals the fractionation happened at shallow upper crust, In contrast, the Olv + Cpx mineral assemblages in basaltic lavas demonstrate that crystal fractionation occurred at a deeper crustal level or at the crust-mantle boundary. The upper part of the volcanic unit is dominated by plagioclase and sanidine phenocrysts, intermediate rock, and trachyte lava. The total thickness of volcanic units in the study area is 700m, partially welded rhyolitic tuff to rhyolite (350m), basalt to trachytic Basalt (150m), and andesite to porphyritic trachyte (200m). This indicates that there is a higher abundance of felsic rocks compared to basic rocks. Overall, the study contributes knowledge of the geological history of the western margin of the Central Main Ethiopian Rift with a focus on the Furi Volcano.

Keywords: Furi Volcano**,** Volcanic stratigraphy, Petrography, Western Margin, Trachyte

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List of Acronyms

Akf……………………………………………………………Alkali feldspars

CMER………………………………………………………..Central Main Ethiopian Rift

Cpx…………………………………………………………… Clinopyroxene

EARS……………………………………………………….....East African Rift System

GPS…………………………………………………………..Global positioning system

Km……………………………………………………………Kilometer

Ma…………………………………………………………….Millions of years

MER…………………………………………………………Main Ethiopian Rift

Msl……………………………………………………………Mean sea level

NE……………………………………………………………Northeast

NMER………………………………………………………Northern Main Ethiopian Rift

NW…………………………………………………………..Northwest

Olv……………………………………………………………..Olivine

Opq…………………………………………………………Opaque

Plg……………………………………………………………...Plagioclase

PPL…………………………………………………………Plane polarized light

pyx……………………………………………………………..Pyroxene

Qtz …………………………………………………………Quartz

SE……………………………………………………………..Southeast

SMER………………………………………………………Southern Main Ethiopian Rift

Snd…………………………………………………………Sanidine

UTM………………………………………………………Universal Transverse Mercator

XPL…………………………………………………………..Cross polarized light

YTVL…………………………………………………Yerer-Tullu Wellel Volcanotectonic Lineament

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The lithosphere expands in continental rift zones due to external forces from plate movements, such as slab pull, ridge push, and traction between the lithosphere and asthenosphere caused by mantle flow (Ring, 2014; Amdemichael Zafu et al., 2018). Normal faulting, which thins the brittle crust, allows the crust to extend (Ring, 2014). Subsidence in the fault-bounded basins is increased as dense rocks of the lithospheric mantle move upward to replace the diminishing crust (Weissel and Karner, 1989, Amdemichael Zafu et al., 2018).

Ring (2014) suggests that the East African Rift System (EARS) can be regarded as a typical representation of a continental rift. The East African Rift System is the result of continental expansion and crustal weakness, and Eduard Suess was likely the first to notice this (Ring, 2014). He developed the idea of the East African rift fracture and produced the first fundamental study on the geology of rift valley in 1891(Ring, 2014).

According to Brune et al. (2017) and cited in Rooney et al. (2020), the phenomenon of continental rifting disrupts the equilibrium of the continental lithosphere, leading to potential material exchange with the asthenosphere beneath and the atmosphere above. Three distinct pulses of basaltic magmatism, each followed by bimodal or silicic magmatic activity, predominated the region's magmatism from around 45 to 20 Ma, according to Rooney et al., 2017:

(A) **Initial Eocene Phase (45–34 Ma),** which was centred in Southern Ethiopia's Omo region. According to our current understanding of geochronology, these basalts are discrete from the overlying and significantly more spatially extensive early Oligocene rocks and The distribution of these rocks is constrained to the regions specified above, specifically Southern Ethiopia and Northern Kenya (Turkana) (George and Rogers, 2002).

(B) **Oligocene Trap period (33.9-27Ma).** From Turkana (in the south), to Yemen (in the north), to Sudan (in the west), and the edge of the Somali plateau (in the east), volcanism is seen to have significantly increased in its aerial expanse at this time. These sequences are mostly composed of 1 to 2 km thick sequences of basalt and are about age similar.

(C) **The resurgence phase during the Early Miocene (26.9-22Ma).** At around 24-23 Ma, basaltic volcanism is evident all over the area, though it is less substantial in terms of volume than the previous two basaltic pulses. Fissural basalts on the Somali plateau, shield-building processes on the NW Ethiopian plateau, and rising basaltic activity in Turkana are some of the expressions of this activity (Kieffer et al., 2004).

Magmatism's distribution throughout the Main Ethiopian Rift, the Turkana Depression, and the Northern Kenya Rift has been primarily influenced by extension within the African lithosphere from approximately 20 Ma to the present, according to Rooney et al. (2020). These data shows region of East Africa that is currently available, when interpreted collectively, show six prominent magmatic phases:

A) **Samburu period (20-16Ma).** This phase may be contiguous with the previously mentioned Early Miocene Resurgence Phase (23 Ma), which caused a huge eruption of basalt throughout the Northern Kenya Rift, Southern Ethiopia, and parts of Turkana (Rooney et al., 2017).

B) **The Silicic Eruptive Phase and Flood Phonolite (16 Ma–12 Ma).** This phase is characterised by a time of widespread developed volcanism, which included explosive silicic eruptions in the Main Ethiopian Rift and phonolite flows in Northern Kenya.

C**) Phase of Mid-Miocene Resurgence (12 Ma–9 Ma).** This dominantly basaltic phase of activity appears centred on the Turkana Depression, and the northern termination of the MER near Afar.

D) **Phase of Early Rift Development (9-4Ma).** In this stage of activity, basalts and trachyte are erupting with widespread silicic volcanism, resuming the bimodal pattern that was previously present. During this time, the Main Ethiopian Rift and the Kenya Rift had the most magmatic activity. Volcanism in the Turkana Depression is suspended during this era.

E) **Stratoid phase (4–0.5 Ma).** The lateral-extensive Gombe Group's eruption in Turkana/southern Ethiopia at around 4Ma marks the beginning of this episode. Subsequently, Turkana experienced continuing magmatism as large shield volcanoes were formed.

F) **Axial Phase (0.5 Ma to Present).** As a result of this phase of activity, the axial grabens of the rift were home to silicic core volcanoes, the majority of which had eruptions that formed calderas.

Seafloor spreading caused by continental rifting causes the border faults to go dormant as strain localises to chains of aligned eruptive centres and minor faults inside the core basin (Hayward and Ebinger, 1996; Ring, 2014). By way of the Afar Triangle, this links the Red Sea and Gulf of Aden to the global system of oceanic rifts (Morley, 1999). The Eastern and Western branches of East Africa's rifting over the past 13 years can be categorized as separate rifts (Macgregor, 2015; Morley, 1999; Amdemichael Zafu et al., 2018).

The Ethiopian Rift (ER), a part of the East African Rift System (EARS), is made up of a number of Rift zone that stretch from the Afar Triple Junction at the Red Sea-Gulf of Aden junction to the Kenya Rift across a distance of around 1000 km (Boccaletti et al., 1999).Volcanism started during the Eocene to late Oligocene and it has been matching the tectonic evolution of the rift up to recent times (Gidey woldegabriel et al.,1990, Abebe et al.,1993; Boccaletti et al.,1999). The Pliocene to quaternary Volcanic products of the MER exhibit a distinct bimodal composition, with the sequence being dominated by alkali basalts and rhyolites (mostly pantellerites), With few rock of intermediate character (Gasparon et al.,1993; Boccaletti et al.,1995, Boccaletti et al.,1999). Along with the basaltic fissural eruptions of the Wonji group, significant rift-bound silicic centres like Aluto, Bora, Corbetti, Gademsa, Gademotta, and Shalla were active during the Pleistocene. These centres are located along the rift floor of the central sector between Lake Awasa and the Awash River due south from Melka Kunturé.

Numerous other writers, such as Giday Woldegabriel et al., 1990, Tsegaye Abebe et al. (2010),and Daniel Meshesha et al. (2021), have examined and well-mapped the Central Main Ethiopian Rift volcanic region from petrological, geochemical, geophysical, and structural viewpoints. There are extremely few volcanic sequences in the Furi volcano portion of the central main Ethiopian rift margin, and petrographic examination and comprehensive stratigraphic analysis have received very little attention.

Petrography and volcanic stratigraphic knowledge are lacking with regard to the Furi volcano region. As a result, the primary goal of this effort is to define the petro-volcanic stratigraphy of the region. The research emphasizes conducting an extensive petrographic analysis, examining each lava flow individually within a large-scale stratigraphic framework. The objective is to fill any existing gaps in scientific knowledge by thoroughly investigating the petrographic characteristics of the volcanic deposits.

1.2 Geographic setting of research area

1.2.1 Location and Accessibility

The study region is located in Shagger city, Galan Guda Woreda administration, Oromia regional state, which is a south-western region and located in Addis Ababa's south-western part. Its geological context is situated within the Western margin of the central main Ethiopian rift zone, 26 kilometres from Addis Ababa. In the UTM (Universal Transverse Mercator) coordinate system, the area is delimited from an easting grid 460000m to 470000m as well as northing from 980000m to 990000m.

The research area is reachable by the Addis Ababa-Alemgena-to Mount Furi road, followed by footpaths to the various parts.

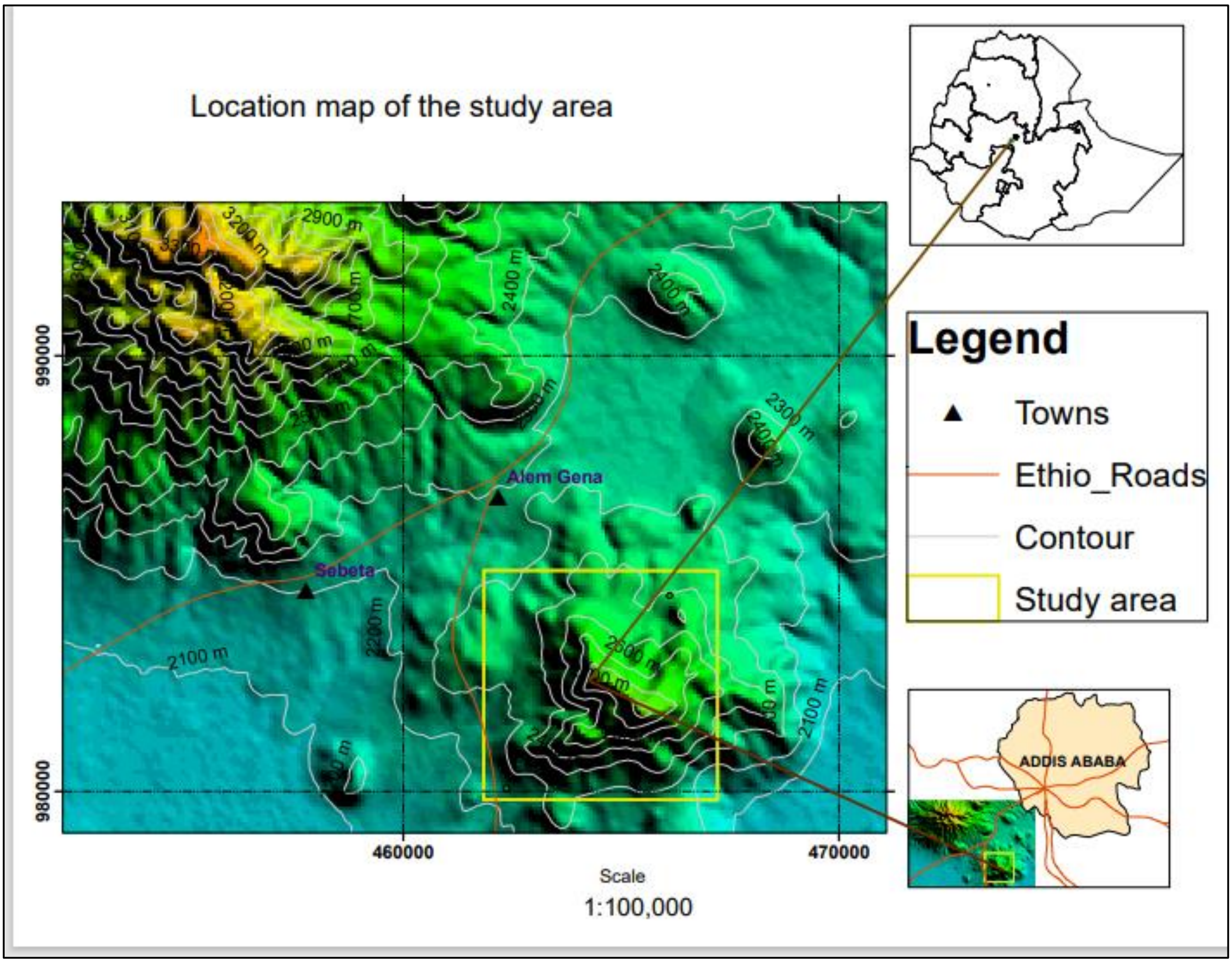


Figure 1.1. Location and accessibility Map of the study area.

1.3 Physiography and drainage

The study region is located on the western margin, in the centre of the main Ethiopian Rift. The area is topographically high, with the plateau level's lowest point being 2100 metres above sea level and the highest point being 2800 metres above sea level atop the mountain on its north-eastern side. The mountain's steep slope and rough landscape define it. The region represents a portion of the Main Ethiopian Rift's western margin which includes varied topography ranging from the deeply dissected, varying flat to highly rough, rocky, and forested mountainous terrains at the highest part of the Furi ridge. Wechecha, Bedegebaba, Ziquala, and Yerer are the principal volcanic ridges and centres located nearby the Furi Volcano. These mountains are covered in forests and are crucial to the city of Addis Ababa's climate policy. The main rivers in this study are the Migira River, Anchorcha River, Akindo River, Fincha'a River, Kersa River, and Koke River, which are found around the research area.

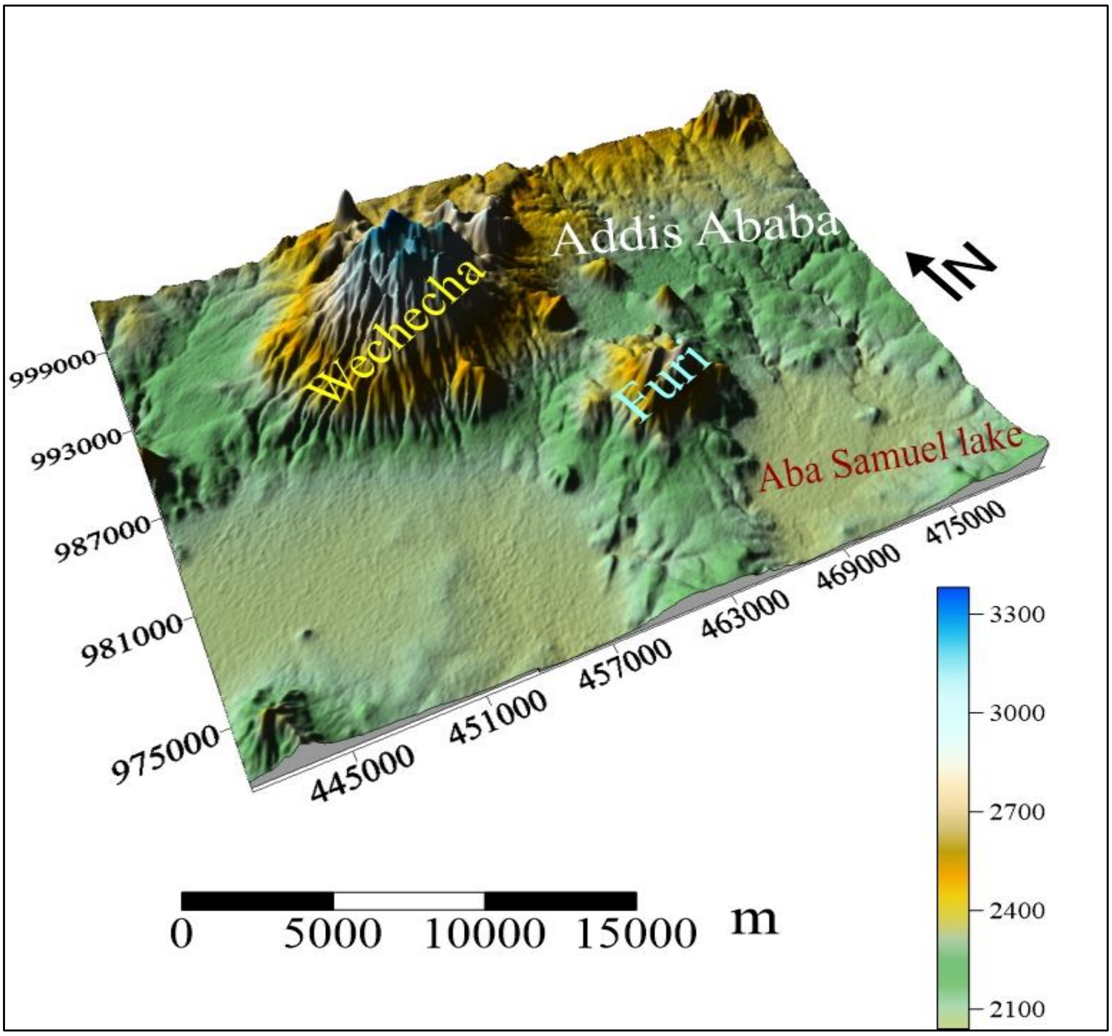


Figure 1.2. Physiographic map of the Furi Ridge Volcano

The northern, western, and south-western parts of Addis Ababa are surrounded by high mountains, and the topography is undulating and creates plateaus there. Bole and the south-western portion of the city are distinguished by their mild topography and flat land areas. As a result, the river flows from the Entoto Ridge in the south, Mount Wechecha in the southeast, Mount Yerer in the southwest, and other elevated hills along the city's eastern borders. Similar to that from Furi Mountain Several intermittent streams with dendritic to sub-dendritic patterns the mountain's tributaries that discharge water (Migira River, Anchorcha River, Akindo River, Fincha'a River, Kersa River) on their downstream sides.

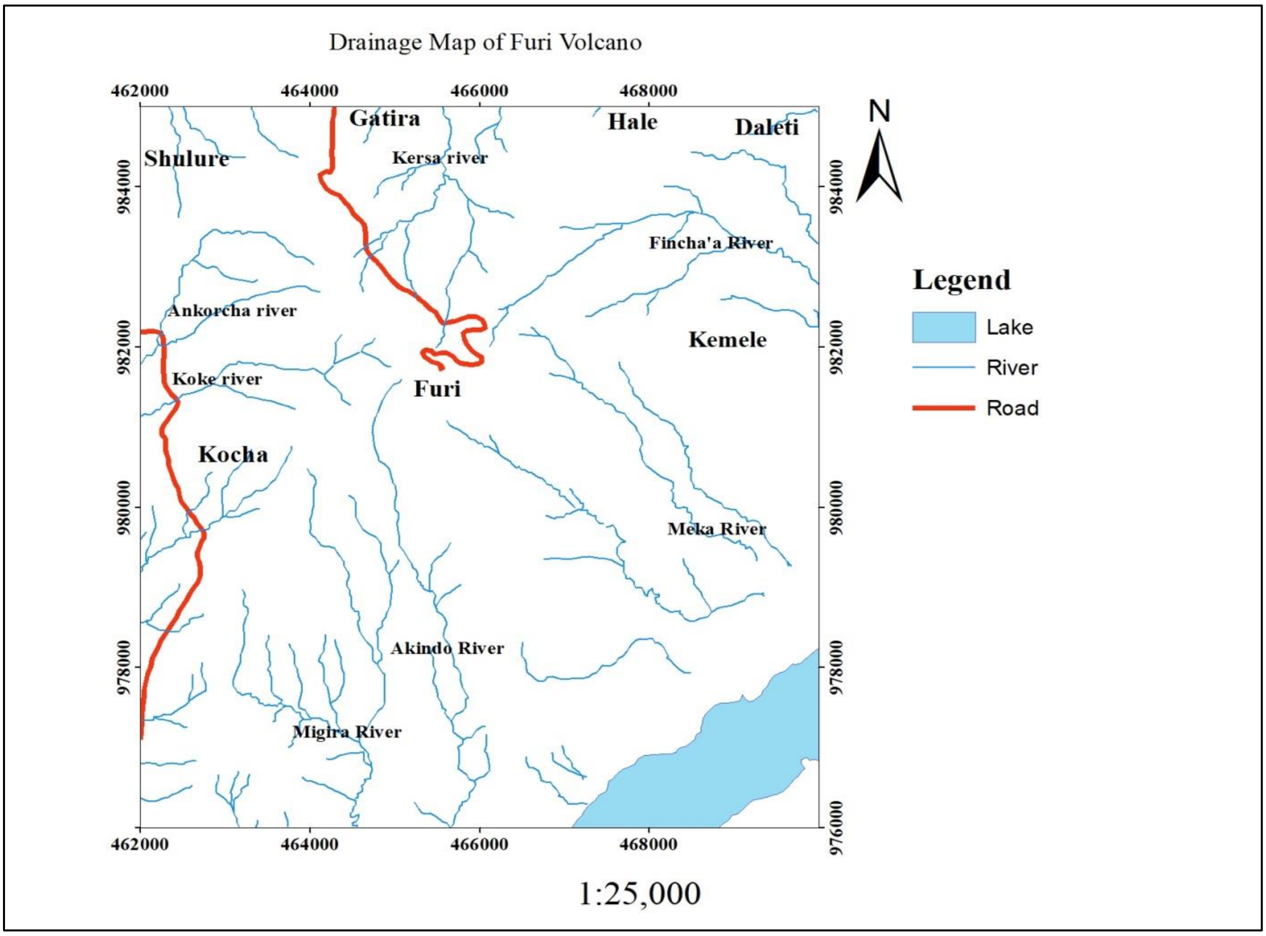


Figure 1.1 Drainage Map of Furi Volcano.

1.4 Climatic condition and Vegetation

The altitude-influenced sub-tropical climate of Addis Ababa has a rainy season from June to September. One area of Shegger City that shares similarities with Addis Ababa is the Furi Mountain. From November to January, it's the driest. Although there are steadily more rain showers from February to May, there are still many hours of sunshine. After the rains, the weather returns to being primarily favourable in October and November. According to climate information.org https://en.climate-data.org/africa/ethiopia/addis-ababa/addis-abeba-532/ the daily average high temperature and low temperature are given on the figure below.

The contrast between day and night is higher during the dry season even if the temperature is generally consistent throughout the year. From November to January, the temperature can sometimes approach freezing. Instead, the highest temperatures of the year, about 22–23°C, occur from February to May, before the rainy season.

The research area's maximum recorded temperature is roughly 23.4 °C in March, while its lowest recorded temperature is 7.8 °C in December. The temperature is 15.6°C on average per year. The average temperature varies between the coldest month of December and the hottest month of April, with a range of 14.65 °C to 17.4 °C.

The amount of precipitation is 1874 millimetres per year; it is therefore quite abundant. It varies between 7 mm in December, the driest month, to 419 mm in August, the wettest month; the difference in precipitation between these two months is likewise roughly 412 mm. An overview of the general climatic conditions in the research region is given by the bar graph (see Figure 1.4).

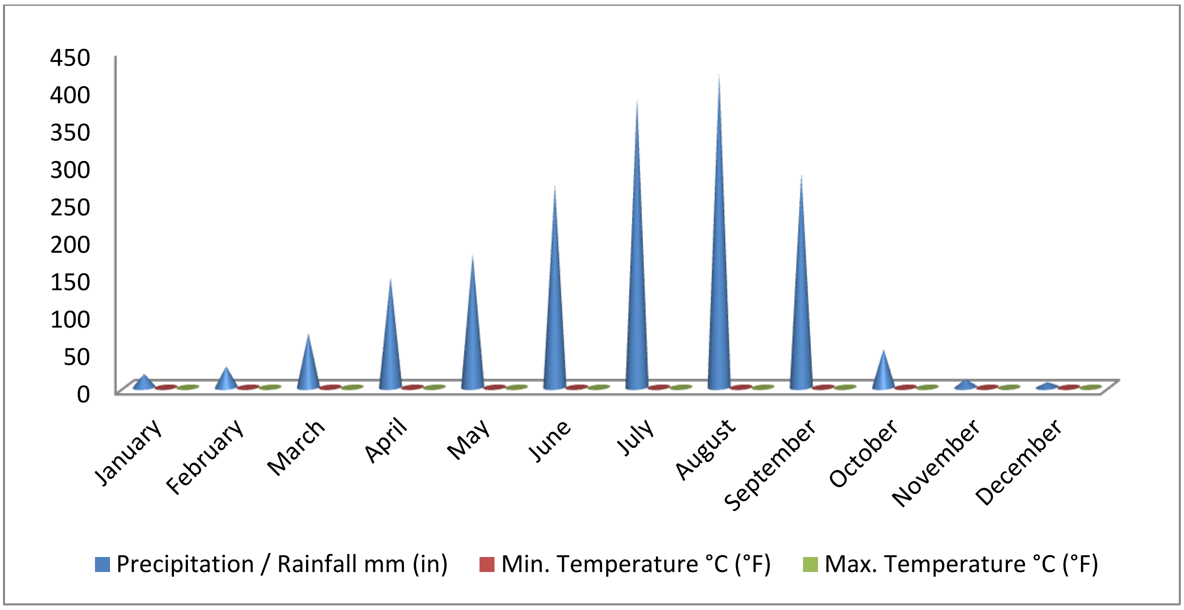


Figure 1.4. A bar graph represents the average monthly temperature and precipitation conditions of the study area.**https://en.climate-data.org/africa/ethiopia/addis-ababa/addis-abeba-532/**

The local climate is a major factor in determining whether there is vegetation there and how much there is. The Eucalyptus trees (Bahirzaf) are the dominating species and are extensively scattered across the hilly terrain, which is particularly evident in the Furi Ridge Highlands. Eucalyptus trees are very frequently seen in populated regions. The lowland near Alemgena and its tributaries contain other vegetation distributed on these areas: shrubs, herbs, and sparse trees like Embachio, Girar, and Tinjut.

On the gently sloping terrain, particularly in the lower part of Furi Volcano, the native population cultivates crops. Teff, Sorghum, fruits, vegetables, wheat, barley, and maize are just a few of the crops that are the focus of farming efforts in this region.

1.5 Population and Settlement

Sebata Hawas is a Woreda from Shagger in Ethiopia's Oromia region. The region is a part of the Shagger Surrounding Finfinne; at this time, it is called Gelan Guda woreda. Alem Gena is surrounded by the Southwest Shewa Zone to the southwest, Walmara to the northwest, Burayu to the north, Addis Ababa to the northeast, and the Akaki to the east. The area is home to a diverse range of ethnic groups, including the Oromo, Amhara, Gurage, and Sidama, among others. Based on the 2007 national census performed by Ethiopia's Central Statistical Agency (CSA), there were 132,294 people living in this district overall, including 7,359 (or 5.56%) urban residents. Of those, 68,133 males and 64,161 women made up the population.

The majority of the population of the area practised Orthodox Christianity, reported to be 87.44%, compared to 5.37% of Muslims, 4.57% of people who follow traditional beliefs, and 2.44% of people who identify as Protestant. According to data from the Central Statistical Agency published in 2005, the district's total population is estimated to be 171,827, consisting of 41,598 males and 85,493 females (https://en.wikipedia.org › wiki › Sebeta_Hawas accessed in 26th june 2023).

1.6 Statement of the Problem

A variety of academics with varying areas of expertise study tectonic and magmatic evolution in the MER. Researchers have devoted a great deal of time to studying the Central Section of the Ethiopian Rift, a part of which of the larger Ethiopian Rift.

In the past, several scholars have concentrated on regional efforts on the Central Main Ethiopia Rift in terms of, geology, structural and chronological analysis, petrography, geophysics, geochemistry, and volcanology (Gidey Woldegabriel et al., 1990, Gasparon et al., 1993; Tadiwos chernet et al., 1998; Corti et al., 2009; Morgan et al., 2012; Daniel et al., 2021). However, there are other locations with igneous terrain in the centre of the Main Ethiopian Rift that require focused research, especially around the Furi Volcano. This entails carrying out a thorough analysis of a given place to recognise various lithologic units, carefully examine the distinctive features of the local geology, and determine the link between mafic and felsic rocks that derive from a constrained magma source.

It was necessary to conduct a more thorough research since the Furi Volcano is specific area located inside the Central Main Ethiopian Rift. According to Gidey Woldegabriel et al. (1990), the Main Ethiopian Rift formed over a period of time from the late Oligocene to the Quaternary, and the evolution of the rift is characterised by six major volcanic occurrences. By examining the stratigraphic Relationships and using K/Ar dating methods to volcanic rocks found in the Main Ethiopian Rift's central sector, it is possible to identify these occurrences. However, the petrographic information on volcanic units in the Furi Ridge of the volcanic province was scarce, incomplete, and poorly understood.

By achieving three main goals creating a detailed geological map of the study area, analysing the petrography of the volcanic unit present in the study area, and creating a volcanic stratigraphic unit unique to the study area this study seeks to close the knowledge gaps currently existing regarding the volcanic stratigraphy and petrography of the rift Margin volcanic unit in the study area. This thorough approach will give a more thorough knowledge of the petrographic properties and volcanic stratigraphy in the rift Margin volcanic unit.

1.7 OBJECTIVE

1.7.1 General Objective

The main goal of this investigation is to establish the stratigraphy and petrography of Volcanic from the Western Margin of the Central Main Ethiopian Rift: The Case of Furi Volcano.

1.7.2 Specific Objective

- ✓ To create a sketch geological map of the research area at a 1:25,000 scale with a geologic cross-section that clarifies lithological units and geological structures that are widely distributed.
- ✓ To develop a comprehensive stratigraphic section of the studied region with information on its geological strata.
- ✓ To identify the volcanic units mineralogical and petrographic characteristics within the designated research region.
- ✓ Establishing volcanic history based on petrography and stratigraphy
- ✓ To correlate the volcanic units to the regional studies

1.8 Expected outcome and the study's significance

As stated in the problem statement, this research will be first to offer detail petrographic and stratigraphic data on the volcanic rock unit in the study area. Finally after finalizing this research work, the following significances are provided.

- ✓ It gives an illustration of the distribution of key lithological units on a geological map with a scale of 1:25,000 and a cross-sectional diagram.
    - They get a conceptual understanding of the studied area's geology and geologic history.
    - Geologic maps are also vital in finding and developing geological resources such as sediment, groundwater, fossil fuels and minerals.
- ✓ In order to comprehend the Furi locality's volcanic history and to identify specific eruptive units in the geological record, a clearly defined volcanic stratigraphy within the research region is essential.
- ✓ To understand the optical properties of minerals found in the rock, a thorough petrographic description of the volcanic unit found in the research region is necessary.

1.9 Previous Works

Different scholars are working on the Ethiopian Rift System in different time and different part of it; these scholars mainly focused on the initiation of the rift, Structural and geochronological implications, composition of the rift, genesis of the volcanic rocks and the different geological structures of it.

According to Keranen et al. (2008), scholars have historically divided the MER into the Northern (NMER), Central (CMER), and Southern (SMER) sectors based on the investigation of surface geology and geomorphology. The NMER extends southward, from the depression of Afar to a point just below Lake Koka. According to Chernet et al. (1998) and Wolfenden et al. (2004), the beginning of volcanic activity occurred between 10 and 11 million years ago, and it was accompanied by boundary faults that were typically N50°E oriented. The CMER, according to Keranen et al. (2008), extends from Lake Koka to Lake Awasa in the lakes region, with boundary faults often aligning in a N30°E to N35°E orientation. The SMER, as defined by Keranen et al. (2008), extends farther south from Lake Awasa into the broadly rift zone of southern Ethiopia.

To investigate the relationship between mafic and felsic volcanic materials, examine the stratigraphy, and define the major collapse zone, several research have been carried out on various core silicic volcanoes. Volcanoes including the Corbeti (Di Paola, 1971), Aluto (Hutchison, 2015), Gedemsa (Dereje Ayalew et al., 2003; Giordano et al., 2014), Kone (Rampey et al., 2010), and Fanta'Ale (Giordano et al., 2014) have all been the subject of prior studies. According to Amdemichael Zafu et al. (2018), the largest volcanoes in the area are positioned along the rift axis in a NNE-SSW orientation. Based on the results of several investigations, it is clear that collapse structures do not overlap or nest, and separate volcanic materials are seen throughout each stage of volcanic activity, indicating individual collapse occurrences (Amdemichael Zafu et al., 2018). One of the theories to explain this bimodal composition was advanced by Peccerillo et al. in 2003 and 2007.

After the extensive volcanic activity during the Miocene period, the Quaternary magmatic activity in the rift floor has become restricted and is linked to the WFB (Amdemichael Zafu et al., 2018). The Quaternary phases of the Ethiopian rift's formation have been characterized by the eruption of large volumes of volcanic materials (Amdemichael Zafu et al., 2018). According to Peccerillo et al. (2003, 2007) silicic rocks make up the majority of the eruptions, with basalts being less common and occurring in minor quantities. Such a bimodal distribution of volcanism is a common feature of many volcanoes, especially in the continental rift, but its genesis is still debated (e.g., Peccerillo et al., 2003).

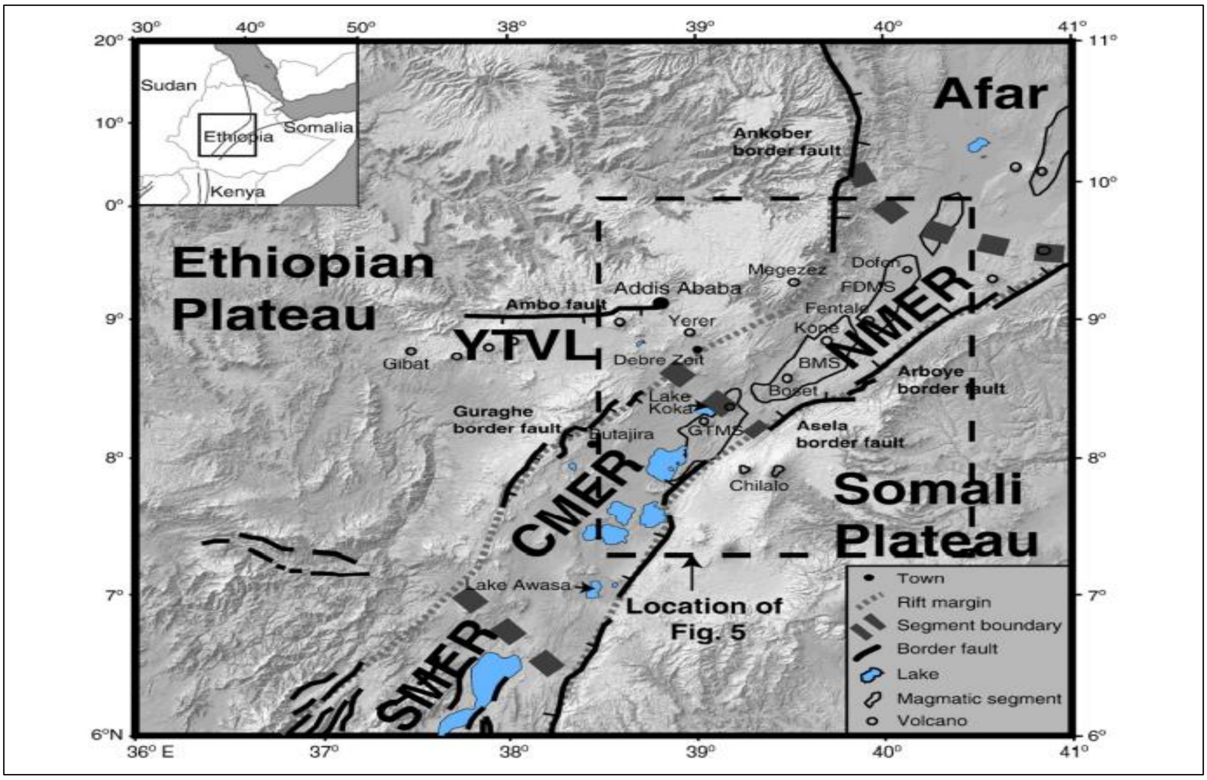


Figure 1.5 The location of the Main Ethiopian Rift. The three main rift segments are the NMER, CMER, and SMER. The southern portion of the NMER is where the Yerer-Tullu Volcano tectonic Lineament (YTVL), which spans 8° and 9°N, begins to spread east-west. Between the Northern, Central, and Southern MERs, it is located, thick dashed grey lines reflect sector boundaries (Ebinger and Hayward, 1996; Keranen et al., 2008).

Studies by Gidey Woldegabriel et al. (1990) and Amdemichael Zafu et al. (2018) claim that the magmatic activity along the Main Ethiopian Rift has been characterised as episodic rather than continuous. According to Amdemichael Zafu and colleagues (2018), it primarily took place throughout the Late Tertiary and Quaternary geological eras. Around 30-35 million years ago, during the Oligocene epoch, large flood basalt eruptions marked the beginning of Ethiopia's magmatic activity (Gezahegn Yirgu et al., 2006). Following this, a sophisticated shield volcano system developed (see, for instance, Kieffer et al., 2004). From the plateau area to the rift axis, the thickness of the crust supporting the Main Ethiopian Rift significantly decreases (Amdemichael Zafu et al., 2018).

The Central Main Ethiopian Rift (CMER) is home to a number of active volcanoes, some of which have caldera structures (Peccerillo et al., 2003), according to Hubert et al. (2018). In addition, it is a significant source of hydrothermal activity and has monogenetic vents (Mazzarini et al., 2016). The volcanic growth within the central portion of the Main Ethiopian Rift demonstrates parallels to that seen in the northern half, with the exception of the volcanism occurring along the western and eastern rift shoulders (Mazzarini et al., 2016). Significant silicic volcanoes developed along the Main Ethiopian Rift's western rift shoulder during the Late Pliocene era (Abebe et al., 1998, 2005; Corti, 2009). Similar to this, large central trachytic and basaltic volcanoes erupted during the Pliocene on the rift's eastern shoulder (Corti, 2009; see also related literature).

According to William et al. (2016), there are a number of distinguishing features that mark the transition from Addis Ababa to the real Rift Valley. These include the Rift Valley's distinctive layers of lake sediments and the existence of a level bottom. Furi, Yerer, and Wachacha are the names of three notable volcanoes that are located to the south and southwest of the city. These volcanoes were produced during the Pliocene epoch, around 4 million years ago, and are made of trachyte, according to William et al. (2016). They are a little bit older than Mt. Chilalo and the volcanoes found near the eastern rift border. The Wachacha volcano is composed of per-alkaline trachytic flows, tuffs, breccias, and possibly plugs and According to Miller and Mohr (1996), sanidine phenocryts from a flow at the summit yielded an age of 4.5 $\pm$0.1 Ma. Generally, it is impossible to list different researchers working throughout the East African Rift System especially on studying the portion of the Ethiopian rift Because it is an active geologic place and attractive for geology to characterise volcanic activities, Petrological, structure, geothermal and ground water.

There is currently little knowledge of the volcanic stratigraphy and petrography of the Furi Volcano section. The Central Main Ethiopian Rift's western margin has been the subject of extensive research by Maerker et al. (2019) (geomorphology), Morgan et al. (2012) (geochronology), Bardin et al. (2004) (drainage pattern and regional morphostructure), and other archaeological researchers. The Furi Volcano is one of the Western Rift Margins of CMER, and this investigation is necessary to improve the stratigraphy and petrography of the volcanic Furi Volcano because they are not yet complete.

1.10 Thesis framework

There are six chapters in this thesis paper. The first chapter provides background information on the subject matter, a statement of the problem, and the thesis framework. Chapter two offers a geological setting of the region in general, i.e., a literature review related to the study area. Under Chapter 3, it includes the research's methodologies, goals, field equipment, and laboratory materials. For a full explanation of the investigation of rock properties and composition and volcanic stratigraphy of the volcanic rock formations that are located in the chosen research region and the interpretation of the volcanic rock (eruptive history) of the Furi Volcano in regard to mineralogy (typical phenocrysts or microphenocrysts), Chapter 4 details the research area's textures and geological formations. The discussion parts are described in Chapter 5. The conclusion and recommendation are included in Chapter 6, which comes to a close.

CHAPTER TWO

2. REGIONAL GEOLOGICAL SETTING

2.1 EAST AFTRICAN RIFT SYTSEM (EARS)

East African Rift System (EARS) is one of the rifts on Earth, and it's important to understand how rifting has changed over time (Gregory, 1896) as well as a location to do archaeological and anthropological research. The idea that continental extension and crust thinning are the causes of the EARS was probably first recognized by Eduard Suess (Ring, 2014). The term "East African Rift System" (or "EARS") is typically only used to refer to rifts that are Cenozoic in age (e.g., Chorowitz, 2005), but Macgregor (2015) suggests that even here there may be confusion because there are three overlapping subsets of Cenozoic rifts, comprising (a) those of Early Paleogene age, which often indicate a continuation of rifting from the Late Cretaceous, (b) those of Eo-Oligocene to Early Miocene age, and (c) the currently active group of rifts, which, in accordance with this analysis, date to the Mid Miocene. By combining the age subsets, he gives general name EARS 1 (Oligocene to Mid Miocene) and EARS 2 (Mid-Late Miocene to recent) (Macgregor (2015)).

According to Ring 2014, there are various distinct and diachronous rift sectors in the East African Rift System. A Western Branch and an Eastern Branch, which includes the Ethiopian Rift, are traditionally distinguished. The EARS 2 eastern branch rifts continue from the Afar region of Ethiopia to northern Tanzania, and the western branch of the rifts begins at the Uganda/Sudan border before joining the eastern branch through the Aswa Fracture Zone (Amdamichael zafu, 2018).

According to Ring (2014), the difference between the two branches of the EARS is that extensive volcanism only occurs in the eastern branch, which is surrounded by a broad regional plateau, the Kenya Dome, and the western branch has only scattered volcanism and is not surrounded by a broad regional plateau but exhibits significant absolute rift subsidence. The western branch shows that regional doming or uplift is less pronounced while it shows the greatest absolute subsidence on the earth (Ring, 2014). The Eastern Branch that Comprises the Ethiopian and Kenya rifts is older and relatively more volcanically active than the Western Branch (Omenda, 2016).

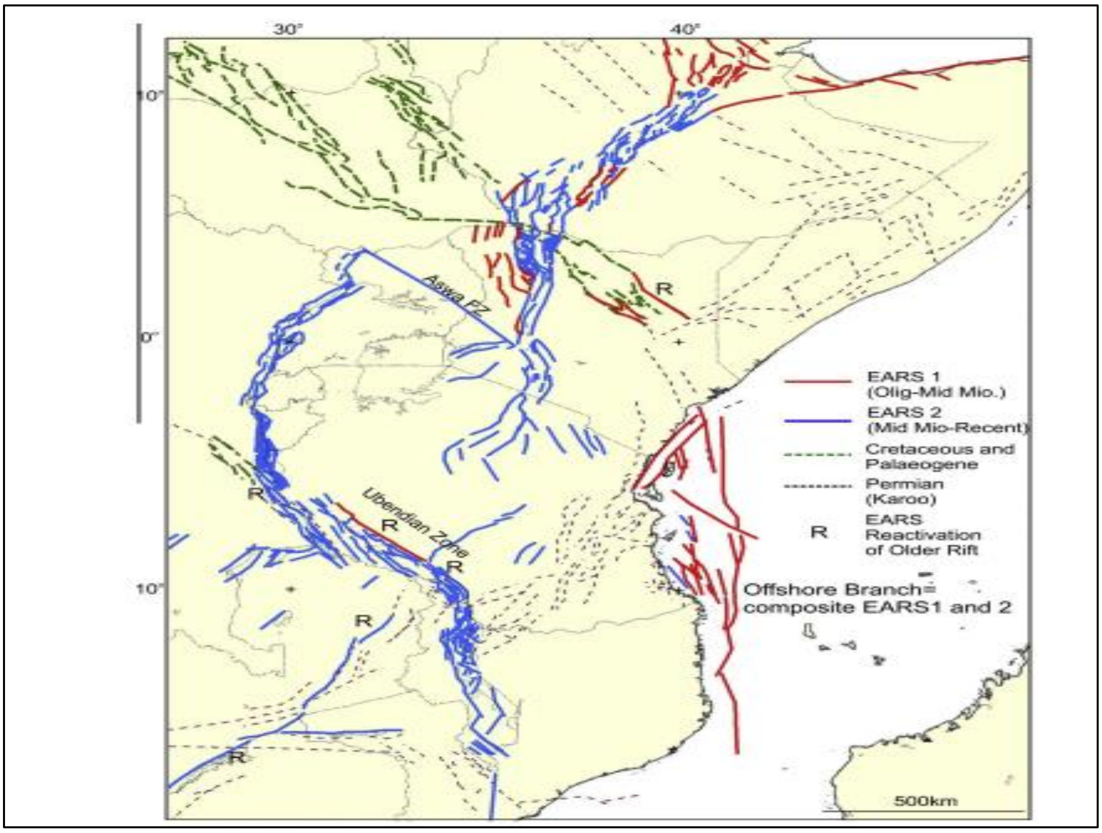


Figure 2.1: Assignment of rift types in the East Africa based on age Permo-Triassic ("Karoo"), Cretaceous-Palaeogene, Eo-Oligocene to Mid Miocene (EARS 1), and Mid-Late Miocene to Recent (EARS 2) periods (Macgregor, 2015, p. 234)

2.2 Main Ethiopian Rift (MER)

The Main Ethiopian Rift, which has a northern portion that trends northeast-southwest, is part of the classic East African Rift System, which is represented by the southern branch of the triple junction (Tsegaye Abebe et al., 1998). The Main Ethiopian Rift (MER) is a component of the East African Rift system that extends from the Afar Triple Junction at the Red Sea-Gulf of Aden intersection to the Kenya Rift, with a general NE tendency (Bonin et al., 2005). The Ethiopian Rift extends for around 1000 km in a NE- SW to N-S orientation, from the Afar depression to the Turkana depression (Corti et al., 2009). The southern border between the overlapping Ethiopian and Kenyan Rift regions, marked at latitude 5° N (Ebinger et al., 2000). According to Wolfenden et al. (2004), the Tendaho-Goba'ad Discontinuity, a left-lateral, oblique-slip Quaternary fault zone, separates the roughly E-W extension in the south (Ethiopian Rift) from the NE-SW extension in the north, where the Red Sea-Gulf of Aden-Ethiopian Rift triple junction is located.

The Ethiopian Rift can be divided into two main physiographic segments, the southern Afar and the Main Ethiopian Rift (Corti et al., 2009). In the latter segment, where an 80 km-wide rift valley

(Ethiopian Rift valley sensu stricto of Mohr, 1983) divides the uplifted western (Ethiopian) and eastern (Somalian) plateaus, the rift morphology is typically developed (Corti et al., 2009).
The main phase of extension in the Main Ethiopian Rift started at about 11 Ma (Ukstins et al., 2002), possibly related to the onset of seafloor spreading in the Gulf of Aden (Manighetti et al., 1997; Bosworth et al., 2005) and the initiation of extension in northern Afar (Manighetti et al., 2001). The Main Ethiopian Rift is a perfect location to study the development of continental extension, the breaking of lithospheric plates, and the dynamics by which diffused continental deformation gradually concentrates at oceanic spreading centres (Corti et al., 2009). From the Somali plateau in the east, it divides the southern Ethiopian plateau to the west (Abbate et al., 2015). The complex Afar triple junction is formed by the gradual widening of the MER toward the north, while the Turkana depression's Gofa basin and range, a 200–300 km2 region that has been tectonically disturbed (Baker et al. 1972), marks the beginning of the Kenyan Gregory Rift (Abbate et al., 2015). Tsegaye Abebe et al., (1998) claim that one distinguishing characteristic of the MER is the existence of huge transverse structures that extend hundreds of kilometres from rift borders and the E-W structures can be shown as a lineament called the Yerer-Tullu Wellel Volcanotectonic Lineament (YTVL). The YTVL stretches from Tullu Wellel, near the border between Ethiopia and Sudan, to Ambo fault in the northern limit (Tsegaye Abebe et al., 1998). The interpretation of the YTVL is debatable. The YTVL is recognised both on satellite images and in the field; it is about 700 km long and about 80 km wide, and several central volcanoes occur within it (Tsegaye Abebe et al., 1998). According to geophysical data, structural analysis, and Oligo-Miocene plateau volcanics, the transverse structure represents pre-existing weak points (parallel to the Gulf of Aden trend, for example; Bastow et al., 2005). In relation to the YTVL, another one is the E-W trending transverse lineament. This is the Goba-Bonga lineament, which crosses the center of the MER (Abbate and Sagri, 1980).

2.2.1 Main Ethiopian Rift Volcanism

MER can be divided into three segments, each of which has been interpreted to represent a different stage of the continental extension process and these segments differ in their fault design, timing of volcanism and deformation, crustal structure, and lithospheric structure (Corti et al., 2009). According to surface geology and geomorphology, the MER has traditionally been classified into three sectors: the northern (NMER), central (CMER), and southern (SMER) sectors (Keranen et al., 2008).

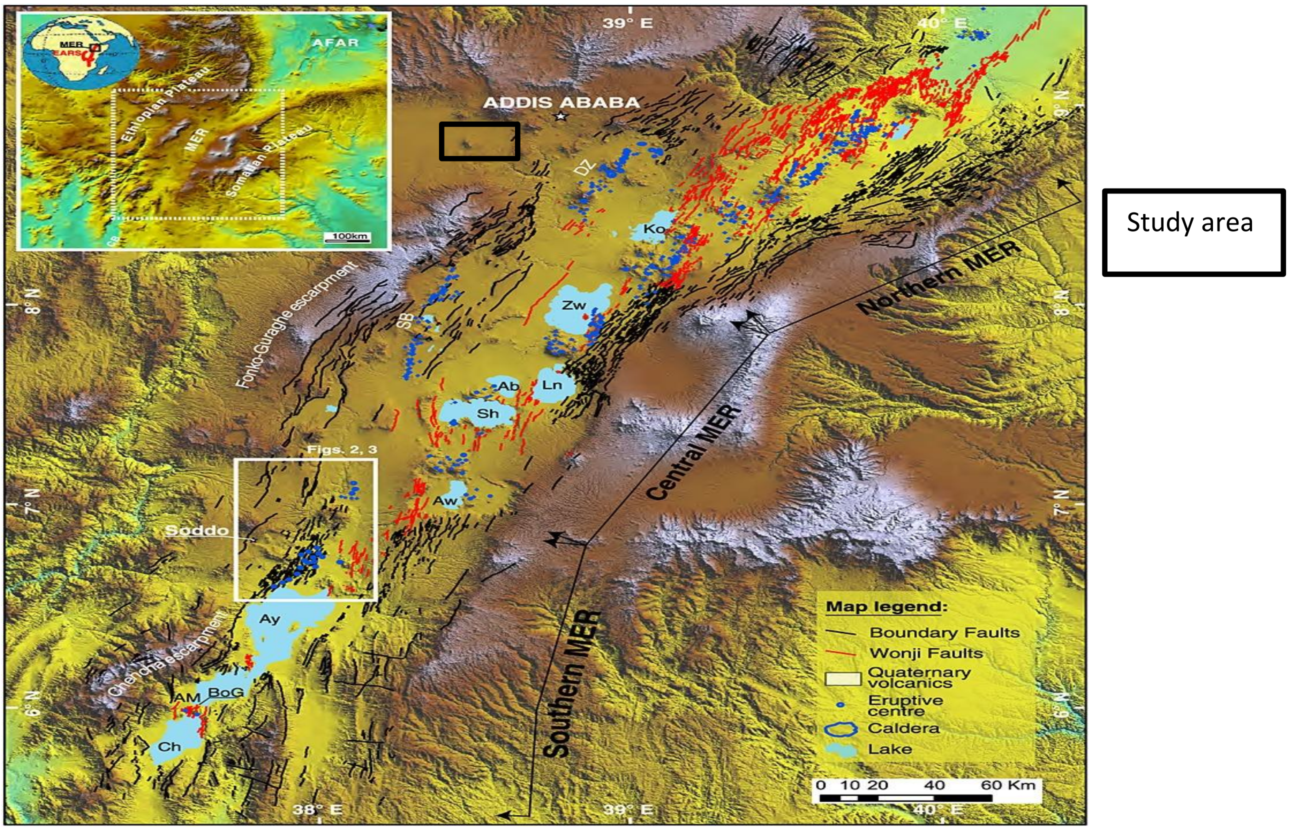


Figure 2.2: Main Ethiopian Rift (MER) fault pattern (modified from Agostini et al. [2011a], Corti et al., 2018) superimposed on a digital elevation model (Shuttle Radar Topography Mission, SRTM data), indicating the three Main rift sectors (Northern, Central, and Southern MER.

The Main Ethiopian Rift (MER) and Afar Rift are considered to be the northernmost portions of the East African Rift, according to Omenda et al., (2010). About 30 million years ago, enormous amounts of basalt were erupted in Ethiopia, marking the beginning of the country's volcanic activity (Mohr and Zanettin, 1988). However, activity has reduced since the Miocene era, with eruptions of the bimodal suite of basalts and more alkaline silicic lavas concentrating in the rift zone (Omenda et al., 2010). Rhyolite volcanoes, domes, ignimbrites, and nonconsolidated pyroclastic were among the more recent geological features in the rift's axis (Omenda et al., 2010). Over 90% of the eruptive are silicic in nature, according to studies by Mohr (1992). The Wonji fault belt, a zone of Quaternary crustal extension, is found in the rift's axis (Omenda et al., 2010).

According to Bekele Abebe et al., 2007 the rate and the total amount of extension of the MER increase northwards, being largest in the afar triple junction, As a result the MER itself gets wider and deeper northwards. At the same time, the erupted products, showing an overall bimodal composition, change in volume and composition along MER (Bekele Abebe et al., 2007). The northernmost part is mainly characterized by widespread basaltic lava flows, associated with shield volcanoes or erupted fissures (Hayward and Ebinger, 1996; Lahitte et al., 2003); these basalts constitute most of the floor of the northern MER (e.g., Chernet et al., 1998). On the other hand, the central and southern parts of the rift are dominated by felsic central volcanoes, which are typically characterised by calderas and responsible for the emission of rhyolite ignimbrites (WoldeGabriel et al., 1990; Chernet et al., 2003).

Rhyolites, ignimbrites, pyroclastic deposits, and minor basalts are the dominant components of Quaternary-Recent volcanism along the MER (WoldeGabriel et al., 1990; Gasparon et al., 1993; Peccerillo et al., 2003; Giordano et al., 2014). Magmatic activity is focused along the Silti-Debre Zeit Fault Zone (SDFZ), Akaki belts, and the WFB [e.g., Rooney et al., 2007, 2014a], Maccaferri et al., 2013, and other sources]. Mafic volcanism along the WFB and SDFZ has taken the form of numerous monogenetic basaltic vents with spatter cones, scoria cones, and maars (see, for example, Mazzarini et al., 2013a).

Volcanism is mainly characterized by a bimodal basalt rhyolite association (Peccerillo et al., 2003), with a distinct lack of lavas of intermediate composition. Rhyolites are associated with regularly-spaced central volcanoes, usually characterized by a summit caldera, with a diameter exceeding 10 km (Ebinger and Casey, 2001). The proportion of the rhyolite was formerly estimated to be reaching about 90% of the total volume of the erupted products in the central MER (e.g. Trua et al.,1999), but recent field investigations reveal that the basalts may constitute up to 60% of the total volume at least in the northern MER (Wolfenden et al., 2004). The MER is, therefore, mostly floored by several basaltic fields, silicic domes and calderas (Bekele Abebe et al., 2007). These are interlayered and covered with Plio-Quaternary fluvio lacustrine sediments (WoldeGabriel et al., 1992). However, the genetic relationships between the basalts and the ryholites are still debatable (Peccerillo et al., 2003).

2.3 Central Main Ethiopian rift and Western rift margin

The Central MER is bordered to the north and south by the Yerer-Tullu-Wellel volcano-tectonic lineament and the Goba-Bonga lineament, respectively (Tsegaye Abebe., 2010). It is also bordered to the east and west by fault escarpments, some of which have an offset of more than 1500 m, including the Munesa and Guraghe rift margins (Tsegaye Abebe., 2010).

Late Miocene-Pliocene boundary faults in the Central MER (post 6-7 Ma; see, for example, Bonini et al., 2005; Tsegaye Abebe et al., 2010) age are well developed and give rise to prominent, poorly eroded rift escarpments (Molin et al.,2015). The Wonji Fault Belt, or axial part of the rift, is made up of a small number of faults that are generally localised close to both rift margins and are typically in the early stages of development (Agostini et al., 2011a). The lack of significant faulting and volcanism in the centre of the rift floor suggests that axial tectonic and magmatic deformation is subordinate in the area (Agostini et al., 2011a). At the margins of the Central MER, there is some limited magmatic deformation associated with intrusion and extrusion processes in regions of locally continuing crustal modification (Rooney et al., 2014). According to Molin et al., 2015 Geological data on both margins of the central MER indicate recent (Late Quaternary–Holocene) activity.

According to Agostini et al. (2011b), the western rift margin of the central MER is primarily defined by a few, significant normal faults that are spaced around 5 km apart and have a vertical offset of up to about 700–1000 m. The Guraghe fault escarpment, a small deformation belt with SE-dipping staircase faults with vertical offset up to around 1000m, dominates the area of the margin adjacent to Butajira (Molin et al., 2015). According to Molin et al. (2015), Late Miocene-Pleistocene pyroclastic rocks (Nazret and Chefe Donsa pyroclastics of Abebe et al., 2005) are most commonly impacted by normal faults of the Western Rift Margin and (in limited places) Oligocene flood basalts and basement rocks, as well as Pliocene–Pleistocene trachytic lava flows and pyroclastic deposits of plateau (off-axis) volcanoes.

Eruption of pre-20 Ma flood basalts [e.g., Ebinger et al., 2000; Kieffer et al., 2004] was followed in the central MER by an episodic volcanic activity. Pre-rift volcanism included eruption of under-saturated intermediate and acidic rocks (at ∼17–12 Ma; Shebele Trachyte of WoldeGabriel et al. [1990]) and Late Miocene (∼11–8 Ma) basalts and trachy-basalts with subordinate silicic flows (Guraghe-Anchar basalts of Abebe et al. [2005] and Bonini et al. [2005]). Scattered volcanic activity (e.g., Addis Ababa basalts [Mazzarini et al., 1999; Abebe et al., 2005]) followed this major Late Miocene volcanic event up to the onset of major extension-related deformation in the central MER, which was marked by eruption of voluminous silicic pyroclastic material (Nazret pyroclastics of Abebe et al. [2005]) with ages typically ranging between ∼5–6 and ∼3 Ma [e.g., Abebe et al., 2005, and references therein]. Synrift volcanism had bimodal character, with predominant acid products and associated basalts [Boccaletti et al., 1999].

Upper Pliocene basalts (known by many names in various places, such as the Bofa basalts of Abebe et al. [2005, and references therein]) succeeded the Nazret pyroclastic and pyroclastic deposits composed by mainly comenditic rhyolites possibly fed by large caldera structures (Chefe Donsa pyroclastics of Mazzarini et al. (1999) and Abebe et al.(2005). The succeeding Quaternary volcanic activity was still characterised by both silicic rocks (Bora-Bericha rhyolites of Abebe et al., [2005]) and basalts (Wonji Basalts of Abebe et al. [2005]), and it was spatially connected with the oblique faults of the Wonji Fault band that affected the rift floor. Silicic rocks form large central volcanoes, some characterized by well-developed calderas, which give rise to ignimbrites, lava flows, domes and phreato-magmatic deposits, with compositions ranging from trachyte to per alkaline rhyolites; basalts form small lava flows, scoria cones and phreatomagmatic deposits. In general, this activity has radiometric ages of around 1.8 Ma [e.g., WoldeGabriel et al., 1990; Abebe et al., 2005], whereas the last eruptions are thought to have occurred in the Holocene historical period [see Abebe et al., 2005, and references therein].

Close to the rift margin the western and eastern plateau is characterised by Miocene-Pliocene volcanic activity (Amdemikael zafu et al., 2018). On western margin, volcanic activity mostly restricted to YTVL (Tsegaye Abebe et al., 1998) that forms aligned central silicic volcanoes. These volcanoes become younger towards the rift from the 7 Ma Nekemt edifice to the Pliocene-Quaternary volcanoes (such as Wenchi, Wechacha, Furi and Yerer e.g., Tsegaye Abebe et al., 1998).

The Addis Ababa–Debrezeyiet area is located on the western margin of the main Ethiopian rift (Tesfaye shewa, 2007). Based on radiometric dating Morton et al. (1979) have showed rift ward younging of sacrificial volcanic units along a 100 Kms wide south, south eastwards from Blue Nile area on the plateau via Addis Ababa-Debrezeit area on the rift Margin to rift floor axis at Wolenchiti. According to their study flood Basalt at sululta plateau immediately north east of Addis Ababa gave an apparent age of 22.8Ma (Morton,1979). In the environment of Addis Ababa, the oldest visible post-dating the Entotto rhyolites are alkali olivine basalts lapping on the southern flanks of the Entotto horst (Morton, 1979).

According to Walde (1996) and Kabeto et al. (2009), the corresponding basic rocks at the rift margins are frequently transitional or alkaline, whereas those at the rift centre are typically transitional. Strongly felsic alkaline rocks at the rift margin and centre are weakly per-alkaline and strongly per-alkaline, respectively (Kabeto et al., 2009). Strongly felsic alkaline rocks are weakly and strongly per-alkaline, respectively, along the rift margins and rift centre (Kabeto et al., 2009).

Petrographically, the fundamental rocks in the rift margin and centre are often aphyric and have trachytic texture, but porphyritic samples are uncommon and contain between 15-25% phenocrysts (Kabeto et al., 2009). The phenocryst minerals are olivine, clinopyroxene, and plagioclase with or without opaques and the groundmass of the basic lavas consists of the above phenocryst stages (Kabeto et al., 2009).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

The three primary phases of the research process are pre-field work, field work, and post-field work that make up the research's total activities. Accessibility, extent, and other factors related to the study region, as well as the methodologies that will be used, are evaluated in the pre-field work phase. Data are gathered, analysed, synthesised, presented, and interpreted both on the field and thereafter. For this study, two types of data were gathered: secondary data and primary data.

A logistical plan is created during the fieldwork's preliminary stages, such as when distinct lithology are distinguished using ArcGIS and a geological map is created nearby and significant geological features are identified. Physical properties of the rocks, structural information, photographs of the topography and the rocks in the study region, and representative samples of each type of lithology that was encountered were all data that were gathered during the fieldwork.

Analysis of the pertinent data is the next stage after data collection from the area. The majority of analyses are performed in laboratories. For petrographic study purposes, the samples gathered during fieldwork are prepared. The analysis, interpretation, and presentation of all the data, including the data gathered for this study as well as the data from earlier studies, are done together. By reviewing pertinent literature on nearby or similar volcanic centres, the data presented is placed into a regional perspective. A final thesis report is being written with an analysis of the interpretation of the data and all the obtained data.

In order to complete each stage, a variety of tools are used, including topographic and geological maps at a scale of 1:50,000, common field sampling and measurement equipment, and software programmes like ArcGIS, Google Earth, and Global Mapper, Hand lens, Sample bag, Geological hammer, Field note book, pencil, pen and marker, Protractor, millimeter paper, Stereo net and tracing Paper, handheld GPS and Geological compass.

The key approaches used in the research study are summarised in the following sections.

3.2 Methodology

The following are the main techniques applied in this study: revision of previous works, field-based methods, remote sensing and GIS methods, and Petrographic analysis. The following tasks are done to accomplish the objectives and specific objectives listed above:

3.2.1 Revision of Previous Work

According to the geology, tectonic setting, petrology, and geochemistry data, secondary data pertinent for the literature review has been gathered from published or unpublished publications, maps, journals, websites, aerial photos, and satellite image interpretation. A greater understanding of petrography and a clearer understanding of the entire geologic framework were made possible by reviewing the collected data. These preceding analyses, synthesises, presentations, and interpretation techniques have been used to finish this work.

Additionally, the secondary data gathered from the northern, central, and southern parts of the Main Ethiopian Rift were analysed in the reference material for this study to see whether they would be relevant to the investigation. Data from both the western Margin and the central Main Ethiopian Rift have been especially collected for this study since the research region is situated on the western Rift Margin of the central Main Ethiopian Rift.

3.2.2 Remote Sensing and GIS based

In this work, lithology, geological structures, and the distribution of hydrothermal alteration zones are presented and identified predominantly using remote sensing and GIS approaches. Geological research relies heavily on remote sensing techniques as a supplementary means of data collection to field investigations. With the use of these techniques, geological characteristics may be mapped without direct physical contact with the study locations. It is also used to identify geological hazards and for the study of economic geology, which means exploration for minerals, petroleum, and other minerals.

3.2.2 Field work and Geological mapping

Primary data is employed in addition; secondary data from a variety of previously published sources was used in addition to the main data that was gathered for this inquiry. The geological field investigation carried out was aimed at identifying and mapping the various lithology units occurring in the study area, thereby also studying geologic structures, topography, drainage, and other aspects. Fieldwork is the primary method of gathering the primary data. The fieldwork is done from February 4 to February 11, 2023. This fieldwork's main goal is to determine how lithology and geological formations are distributed in both vertical and horizontal dimensions. It also seeks to record the changes in lithological unit-to-unit in terms of colour, texture, mineral content, and degree of weathering. The procedure entails collecting representative samples for additional laboratory investigation with an emphasis on petrographic inspection while traversing through the major lithological formations in order to map and describe the rock units. A geological map of the region is created using ArcGIS software by combining data from GPS readings, pictures, measurements of geological features, and field observations. A geological map that is scaled at 1:25,000 is used to represent the lithology variation and geological features. Following traverses and utilising observable outcrops are used to carry out the geological mapping.

3.2.3 Petrographic Analysis

Depending on the representativeness of the variation, 25 of the collected samples were sent to the Geological Survey of Ethiopia's Central Geological Laboratory for preparation of thin sections, and sample analysis was done in the petrology labs the Earth Science Department at Addis Ababa University. The thin section preparation, such as cutting to an appropriate size of rock, slabing, grinding, mounting, and again grinding and covering, was done at the geological survey of Ethiopia. When choosing the thin section samples, consideration is given to the variety of lithologies, their significance, and how difficult it is to identify them differently in the field. To enable mineralogical and petrographic studies using a polarising microscope, thin slices were made from the obtained materials. This investigation made it possible to identify correlations between fabric, texture, modal proportion, and mineral compositions. It also made it possible to compare the petrographic features of rock samples collected from diverse sites. The other main outcomes of the thin section investigation are the grain-to-grain connections of the phenocrysts, the maximum grain size diameter along each mineral's longest dimension, and the modal fraction of minerals. Last but not least, this information will make it easier to understand how rocks are classified and how they evolve from magma.

3.2.4 Interpreting and presenting petrographic analysis data

Basic duties for this research activity include petrographic analysis, synthesis, and interpretation. Petrological models were used to create the data to provide consistent also significant data to provide the final interpretation. This final report was created using data that was gathered through fieldwork and laboratory analysis, and it also includes text, tables, graphs, figures, and maps. In the paper, volcanic stratigraphy and petrographic findings are described. However, the information regarding the thin-section descriptions and the weather has been displayed in tables. The previously recorded data was used as a source of support for the real task.

CHAPTER FOUR

4. RESULTS: GEOLOGY OF FURI VOLCANIC COMPLEX

4.1 Introduction

In the study area, reasonably good outcrops are found along ridges and escarpments, across road cuts, river cuts, and in quarries. This Furi volcano area in the central part of the Ethiopian Rift, exposes a 700-m-thick volcanic sequence (2100-2800msl).There are three different sections which have been studied in detail. These are: the Gara Bolo section, which is found near the Alemgena town, Daleti section, which is near the Kemele area, and the Gedamba section, which is found on the roads to the Butajira. Exposures have been found at river cuts, road cuts, hillsides and quarry sites. The following are the types of volcanic units found in the research area:

1. Basaltic units
    - 1.1 Aphyric Basalt
    - 1.2 Scoraceous basalt
    - 1.3 Trachytic basalt
2. Felsic units
    - 2.1 Partially Welded rhyolitic Tuff
    - 2.2 Welded rhyolitic Tuff
    - 2.3 Welded Andesitic Tuff
    - 2.4 Welded Trachyte Tuff
    - 2.5 Rhyolite lava
    - 2.6 Trachyte lava
3. Intermediate Rock Unit
    - 3.1 Andesite

The sections that follow will include detail field observations of several locations where petrographic samples were acquired. The presentation will be done in chronological order, going from the oldest to the youngest litho-stratigraphic unit. The stratigraphic arrangement of the rock layers as seen in the field, as well as details gathered from earlier absolute dating data, will be used to define the rock units.

4.2 Geology, Volcanic succession and petrography of study area

The Furi Ridge volcanoes and their varied lithological variations have been carefully studied via extensive field observations and petrographic investigation. Based on their field relationship, thickness, mineralogical compositions, and textural properties, lithological differences were found and categorised. These separate flows and marker contacts were then combined to create the composite volcanic stratigraphy.

The main volcanic units found in this study are aphyric basalt, trachytic basalt, trachyte, andesite; welded andesitic tuff; welded trachyte tuff; basaltic scoria; partially welded rhyolitic tuff; welded rhyolitic tuff; and rhyolite lava.

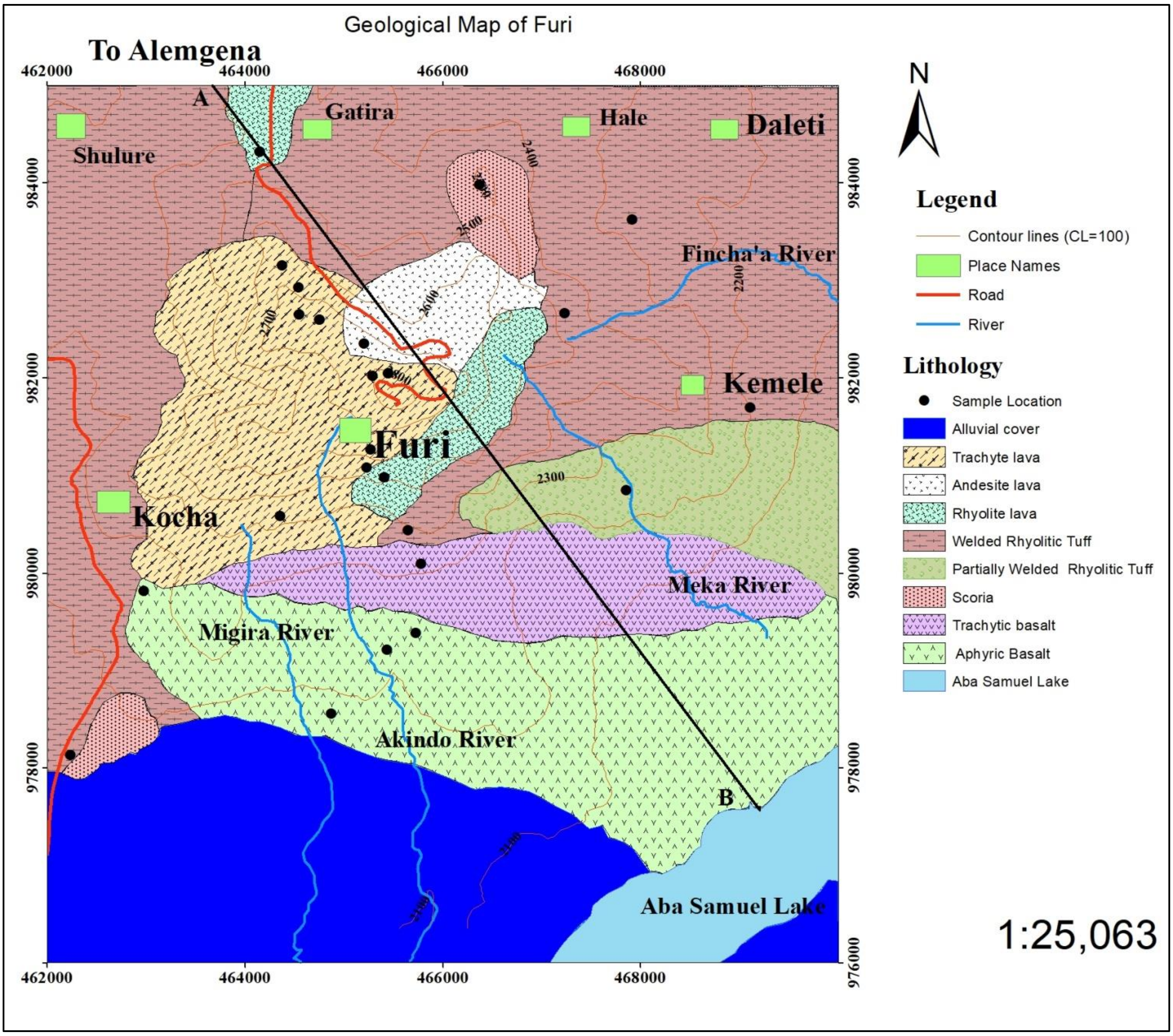


Figure 4.1: Sketch Geological map of the Furi Volcanic Complex

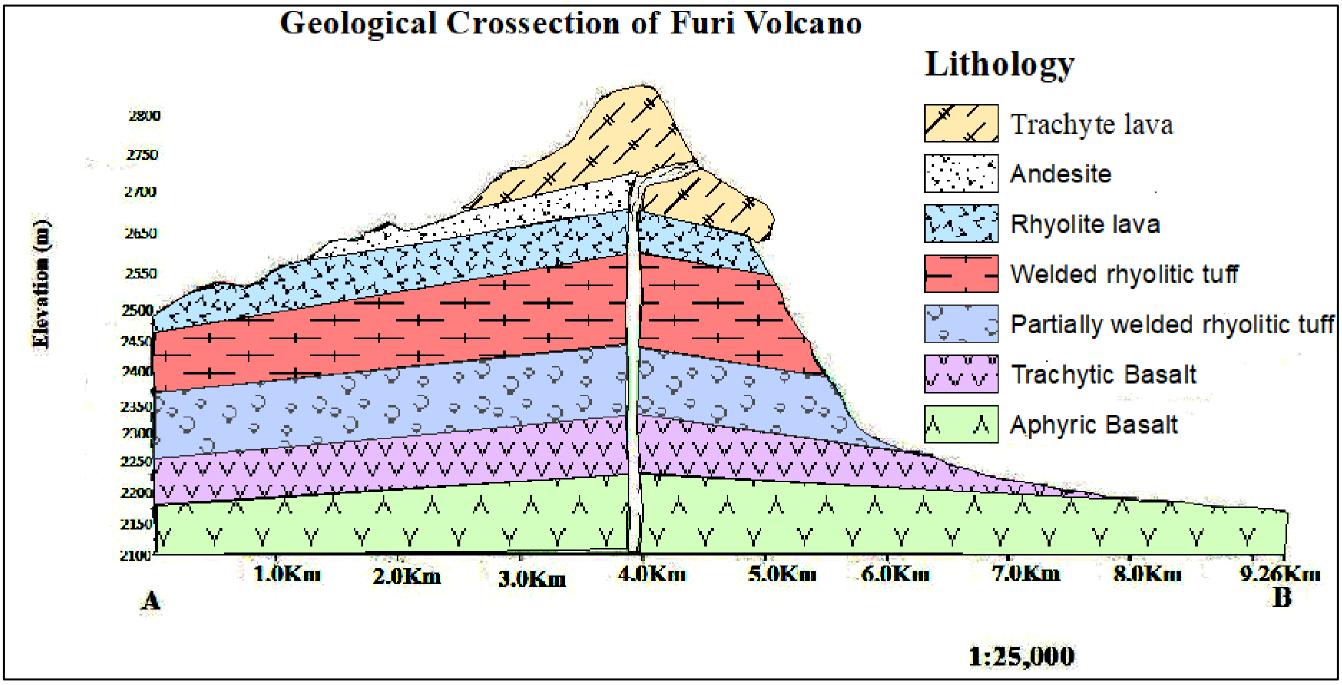


Figure 4.2. Shows a geological cross-section of the selected study area.

The volcanic unit identified in three sections, are as follows:

4.3 Lithology and Petrographic Description of the Furi Volcanic Complex

4.3.1 Alluvial Soil

They are fine-grained deposits that are generally brown-yellowish, very friable, less compacted, and often contain volcanic matrix. This alluvial soil is one of the soils that are exposed at the bottom of the Gara Bolo section and the Gedanba section near the Mesalamia area. This soil is exposed in a very flat area that is used for agricultural purposes. The colour of the soil is black and contains small fragments of rock that are intercalated with this soil. For instance, at the right side of the Mesalamia area at the river of the Migira, the clay soil is intercalated with lithic fragments of the rock, as shown in Figure (4.3).

This alluvial soil is one of the most fertile in the study area but generally lacks nitrogen. The soil has a fine texture and contains a sizable amount of clay, sand, and silt.

The most common crops grown in alluvial soil are teff, wheat, maize, and vegetable.

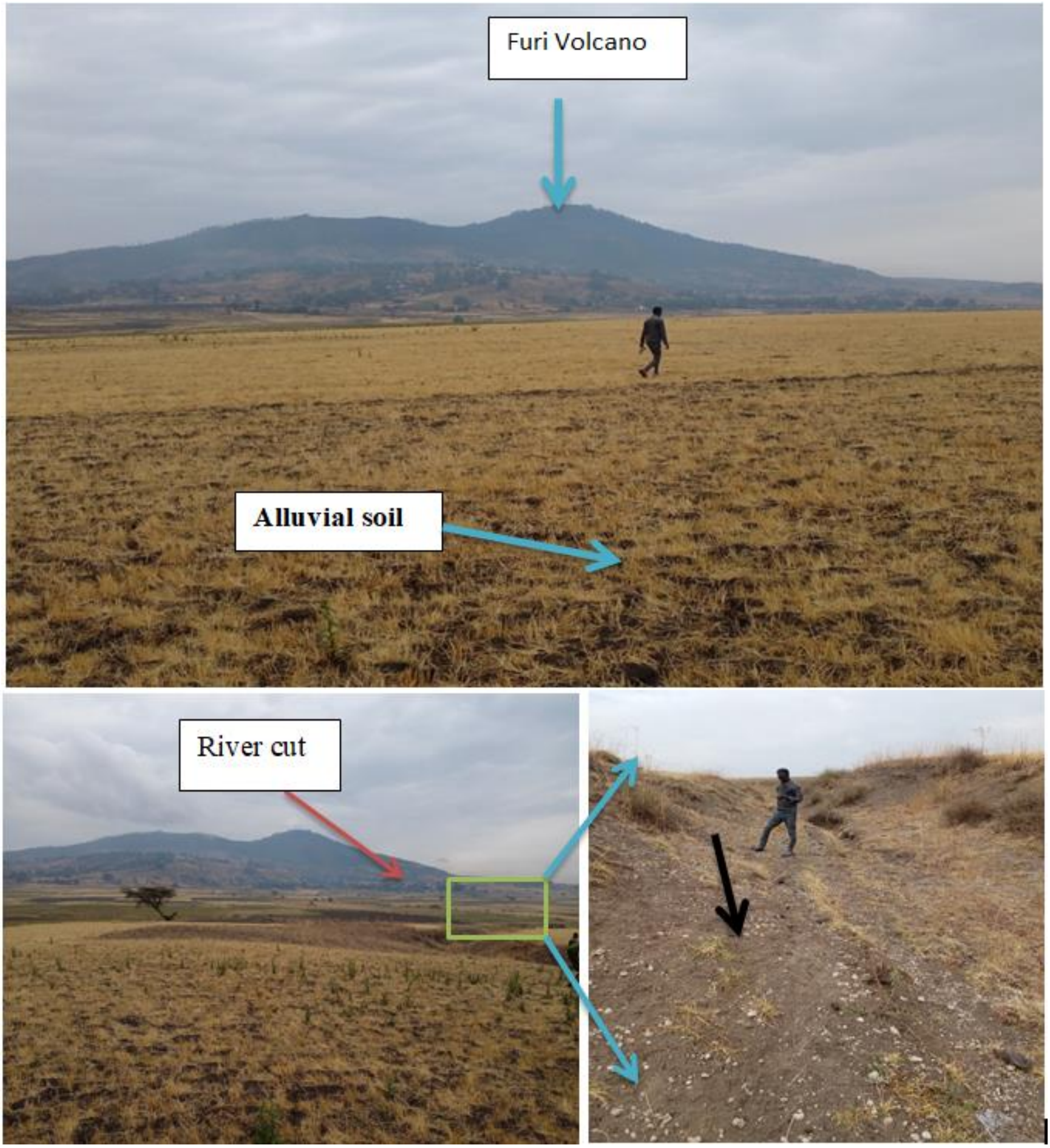


Figure 4:3: Shows A) the alluvial soil on flat area of Gedanba section B) the Clay-soil intercalated with lithic fragments of rock Migira river of Gedanba section.

4.3.2 Basaltic Units

4.3.2.1 Aphyric basalt

This unit is either exposed or visible at a river cut near the Migira area, and in a similar way, it is also visible on the study area's hillside with a different character. It is characterised by being fine-grained, having a degree of weathering from weathered to fresh, having an aphanitic texture, and also containing vesicles on some basalt. The basalt (Figure 4.4 A) exposed at River Cut is fresh and black in colour, porphyritic in texture, and contains minerals like olivine, plagioclase feldspars, and pyroxene in small proportions. The basalt in Figure 4.4 B is exposed on the hillside of Gedanba section. The black colour of basalt comes from high levels of magnesium oxide in the rock and in the magma from which basalt is made.

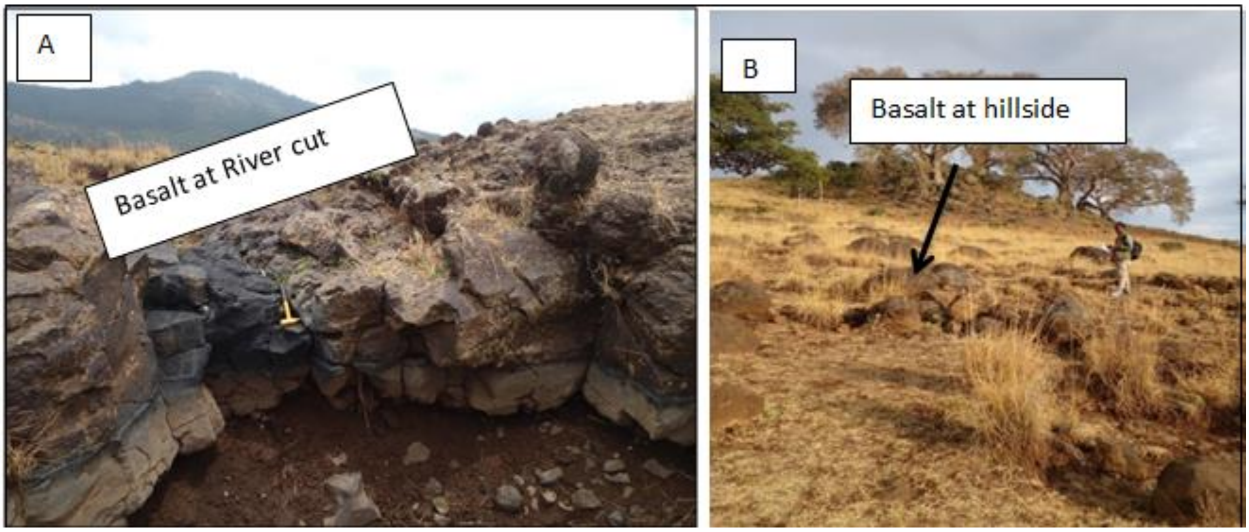


Figure 4.4: shows A) Basalt exposed at River cut B) Basalt exposed at hill side area

Basalt is the most common type of volcanic rock found in the Daleti section. This basalt is also exposed at the road cut. This unit exposed near to Gara Bolo area and degree of weathering is weathered in small part. On this basalt, different geological structures like fractures and other structures are found. The Basaltic rock unit that is situated nearby Gara Bolo Woreda Administration demonstrates the following characteristics: having a light-grey colour, a porphyritic texture, and having a vesicular appearance, and contains minerals such as olivine, plagioclase, and other minerals. This is shown on basalt in Figure 4.5.

Figure 4.5: Shows the Basalt exposed at road cut at Daleti section

Four samples are prepared for petrographic analysis. The sample with code of GS-6, GS-4, GS-7 and GS-15 shows all the characteristics of the basalt with different composition of modal proportion of minerals like olivine, pyroxene, plagioclase and other accessory minerals. All basalts are fine-grained, containing essential plagioclase and pyroxene. Quartz, hornblende, biotite, orthopyroxene, and feldspathoids may be present as accessory minerals. This rock unit is exposed at the river cut, road cut and the hillside of the Gedamba and Daleti section.

The basalt with code of **GS-6** contains phenocrysts of olivine, plagioclase feldspars, and pyroxene with plagioclase in the plagioclase matrix, opaque grains, and glass. The minerals found in the rock shows different shape like for instance olivine shows subhedral to anhedral, plagioclase shows the subhedral and with groundmass of which shows the subhedral to anhedral shape. The modal proportion of the minerals are plagioclase 55% with groundmass of plagioclase, olivine 32%, others minerals like biotite and opaque contain 12%. In phenocryts phase the maximum grain size of plagioclase is (2.6mm), olivine with (1.4mm). The groundmass is fine-grained and has a trachytic or felty texture. This basalt shows that there is dominance of plagioclase feldspars with medium in dominance of olivine which shows the rock is called as **Plagioclase-Olivine-phyric basalt** shown on figure.

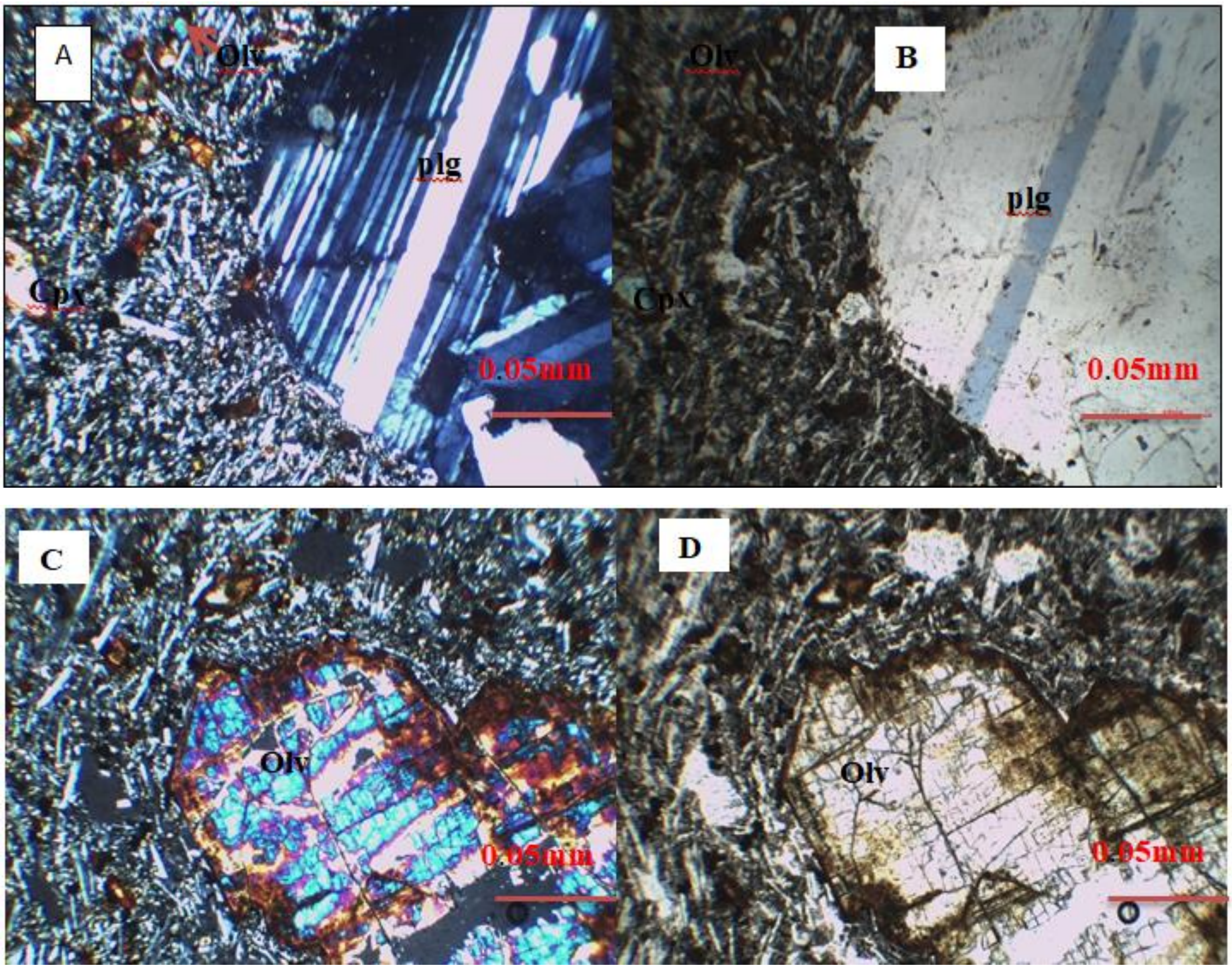


Figure 4.6. Micro-photo picture of Plagioclase-Olivine-phyric basalt sample; GS-6 under optical microscope in XPL (A, C) and PPL (B, D) view. The labels stand for Plg-plagioclase. The photos were taken at 5X magnification.

The other basalt with codes of GS-7 and GS-15 shows different characteristics and contains different minerals like olivine, pyroxene and plagioclase. For example, the sample with code of **GS-7 and GS-15** contains minerals like plagioclase feldspars, Alkali feldspars, pyroxene, biotite and olivine. The minerals show the different grain shape like plagioclase subhedral to euhedral shape, pyroxene shows the subhedral and olivine shows the anhedral and others minerals show the anhedral. Olivine is fresh, iddingsitized, (Fig. 4.7 C and E) or partly or wholly altered. Some parts of the sample show the Intergranular texture in which small discrete of pyroxene and olivine fill the interstices of plagioclase (Fig.4:7 E and F).

The modal proportions of mineral found in this rock unit are plagioclase feldspars phenocrysts with 45%, Clinopyroxene 20%, olivine 15% and 20% with fine grained groundmass of plagioclase, olivine and other minerals like biotite, opaque minerals. From the modal proportion and the characters of minerals from the petrographic analysis the rock name is **plagioclase -Clinopyroxene - Olivine phyric Basalt**.

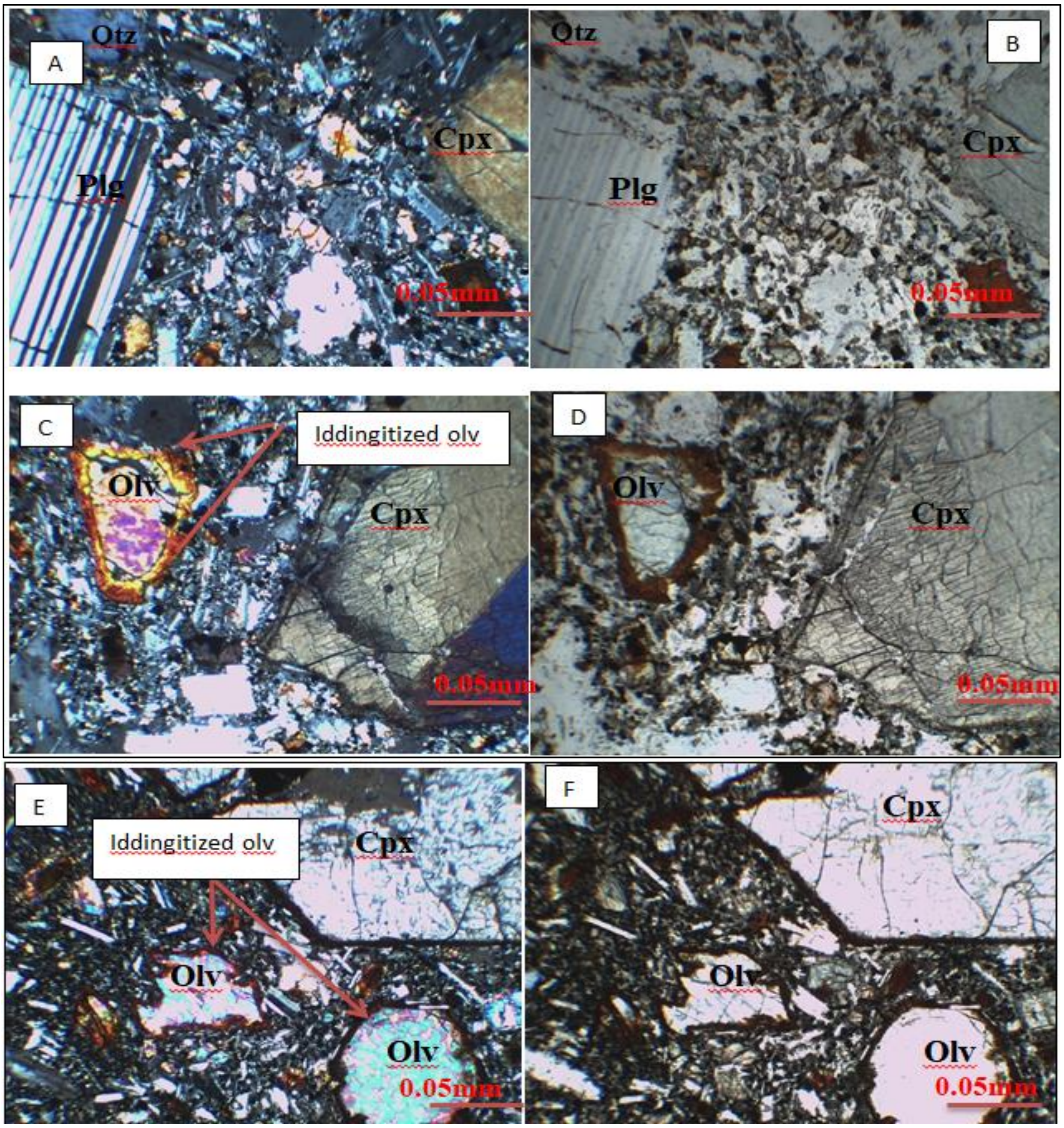


Figure 4.7: Micro-photo of plagioclase - Clinopyroxene - Olivine basalt; GS7 (A, B, C and D) and GS-15 (E and F) under optical microscope in XPL (A, C, and E) and PPL (B, D and F) view. The labels stand for Plg-plagioclase, Alkali fld- Alkali feldspars, Olv-Olivine, Cpx-Clinopyroxene. The photo is taken at 5x magnification.

4.3.2.2 Scoraceous Basalt

Scoria is highly vesicular basaltic lava with tiny (<1mm) vesicles. The red form of scoria is present in the study area. The basaltic lava is initially black, but iron oxidation during an eruption and the positioning of the scoria convert it to red. The rock is primarily exposed on cliff-like outcrop. Quarry-type exposures are also noted as a result of excavation activities for the production of raw materials for cement factories and aggregates for gravel roads in neighbouring regions. This scoria cone is found at the bottom of the Furi ridge in the SW western part.

An example of a quarry-like outcrop that is typical is on the bottom part of Furi, which contains a scoria cone (Fig. 4.8 (A)) that exposed a 100-metre thick scoria deposit stacked vertically. Limonitization alteration, which is the transformation of a mineral or rock into limonite, typically occurs on scoria and is characterised by weathering with a yellowish hue.

Figure 4.8: shows A) Scoria cone which is found at bottom of furi SW B) Limonitization alteration on scoria cone.

The other scoria is called as basaltic scoria which is exposed at Gedamba section near to kocha area which is overlain by partially welded rhyolitic tuff. Scoria and cinders also usually have basaltic compositions. This quarry site is found near to Kocha area at Southern part of the Alemgena town. The scoria which is found at figure 4.9 A) exposed at quarry site and show that it is reddish colour and overlain by tuff. The scoria which is shown on Figure 4.9B) exposed at quarry site near to Kocha and called scoriaceous basalt. The colour of this scoriaceous basalt is dark when compared to scoria which is found at figure 4.9 A).

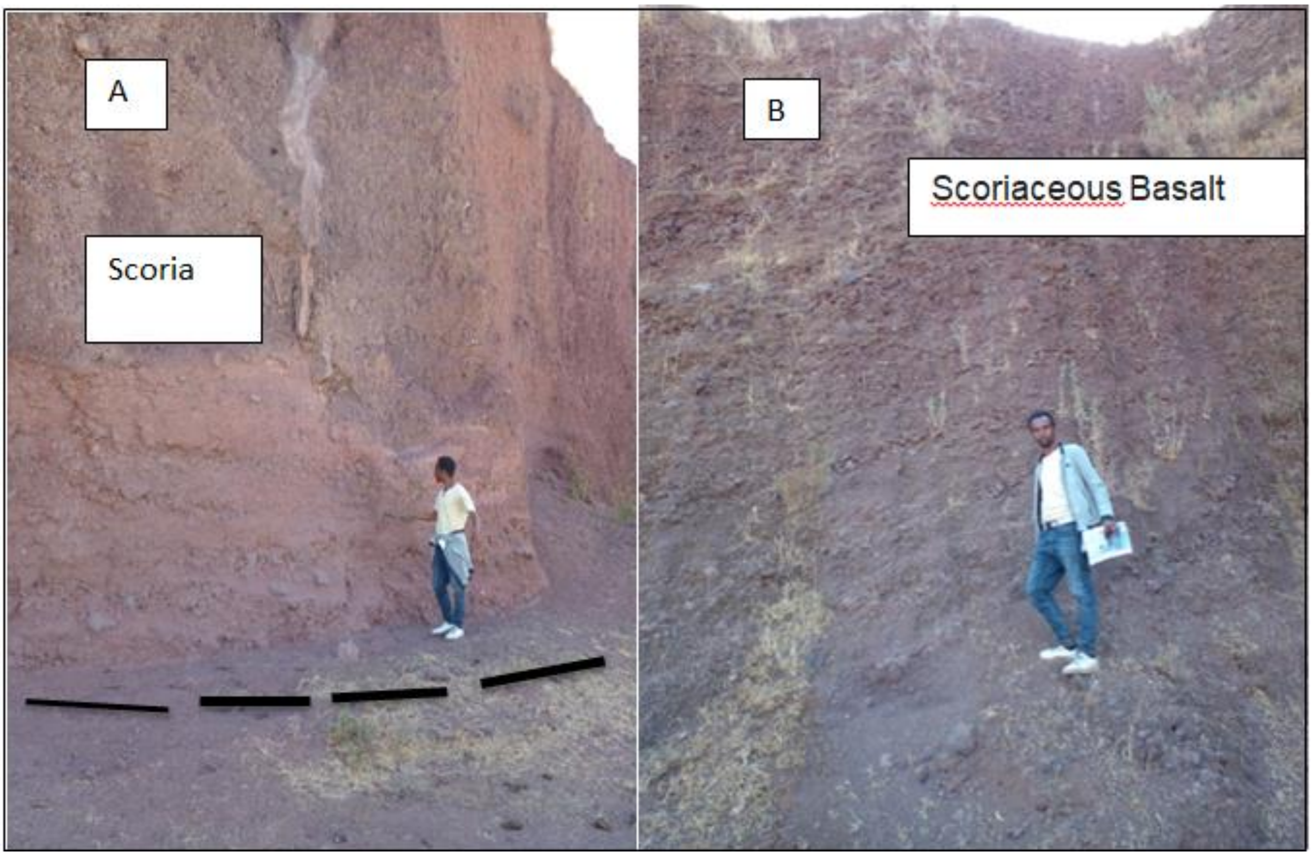


Figure 4.9: Shows A) scoria which is exposed at quarry site at kocha area B) Scoriaceous Scoria exposed at quarry site near to kocha area.

4.3.2.3 Trachytic basalt

The Trachytic basalt that is exposed at the hill site of the Gara Bolo section is characterised by porphyritic, plagioclase-rich rock having vesicles filled with secondary minerals. It is light grey, and it is fine-medium grained minerals. This component has several tiny holes or vesicles as they are more formally termed, similar to vesicular basalt. Figure 4.10 A) shows Trachytic basalt exposed at the hill site of Furi Ridge and B) Shows Trachytic basalt exposed at the top part of Furi Ridge.

The hillside of the section, near the base of the Furi ridge, is where the other lithologic unit known as trachytic basalt is exposed. This unit exhibits a coarse-grained texture and is distinguished by a variety of compositions, including quartz, feldspar, and pyroxene. Figures 4.10 C and D show the trachytic basalt at the Gedamba section with different characteristics.

Figure 4.10: Shows A) Trachytic basalt exposed at the hillside of Furi Ridge B) Trachytic basalt; C) The trachytic basalt lava exposed at the dome; and D) Trachytic basalt at the hillside exposed at the top of Furi**.**

Three samples of Trachytic basalt with the sample code are (FS5), (FS62) and (FS72) prepared for petrographic analysis. The samples are taken from different places at Gara bolo at the bottom of Furi section. This unit is a volcanic rock that is composed of basalt with trachytic texture. Despite having a high concentration of alkali metal oxides, it has the appearance of basalt. Alkali feldspar, calcic plagioclase, olivine, clinopyroxene, and other groundmass are among the minerals found in this unit. This trachytic basalt unit are exposed at hillside with light grey colour. The rock show trachyte texture or the flow texture, which is the consequence of lava flowing on the surface of the Earth, is characterised by a groundmass made up of aligned microlites that point in the direction of flow.

The sample with code of (**FS5**) shows the following characters which is exposed at hillside at Gara Bolo section. The modal proportion of minerals found in the rocks are 65% plagioclase, 10% olivine, 5% biotite, 5% Alkali feldspar and there is also small amount of clinopyroxene 15% are constituted with total of 81% Phenocryts (Fig: 4.11). The minerals found in the rock show different types of twinning for example plagioclase feldspar show polysynthetic twinning, Alkali feldspar show the Carlsbad twinning and the others minerals show different colours with different shape. For instance, an opaque mineral shows anhedral shape with black colour under XPL and PPL, plagioclase feldspar subhedral shape with light grey under the PPL petrographic microscope, the olivine minerals show the greenish colour with anhedral shape and the other mineral like clinopyroxene shows the subhedral to anhedral shape with brown colour. Sometimes, it displays the intergranular groundmass texture. But, Plagioclase feldspar is the distinctive component of the volcanic rock unit, which has a trachytic texture overall. From the mineral composition and different character on the rock the rock name is **Plg-Cpx-Olv phyric Trachytic basalt**.

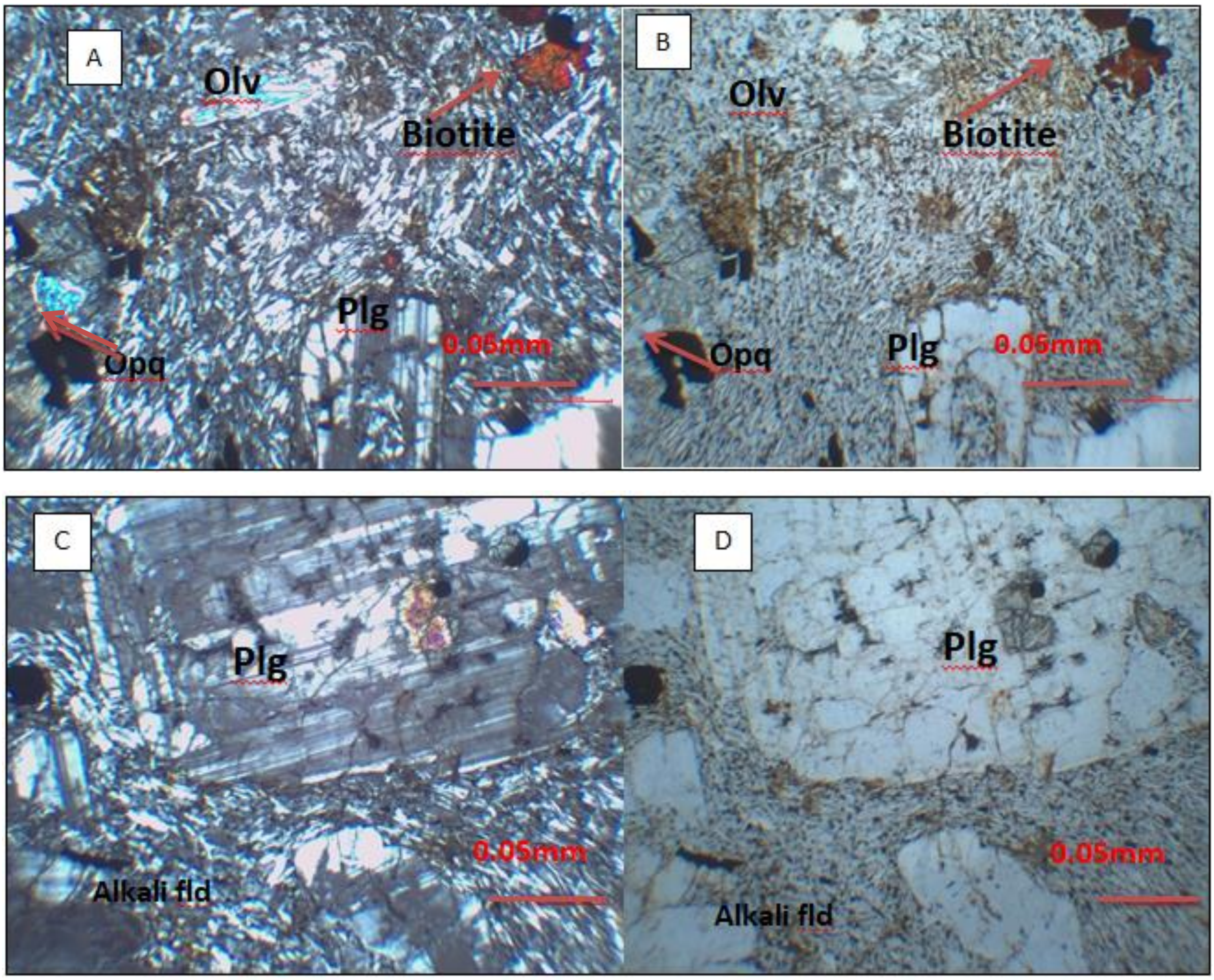


Figure 4.11: Micro photo picture of plagioclase, Alkali feldspar, opaque and olivine in Trachytic basalt (FS5); XPL (A and C) and PPL (B and D) view at 5XMagnification. Plg- plagioclase, Alkali fld- Alkali feldspar, Opq- opaque and Olv- olivine.

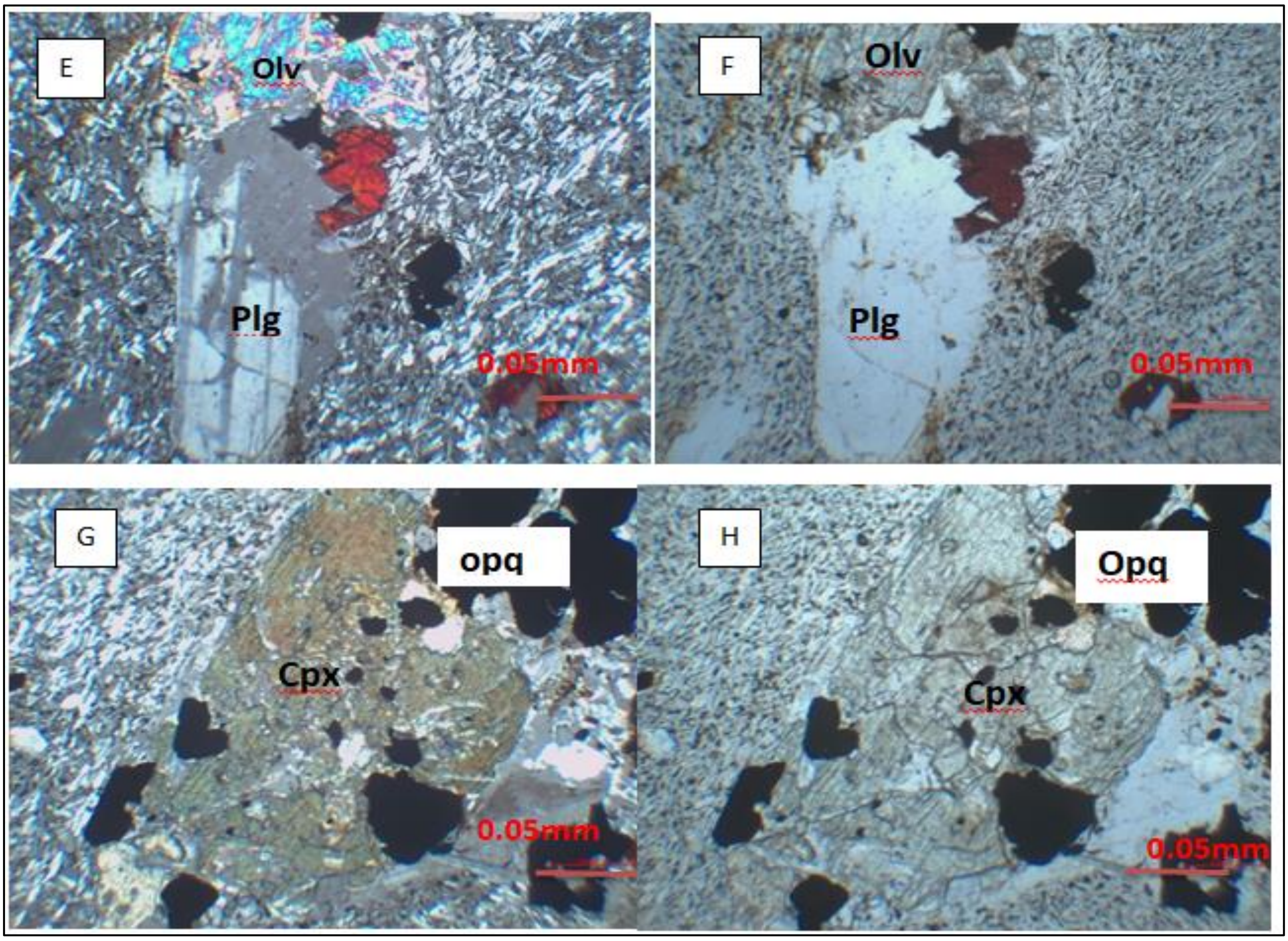


Figure 4.12: Micro photo pictures of Clinopyroxene, olivine, plagioclase and opaque in Trachytic basalt (FS5); XPL (E) and (G) and PPL (F) and (H) view at 5X magnification. Cpx- Clinopyroxene, Plg- plagioclase, Opq- opaque, Olv-olivine

On the sample code (**FS62**) there is different minerals that show different characters such as plagioclase feldspar, Alkali feldspar, Sanidine, Biotite, and Olivine, Clinopyroxene and Microcline feldspars. The plagioclase feldspar show polysynthetic twinning, Sanidine implies that distinguish by its tabular crystals, simple twin. The rock unit shows the trachytic texture (containing of feldspars microlites aligned due to flow) with the Sanidine as phenocryts (Fig.4.13A).

The phenocyts of plagioclase feldspars, Alkali feldspars and Olivine occur clustered together which shows the Cumulophyric texture (Fig.4.13C). Plagioclase feldspars with lamellar twinning and the other mineral like biotite, olivine and pyroxene show yellowish, greenish and yellowish respectively. The rock thin sections show porphyritic textures with a low volumetric percentage (50% to 60%) of Phenocryts and it shows the Glomeroporphyritic texture (porphyritic texture in which phenocryts like Alkali feldspars, clinopyroxene and plagioclase are clustered together (see Fig.4.13E).

The phenocrysts are 10% sanidine, 5% opaque and 7% alkali feldspar, Olivine 10%, Clinopyroxene 5%, plagioclase feldspar 23% and With respect to modal proportion, the groundmass has the highest value (30-40%) and consisting of Directivity microlites found in the groundmass suggest flowing. From the mineral composition and characteristics of different minerals on thin section the rock type is **Plg-olv-sanidine-phyric Trachytic basalt**.

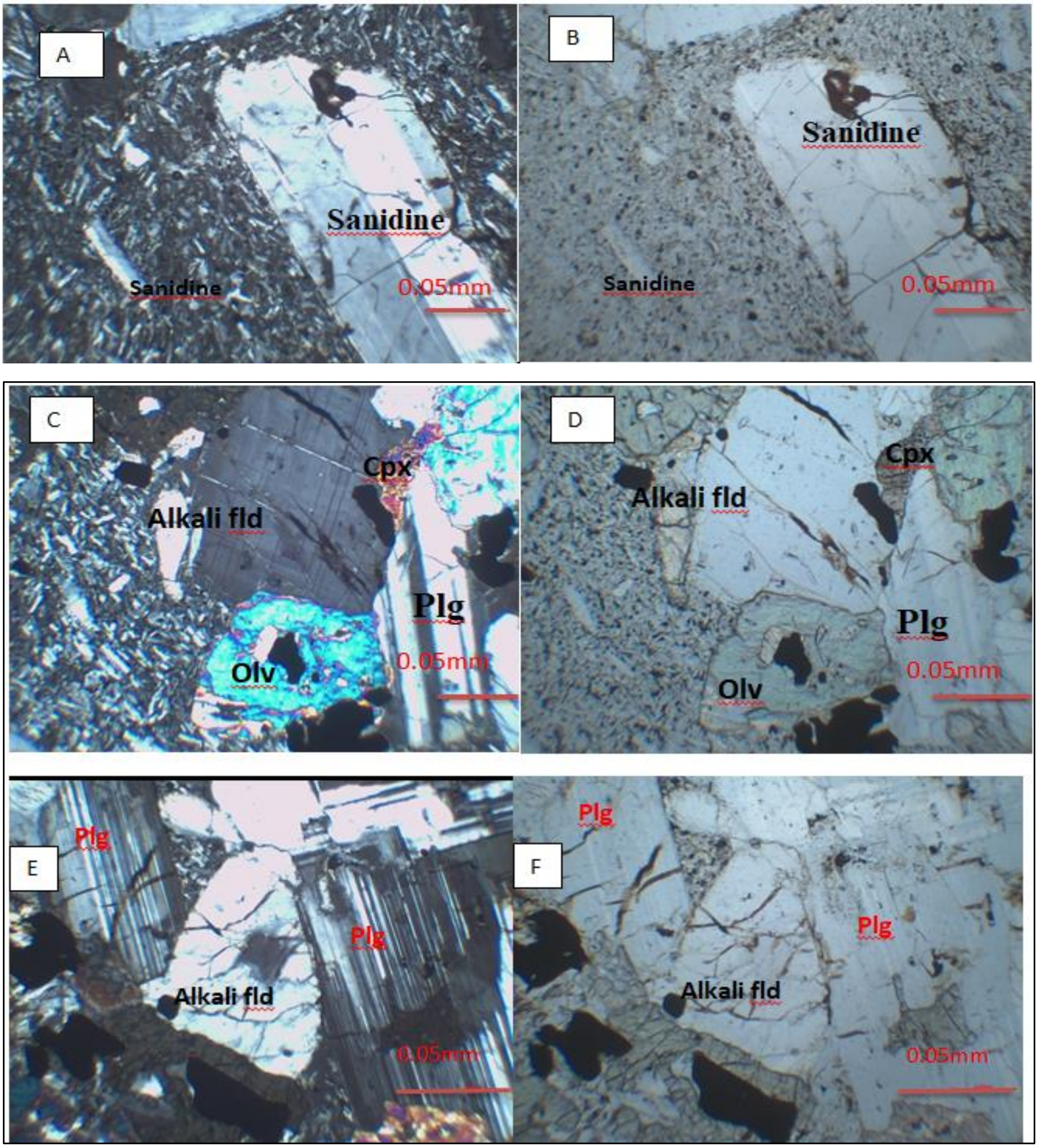


Figure 4.13: Micro photo picture of Plagioclase feldspar, olivine, Sanidine and opaque in Trachytic basalt (FS62); XPL (A), (B) and (E) and PPL (C), (D) and (D) view at 5X magnification. Cpx- Clinopyroxene, Plg-plagioclase, Opq- opaque, Olv-olivine, Plg-plagioclase with lamellar twinning.

4.3.3 Felsic Rock Units

4.3.3.1 Partially Welded and Welded Rhyolitic tuff

This unit covers most located at the research area's lowest point of the Gara Bolo then near the top of the Furi Ridge. Several flattened juvenile clasts, many of which were formerly pumice, are found in a tuff, which is a pyroclastic rock that has been welded together. The lowest part of the Gara Bolo section exposes a tuff rock unit with slightly distinct features. The grey rock has pieces of rock and fiamme inside of it. The Tuff that is found in the Gara Bolo section contains welded and partially welded rhyolitic tuff. The first tuff that dominates the hillside of the area is welded rhyolitic tuff. A black lens structure known as a fiamme can be seen on rock surfaces where the pumice lapilli have usually flattened. The fiamme is light grey to black in colour. Such deposits usually have vesicular, low-density rock at their peaks, but as one descends, the weight of the material above crushes the pyroclastic rock to produce thick, non-vesicular rock. The weight of the material above determines the degree of welding. So, the welded rhyolitic tuff that is found at the bottom of the Gara Bolo section is overlain by weathered tuff, and it has slightly decomposed and changed to soil. This welded rhyolitic tuff contains volcanic glass, crystal, brownish lithic, and pumice fragments.

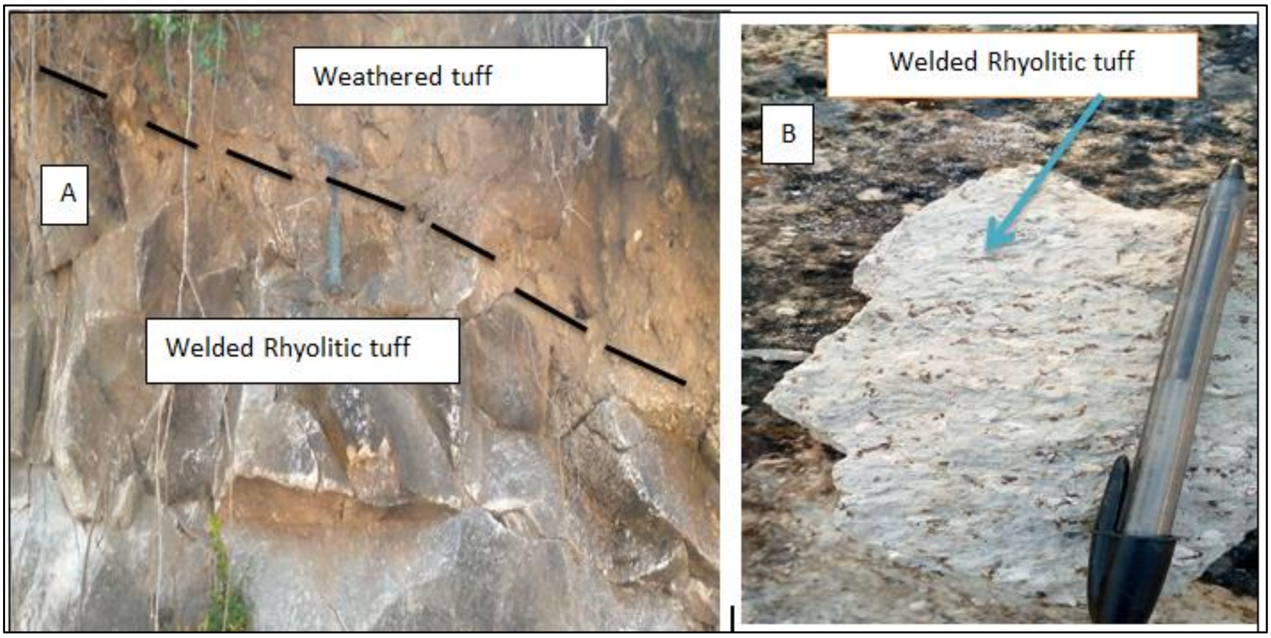


Figure 4.14 shows the welded rhyolitic tuff at the location of the bottom Gara Bolo section.

The second tuff which is found at the bottom Gara Bolo section is partially welded rhyolitic tuff. When a tuff deposit is sufficiently hot, the particles may weld together, turning it into a "welded tuff. This partially welded rhyolitic tuff is exposed at the road-cut bottom of the Gara Bolo section. Conversely, welded rhyolitic tuff flows are typically dark grey to black, while less frequently welded flows tend to be white or grey. Thick soil is layered atop partially welded rhyolitic tuff. Under this thick soil, there is welded rhyolitic tuff, which is extended to the foot of the furi ridge. Less welded rhyolitic tuff crystal, brownish lithic, pumice fragment, and the pumice content are poor.

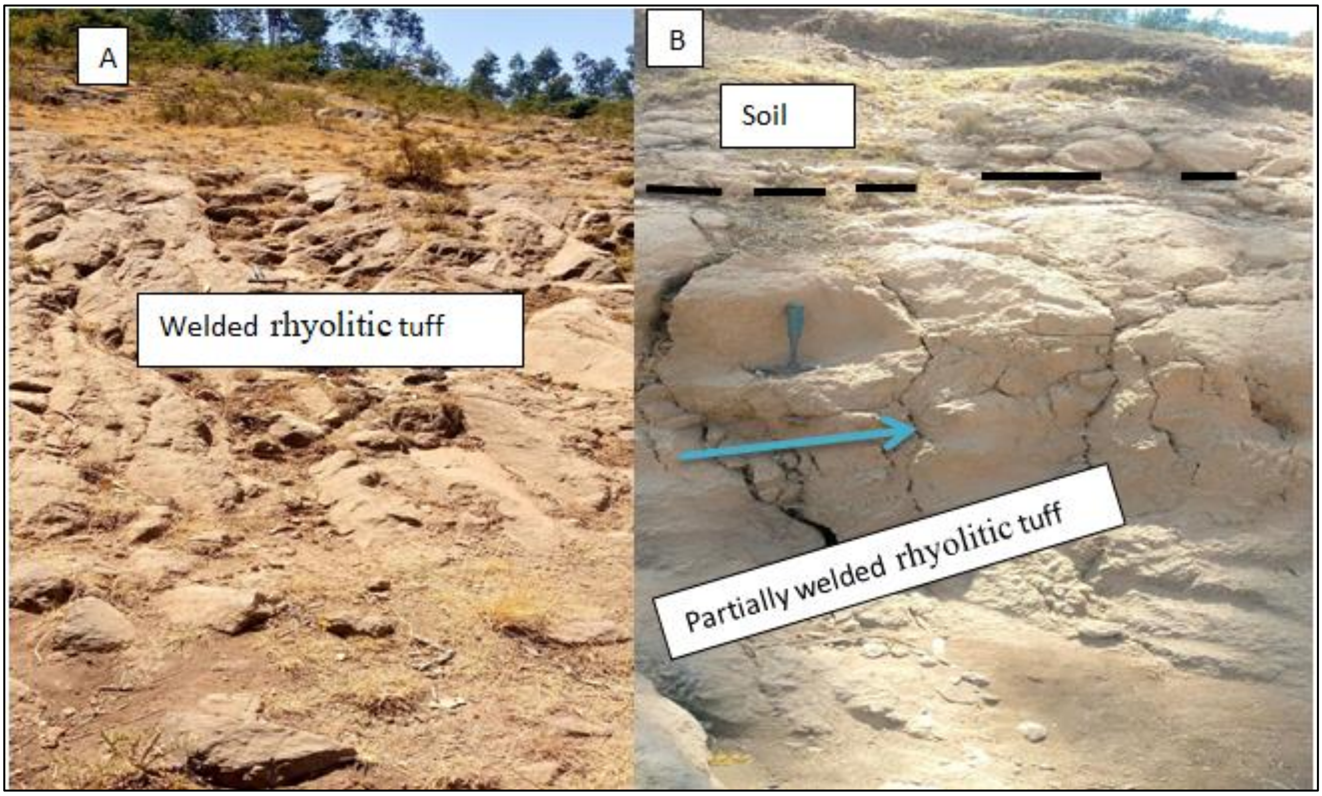


Figure 4.15: shows A) Welded rhyolitic tuff at upper part of partially welded rhyolitic tuff B) Partially welded rhyolitic tuff contain top part soil which underain the welded rhyolitic tuff.

There are more units with varied characteristics that are revealed at the Daleti section and are only partially welded to welded rhyolitic tuff. It is distinguished by the colour known as light grey and by the texture or grain size that ranges from fine to coarse. This unit is on display at the Daleti section quarry site, close to the Addis Ababa to Djibouti road. Other geological features of this lithologic unit include joints and fractures. Additionally, this partially welded rhyolitic tuff contains more lithic fragments and has a texture that ranges from medium to coarse. The lithic fragments range in size from 2-4 cm. There is welded rhyolitic tuff that is exposed at the quarry site of the Daleti section. This rock unit is light grey in colour. It is one type of tuff, and it is pyroclastic rock that is exposed at the quarry site of the Daleti section and underlain by partially welded rhyolitic tuff. It contains the lithic fragment and light grey pumice fragments in white ash.

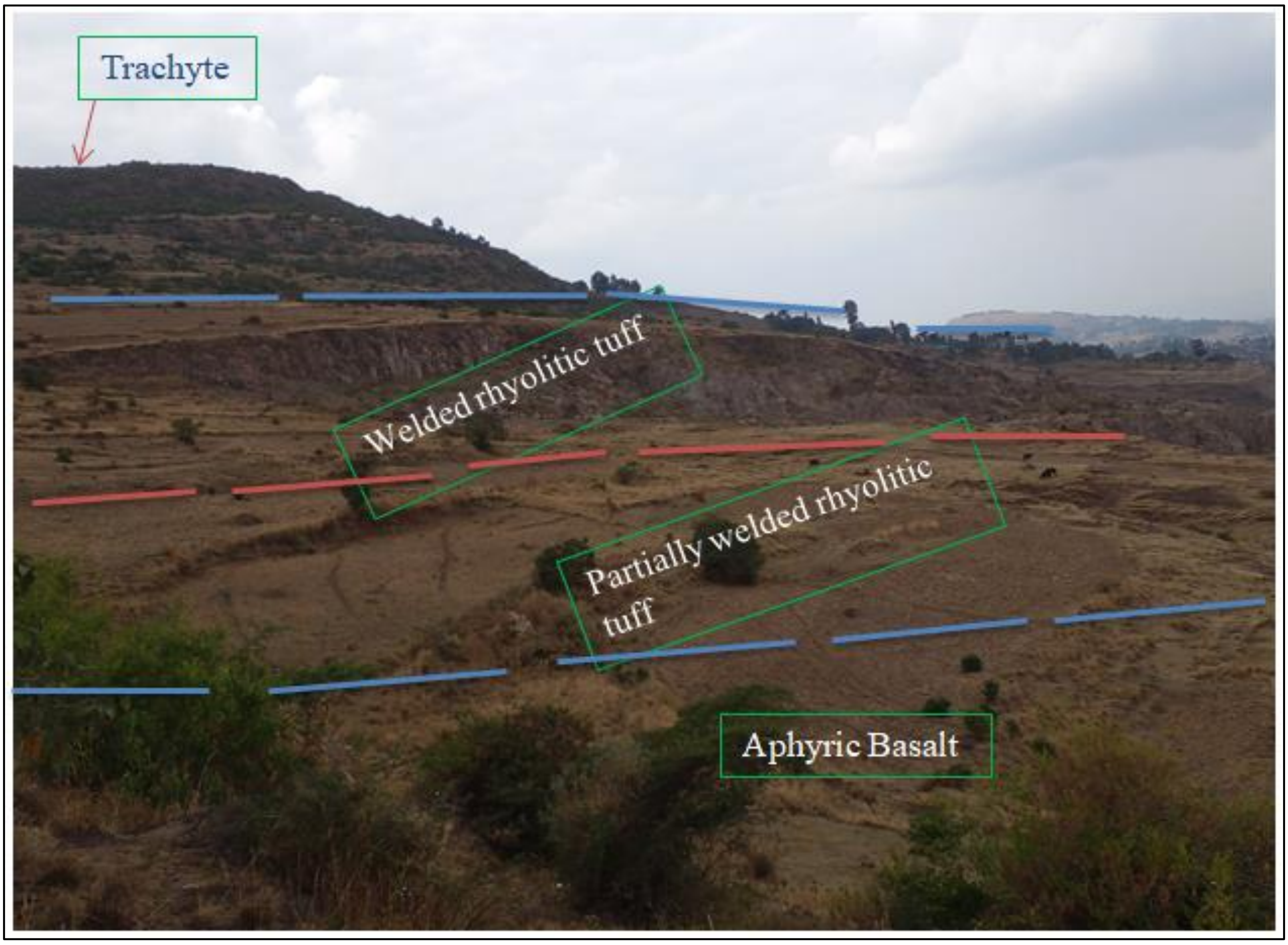


Figure 4:16: Shows the partially welded to welded rhyolitic tuff exposed at Quarry site of Daleti section

One sample of partially welded rhyolitic tuff with sample code **FS4** is prepared for petrographic analysis. The main minerals identified in the partially welded rhyolitic tuff and its associated pyroclastic are small amount of plagioclase feldspar and quartz, pumice fragments, biotite and the other dominant one glassy groundmass (Fig. 4.17).

The rock sample is represented as **FS4** on the field and exhibits a Eutaxitic texture, which denotes that it is employed for the parallel alignment of pumice particles in partially welded rhyolitic tuff, which are pyroclastic rocks. Alkali feldspar has subhedral crystals that are different from quartz, which has dominant anhedral crystals. Each phenocryst had a maximum length for the longest length of grain measurement that was 0.35 mm alkali feldspar and 1.94 mm quartz.

The phenocryts' modal composition, which is about 77%, is composed of 27% quartz, 2% opaque, 25% alkali feldspar, 20% plagioclase feldspars and 3% biotite and 23% as groundmass. We can infer that the rock is **Qtz-Akf-Plg- Phyric partially welded rhyolitic tuff** based on the modal percentage distribution of phenocrysts.

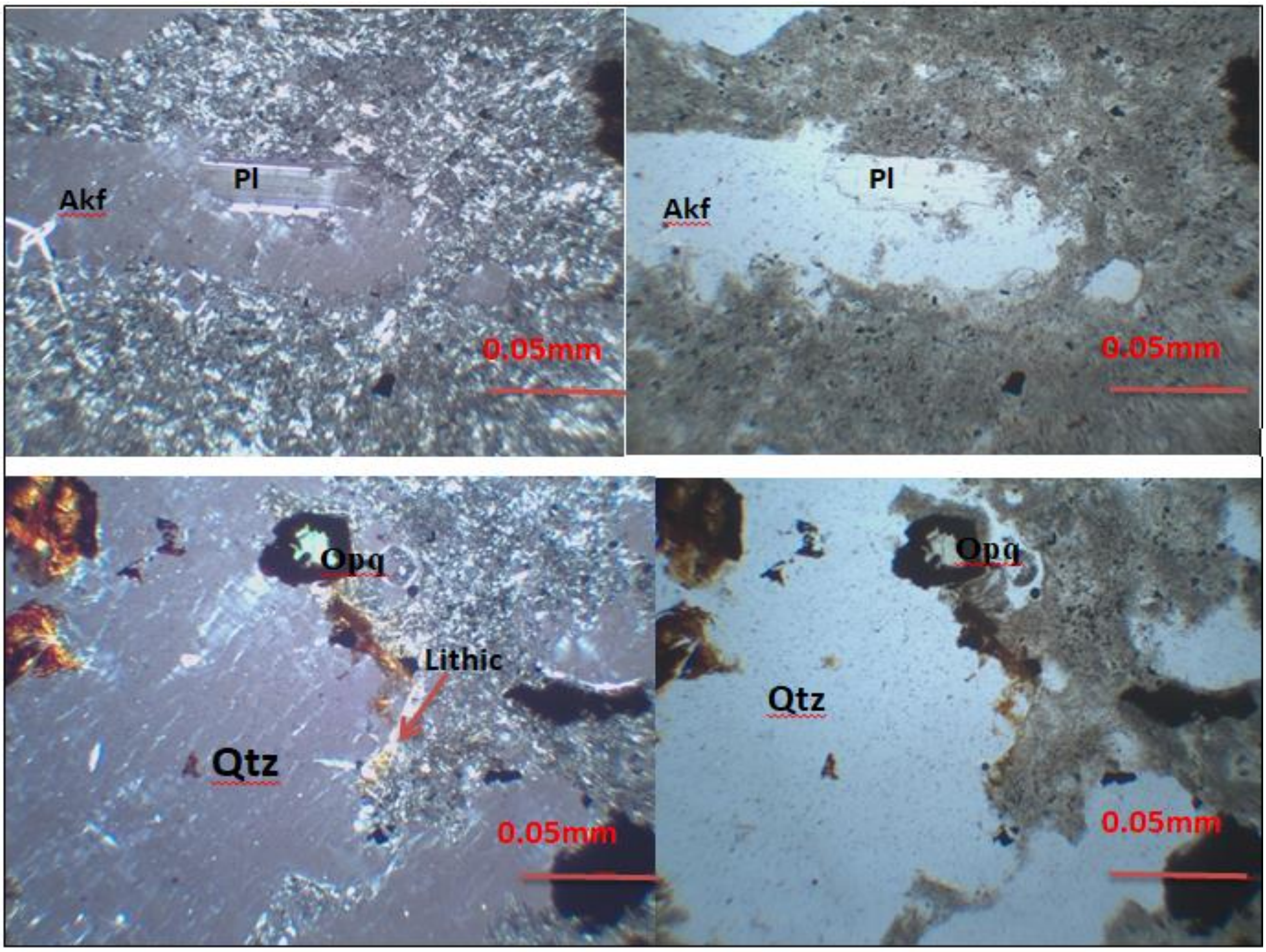


Figure 4.17: A microphotograph of a partially welded rhyolitic tuff (FS4) taken in the XPL (A) and PPL (B) perspectives at a 5X Magnifications. The terms are phenocrysts (Qtz-quartz Akf-Alkali feldspars, Opq-opaque and), lithic-lithic fragment, Pl-plagioclase and microcrystalline groundmass.

Four Samples (FS1B, FS71, DS10 and DS11) of Welded rhyolitic tuff are prepared for petrographic analysis. Ash flows are widely deposited and then solidified to create tuff. The welded rhyolitic tuff, an exposed rock unit with somewhat differing properties, is located in the bottom part of the Gara Bolo region; among the partially welded rhyolitic tuff and weathered trachyte at top part of Furi Ridge. Exposure of this kind is a hillside which is primarily made of this rock unit underneath by partially welded rhyolitic tuff. The rock sample is represented on the field and exhibits a Eutaxitic texture, which denotes that it is employed for the parallel alignment of pumice particles in welded rhyolitic tuff. The sample code is shown by **FS1B**, which contains different minerals. The modal proportions of this unit are Alkali feldspar 30%, biotite 5%, and quartz 20%, opaque 2% and generally it contains 57% phenocyts. This flow unit contains microphenocrysts of Qtz with subhedral to anhedral shape and subhedral to anhedral phenocrysts of alkali feldspar, as seen through thin section observation. With an estimated 1% prevalence of opaque phenocrysts, this form makes them easily visible. In this flow, glassy groundmass occurs in greater proportions. From the Modal proportion the rock name is **Qtz- Akf-Phyric Welded rhyolitic tuff.**

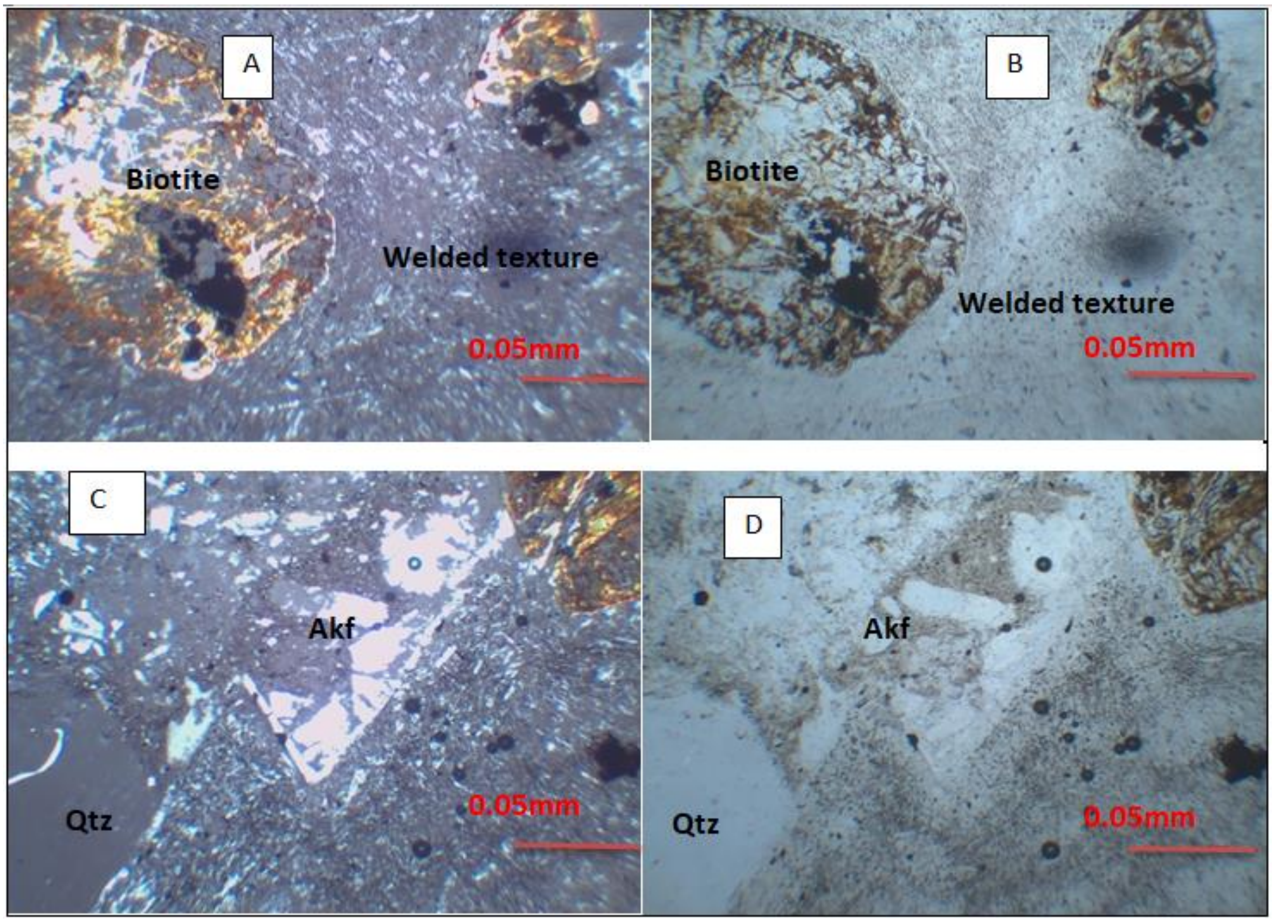


Figure 4.18. Micro-photo of Welded rhyolitic tuff under XPL (A and C), PPL (B and D) view, respectively. This photos were taken with a 5x Magnification.

The other welded rhyolitic tuff rock unit is exposed at Daleti section at bottom of Furi Volcano. It is exposed at road cut and it is light grey in colour. The sample has field code with **DS-11** which contains different minerals like pyroxene, quartz, plagioclase feldspars, Alkali feldspars and opaque minerals with different characteristics. Those minerals like pyroxene shows subhedral in form and the interference colour change from the yellow to dark grey, Alkali feldspars with anhedral in shape, plagioclase feldspars with subhedral to anhedral in form and opaque minerals form the anhedral in shape.

The modal percentage of the rock unit's minerals are plagioclase feldspars with 20%, Alkali feldspars with 17%, opaque minerals with 3%, pyroxene with 7% and others as fine grained groundmass of plagioclase and other mineral are found. From these the rock name is **Plg-Akf-Cpx-Phyric welded rhyolitic tuff**.

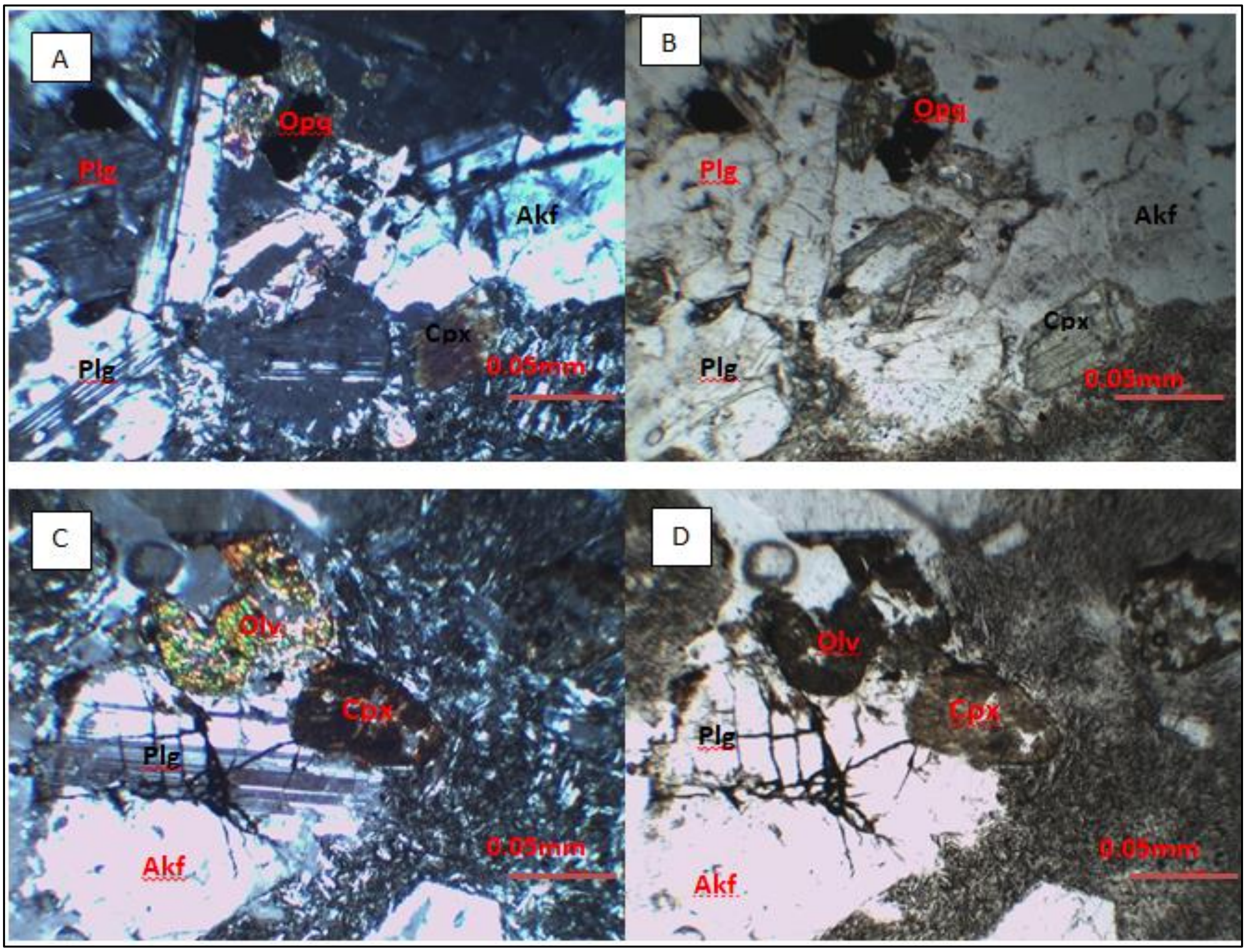


Figure 4.19: Micro-photo of Welded Rhyolitic tuff under XPL (A and C) and PPL (B and D) view respectively. This photos were taken with a 5x Magnification.

The exposure of this rock unit is at the Quarry site of the Daleti section of the research area. The field observation sample code is **DS-10** which shows different characteristics and contains different mineral compositions. The different minerals like plagioclase, Alkali feldspars, and biotite with one set of cleavage, plagioclase feldspars as microphenocryts, and groundmass, Plagioclase shows polysthetic twinning and is subhedral in crystal form; quartz is anhedral in form and radiating in texture. It shows also the trachytic texture. Alkali feldspars are subhedral in shape and biotite crystals that range from subhedral to anhedral.

The modal proportion of the rock unit Plagioclase feldspars with 15%, Quartz with 20%, Pyroxene with 10 %, Alkali feldspars with 30% and others with Microphenocrysts of plagioclase 15%, and other Groundmass of Olivine, biotite and pyroxene are found with 2%. From the Modal proportion the name of the rock is **Akf-Qtz-Plg-Cpx-Phyric Welded rhyolitic tuff.**

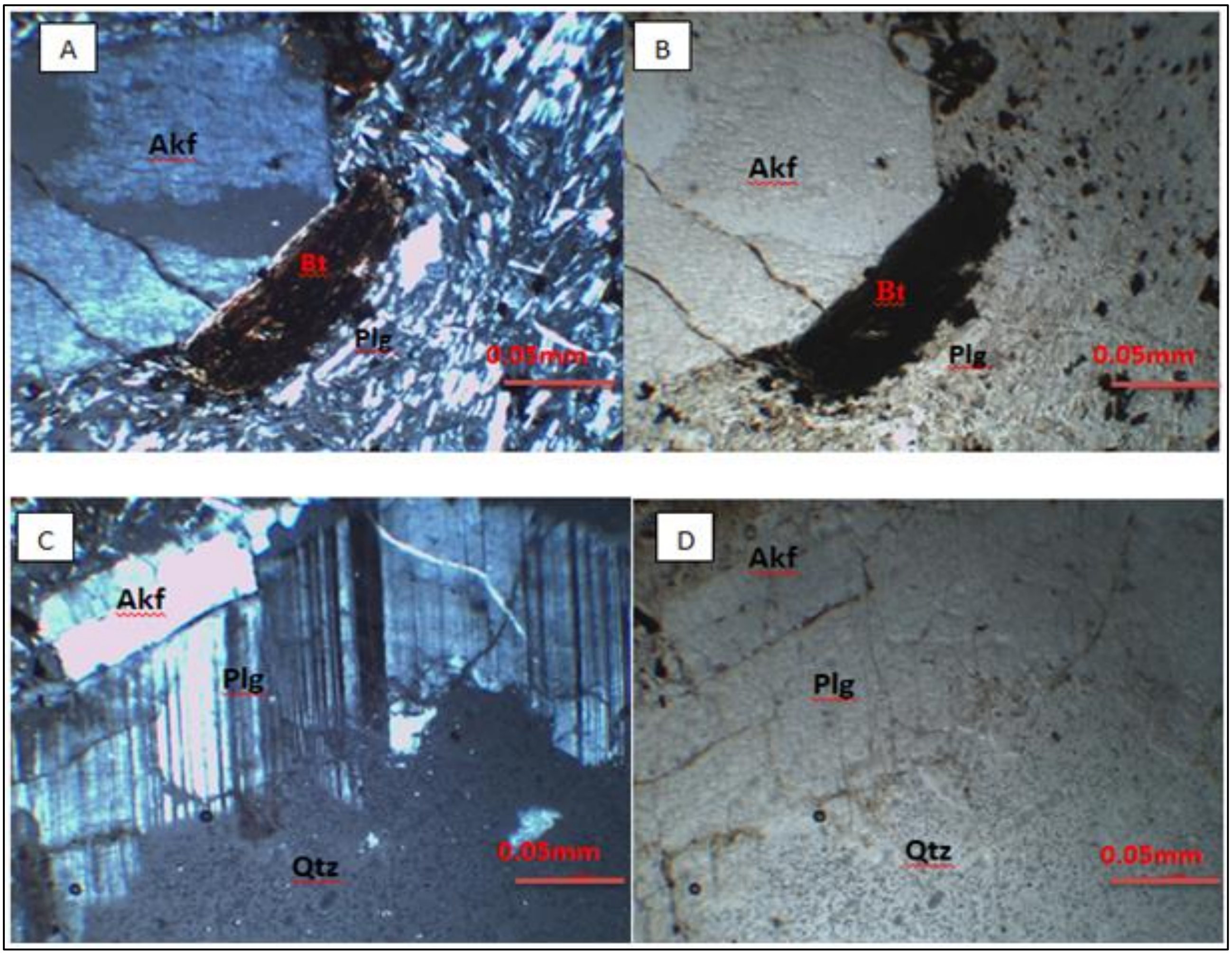


Figure 4.20: Microphoto picture of Welded rhyolitic tuff (DS-10); XPL (A, and C) and PPL (B and D) view at 5x Magnifications. The labels stand for Plg-Plagioclase, Akf- Alkali feldspars, Bt-biotite and Qtz-quartz.

4.3.3.2 Welded Andesitic tuff

The andesitic rock unit is one of the lithology which exposed on area of Daleti section. The Rock unit is visible on the hillside of the research area. It's characterised by light grey in colour and from medium grained to coarse grained. The degree of weathering of this unit is small part of the lithologic unit is weathered and exposed at elevation of 2532m with Easting of 467236 and Northing of 982664.

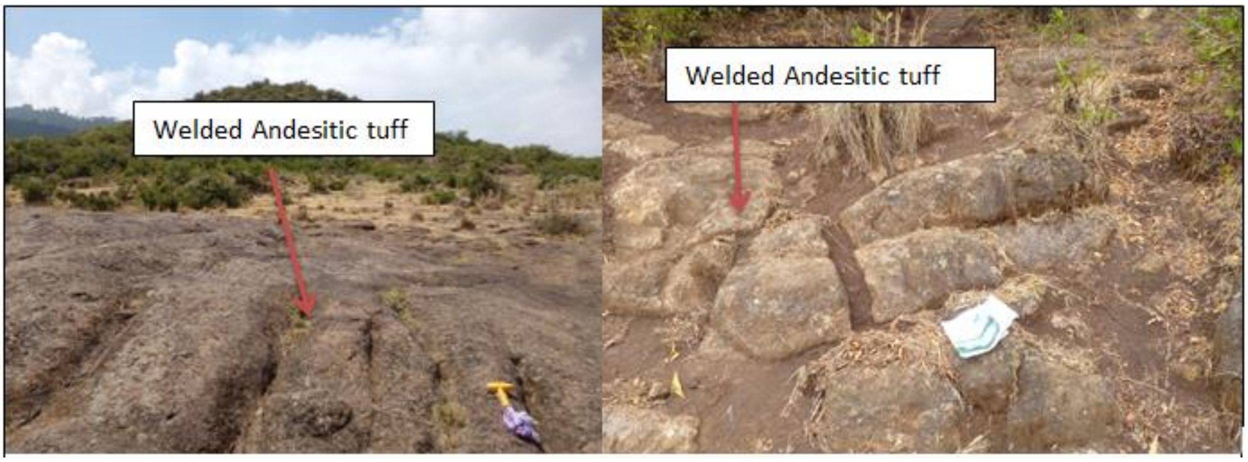


Figure 4:21: Shows the Welded Andesitic tuff at Daleti Section area at hillside

For petrographic study, two samples (GS-9 and DS-3) are produced. One of the rock types in the study region, this rock unit is an extrusive igneous rock of intermediate composition. The two samples with field codes **GS-9** and **DS-3** were obtained from the Gedamba and Daleti parts of the Furi Volcano. Plagioclase feldspars, Clinopyroxene, opaque Alkali feldspars, and volcanic glass are among the minerals present in the rock sample in varying amounts.

The minerals found in the rock unit are characterized by different crystal forms, like plagioclase subhedral, clinopyroxene anhedral in form; Volcanic glass is anhedral in form, opaque is subhedral in crystal and alkali feldspars with subhedral in crystal form. The textural description of the sample is porphyritic, which means that phenocryts of plagioclase lie on the groundmass of fine grained plagioclase; pyroxene, Volcanic glass and opaque. The proportion of the minerals as phenocryts is 50% plagioclase, 10% alkali feldspars, 10% clinopyroxene, and 5% opaque, and the estimated general groundmass texture of the sample is 25% of the modal proportions. Fine-grained minerals on the groundmass like plagioclase, pyroxene, and biotite are a left portion of the minerals. Overall, from the modal proportion and mineral content of the sample the rock name is called as **Plg-Akf-cpx-Phyric Welded Andesitic tuff**.

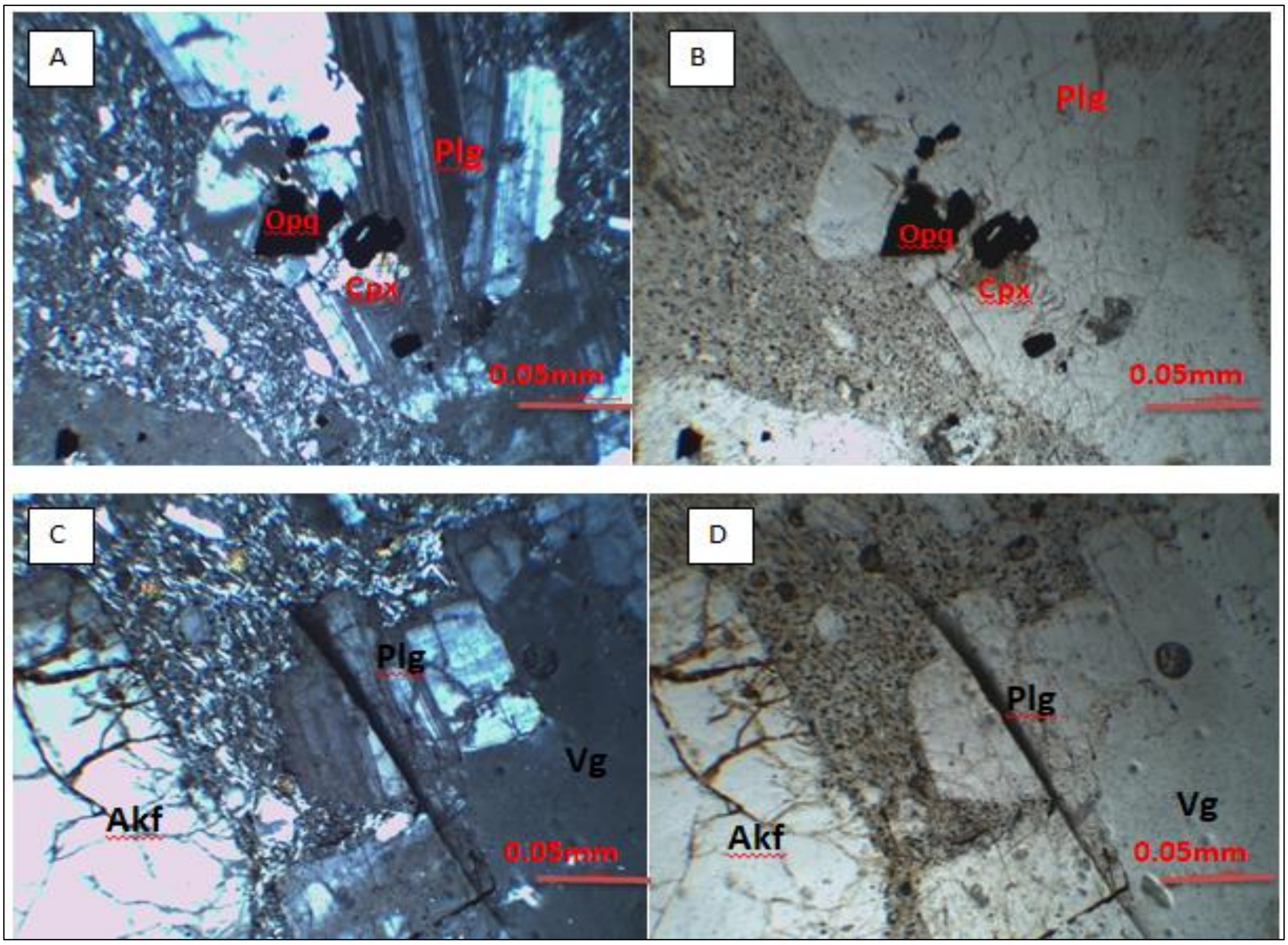


Figure 4.22: Microphotographs of Welded Andesitic tuff under PPL (B), (D) and XPL (A), (C) respectively with 5x magnification. The label stands for Plg- Plagioclase, Akf-Alkali feldspars, Olv-Olivine, Cpx-clinopyroxene, Vg-volcanic glass and opq-opaque.

4.3.3.3 Welded Trachyte tuff

This unit is exposed at hillside of Gedamba section. Welded Trachyte tuff is a type of volcanic rock that is composed of angular fragments of trachyte. It may also contain lithic fragments, Quartz, Alkali feldspars, and other mafic minerals. The Welded trachyte tuff unit is light grey to pink in colour, and the degree of weathering for this unit is fresh to weathered. It is fine- to coarse-grained in texture.

This rock is exposed on the hillside of the Gedamba section at the bottom of the Furi Ridge.

Figure 4:23: Shows the lithology of Welded Trachyte tuff on the hillside of the Gedamba section.

There are two samples with code of **GS-13** and **GS-11** which exposed at hillside of the Gedamba section and shows the characteristics of Welded trachyte tuff and prepared for petrographic analysis. It is characterized by light grey colour at hand specimen. The samples contain plagioclase feldspars with Polysthetic twinning on the groundmass of fine grained plagioclase and opaque. Alkali feldspar shows subhedral to anhedral. Alkali feldspars shows first order grey to white interference colour with parallel extinction. The groundmass of this rock comprises very small microcrystals of diverse shapes along with some glass, and the Alkali feldspar/sanidine phenocrysts are fairly small. Trachyte frequently has a felsitic structure. The texture of the Welded trachyte tuff is porphyritic and Trachytic texture. Sanidine/Alkali Feldspar Phenocrysts and plagioclase lie on the groundmass of fine grained sanidine, plagioclase, quartz, biotite, opaque and other minerals.

The mineral proportions on the rocks are Quartz 10%, Sanidine 65%, and plagioclase 20% and opaque minerals 5% with Quartz anhedral shape, sanidine with subhedral and plagioclase with subhedral to anhedral in shape. From these and other characteristics the rock name is **Snd-Plg- Qtz Phyric Welded Trachyte tuff.**

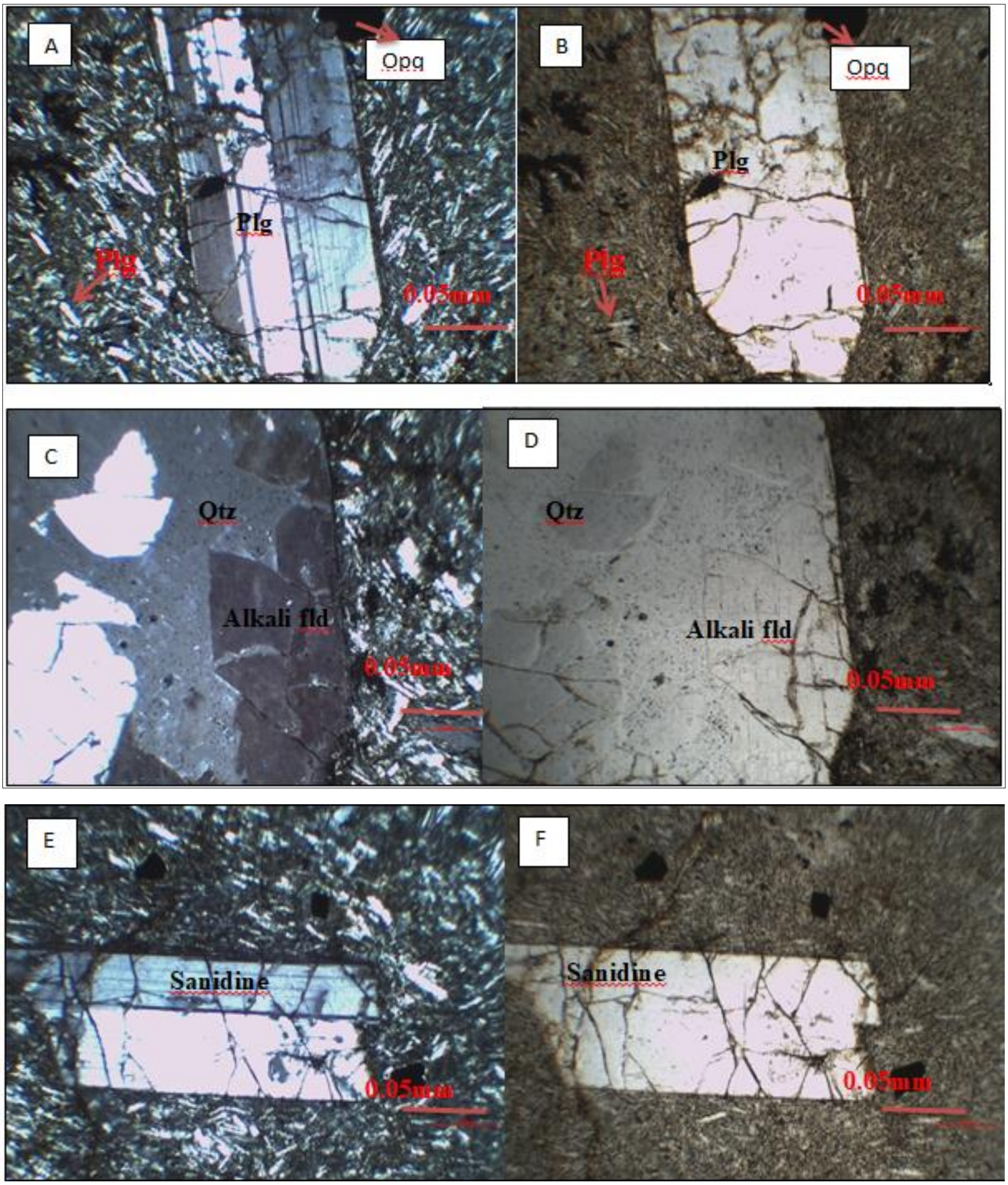


Figure 4.24: show the Microphotographs of welded Trachyte tuff of GS-13 and GS-11under XPL (A, D and E) and PPL (B, D, and F) view respectively. This photo were taken with 5x Magnification.

4.3.3.4 Rhyolite Lava

This type of rock has an acidic or felsic composition, meaning it contains a significant amount of silica. Rhyolite lava and welded rhyolitic tuff flows alternate in the Gara Bolo sector, which is part of the welded rhyolitic tuff rock unit's top section.

In contrast to basalt's dark colour, rhyolite has a lighter colour. This is because of its felsic makeup and fine-grained texture, both of which are results of solidification that took place at or near the Earth's surface. The Rhyolite that is found in the Research area is light grey to pinkish in colour and contains white k-feldspar and quartz. It is characterised as aphanitic (fine-grained) in terms of texture. This rhyolite is one of the exposed rock kinds in the hill slope region, and then it is intercalated with tuff that has been welded. The Gara Bolo section features weathered trachyte in the upper portion of this lithology and rhyolite lava that intercalates with welded Rhyolitic tuff. In this exposure, rhyolite lava with a vertical thickness of around 50 m is seen. Rhyolite is light-grey to pinkish in colour, and it has weathered parts on the lithological unit.

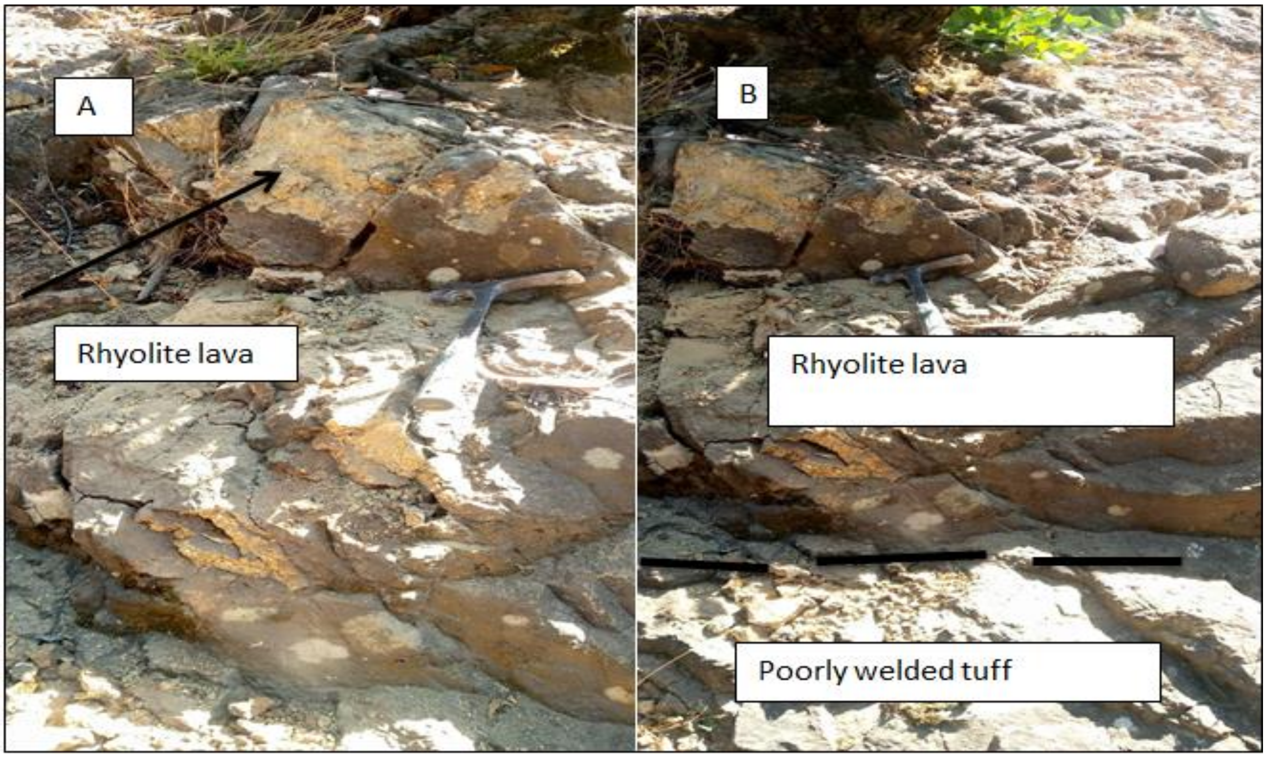


Figure 4.25: Shows A) Rhyolite lava flow B) Rhyolite lava flow intercalated with Welded Rhyolitic tuff

Two samples (**FS1A** and **GS10**) are prepared for petrographic analysis. The rock has shown the Spherulitic texture (in which a radial intergrowth of fibrous minerals). Usually Alkali feldspar and quartz in devitrified silicic volcanic). Quartz and alkali feldspar make up a large portion of the phenocryst assemblage (see Fig. 4.26).

The sample Code is expressed as **FS1A**, which contain different minerals with different character. According to petrographic analysis, this flow unit consists primarily of Plagioclase feldspars (plg) phenocrysts (20%), which can occasionally have Carlsbad twining. The crystal forms range from subhedral to elongate. The Qtz phenocrysts (5%) are typically subhedral, but they make up 10% of the microphenocryst phase and have an anhedral shape.

Phenocrysts diameters in plagioclase feldspar range from 1 to 5mm in length. The plagioclase feldspars make up 27% of the rock unit's modal composition, followed by quartz (35%), Alkali feldspars (30%), biotite (3%), and a glassy groundmass of 5%. Due to the abundant intergrowth of quartz and plagioclase feldspars in the groundmass, it also demonstrates Vitrophyre texture.

The rock is known as **Qtz-Akf- Plg- phyric rhyolite flow** because of the larger proportions of Plg phenocryst and overall porphyritic texture of the flow.

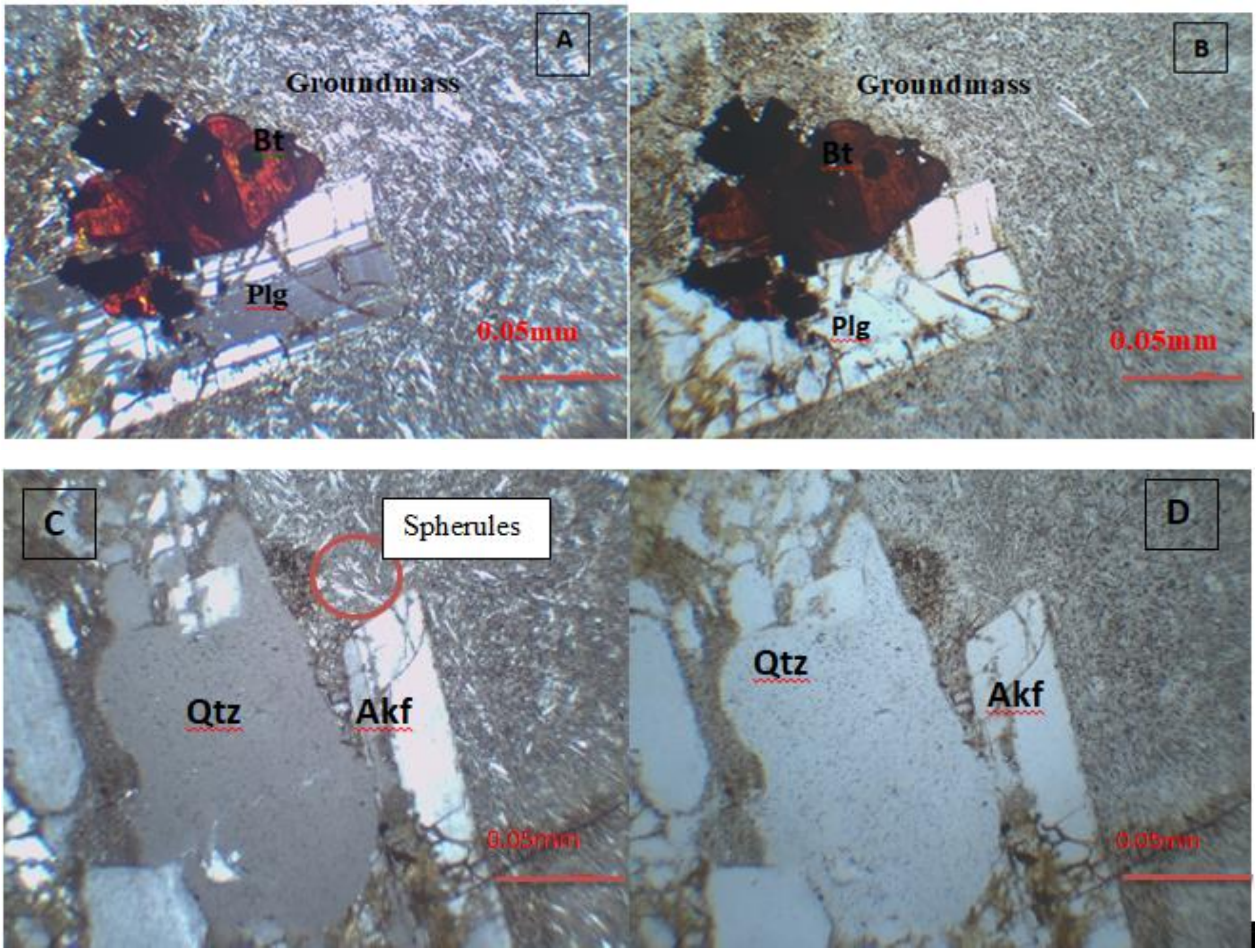


Figure 4.26: High proportion of glassy groundmass in plagioclase feldspar and quartz rhyolite microphotographs taken under XPL (A) and PPL (B), respectively. Both XPL (C) and PPL (D) exhibit the Qtz, Akf phenocrysts. Photographs of thin sections are obtained at a 5x magnification.

The other rhyolite rock unit is located on an exposed slope in the Gedamba part of the study area. **GS-10** is the field code for this extrusive felsic igneous rock. Quartz, hornblende, plagioclase feldspars, alkali feldspars, and opaque are the minerals present in this unit. Plagioclase, the most abundant phenocryst, has polysynthetic twinning. These were also present in the rock sample. The texture of the sample is porphyritic, with large phenocryts embedded in a glassy groundmass. The minerals include hornblende with subhedral form, quartz with anhedral shape, Alkali feldspars with anhedral form, plagioclase with subhedral form, and opaque with anhedral crystal form. Plagioclase and alkali feldspar, shaped feldspars, are the most important coarse crystals.

The modal mineral proportions of the sample are Quartz with 25%, Alkali feldspars with 32%, plagioclase feldspars with 35-37%, hornblende 15-20%, opaque with 3% and other minerals with fine grained groundmass of plagioclase with hornblende, biotite, quartz and other minerals. From the composition and characteristics of minerals found in the unit the rock name is **Plg-Akf-Qtz Phyric Rhyolite**.

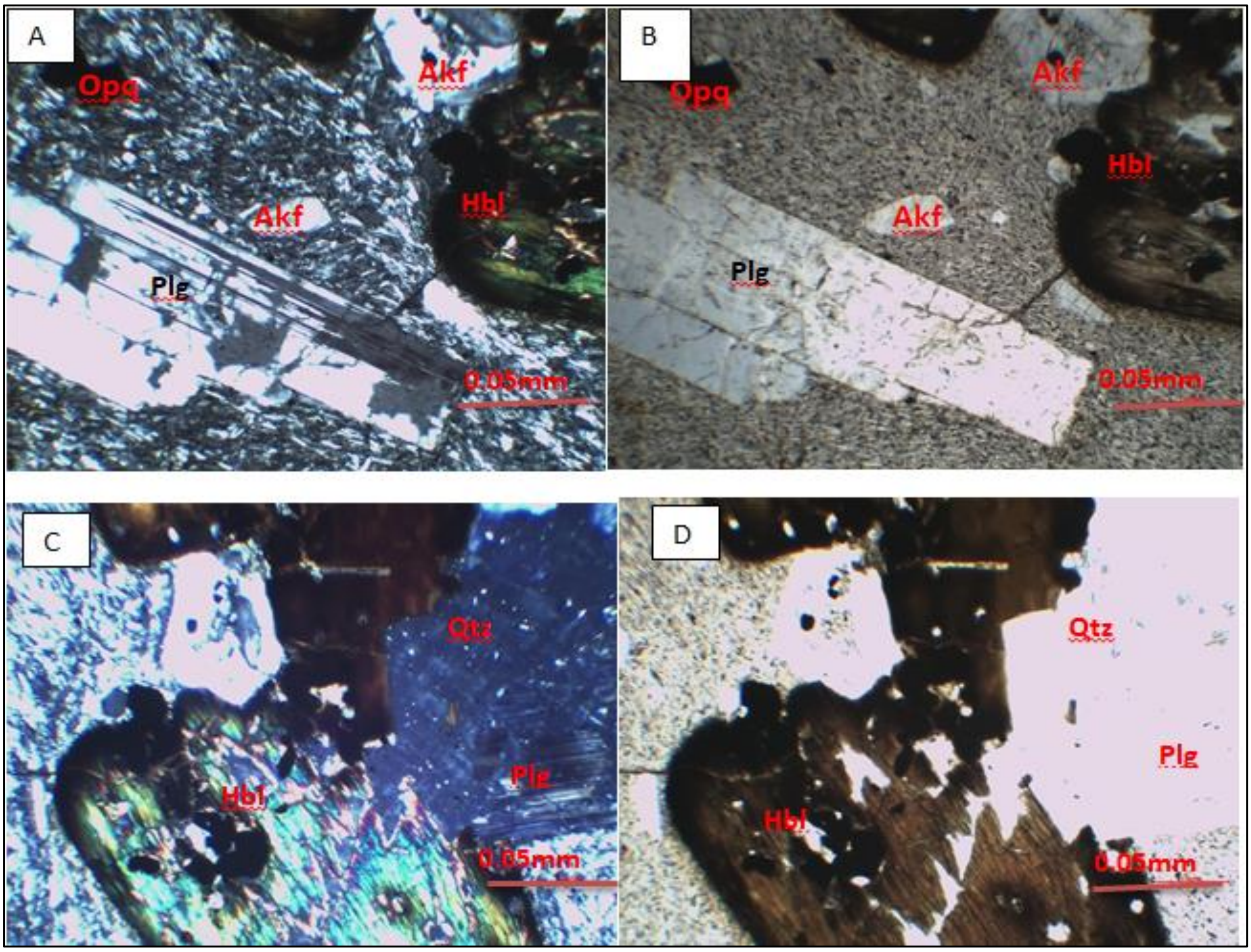


Figure 4.27: Micro-photo picture of Rhyolite (GS-10); XPL (A and C) PPL (B and D) View at 5x Magnifications.

4.3.3.5 Trachyte Lava

This rock unit may be seen near the top of Furi Ridge and adjacent to Furi Ridge. This unit mainly covers relatively elevated areas of the study area. These rocks are the most Exposed part of the unit on the Furi volcano. It is exposed at top part of the Furi ridge with different characters. Trachyte looks as a coarse-grained, light grey rock when seen in its natural outcrop. The trachyte can have shades ranging from brown-gray to dark-gray while it is in its fresh stage, but when it has weathered, it can have shades of pinkish yellow to reddish brown. The Gedamba section also contains trachyte with colours ranging from light grey to black, is aphanitic, and contains trace amounts of mafic minerals. It is created when silica- and alkali-rich lava is rapidly cooled.

This unit is an extrusive igneous rock that is light to dark coloured, composed of alkali feldspar and also dark minerals such as biotite, amphibole, or pyroxene, and shows a porphyritic texture. On the figure 4.28 A) the trachyte is porphyritic in texture, contains large phenocryts, and contains feldspar, which is exposed at the top part of the furi near the station; B) it is porphyritic, contains massive trachyte, has rare feldspar content, and is reddish in colour; and lastly, on the figure 4.28 C) it has similar characteristics with the trachyte at figure 4.28A).

Figure 4.28: Show A) The porphyritic trachyte, which is visible near the furi ridge's summit. B) Massive Trachyte, which is exposed at the top of Furi and is light grey in colour; C) Porphyritic Trachyte, which is similar to Figure a; D) Porphyritic Trachyte, exposed at the near end of Furi Ridge.

Five samples (**F2S1**, **F2S2 (A), F2S2 (B)**, **F2S2(C)** and **GS12**) are prepared for petrographic analysis. The sample code number such as FS61,F2S1,F2S2(A),F2S2(B) and F2S2(C) the minerals found and the character of the minerals found in that rock unit show that the rock unit is called trachyte lava. The rock unit shows the porphyritic texture with small and large mineral crystals. The huge crystals are the plagioclase feldspars and Alkali feldspars with small crystals are mafic minerals.

For instance, the sample with code number F2S1 is one of the trachyte rock units that are exposed on the hillside of the Gara Bolo section, with Alkali feldspar as the dominant mineral and different other minerals found. The phenocryts are usually sanidine and plagioclase. Microscopically, it is composed of 60% Alkali feldspar, 25% plagioclase, 5% biotite and opaque 5% showing Felty or pilotaxitic texture (in which the microphenocryts are randomly oriented).The rock name is **Akf-Plg-Phyric Trachyte lava**.

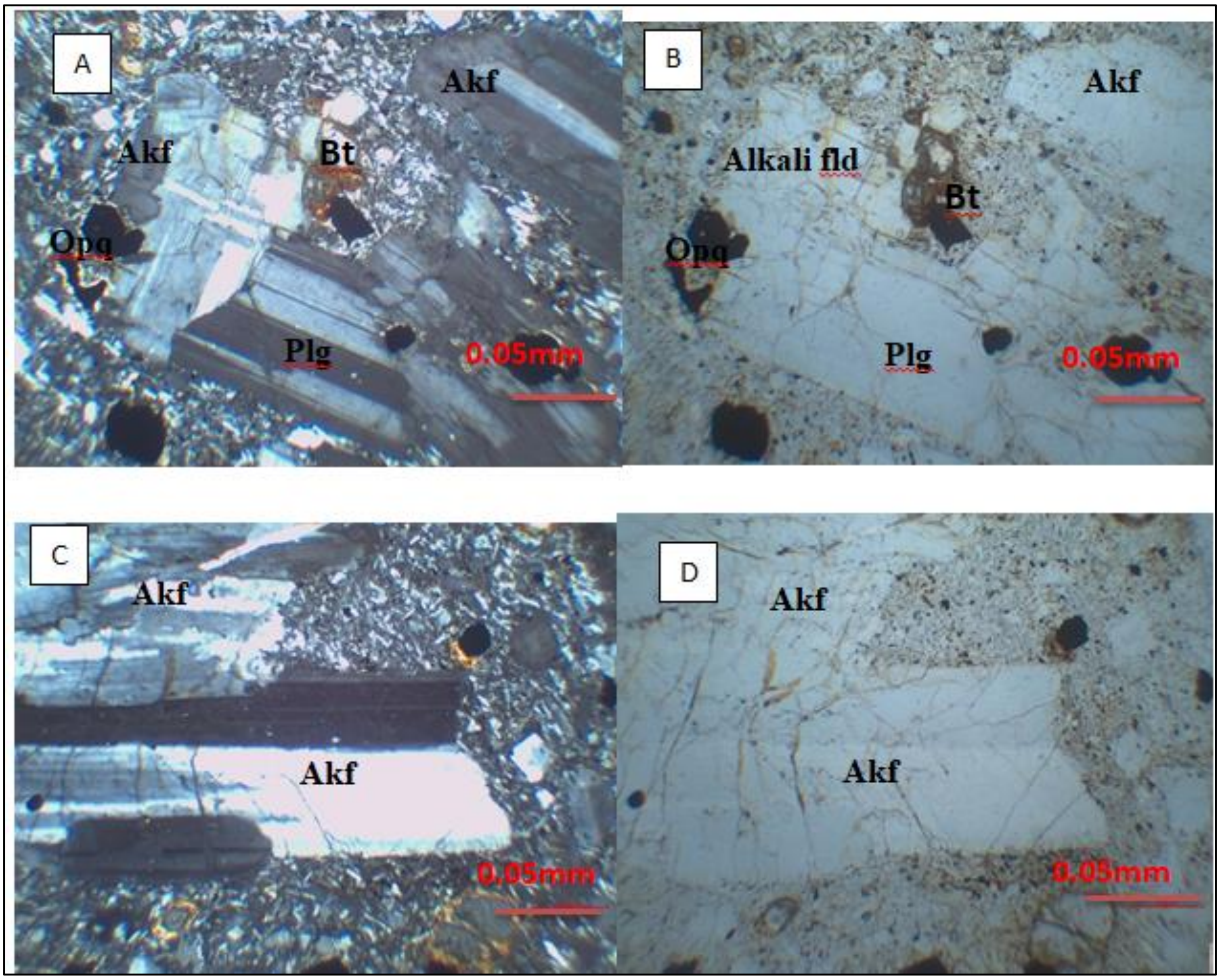


Figure 4.29 Microphotographs of Trachyte lava of the sample code (F2S1) Under XPL (A and C) PPL (B and D) view respectively. This photo were taken with a 5x Magnifications.

The rock unit with sample code F2S2 (A) contain different types of minerals with different character like plagioclase, Sanidine, with small microlites of plagioclase which shows flowing and other types of minerals are found. The rock shows the trachytic texture or flow texture which means that on the surface of the earth, lava is flowing, as evidenced by the groundmass's directivity microlites. This flow unit exhibits subhedral to euhedral sanidine phenocrysts (35%) and plagioclase microphenocrysts (25%), as well as groundmass containing up to 40% plagioclase feldspars, under thin section analysis. In this flow, there is a higher proportion of groundmass. Due to the high proportion of Plagioclase feldspar (Sanidine), the rock name was established as **Plg- Snd-Phyric Trachyte.**

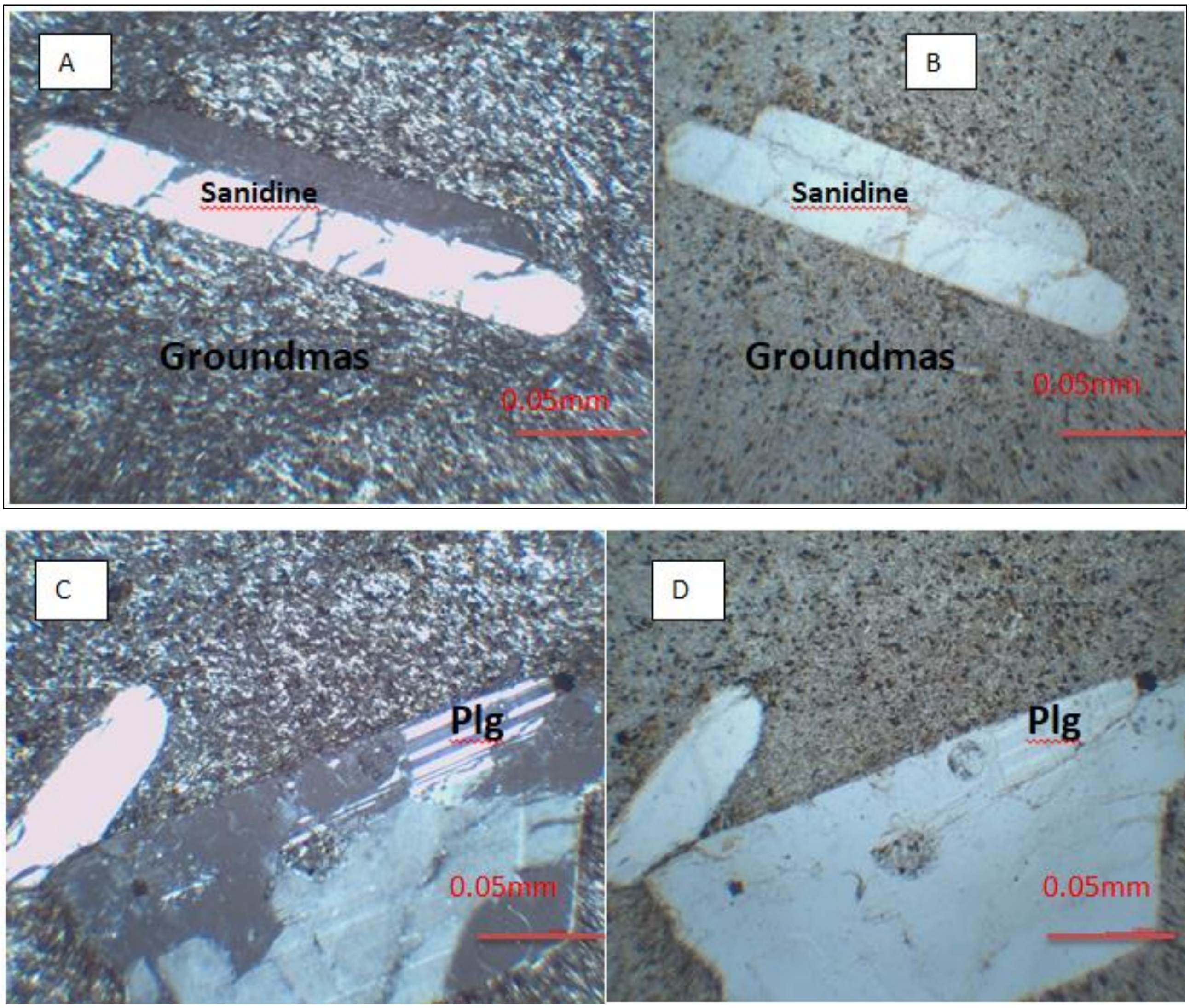


Figure 4.30: Microphotographs of plg- Snd-phyric Trachyte under XPL (A) and XPL (C), PPL (B) and (D) respectively with high proportion of glassy groundmass. Thin section photos are taken with 5x magnification.

The trachyte unit is also exposed at hillside of the Gedamba section which is dark grey in colour with a yellowish piece in the hand specimen. There are various mineral compositions with distinct characteristics in the sample with field code **GS-12**. Plagioclase feldspars, Alkali feldspars, hornblende, quartz, and other minerals like biotite are present in it.

Potassic feldspar (likely orthoclase) make up the feldspar in the sample code of **GS-12** in the Furi volcano, as opposed to the orthoclase of trachyte’s in the other locations. The composition of the modal mineral found inside a rock is 20% K-feldspar (sanidine), 60% alkali feldspar, 20% plagioclase, 2% opaque, 5% quartz as groundmass, which shows the radiating texture, and 10% hornblende, with the remainder being groundmasses of plagioclase, pyroxene, and olivine, with the sample showing a trachytic texture. The minerals display the grain structure, which ranges from anhedral to euhedral. For instance, the subhedral form is displayed by plagioclase feldspars, the euhedral shape is displayed by Sanidine, and the subhedral shape is more prominent in Hornblende. From these and others characteristics of the sample the rock name is called as **Akf-Plg-Sanidine-Phyric Trachyte.**

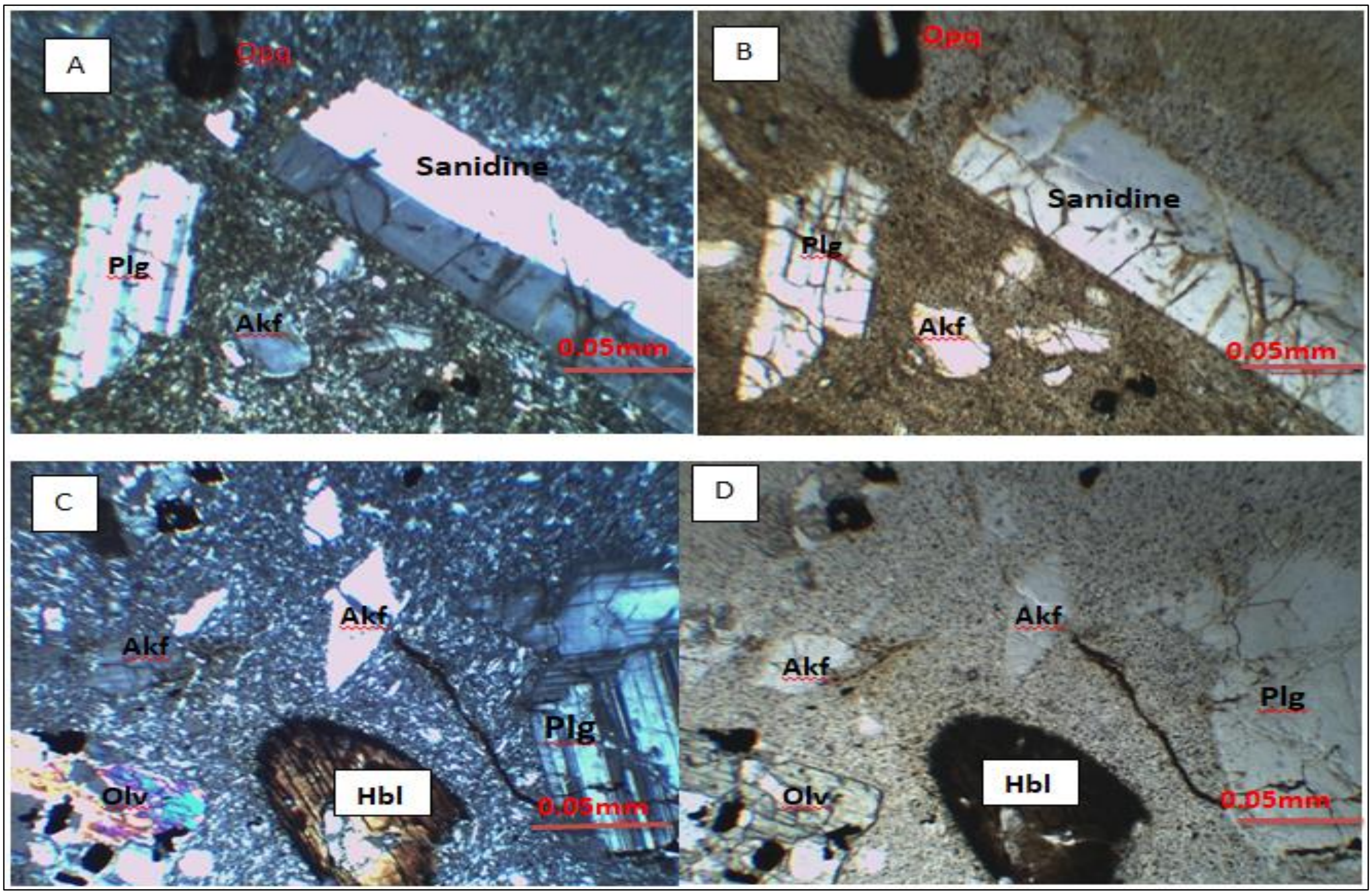


Figure 4.31: Microphotographs of Trachyte under XPL (A, C) and PPL (B,D) View Respectively. This photo were taken with 5x Magnifications.

4.3.4 Intermediate rock unit

4.3.4.1 Andesite

The rock unit may be visible at the road cut of Gara Bolo section of the Furi Ridge Volcano. This unit is a volcanic rock intermediate in composition between basic and acid. It is grey to black in colour, and the degree of weathering is fresh. It is an extrusive igneous rock that developed on the surface of the earth. This rock unit has an aphanitic to porphyritic texture and is made up of black augite and plagioclase, which is high in sodium. There is a void that shows secondary minerals have been removed from the unit.

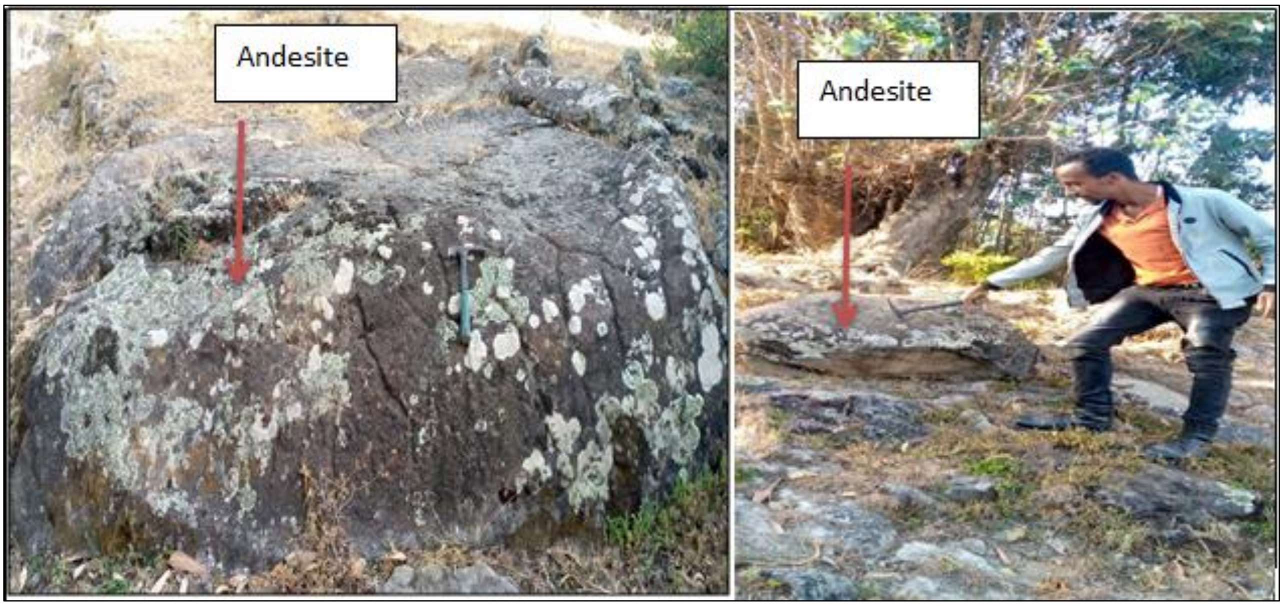


Figure 4.32: shows the Andesite rock unit at Road cut

One Sample (FS9) is prepared for petrographic analysis. A sample of andesite with a fine-grained groundmass and crystals of both plagioclase (Plg) and clinopyroxene (Cpx). This sample is shown on the code called (**FS9**) which shows the grey in colour and grain size, fine to medium in hand specimen description. The sample is taken from road cut of Gara Bolo section at the top of furi ridge. The other description is the mineral found in Andesite rock unit are Plagioclase feldspars, Pyroxene and opaque mineral are the dominant. The phenocrysts of plagioclase lie on the groundmass fine grained plagioclase, pyroxene and opaque minerals. The arrangement of groundmass texture shows the radiating crystal patterns but, generally they show sub-parallel to parallel orientation.
The average amount of minerals detected inside a rock units are plagioclase together microphenocryts 75%, pyroxene 20% and opaque minerals 5%. Each phenocryst exhibits anhedral grain structures (pyroxene and opaque) and plagioclase is subhedral in shape.

Based on the modal mineral content of the rock and its various characteristics of minerals found in the rock the type of the rock unit is **plagioclase-Pyroxene-phyric Andesite**.

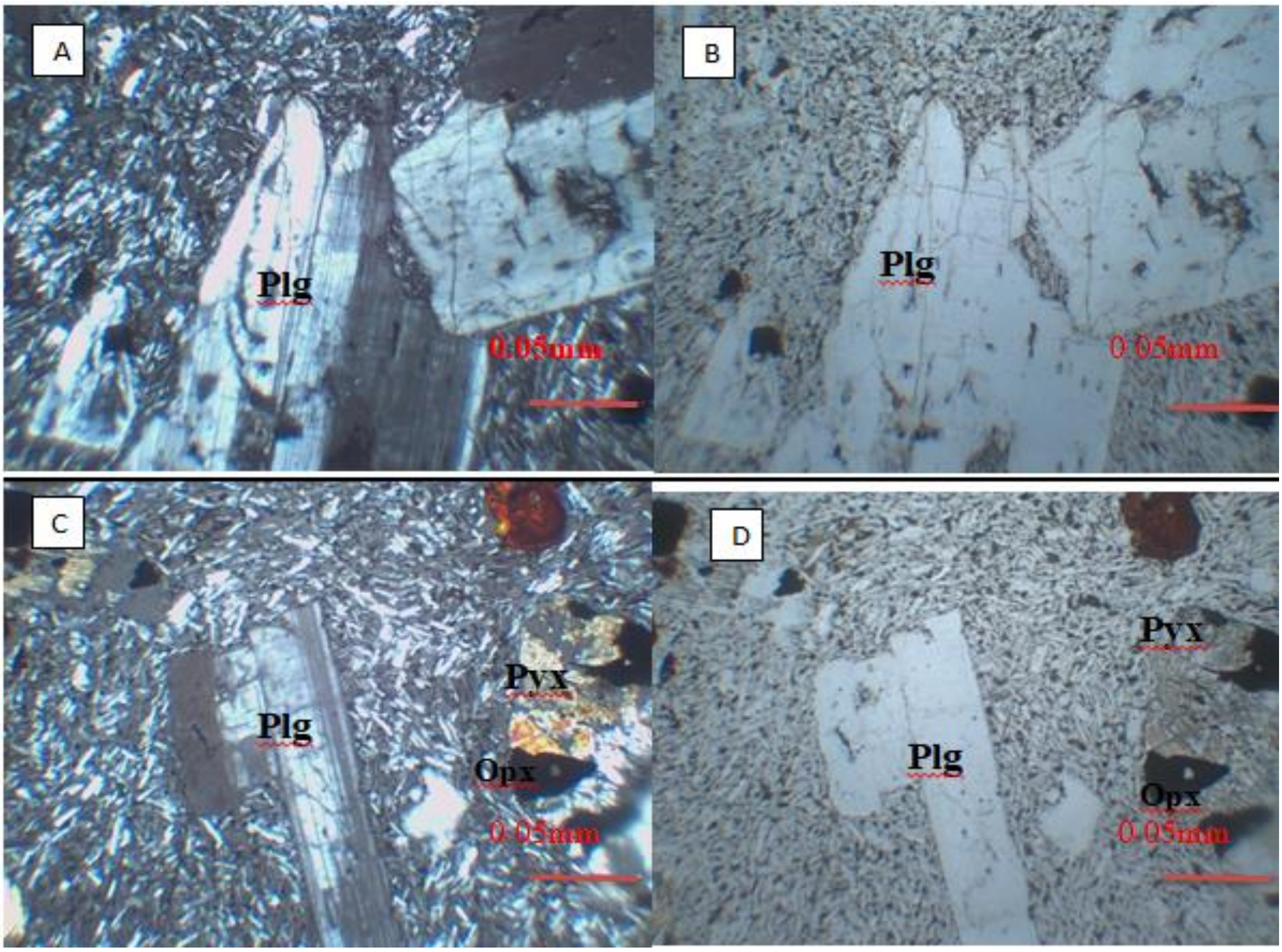


Figure 4.33: Microphoto picture of Andesite; FS9 under XPL (A and C) and PPL (B and D).The label stands for Plg- Plagiocalse, Pyx-pyroxene, and Opx.-Opaque. The photo picture is taken at 5X magnification.

The stratigraphy of the Furi Volcano was created utilising both petrographic and field observations. Variations in textural characteristics, petrographies impose new restrictions on the stratigraphy. The composite stratigraphy of the study is the following:

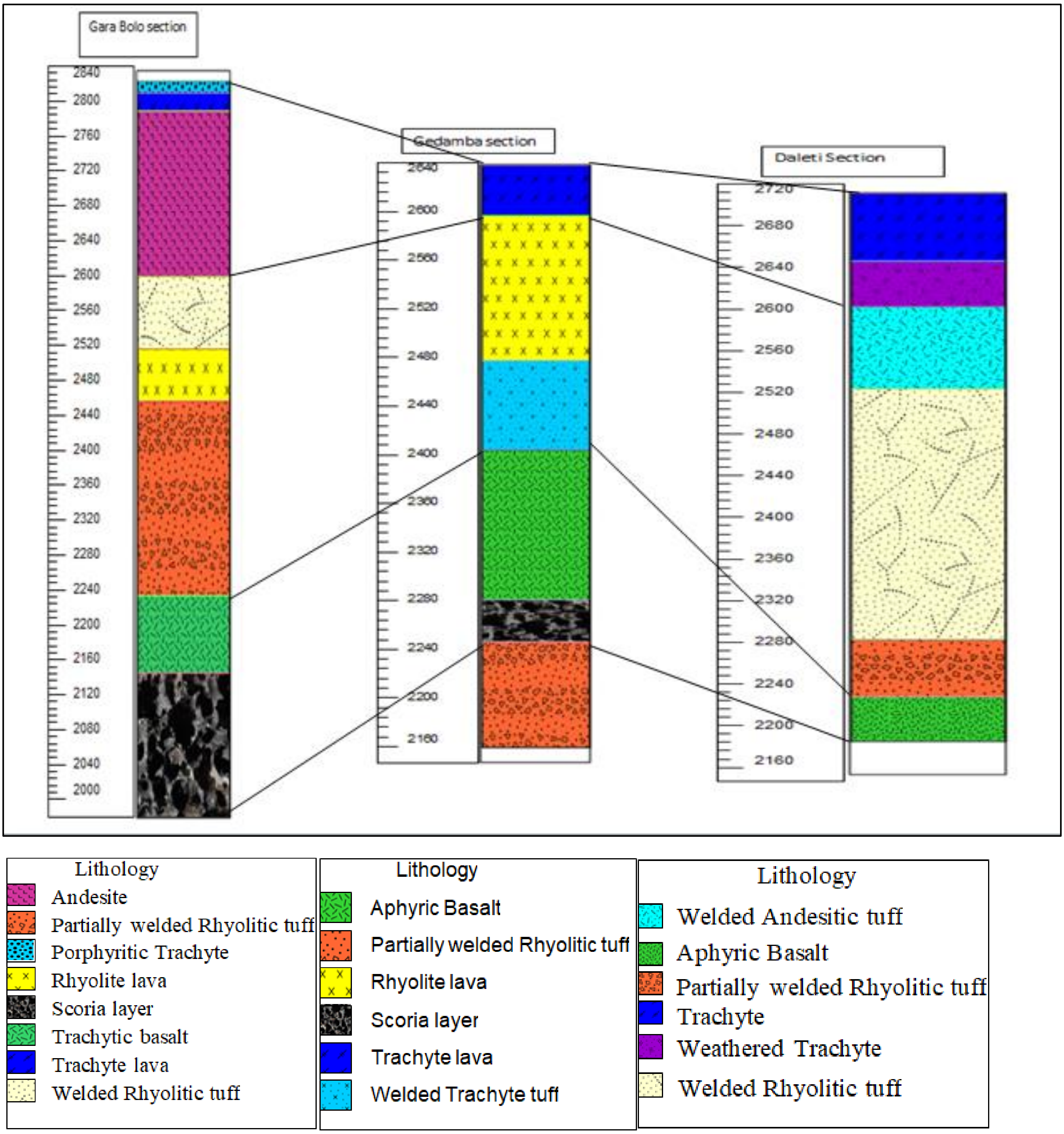


Figure 4.34: stratigraphy of (Gara Bolo, Gedamba, and Daleti) section of Furi Volcano. Similar formations are connected and the scale labelled vertically displays the Elevation (M).

Table 4.1. Summarised textural characteristics of rock samples with petrographic analysis

Sample code (Elv)	Location UTM (37p)	Lithologic - stratigraphic unit	Textures	Mineral composition	% of phen ocrysts	Dominant phases in phenocryts	Ground mass texture	Modal Name
FS1A-2469m	E-464157 N-984316	-Rhyolite	Spherulitic, Felsophyric texture	-Alkali fld, quartz, glassy groundmass	-	-Alkali fld (30%), Qrtz (35%),Plg (27%).	Vitric	- Qtz- -Akf-plg phyric Rhyolite
FS1B-2469m	E-464157 N-984316	Welded tuff	- Eutaxitic texture - Porphytic	- Alkali fld, biotite, quartz	- 57 %	- Akf (30%), biotite (10%), quartz (20%)	vitric	Qtz- Akf-phyric Welded rhyolitic tuff
FS4-2686m	E-464381 N-983152	Partially welded rhyolitic tuff	- Eutaxitic texture -Porphytic	plagioclase fld, quartz, Alkali fld	- 37 %	-Quartz (27%),Plg fld (20%),Alkali fld (25%)	Vitric,Felty	-Qtz-Akf-plg-phyric Partially Welded rhyolitic tuff
FS5-2722M	E-464543 N-982926	Trachytic basalt	- Trachyte or Flow texture,Inter granular	Plagioclase, olivine, Alkali fld,Cpx		- Plagioclase (65%), cpx(6),olivine (5%),	Trachytic	- Plg-Cpx-Olv Trachytic basalt.
FS61-2785M	E-464552 N-982648	Trachyte	Trachytic texture	Plg,Alk fld,	10	Plg(20),Alk fld(10)	Trachytic	Plg-phyric Trachyte
FS62-2785M	E-464552 N-982648	Trachytic basalt	Trachytic, Cumulophyric,	- plg fld, Alk fld, Sanidine, Olv, Cpx	-	- plg fld(23), Alk fld(10), Sanidine(10), Olv(10),	Trachytic	- Plg-olv-sanidine-Trachytic basalt
FS71-2796m	E-464760 n-982593	Welded rhyolitic tuff	Eutaxitic texture	plg fld, Alk f,qrtz	-	plg fld(21), Alk f(5),qrtz(5)	Flow	Plg-Akf-Qtz Phyric Welded rhyolitic tuff
FS72-2796m	E-464760 N-982593	Trachytic basalt	-Trachytic Porphyritic	Plg,Sanidine,Alk fld	10	Plg(20),Sanidine(5),Alk fld(10)	Trachytic	Plg-phyric Trachytic basalt
FS9-2776m	E-465206 N-982351	Andesite	-Flow, Radiating	-Plg, Cpx,	-	Plg(75 %), Cpx(20 %)	Felty	plg-Cpx-phyric Andesite
F2S1-2786m	E-465293 N-982016	Porphyritic Trachyte	Porphyritic, pilotaxitic	- Akf, plg,opaque	-	Akf (60), plg(25),opaque(5 %)	Felty	Akf –Plg phyric Trachyte
F2S2(A)-2816m	E-465454 N-982044	Massive Trachyte	Trachytic texture	Sanidine, Plg	20	Sanidine(35), Plg(25),40 Gm Plg	Felty	plg- Snd-phyric trachyte
F2S2(B)-2816m	E-465454 N-982044	Trachyte lava	Trachytic texture	Sanidine, Plg	10	Sanidine(8), Plg(2),opaque	Felty	Sanidine phyric trachyte

F2S2(C)-2816m	E-465454 N-982044	Porphyritic Trachyte	Trachytic texture	Plg, Sanidine	5	Plg (22 %), Sanidine(50 %)	Felty	Sanidine phyric trachyte

GS4-2184m	E-464875 N-978553	Basalt	-Porphyritic -Trachytic texture	Plg, Olv, Cpx	-	Plg(30%)),Olv (25%)),	Felty	Plg-Olv-phyric basalt
GS6-2222m	E-465441 N-979209	Basalt	-Trachytic texture	Plg,Olv,Cpx	20	Plg(55%)),Olv (32%)),Cpx(5)	felty	Plg-Olv-phyric basalt
GS7-2257m	E-465734 N-979382	Basalt	Intergranular texture -Trachytic texture	Plg,Olv,Cpx,	18	Plg(45%),Olv(15%),Cpx(20%)	felty	plg-Cpx-Olv phyric Basalt.
GS9-2364M	E-465653 N-980435	Welded Andesite tuff	-Porphyritic -Trachytic texture	Plg, Alkali fld, Cpx,	-	Plg(50%),Alkali fld(10%),Cpx(10%),	Trachytic	Plg-Akf-cpx phyric welded Andesite tuff.
GS10-2483M	E-465411 N-980975	Rhyolite	Hemicrystaline Texture	Plg,Hbl,Alkali fld	10	Plg(35%),Hbl(15%),Alkali fld(32%),qtz (25%)	Felty	Plg- Akf- Qtz-phyric Rhyolite
GS11-2490M	E-465235 N-981077	Trachyte tuff	Porphyritic and Trachytic texture.	Quartz, sanidine and Plg	10	Qtz(10%) sanidine(65 %) and Plg(20%)	Trachytic	Snd-plg- Qtz-phyric Welded Trachyte tuff
GS12-2600m	E-465274 n-981262	Trachyte	-Radiating -Trachytic texture	Plg, Sanidine, Cpx,Hbl	5	Plg (20%), Sanidine (10%)	Trachytic	Plg-Snd-Phyric Trachyte
GS13-2411m	E-464357 N-980580	Welded Trachyte tuff	Trachytic texture.	Quartz, sanidine and Plg	10	Qtz(10%) sanidine(65 %) and Plg(20%)	Trachytic, Felty	Snd-plg- Qtz-phyric Welded Trachyte tuff
GS15-2272m	E-462982 N-979809	Basalt	Intergranular texture	Plg,Cpx,Olv,	Less than 7	Plg(45%),Cpx(20%),Olv(15%),	Felty	plg- Cpx-Olv phyric Basalt
DS3-2532m	E-467236 N-982664	Welded Andesite tuff	-Porphyritic - Trachytic texture.	Plg, Cpx, Alkali fld	-	Plg (50%), Cpx (10%), Alkali fld (10%),	Trachytic	Plg-Akf-cpx phyric welded Andesite tuff.
DS10-2235m	E-469115 N-981692	Welded rhyolitic tuff	-Radiate - Trachytic	Plg,Cpx,Alkali fld	20	Plg(15%),Cpx(10%),Alkali fld(30%),qtz-20	Vitric	Akf- Qtz-Plg-Cpx-Phyric Welded rhyolitic tuff
DS11-2303m	E-467920 N-983622	Welded rhyolitic tuff	-Eutectic texture -Radiate	Plg, Alkali fld,Cpx,Opaque	10	Plg (20%), Alkali fld (17%), Cpx (7%)	Vitric	Plg-Akf-Cpx-phyric Welded rhyolitic tuff

4.2 Geological structures

4.2.1 Introduction

The Furi volcano is described as a stratovolcano and is situated approximately 26 kilometres southwest of Addis Ababa. It is part of the Ethiopian Rift Valley, which is known for its volcanic activity. The two main categories of geological features found in the region are secondary and primary. The main geological structures are those that develop as rocks are produced. Lava flow and layering on pyroclastic deposits are two examples of primary structures. The secondary structures were created on the rock as a result of a process that took place after the rock's initial creation. Joints and faults serve as secondary structures. The geological structures that are found in the research area are joints on pyroclastic deposits.

4.2.1.1 Joint

This joint is mainly detected in basaltic, Welded tuff, and trachyte. The joint that is observed on the lower basalt is a columnar joint (Figure A below). When thick basalt lava flows cool, columnar joints develop, which frequently result in hexagonal crack.

The structure is detected on the Basalt rock unit has a general orientation of NE-SW (some SE-NW present). The joint observed on the trachyte is oriented NE-SW (some NW-SE) and has an amount of a vertical to sub-vertical dip (see Fig.4.36 (B)).

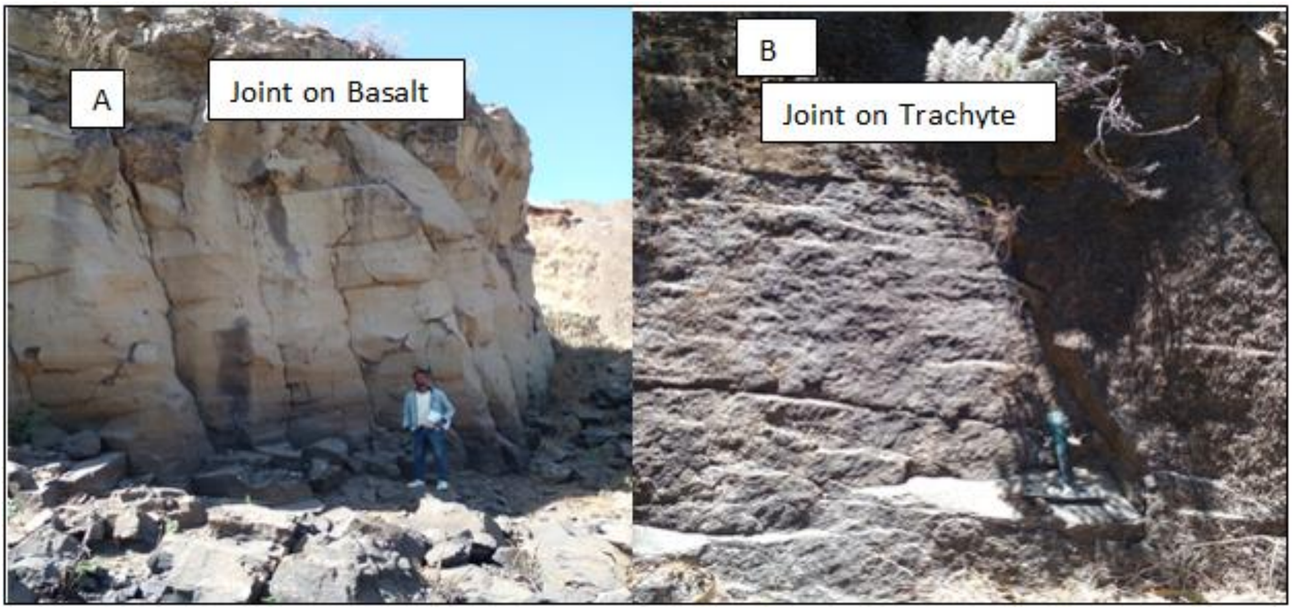


Figure 4.35: A) Columnar joint on basalt B) Joint on trachyte rock unit

There is a joint on the tuff that has different orientations. The tuff has joints that are characterised by non-systematic joints that are irregular in form. The joint, which is found on the ignimbrite in figure A, has an orientation SE-NW strike and a horizontal dip amount; the dip direction falls on the NS directions.

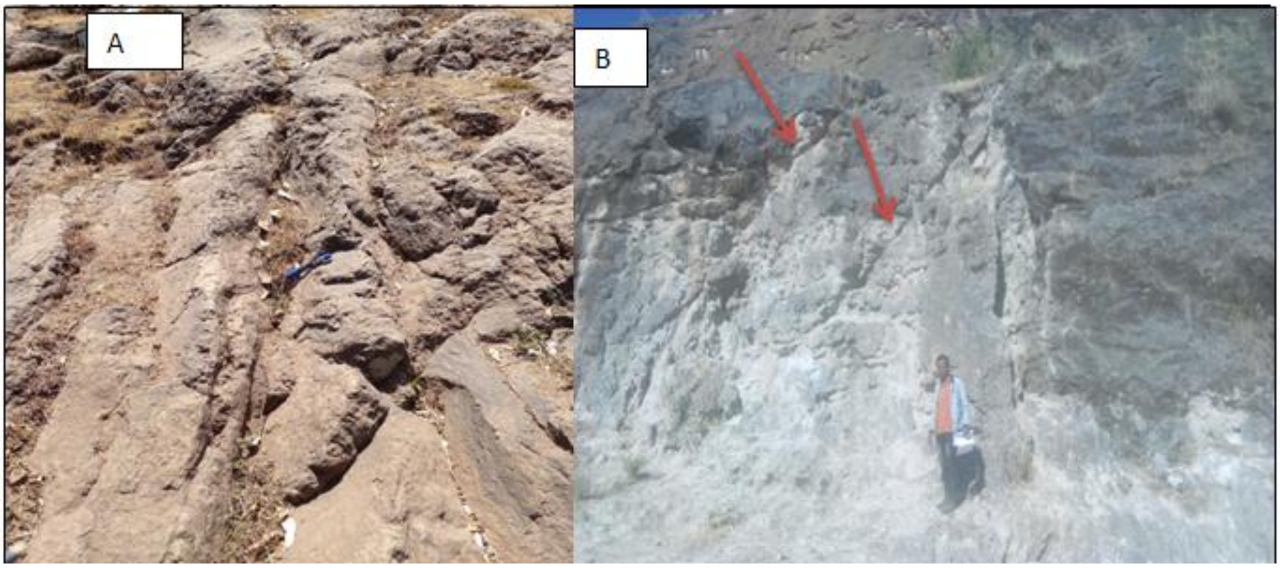


Figure 4.36: shows the joint on the tuff exposed at hillside

Welded rhyolitic tuff is a type of volcanic rock that is formed from the compaction and welding together of volcanic ash particles that were deposited during a volcanic eruption. There is layering or bedding in welded tuff, which is visible to the naked eye. This layering is caused by variations in the composition or temperature of the volcanic ash being deposited or by changes in the flow velocity or direction during the eruption. The layers can range in thickness from 2 mm to 5 mm and be deposited one over the other. The orientation of the layered welded tuff has a dip in the NW-SE direction (N20W strike, 50SE). The figure on A) shows the layered welded tuff one over the other, and the figure on B show the joint structure, which has a diameter of 5-7m and a thickness of 2 mm. The orientations of the joint on the Welded tuff rock have a dip in the NE-SW direction. The rock unit that has been layered is exposed on the hillside of the Gara Bolo section, while the tuff in figure B is exposed on the hillside of the Gadamba section.

Figure 4.37: shows the A) layered Welded tuff at Gara Bolo section and the B) Joint structure at Gadamba section.

CHAPTER FIVE

5. DISCUSSION AND CORRELATION

5.1. Discussion

This study is part of the Western Border of the CMER, which discusses the petro-stratigraphic construction of volcanic units in the Furi Volcano, starting from the bottom part called basalt up to the top-most part of the succession (Trachyte). In terms of the magmatic system, petrography, petrology, and linkages between field geological features, the data from chapters four (4), which are the geology of the study area and Petrographic analysis, are combined in order to be discussed with regional research. Every stratigraphic unit is compared to its corresponding prior stratigraphic nomenclature accessible by the various researchers as part of the discussion.

This study uses a combination of field relationships and petrographic investigation to identify the volcano-stratigraphic setting of lava flows. The areas have been demonstrated by these in-the-field observations and petrographic investigations are covered by vast trachyte lava flows, rhyolite, partially Welded rhyolititic tuff, Welded rhyolitic tuff, aphyric basalt, Andesite, Welded andesitic tuff, Welded trachyte tuff, and Trachytic basalt.

5.1.1 Petrographic characteristics of Furi Volcano

From the study area, 25 samples were taken and analysed for petrographic analysis on the basis of mineral assemblages like phenocryts, microphenocryts, groundmass, and textures like trachytic texture, Glomeroporphyritic texture, porphyritic texture, felty or pilotaxitic texture, eutaxitic texture, and spherulitic texture with field observation. Depending on the field observation and petrographic analysis of the sample taken from the study area, it contains volcanic units like rhyolite, trachyte lava flows, partially welded to welded rhyolitic tuff, Ol/plg/pyx/phyric Basalt, Andesite, Welded Andesitic tuff, Welded Trachyte tuff, Trachytic basalt and Sanidine/phyric trachyte.

5.1.2 Volcanic stratigraphy Research area

The petrographic investigation of the volcanic rock in the research area and textures in the minerals discovered are used to determine the volcanic stratigraphic column section. The research area is located within the Central felsic volcano, which is one of the stratovolcanoes near Addis Ababa city. The area around Addis Ababa the felsic centres like Wechecha, Furi, Yerer, and Menagasha formed along an important E-W structure identified as the Ambo lineament near the junction of this feature with the cross-rift Yerer-Gugu lineament (Tadiwos Chernet et al., 1999).
Based on the petrographic analysis and field observation, this study establishes different volcanic units that have been examined by analysing the mineral assemblages and textures of certain lava flows, such as

partially welded rhyolitic tuff, Welded rhyolitic tuff-rhyolite lava flows, Andesite, welded Andesitic tuff, welded trachyte tuff and trachyte lava flows.

Take into account each unit's maximum thickness at particular parts to gauge the overall thickness of the volcanic units. The thickness of the bottom part of the study, from basalt to trachytic basalt, is 150m. A pyroclastic deposit with a felsic composition can be found in the 350-metre-thick geological succession. The intermediate rock to trachyte rock unit is visible across the stratigraphic column's 200-metre thickness. The general thickness of volcanic rock units in the study zone is 700 m. Rocks such as Basalt and trachytic basalt, with a relative proportion of 22%, are classified as mafic minerals by their thickness. The rock under the pyroclastic deposit has a relative proportion of 50% that is classified under the Felsic minerals, and the rock unit from the intermediate unit to trachyte has a relative proportion of 28% that is classified under the Felsic composition with their thickness. Knowing the relative proportion of acidic and basic rocks is important because it can provide information about the region's geological history. For example, a higher proportion of acidic rocks may indicate that the area has experienced more explosive volcanic activity, while a higher proportion of basic rocks may indicate more effusive or non-explosive volcanic activity. From these, we concluded that the Felsic rock units are more abundant than the mafic rock units in the study area.

5.2.1.5 Basalt-Trachytic basalt (2100-2250m)

That unit is the bottom part of the stratigraphic column section, which contains the scoria fallout, Trachytic basalt, and basalt next to the alluvial soil at the bottom of the research area. The thickness of this rock unit is 150 metres. The Scoria found in the research area is considered by vesicular basaltic lava. The scoria rock unit is mainly outcropped on a quarry type of exposure; it has a red colour. It is detached from the partially welded rhyolitic tuff-rhyolite by a thin layer of paleosol separates an alteration surface covered by pyroclastic deposit layers. The Trachytic basalt exposed at the hill site of the Furi volcano is characterised by porphyritic, plagioclase-rich vesicles filled with secondary minerals. There is also Limonitization alteration, which means the transformation of minerals into limonite on the scoria rock unit in the study area. The phenocryst composition of the rock units ranges from 5% to around 40% of the total rock volume, and they have an aphyric texture. Olivine, clinopyroxene, and plagioclase occur as phenocrysts, microphenocrysts, and in the groundmass. The basalt illustrates that there is a dominance of plagioclase feldspars with a medium dominance of olivine and a minor amount of pyroxene, which is why the rock is named plg-olv-pyx phyric basalt.

5.1.2.2 Partially Welded Rhyolitic tuff-Rhyolite lava (2250-2600)

The rock units called partially welded rhyolitic tuff are underlain by basalt-Trachytic basalt and intercalated with the rhyolite lava flow, which is overlain by an intermediate rock called Andesite. The total thickness of this partially welded rhyolitic tuff-rhyolite lava flow is 350 m. The rhyolite and tuff flows are located in the upper part of the Basalt rock unit. Palesoil forms a layer that divides the sections partially welded rhyolitic tuff from the basalt at the bottom.

The partially welded rhyolitic tuff-Rhyolite lava flow, which is regionally called the Naziret pyroclastic group, is 350m thick and is exposed in the middle section of the area. This Naziret pyroclastic group contains partially Welded Rhyolitic tuff, Welded Andesitic tuff, welded Trachyte tuff, welded rhyolitic tuff, and rhyolite lava flow. It is light to light-grey in a hand specimen of freshly obtained samples and reddish to yellow to pink in samples that have been used. A fine-grained,moderately welded tuff rock that includes vitrophyric fragments and lithic shards as well as accompanying rhyolite lava flows that are encased in unwelded tuffs. The partially welded ignimbrite or unwelded tuff that is exposed at the bottom of the Daleti section contains different geological structures, such as joints and different fractures found on the rock unit.

5.1.2.3 Andesite-Trachyte lava (2600-2800m)

These rocks is that are visible from the escarpment of the ridge to the top of the ridge are Andesite and Trachyte lava with different thicknesses in the research area. All the rock units that are found in these areas contain the above units with different thicknesses. The total thickness of those rock units is 200 metres. The trachyte unit at the study area is underlain by partially welded rhyolitic tuff, Welded Andesitic tuff, Welded Trachyte tuff, welded rholitic tuff, and rhyolite, respectively. This trachyte at the top part of the furi ridge is massive and porphyritic, and the colour is light-grey, red, and dark, with different characters.

Mazzarini et al. (2004) claim that the radiometric ages of the Central volcanoes, which include Furi, Wachacha, Zikwala, Yerer, and Bede gebebe range from 4 Ma to 3 Ma, and produced intermediate to strongly evolved lavas. The intermediate rock units found in this research area are Andesite. The age of the volcanic rock discovered in the Furi volcano is from the Miocene to the Pliocene, as evidenced by the age information displayed on the map of the Western border of the CMER and NMER.

5.2 Magmatic evolution inferred from volcanic stratigraphy and petrography

In this discussion, a comprehensive explanation of the magmas that erupted to create the series of pyroclastic deposits, Felsic flows, and intermediate rocks exposed at the Furi volcano is developed.

In the stratigraphic context, the petrography of the samples from this study that were examined displays a diversity of mineral compositions and textural features. There may have been differences in the depth of mineral fractionation and magma flow in the lithosphere based on the variety of mineral compositions and textural characteristics found in the samples. The flows, which have varying modal percentages, represent a variety of mineral phases at the phenocryst, microphenocryst, and groundmass levels. Plagioclase and olivine, for instance, make up some of the groundmass and microphenocryts in basalt flows, whereas cpx, Olv, and plg make up the primary phenocryts. Furthermore, it has been suggested that plagioclase concentrations rise from the lower to the top strata of the rock formation and Alkali feldspars is dominant at the top part of the rock unit like on the trachyte. In contrast, the felsic parts are made up of pyroclastic deposits with a more significant groundmass and phenocrysts such alkali feldspar and quartz as well as microphenocrysts like plagioclase feldspars. Microscopically, the rhyolites and welded rhyolitic tuff units are moderately to very porphyritic up to 10–35% phenocrysts and are composed of alkali feldspar, quartz, plagioclase, and opaque minerals. The groundmass of rhyolites is microlites of similar minerals embedded in a glassy matrix (Felsophyric texture), and the Ignimbrite (welded rholitic tuff) unit contains crystals of feldspar, alkali feldspars, and quartz together with lithic fragments, displaying a Eutaxitic texture with the groundmass. In addition to the deposition of tiny clastic sediments (paleosols), the distinct eruption episodes may be identified by the presence of weathered or changed surfaces between them. These indicate significant time gaps between the emplacement of each lava flow layer and periods of inactivity during the development of lava flows. These pauses in lava flow indicate a decrease in the flow of magma into the Earth's crust, resulting in an insufficient magma flow rate to trigger surface eruptions (Krans et al., 2018).

There are three major units of volcanic stratigraphy in the studied region: the lower unit, the middle unit, and the upper unit. Mafic volcanic rocks including trachytic basalt, scoria, and basalts make up the bottom unit. The middle unit is composed of pyroclastic deposits such as partially welded rhyolitic tuff, welded rhyolitic tuff, rhyolites, welded Trachyte tuff, and welded Andesitic tuff. The upper unit is composed of an intermediate to Felsic volcanic rocks, including andesite and different types of trachyte.

The petrography of the volcanic rocks of the Furi volcano shows a wide range of variations. The lower unit is characterised by a high degree of mafic minerals, such as olivine, plagioclase and pyroxene. The middle unit is characterised by a high degree of felsic minerals, such as quartz and feldspar. The upper unit is characterised by felsic minerals. There is a dominance of Plagioclase and sanidine in these petrographically studied trachyte samples, as well as the occurrence of plagioclase in the small intermediate rock samples. These eruption stages are frequently accompanied by rising silica content and explosive eruptive products

(Jerram and Widdowson, 2005). Mafic magmas may pond in the lower crust or at the Moho (e.g., Corti et al., 2003) while undergoing high-pressure evolution and the creation of trachytic magmas (Peccerillo et al., 2007).

According to Peccerillo et al. (2007), the Ethiopian rift magmatism scarce intermediate rocks because the most likely petrogenetic process for the rift magmatism is the derivation of rhyolites from basalts by dominant fractional crystallisation happening at shallow depths. As a result, intermediate rocks are not commonly found in the Ethiopian rift because the magma does not spend enough time at intermediate compositions for these rocks to form. Because of that, the Intermediate rocks are small on the western margin of the central Main Ethiopian rift in the case of the Furi volcano. The Intermediate rock and rift margin magmas differentiated at deeper levels, whereas the more felsic trachytes and rhyolites of the rift center originated at shallow crustal levels (Kabeto et al., 2009).

For evaluating the magmatic processes associated with the volcanic sequence on the basis of their stratigraphic position, an assessment is required of certain parameters that control the crystallization of mineral phases in both basaltic and felsic rocks during eruption. These parameters are: (1) composition of the parental magma, (2) pressure or depth of crystallization, and (3) the amount of volatiles in the magma (Mountener et al., 2001; Krans et al., 2018 and references therein). Plagioclase, clinopyroxene, and olivine minerals are found in magma, which suggests that crystal fractionation occurred at a shallow level in the upper crust. Ol + Cpx mineral assemblages are found in basaltic lavas, which suggest that crystal fractionation occurred at a deeper level in the crust or at the crust-mantle boundary (Pik et al., 1998; Krans et al., 2018 and references therein). Aphyric basalt in the study area contains plagioclase, clinopyroxene and olivine, which shows fractionation, occurs at the upper crust.

Understanding the behaviour of the magmatic plumbing system in the research area requires an understanding of the crystallisation phases of various minerals throughout lava flows. Increasing the water concentration in liquid magma is also known to alter the order of mineral crystallisation or crystallisation sequence (Mountener et al., 2001). Under such circumstances, a relatively hydrated magma that contains water (>3wt %) clinopyroxene is crystallized over plagioclase at shallow crustal depths/pressure (Feig et al., 2006). On the other hand, in a relatively dry magma, crystallization of clinopyroxene and olivine minerals are favored at high pressure (10-20 kbar) at the expense of plagioclase, whereas the plagioclase minerals preferably crystalize over clinopyroxene crystals at lower pressures. The predominant phases to crystallise at low pressure are feldspars and per-alkalinity melts, which are characterised by a high proportion of alkali metals relative to silica (Peccerillo et al., 2007). At high pressure, consistent clinopyroxene crystallisation takes place in the early stages of simulation, which inhibits magma evolution to high silica contents, which means magma will have a lower proportion of silica relative to other components (e.g., Lowenstern and Mahood, 199), cited in Peccerillo et al., 2007.

The research region provides details on the petro-volcano stratigraphy and magmatic history of a well-preserved volcano-stratigraphic sequence from the lower mafic deposit to the upper intermediate-trachyte unit. The mineral compositions and textures of the volcanic rocks in the research region vary, suggesting that magma flow and mineral fractionation in the lithosphere have varied depths. Several volcanic units, ranging in size from the bottom to the top, including Basalt, trachytic basalt, scoria, partially welded to welded rhyolitic tuff, welded trachyte tuff, rhyolite, welded andesitic tuff, andesite and trachyte lava flows, suggests a complex volcanic history of the rock.

5.3 Correlation of Furi Volcano with Previous Regional Works

The combined stratigraphic of the Furi volcano is correlated with the regional stratigraphy made by Tadiwos Chernet et al. (1998), depending on the petrological and geochronological characteristics of the volcanic rocks of the study area. According to Mazzarini et al. (2004), the region's central volcanoes Wachacha, Furi, Yerer, Zikwala, and Bede Gebabe developed between 4 Ma and 3 Ma and produced intermediate to strongly evolved lavas.

The correlation result indicates that at the top part of the Furi area Andesite, trachyte lava, and porphyritic trachyte are correlated with the Wechecha formation. The volcanic products at the middle part of the stratigraphy of the Furi volcano, partially Welded rhyolitic tuff, welded Andesitic tuff, welded Trachyte tuff, Welded rhyolitic tuff, and Rhyolite, are correlated with Naziret group Ignimbrite. Finally, the lower portion of the area scoria layer, Aphyric Basalt and Trachytic Basalt are correlated with the Addis Ababa Basalt.

The Addis Ababa region had Pliocene silicic activity at mainly trachytic volcanoes such Wechecha, Yerer, Furi, and Menagesha, the latter of which is a satellite of Wechecha (Tadiwos Chernet et al., 1998). The Wechecha Formation, which dates from 4.5 to 3 Ma, is made up of the product of this Pliocene silicic volcanism (Tadiwos Chernet et al. 1998). According to Tadiwos Chernet et al. (1998), the Nazret Group ignimbrite along the western escarpment has an age range of 6.8 to 5.8 Ma. These volcanoes are composed of Late Miocene-Pliocene flood basalts that are known as Addis Ababa Basalt (Morton et al., 1979; Tadiwos Chernet et al., 1998). The K-Ar age determinations from the basalts in the Addis Abeba region, according to Tadiwos Chernet et al., 1998, vary from 6.6 to 5 Ma, which is comparable to the range described above for basalts intercalated with ignimbrites from the Nazret Group.

The Bishoftu Basalt is between 2.8 and 2 Ma old and is connected to several scoria cones found on the serene escarpments of the MER in the Addis Abeba region (Tadiwos Chernet et al., 1998). According to Tadiwos Chernet et al. (1998), Bishoftu basalts have a distinctively alkaline composition that sets them apart from the contemporaneous transitional-tholeiitic stratoid basalts of the Afar Depression. According to Tadiwos Chernet et al. (1998), a sample from the Bishoftu basalt flow south of the Furi Volcano is 2 Ma old.

The stratigraphic arrangement of the volcanic products in the Furi volcano unit tells the nature of the eruption is non-explosive at first then explosive and finally the explosive.

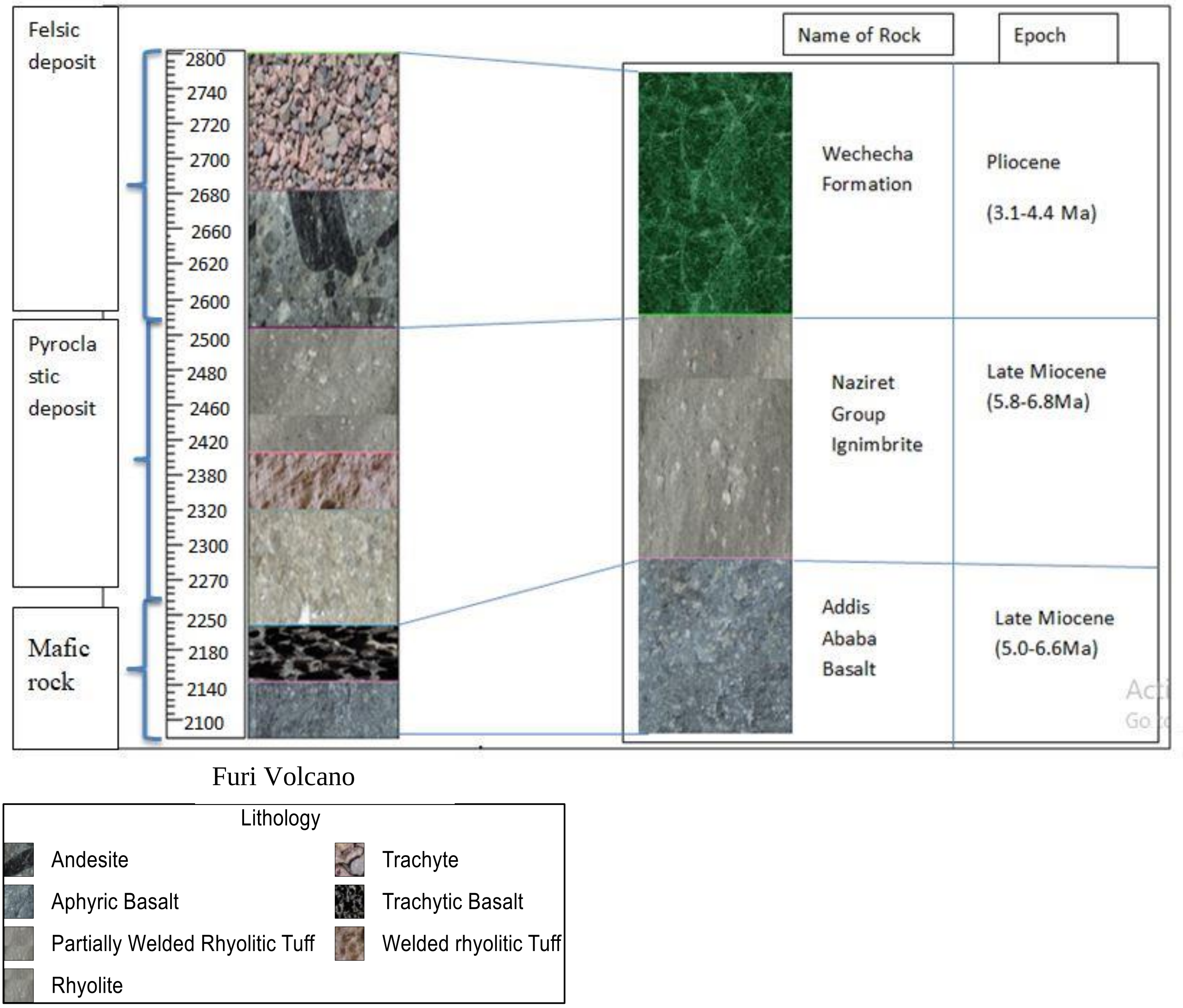
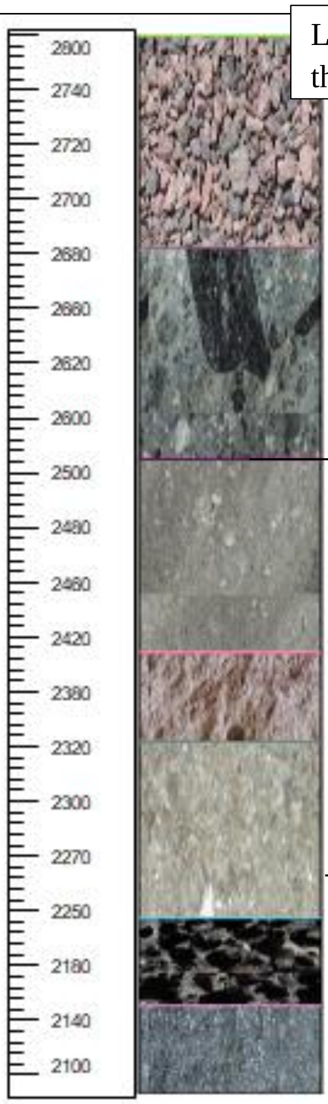


Figure 5.1: Correlation of Volcano-stratigraphic between Furi Volcano and Northern Main Ethiopian Rift-southern Afar transition zone (Ethiopia) which has developed by Tadiwos chernet et al., 1998.

Table 5.1: Summary descriptions of the research area's composite litho-stratigraphy



Lithology with thickness	Summary description
Andesite-Trachyte lava (150m)	Dominantly, it is composed of different types of trachyte, like Porphyritic, massive, and reddish trachyte. It is also composed of Andesite rock. Porphyritic trachyte is composed of phenocryts like plg, sanidine, and Alkali feldspars as microphenocryts. The Andesite rock type is composed of phenocryts like plagioclase, pyroxene, and others as fine groundmass, which shows radiating texture. The groundmass of trachyte shows the Trachytic texture or flow texture.
Partially Welded rhyolitic Tuff-Rhyolite (350m)	It is composed of pyroclastic deposits like partially welded rhyolitic tuff, Welded rhyolitic tuff, welded Andesitic tuff, welded Trachyte tuff, and a felsic unit called rhyolite. Partially welded and welded rhyolitic tuff contains minerals like plg, Akf and quartz as phenocrysts and others as groundmass with Eutaxitic texture. The texture of the welded trachytic tuff is porphyritic and trachytic. Rhyolite is one of the felsitic units that contain plg, Akf, and hbl as phenocryts and others as groundmass with felsophyre texture and also show Spherulitic texture (in which there is a radial intergrowth of fibrous minerals).
Aphyric Basalt-Trachytic basalt (150m)	- It comprises basalt, scoraceous basalt, and Trachytic basalt at the bottom of the volcanic stratigraphic succession. Basalt contains Olv, Plg, and Cpx as phenocryts and others as groundmass. Trachytic basalt comprises Plg-Cpx-Olv, which displays the trachytic groundmass texture.

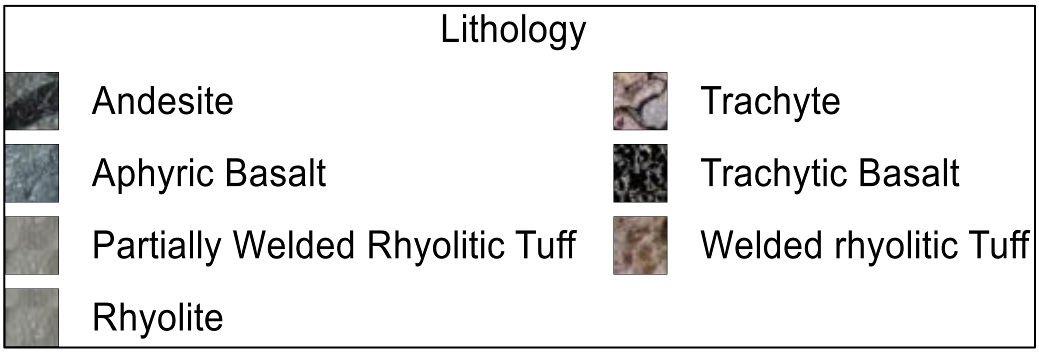


Table 5.2 Correlation of the research region's volcanic litho-stratigraphy to earlier investigations in the area

Previous works	Volcanic stratigraphy of Furi volcano (this study) Total thickness is **700m** from the **2100-2800m**.	Riftward younging of volcanic units in the Addis Ababa, Ethiopia rift valley by Morton et al.,1979	Northern Main Ethiopian Rift–southern Afar transition zone by Tadiwos chernet et al.,1998
Volcanic stratigraphy	**-**The stratigraphic sequence is composed of Felsic, Mafic and intermediate volcanic rocks. Silicic increase from the bottom to top part of successions and shows that it is per- and sub-alkaline. ✓ Basalt –Trachytic basalt (150m) ✓ Partially welded rhyolitic tuff-Rhyolite lava (350m) ✓ Andesite-Trachyte lava (200m)	-The area is covered by the Oliogo-Miocene plateau unit (Termaber and Alaji units-basalts, rhyolites and trachytes), Miocene rift shoulder basalts, ignimbrites, rhyolites and quaternary basalts and alluvio-lacustrine sediments. Those are; ✓ Oligo-Miocene Plateau Unit (300m) ✓ Upper Miocene Addis Ababa basalt (less than 130m) ✓ Upper Miocene-Pliocene rift series (greater than 300m)	The area is covered by the plateau basalt, Afar Rift floor basalts, Rift Margin Silicic Centers and associated basalts, Addis Ababa Rift Embayment, Young Rift Floor Basalts and Rhyolites. But, the stratigraphic succession correlated with the study area is with Rift Margin Silicic Centres and associated basalts (Addis Ababa Basalts and Naziret group ignimbrite), Addis Ababa Rift Embayment (Wechecha formation). ✓ Addis Ababa Basalts (130m) ✓ Naziret group ignimbrite (200-250m) ✓ Wechecha Formation (500m) The sample ranges from tholeiitic and alkaline basalts and basanites to trachytes and rhyolites (per-and sub-alkaline). Therefore, both per-alkaline and alkaline rocks are present in the area.
Petrography	- Rhyolites and ignimbrite samples had porphyritic contents ranging from 10 to 35% phenocrysts and are composed of alkali feldspar, quartz, plagioclase, and opaque minerals. In the basalt, plg, Ol, and Cpx (phenocryts), plagioclase, and olivine (microphenocryts and groundmass). In Trachytic basaltic-Trachyte samples and the intermediate rock samples, plagioclase, sanidine (phenocryts), opaque quartz, biotite occur as (microphenocrys, groundmass.)		

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following findings are reached based on the stratigraphic and petrographic examination of the volcanic unit in the Western Margin of the Central Main Ethiopian Rift in the instance of the Furi Volcano. There are various litho-stratigraphic units in the study's Rock units, such as the lower part of the Furi ridge with the unit like (Basalt, Scoria and Trachytic basalt) at the middle part of the study area like Felsic Pyroclastic deposits (Partially Welded rhyolitic tuff, Welded Andesitic Tuff, Welded Trachyte tuff, Welded Rhyolitic Tuff, Rhyolite) and from the middle to top part of the study area like Andesite, Trachyte lava, and porphyritic trachyte, which represent the Miocene to Pliocene, which is part of the Western Margin of the Central Main Ethiopian rift.

- ✓ The overall thickness of volcanic units in the study is (700m), Basalt to Trachytic Basalt (150m), Partially welded rhyolitic tuff to Rhyolite (350m), and Andesite to Porphyritic Trachyte (200m).This show that the Felsic rocks are more abundant than basic rocks.
- ✓ The Volcanic unit in the study area is composed from basalt to trachyte rock units with a small amount of intermediate rock units, and the Rhyolite rock units are intercalated with the Welded rhyolitic tuff which is found at the study area.
- ✓ The stratigraphic arrangement of the volcanic products in the Furi volcano unit provides information on the eruption's nature: Non-explosive at first, then explosive, and explosive in the end. Trachytic basalt, Scoria and aphyric basalt are the volcanic products that are produced during the non-explosive activity, which occurs between 6.6 and 5 Ma. The principal volcanic products of this explosive activity were Rhyolite lava, partially welded rhyolitic tuff, and welded rhyolitic tuff, which occurred between 6.8 and 5.8 Ma. Finally, the beginnings of explosive volcanic activity occur between 4.5 and 3 Ma, and the units are intermediate rock and the more felsic rock known as trachyte lava.
- ✓ The silicic volcanism's thickness increased from the research area's bottom to its top, and plagioclase predominated as phenocryts and groundmass.
- ✓ The petrography of the volcanic rock shows from the From aphyric to plagioclase, Sanidine and Clinopyroxene phyrics with a few phenocryts of clinopyroxene and olivine, and the rock has a scarce number of mega phenocryts, indicating that the magma did not have enough time to form larger crystals before it solidified.
- ✓ The presence of fine clastic sediments or paleosols or weathered or altered flow surfaces indicates a significant time interval between the emplacements of each layer of lava flow.

- ✓ The presence of plagioclase, clinopyroxene, and olivine minerals in basaltic magma indicates fractionation at the upper crust, while olivine-clinopyroxene mineral assemblages suggest deeper fractionation levels.

6.2 Recommendations

For a complete understanding of magmatic development, the findings required more research.

- ✓ A thorough geochemical analysis of the area to establish a direct link between the different lava products.
- ✓ Magma flow and depth of fractionation to evaluate the spatial distribution of felsic and mafic lavas and their link to their genesis.
- ✓ The research area is a portion of the Western Rift Margin, making it challenging to get a stratigraphic section that is well exposed. The Isotopic analysis is needed to understand magma evolution and the rock's geochronology history.

REFERANCES

Abbate E., & Sagri, M.(1980). Volcanite of Ethiopian and Somali plateau and major tectonic lines. Atti Convegni Lincei, 47, 219-227

Abbate, E., Bruni, P., & Sagri, M. (2015).Geology of Ethiopia; A review and Geomorphological perspectives. In P. Billi (Ed.), Landscapes and Landforms of Ethiopia (pp. 33–64).

Abebe,T., Manetti, P., Bonini, M., Corti, G., Innocenti, F.,Mazzarini, F.,and pecksay,Z.,(2005). Geological map (scale 1:200,000) of the northern main Ethiopian rift and its implication for the volcano-tectonic evolution of the rift: Geological society of America map and chart series MCH094, 20 p., doi: 110.1130/205GMOTNMERTXT

Agostini, A, Bonini, M, Corti,G, Sani,F, & Mazzarini,F.(2011). Fault architecture in the main Ethiopian rift and comparision with experimental models; Implications for rift evolution and Nubian-somalia kinematics. Earth and planetary sciences letter,301(3-4),479-492.

Amdemicael Zafu T, Dereje A,., Pik, R. Gezahegn Y., & Fontijn, K. (2019).Magmatic evolution of the Boku Volcanic complex Main Ethiopian rift. Journals of African Earth sciences, 149, 109–130

Baker, B. H., Mohr, P. A., & Williams, L. A. J. (1972). Geology of the eastern rift system of Africa. In Geological Society of America Special Papers (Vol. 136, pp. 1–68). Geological Society of America.

Baker, J.A., Thirlwall, M.F., and Menzies, M.A., 1996, Sr-Nd-Pb isotopic and trace element evidence for crustal contamination of plume-derived flood basalts: Oligocene flood volcanism in western Yemen: Geochimica Et Cosmochimica Acta, v. 60, p. 2559–2581

Bardin, G.,Raynal, J.,P., & Kieffer, G. (2004). Drainage pattern and Regional Morpho structure at melka kunture (Upper awash,Ethiopia)

Bekele, A., Acocella, V., Korme, T., & Dereje ,A. (2007).Quaternary faulting and volcanism in the main Ethiopian rift. Journal of African Earth Sciences, 48(2–3), 115–124.

Beutel, E., Van Wijk, J., Ebinger, C., Keir, D., & Agostini, A. (2010).Formation and stability of magmatic segments in the main Ethiopian and afar rifts. Earth and Planetary Science Letters, 293(3–4), 225–235.

Boccaletti, M., Getaneh, A., Mazzuoli, R., Tortorici. L., Trua, T., 1995. Chemical variation in a bimodalk magma system;The plio-Quaternary volcanism in the Dera Naziret area (Main ethiopian rift,ethiopia). Afr. Geosci. Rev 2, 37-60.

Boccaletti,M., Mazzuoli,R., Bonini,M.,Trua, T., & Abebe, B.,(1999). Plio-quaternary volcanotectonic activity in the Northern sector of the Main Ethiopian Rift: Relationships with oblique rifting. Journals of African Earths Sciences, 29(4), 679–698.

Bonini, M.,Corti, G.,Innocent, F.,Manetti, P.,Mazzarini, F.,Abebe, T.,&Pecskay, Z.(2005). Evolutions of the Main Ethiopian Rift in the frame of Afar and Kenyan rifts propagations: Tectonics, 24(1).

Bosworth, W., Strecker, M. R., & Blisniuk, P. M. (1992).Integration of East African pale stress and present –day stress data: Implications for continental stress field dynamics. *Journal of Geophysical Research, 97*(B8), 11851.

Brune, S., Williams, S.E., and Müller, R.D., 2017, Potential links between continental rifting, 1743 CO2 degassing and climate change through time: Nature Geoscience, v. 10, p. 941– 1744 946, doi:10.1038/s41561-017-0003-6.

Chorowicz, J. (2005). The East African rift system. Journal of African Earth sciences, 43(1-3), 379-410

Corti, G. (2009). Continental rift evolution: From rift initiation to incipient break up in the Main Ethiopian Rift, East Africa, Earth-science reviews,96(1-2),1-53

Corti, G., Molin, P., Sembroni, A., Bastow, I. D., & Keir, D. (2018). Control of Pre-rifts Lithospheric Structures on the Architecture and evolution of Continental Rifts: Insights from the Main Ethiopian Rift, East Africa. Tectonics, 37(2), 477–496.

Corti,G.,Bonini,M.,Conticelli,S.,Innocenti,F.,Manetti,P., & Sokoutis,D., (2003).Analogue Modelling on the relations between the pattern deformation and the presence of magma. Earth-Science Reviews, 63(3–4), 169–247.

Daniel, M, D., Chekol, T., & Negussia, S. (2021). Major and Trace elements Compositions of basaltic lavas from western margin of central main Ethiopian rift; Enriched asthenosphere vs. mantle plume contribution. Heliyon, 7(12), e08634.

Dereje, A., & Gibson, S.A (2009). Head-to-tails Transition of the Afar mantle plume: Geochemical evidences from a Miocene Bimodal Basalt-Rhyolite succession in the Ethiopian large Igneous province. Lithos, 112(3–4), 461–476.

Dereje, A., Di Vito, M., Isaia, R., Orsi, G. and Gezahegn Yirgu (2003). The Gedemsa Caldera (Main ethiopian rift); an example of interplay among Regional tectonism, volcanism and volcano-tectonics. In: EGS-AGU-EUG Joint Assembly, PP. 5919.

Di Paola, G. (1971).Geology of the corbetti caldera (Main Ethiopian rift valley), Bulletin Volcanologique 35(2):497-506.

E. Wolfenden, C. Ebinger, G. Yirgu, P. Renne, S.P. Kelley, Evolution of the southern Red Sea rift: birth of a magmatic margin, Geol. Soc. Am. Bulletin (2004) in press

Ebinger, C. and Casey, M. (2001). Continental breakups in magmatic Provinces: an Ethiopian example. Geology 29(6):527-530.

Ebinger, C. J., Deino, A. L., Tesha, A. L., Becker, T. and Ring, U. 1993. Tectonics control on rift basin Geometry: Evolution of the Northern Malawi (Nyasa) rift. Journal of Geophysical Research, 98, 17821–17836.

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

Eyasu Leta. (2014). Application of Integrated Geophysical Techniques to Map Deep Groundwater Potential Zones and Geological Structures at South-West Akaki, South-East of Addis Ababa, Ethiopia (Doctoral dissertation, Addis Ababa University).

Gasparon, M.,Innocenti, F., Mannetti, P., Peccerillo,A., & Tsegaye,A.(1993). Genesis of the pliocene to recent bimodal mafic-felsic volcanism in the Debre Zeyt area, central Ethiopia: Volcanological and geochemical constraints. Journals of African Earth sciences (and the Middle East), 17(2), 145-165.

George, R.M., and Rogers, N.W., 2002, Plume dynamics beneath the African Plate inferred from the geochemistry of the Tertiary basalts of southern Ethiopia: Contributions to Mineralogy and Petrology, v. 144, p. 286–304.

Gezahegn Yirgu., Ebinger, C. J., & Maguire, P. K. H. (2006). The Afar Volcanic province within the east african rift sytstem:Introduction.Geological society,London,special publications,259(1),1-6

Giday Woldegabriel, Aronson, J. L., & Walter, R. C. (1990). Geology, Geochronology and rift basin developments in the Central Sector of the Main Ethiopia rift. Geological Societies of America Bulletin, 102(4), 439–458.

Gidey WoldeGabriel, G., Walter, R. C., Aronson, J. L., & Hart, W. K. (1992).Geochronology and distribution of silicic Volcanic rocks of Plio-Pleistocene ages from the Central Sector of the Main Ethiopian Rift. Quaternary International, 13–14, 69–76.

Gidey WoldeGabriel., Heiken, G., White, T. D., Asfaw, B., Hart, W. K., & Renne, P. R. (2000). Volcanism, tectonism, sedimentation, and the paleoanthropological record in the Ethiopian Rift system. In F. W. McCoy & G. Heiken, Volcanic Hazards and Disasters in Human Antiquity. Geological society of America.

Giordano, F., D’Antonio, M., Civetta, L., Tonarini, S., Orsi, G., Ayalew, D., Yirgu, G., Dell’Erba, F., Di Vito, M. A., & Isaia, R. (2014). Genesis and evolution of Mafic and Felsic magmas at Quaternary volcano within the Main Ethiopian rift: Insights from Gademsa and Fantale complexes. Lithos, 188, 130–144.

Hayward, N.J. and Ebinger,C.J.,1996. Variation in the along axis segmentation of the afar rift sytstem. Tectonics, 15, 244–257. doi:10.1029/95TC02292.

Hübert, J., Whaler, K., & Fisseha, S. (2018). The Electrical Structure of the Central Main Ethiopian Rift as Imaged by Magnetotellurics: Implications for Magma Storage and Pathways. Journal of Geophysical research:solid earth,123(7),6019-6032.

Hutchison, W., Mather, T. A., Pyle, D. M., Biggs, J., & Yirgu, G. (2015). Structural control on fluid pathways in an active rift sytstem: A case study of the aluto volcanic complex. Geosphere, 11(3), 542–562.

Kabeto, K., Sawada, Y., & Roser, B,(2009). Compositional Differences between Felsic volcanic rocks from the margin and centre of the Northern Main Ethiopian rift. Momona Ethiopian Journal of Science, 1(1).

Keranen, K., & Klemperer, S. L. (2008). Discontinous and diachronous evolution of the Main Ethiopian rift:implication for development of continental rifts. Earth and Planetary Science Letters, 265(1–2), 96–111.

Keranen, K., Klemperer, S.L., Gloaguen, R. and Eagle Working Group, 2004. Three-Dimensional seismic imaging of a protoridges axis in the Main Ethiopian rifts. Geology 32, 949–952

Kieffer,B.,Arndt,N.,Lapierre,H.,Bastien,F.,Bosch,D.,Pecher,A.,Yirgu,GT.,Ayalew,D.,weis,D.,Jerram,D.A.,Keller,F., & Meugniot,C.(2004).Flood and shield basalts from Ethiopia: Magmas from the African Supers well. Journal of Petrology, 45(4), 793–834.

Krans, S. R., Rooney, T. O., kappelman,J.,Yirgu,G.,& Ayalew,D.,(2018).From initiation to termination: A petrostragraphic tour of the Ethiopian low-Ti Flood basalt province. Contributions to Mineralogy and Petrology, 173(5), 37.

Macgregor, D. (2015).History of the development of the east African system: a Series of interpreted maps through time. Journal of African Earth Sciences, 101, 232–252.

Maerker, M., Schillaci, C., Melis, R. T.,Kropacek, J.,Bosino,A.,Vilimek, V., Sommer,C., Altamura, F., & Mussi ,M.(2019).Geomorphological processes, forms and features in the surroundings of the Melka Kunture Palaeolithic sites , in Ethiopia. Journal of maps, 15(2), 797–806.

Mazzarini, F. (2004). Volcanic vent self-similar clustering and crustal thickness in the Northern Main Ethiopian rift, Geophysical Research Letters, 31(4), L04604.

Mazzarini, F. (2004). Volcanic vent self-similar clustering and crustal thickness in the Northern Main Ethiopian rift, Geophysical Research Letters, 31(4), L04604.

Merla, G., Abbate, E.,Azaroli, A., Bruni, P.,Fazzuoli, M.,Sagri, M. Taconi, P., 1979. Comment and Geological Map of Ethiopia, Somalia. Scale 1:2,000,000. Firenze, Italy, Consiglio Nazionale delle Ricerche, 89 p

Mohr, P. (1992). Nature of the Crust beneath magmatic ally active Continental rifts. Tectonophysics, 213(1–2), 269–284.

Mohr, P. A. (1971). Ethiopian Rift and plateaus: some volcanic petrochemical differences. Journal of Geophysical Research, 76(8), 1967–1984.

Mohr, P.A., Zanettin, B., 1988. The Ethiopian flood basalt province. In: Macdougall, J.D. (Ed.), Continental Flood Basalts. Kluwer, pp. 63–110.

Morgan, L. E., Renne, P. R., Kieffer, G., Piperno, M., Gallotti, R., & Raynal, J. P. (2012). A chronological framework for a long and persistent archaeological record: Melka Kunture, Ethiopia. *Journal of Human Evolution*, *62*(1), 104-115.

Morley, C., 1999. Tectonic evolution of the East African Rift system and the modifying influence of magmatism. Acta Vulcanol. 11, 1–20.

Morse, S. A. (1980). Basalts and phase diagrams: an introduction to the quantitative use of phase diagrams in igneous petrology (p. 493). New York: Springer-Verlag.

Morton, W. H., Rex, D. C., Mitchell, J. G., & Mohr, P. (1979). Riftward younging of volcanic units in the Addis Ababa region, Ethiopian rift valley. Nature, 280(5720), 284–288. https://doi.org/10.1038/280284a0

Omenda, P. A. (2010). The Geology and Geothermal activities of the East African Rift. Short Courses V on Explorations for geothermal Resource, organized by UNU-GTP, GDC and KenGen, at Lake Bogoria and Lakes Naivasha, Kenya, Oct.

Peccerillo, A., Barberio, M. R., Yirgu, G., Ayalew, D., Barbieri, M. W. U. T. W., & [] 8Wu, T. W. (2003). Relationships between mafic and peralkaline silicic magmatism in continental rift settings: a petrological, geochemical and isotopic study of the Gedemsa volcano, central Ethiopian rift. *Journal of Petrology*, *44*(11), 2003-2032.

Peccerillo, A., Donati, C., Santo, A. P., Orlando, A., Yirgu, G., & Ayalew, D. (2007). Petrogenesis of silicics peralkaline rocks in the Ethiopian rift: Geochemical evidence and volcanological implication. Journal of African Earth Sciences, 48(2–3), 161–173.

Rampey, M. L., Oppenheimer, C., Pyle, D. M., & Yirgu, G. (2010). Caldera forming eruption of the Quaternary Kone Volcanic Complexs, Ethiopia. Journal of African Earth Sciences, 58(1), 51–66.

Ring, U. (2014). The East African Rift System. Austrian J Earth Sci 107(1):132-146.

Rooney, T. O. (2020). The cenozoic magmatism of east Africa: Part III – Rifting of the craton. Lithos, 360–361, 105390. https://doi.org/10.1016/j.lithos.2020.105390

Rooney, T. O., Nelson, W. R., Dosso, L., Furman, T., & Hana, B. (2014). The Role of continental lithospheres metasome in the productions of HIMU-like magmatism on the northeast Africans and Arabian plates. Geology, 42(5), 419–422.

Rooney, T., Furman, T., Bastow, I., Ayalew, D., & Yirgu, G. (2007). Lithospheric modifications during crust extension in the Main Ethiopian Rift. Journal of Geophysical Research, 112(B10), B10201.

Tadiwos Chernet, Hart, W. K., Aronson, J. L., & Walter, R. C. (1998). New Age Constraint on the timing of volcanism and tectonism in the northern Main Ethiopian Rift–southern Afar transition zone (Ethiopia). Journal of Volcanology and Geothermal Research, 80(3–4), 267–280.

Tesfaye Shewa,. (2007). Assessments of Groundwater And its vulnerabilities to pollution by Vertical Electrical Sounding in Ada'A plain. Unpublished masters dissertation, Addis Ababa University.

Trua, T., Deniel, C., & Mazzuoli, R. (1999). crustal Control in the genesis of Plio-Quaternary bimodal Magmatism of the Main Ethiopian Rift (MER): geochemical And isotopic (Sr, Nd, Pb) evidence. Chemical Geology, 155(3–4), 201–231.

Tsegaye Abebe., Balestrieri, M. L., & Bigazzi, G. (2010). The Central Main Ethiopian Rift is younger than 8 Ma: Confirmations through apatite fission-track thermochronology: The Central Main Ethiopian Rift is younger than 8 Ma. Terra Nova, 22(6), 470–476.

Tsegaye Abebe., Mazzarini, F., Innocenti, F., & Manetti, P. (1998). The Yerer-Tullu Wellel volcanotectonic lineament: transtensional structure in central Ethiopia and the associated magmatic activity. Journal of African Earth Sciences, 26(1), 135–150.

Ukstins, I. A., Renne, P. R., Wolfenden, E., Baker, J., Ayalew, D., & Menzies, M. (2002). Matching Conjugate volcanic rifted margins: 40Ar/39Ar chrono-stratigraphy of pre- and syn-rift bimodal flood volcanism in Ethiopia and Yemen. Earth and Planetary Science Letters, 198(3–4), 289–306.

Weissel, J. K., & Karner, G. D. (1989). Flexural uplift of rift flanks due to mechanical unloading of the lithosphere during extensions. Journal of Geophysical Research: Solid Earth, 94(B10), 13919–13950.

Williams, F. M., & Williams, F. M. (2016). The rift margins and the Great Western Escarpment. Understanding Ethiopia: Geology and Scenery, 225-242.

Wolde, B. 1996. Spatial and temporal variation in the compositions of Upper Miocene to Recent basic lavas in the Northern Main Ethiopian rift: implication for the causes of Cenozoic magmatism in Ethiopia. Geol. Rundsch, 85: 380-389.

Wolfenden, E., Ebinger, C., Yirgu, G., Deino, A., & Ayalew, D. (2004) Evolution of the Northern Main Ethiopian rift: Birth of a triple junction. Earth and planetary science Letters, 224(1–2), 213–228.