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ADDIS ABABA UNIVERSITY  
COLLEGE OF NATURAL SCIENCE  
SCHOOL OF EARTH SCIENCES

**ASSESSING VOLCANIC HAZARDS FROM FUTURE ERUPTIONS OF CHABBI  
VOLCANO, CENTRAL MAIN ETHIOPIAN RIFT, ETHIOPIA.**

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Advisor: Gezahegn Yirgu (Professor)

February 2014

Addis Ababa

Assessing volcanic hazards from future eruptions of Chabbi volcano, Central Main  
Ethiopian Rift, Ethiopia

By

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School of Earth Sciences

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## **Abstract**

Chabbi Quaternary volcano is located on the Wonji Fault Belt or magmatic segment of the Main Ethiopian Rift (MER) where active extensional tectonics and volcanism is taking place. Particularly, it is found in the southern part of the MER between Lake Shalla to the north and Lake Hawassa within Corbetti caldera to the south. From field observation, previous work, satellite image and GIS and Remote sensing incorporation, the volcanic evolution and current activity of Chabbi has been interpreted. It has been established that Chabbi is a composite rhyolite volcano built during the Holocene. The eruption sequence of this volcano consists of rhyolitic lavas and domes, at the base followed by explosive eruptive products in the intermediate and degassed obsidian flows in the final phase. The volcano has emitted very young products in recent geological times and is currently at fumarolic stage.

The volcano has proximity to Hawassa city, Shashamane town and Tikur Wuha, Bura and Aje villages as well as to densely populate rural farming communities. The surrounding region further includes major infrastructures and growing agricultural and industrial activities. As Chabbi volcano currently shows vigorous fumarolic activity, its potential future eruptions poses a significant volcanic hazard to a large population, important infrastructures and booming economic activity.

An assessment of the potential volcanic hazard from its future eruptions has been attempted based on the volcano's past eruptive behavior and probable future scenarios. Tentative volcanic hazard maps and zones have been attempted in GIS environment considering eruption scenarios from six identified vents affecting an area over a moderate distance of 15km radius.

## **Acronyms**

ETM	Enhanced Thematic Mapper
MER	Main Ethiopian Rift
GIS	Geographic Information System
GPS	Global Positioning System
ERDAS	Earth Resources Data Analysis Systems
SPOT	Satellite Probatoire d'Observation de la Terre Sensor Placement
3D	Three Dimensions
DEM	Digital Elevation System
SRTM	Shuttle Radar Topographic Mission
m.a.m.s.l	Meter above Mean Sea Level
WFB	Wonji Fault Belt

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# 1. Introduction

## 1.1 Back ground of study area Geographic setting and previous Work

Volcano is typically a cone-shaped hill or mountain formed at a vent from which molten rock, called magma, or magmatic gases reach the Earth's surface and erupt (D. Hyndman and D. Hyndman, 2010).

Volcanic hazard is constitute varies problems in developing countries. Poor land use management, establishment of some facilities in ad joint to population growth may increase the susceptibility to volcanic catastrophe (M.T. Pareschi et. al 2000).

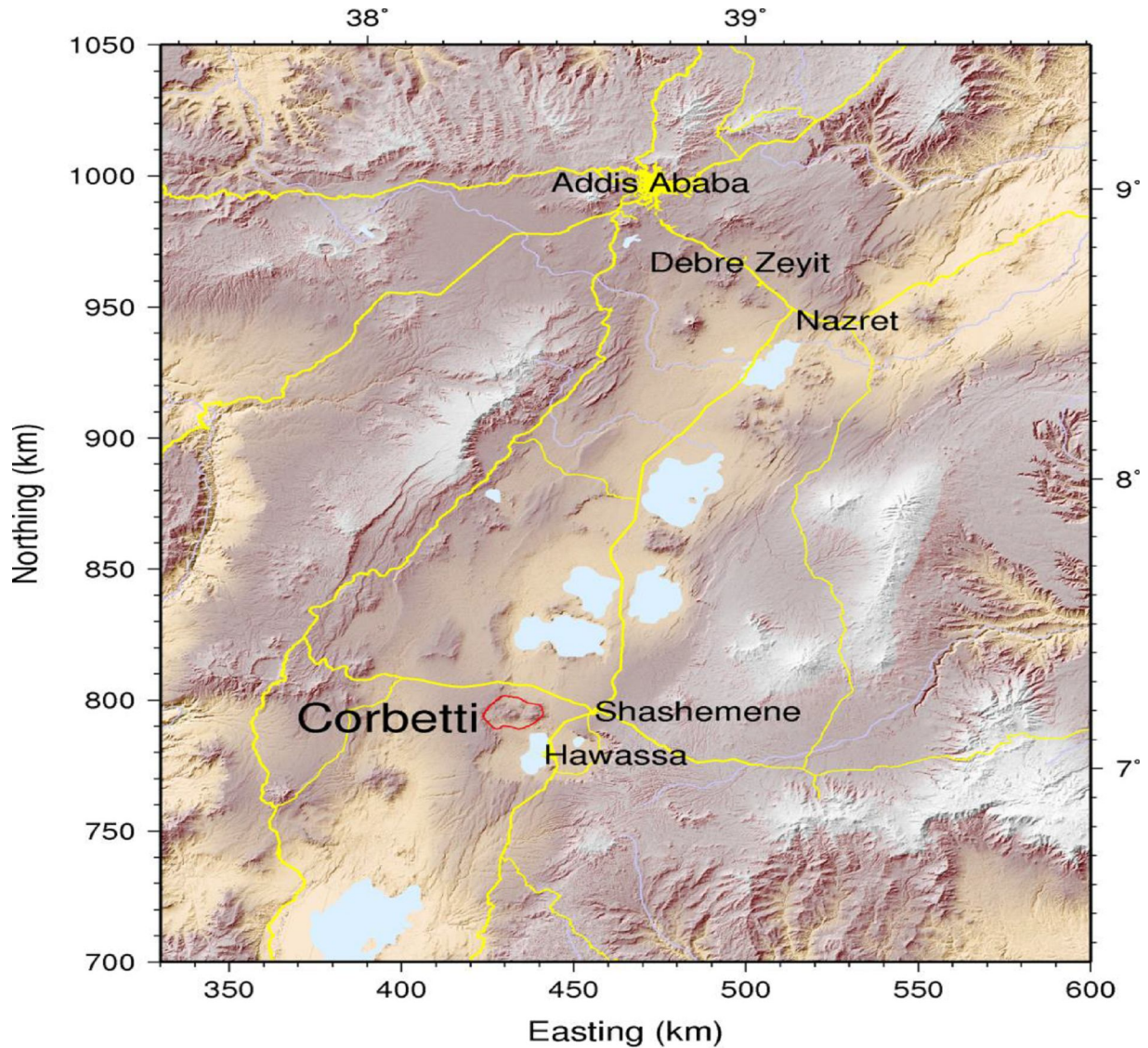
Seismically and volcanically active East African rift system has long been a classic area for investigation of rifting and break-up; because its sectors encompass basins in all stages of rift to passive margin development (GezehagnYirgu et.al. 2006). Its architecture is defined on the basis of both structural and magmatic components. It extends 3000 km from the Afar depression in the north to the Okavango Delta in the south, through Djibouti, Ethiopia, Kenya, Uganda, Burundi, Rwanda, Democratic Republic of Congo, Tanzania, Zambia, Malawi, Zimbabwe and Botswana (GezehagnYirgu et.al. 2006).

Main Ethiopian Rift is a region where extensional tectonic processes and massive volcanic activity are taking place. Ongoing lithospheric thinning has been generating a regional heat flow anomaly that extends along all parts of the rift with present day volcanic activity as a result there are much surface hydrothermal activity over large areas. The Erta'ale lava lake, the eruption of Dabbahu volcano in 2005, Karbahi in 2007, and 2009, the explosive eruption of Nabro volcano in 2011, hydrothermal manifestations in Afar rift, and Central MER (particularly at Aluto and Chabbi Volcanoes) and surface deformation of volcanoes such as Aluto, Corbetti, Haledebi (Biggs, 2011) are indicators of shallow magma beneath the Ethiopian and Afar rifts.

Chabbi Quaternary volcano is found in southern part of the MER between Lake Shalla to the North and Lake Hawasa to the South and adjacent Eastern escarpment to the East at coordinates  $7^{\circ} 10' N$  and  $38^{\circ} 27' E$  in Corbetti caldera on Wonji Fault Belt. Corbetti caldera has two volcanoes (Chabbi and Urji). Thus it is visible from main road Addis Ababa - Hawassa to the west ward on the distance 270km from Addis Ababa.

Chabbi volcano is about 8.5km to the north west of Hawassa city and 14km from Shashamane town. The people inhabiting the Corbetti caldera where Chabbi volcano is nested in are farmers

and some are pastoralists. Hawassa is the capital of the Regional Government of the Southern Nations, Nationalities and Peoples (SNNP). It is so known business and tourism city. Closer and closer to this volcano the people are settled. Even on the vent of hot cone there are seasonal shelter of farmers and nomads.



*Figure 1. Location of Chabbi volcano within the Main Ethiopian Rift.*

Some scholars were not clear with naming of Chabbi volcano. Thus since 1898 it gets different names which was almost nearby each other. Darragon used “TChobbe” after his expedition in south part of the country by 1897 and he used the same name in his report and map used to show the Chabbi as volcano for the first time (Mohr, 1966). Mohr (1966) also wrote that other scholar called Erlanger visited Lake Hawassa by 1900 and he used the name of volcano as “Djabi”. Here

the writer didn't use "Ch", perhaps 'Dj'. Even though there was such controversy, the local people are clear with the original name of the volcano. They call it with name "Chabbi" which come from the word "Chabbi Gurraacha"; it means that "black snow". The glassy like nature of the obsidian lead the locals to call it black snow. The origin of the name also started by "ch" a known letter in "afaan oromoo" which is the local language nearby Chabbi volcano.

## **1.2 Statement of the problem.**

The Main Ethiopian Rift, together with the Afar rift, is a region where extensional tectonic processes and intense volcanic activity are taking place. Ongoing lithospheric thinning has been generating a regional heat flow anomaly that extends along all parts of the rift with present day volcanic activity and surface hydrothermal activity over large areas. The Erta'ale lava lake, the eruption of Dabbahu volcano in 2005, Karbahi in 2007, and 2009, the explosive eruption of Nabro volcano in 2011, hydrothermal manifestations in Afar rift, and Central MER (particularly at Aluto and Chabbi Volcanoes) and surface deformation of volcanoes such as Aluto, Corbetti, Haledebi (Biggs, 2011) are indicators of magma beneath the Ethiopian and Afar rifts. Further, Aspinall et al (2011) report the presence of 65 active volcanoes in Ethiopia distributed within the MER and Afar (Fig. 1).

Chabbi is an active volcano where a lot of thermal manifestations are visible. The location of this volcano is nearby Hawassa city, Shashamane, Bura, Aje towns and surrounded by farm communities. It is about 8.5 km North West of Hawassa city and about 14km from Shashamane town toward South West. The area is geologically active that magma may exist at shallow depth and that is why ongoing fumaroles are visible. Thus in the future it is expected to get eruption from this volcano. Consequently some human life and property damage may result from it. So to escape from such risk it is so important giving due attention, monitoring and use of early warning system may reduce such unexpected loose. Assessing possible volcanic hazard prone area and zoning will take place. So the aim of this thesis is the first phase to reduce the hazard.

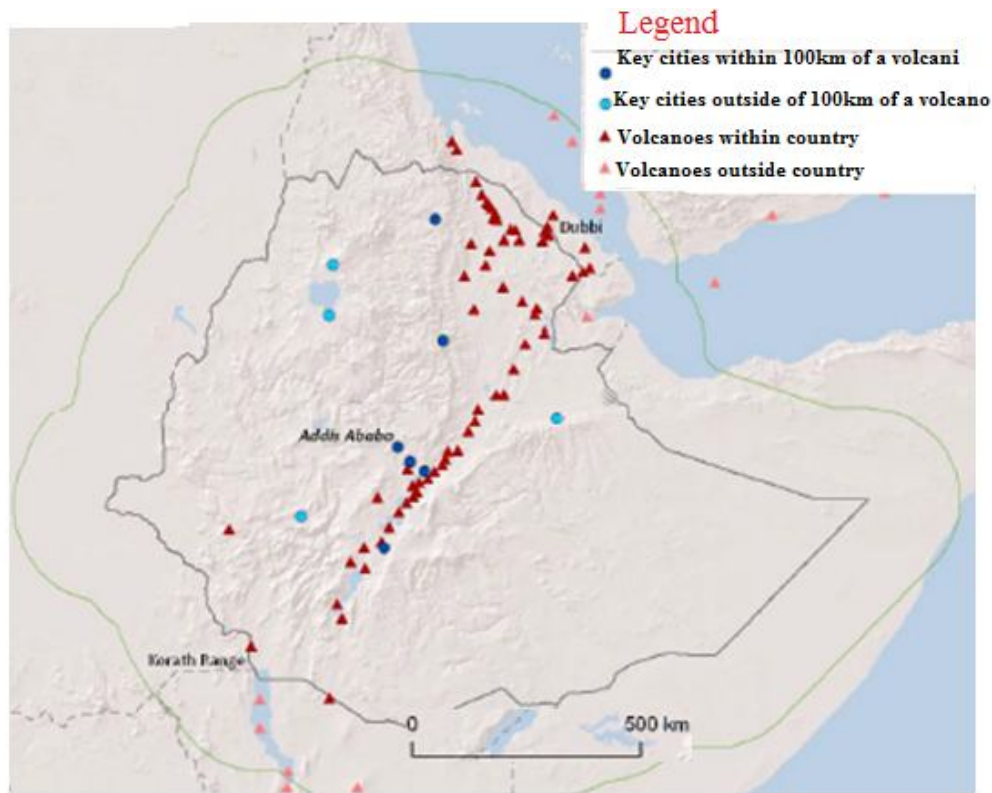


Figure 1.2 Distribution of active volcanoes in Ethiopia and surrounding countries (Aspinall et al., 2011).

Either than dealing with the geology of the area, no study has been made about detail explanation of volcanic products, bedding, sorting and morphology of the volcano to trace the future eruption and its exposure to volcanic hazard. If it is continued as it is ignored as present situations and based on the rate of population development and expansion of infrastructure, one can guess how much the hazard will be erroneous. The base idea of this paper is studying its past product and tentative zoning its future potentially vulnerable to volcanic hazard.

Chabbi didn't get any attention until 1960 when Mohr (1966) who made a preliminary study of its geology. He tried to explain and map the volcanic geology of Chabbi. This was done based on field visit only. Thus the difficult part of the scholar faced was the bush coverage of the area and absence of remotely sensed data.

The other activity took place here was the Pantellirite analysis of Chabbi obsidian by R Mc Donald and I L Gibson in (1969). Later geologic explanation of Corbetti caldera area was done by G. M Diapola (1972). This explanation was about the caldera and volcanoes found within the caldera.

Mohr (1966) interpreted Chabbi as a dormant volcano, but this may contradict with his recommendation of evacuation. He related the character of volcano with its location in rift valley. But he didn't make even single zoning which may use the authority to have some knowhow which area will be affected. Even if he suggested evacuation for both Hawassa and Shashamane, he said the volcano is dormant. So his recommendation is contra-version to his explanation to the volcanic activity. . Thus to fill these gaps this paper will consider volcanic products, its bedding, morphology and stratigraphy to discuss type eruptions from its evolution and explain the future eruption by producing tentative hazard zoned map. Furthermore the future eruption will trace back to the earlier eruption mode.

### **1.3 Objectives**

- ❖ The main objective is to assess the types and magnitudes of volcanic hazards from future eruptions and to produce tentative volcanic hazard zonation maps for Chabbi volcano.

#### **Specific objectives**

- Identify the types, succession and distribution of earlier eruptive products of Chabbi volcano.
- Produce geomorphologic and volcanic maps of Chabbi volcano.
- Reconstruct the volcanic evolution and eruptive styles of the volcano
- Assess the probable future centers of eruption and eruption styles Produce tentative volcanic hazard maps overlaying all parameters in GIS environment.

### **1.4 Limitations**

It is obvious that the explosive eruption will be controlled with the wind direction. The wind speed and direction could determine the extent of coverage for explosive products and manage the hazard facing direction. During the conduction of this thesis I could not get the clear and recorded wind data of the study area. Therefore, I was forced to delineate the tentative hazard zone to by following the earlier volcanic product coverage directions.

## **2 Materials and Methodology**

### **2.1 Materials**

Different materials have been used to conduct this research both in the field and in the office. During field work materials like hammer, hand lens, sample bags and hand held GPS. The other are of office used materials like computer, geologic Map, GIS software, etc. are crucially used.

### **2.2 Methods**

To reach at the specified objectives the following methodologies were used. These include literature review, field investigations, using GIS and Remote sensing techniques.

#### **2.2.1 Literature review**

All previous published and unpublished works including journal articles, reports and maps on Chabbi volcano and adjacent areas were collected and critically evaluated for useful data and information. The available information was compiled and used in the field investigations along with remote sensing techniques.

#### **2.2.2 Field investigations**

Field investigation is primary and the most useful activity in understanding volcano it was made to attain the stated objective. Thus during field investigation, various activities were done. In all direction the extent of both altered and unaltered past products were visited. The detail observations of outcrops were done. The morphology and lithological units of area is characterized. The product types and contacts were observed. Physical Volcanology characteristics of the eruptive products including, rock and pyroclastic textures, grain size and degree of welding were determined. Thickness of lithological units were measured; bedding, and flow morphologies were characterized

Using hand held GPS and previous map produced by Mohr (1966) and Di Paola (1972) ground verification was done. Satellite image interpretation and ground verification was linked for image verification. Fractures and faults were observed, fracture directions and vent location was identified. Tectonic and geologic activity of the area was viewed. The comparison of (Mohr 1966) geologic descriptions and current activity were compared. The contacts of earlier Chabbi volcano product and its current activity were related to estimate its future activity. All vents of Chabbi volcano were observed. The location, vent orientations, vents current activity and their geological coherence and link were technically identified. From the contacts and bedding

structures of their products, the eruption sequences of these vents were estimated. In all directions the product types and their thickness were measured.

### **2.2.3 Remote sensing and Geographic information system techniques**

Remote sensing and GIS techniques have been incorporated to reach at the proposed objective. The general objective was achieved after the operations of those techniques equipped within software of ArcGIS 10 and ERDAS imagine (Lica Geosystems, version 2011).

#### **2.2.3.1 Remote sensing applications**

Remote sensing, particularly satellites offer an immense source of data for studying spatial and temporal variability of the environmental parameters (K. Perumal and R. Bhaskaran, 2010).

Image processing software ERDAS Imaging (Leica Geosystems version 2011) was used for interpretation of remotely sensed data/satellite images. SPOT satellite image 10m resolution was acquired and used. Using ERDAS, supervised classification was performed to identify the product types and coverage area. For image classifications, band combinations were applied.

#### **2.2.3.2 GIS techniques**

Geographic information system (GIS) has tools that enable us to map geology of the eruption area and to delineate the vulnerable area for future eruption hazards. ArcGIS version 10 was utilized for the GIS data integration, geologic mapping and delineations of possible hazard zones as per decision made. Using spatial analysis and 3D analysis tools, SPOT image was interpreted with image processing software ERDAS Imaging (Leica Geosystems, version 2011) was mapped. Mapping activity is based on ground truth and review of previous works. Therefore, the area coverage of visible Chabbi product is estimated.

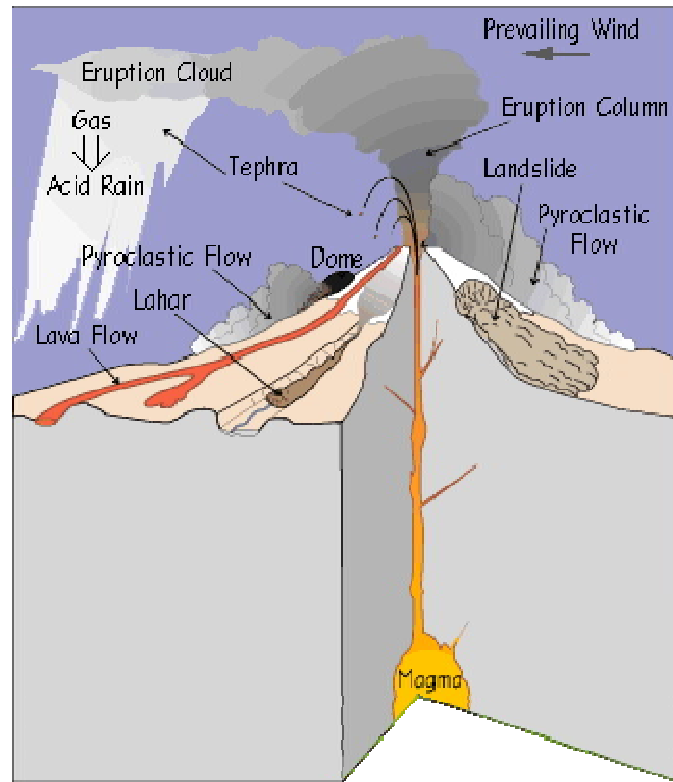
Using DEM of the study area from SRTM of Landsat image the elevation profile is delineated. Elevation versus distance profile paves the way to estimate coverage by lava flows and explosive fall products. Image classification with Remote sensing techniques, incorporated previously produced volcanic geology of Chabbi by Mohr (1966) and Di Paola (1972). The overall geological information has been overlaid to produce a modified volcanological map of Chabbi volcano. Possible flow and fall hazard for future eruptions were estimated and mapped. Tentatively possible volcanic hazard for lava flow was estimated and zoned by incorporating the elevation, morphology and magma physical properties alternative pyroclastic fall hazard was produced and zoned. The current wind direction was considered.

### 3 Background on Volcanic Hazard

A volcano is an opening in Earth's surface. Magma contains a mixture of silicates and dissolved gases. As magma rises closer to the Earth's surface the pressure decreases and the dissolved gases come out of solution to form bubbles. As the bubbles expand the magma is pushed into the volcanic vent until it breaks through weaknesses in the Earth's crust. The explosive potential of the volcano is dependent on the effervescence of the gases and the viscosity of the magma. High gas effervescence and low viscosity cause the most explosive eruptions.

Magma and gas rise through the opening and burst forth. The opening is usually found at the top of a cone shaped mountain. These mountains are often called volcanoes. Volcanoes are not all the same. They can look very different. Layers of magma form volcanoes. The size and shape of a volcano depend on the magma's thickness. The type and timing of eruptions also change how volcanoes look.

A volcano is typically a cone-shaped hill or mountain formed at a vent from which molten rock, called magma, or magmatic gases reach the Earth's surface and erupt, (D. Hyndman, 2010). Volcanism is a spectacular display of the complex way in which energy and materials are exchanged between three major components of our planet: the solid Earth, oceans, and atmosphere. The science of Volcanology draws from many different fields, including petrology, geochemistry, seismology, and sedimentology. It began with mainly qualitative observations about the distribution of volcanoes, their eruptive behavior, and the types of products they create (J. Mart'ı and G. G. J. Ernst, 2005).



*Figure 3.1 Cartoon showing a central volcano, major eruption styles and associated hazardous products*

The concept of volcanic hazards refers to the group of events that takes place at volcano and can cause damage to people or exposed properties. That means volcanic eruption is a fascinating catastrophe to the vulnerable people worldwide. Volcanic hazards can be defined as the probability for a point being affected by a hazardous process during a considered time interval  $\Delta t$  (A. Felpeto et al, 2007). It will take place where there is population settlement and infrastructures nearby volcanic site. Thus active site should be assessed and tentative mapping of the vulnerable areas will be done with the below described methods. It is estimated that about 10% of the world's population live within proximity of active and potentially active volcanoes. With projected population growth, by the twenty-first century more than 500 million people could be at risk from volcano hazards (Peterson, (1986); Tilling and Lipman, (1993)). Of this half billion people at risk, roughly equal to the estimated entire world population at the beginning of the seventeenth century, about 90% live in the circum-Pacific region. Also in the twenty-first century, with continued increasing urbanization there will be more than 100 cities with greater than 2 million population and many of these will be located within 200 km of volcanically active

subduction zones (McGuire, 1995a). Compared to other hazards, natural or manmade, volcano hazards have caused far fewer fatalities, largely because they occurs infrequently; floods, storms, earthquakes, and droughts are the most frequently occurring natural hazards and affect far more people (Tilling, 1989b).

Hazardous processes associated with volcanic eruptions largely were little appreciated perhaps until the 1883 eruption of Krakatau (Sunda Strait, between Java and Sumatra, Indonesia), when more than 36,000 people were killed, mostly by volcanogenic tsunamis (J. Mart'ı and G. G. J. Ernst, 2005).

Understanding the specific hazards associated with volcanoes is important for reducing losses from future eruptions, especially considering that millions of people live close to active volcanoes. Some of the hazards are obvious, such as being overrun by lava flows, being buried by layers of ash, or being hit by hot glowing avalanche clouds known as nuéardents (T. Kusky, 2008).

There are about 500 active volcanoes throughout the world. In an average year approximately 50 of these erupt. Volcanic hazards create fewer disasters and deaths compared with earthquakes and severe storms. Many of the deaths associated with volcanoes are indirect hazards such as famine due to crop damage or from secondary hazards such as lahars. Volcanoes are composite hazards. There are both primary and secondary hazards which can be caused by volcanic eruptions. The primary hazards include pyroclastic flows, air-fall tephra, lava flows and volcanic gases. The secondary hazards include ground deformation, lahars (mudflows), landslides and possibly tsunamis in ocean floor volcanic eruptions (<http://www.n-d-a.org/volcano.php>).

### **3.1 Hazards of Lava flow**

Lava flows constitute the most common volcano hazards from non-explosive eruptions, especially at basaltic systems. How far a lava flow can travel from the vent depends on its viscosity (itself determined by temperature, chemical composition, gas content, and crystallinity), effusion rate, and ground slope. Rates of movement of lava flows vary considerably, from a few to hundreds of meters per hour for silicic lava flows to several kilometers per hour for basaltic lava flows on steep slopes. Because of their slow rates of movement, lava flows seldom threaten human life, but they can be highly destructive, burying, crushing, or burning everything in their paths. In addition, fires started by lava flows can affect areas far beyond their borders (J. martin and G. Ernst, 2005).

Some types of volcanic eruptions' lava may bubble up or effuse from volcanic vents and cracks and flow like thick water across the land surface (T. Kusky, 2008). The lava may flow very quickly in the speed such people could not get time to leave the area. So such hot lava can cause extinction of life and property damage.

### **3.2 Hazards of Pyroclastic Flows and surges**

Pyroclastic flows and surges are masses of hot dry, pyroclastic debris and gases that sweep along the ground surface at extremely high velocities, ranging from ten to several hundred meters per second. Such processes are initiated by discontinuous or continuous collapse of an eruption column, buoyant upwelling at the vent, and gravitational or explosive collapse of a growing lava dome (Scott, 1989a).

Pyroclastic surges are distinguished from pyroclastic flows by having a relatively low ratio of solid materials to gases and, hence, lower density, even though a continuum exists between them. Because of the density difference, pyroclastic flows tend to be more controlled by topography, mostly restricted to valley floors, whereas less dense, more mobile surges can affect areas high on valley walls and even overtop ridges to enter adjacent valleys. Pyroclastic surges can either be hot or cold.

Hot pyroclastic surges are closely associated with pyroclastic flows, both generated by the same processes; cold pyroclastic surges, however, are generated by hydro magmatic or hydrothermal explosions (Scott, 1989a).



*Figure 3.2 Looking eastward from the site of the former capital city of Plymouth, near Sagar Bay on the southwestern side of Montserrat. Structures have been damaged and destroyed by a combination of pyroclastic flows and lahars. Soufrière Hills Volcano is visible in the background; the pyroclastic flows originated from collapse of the unstable lava some located between the two prominent peaks. (Photograph by Richard P. Hoblitt, US Geological Survey).*

Convecting clouds of finer ash commonly accompany pyroclastic flows and surges and form one type of tephra-fall deposit. Hot pyroclastic surges are closely associated with pyroclastic flows, both generated by the same processes; cold pyroclastic surges, however, are generated by hydro magmatic or hydrothermal explosions (Scott, 1989a). Convecting clouds of finer ash commonly accompany pyroclastic flows and surges and form one type of tephra-fall deposit.

### **3.3 Debris Avalanches and mud flow**

Structural collapse at restless volcanoes can precede, accompany, or follow eruptive activity, triggering rock-falls, rockslides, and debris avalanches, which can move rapidly down slope and may pose significant hazards. Most volcanic debris avalanches have followed days to months of precursory activity (e.g., seismicity, ground deformation, phreatic explosions), but some apparently have occurred with little detectable precursors. Mudflows caused by an eruption are known as lahars. They are caused when rain and surface water mixes with ash. Thus lahars destroy everything in their path.

## 4 Geological setting

### 4.1 Regional Geology

The East African Rift System is a part of major tectonic structure resulting from diverging lithosphere movement began about 25 – 30 million years ago (Tertiary times), (Elias, 1984). During the uplifting of the Ethiopian Plateau a long sequence of rigid tectonic movements took place. These movements produced, in a recent but unknown age, a great number of step faults which originated the present Ethiopian Rift Valley. These faults usually stretch parallel to each other with NNE-SSW or NE-SW direction. Only few and short secondary NW-SE faults occur.

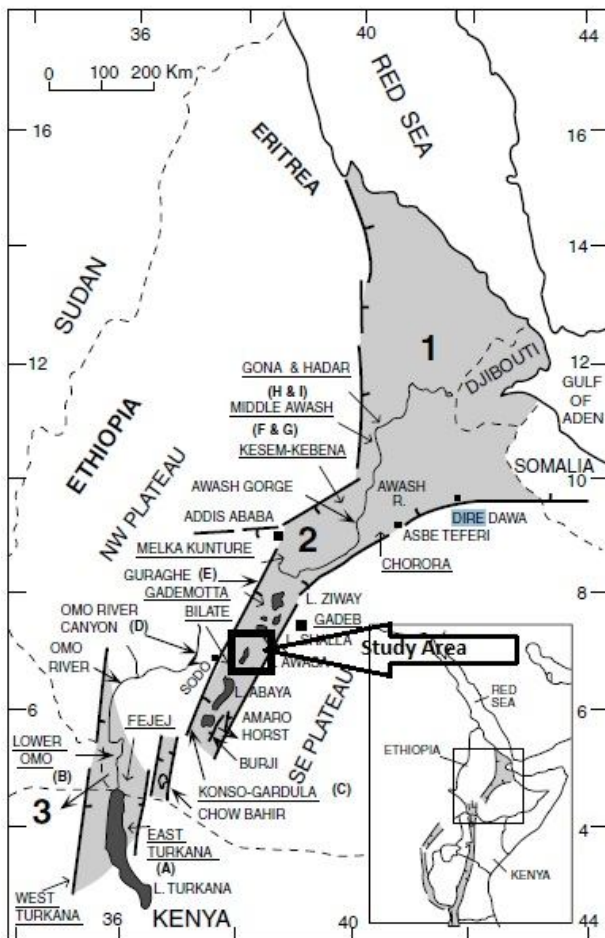


Figure 4.1 Location of the Ethiopian Rift System. Stippled and dark areas represent the rift basins and rift valley lakes, respectively. Inset map shows the distribution of the East African Rift System. 1 = Afar Rift, 2 = Main Ethiopian Rift, and 3 = Omo rift zone. After Woldegerel et. al (2000).

All these faults seem to be normal faults with only a few localized examples of horizontal displacement of few tens of meters. This tectonics is still active as it is indicated by the faults affecting even the most recent volcanic products. Another tectonic feature of the Rift Valley is the presence of some depressions that occupied by lakes (G.M. Dia Pola, 1972). East African rift system is known by continental extension. It is believed that there will be new oceanic crust on the breakage of Nubian plate and Somalian plate. An interesting feature marking the evolution of continental rifts is that, at a general scale, the type of volcanism changes accordingly with the amount of extension, reflecting the involvement and differentiation of various volumes of magma (Latin and Waters, (1991); Metcalf and Smith, (1995)). The age of rift can be calculated from the investigation of magma composition of EARS (East African Rift System) with the amount of extension (B. Abebe et al 2007).

## **4.2 General geology and structure of Main Ethiopian Rift (MER)**

Following the epeirogenic sinking, which caused marine transgression in early Mesozoic, uplift of Arabo -Ethiopia swell took place during Eocene. Late in Oligocene extrusion of the trap Series lava took place, which was accompanied by rifting during Miocene. The rift system is one of the largest structural features of the Earth's crust, extending for a distance of 6000km from Mozambique to Syria, equivalent to 1/6th of the earth's circumference (Mohr, 1970). The Main Ethiopian Rift (MER) which makes part of the Eastern Branch of the East African Rift, extends some 400 km NNE from latitude of 6°N to latitude of 9°N (Figure 8). The MER has an average width of 70 km and is bounded by large normal faults with displacements of as much as 1000 m. (Di Paola, 1972).

The rift system in Ethiopia has divided the uplifted swell into two separate units. These are North-western plateau in the west and the South-eastern plateau to the east. In Ethiopia the rift system extends over 1000km in a general NE direction. It covers 150,000km<sup>2</sup> and it can be divided into two broad units: The Main Ethiopian Rift (MER 5° to 9°N and 37°30' to 40°E) and the Afar Depression. The relative displacement of the rift floor below the edge of the uplifted plateaus varies up to as much as 2000m (Mohr, 1971).

The rift margins are marked by high angle normal faults with large throw that comprises several step-faulted blocks. At places the rift escarpment adjacent to the Quaternary silicic centers located along rift axis (Aluto, Shalla, and Corbetti Caldera) are generally subdued in part due to pyroclastic accumulation along the margins.

The central MER is characterized by a set of NNE-SSW normal faults. "En echelon" arrangement, rift in rift structures, asymmetry and open tensional fissures are its most important features. The down throw of a single step fault can easily exceed 300m.

A great number of step faults produce a total difference of altitude of more than 1000m between the top of the plateau and the floor of the rift valley. All these faults are normal faults, which run for hundreds of kilo meters in the NE and rarely in NS directions.

Some differences in the tectonic lineaments between the eastern and the western escarpment exist; the former is characterized for all its length by step faults with an important throw. The latter (Western) shows in its NE sector an abrupt displacement, sometimes exceeding 1500m (Mt. Guraghe) between the top of the plateau and rift floor, whilst in its SW sector the main faults have a small down throw and progressively die out. This could be interpreted as due to the fact that the main faults are hidden by a huge quantity of volcanic products filling a possible former depression existing in this area. The more active and younger faults are located in the east than in the west.

The Wonji Fault Belt of Mohr (1962) shattered the rift floor into several relatively small horst and graben. Holocene age has been generally attributed (Mohr, 1972) to the Wonji faults. This volcano tectonic axis is considered to be the current axis of the crustal extension. This fault forms a belt of normal faults 8 to 15 kms wide and maintains NNE structural orientation along the entire length of the Main Ethiopian Rift. In the central sector of the MER, the Wonji Fault Belt is dextrally offset into four en echelon rift axis segments. From north to south, these are the Gadamsa-East Ziway, Ziway-Shalla, Shalla-Corbetti, and Duguna-Abaya segments (Caroline, et al, 1999).

Caldera-topped shield volcanoes occur at each Wonji Fault Belt (WFB) offset: the Aluto Caldera between Gadamsa-East Ziway and Ziway Shalla Segment, the O'a Caldera (presently occupied by Lake Shalla) between the Ziway-Shalla and Shalla-Corbetti Segments, and the Corbetti Caldera at the south end of Shalla-Corbetti Segment (Mohr, et al., (1980) in Caroline, et al, (1999)).

The Wonji Fault Belt represents renewed volcano-tectonic activity from early Pleistocene and is continuing at the present day. Tectonic movements are still active, as confirmed by young faults, often affecting very recent formation and by the high seismicity of the whole graben.

The Wonji Fault Belt breaks the monotony of an otherwise flat surface, which formed the bed of a large lake in pluvial time. The ancient lake, deposited sediments, which caused partial or complete burial of some of the floor faults and older lavas.

Structural and stratigraphic relations of volcanic rocks along both Rift escarpments of the central sector of the Main Ethiopian Rift indicate a two-stage rift development (Wolde Gabriel et al.,

1990). The early phase started during late Oligocene– early Miocene time and was characterized by a series of alternating and opposed half grabens. The half-grabens subsequently evolved into a symmetrical rift during the late Miocene. The present symmetrical rift was fully developed by 3.5Ma, contemporary with a paroxysm of ignimbrite eruption when a 2000 km<sup>3</sup> ash flow tuff (the Munesa crystal tuff) issued from large caldera located on the rift floor (WoldeGabriel, (1987) in Wolfenden et al. (2004)). Since this period, major vertical displacement of up to 2 km has occurred in the central sector of the MER (WoldeGabriel et al., 1992). According to Wolfenden et al. (2004); continental rifting in the northern MER started ca. 11 Ma ago, about 20 Ma after the beginning of the flood basalt activity, and propagated southwards until present.

The overall stratigraphy of the Ethiopian Rift varies along its length as shown in Figure 4.3. The western rift margin exposes localized Precambrian crystalline basement, Mesozoic sedimentary rocks, and Miocene and Pliocene mafic and silicic lavas and tephra.

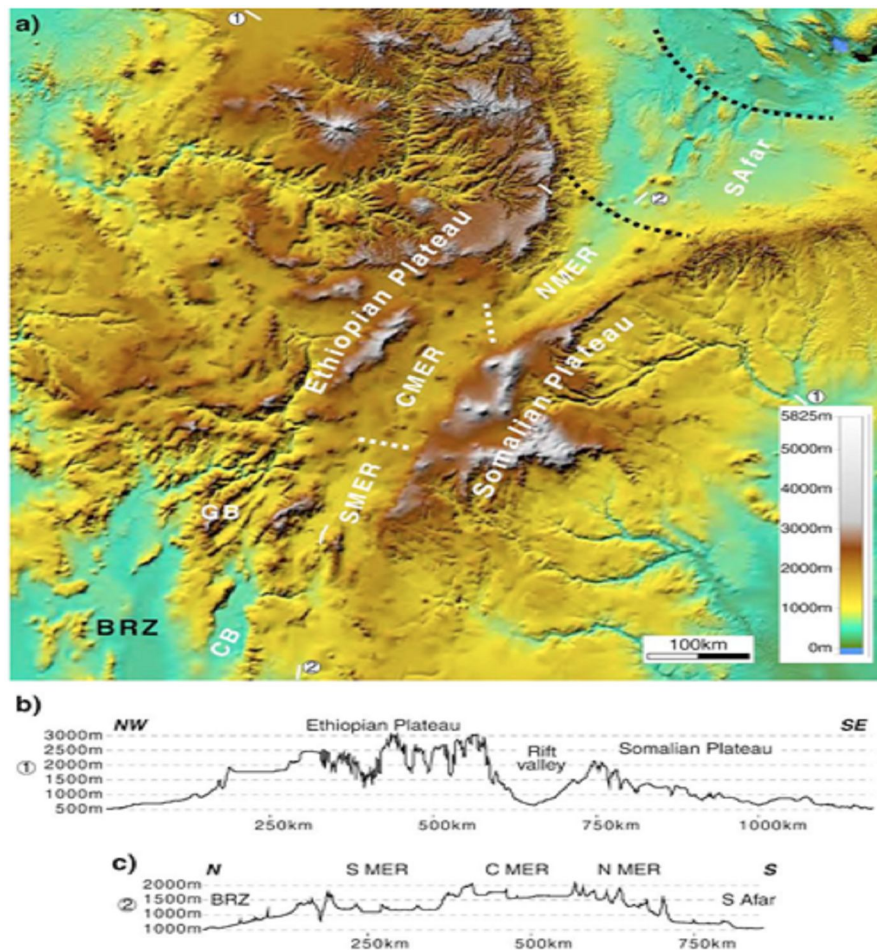


Figure 4.2 Physiography of the Ethiopian Rift and its subdivisions (from Corti G., 2009).

The area was characterized by active rifting during the Pliocene–Pleistocene. For example, Pliocene silicic tephra correlative to those exposed along both sides of the rift escarpments occurs below 1.5–2 km of rift-fill sediments in the adjacent rift floor. The rift floor is covered today by lakes, lacustrine sediments, mafic lavas from fissure eruptions, and silicic tephra from the nearby Quaternary volcanoes of Aluto (0.27–0.021 Ma), along the southern edge of Lake Ziway and the Shalla caldera (0.28–0.18Ma) (White T.D., et al, 2000?, WoldeGabriel et al., 1990).

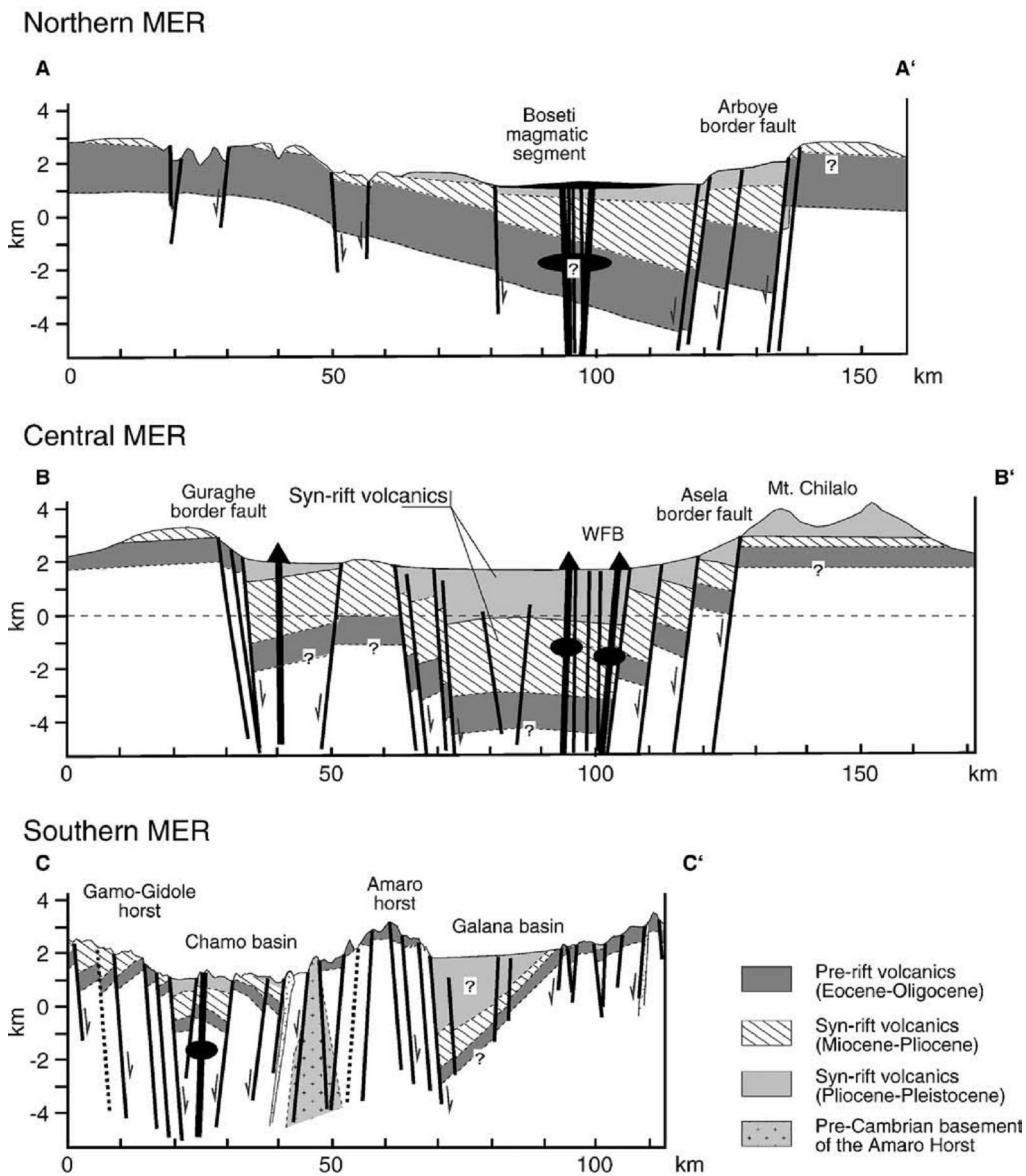


Figure 4.3 Principal stratigraphic units across the three sectors of the Ethiopian Rift (from Corti, 2009)

### **4.3 Geological setting of Chabbi volcano area.**

Chabbi Quaternary volcano lies within the Corbetti caldera which is located along the axis of lowest MRE (Di Paola, 1971). Corbetti caldera is elliptical in form with an axis of about 15 km in east-west direction (Figure 5.1). It has distinct boundary in all directions except the eastern flank which is covered by Chabbi young volcanic products. Corbetti caldera walls have variable heights. The northern wall is about 40 m high while the western and south western walls reach ~80-120m. The caldera floor has an average elevation of ~1680 m. Chabbi volcano is the highest point on the border of the caldera and is 2310 m high.

The Corbetti caldera and surrounding area are covered by Quaternary volcanics (rhyolite, pumice and ignimbrites) and sediments. The north-eastern, eastern and western caldera rims are covered by pumice fall deposits. On the northern and western rims of the caldera, a continuous layer (about 3 m thick) of coarse ignimbrite occurs, inter-bedded with the pumice half-way to the top (Di paola, 1972).

After the collapse of the Corbetti caldera, two major volcanoes, Urji and Chabbi have emerged within it (Figure 5.1). Urji which is located in the center of the caldera has produced thick pumice and ash products whilst Chabbi volcano has same history of Urji except that it has a final phase eruption which produced rhyolite obsidian flows.

Chabbi volcano is located on the northern end of Lake Hawassa basin, a tectonic depression within an uplifted region against the eastern margin of the Central sector of the Main Ethiopian rift. The volcano has five visible parasitic vents. .

The boundary escarpment is sharply defined in Lake Hawassa basin to the south of the caldera and not well-defined east of Shashamane. Mohr (1966) stated that even though transverse fault is very rare in the Ethiopian Rift, the Northern limit of the Hawassa Lake Basin is formed by transverse E-W rift fault downthrown to the south with slight upwarping from the North toward the escarpment. Chabbi volcano is situated close to Western termination of this fault. The fault cuts the pumice clayey lacustrine sediments which were deposited probably in pluvial time when Lake Hawassa was almost certainly continuous with Lakes Shalla, Langano, Abijata and Ziway to the north and perhaps possibly with Lakes Abaya and Chamo to the south.

## 5 Volcanic geology of Chabbi

### 5.1 Volcanic morphology

Chabbi volcano is located adjacent to the eastern edge of Corbetti caldera on the Wonji Fault Belt or magmatic segment.

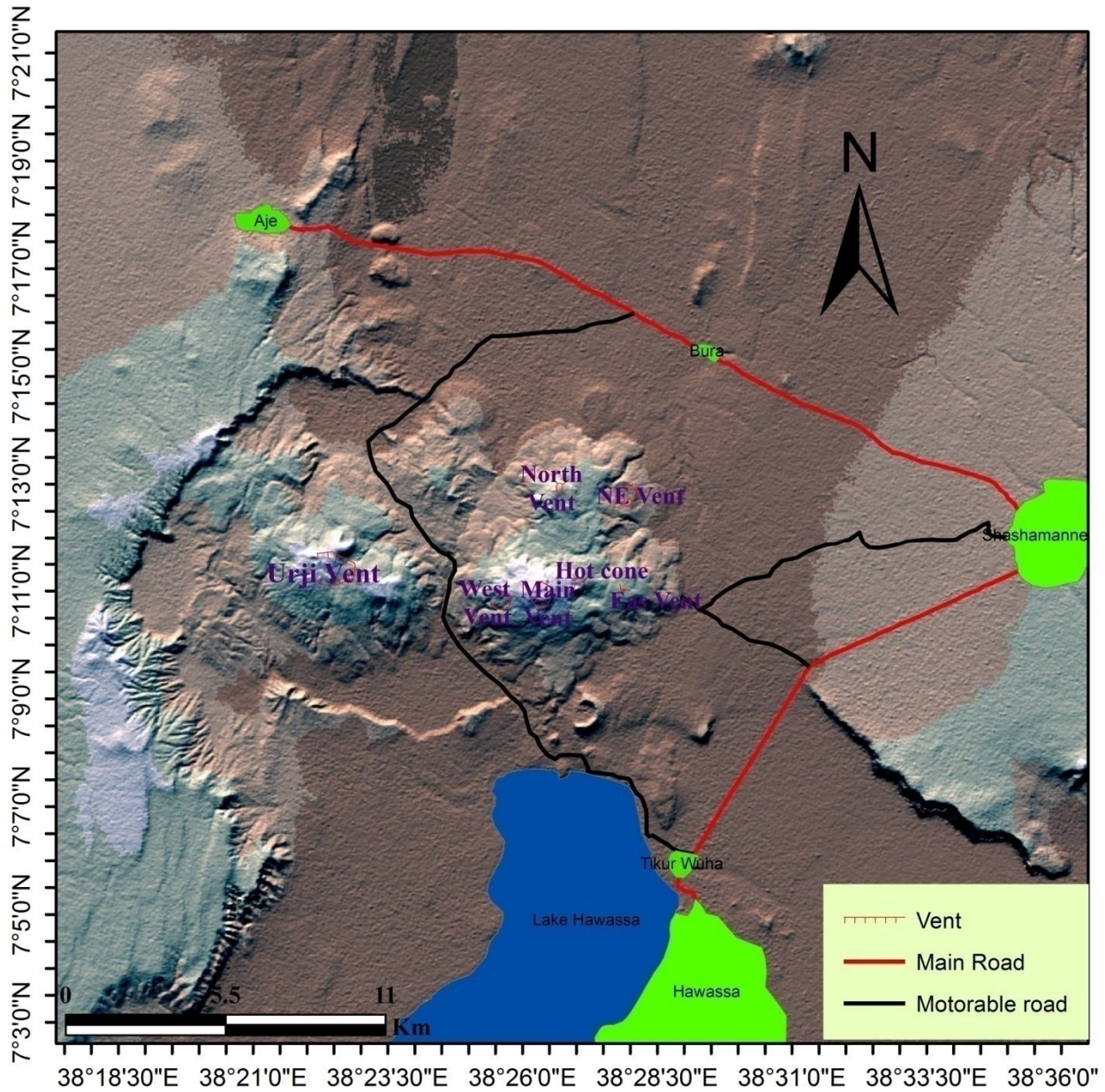


Figure 5.1 Digital Elevation Model (DEM) of Corbetti caldera and surrounding region. Chabbi volcano geomorphology and main vents are shown. The color variation shows the reflection of the products in early morning. The color reflectance is value of near infrared energy level.

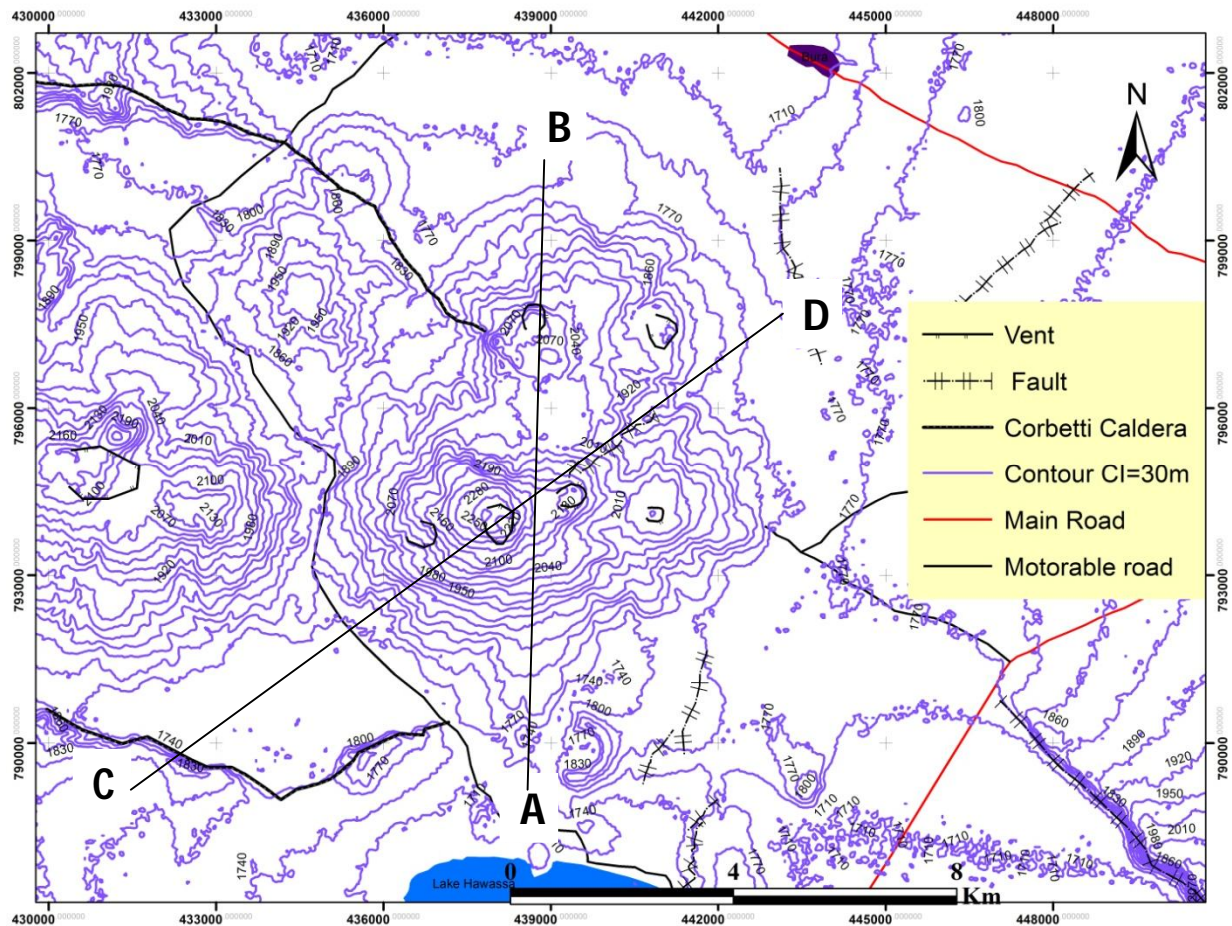


Figure 5.2 Topographic map showing the geomorphology of the eastern part of Corbetti caldera and Urji and Chabbi volcanoes. Contour Interval = 30m. Lines AB and CD are lines along which elevation profiles have been shown in Figure 5.3 shows it.

Chabbi volcano has a maximum height which is about 2314m.a.m.s.l and rises more than 714m from the surrounding rift floor. The adjacent lake Hawassa has an altitude of 1650 m. The volcano is characterized by steep cliffs in its southern and south-western flanks and gentle slopes relatively on the remaining directions. It has rugged morphology which is formed by volcanic products. The elevation profile of the volcano is shown in Figure 5.3

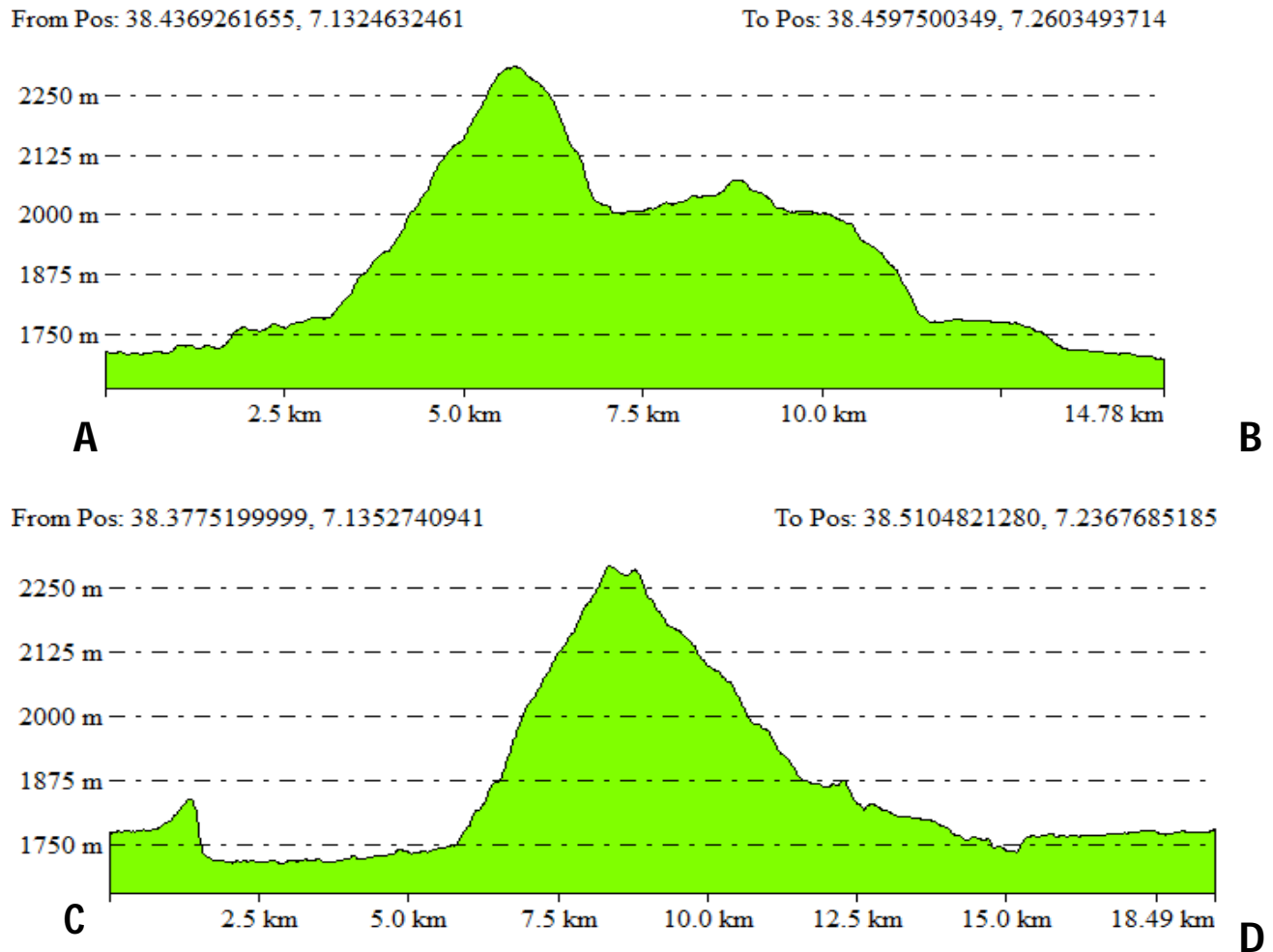
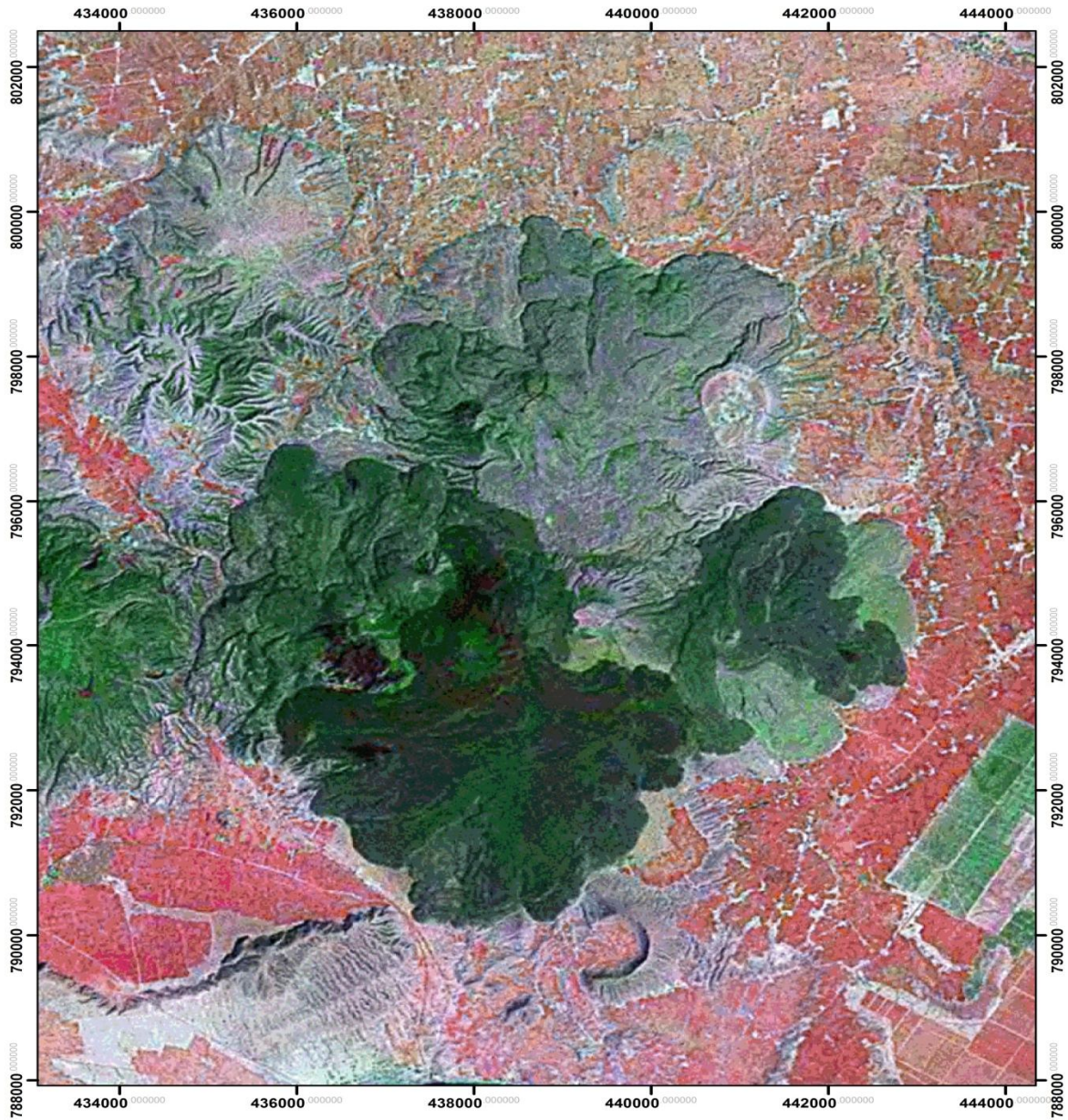


Figure 5.3 Elevation profiles of Chabbi volcano along lines A-B (north-south) and C-D (north-east-southwest) with Vertical Exaggerations of ~5X. The profile is extracted from SRTM of Ethiopia which has 30m resolution.

## 5.2 Volcanic Stratigraphy and Lithologic Units

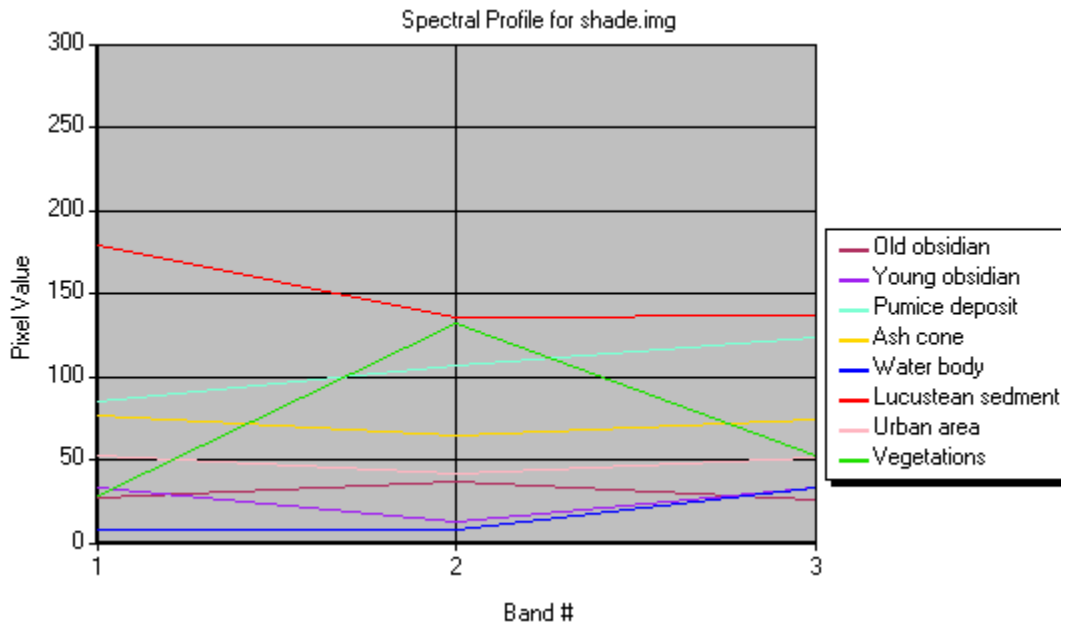
The volcanic successions of the Corbetti Caldera and surrounding areas have been described by Di Paola (1972). In the present study, field observations and image interpretation have been conducted to improve the previous maps and lithologic descriptions.

Accordingly, remote sensing is used to interpret the satellite image of Chabbi volcano and its surrounding area. Various features have various spatial reflectances within different bands. Thus seven band combinations were used to perform supervised classifications within three major bands (RGB/ Red, Green and Blue). Band 7, 4 and 1 are used to identify/map Lava flow and pyroclastic (Pumice and ash) flow and fall deposits.



*Figure 5.4 True RGB color composite used to interpret the volcanic geology of Chabbi.*

Each lithology has its own reflectance value. The reflectance value is the pixel (picture element) value that it might earn. The pixel value, which ranges from 0-255, is crucial to interpret the satellite image. The lower reflectance will get the lower value whilst the higher reflectance will be assigned to higher pixel value on energy level.

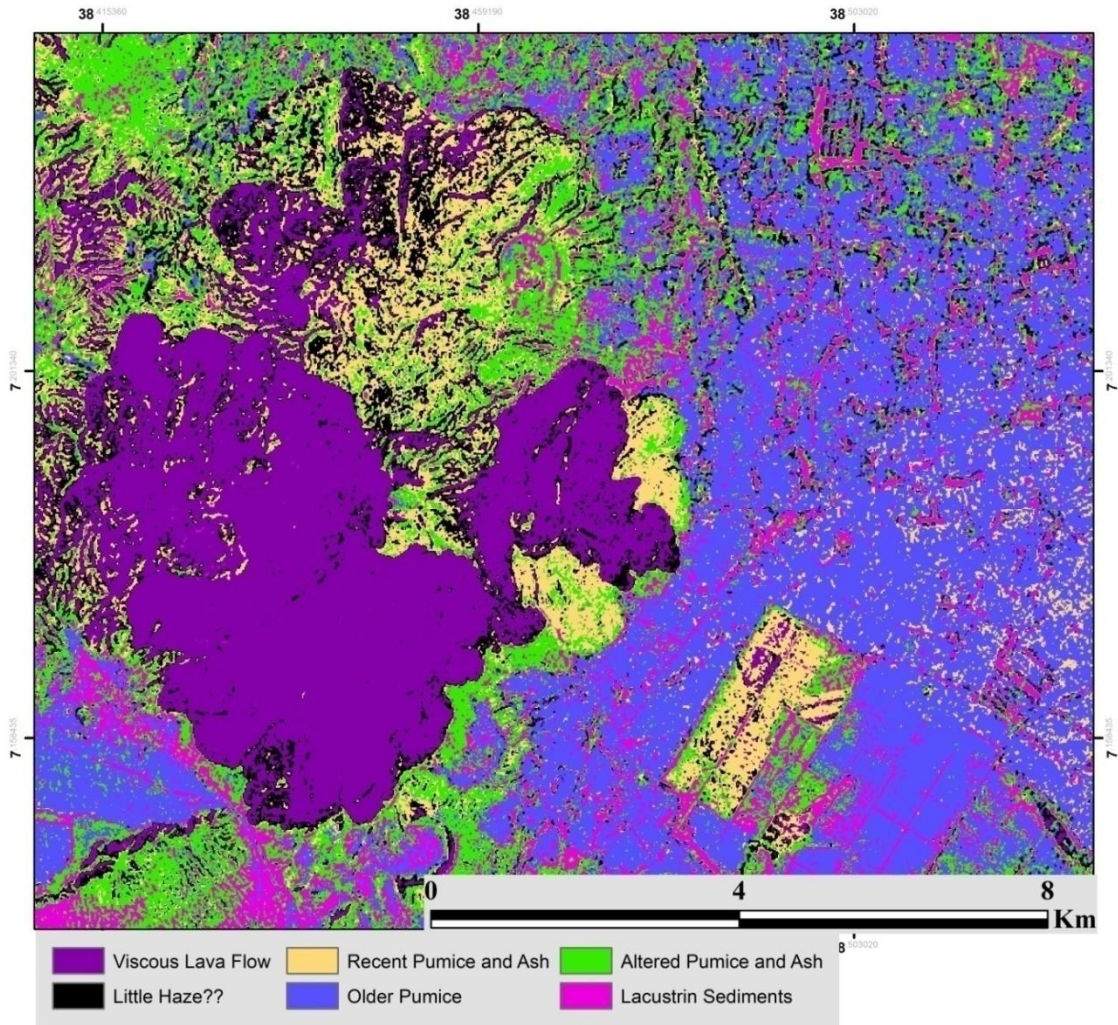


*Figure 5.5 Spectral profiles of different lithologies and other basic features within basic bands using remote sensing. These profiles are the bases for supervised classifications.*

Lithological units have different reflectance with its degree of alterations. Thus obsidian has unique reflectance value compared with the other units.

To discern the lithological units, band combination is crucial. Band combination shows clear spatial reflectance to discern different lithological units based on the spatial resolutions and the pixel value it may obtain from spectral reflectance. Band selection is an expert defined method.

The band combination is helpful when it is incorporated with field verifications. Thus the comparisons between true and false color composite and field verification is done before deciding lithological unit classification from satellite image. Band combination is useful to perform pixel clustering. Pixel clustering is done with the method called maximum likelihood. So the pixels with closer reflectance value will be clustered with nearly same lithological spatial reflectance.



*Figure 5.6 RGB (741) band combinations of Chabbi volcano area showing the reflectance values lithological units with respect to the pixel values.*

Image classification is the process of sorting pixels into finite number of individual classes or categories of data based on their data file values. A pixel is assigned to a class which corresponds to those criteria. Thus the methods are divided in to supervised and unsupervised classifications. In supervised classifications, the identity and locations of some Lithologic types are obtained beforehand from combination of previous work, field work, interpretation of satellite image, and personal experiences. Using this approach, Figure 5.6 has been produced.

A modified geological map of Chabbi area shown in Figure 5.7 has been produced based on existing maps of Mohr (1966), Di Paola (1972) and Elias Altaye (1984) and integrating new field observations and interpretation of satellite images.

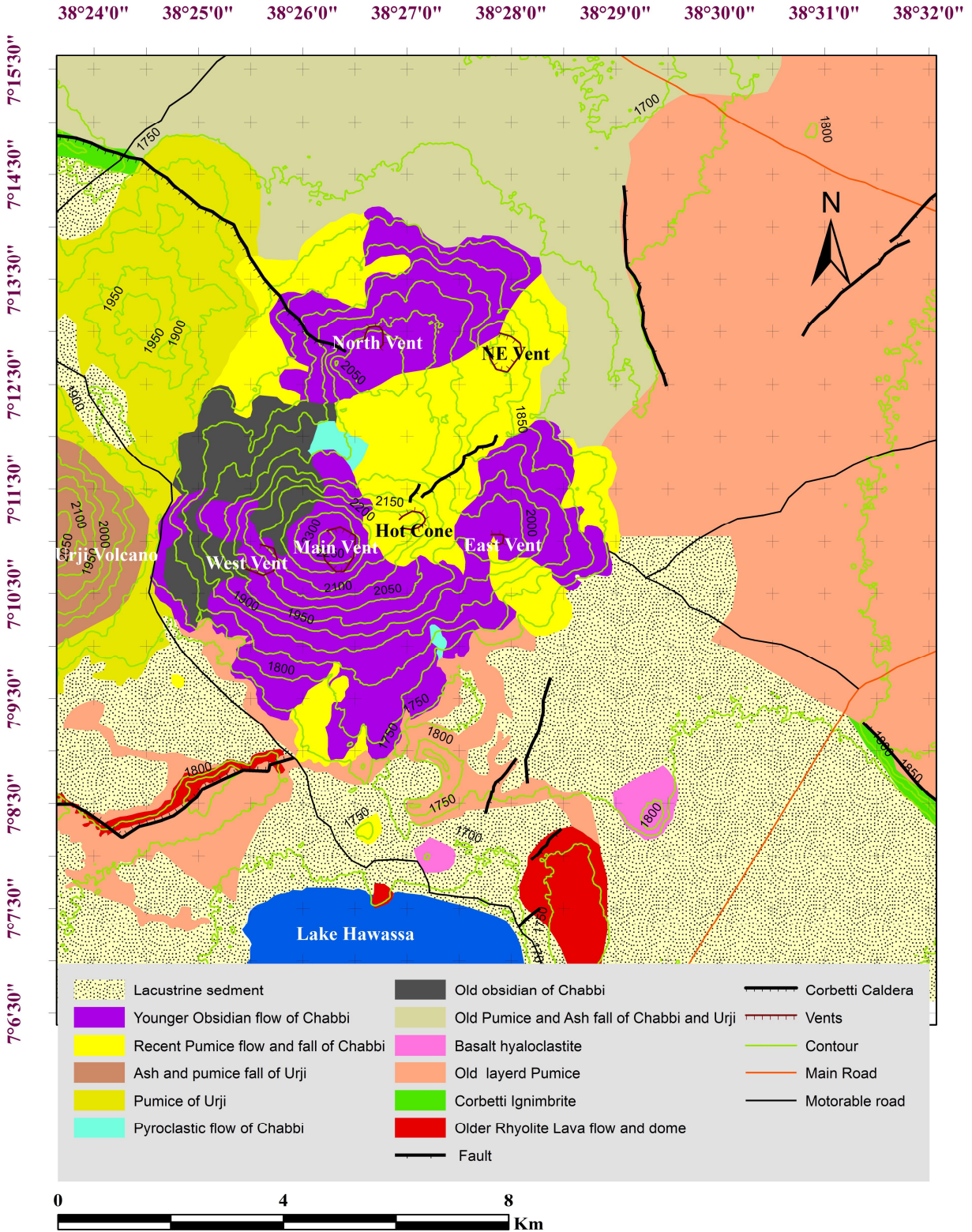


Figure 5.7 Geological map of Chabbi volcano and surrounding area based on SPOT image processing and interpretation and controlled using existing maps from Mohr (1966), Di Paola (1972) and Elias Altaye (1984) and field observations . CI=50m

### 5.3 Descriptions of volcanic products

The following volcanic units and composite stratigraphy of Chabbi have been reconstructed based on present field studies, image interpretation and the works of Mohr (1966), Di Paola (1972) and Elias Altaye (1984). Each volcanic unit is described in some detail, from the oldest to youngest as follows.

Table 1. Summary of Chabbi volcanic units from the oldest to youngest

Volcanic Activities		Volcanic unit	Ages by (WoldeGebriel et al., 1990) and others.
Post-caldera activity	Chabbi volcanic formation	Lacustrine deposits	
		Chabbi Younger Obsidian lavas	
		Recent Pumice and ash fall products of Chabbi deposits	
		Basaltic scoria and lapilli deposits	
		Pyroclastic flow deposits of Chabbi	
		Ash and pumice fall of Urji	
		Older Obsidian flow of Chabbi	~0.021Ma
		Older Pumice and ash of Chabbi and Urji	~0.021Ma
Corbetti caldera sequence		Basaltic Hyaloclastite	$\leq 0.2\text{Ma}$
		Old Layered Pumice	~0.2Ma
		Corbetti ignimbrite	~0.2Ma
		Older Rhyolite Lava flow and dome	1.27 – 0.86Ma

Corbetti caldera has pre- and post-caldera eruptive activities. Corbetti volcano possibly erupted at the same time as O'a and Aluto volcanoes, evolving to a caldera-forming shield volcano type (Di Paola, 1972; Lloyd, 1977; Mohr et al., 1980; Wolde Gabriel et al., 1990).

The most ancient product outcropping in the area is a coarse and unwelded ignimbritic formation made up of a cemented soft and fine material which contains a large amount of pumice fragments (Di Paola, 1972). The ignimbrite exposed on the caldera wall at NW of Chabbi in a horizontal layered formation. But the centre of eruption of this product is difficult to recognize.

The entire caldera area is formed exclusively by volcanic products that are characterized by ignimbrite, older pumice and post caldera volcanic activity products like pumice and ash fall deposit and younger obsidian lava flow.

The eruptive activity of Chabbi volcano has produced a wide variety of explosive and effusive products. The volcanic activities are probably Holocene age representing multiple rhyolitic flows and domes as well as pyroclastic falls and flows dominated by pumice, ash and recent obsidian flows.

### **5.3.1 Older Rhyolite Lava flows and domes**

The unit is located on the basaltic volcanic belt that exposed on the western of Corbetti caldera wall. The rhyolite lava flow and dome form partly volcanic bodies of the caldera about 1.27 to 0.86Ma (WoldeGebriel, 1990). From the locality the unit has (~50m) thickness that colored in grey to dark. The felsic lava flow is over-bedded by unwelded ignimbrite on the Northern and NNW of the caldera wall.

### 5.3.2 Corbetti ignimbrite

Corbetti ignimbrite is exposed on the eastern and north-eastern wall of the caldera rim. The ignimbrite occurs as a horizontal layered formation. It is generally pinkish in color and strongly welded to poorly welded. The rock is fine grained and contains about 5% lithic fragments of different sizes and compositions, including, coarse-grained rocks and basaltic lapilli measuring up to 1.2 mm in size. The rock is further characterized by black, glassy, flattened and elongated fiamme measuring up to 10cm in length. The rock might be called welded rhyolitic ignimbrite. At its exposure, the rock unit shows vertical variations in degree of welding and in abundance of lithics and crystals.

The unwelded ignimbrite of this area represents the most common ignimbrite rock type of the Ethiopian Rift Valley, outcropping over a large area and they are constituted by several units. In the lowest part of the formation, it is well welded with the typical, fiamme, structure. Layers of pumice and ashes are frequently inter-bedded with the ignimbrites (Di Paola, 1972).



*Figure 5.8 An outcrop of Ignimbrite of Corbetti caldera. This image was taken on the NW flank of the caldera. 1) Less welded part and 2) more welded portion*

### 5.3.3 Old Layered Pumice and Ash

The old layered pumice is bedded adjacent to lacustrine sediments. But it is altered and sometimes covered by obsidian flow and recent pumice fall. It has light to yellowish gray color, with exhibiting density variations (greater than  $1.1\text{g/cm}^3$ ). It is characterized by flattened vesicles. The individual pumice clasts are angular to sub-angular and show wide variation in grain size, 1mm to 5cm. the deposit has negligible abundance of lithic fragments and crystals.

Older pumice and ash covers the most northern parts of Corbetti caldera rim and its surrounding areas. To the north of Corbetti caldera there is altered pumice and ash fall. Furthermore, most of South, East, North east and Northern of Chabbi volcano are where old layered pumice covered. It has important formation where composed of several layers of completely unwelded pumice outcrops seen. On the West of the Corbetti Caldera, such formation reaches a maximum thickness of more than 20m. The source of the pumice is probably Corbetti volcano?



*Figure 5.9 Altered pumice deposits. The unit is at North of Chabbi volcano. It has angular and well sorted morphology.*

Old pumice formation locally shows (West of Lake Awasa) a sequence of pumice layers interbedded with thin layers of lacustrine deposits and fine ash. Some xenoliths are found even in the pumice, but their amount is always very small. The relations between the ignimbrites and the pumice are not clear. In several places there are evidences of a horizontal transition between ignimbrites and pumice.

The old layered pumice is bedded adjacent to lacustrine sediments. But it is altered and sometimes covered by obsidian flow and recent pumice fall.

Generally there was high explosive eruption of Corbetti volcano. From above older volcanic descriptions the eruption could be characterized by pumice and tuff eruption. An outcrop at Worensa fault (East of Corbetti caldera that dies at edge of Shashamane Hawassa road) shows the unwelded ignimbrite under-lying the older pumice deposit. Similarly on most of the caldera rim, except on the Eastern flank where the post caldera activities covered the earlier Corbetti products, the stratifications and bedding of older pumice, ash and ignimbrite might be evidence for that Corbetti volcano was formed by explosive eruptions.

### **5.3.4 Basaltic Hyaloclastite**

Near the southern shore of Lake Shalla and just East of Lake Hawassa, there are some evidences of subaqueous volcanic activity that produced basaltic hyaloclastites. These hyaloclastites occur both as small monogenic cones and as horizontal layers of local extension covering the ignimbrites. The small central hyaloclastitic volcanoes are found mainly south of Lake Shalla. They show a very large top crater which in some cases is filled by water (such as Lake Chitu). The morphology is that typical of the hyaloclastitic cones in the Danakil Depression of Ethiopia (Di Paola, 1972).

These hyaloclastitic volcanoes have been formed during an explosive activity of basaltic magma under shallow water. All around these hyaloclastitic cones and even inside one of them, there are some occurrences of sub-aerial basaltic activity. In fact several small basaltic scoria cones are found associated with extensive basaltic flows which gave rise to small lava fields. The scoracious surfaces of the lava flows are well preserved. Therefore all these products have been erupted in a very recent time.

## **5.4 Intra-caldere volcanism**

After the collapse of Corbetti caldera there were volcanic activities on Corbetti-Shalla segments of WFB. Therefore the birth of Urji and Chabbi volcanic eruptions are the post caldera activities.

### **5.4.1 Older Pumice and ash (Chabbi or Urji)**

This rock unit covers from Eastern and Northern of Chabbi volcano to the Northern up to Lake Shalla. It covers the upper most of older layered pumice. It is light grey, rounded and sub-round

texture. The grain size is up to 3cm, which has 1m thick on Shashamane exposure and 3m on Bura town out crop. Similarly the pumice has 1.5cm thick at Aje town on NW of the Corbetti caldera. The unit is affected by alterations. These products are from both Chabbi and Urji younger volcano? The unit is extended just adjacent to the recent pumice fall deposit. The contact of the product doesn't show any over or under bedding. Therefore the pumice might has same age with recent deposit and affected by alterations.

#### 5.4.2 Ash and pumice fall of Urji

Urji volcano occupies most center of Corbetti caldera. It is formed of pyroclastic (pumice and ash) flow and fall deposits. Several pumice and ash emanated from large summit crater covers the eastern and northern of Urji and/or Corbetti caldera. On the eastern of Urji there is the contact with Chabbi products where obsidian flow from west vent of Chabbi inter-bedded with pumice out crop on the eastern side of the volcano figure 5.10a and 5.10b.

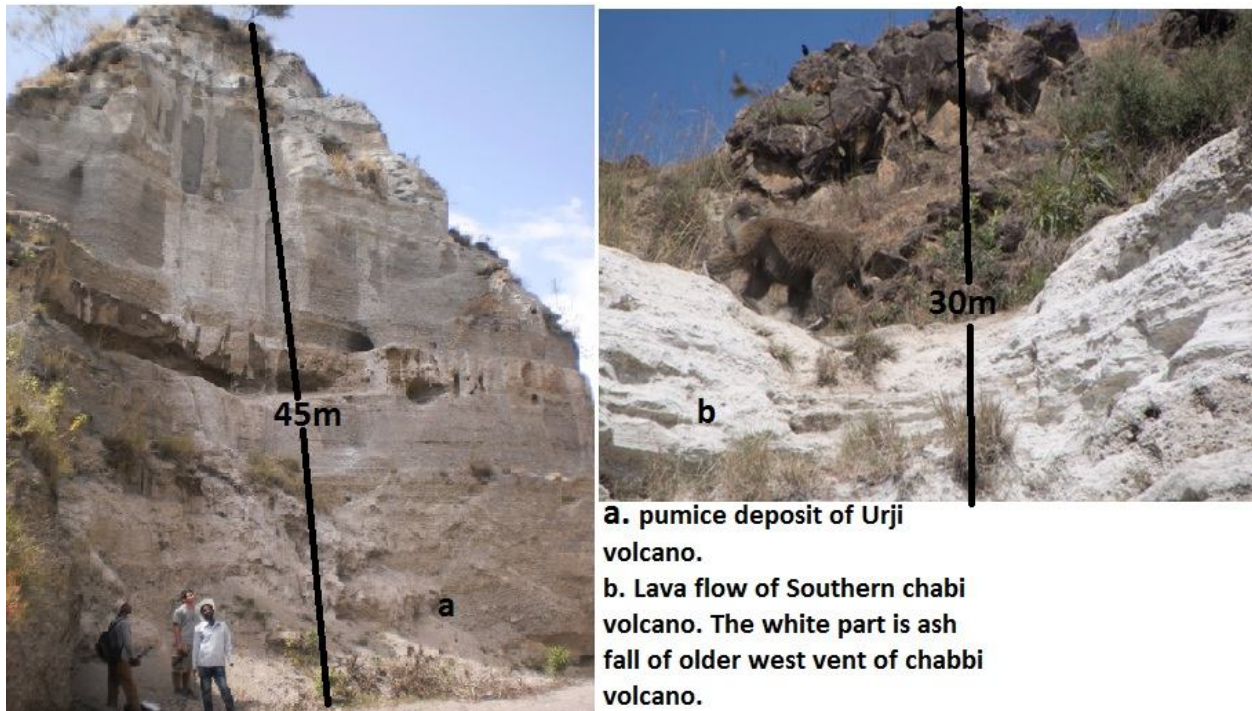


Figure 5.10 East part of Urji pumice fall deposit B) West part of Chabbi obsidian intercalated with ash fall.

## **5.5 Chabbi volcanic products**

### **5.5.1 Older Obsidian flow of Chabbi**

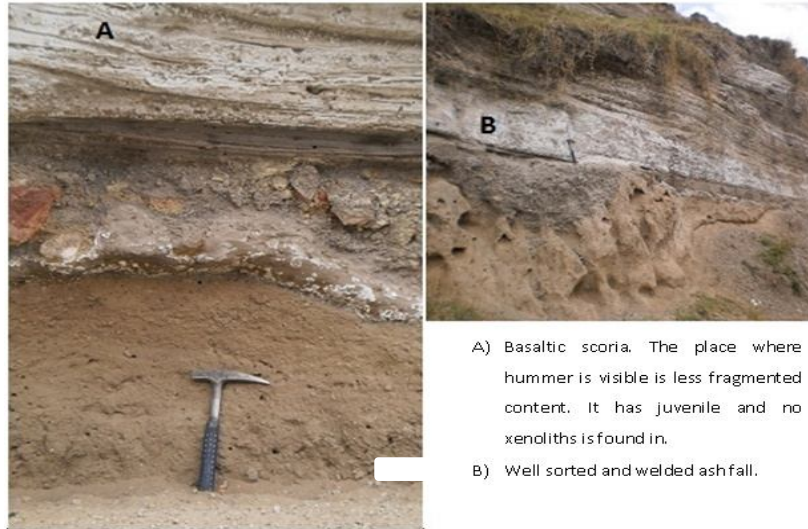
The unit is dark in color and less glassy; it is pantelleritic non-phenocryst and has very rare flattened crystals with thickness up to 7m at type locality. The unit is fine grained, flow-banded very poorly crystalline felsic underlying a thick bedded pumice fall. Dense and vesicular felsic lava flows, containing small amounts of crystals (~3 %) observed at Western to Northern of Chabbi has (~1 - 3m) in thickness.

### **5.3.1 Pyroclastic flow deposits of Chabbi**

This rock unit is medium grey in color, fine grained, poorly sorted and unwelded pyroclastic deposit. It is dominated by ash which has grain size on average mostly less than 1mm. The deposit also contains abundant angular pumice fragments which measure up to 1.5cm. In addition lithic fragments up to 2cm long are present. The lithic fragments mostly consist of light color felsic lavas, basaltic scoria. The deposit contains thin and glassy crystals which are 5-8% in averages. This deposit is probably an unwelded ash flow deposit. The pyroclastic flow has rare red and dark colored scoria that sizes range from 43 X 74 cm to lapilli size that has 1m thickness. Thus it can be defined as relatively thin mantle of rock found around a volcanic vent; the thickness is not uniform. The eastern hot cone out crop that shown in (figure 5.12 and 5.13 as layer 5) is significantly shows deposition characteristic of the pyroclastic flow deposit. The pyroclastic flow layer has higher temperature than the over topped layers. Perhaps it might be defined as hot ground that lies to the bottom of other products.

### **5.5.2 Basaltic scoria and lapilli deposits**

Scoria fall deposit is the other product which is seen on the eastern flank of Chabbi volcano. It has parallel bedding structure with ash and pumice fall deposit. The color of this scoria is from reddish to dark yellow.



*Figure 5.11 Outcrop at Eastern of hot cone. The most likely parallel bedding of scoria, pumice and ash fall deposit.*

From the out crop of eastern Hot cone, beneath pumice and ash fall there is thin layered which is about 83cm basaltic scoria is visible at figure5.11A and B. From figure5.11A place where hammer visible, shows a highly fragmented pyroclastic mixed scoria flow, at most top of hammer where the pyroclastic flow is found. It has block which grain size ranges from 44cm to lapilli. The thickness of scoria fall deposit is about 3m. The location of such scoria is shown in (figure5.12 layer 4) out crop. Based on amount and size of blocks and/or pyroclastic bombs the source of the product might be hot cone. The unit is not mapable to the scale in comparisons.

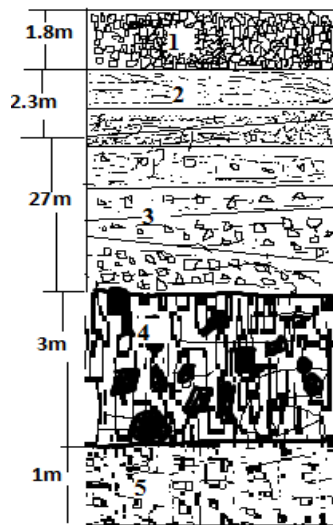
From figure5.11 at the peak of hammer there is wet muddy like reddish basaltic scoria. This quarry also contains juveniles than xenoliths of country rocks. The continuity of product has too much similarity from this outcrop to the mouse of hot cone. Thus the eruption had vesicles and may also be phreato-Plinian eruption was took place?

### **5.5.3 Recent Pumice and ash fall products of Chabbi**

The rock units are light grey in color and not affected by alteration; it consists of layered pumice with thin inter-bedded fine ash. The pumice deposit below the fine ash shows layering and fining upwards (figure 5.12). The pyroclastic fall part has fragments sized lapilli, lithics to fine grained ash.



Figure 5.12 Detail descriptions of stratigraphy and bedding characters of Eastern quarry from 1) Pumice deposit, 2) Ash fallout, 3) Ash and Scoria, 4) Basaltic Scoria, 5) Pyroclastic flow



The stratigraphy shows mostly all products of Chabbi volcano either than rhyolite lava. The bedding from top to bottom is 1) Recent pumice fall deposit, 2) Ash fallout, 3) Ash and scoria 4) Scoria fall and 5) Pyroclastic flow that contain limited crystals.

The locality out crop is on East of Hot cone about 1.5km from the vent which elevated about 45-50m. The upper pumice is over bedded by obsidian flow (Figure 5.13).

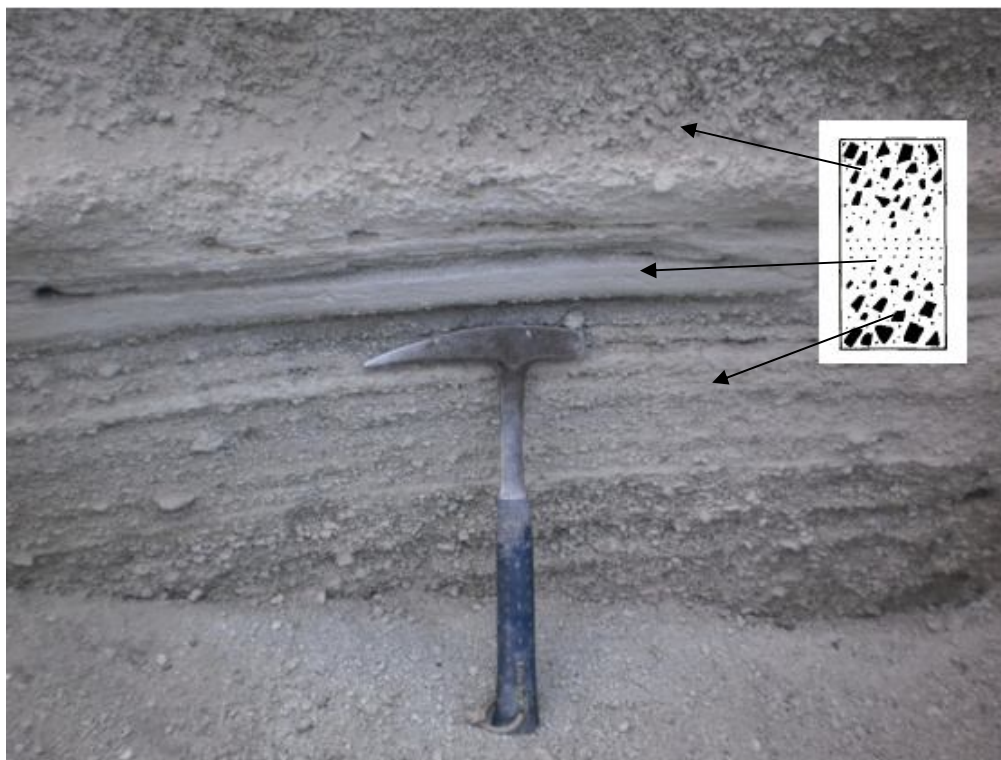
Figure 5.13 description of bedding at exposure of figure 5.12.

The upper ash fall has 6m thickness and has cross bedding structure. During deposition there might some air turbulence? To the top 5.2m, thick pumice has round and angular morphology. It is bedded

in normal bedding stratigraphy. In the middle of quarry there is clear cross bedding of pumice and ash fall. The pyroclastic deposit is highly bedded which is about 27m thickness and to the most top there is moderately bedded tuff fall deposit. The ash is fine grained and has normal sorting and well bedded which is about 2.3m thick.

The pumice deposit above the ash layer shows poor layering and coarsening upwards. Pumice fragments in the deposit vary in size from up to 3cm and have sub-rounded to angular shapes. Pumice fragments are light in density and have highly flattened vesicles. The deposits have insignificant abundance of lithic fragments and crystals.

The upper most pyroclastic deposit in this unit (just below the obsidian flows) is very fresh (unaltered) medium grey colored and coarser grained pumice fall deposit. The pumice clasts are light in density, range in size from 5cm to 15cm and characterized by rounded elliptical vesicles.



*Figure 5.14 Ash falls on eastern Hot cone that shows symmetrical grading (normal to reversal) bedding characteristics (K. Nemeth and U. Martin, 2007).*

The area has pyroclastic (pumice and ash) flow and fall. Both pumice and ash fall deposit is not altered to the central part of the volcano and has distinct boundary in most directions. Figure 5.13 shows the stratification of pumice and ash deposit. The mode of bedding is formed in well sorted

and symmetric bedding of pumice and ash fall. Such type of bedding is the common characteristics of highly explosive pumiceous eruptions. The grain size of pumices at upper and lower of hummer is similar, whereas the ash inter-located in between the product that is at the top of hummer is fine-grained ash fallout.

The pyroclastic (pumice and ash) of the area has grain size from 0.02cm to microscopic fine grain material.

The Northern of Chabbi volcano has similar products. However, the most products are vesiculated pumice deposit. Towns like Bura, Aje, Shashamane and Hawassa city has thin and fine-grained ash fall. The water interaction played vital role to diminish the coverage extent of post caldera eruptions. But these areas have some out crops that show there were the coverage of these eruptions was there. To the south of Lake Shalla, we can find similar recent pumice and ash deposit. Though surface water alteration disturbs the continuity of the pyroclastic products, from satellite image it has good reflectances that help to describe the extent and fall directions in figure 5.8.

#### **5.5.4 Obsidian lava flow of Chabbi**

The obsidian lava flow covers the most central part of volcano. The main vent, East vent, West vent and North vents are dominated with obsidian coverage.

Chabbi volcano's obsidians are glassy and dark which have no phenocrist and it is non-porphyrific. The unit contains about 74.4 SiO<sub>2</sub> in average with much existence of NaO<sub>2</sub>+KO<sub>2</sub> than Al<sub>2</sub>O<sub>3</sub> and it is pantelleritic obsidian (Mc Donald, 1969). Based on the content of SiO<sub>2</sub> it is rhyolite magma, which passed through super cooling. Non-Porphyrific and the non-phenocrist is nature of lava could be formed from super cooling processes. Since phenocrist grow relatively slowly cooling and are suspended in the melt (J. McPhie et al. 1993).

The eruption of obsidian is younger than the tephra fall deposit. The contacts of Chabbi volcanic products shows that obsidian younger and it overridden the earlier products. The nature of this obsidian is less vesiculated and not altered yet.



A) Obsidian lava flow on south flank

B) Contact of obsidian flow with pumice fall

Figure 5.15 Chabbi Volcano's products contact between pumice deposit and obsidian flow at Eastern of main Vent. Obsidian flow overrides the ash fall.

The locations and coverage areas of obsidian lava flows are the most central and southern of Chabbi volcano. West vent, hot cone and East vent are covered by preserved glassy black obsidian flow. Primary product of the first phase eruption was overridden by fresh obsidian flow figure 5.15.

Voluminous parasitic silicic volcanism has continued up into Holocene times from the Corbetti (Urji and Chabbi volcanoes) Caldera (Dakin & Gibson, 1971; Di Paola, 1972).

### 5.5.5 Lacustrine sediments

The units are found on West and South Chabbi volcano at Northern and North West of Lake Hawassa. It forms terrace elevation 1700m a.m.s.l. The unit has an expose at the locality on Northern Lake Hawassa with thickness of 10m above alluvium are generally composed of cemented volcanic sands and ashes. The unit has two layers, the older and thins layered and the younger and thick layered deposit. On SE of Corbetti caldera and to the foot of woransa fault, the older deposit has about 20cm thickness. The northern of Lake Hawassa is covered by younger volcanic products formed the recent lacustrine deposit just above alluvium deposit.

## **5.6 Eruptive Vents and their descriptions**

Chabbi composite volcano has one main vent and five parasitic vents. Mohr (1966) stated this volcano with one main vent and six parasitic vents. The NEII of Mohr (1966) is either collapsed or he wrongly states it. All vents are active and are at fumaroles stage. The detail descriptions of each vent will be discussed below.

### **5.6.1 Main vent**

Main vent is active and the highest point of Chabbi volcano and/or Corbetti caldera which formed by a gently shaped dome rising above the flat, shield-profile of the volcano (Mohr, 1966). It has surface thermal manifestation activity which is fumaroles.

Mohr (1966) stated the dome of Main Vent is formed of older pyroclastic beds, now exposed only on the western flanks and briefly west of Hot Cone, over which extensive obsidian lavas had flowed in very recent times.

### **5.6.2 Hot cone**

The second vent is hot cone which is about 2km on NE of main vent. Hot cone is covered by scoria and pumice which is altered by thermal activity from the subsurface that is visible following from top of vent to its eastern fracture which looks like fissural structure. That means there are intense fumaroles visible following the fracture which lies from the top of hot cone vent to Eastern of Chabbi volcano.

### **5.6.3 West vent**

It is about 1km west of main vent and dominated by obsidian lava flow. This vent has both effusive and explosive products. As expressed by Mohr (1966) it is younger than main vent. The evidence of the products age is the contact between obsidian flow from main vent and west vent.

The west vent which is over-bedded by obsidian lava has white fine grained ash sagged in between obsidian flow. Thus some Di Paola (1972) discussed it as paleosoil. But it has no sign that correlates the fine grained white ash with paleosoil. Rather it is fine ash deposit. The thickness of white fine grained ash increases from 3cm at South to 2m at North of the south west of the volcano fig 5.10b. The white fine grained ash is probably of Urji volcano?

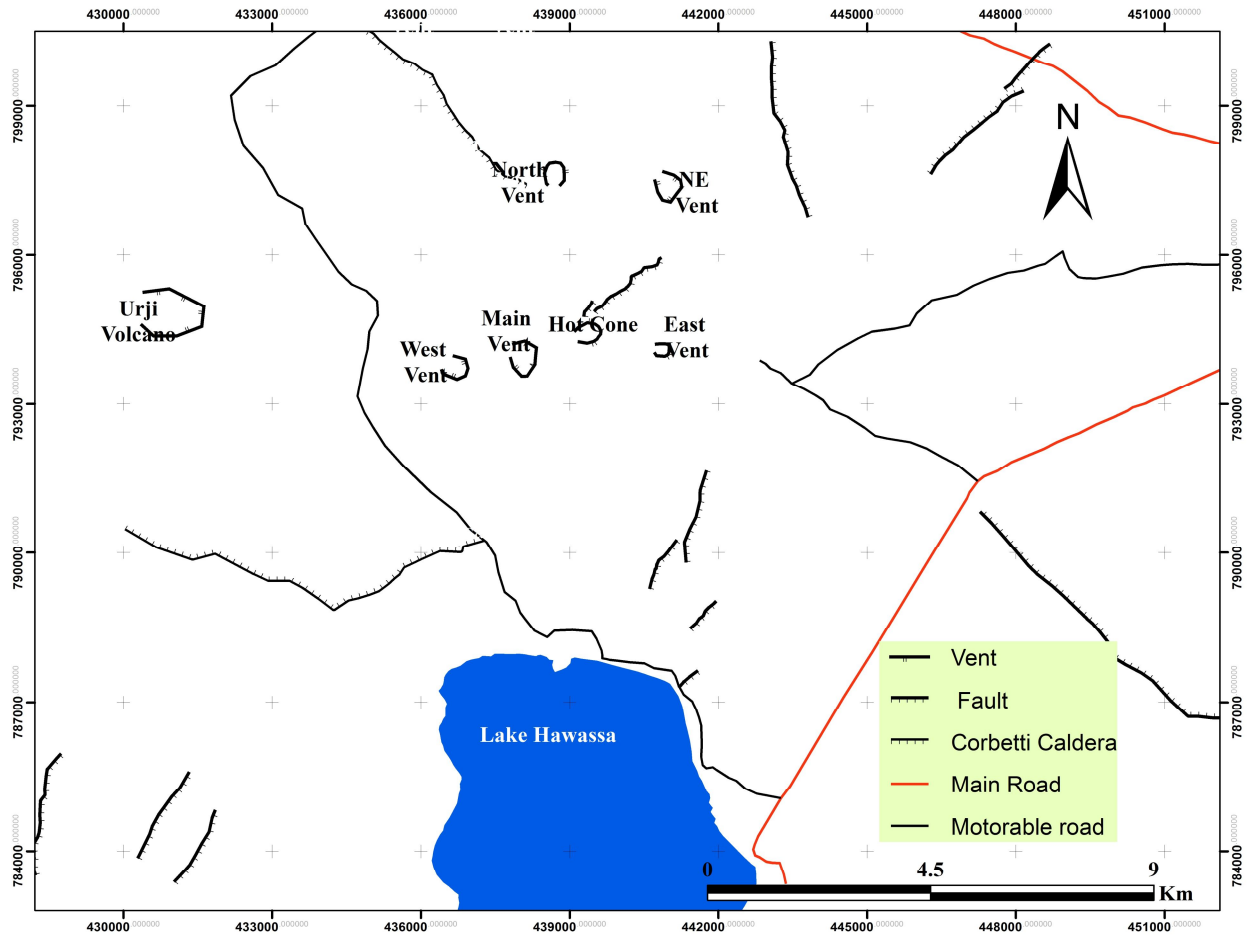


Figure 5.16 Vents of Chabbi volcanoes within Corbetti caldera.

#### 5.6.4 North vent

The Northern parasitic vent has similar product with main, East and west vents. The younger obsidian lava flow covers the pyroclastic (ash and pumice) deposit. The obsidian flow visible here is partly vesiculated and partly has no vesicles. North vent has clear orientation to North direction.

#### 5.6.5 North East vent

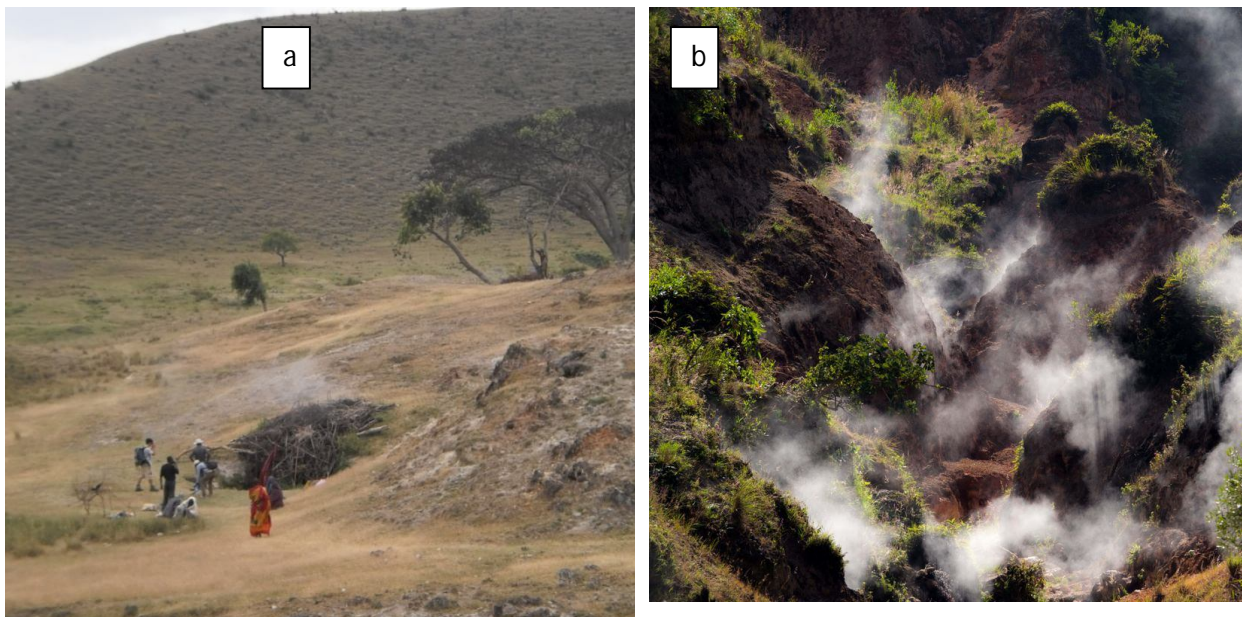
North East parasitic vent has explosive and effusive eruption history based on the earlier product. The northern of this vent has well bedded pumice and ash fall deposit that elongated to south of Lake Shalla. Most east of the vent has viscose lava flow which has thickness of about 12m. So the vent might followed by obsidian lava flow after the history of explosive eruption ended. Sometimes this vent is named with the local name “Danshe”. Danshe vent is as active as hot cone and has huge fumaroles.

### 5.7 Thermal manifestations and current geologic activities of Chabbi volcano.

In the rift system fumaroles and hot springs are most commonly associated with manifestation of recent volcanicity, ranging in observed temperature from 28<sup>0</sup>C to 130<sup>0</sup>C (average is about 60<sup>0</sup>C). Geysers are observed a few localities in the rift valley such as Allalobeda in Afar depression and Kulito area (the MER). Hot springs are numerous on the western plateau or the Ethiopian plateau but are very few on the Somalia plateau. The hot springs of the plateau ranging from 27 to 58<sup>0</sup>C with an average of about 40<sup>0</sup>C fail to show such high temperate as those of the rift system (MoWr, 2008).

Regional heat flow anomalies exist within the rift due to an upper mantle intrusion beneath the very thin crust layer. Local intrusion of silicic magma chamber is inducing higher heat flow anomalies like the one at Corbetti. Quaternary sediments in the rift floor serve as impermeable "Cap" to convective hot water systems in the basin (L. loyd, 1977).

Chabbi composite volcano is an active volcano that located on wonji fault belt specifically in Main Ethiopian Rift (MER). Thus it has significant activities which make it more active. Thermal manifestations common here are fumarolic manifestations and hot grounds figure 5.17. Following fracture from top of hot cone to East there are intense fumarolic manifestations and hot grounds. From figure 5.17 it is possible to see how huge the manifestations are?



*Figure 5.17 Hot cones fumaroles. The fumaroles are located in the crack that extended from the top vent of hot cone to the East of it. It runs about 2km to the East from top of the cone.*

## **6. Results and discussions**

### **6.1 Evolution of Corbetti caldera volcano**

Corbetti Caldera is the caldera developed in bigger Hawassa caldera. There were volcanoes that formed Corbetti caldera based on exposures at caldera rim which is dominated by older pumice fall deposits and moderately welded to unwelded ignimbrites. The Hawassa-Corbetti calderas belong to the Wonji Group (< 1.6 Ma) (WoldeGebriel et al., 1992) has Pleistocene rocks.

The Corbetti caldera walls and the two resurgent domes within the caldera consist of several layers of pyroclastic flows and aphyric and crystal-rich obsidian units. Awasa caldera yield K-Ar results ranging from 3.69 to 0.021 Ma (Wolde Gabriel et al., 1990).

Generally the initiation of the caldera might be of explosive eruption that formed in the Hawassa post caldera activity. The base reason is the ignimbrite formed from Corbetti volcano? exposed on the caldera wall that underlain by older rhyolite on the western rim. The older rhyolite might be the unit formed from the Hawassa caldera volcano which is visible on wondo genet exposure. The older pumice that covers the older rhyolite on of Hawassa caldera that out cropped on the southern rim of Corbetti caldera and northern of Lake Hawassa is covered by older pumice layered. Therefore it is possible to guess the Corbetti caldera passed through explosive eruption both in its pre and post caldera.

#### **6.1.1 Corbetti caldera**

Corbetti caldera is resulted from quaternary volcanic activities about 0.021Ma (Wolde Gebriel, 1990). It is located on Northern of Lake Hawassa on WFB. The caldera has two known volcanoes named Urji and Chabbi with elevation ranges from 1710m to 2314m a.m.s.l. the caldera has recent volcanic products and older products. The recent pumice and obsidian of Urji and Chabbi volcano over-bedded the welded tuff and rhyolite of the caldera volcanic products.

### **6.1.2 Corbetti Caldera structure**

Corbetti caldera is formed likely elliptical which has axis about 15km in east west directions. It has distinct boundary in all directions except to the eastern and NE flank. The eastern flank is covered by Chabbi and Urji young volcanic products. Corbetti caldera rim has a variable height. The northern rim is about 40m when the western and south western rim might reach ~80-120m. The north-eastern, eastern and western rims are covered by pumice fall deposit.

On the northern and western rims of the caldera, a continuous layer (about 3 m thick) of coarse ignimbrite occurs, inter-bedded with the pumice half-way to the top (Di paola, 1972). The caldera has elevation that ranges from ~1680 - 2314m a.m.s.l from the lower floor to the main vent of Chabbi volcano. Chabbi volcano is the highest point of the caldera.

Urji which located in the center of the caldera is known by explosive pumice and ash product whilst chabbi volcano has same history of Urji either than its effusive of rhyolite lava flow of first and third phase eruption.

### **6.2 Volcanic evolution of Chabbi**

The volcano has no recorded history as almost all Ethiopian volcanoes do. Including the previous explorers, the dearth of recorded history challenged to be sure the eruption type, repose time of eruption and discontinuity of earlier product outside of the caldera. Previous investigators specifically Mohr (1972) and Di Paola (1972) tried to map and study volcanic products.

Chabbi non-porphyratic obsidians are chemically transitional between comendites and Pantellirites (McDonald and Gibson (1972) and Elias Altaye, (1983)). The petrologic composition of the volcano shows as it is rhyolite.

The contacts between products are used to reconstruct the volcanic evolutions. Thus the central part of the volcano is covered by viscous lava flow whilst underlay products are pyroclastic and older rhyolite lava. The thickness of pyroclastic visible on Eastern, southern and Western part of the volcano that underlay the obsidian flow ranges from 20cm – 45m when the thickness of obsidian is from 3-5m.

Based on bedding, stratification and flow morphologies of earlier products, it is tried to reconstruct the volcanic evolution like eruption types and eruption sequences. The used method is by considering the youngest eruptions and events preserved in the produced deposits. So from field observation and review of previous works, it has three eruption phases.

### **6.2.1 First phase eruptions**

The Chabbi post-caldera volcanic activity started with the effusive style of eruption resulting in the emplacement of rhyolitic lavas and lava domes which are currently exposed in limited areas at the northern feet of the volcano below younger pyroclastic deposits. These lavas and domes probably spread at the base of the volcano and constructed a steep volcanic morphology which was later covered by younger eruptive products.

### **6.2.2 Second phase eruption**

The second phase of eruption is dominated by explosive eruption style. The major products emitted during this eruption phase are thick pyroclastic flows and fall deposits (pumice, ash and basaltic scoria) that overlie the older rhyolitic flows and lava domes. These pyroclastic deposits are dominated by tephra fall and cover the northern and north-eastern parts of the volcano and the adjacent Corbetti caldera floor. These pyroclastic products are observed to extend north and north-east of Chabbi over a large area up to Aje and Shashamane towns.

### **6.2.3 Third eruption phase**

The third and final phase of eruption from Chabbi is of effusive style which produced silicic viscous lava flows. These eruptions resulted in obsidian flows that were most likely emitted from the Main vent, the West vent and the East vent of the volcano. The petrology of these obsidian flows are well described by MacDonald and Gibson (1969).

#### **6.2.4 Possible Chabbi volcanic eruption style.**

Classification of volcanic eruptions from modern volcanic systems is commonly based on the pyroclastic fall deposits and lava flows generated by a volcanic eruption (Walker, 1973). In this classification scheme the dispersal and the degree of the fragmentation of the magma is taken into account. The degree of the fragmentation of the magma is closely related to the grain size of the eruptive product (e.g. finer the grain size the higher the fragmentation). A casual relationship also exists between the height of the eruption cloud and the degree of fragmentation; the higher the eruption column the greater the fragmentation (Walker, (1973) and K. Nemeth and U. Martin, 2007).

Therefore, considering the layered nature and fine-grained texture of the fragmented explosion products, the eruption style for the second phase of Chabbi might be classified as Vulcanian and/or sub-Plinian whilst the first and third phase eruption would be categorized in to rhyolite lava flow. Vulcanian eruption style is known by its tephra, ash clouds, and pyroclastic density currents which the most part of Chabbi volcano products habited. The products form Vulcanian eruption styles include blast of larger bombs to fine grain ash. The pyroclastic flows are also the known products from Vulcanian eruption styles. After the pyroclastic eruptions, effusion of lava commonly takes place (Nemeth and U. Martin, 2007). The eastern Chabbi flank has the surge deposit, ash and pumice flow and fall deposit with basaltic scoria falls. The existence of lithics and bombs are the base to guess the eruption style of the volcano might be volcanic eruption.

#### **6.3 Assessments of Potential volcanic hazard from future eruptions of Chabbi**

Possible Chabbi volcanic hazard assessment and zonation started from the assumption that future volcanic eruption will have similar scenario of its past volcanic evolutions. From the preceding discussion, it has been established that Chabbi is an active volcano with a recent history of both effusive and explosive eruption styles. Eruptions have occurred from a number of vents which are currently in fumarolic stage. Furthermore, it has been mentioned above that no recorded eruption history exists and hence the time intervals between eruptions are not well known. However, the very young age of the eruptive products together with the present thermal manifestations (the existence of numerous fumaroles, hot grounds, high temperature at the surface and shallow depths) are strong indications that the volcano is currently in a dormant state and may turn into an eruptive phase any time in the future.

In the absence of any volcano monitoring, it is reasonable to assume that future eruptions from Chabbi will follow similar eruptive characters and patterns that occurred in the past recent. Hence, a potential future eruption may take either an effusive or explosive character and will possibly include lava flows and pyroclastic flows and falls. The different types of volcanic products existing at different places on Chabbi volcano and surrounding areas are indicative of the areal extent that resulted from the past eruptions. Based on the variety of past eruptive products described in earlier sections as well as eruption types inferred from them, the types of main potential volcanic hazards that may occur from the possible future eruption are identified as follows:

- Flowage hazards (Lava flows and pyroclastic flows).
- Fall Hazards (Pumice and ash fall).

Flow hazards may result from both explosive and effusive volcanic eruptions. The explosive eruption styles have pyroclastic flows and fall hazards. The non-explosive eruption styles have lava flow hazards. Sometimes, pyroclastic flow and volcanic avalanche will result from dome collapse.

Viscous lava flows and dome growth will be probably of dominantly felsic eruption type including obsidian flows. Basaltic flows, while commonly associated with other active volcanoes in the MER, have not been produced in significant volumes on Chabbi indicating a lesser probability of such eruptions in near future. The possible eruption types from Chabbi may include any one of the following:

- Rhyolite lava flows and domes from the main vent or/and other parasitic vents.
- Pyroclastic flow and fall deposits which might accompany dome collapse or column collapse from Vulcanian and sub-Plinian types of eruptions that will consist of pyroclastic flows and falls (pumice and ash).
- Unlikely ignimbrite-forming eruptions.
- Possible small volume basaltic eruptions in the form of lava flows and scoria cones.

### **6.3.1 Flow hazard**

Flow hazards might result from both of lava and pyroclastic flows products. The lava flow hazard will be controlled by viscosity of magma, volume of magma chamber, vent orientations and slope of the surface; whilst the pyroclastic flow hazard will be controlled by vent orientations, slope of the flow surface, column height, eruption pressures and nature of the

magma. If the magma nature is dominated by much of less fragmented denser particles, it might cover lower distance from eruptive vents. But if it is dominated by less denser fragments, the column height might be high and could result in hazard that might go further distance from the eruptive vents.

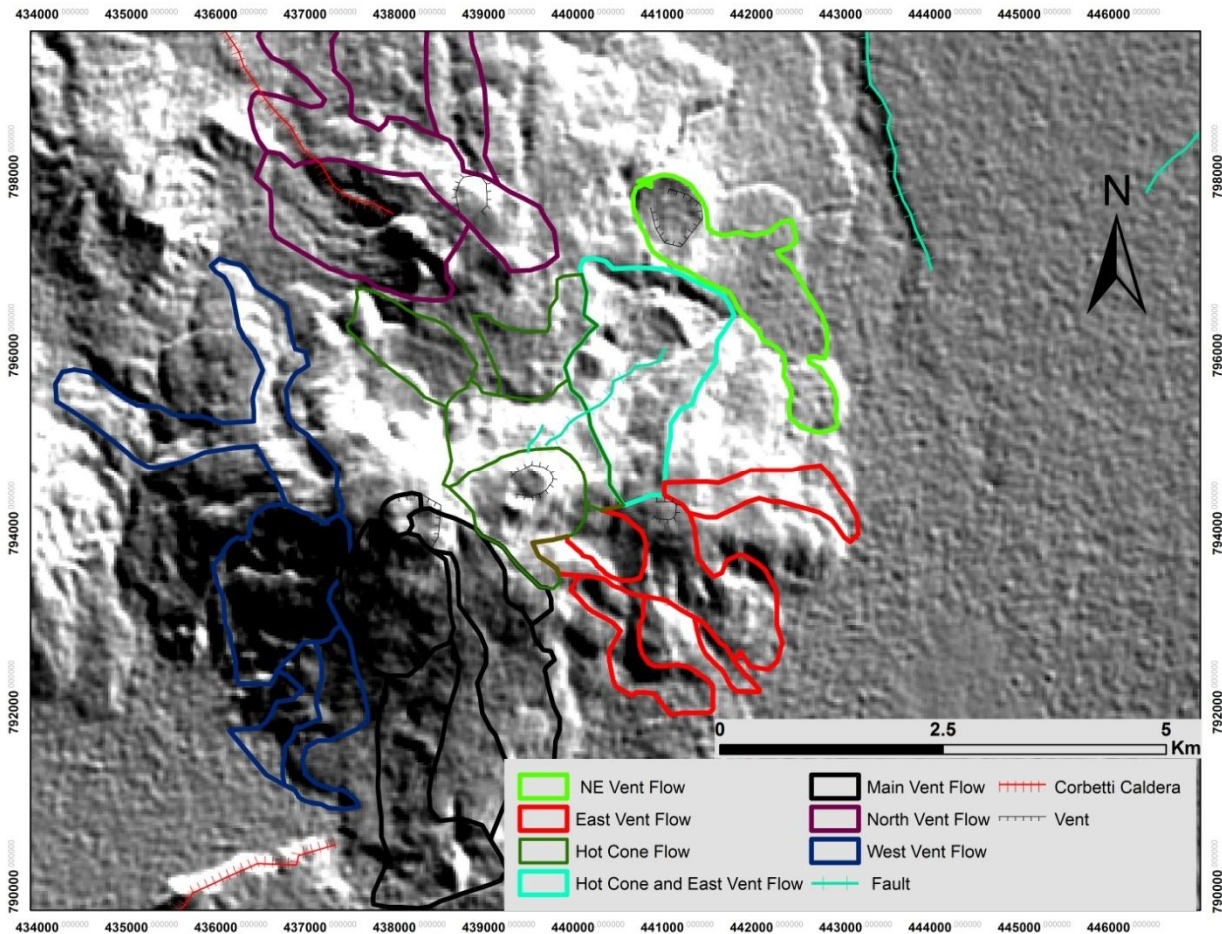
### **6.3.2 Lava Flow**

Based on the definition of (William and Mc Birney, 1979 as cited in Scott, W. E. 1989a), the rate of flow of lava is determined by the slope of the surface onto which it is erupted and the viscosity of the lava determine the morphology of extrusion. Viscous lavas such as dacite and rhyolite which are typically erupted at low rates form short stubby lava flows or steep sided domes that cover only a few square kilometers Scott, (W. E. 1989a).

Thus Chabbi volcano is a dominantly rhyolite volcano. This volcano has massive obsidian lava and viscous history during the first and third eruption phases. Even though rhyolite lava flow may cover limited square kilometers, it can cause brutal hazards within some tens kilometers radius. Using DEM of Corbetti caldera, the possible flow prone area from existing vents is delineated using rhyolite magma rheology.

Even though magma is not pure fluid, it has rheological properties and has ability to flow depended on its viscosity V.M Zobin, (2003). The flow of material is defined by its flowing viscosity and flow path. Thus the aspect of the volcanic area is determinant for magma flow. The elevation difference shown is the base for Chabbi volcano's hazard zonation. This means for the future eruption of Chabbi volcano elevation profile is used as the analytical criteria. The magma nature of this volcano is rhyolite.

Lava flows generally will be based on topography, flow path, magma nature, volatile content vents orientation, and vent diameter and slope percent. From elevation profile of the volcano, the lava flow will follow the down slope of Chabbi to south, west, east and north. Because, south, east and northern of the volcano is low land and has plain like morphology. All vents have elevation which ranges from 1850m to 2314m.a.m.s.l( from SRTM of Landsat 30m). soon to bottom of Chabbi volcano the elevation fallen to 1700m to 1610m.a.m.s.l.



*Figure 6.1 Possible lava flows from each vents and the estimated travel distance.*

From volcanic evolution and reconstruction of the past vents' activity, main vent, west vent and east vent has younger obsidian flow. The obsidian of main vent and west vent is younger than of others based on the degree of alteration and stratifications. So the lava flow coverage estimation is based on the product type (rhyolite obsidian), degree of slope, Geomorphology and availability of quarries to the down bottom of the volcano from DEM. All vents are located on steepest of the caldera that surrounded by lower land areas might be affected by lava flow hazards as shown in figure 6.1. Since lava will flow from higher points to lower point, the magma of all vents can reach these lower parts of the locale based on the viscosity of lava. From tentative hazard map of the radius of 5km is mostly high probable to such hazards. Thus from the GIS technique probable rhyolite lava flow hazard map is produced in figure 6.2.

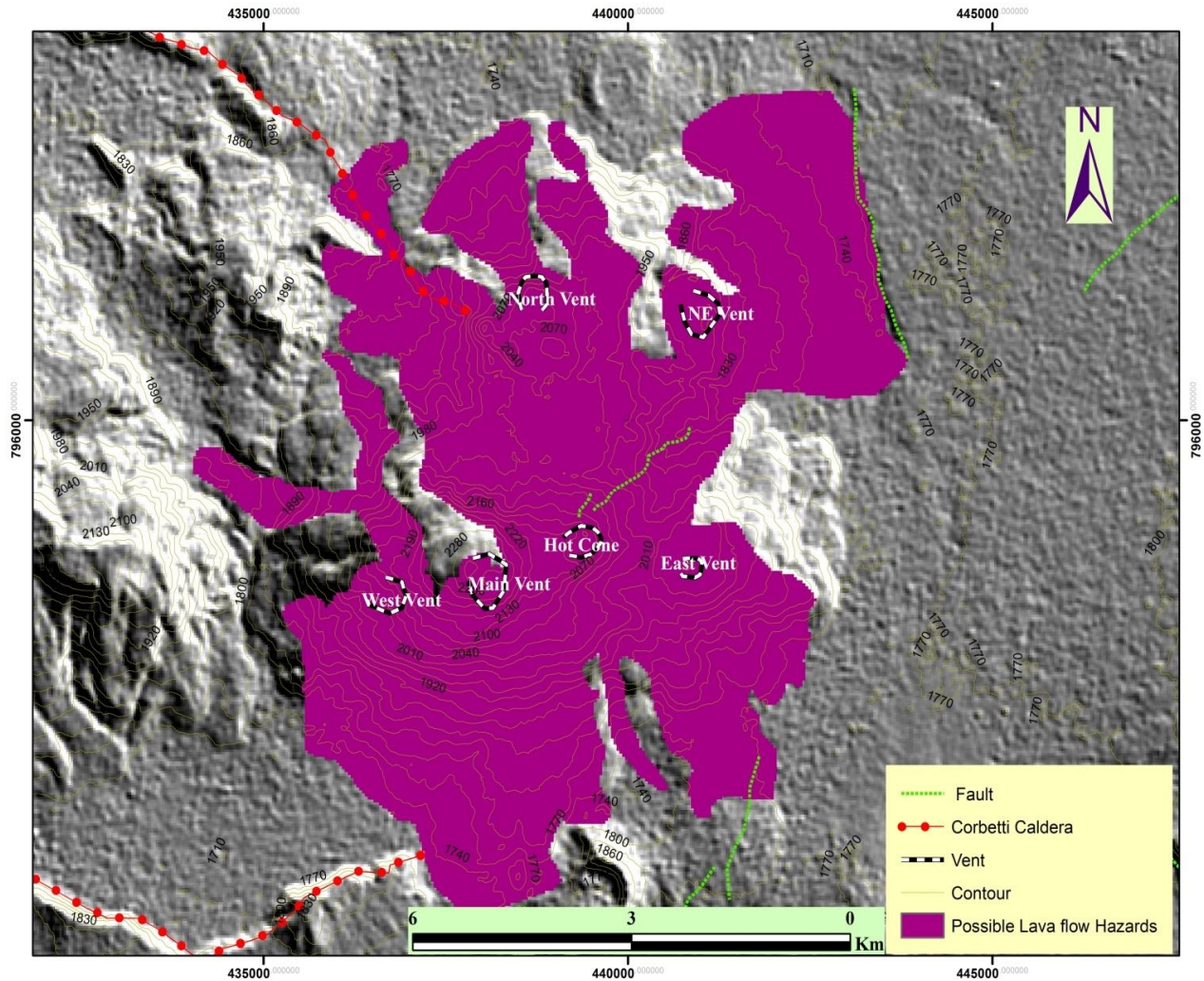


Figure 6.2 Tentative volcanic Lava flow hazard Zone. The magnitude of the hazard is characterized from Very high hazard to possibly low hazard.

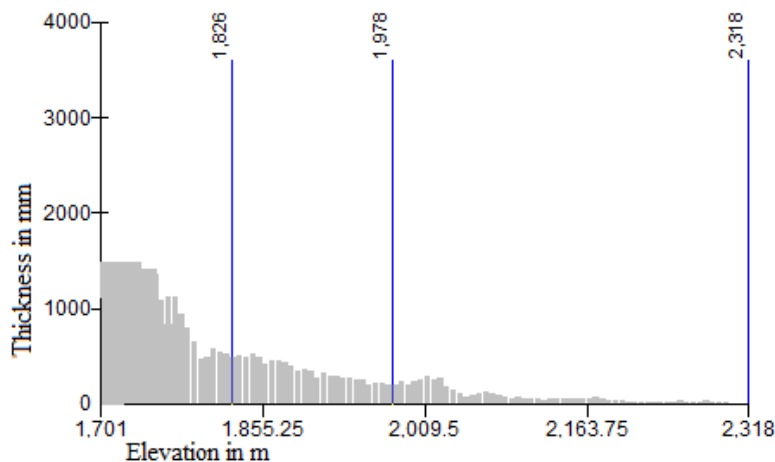
### 6.3.3 Pyroclastic flow hazard

Pyroclastic flows are masses of hot (300 to >800 degrees  $^{\circ}\text{C}$ ), dry, pyroclastic debris and gases that move rapidly along the ground surface at velocities ranging from 10 to several hundred meters per second. A flow is composed typically of two parts those of a ground-hugging dense base flow that is the pyroclastic flow proper and a preceding or overriding turbulent ash-cloud surge of ash elutriated from the flow. Convecting clouds of ash also are associated with pyroclastic flows and form one type of tephra-fall deposit (W. E. 1989a).

Pyroclastic flow is common product of andesitic (W. E. 1989a) and rhyolite composite volcanoes. Major controlling factors for the degree of pyroclastic flow as described by W. E.

(1989a) is that they vary widely in composition, temperature, volume and eruption rate that is reflected in their greater range in extent. Block-and ash flows composed mostly of dense to slightly vesicular lithic fragments in an ash matrix are of lower volume, are less mobile, and are typically restricted to within a few tens of kilometers from vents. In contrast, large pumiceous pyroclastic flows composed mostly of lapilli and ash can extend up to 200km from vents and cover thousands to tens of thousands of square kilometers. Column collapse is a major cause for the occurrence of pyroclastic flow.

Chabbi volcano has a history of pyroclastic flow eruptions as shown by an unknown thickness of exposed moderately welded ash flow deposit underlying a thick-bedded ash and pumice fall sequence. So it is possible to consider moderate to strong explosive eruptions from the present vents on Chabbi to produce pyroclastic flows by column collapse. Pyroclastic flows resulting from lava domes that could grow on the vents are also possible. Pyroclastic flows are principally controlled by topography moving down valleys. In addition, the eruptive column height also controls the topographic barriers that could be climbed by pyroclastic flows. The existing vents on Chabbi could be considered as highly improbable but possible sites for explosive pyroclastic eruptions. In this case, the elevated position of Chabbi volcano may facilitate the easy pyroclastic flow in almost all directions. Using elevation difference that extracted from DEM of Corbetti caldera, possibly the thickness of pyroclastic flow is estimated for chabbi volcano. The thickness of pyroclastic flow is higher for lower elevation than the elevated place. Because pyroclastic flow runs down to the lower elevation or some gorges.



*Figure 6.3 Elevation versus probable flow thickness with classified elevation value based on the possible flow hazards.*

Based on the composition and products from earlier Chabbi vents, it is characterized by the exclusiveness and thickness of flow from central located vents (figure 6.3), the main vent, hot cone, East vent, East vent and North vents are considered as the major sources for pyroclastic flow hazards. So there will be intense probability of pyroclastic flow hazard from their future eruption.

Using the energy line concept of (M.F. Sherdina(1979) sited in M. Rosi, et.al. 1980/1981) and estimated elevation difference versus flow thickness, earlier product coverage, Figure 6.4 was produced to shows the probable and primary pyroclastic flow hazard map in GIS techniques.

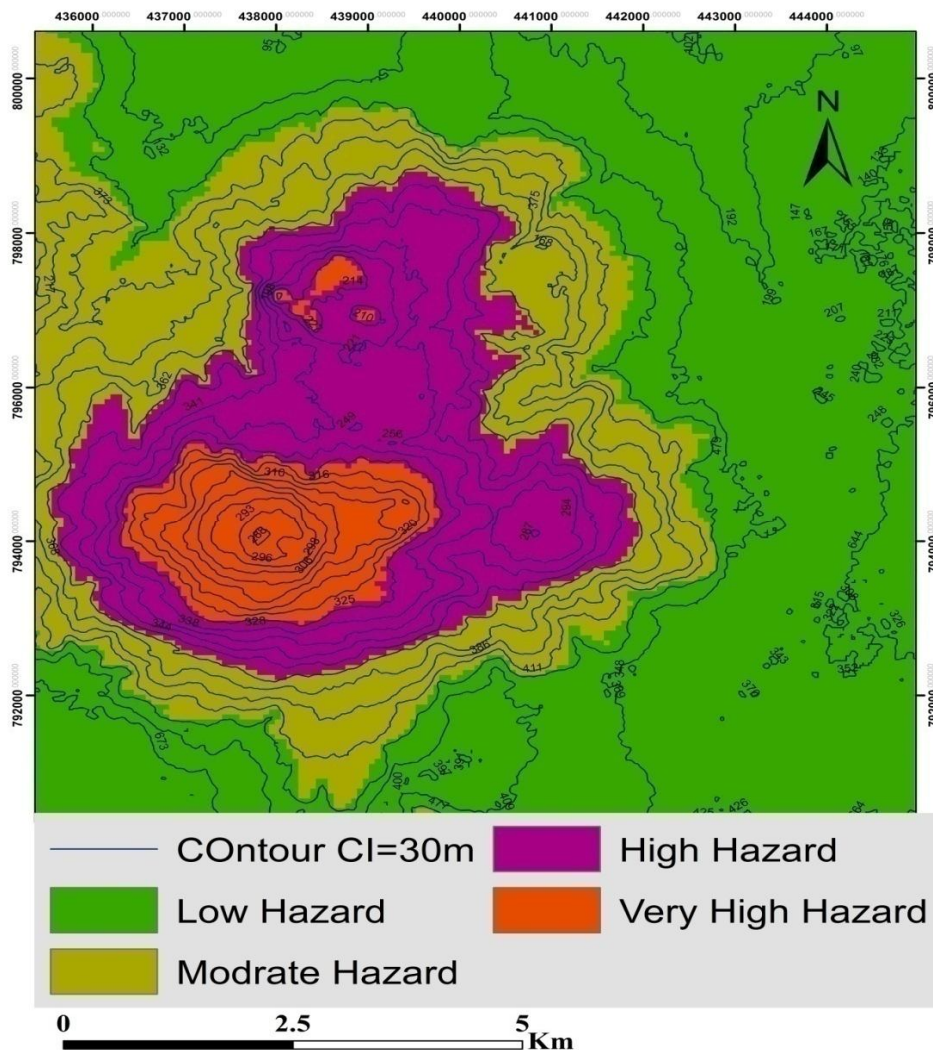


Figure 6.4 Probable future pyroclastic flow hazards of Chabbi volcano.

#### **6.3.4 Pyroclastic fall deposit Hazard.**

Pyroclastic falls occur when tephra which is fragmented rock ranging in size from millimeter to tens of centimeter is ejected from a volcanic vent and falls to the ground on some distance away from the vent. Falls are usually associated with Vulcanian and Plinian eruptive columns, ash clouds or volcanic plumes. Tephra in pyroclastic fall deposits may have been transported only a short distance from the vent (a few meters to several kilometers). (<http://geology.com/volcanoes/volcanic-hazards/>).

Chabbi volcano has pyroclastic (ash and pumice) fall from its central volcano to the northern and Eastern of Corbetti caldera. Thickness of ash and pumice fall deposits is remarkably decreased to Bura town on the north part and Shashamane town on eastern directions. Furthermore, the thickness of pumice fall deposit reaches 3-4meter near NE vent (Danshe) and 5-15cm thick at outcrop of Bura town and west of Shashamane town.

Tephra ranges in size from ash (has less size of 2 mm), to lapilli (2 to 64mm), to blocks and bombs (greater size than 64mm) that may reach several meters in diameter (Fisher, 1961). Densities vary from low density, vesicular pumice and scoria to dense crystals and lithic fragments. Tephra fall and ballistic projectiles endanger life and property by:

- 1) The force of impact of falling fragments, over place close to an eruption,
- 2) Loss of agricultural lands if burial is greater than 10 cm depth,
- 3) Producing suspensions of fine-grained particles in air and water which clogs filters and vents of motors, human lungs, industrial machines, and nuclear power plants, and
- 4) Carrying of noxious gases, acids, salts, and, close to the vent, heat.

Burial by tephra can collapse roofs of buildings, break power and communication lines and damage or kill vegetation. Even thin (<2 cm) falls of ash can damage such critical facilities as hospitals, eclectic-generating plants, pumping stations and short circuit electric-transmission facilities and telephone lines. (<http://volcanology.geol.ucsb.edu/hazards.htm>).

The severity of tephra fall and ballistic projectile differs based on eruption size and concentration of vesicles. Description of (walker 1980 as cited in Wright et al.1980), categorized the degree

and type of tephra fall and ballistic projectiles' hazard in to four types and model it in texture size Versus distance it could travel.

- 1) The force of impact of falling fragments.
- 2) Burial.
- 3) Producing a suspension of fine-grained particles in air and water and
- 4) Carrying noxious gases acids salts and closes to the vent, heat.

Based on above discussed concept Chabbi volcano may result tephra fall hazard in its future eruption. The huge pumice deposit that covers the Northern and NE of caldera rim is the base to guess the probable future fall hazard from it. Primarily fall hazard is delineated within 15km from main and other parasitic vents. The air distance of Shashamane town to the NE of Chabbi volcano is about 12km. Bura town has about 8 km distance to the Northern of Chabbi volcano. To the NNW there is other town called Aje which has about 14 km distance. To the south east of the volcano Tikur Wuha and Hawassa city is there. These places have 7km and less than 10km distances consequently from Chabbi. To the SSW there is other village which is highly populated of farmer's village has about 3km distance from West vent. Either than distance proximity, the elevation profile facilitate the hazards.

Wind direction is the other controlling factor for tephra fall. The wind direction can play a great role to divert the risk area to one sided. Wind direction of the earlier product can be identified based on the thickness of pyroclastic fall deposit and the extent it travels from the interpretation of satellite image in figure 5.6 and field observations. Corbetti caldera volcanoes eruptive products dominantly fall from all vents to the north, north east and east. Therefore earlier volcanic fall of Chabbi and Urji was derived by wind direction which might be from south west to north and north east of Corbetti caldera. The thickness of ash and pumice fall of these volcanoes extends mostly from each vent to the northern and north eastern of its self to the lake shalla. To the south of Lake Shalla there is pumice and ash deposit which is little bit altered and has similar bedding structures with of Chabbi volcano. But the thickness of fall deposit is less in this direction than to the north and north east of the volcano. Therefore it is reasonable to say the wind direction was from south to north and the regional analysis of Aspinall et al., (2011) shows it.

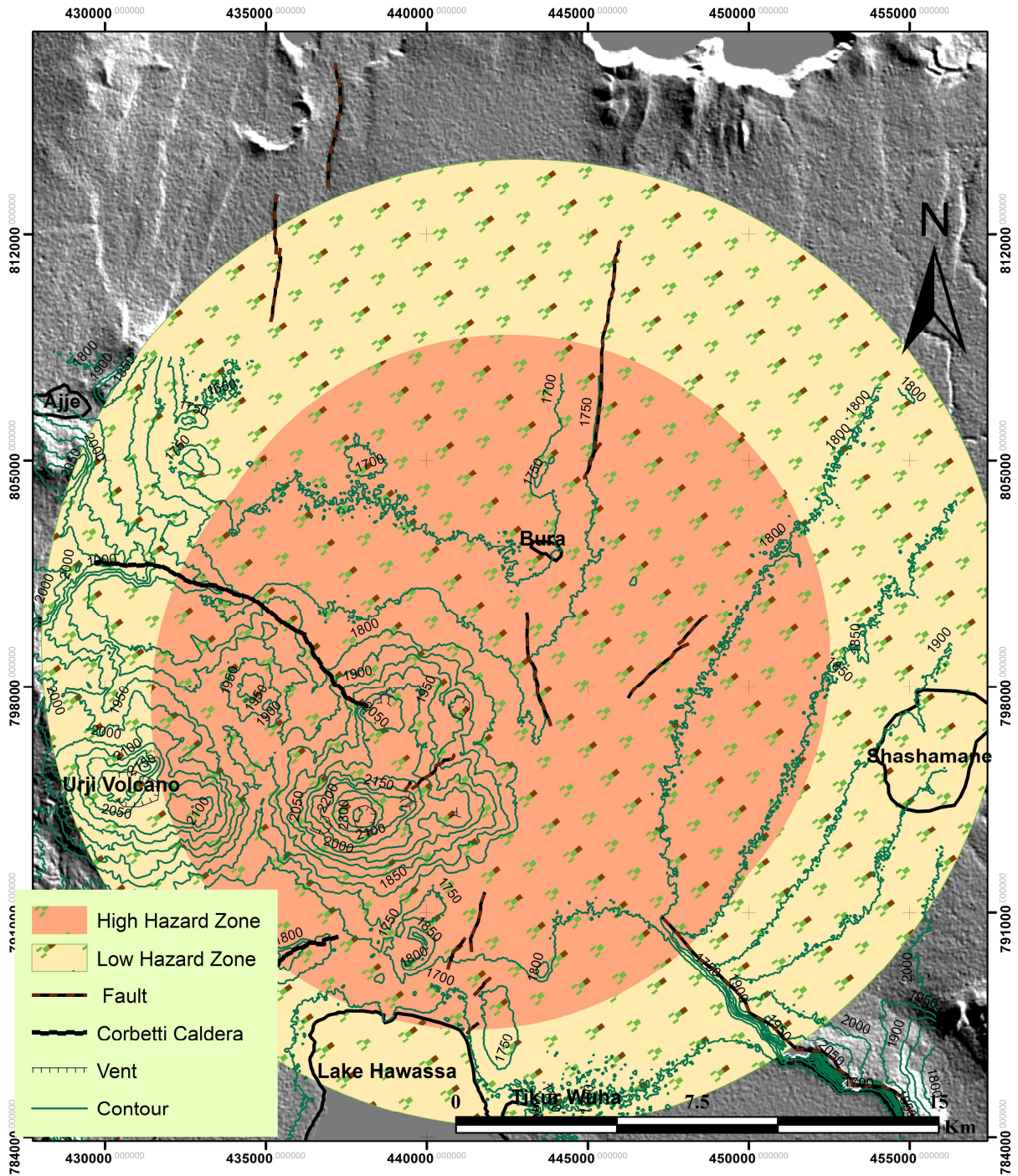


Figure 6.5 Possible volcanic fall hazard from Chabbi future eruptions. The wind direction is probably assumed to be from south west to NNE.

#### **6.4 Map of Tentative possible future Chabbi volcanic eruption hazard.**

Based on interpretation of its earlier products, Chabbi quaternary volcano is known by its fragmented pyroclastic (ash and pumice) flow and fall and non-Porphyritic and non-pheynocrist obsidian flow. The volcanic eruption style is also estimated to Vulcanian or sub-Plinian eruption style from the stratification earlier products. Chabbi has explosive and effusive eruption history.

After incorporation of all methodology and criteria, tentative hazard zone map could be produced using GIS and Remote sensing approach. The area is divided in to three zones based on earlier product evolution and coverage, possible wind direction and elevation profile. The tentative map of the hazard zone is primary that limited to 15km radius currently with the limited data and resource, the remarkably probable output is made.

Generally Northern and NE of Corbetti caldera areas are tentatively estimated as hazardous zone. The estimated area is within 15km form each vent to direction of the wind that is adopted from the deposition direction of earlier products of both Chabbi volcano and Urji volcano that extended to Northern and Eastern of Corbetti caldera. The other criteria are that elevation profile allows transporting for both explosive and non-explosive eruption easily for that all Chabbi vents are located on higher points.

Therefore from the observed past volcanic products, possible future eruption and current manifestations the future possible volcanic hazard of Chabbi volcano can be categorized into three major hazard zones: very high hazard zone, high hazard zone and low hazard zone.

Very high hazard zone is where possible future flowage hazards (lava flows and pyroclastic flows if column collapse perpendicularly down to the vents) and past tephra fall overlaying. Its area coverage is about 94.23km<sup>2</sup>.

High hazard zone is the area where flowage hazards from dome collapse, pyroclastic flows of column collapse perpendicularly down to the vents and thick pyroclastic fall will reached due to topographic setting of the area. It is the zone where past tephra falls including blocks and fragmented rocks and pumice and ash falls are found. It may coverage area about 314 km<sup>2</sup> within 10km radius.

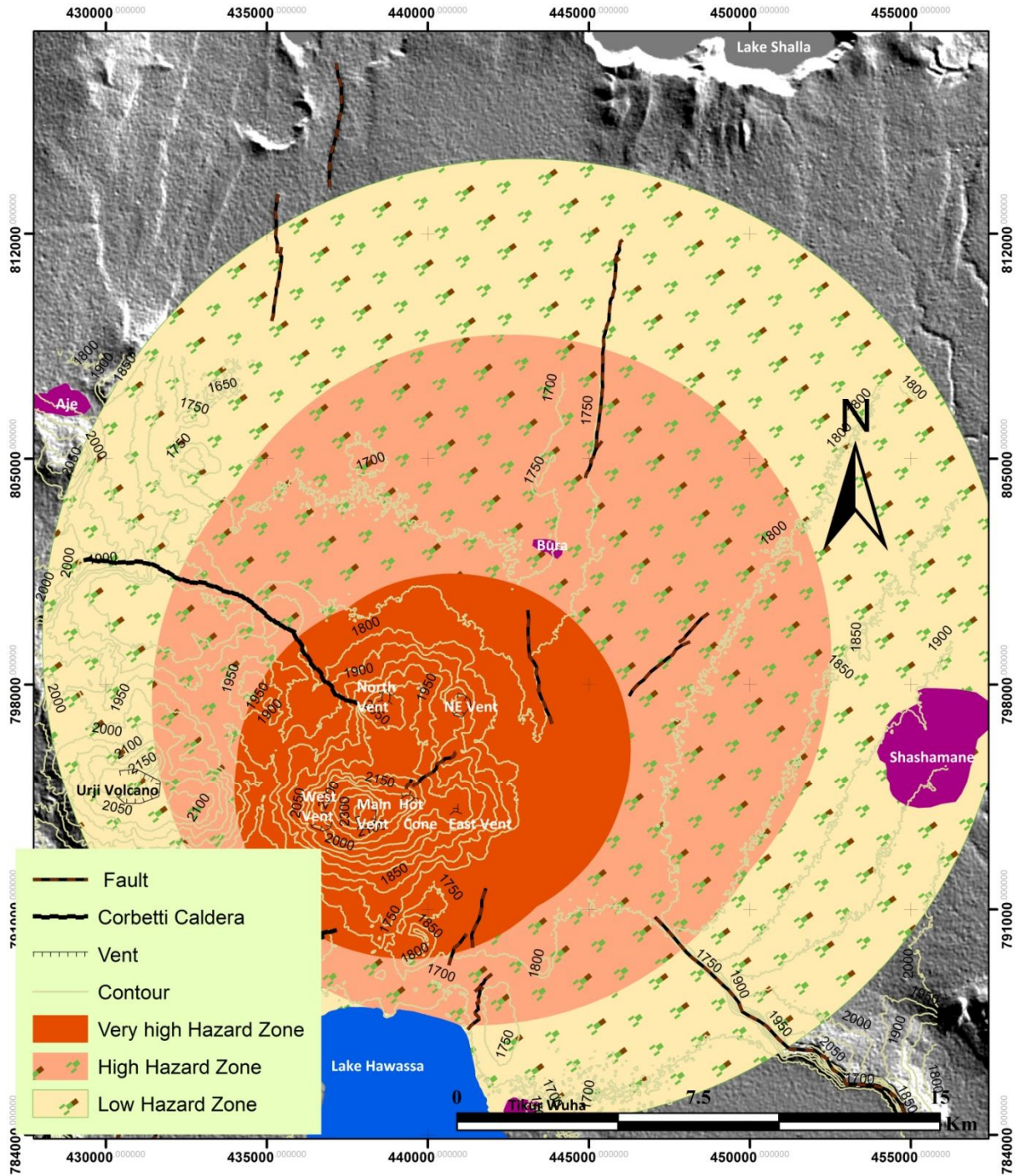


Figure 6.6 Zoned map of possible future Chabbi eruption hazard. It is started from minimum possible hazard prone area.

The third zone is assigned Low hazard zone that is assumed to be of fall deposit hazards. It may be of ash fallout or pumice deposit. Based on magma's gas content, magma concentration, humidity of the atmosphere, wind direction and column height the coverage area of pyroclastic fallout will be defined. Therefore tentatively third zone is assumed to such hazard zone.

The reason why it is zoned as low hazard zone is the severity fall hazard is based on the fall thickness. It is discussed in section 6.1.3. Therefore figure 6.6 is the zoned probable hazard map of chabbi volcano future eruption.

### **6.5 Previous works and results of this work**

The geologic descriptions of chabbi are done by Mohr (1966), Di Paola (1972) and Elias (1984). The younger obsidian flow is shown clearly as it is in the field and satellite image which verified by this study. Both Chabbi and Urji volcano are post Corbetti caldera activities and the evidence is the succession of resent products and older rhyolite lava exposed at localities. Chabbi and Urji volcano might have similar age though Chabbi has later obsidian flow as it is discussed by Wolde Gebriel et al., (1990).

The product visible on the SW to west of main vent is fine ash (see in Figure 5.10b), not paleosoil as discussed by Di Paola (1972).

The unit shown in the volcanic geology of Chabbi in Figure 5.7, the pyroclastic flow exposed on the northern of Hot cone vent is described as older rhyolite lava flow by Elias (1984); but it is pyroclastic flow. The ignimbrite of the area is not mappable.

Chabbi in MER is the areas where there are huge economic activities are widely infrastructures are available around it. Hawassa city which has population more than 300,000, Shashamane town has population about 155,000, Tikur Wuha has population more than 5648, Bura has population 1300 and Aje town which has population about 2100 are within the range of 15km radius.

Infrastructure and industries like floury cultures, university and colleges, hotels, aquatic zoos, Biscuit factories, etc are available. So there is probability for such infrastructures and population to be affected by future Chabbi volcanic hazards. In the concept of volcanic hazards, this paper presented the result of possible primary volcanic hazard coverage areas as per hazard degree and possible hazard magnitude in figure 6.6.

## **7. Conclusion and recommendations**

### **7.1 Conclusion**

Chabbi quaternary volcano is active volcano. Geological activity manifestations are indicators for its activeness and the re-eruption of the volcano in near future might be expected. All vents are at fumarolic stage. The fracture width from hot cone to the east of hot cone extended from 5m is (Mohr, 1966) to 25m currently.

The evolution of Chabbi is identified from incorporated methodologies. From satellite image the earlier volcanic products were interpreted and delineated using remote sensing and GIS. The geomorphic and volcanic map of the volcano is produced. From the petrologic review the volcano is composite rhyolite. The earlier products contacts show that Chabbi volcano evolved probably vulcanian eruption style that occurred in three phase eruptions; which were explosive and non explosive eruption.

Magnitude of hazard and probable coverage of products' area for flow and fall hazards are assessed, delineated and tentatively zoned as its brutality. There were three zones delineated within 15km from all vents to possible wind directions at GIS environment. Its earlier products for geological mapping and current coverage area are used to produce hazard zones.

The first zone is prepared within 5km labeled high hazard zone which is considered as very high hazard zone for both explosive and non-explosive eruption. Within this radius residences and economic activity is seen in East, South, Northern and North West of Chabbi vents.

Second zone is labeled is high hazard zone which has radius 10km from each vent in all directions. This zone is described as moderately hazardous for non-explosive and highly hazardous for explosive eruption. High hazard zone has low probability to be covered with lava flow and saver for pyroclastic flow, pyroclastic surge, and column collapse and pumice fall.

The third zone is Low hazard zone. This zone has 15km radius and described as no hazardous for non-explosive and probably hazardous for explosive eruption. Tikur Wuha, Shashamane, Bura and Aje towns are within the radius of 15km zone based on the possible wind direction that trace of the past coverage.

## **7.2 Recommendation**

Once volcano erupted there will be high probability for re eruption. More over geologically active like Ethiopian Rift Valley where there is continuous tectonic activity is found needs due attention to save human life and economic loose.

In developing countries like Ethiopia where there is scarcity of volcanic awareness, the government should use society awareness creation about volcano for those living nearby it. In such case people may know and get ready if the will be some geologic changes happened over active areas like Chabbi volcano.

The other major option to reduce volcanic hazard are continuous volcanic monitoring and early warning system. For this method early warning and disaster management bureau of the federal and regional government should implement in jointly.

Scientists and researcher should also use detail investigation using both geological and geophysical methods to come out the reasonable outcome that may use the habitats in escaping from future eruption of Chabbi.

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I, **Fekadu Aduna**, declare that this thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for the thesis have been appropriately acknowledged.

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