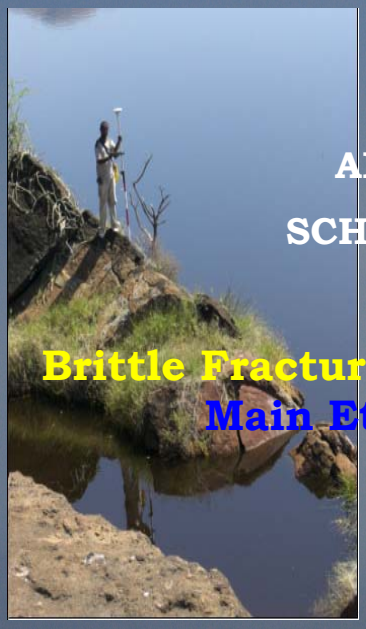


ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUTE STUDIES

Brittle Fracture and Lake Level Change at Beseka: Main Ethiopian Rift, Metehara Area

A Thesis
Submitted to

The School of Graduate Studies
of Addis Ababa University

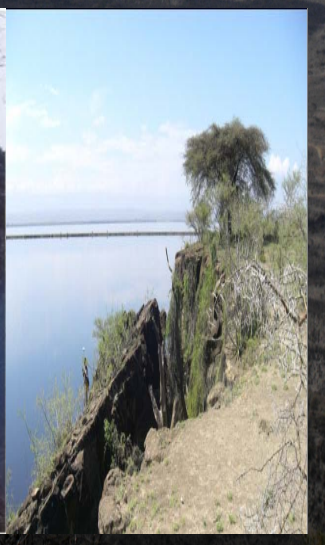
In partial fulfillment for the degree masters of Science in Structural Geology-Tectonics and Rock Mechanics





Berihu Abadi Berhe

July 2007





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Brittle Fracture and Lake Level change at Beseka; Main Ethiopian Rift, Metehara area

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Abstract

In early 1960's, the surface area of Lake Beseka was only 3 km^2. In 1976, the lake area was estimated at 27.5 km^2 and now it covers around 41km^2 (Tamiru et al., 2006). The lake gauge height is about 0.71m in 1976 and 5.6 m in 2006 which almost increased by about 5 m in the last 30 years.

The rocks are affected by NNE-SSW faults and fissures. The faults within the area of investigation have very atypical morphologies. Profiles across fissures constructed by Trimble GPS and field observation indicate that the fractures do not show the morphology of typical faults. The footwall remains flat and the concave hanging wall curves up to ward the fault plane.

Generally 487 data of edge matching opening direction are taken and weighted according their horizontal displacement to gave the total opening direction 113.4^o, which is in agreement with the overall E-W direction.

The elevation of water level Lake Beseka is lower than the elevation of water table of wells in the Abadir farm as well as the elevation of Awash River. Hence, the flow of groundwater is towards Lake Beseka.

The Abadir Farm- a suger cane plantation south of Beseka-is mainly placed within the lake's catchment area, which is affected by ground cracks in rainy seasons. The recharge to the groundwater coming from this plantation affects the lake level to rise. In addition to the flow of ground water, the tectonic hot springs as well as cold springs, which are also the main factors to the expansion of the lake, come through these structures in the direction of SSW-NNE.

The curve of the lake level fluctuation shows an increment with time while climatic data do not show any anomalies. Therefore, climate has not any impact/influence on the lake level rise.

The extension of Lake Beseka results with flooding and salinity of Abadir farm land and endangering of the routes (road and railway) from Addis Ababa to Djibouti. The expansion of Lake Beseka has necessitated the raising of the level of the road and railway line repeatedly.

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Table of contents

Content page

Abstract.....I

Acknowledgment.....III

List of figures.....VI

List of tables.....VIII

Annexes.....IX

Acronyms X

1. INTRODUCTION.....1

1.1 Background 1

1.2 Objective of the study.....3

1.3 Methodology.....4

1.4 Material Used.....5

2. GENERAL OVERVIEW OF THE AREA.....6

2.1 Location and Accessibility 6

2.2 Phyiography 8

2.3 Climate 10

2.4 Soil and Vegetation.....12

2.5 Land use-Land cover 12

3. HYDROMETEOROLOGY.....14

3.1 Rainfall 14

3.2 Temperature.....15

3.3 Relative humidity 16

3.4 Wind speed 17

3.5 Sunshine.....18

3.6 Pitche Evaporation 18

4. GEOLOGY.....21

4.1 Geology of Main Ethiopian Rift.....21

4.1.1 Lithology 22

4.1.1.1 Anchar Basalts....22
4.1.1.2 Arba Gugu basalts....23
4.1.1.3 Chilalo and Badda Trachytes....23
4.1.1.4 Bofa Basalts....23
4.1.1.5 Rhyolitic Volcanic Complexes....24
4.1.1.6 Lacustrine sediments....25
4.1.1.7 Alluvial deposits....25
4.1.2 Regional Structures....25
4.1.2.1 Western margin....27
4.1.2.2 Eastern margin....28
4.1.2.3 The Rift Floor....28
4.2 Geology of the study area....29
4.2.1 Lithology....29
4.2.1.1 Bofa basalts....29
4.2.1.2 Dino Ignimbrites....30
4.2.1.3 Pleistocene-Sub recent basalts....30
4.2.1.4 Pantelleritic volcanics of Fantale rhyolites, trachytes and agglomerates....31
4.2.1.5 Alkalic and peralkali rhyolites, trachytes domes and flows of Boseti and Hada Mountain....31
4.2.1.6 Tuff cone....31
4.2.1.7 Recent to subrecent rhyolitic domes and flows....32
4.2.1.8 Unwelded rhyolitic pumice and unwelded tuff....32
4.2.1.9 Pitchstone flows and domes....32
4.2.1.10 Young Ignimbrites of Fantale....33
4.2.1.11 Lava flows of Tinish Sabober and Fantale....34
4.2.1.12 Lacustrine Sediments....35
4.2.1.13 Alluval sediments....36
4.2.2 Structures....38
4.2.2.1 Morphology Faults and Fissures....40
4.2.2.2 Formation of Fault-Fisure-Monoclinal-System FFMS)....44

4.2.2.3 Interpretation from aerial photograph 46
4.2.2.4 Extension direction..... 47
4.2.2.5 Geometric features of interacting fractures 51
5. Tectonics and Volcanism..... 54
6. Result and Discussion..... 59
6.1 Interpretation of climatic data and lake level..... 59
6.2 Groundwater flow and structures 61
6.2.1 Groundwater and streams 61
6.2.2 Groundwater and Lake..... 62
6.3 Spring and structure 65
6.4 Ground crack 65
6.5 Lake Beseka Graben..... 66
6.6 Remedial Measure 69
7. Conclusion and Recommendation..... 70
7.1 Conclusion 70
7.2 Recommendation..... 72
Reference..... 73

List of Figures

Fig.2.1 Location map of the study area. 7
Fig.2.2 Topographic map of the study area 9
Fig.2.3 LU/LC map for the year 1973 13
Fig.2.4 LU/LC map for the year 2003 13
Fig. 3.1 Mean Monthly Rain fall 15
Fig. 3.2 Mean Monthly Temperature 16
Fig 3.3 Mean Monthly Relative Humidity 17
Fig. 3.4 Mean Monthly Wind Speed 17
Fig. 3.5 Mean Monthly Sunshine Hours 18
Fig. 3.6 Mean Monthly Pitche Evaporation 20
Fig.4.1 Structural Map of MER 27
Fig.4.2 Out crops basalts 30
Fig. 4.3 Outcrop of tuff cone from western rim of Tinish Sabober. 31
Fig. 4.4 Pitchstone rock south of Tinish Sabober. 32
Fig. 4.5 Young ignimbrite of Fantale 34
Fig. 4.6 Lava flow from Tinish Sabober. 35
Fig. 4.7 Lake Sediments 36
Fig. 4.8 Geological map of study area 37
Fig. 4.9 Structural Map of the study Area 39
Fig.4.10 Atypical fault morphology located north of Lake Beseka 40
Fig.4.11 Location map of the detailed kinematic measurements taken 41
Fig.4.12 Along and across the fissure measurements 42
Fig.4.13 3-D of the fissure 42
Fig.4.14 Fracture outcrops 43
Fig.4.15 Vertical extension fracture 44
Fig.4.16 Dyke induced faulting (photos) 45
Fig.4.17 Dyke-induced faulting (Model) 45
Fig.4.18 Sections from aerial photograph 46

Fig.4.19 Edge matching of opened fissure 49
Fig.4.20 Measurements on opening Direction of Fissures their values 50
Fig.4.21 Measurements on Horizontal offset of Fissures their values 50
Fig.4.22 Frequency of values of opening direction 51
Fig.4.23 Geometry of Fissures 52
Fig.4.24 Fracture interaction 53
Fig.4.25 Combination of Tectonic Fissure and Cooling Fracture 53
Fig.5.1 Structures and Volcanism relationship map 57
Fig.5.2 Alignment of Scoria cones along the fissure 58
Fig.5.3 Lava flow from Tinish Sabober 58
Fig.5.4 Lava flwos in to fissure of Young ignimbrite of Fantale 58
Fig.6.1 Lake level change of Beseka (1976 - 2006) 59
Fig.6.2 Climate (rainfall & temperature) and Lake Level change 60
Fig.6.3 Climate (Relative humidity, sunshine, and wind speed and pitche evaporation) and Lake Level change 61
Fig.6.4 Ground water flow map 64
Fig.6.5 Lake Beseka Graben 66
Fig.6.6 Great circles for the faults east and west of Lake Beseka graben 67
Fig.6.7 Great circles for the fissure/faults northeast and west of Lake Beseka graben 67
Fig. 6.8 Extend of Lake Beseka's expansion 68

List of Tables

Table 2.1 Climatic classification of Ethiopia 11
Table 3.1 Mean Monthly Rain fall 15
Table 3.2 Mean Monthly Temperature 16
Table 3.3 Mean Monthly Relative Humidity, Wind speed and Sunshine Hours. 18
Table 3.4 Mean Monthly Pitche Evaporation 19

Table 6.1 Lake Level in meter 59
Table 6.2 Rainfall, Average temperature and Lake Level 60
Table 6.3 Sunshine, Wind Speed, Relative Humidity, Pitche Evaporation and Lake Level 60
Table.6.4 Chemical analysis of lake beseka.....63
Table 6.5 Amount of water blended in to Awash River from Lake Beseka 69

Annexes

Annex 1. Mean Monthly Maximum Temperature.....82
Annex 2. Mean Monthly Minimum Temperature 83
Annex 3. Mean Monthly Air Temperature.....84
Annex 4. Mean Relative Humidity at 1800 LST 85
Annex 5. Mean Relative Humidity at 1200 LST 85
Annex 6. Mean Relative Humidity at 0600 LST 86
Annex 7. Mean Monthly Sunshine hours 86
Annex 8. Mean Monthly Wind Speed 87
Annex 9. Mean Monthly Rain fall.....88
Annex 10.Mean Monthly Pitche Evaporation.....89
Annex 11.Gauge height of Lake Beseka 90
Annex 12.Location matching edge of the extensional fractures and their measured values.....91
Annex 13. Elevation Measurements Lake Beseka, well and Awash River..... 102

Acronyms

ASTER	Advance Spaceborn Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
EARS	East African Rift System
EMA	Ethiopian Meteorological Agency
EIGS	Ethiopian Institute of Geological Survey
FFMS	Fault-Fisure-Monoclinal-System
GIS	Geographic Information System
GPS	Ground Position System
ITCZ	Inter Tropical Convergence Zone
MER	Main Ethiopian Rift
MSE	Metehara Sugar Estate
MWR	Ministry of Water Resource
STRM	Shuttle Radar Topography Mission
UNDP	United Nations Development Program
UTM	Universal Transverse Mercator
WFB	Wonji Fault Belt
XRD	X-Ray Diffraction

1. INTRODUCTION

1.1 Background

The Main Ethiopian Rift (MER), which belongs to the northern most braches of the East African Rift System (EARS), is characterized by active extensional tectonics. It is seismically, tectonically and volcanically active since early Miocene time (WoldeGabriel et al., 1990). To the south, the MER continues to the Kenya rift and to the north it is connected with oceanic rift system of Red Sea and Gulf of Aden at the Afar triple junction. Lakes in the MER are generally located in three basins: Awash basin, central Main Ethiopian Rift and southern basin. Lake Beseka is one of the lakes which are found within the volcanically active rift floor at the northern end of the MER in the Awash basin.

Lake Beseka is located immediately south of Fentale Volcano in the MER. Zones of seismicity (Keir et al., 2005) generated a deepening basin at the site of the present Lake Beseka. The Endorheic Lake is situated in a region characterized by normal faults trending N10-20°E, which also form its borders and control numerous hot springs (Mamo and Getaneh, 2003).The lake has a closed catchment with no surface water out flow. Near the lake, there is the Metehara Sugar Estate (MSE) with a developed farmland of about 10,000ha (Tesema, 1998). In early 1960's, the surface area of Lake Beseka was only 3km^2. In 1976, the lake area was estimated at 27.5km^2 and now it covers around 41km^2 (Tamiru et al., 2006)

The Abadir Farm, a sugar cane plantation south of Beseka, is mainly placed within the lake's catchment area. Both the Abadir Farm and the Metehara Sugar Estate east of the water divide rely on the nearby Awash River for water supply. According to Tesema (1998), the Koka dam was constructed 152 km upstream of the project area in 1960, ensuring a steady flow of the river Awash. The irrigation project became operational in 1964 (Tesema, 1998) and

most of the previous studies tend to agree, that this marked the beginning of the lake's abnormal expansion (i.e. Halcrow et al., 1979; Ayenew, 2004). The influence of neotectonic activity has barely been taken into account; the basin morphology has not been quantified in previous approaches (Tesema, 1998; MWR, 1998, Engda and Russom, 2004).

Meteorological variations and irrigation alone cannot explain the water level increase. The analysis of remote sensing data proved to be essential to address the temporal fluctuation of the lake's surface area and the spatial distribution of its temperature as well as for the characterization of the catchment (Gorner, 2005). According to Gorner, the lake is strongly associated with the structures of the rift and the hot springs influenced it as well.

Accompanying the rise of lake level, the chemistry of the lake water has been continuously changing leading to the reduction of ionic concentration. This change is related to increase in the inflow due to over irrigation in the lake catchments (Tamiru et al., 2006). According to Tamiru et al., (2006), water for irrigation is derived from Awash River, where excess water recharges the lake through the open rift faults. They also describe that the main changes in the water balance of the Lake Beseka come from the ground water inputs, which are related to the recent increment of recharge from irrigation fields and due to the rise of Awash River level after the construction of Koka dam.

The extension of Lake Beseka resulted in flooding and salinization of Abadir farm land and endangering of the routes (road and railway) from Addis Ababa to Djibouti. The expansion of Lake Beseka has necessitated the raising the level of the road and railway line. The lake, to date has inundated fully and partially about 150 ha of the sugar cane plantation and over 2000ha of grazing land (MWR, 1999). It has also submerged and dried up trees near the lake.

The structures in the study area are normal faults and fissures trending of N-S to N 20°E. They belong to the Wonji Fault Belt (WFB) (Mohr 1962, 1967, 1987), and exhibit a number of sigmoidal, overlapping, right-stepping en-echelon fault zones obliquely cutting the rift floor. The lithological units of the investigated area consist of basalt, ignimbrite, rhyolite, tuff, scoria and sediments.

1.2 Objective of the study

I) General objective:

The general objective of this research is detailed mapping of structures and modeling of ground water flow in order to gain understanding on the basic mechanisms controlling the interaction of the lake and the surrounding surface, and ground water systems. Hence, it helps to understand the dominant factor of lake level rise.

II) Specific objective:

- Detailed structural and lithological mapping and characterization the orientation of the structures;
- Characterizing fractures and investigating of the kinematic indicators of the fractures;
- Determine the value of vector opening direction of the fissures and their morphology;
- understand the relation between structures and volcanism;
- Reconstruct the position of different shorelines at different time and interpret the shape of the lake with time in relation to the orientation of structures; and
- Determine the relation of springs of the area with the structures and their impact on the lake level.

1.3 Methodology

This study is conducted using data obtained from literature review and field work. A detailed structural map was done in the field as well as from high resolution ASTER image, aerial photos and landsat images. The geological map for the area is produced from field work and existing published (e.g. geological map of Nazreth sheet, 1:250,000) and unpublished maps. The morphology of faults, water level of the lake, Awash River and wells were determined by Magellan and Trimble GPS with vertical and horizontal accuracy of 2-3cm. To reconstruct the position of shorelines of the lake at different times, the author employed topographic maps, multi-temporal satellite images and panchromatic aerial photographs. Moreover, Using ASTER image, the Digital Elevation Model of the project area was built from SRTM.

The activities are classified in to office and field works.

Office work:

- Collection and organization of previous works within and around the study area;
- Analyzing the orientation, density and location of fractures from aerial photographs and satellite images;
- Preparation of DEM from aerial photographs and landsat images; and
- Interpreting meteorological data.

Field work:

- Collecting of data of the orientation, morphology, density and location of fractures;
- Observation of the lithology of the area;
- Measuring of amount and direction of extension from fissures;
- Note the types of rocks affected by fractures;
- Determine the location of hot springs and measure the orientation of associated structures;

- Measuring the heights of Lake Beseka and Awash River and some wells; and
- Rock sampling.

1.4 Material Used

To achieve the objectives of this research work, the following materials were used.

1) Digital materials:

i) Hardware components

- scanner
- printer

ii) Software components

- Arc GIS 9.1
- Arc View 3.3
- ERDAS
- Surfer
- Trimble Business Center
- Tectonic FP
- Global Mapper

2) Auxiliary materials:

- Aerial photographs, ASTER images and DEM maps
- Topo maps of scale1:250,000 and 1:50,000
- Geological map of Nazareth (1:250,000)
- Field equipments:
  - GPS: Trimble and Magellan
  - Compass
  - Meter
  - Hammer
  - Camera

2. GENERAL OVERVIEW OF THE AREA

2.1 Location and Accessibility

The study area is located about 195 km east of Addis Ababa, in Oromiya Regional State, Shoa Zone, in the district of Metehara. It is within the Main Ethiopian Rift (MER) in the Awash basin. The study area is crossed by one main asphalted road and the Addis Ababa-Djibouti rail way line. There is also a road from Metehara to Addis Ketema and to Metehara Sugar Factory then to Nurahira which is very important to see the southern part of the catchment.

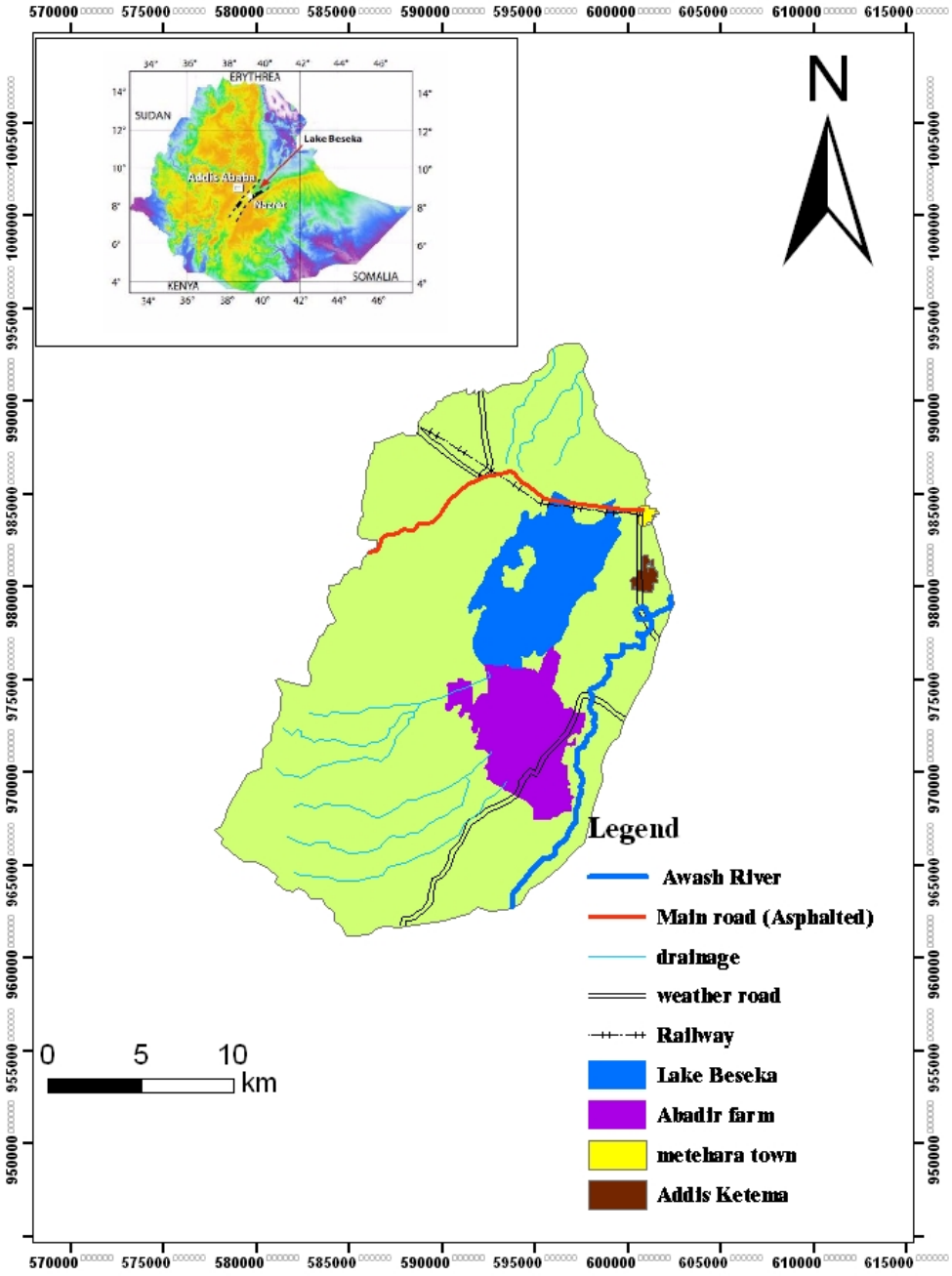


Fig. 2.1 Location map of the study area.

2.2 Phyiography

The Lake Beseka area is an important natural landscape of the country. It has mount Fentale in the north and Awash River to the south and east. The altitude of the area ranges from 934 to about 1850 m.a.s.l at the top of Mount Fentale. Other major topographic features of the lake Beseka area are the lava flow from Tinish Sabober (Williams et. al., 2004) scoria cones and spatter and scoria cones. For the lake catchment, there is no well defined drainage pattern except west of Abadir farm where a dense stream net work originated in the mountains situated to south west of the lake area and along foot hills of mount Fantale. The streams have steep parts with well defined drainage pattern that disappear in short distance down stream. They are intermittent and seasonal, which disappear before reaching Lake Beseka. The study area is crossed by Awash River in south. Geographically the study area is bounded by 577700mE – 602600m E and 961100m N – 993300m N UTM and has aerial extent of about 470 km^2.

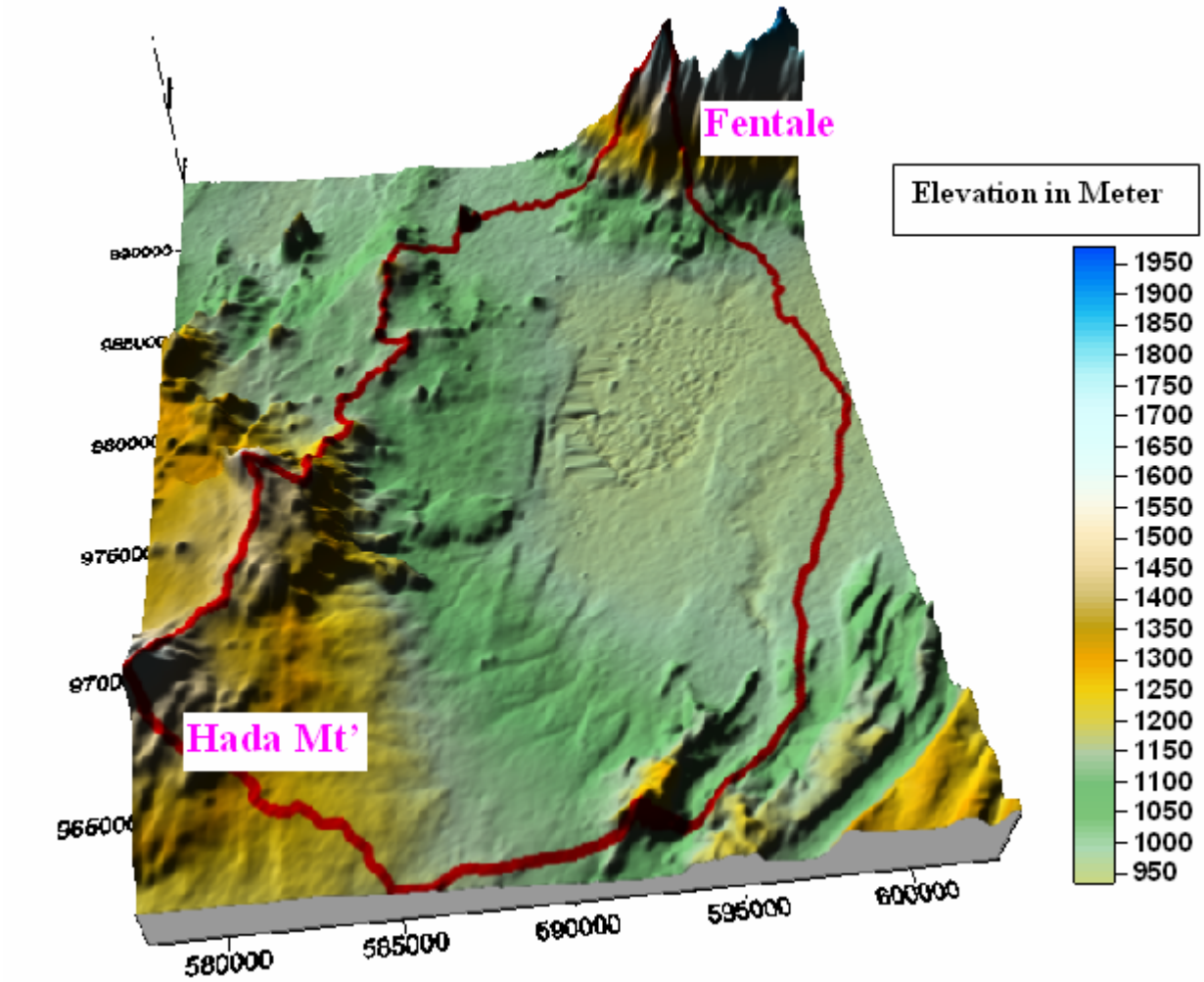


Fig.2.2 Topographic map of the study area

2.3 Climate

The sources of moisture that account for almost all rains in Ethiopia are the Indian and Atlantic Oceans (Degefu, 1987; Camberlin, Richard et al., 1994). The region is characterized by three main seasons. The long rainy season in the summer (June – September, locally know as 'Kiremt') is primarily controlled by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ) which lies to the north of Ethiopia at that time. The 'Kiremt 'rain represents 50 - 70% of the mean annual total (Degefu, 1987).

The dry period extends between October and February (known as 'bega') when the ITCZ lies to the south of Ethiopia during which time northeasterly trade winds traversing Arabia dominate the region. Occasional rains during this period bring 10-20% of the annual mean rainfall (Degefu, 1987). The 'bega' is the main harvest season in the region.

The 'Small rain' season (known as 'belg'; 20-30% of the annual amount) from March to May coincides with a dimination of the Arabian high as it moves towards the Indian Ocean causing warm, moist air with a southerly component to flow over most of the country (Griffiths, 1972). Agriculturally, the 'belg' is extremely important in many parts of the country, especially in southeastern parts of Ethiopia, where it is the major rainfall.

Table 2.1 Climatic classification of Ethiopia

Altitude (m.a.s.l)	Mean annual Temperature (ºC)	Descriptions	Local name
3,300& above	10 or less	Cool	Kur
2,300-3,300	15-Oct	Cool temperate	Dega
1,500-2,300	15-20	Temperate	Woina Dega
500-1,500	20-25	Warm temperate	Kola
Below 500	25 and above	Hot	Bereha

The climate of Ethiopia ranges from equatorial desert to hot and steppe, and from tropical savannah and rain forest to warm temperate, from hot lowland to cool highlands. The altitude ranges from around 120m below sea level in the Dalol Depression up to 4600 m.a.s.l. on the Ras Dashen in the Semien Mountains. The Main Ethiopian Rift (MER) and Afar are semi arid to hyper arid. Based on the altitude, the climate can be classified in to five groups.

In the study area the hottest month is June with a mean maximum temperature of 36.77 ºC and a mean minimum of 21.7 ºC. The coldest month, December, is cooler with about 22.49 ºC, the corresponding maximum and minimum values being 30.93 ºC and 13.8 ºC, respectively. As far as precipitation is concerned, from the long-term rainfall record, the highest average rainfall is recorded in the month of July with values 118.05mm and the minimum is in the month of November with average rainfall of 3.38mm. The mean annual precipitation is 498.80mm.

The maximum and minimum relative humidity of the area are calculated to be 60.4 % and 46.33 %, respectively. Wind speed at 2m heights from ground surface and sunshine hours range from 129.17 to 207.31 km/day and 7.3 to 9.68 hrs respectively. The maximum and minimum pitche evaporation of the

area are 300mm and 183.88mm and occur in the months of June and August, respectively. The mean annual pitche evaporation is 2982.46mm

2.4 Soil and Vegetation

It is known that soil type is closely related to the soil parent material and its degree of weathering. The main parent materials are basalt, ignimbrite, acidic lava, volcanic ash and pumice, and alluvial and lacustrine sediments. The most common soil types of the study area include: cambisols, pedzol, fluvisols, lepthosols, solonchks and luvisols (MWR, 1999).The vegetation of the rift valley is mainly characterized by wooded grassland with Accacia of various species. In the area of study, there are examples of Accacia woodland extensively used by local people for charcoal production.

2.5 Land use-Land cover

Land use–Land cover (LU/LC) changes can play a significant role in causing or triggering lake level changes. Land use-land cover maps for the years 1973 and 2003 of the Beseka catchment have been developed from satellite images following standard principles and procedures of image classifications (Lillesand, Met.al., 1999). The major land use-land cover units in the Beseka catchment are the water body, shrub land active volcanic area, grassland, cultivated (irrigated and seasonal)land , and degraded lands (Fig.2.3 & 2.4)

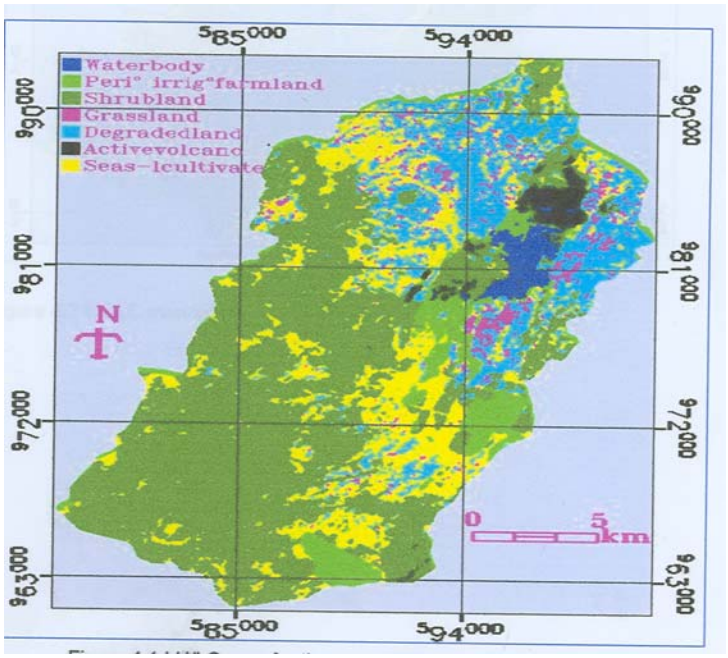


Fig.2.3 LU/LC map for the year 1973 (After Lillesand, M et.al., 1999: In Fasica Abebe (2007))

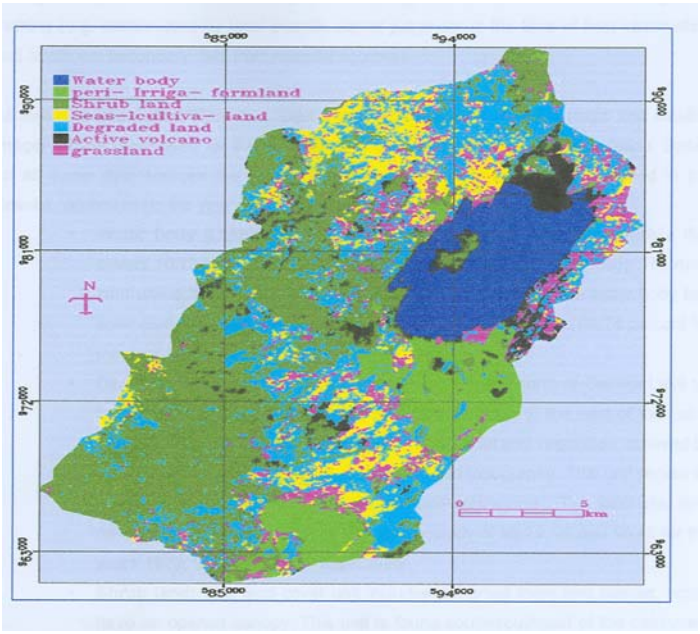


Fig.2.4 LU/LC map for the year 2003 (After Lillesand, M et.al., 1999: In Fasica Abebe (2007))

3. HYDROMETEOROLOGY

General

The process by which water enters the atmosphere through either evaporation or transpiration and returns to the earth through condensation and precipitation is called hydrologic cycle. Meteorological data are basis for water resource investigation.

The available data in the study area includes meteorological data on precipitation, air temperature, relative humidity, wind speed, and sunshine which are crucial for climatological analysis and are gained from Ethiopian Meteorological Agency (EMA). In addition to the above data, gauge heights of Lake Beseka and Awash River are also used to understand the changes in the level of the lake.

3.1 Rainfall

Precipitation is a general form of atmospheric moisture, which may occur in any forms and may change from one form to another during its descent. In other words, precipitation can be defined as the total amount of water falling from the atmosphere in the form of rain, snow, mist etc. (Shaw, 1994). Rainfall is the most important form of precipitation. It consists of water droplets less than 0.5mm in diameter.

Seasonal variation of Rainfall regime is observed with two rainy seasons. Small rains from March to April and brings about 20% of the total mean annual rainfall. Big rains from July to August cover about 47% of the total rainfall of the area (Fig. 3.1). From the data period of 1986-2006, the mean annual precipitation is 498.80mm.

Table 3.1 Mean Monthly Rain fall (1986-2006)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	9.73	30.16	50.39	50.54	26.97	27.38	118.05	117.9	41.95	23.44	3.38	7.03

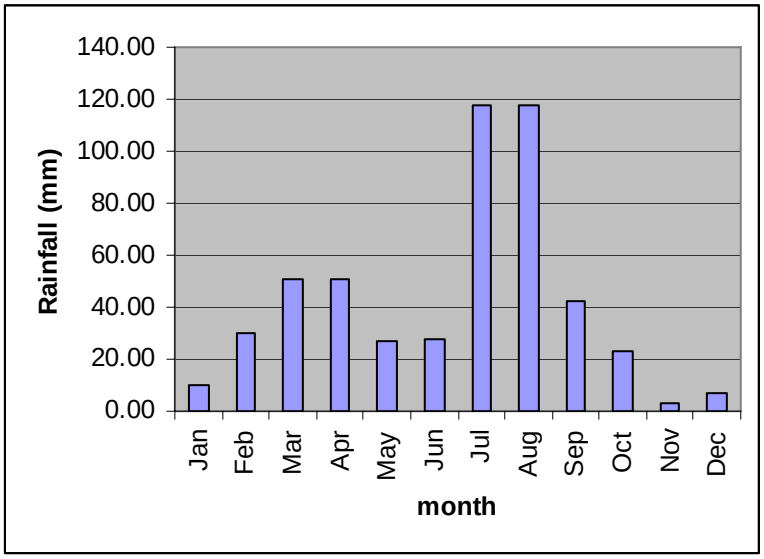


Fig. 3.1 Mean Monthly Rain fall (mm) (1986-2006)

3.2 Temperature

Mean monthly temperature values of the study area presented in table 3.2, are recorded at Metehara Station (1986-2006). The maximum and minimum mean monthly temperatures occurred in June and December, respectively. The mean annual maximum and minimum temperatures of the site are 33.58 ºC and 17.96 ºC, respectively. The mean annual air temperature of the area is 25.76 ºC. From the data, it is clearly seen that the highest temperature is always before the onset of the rainy months.

Table 3.2 Mean Monthly Temperature (0^c) (1986-2006)

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max Temp	31.17	32.8	34.15	34.8	36.39	36.77	33.12	32.55	34.18	33.8	32.26	30.93
Min Temp	14.9	16.3	18.6	19.3	19.6	21.7	20.3	19.9	15.6	19.7	14.1	13.8
Mean Temp	23.1	24.58	26.37	26.97	28.02	29.26	26.71	26.23	26.86	25.29	23.27	22.49

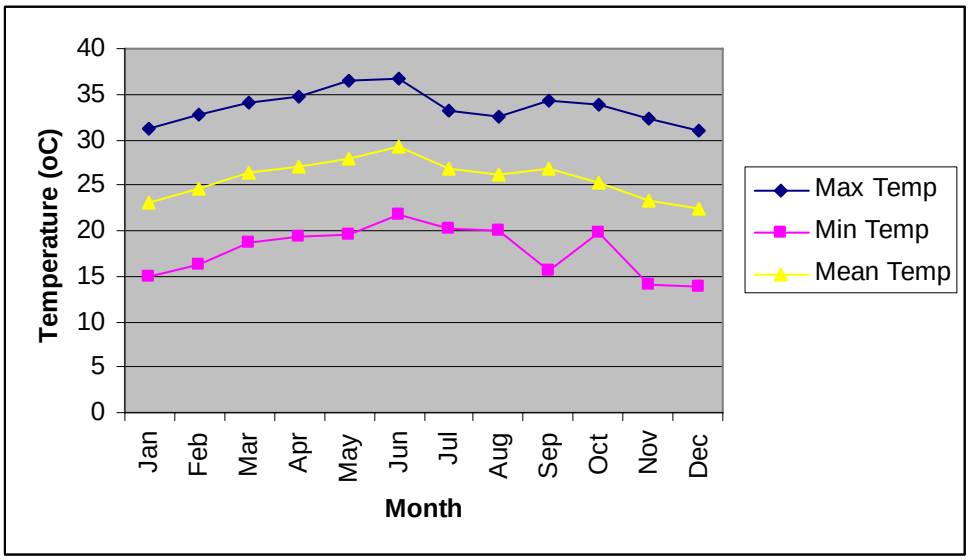


Fig. 3.2 Mean Monthly Temperature (0^c) (1986-2006)

3.3 Relative humidity

Relative humidity is the ratio between the amounts of water vapor actually contained per volume and the amount that it can hold at the same time when it is saturated or the actual vapor pressure and the saturation vapor pressure at the same temperature. Relative humidity of the area is measured three times a day at Metehara station. The maximum and minimum relative humidity of the area are calculated to be 60.4 % and 46.33 % in August and June, respectively as shown in Table 3.3. Here, it should be noted that irrigation area has impact on the values.

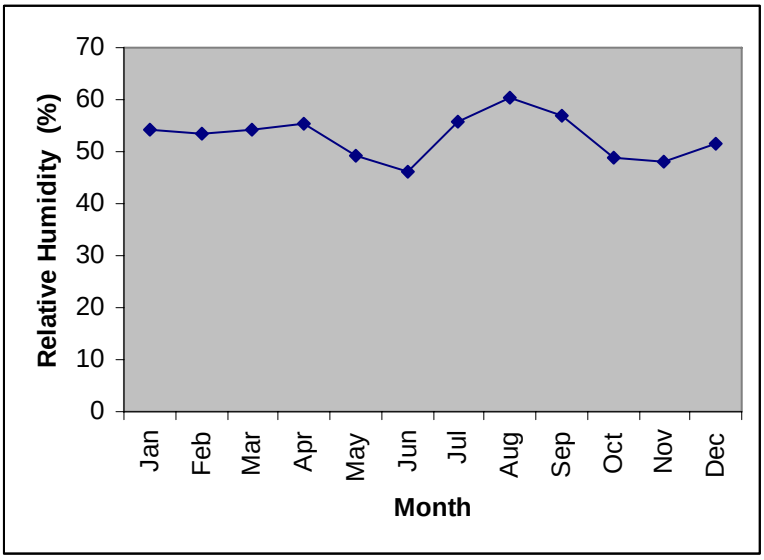


Fig 3.3 Mean Monthly Relative Humidity (%)(1986-2005)

3.4 Wind speed

The mean monthly wind speed of the area measured at two meters above the ground varies from 129.17 km/day to 207.31 km/day with maximum values observed in the months of October and July, and the minimum values were observed in the months of September and October Table 3.3.

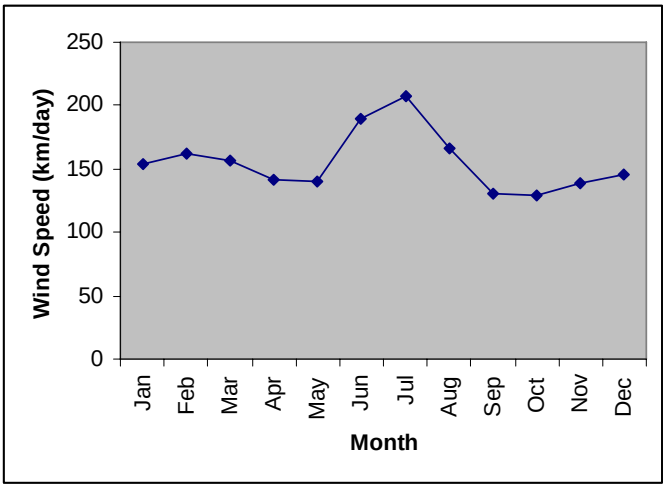


Fig. 3.4 Mean Monthly Wind Speed (km/day) (1986-2006)

3.5 Sunshine

From the data range 1986-2005, it was found values of mean monthly sunshine hours in the study area ranges from 7.3 to 9.68 hrs (Table 3.3). The lowest and the highest values occur in August and November, respectively (Fig. 3.5).

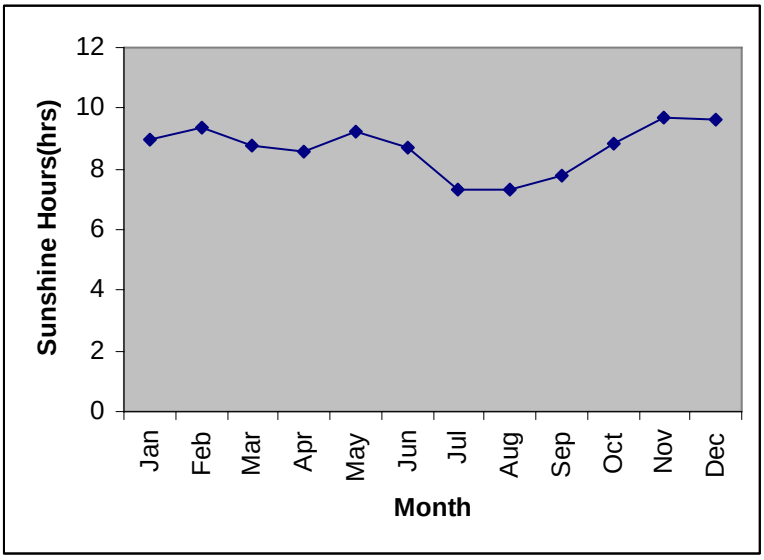


Fig. 3.5 Mean Monthly Sunshine Hours (hr) (1986-2005)

Table 3.3 Mean Monthly Relative Humidity, Wind speed and Sunshine Hours (1986 - 2005).

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RH (%)	54.27	53.48	54.27	55.23	49.37	46.33	55.68	60.4	56.82	48.67	48.19	51.72
WS(km/day)	153.36	162.43	156.82	140.83	140.06	190.08	207.31	166.75	130.03	129.17	138.24	145.58
SS(hrs)	8.94	9.35	8.74	8.57	9.23	8.72	7.33	7.3	7.77	8.84	9.68	9.61

3.6 Pitche Evaporation

The pitche evaporation consists of a glass tube 14 mm in diameter and 225 mm long with one end closed, having circular disc 32mm diameter of absorbent plotting paper held against the open end by a small circular metal disc with a

spring collar installed at Metehara Station used in open water evaporation for the study area. The evaporation surface area is 1300 mm^2 and fed constantly by the water in the tube hung up by its closed end. The tube is graduated to give a direct reading of evaporation over a chosen time period, usually a day. The measurement in mm is related to the evaporating surface of both sides of the paper.

The tube holds an equivalent of 20mm evaporation and the water is replenished when necessary. When the pitche evaporimeter is exposed in a standard temperature screen, the annual values have been found to be approximately equivalent to the open water evaporation from a US Class A pan (Shaw, 1988).

Pitche evaporation data of 20 year is recorded at Metehara Station (Annex 10). This data shows that the high pitche evaporation occurs during the dry months of May and June and lower pitche evaporation values occurred in August and September. Similar to class A pan, a pan coeffient of 0.75 to 0.85 is commonly used for evaluation of open water evaporation. The mean annual pitche evaporation is 2982.46mm, so the highest pan co-oeffient of 0.85 is used due to the high temperature of the area. The annual evaporation from the storage reservoir is 2535.091mm.

Table 3.4 Mean Monthly Pitche Evaporation (mm) (1986 – 2005)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ave.P.Evapo.	244.25	236.53	261.22	240.79	298	300	233.64	183.88	196.2	269.7	270.17	248.50

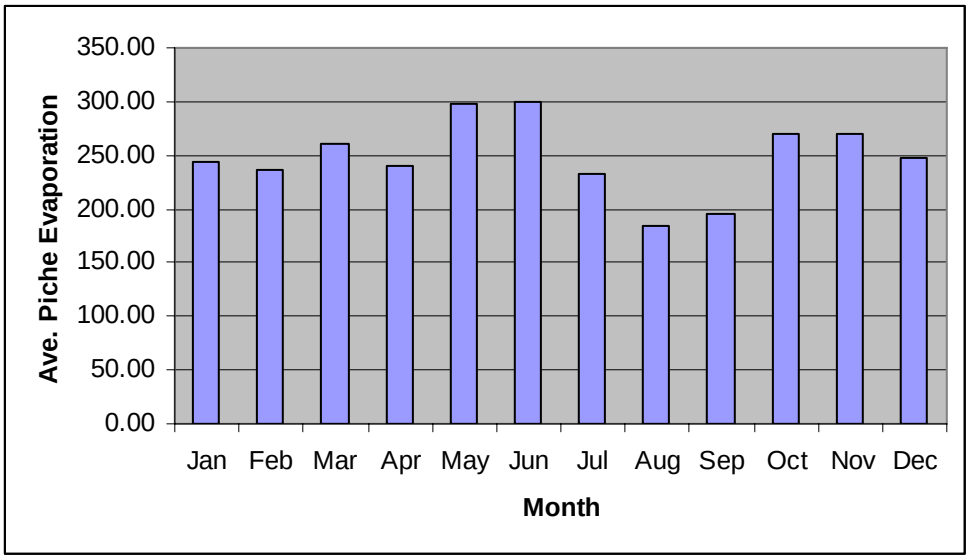


Fig. 3.6 Mean Monthly Pitche Evaporation (1986-2005)

4. GEOLOGY

4.1 Geology of Main Ethiopian Rift

Volcanic and tectonic events in the study area constitute an essential part of the history of the Main Ethiopian Rift. The Main Ethiopian Rift is part of the great East African continental rift and lies between lat. 5º00`-9 º 00`N and long. 37º30`-40º00`E. The MER is divided geographically in to three sectors: northern, central and southern (WoldeGabriel et.al., 1990). It divides the 1000km wide uplifted Ethiopian volcanic province asymmetrically into the northwest and southeast plateaus. The adjacent plateaus on either side of the rift are characterized by huge piles of basaltic and ignimbritic flows and a number of large and small shield volcanoes and by relatively less intense tectonism. Older volcanic units (Pre-Pliocene) outcrop on the rift margin and the recent volcanics cover the entire rift (Kazmin et al., 1980). The Ethiopian Rift valley contains abundant acidic lavas and ignimbrites associated with central volcanoes containing wide calderas (Mengesha et al., 1996).

Most of the geologic sections exposed along the rift margins are dominated by Tertiary volcanic rocks except for a few locations where crystalline basement is uncoformably overlain by Mesozoic marine sedimentary and /or Tertiary volcanic rocks. Such pre-Tertiary rocks are present along the eastern, western and southern Afar margins (Huchinson and Engles, 1970; Zenettin and Justin-Viseotin, 1974; Black et al., 1975; Chessex et al., 1975), western rift margin (Guraghe Mountains) of the central sector of the MER (WoldeGabriel and Aronson, 1986), and at Amaro Horst of southern sector of the MER (Levitte et al., 1974; Zenettin et al., 1978). In the broad rift zone of southwest Ethiopia, crystalline basement is unconformably overlain by various Tertiary (12.7-49.4Ma) and Quaternary volcanic rocks, including the oldest known (Eocene) flood basalts in Ethiopia (Davidson and Rex, 1980; Davidson, 1983). In general,

the floor of Ethiopia the Rift is characterized essentially by Mio-Pliocene to present volcanism and volcano-sedimentary products (Merla et al., 1979). The strongly peralakaline suit is largely restricted to Quaternary zones of slow crustal attenuation in the Afar and the northern part of the rift valley (Barbieri and Santacroce, 1980).

Many authors (Burke and Dewey1970, and others) relate the development of the East African Rift to the Afro-Arabian doming in lower Tertiary times. On the other hand, Bahat (1979) and McConnel et.al. (1980) maintain that the East African Rift as a whole, initiated as an ancient fracture. A recent view by WoldeGabriel et al, (1990) based on structural and stratigraphic relationships from the central sector of MER indicated a two-stage rift development (in Late Oligocene or early Miocene) of a series of half-grabens along the rift with alternating polarity, such as that in the present Gregory and western Rifts of East Africa followed by a second phase of symmetrical rifts that evolved from these half grabens in the late Miocene and early Pliocene times. Thus, evolution from alternating half graben to a full symmetrical graben with medially located neovolcanic zone that is bifurcated to marginal grabens in the northern sector of the MER may be a fundamental part of the rift process.

4.1.1 Lithology

4.1.1.1 Anchar Basalts

Along the eastern margin of the Rift, Alaji basalts are conformably overlapped by a unit of flood basalts and siliceous rocks which are, in turn partly covered with slight unconformity by silicis of the Nazreth group. In the Anchar area the unit is represented by about 400m of basalts with general intercalation of ignimbrites, the one at the base being 12.4 Ma. To the south and north east, the basalts are laterally replaced by welded and unwelded ash flows.

4.1.1.2 Arba Gugu basalts

This unit erupted from Arba Gugu Shield volcano and represented by successive lava flows up to 300m thick made up of mostly porphyritic pyroxene or plagioclase basalts with an age of around 8.5 Ma.

4.1.1.3 Chilalo and Badda Trachytes

Chilalo volcano first erupted followed by trachytes while Badda evolved from basalts and trachybasalts to Trachytes. Lava flows of both volcanoes are contemporaneous with the young ignimbrites of Nazareth group and partly inter finger with them. The formation of these shield volcanoes coincides with the important stage of rifting around 4 to 4.5 Ma. This rifting is supposed to correspond to the peak of the sillicic volcanism in the rift (Morbidelli et al 1975) and preceded of the fissural eruption of Bofa Basalt.

4.1.1.4 Bofa Basalts

Late Pliocene (4 to 1.6Ma) flood basalt volcanism is widespread in the Main Ethiopian Rift and other related rifts. The Pliocene basalts were known by different names in different localities: Welenchiti Basalts (Meyer et al., 1975), Bishoftu Basalts and rhyolites (Zanettin and Jusetin Vesentin, 1974), Old floor rift basalts (U.N Geothermal project, 1978). The name Bofa Basalts was coined by the E.I.G.S. (Kazmin et al., 1980b) to all rift floor Basalts. The Bofa Basalts are well developed in the northern and central part of the MER forming a wedge between the Nazret Series and Dino Formation and a lower age limit of 3.5Ma has been reported by Kazmin et al., (1980b).

The Bofa Basalts are flood basalts mostly aphyric, locally vesicular and fresh with several flow separated by scoracious horizons. In most outcrops the Bofa Basalts have a thickness of about 80 meters; however, deep drilling for geothermal energy exploration at the Aluto-Langano Geothermal Prospect has shown that the Bofa Basalts or a contemporaneous basaltic unit has a

thickness in excess of 500 meters in many of the wells. This attests to the presence of an important Pliocene flood volcanism in the central MER, which is concealed by the Quaternary pyroclastic volcanic products and continental sediments.

4.1.1.5 Rhyolitic Volcanic Complexes

The Quaternary central volcanic complexes which are situated along the axial zones of the Main Ethiopian Rift (Wonji Fault Belt) and Afar have produced peralkaline lavas and pyroclastics. Recent stages of activity are marked by obsidian flows, pumice, ignimbrite, tuff, and scoriaceous basalt eruptions. However, most of the basalt flows have fissural origin from later fractures of the Wonji Fault. The oldest reported K/Ar age from the central volcanoes of the Wonji Fault Belt is from Boseti volcano, which is 1.6Ma (Morbidelli et al., 1975).

This unit corresponds to the ´Nazret Series` of Meyer et al. (1975). The Nazret Unit is made up of a sequence of ignimbrite sheets interbedded with paleosol layers, indicating frequent breaks in the volcanic activity and aphyric flood basalts. The ignimbrite units are frequently strongly welded at base and unwelded at the top. They are mainly characterized by glassy ´fiamme`, showing pantelleritic composion and abundant basaltic lithic fragments. The basaltic lavas are mainly transitional and subordinately alkaline. The age of this unit ranges from 1.7 to 1.5 Ma. Silicic centers were especially abundant during the latest stages of the Nazareth volcanism, as is evident from the wide distribution of rhyolitic domes cutting through older ignimbrite sheets (Older Alkaline and Peralkaline Rhyolite domes).

In the Main Ethiopian Rift, the Bofa Basalts and the Nazret Series are, in most places, overlain by green and gray ignimbrites with well-developed fiamme and associated unwelded pyroclastics and water lain pyroclastics with occasional intercalated lacustrine beds and aphyric basalts which have a maximum

reported thickness of 50 meters were named as the Dino Formation (Kazmin and Berhe, 1978 and 1980).

In the Awash Gorge an ignimbrite member of the Dino Formation was isotopically dated to be 1.5Ma old (Kazmin and Berhe, 1978). The pyroclastics of the Dino Formation may have sources from axial felsic volcanic eruptions complexes such as the partly eroded volcano known as Tinsh Fantale and /or earlier of the other axial center.

4.1.1.6 Lacustrine sediments

The lacustrine deposits are purely lake or swamp deposits or those of volcano-lacustrine type of the rift valley and consist of clay, silt, tuffs, travertine, and Diatomites with intercalation of pumices. They are Pleistocene to Holocene in age and they are deposited from extensive lakes during the Pleistocene pluvial. In Nazareth, Welenchiti, Wonji and koka the thickness of the lacustrine sediments varies from 30 to 40 meters (Mengesha et.al., 1996).

4.1.1.7 Alluvial deposits

The alluvial deposits are of two types: those spread out in alluvial plains and those strips along rivers and streams. Alluvial plains are filled up grabens and large stretches of flat land in the rift valley. These are troughs in the lowland where during the pluvial period streams deposited large amounts of sediments carried down from the highlands.

4.1.2 Regional Structures

The Main Ethiopian Rift (MER) is a 60km wide depression with an overall northeasterly orientation and constitutes an area characterized by active extensional tectonics. Although the average elevation of the plateau on both sides of the rift is 2300m, the mean elevation within the rift floor is 1250m. Two main fault systems have been distinguished in the MER: a N30°E- N40°E trending fault system which characterizes mainly the rift margins, and a N-S to

N20°E trending fault system, the Wonji Fault Belt (WFB) of Mohr (1962, 1967, 1987), which exhibits a number of sigmoidal, overlapping, right-stepping en-echelon fault zones obliquely cutting the rift floor. Similar to other rift systems, the overall architecture of the MER is well expressed by the topography (e.g. Hayward and Ebinger, 1996). The MER progressively deepened during the Pliocene and Quaternary, evolving through a sequence of interacting half-graben segments, marking the boundary between the Nubian and Somalian plates. (Hayward and Ebinger, 1996).

The present MER is made up of northern, central and southern sectors (WoldeGabriel et.al. 1990). There is a difference of ~15° in the trend of the northern and southern sectors (Fig.4.1); nevertheless, the overall mean direction of the MER remains NE-SW (N40°E) (Acocella et. al., 2002). The youngest part of the MER is the axial zone, which coincides with the so-called Wonji Fault Belt (WFB), mainly formed during the Quaternary (Mohr1967, Mohr1987; Boccaletti et. al., 1998, 1999). Despite the overall NE-SW trend of the MER, the WFB is characterized by active NNE-SSW-trending extension fractures and normal faults. These are often set in a dextral en-echelon arrangement and are associated with volcanic activity. The slightly different trend of the Quaternary WFB with regard to the MER margin suggests a change in the extension direction during Quaternary (Bonini et al., 1997; Boccaletti et al., 1998).

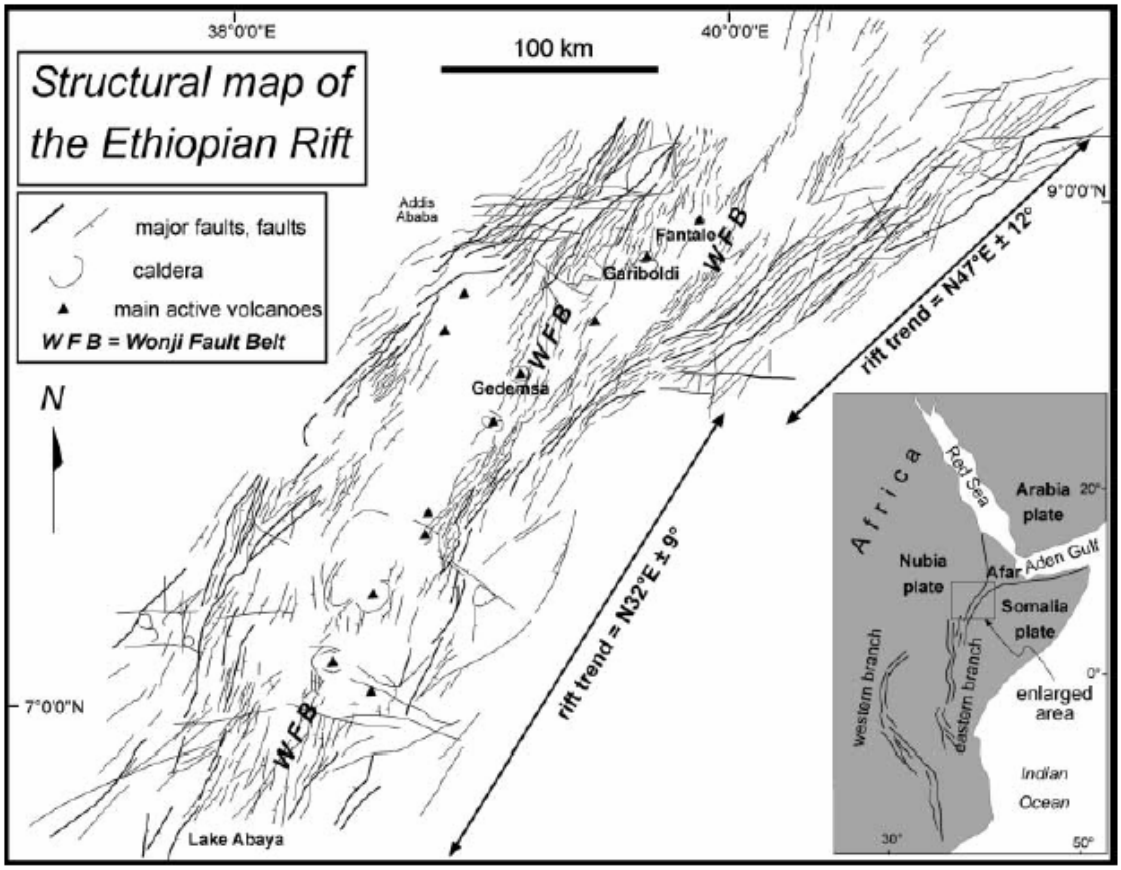


Fig.4.1 Structural Map of MER: (After Acocella et al 2002)

4.1.2.1 Western margin

The Western margin of the Main Ethiopian Rift shows a change in fault trend at about 7°50'N. North of this latitude, the margin is well represented by the N30°E- N40°E trending and ESE dipping high-angle (>60°) Guraghe fault, while to the south the margin is marked by N-S to N20°E striking faults(Boccaletti et al., 1997). Topographic profiles across Guraghe fault indicate that the vertical throw of the can reach values up to 1000m. By contrast, N-S to N20°E trending faults located south of 7°50'N exhibit small lateral extent and displacements in the order of few tens of meters. Northeast of Mt.Guraghe, the rift margin between Ziquala and the Kessem valley is characterized by faults trending N-S to N20°E, as well as by faults trending NE-SW. These faults cut, and are at times covered by; Quaternary volcanic rocks (Boccaletti et al., 1997).

South of Fonka, the Guraghe fault margin is obscured by the widespread Plio-Quaternary pyroclastic products and rhyolitic lava domes (Moore and Davidson, 1973; Davidson, 1978; WoldeGabriel and Aronson, 1987). Southward, at the end of the pyroclastic cover, faults with the same trend as the Guraghe fault (Bofa Basin and Range) are again evident (Boccaletti et. al., 1997).

Some meso-structures observed west of the Kella area suggest a sinistral shear component along the western margin. Particularly, the Pliocene Butajira ignimbrites (WoldeGabriel et al., 1990) frequently display decimeteric-scale pull aparts and en-echeolon tensional fissures connected by short oblique slip faults (Boccaletti et al., 1997).

4.1.2.2 Eastern margin

The eastern margin of the MER is characterized by high-angle W-dipping N30°E- N40°E trending border faults which separate the MER from the Southwestern plateau. The fault system is articulated and segmented but the overall direction strikes about NE-SW. The segmented shape is probably related to the interaction of the margin system with the N-S to N20°E trending faults characteristics of the floor (Boccaletti et al., 1997). Locally the border zone assumes a nearly E-W trending direction, which is likely related to transversal structures. From Asela northwards, the fault distribution defines a dominantly N40°E trending border zone and locally, the faults are connected by short E-W oriented segments. South of Asela, the overall trend of the border fault is about N25°E as far as the Dilla area, south of which the direction becomes more or less N-S (Boccaletti et al., 1997).

4.1.2.3 The Rift Floor

There is a fundamental change in tectonic style as one proceeds from the margin of the MER, which are characterized by a few widely spaced faults with

large vertical displacements, to the rift floor, which is affected by dense fault swarms, exhibiting relatively small throws (< 100 m) (Boccaletti et al., 1998; Abebe et. al., 2007) The rift floor faults have steep scarps and constitute a right-stepping arrangement of en-echelon N-S to N 20°-trending faults (WFB), which began to develop around 1.6 Ma (Meyer et al., 1975). The Late Pliocene-Quaternary volcanic and sedimentary rocks of the rift floor are affected by this fault system reflecting Quaternary tectonics (Boccaletti et al., 1998). According to Boccaletti et al. (1998), the several subparallel Quaternary fault belts (WFB), making angles of ~20° with respect to the main direction of the margin give rise to a widespread deformation affecting the MER floor. In the rift floor, both faults and open fissures also commonly form a right-stepping en-echeolon array and affect Quaternary rocks. These geometric arrangements are in accordance with a Quaternary nearly E-W- oriented direction of extension, resulting from a component of left- lateral shear along the rift strike (Boccaletti et al., 1997).

4.2 Geology of the study area

4.2.1 Lithology

The principal rock units in the study area are of two types: volcanic rocks mainly basalts and ignimbrites of different ages and different mineralogical composition and sedimentary rocks of fluvio-lacustrine origin located at the southern part of the study area (Abadir farm) and at the floor of Lake Beseka.

4.2.1.1 Bofa basalts

This is the oldest rock unit in the study area. It is found between Abadir farm and Metehara Sugar Plantation on both sides of the Awash River. According to Abebe et al. (2005) Bofa basalts are mostly porphyritic with plagioclase phenocrysts, some times scoracious, and have ages between 3.5-1.6 Ma.

4.2.1.2 Dino Ignimbrites

It is found south of Abadir farm and it is also affected by faults. This unit has green and gray color with well-developed fiamme and associated unwelded pyroclastics and water-lain pyroclastics with occasional intercalated lacustrine beds and aphyric basalts. They have a maximum reported thickness of 50 meters (Kazmin and Berhe, 1978 and 1980); it is the oldest rock of Wonji Group rocks.

4.2.1.3 Pleistocene-Sub recent basalts

Compared to the other rocks found in the study area, this rock unit covers larger area. It is affected by atypical normal faults with varying vertical displacements characterized by hanging wall tilted away from the fault face. Some of the faults are now the boundary of the southeastern and western edges of Lake Beseka (Fig.4.2). These basalts are mostly dark greyish, massive, fine-grained, often subaphyric with large phenocrysts. According to Buctwitz (2006), thin section of this rock shows a groundmass of needle-shaped plagioclase and pyroxene.

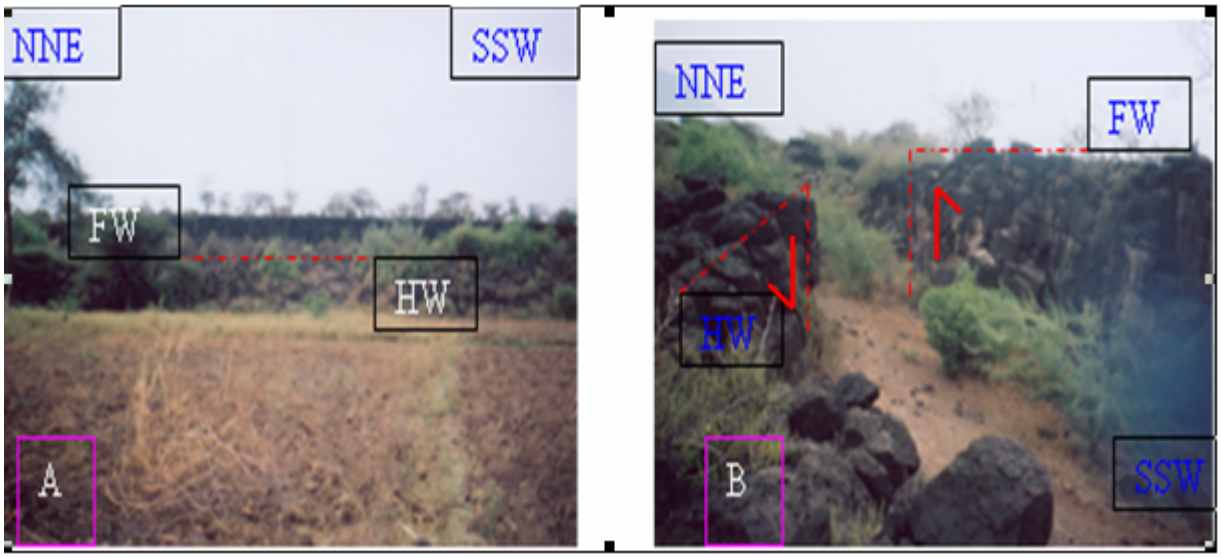


Fig.4.2 Out crops basalts: Southeastern of Lake Beseka.

4.2.1.4 Pantelleritic volcanics of Fantale rhyolites, trachytes and agglomerates

The products of volcanoes ranging from trachytes to peralkaline rhyolites are pantellerites (Mengesha et al., 1996). In the study area, this unit is found locally north of Lake Beseka between Tinish Sabober (Williams et.al., 2004) and Fantale. It is the product of Fantale volcano and it is not affected by fractures. It is Pleistocene in age.

4.2.1.5 Alkalic and peralkali rhyolites, trachytes domes and flows of Boseti and Hada Mountain

From geological map of Berhe et.al. (1978), this unit erupted from Boseti and Hada Mountains. Locally this rock type is found on the southwest part of the study area in the Hada Mountain. It is highly affected by west dipping faults.

4.2.1.6 Tuff cone

This rock unit is found locally at the eastern and western rims of Tinish Sabober and at Sabober. It has yellowish to reddish color and it consists of greenish glass fragments and feldspar crystals, mostly sand size, with coarser – grained layers (Fig.4.3).

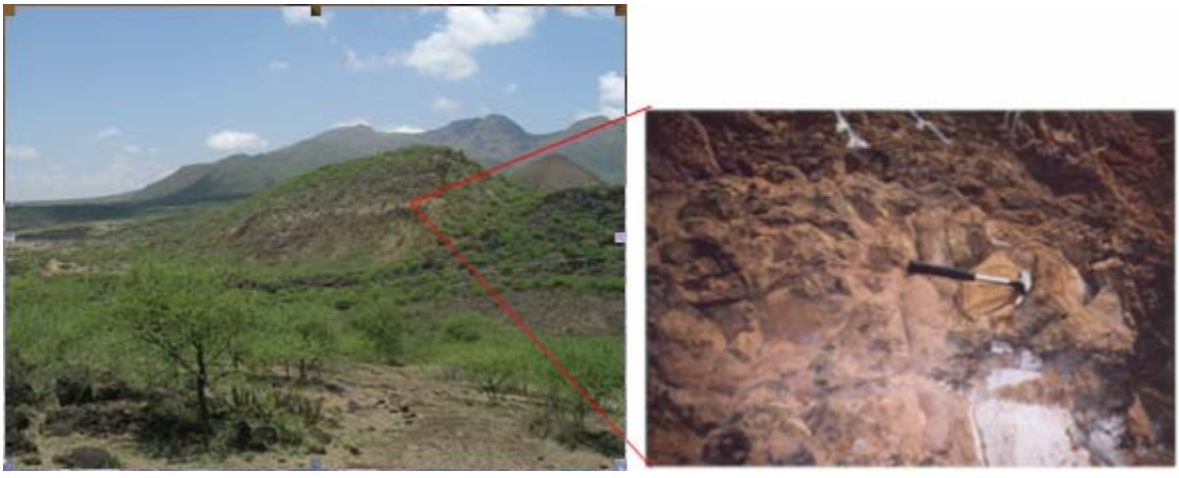


Fig. 4.3 Outcrop of tuff cone from western rim of Tinish Sabober.

4.2.1.7 Recent to subrecent rhyolitic domes and flows

Rhyolites are usually associated with regularly-spaced central volcanoes, usually characterized by a summit caldera, with a diameter exceeding 10km (Ebinger and Casey, 2001; Acocella et al., 2003).Flows and domes of rhyolitic rocks are found in the southern part of the study area. It is also one of the youngest rocks in the study area.

4.2.1.8 Unwelded rhyolitic pumice and unwelded tuff

Both unwelded rhyolitic pumice and tuff are found together in the western part of the study area as they are mapped in the geological map of Berhe et.al. (1978).

4.2.1.9 Pitchstone flows and domes

It is a volcanic glass with a conchoidal fracture and is found at the rim of Fantale. It is also exposed south of Tinish Sabober but it is not mappable (Fig. 4.4). According to Buchwitz (2006), it could be a source for the lithic fragments of Pitchstone found within Fantale ignimbrites which is shown in figure 4.5 D.



Fig. 4.4 Pitchstone rock south of Tinish Sabober.

4.2.1.10 Young Ignimbrites of Fantale

In the study area, this unit is found at the northern part as it comes from Fantale Mountain and to Metehara town. This rock is highly affected by fissures (Fig.4.5C). North of the lake, there are a number of blisters on the Fantale ignimbrites. According to Tesema (1998), the blisters are formed as particularly a consequence of pyroclastic flows running over water on wet sediments. Thus, we can conclude that blisters would be best demonstrators of paleo-lake environment at that time (Fig.4.5).

According to Buchwitz (2006), from XRD analyses, Fantale ignimbrite is characterized by glass, a series of high T-alkali feldspar with variable Na/K ratio, aegirine and quartz. There are also up to 50cm diameter glassy, porphyritic fragments, most likely being lithic fragments of pitchstone than compressed fiamme. According to William et al (2004), the pitchstone fragments are 168,000 ± 38,000 years of age as dated by fission track dating method.

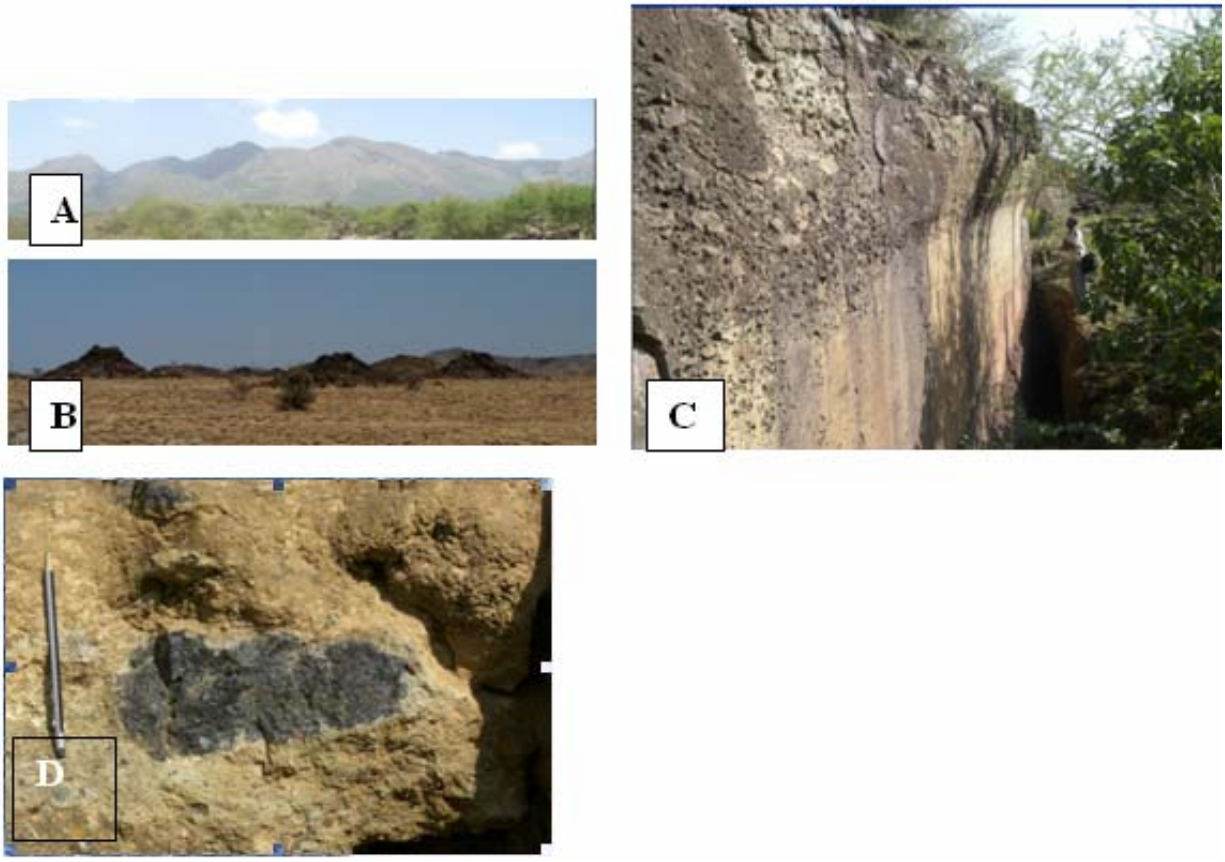


Fig. 4.5 Young ignimbrite of Fantale: **A**) Fantale Volcano. **B**) Blisters on Fantale ignimbrite **C**) Grain size variation of different flows of Fantale ignimbrite, The author is standing on the hanging wall. **D)** Lithic fragments of pitchstone

4.2.1.11 Lava flows of Tinish Sabober and Fantale

The Fantale complex comprises two silicic caldera volcanoes: the older Tinish Sabober and the younger Fantale volcano which have a similar history according to William et. al. (2004). The caldera eruption led to the deposition of Fantale ignimbrites which dominates the northern Lake Beseka basin. The lava flow which earlier observers attributed to an eruption in the 1820's (William, 1977) is unvegetated. From aerial photographs and field interpretation, the lava from Tinish Sabober flowed two times in its history. The second flow is darker in color and photographic tone than the first (Fig.4.6). This is youngest rock type in the study area which is Holocene in age.

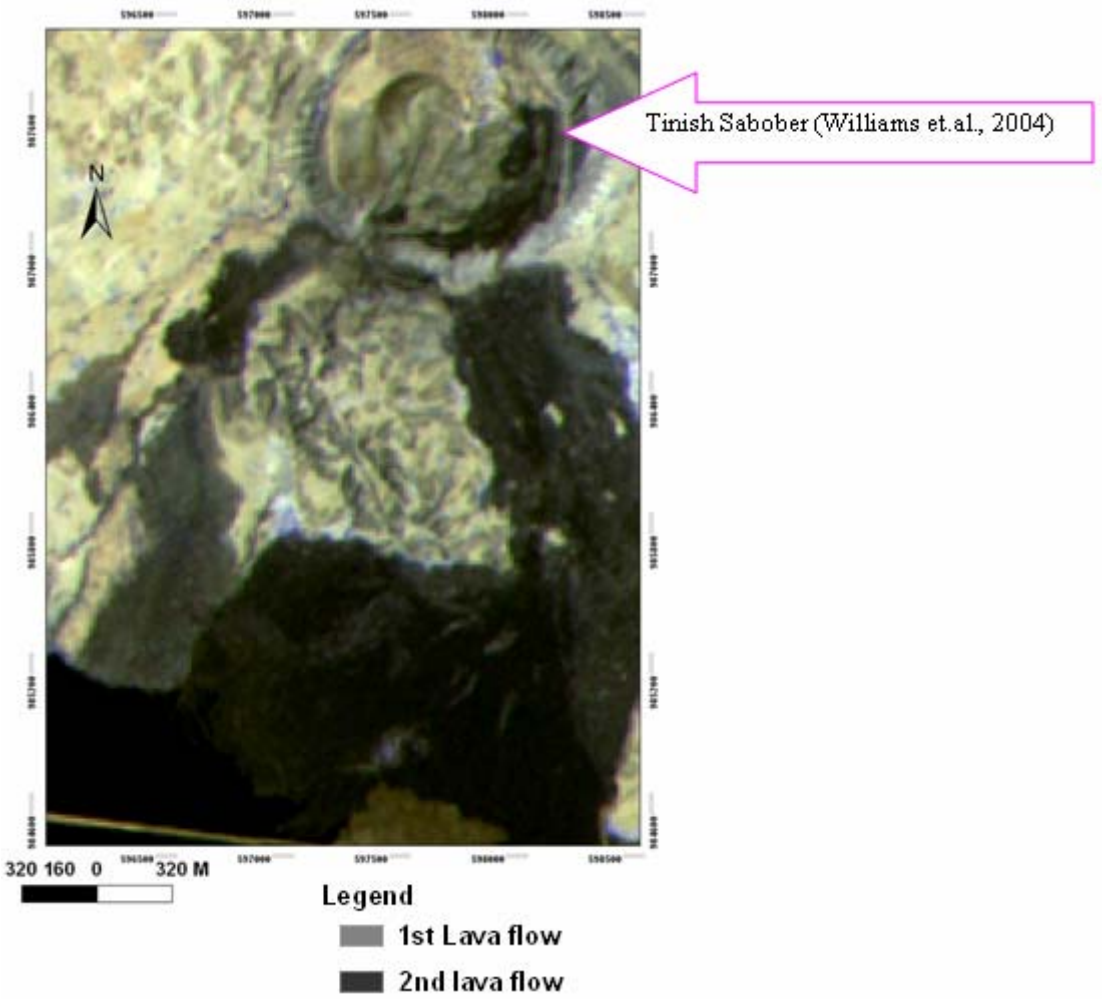


Fig. 4.6 Lava flow from Tinish Sabober.

4.2.1.12 Lacustrine Sediments

From geological map of Berhe et.al. (1978), lacustrine sediments are found at the floor of Lake Beseka and now outcrops of these sediments can be found on the northwestern shore of the lake along the NNW-SSE running faults (Fig.4.7). A sophisticated analysis of these deposits was carried out by William et al., during the 1970s, including the digging of numerous trenches along two E-W transects. From correlation of layers from neighboring trenches and radiocarbon dating of charcoal and shell carbonate, they found a Late Pleistocene to Holocene history of water fluctuation.

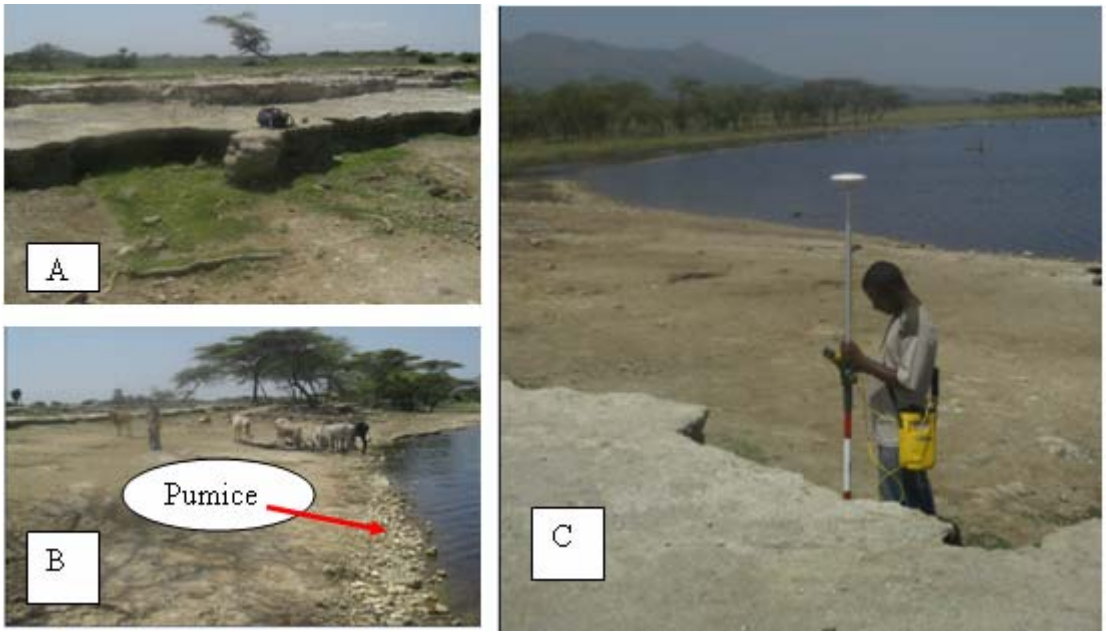
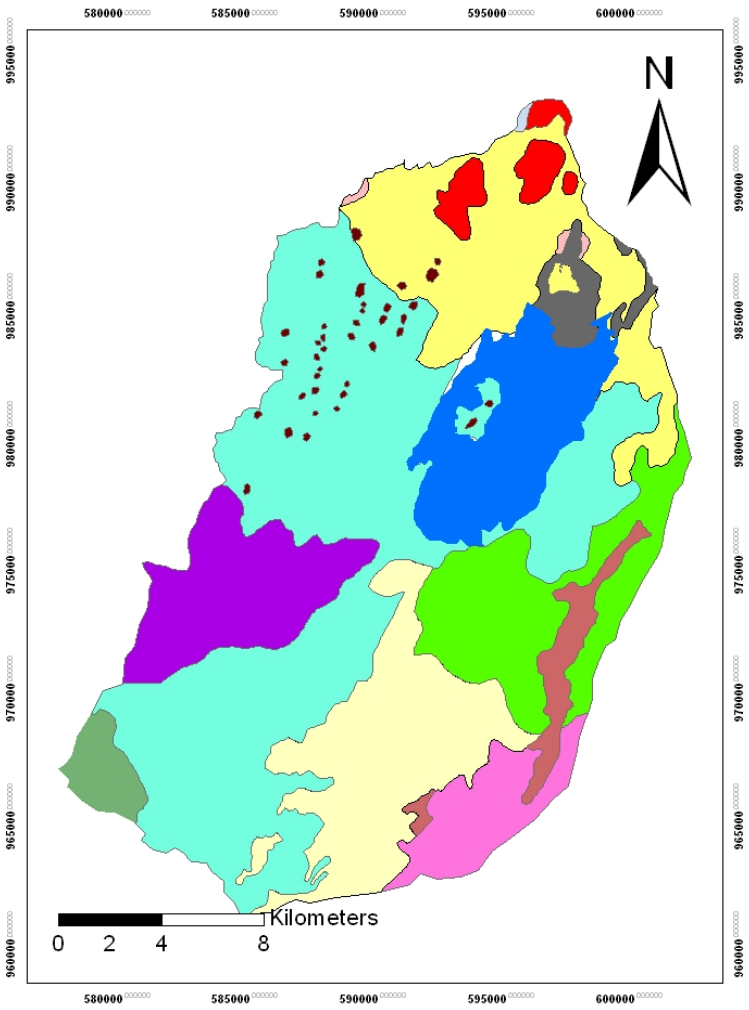


Fig. 4.7 Lake Sediments deposited at different time

4.2.1.13 Alluval sediments

These deposits are also youngest among the units found in the area and are found in Addis Ketema town, in Abadir farm, Merti sugar plantation and alomg the Awash River. This unit is very important for agricultural purposes and almost all the area it covers used for sugar plantation.

The alluvial deposits are two types: those spreading out in alluvial plains and those strips along the rivers and streams. Alluvial plains filled up flat land around Abadir and Metehara areas and in the streams and are formed during the pluvial period when streams deposited large amount of sediments carried down from the highlands. Their grain size ranges from silt to gravel.



Legend

- volcanic cones
- Lake Beseka(2002)
- Alluvial sediments
- Bofa Basalts
- Lacustrine sediments
- Pleistocene-sub recent basalts
- Lava flows of Tinsh [illegible] Fantale
- Tuff cone
- Dino Ignimbrites
- young ignimbrites of Fantale
- Pitchstone flows and domes
- Pantelleritic volcanics of Fantale rhyolites, trachytes and agglomerates
- Unwelded rhyolitic pumice and unwelded tuffs
- Recent to sub recent rhyolite domes and flows
- Alkali and peralkali rhyolites, trachytes, domes and flows of Boset and Hada mountains

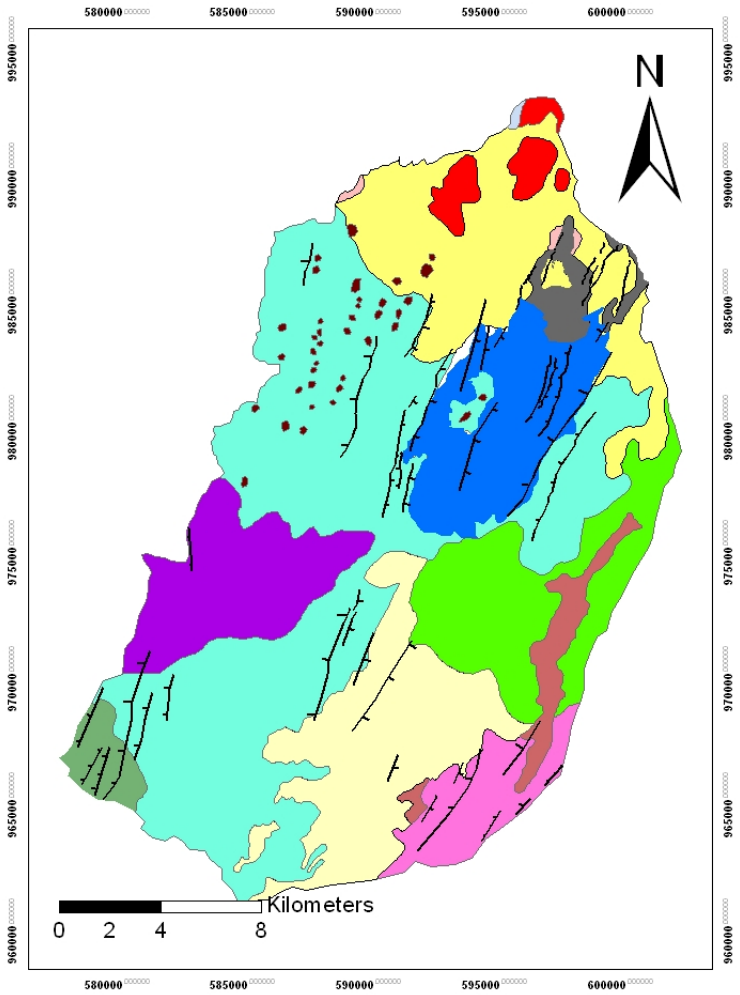
Fig. 4.8 Geological map of study area (Modified from Geological map of Nazreth sheet 1:250000, and unpublished map)

4.2.2 Structures

Fracture is a general term for all types of mechanical discontinuities or breaks in the host rock, including the two main types of fractures: extension fractures and normal faults. The term extension fracture is used when the separation is primarily by movement normal to the failure surface, but shear fracture (fault) when the separation is primarily by movement parallel to the failure surface.

In the field, extension fractures appear as valleys and are several meters to some kilometers long and reach up to 9m wide and 16m deep. These valleys are typically V-shaped that distinguishes them from stream valleys and their orientations are not necessarily parallel to the local or regional slopes. They are mostly filled with blocks falling from their margins as well as alluvium as a result of erosion and deposition there.

The lacustrine sediments of the lake have tectonic joints. These joints have similar orientation as the fault direction at that place. Hence, they are very important to describe the continuity of the fault which is covered by sediments.



Legend

- volcanic cones
- Lake Beseka(2002)
- Alluvial sediments
- Bofa Basalts
- Lacustrine sediments
- Pleistocene-sub recent basalts
- Lava flows of Tinsh Sabober & Fantale
- Tuff cone
- Dino Ignimbrites
- young ignimbrites of Fantale
- Pitchstone flows and domes
- Pantelleritic volcanics of Fantale rhyolites, trachytes and agglomerates
- Unwelded rhyolitic pumice and unwelded tuffs
- Recent to sub recent rhyolite domes and flows
- Alkali and peralkali rhyolites, trachytes, domes and flows of Boset and Hada mountains
- fissure
- Fault

Fig. 4.9 Structural Map of the study Area

4.2.2.1 Morphology Faults and Fissures

Recent faults seem to be affected by dyking. Gloaguen et al., (2003) explains these fault morphology by dyking. The faults within the area of investigation have very atypical morphologies. Profile across the fissure from field observation (Fig.4.10) indicates that the faults do not show the morphology of typical faults. The footwall remains flat and the concave hanging wall curves up and dips away the fault plane (Kurz et al., 2005) as shown in figure 4.10C.

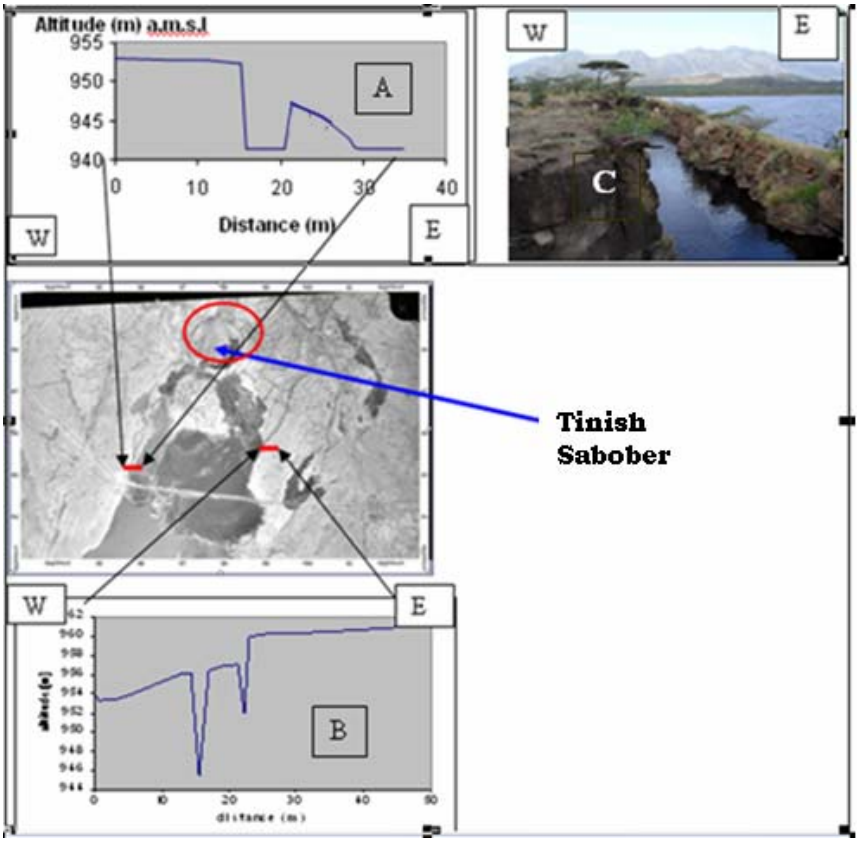


Fig.4.10 Atypical fault morphology located north of Lake Beseka: (A) From northwest has 5 m vertical offset & 6 m horizontal offset, (B) From northeast with 40 cm vertical offset, 2.57 m horizontal offset and 11m deep and 2.88 m vertical offset 1.75 m horizontal offset and 8 m deep left to right fractures respectively.

For the total length of the fissure located northwest (as shown by large rectangle) and parts of a fissure located northeast (as shown by small rectangle) (Fig.4.11), detailed kinematic GPS measurements were taken along the direction of the fissure at both sides of the fissure and across the fissure at intervals about 50m.

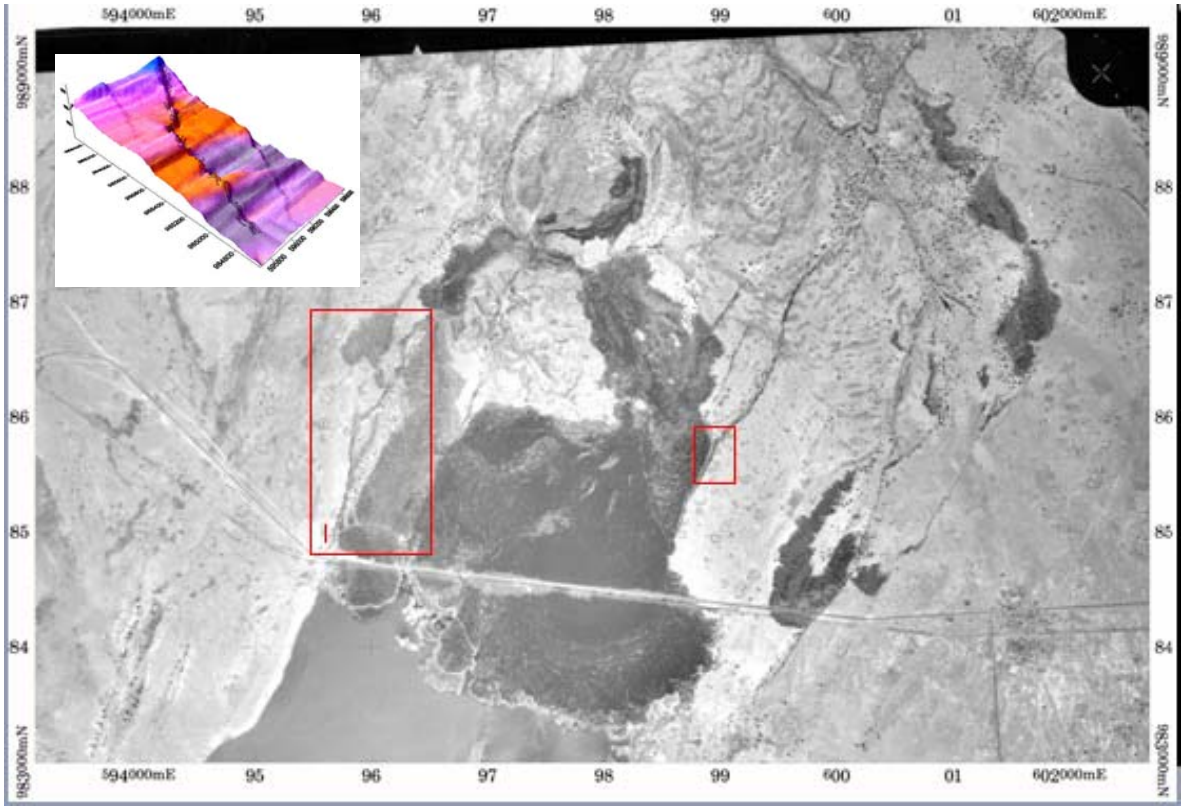


Fig.4.11 Location map of the detailed kinematic measurements taken: Inset map shows 3-D for the fissure bounded by large rectangle

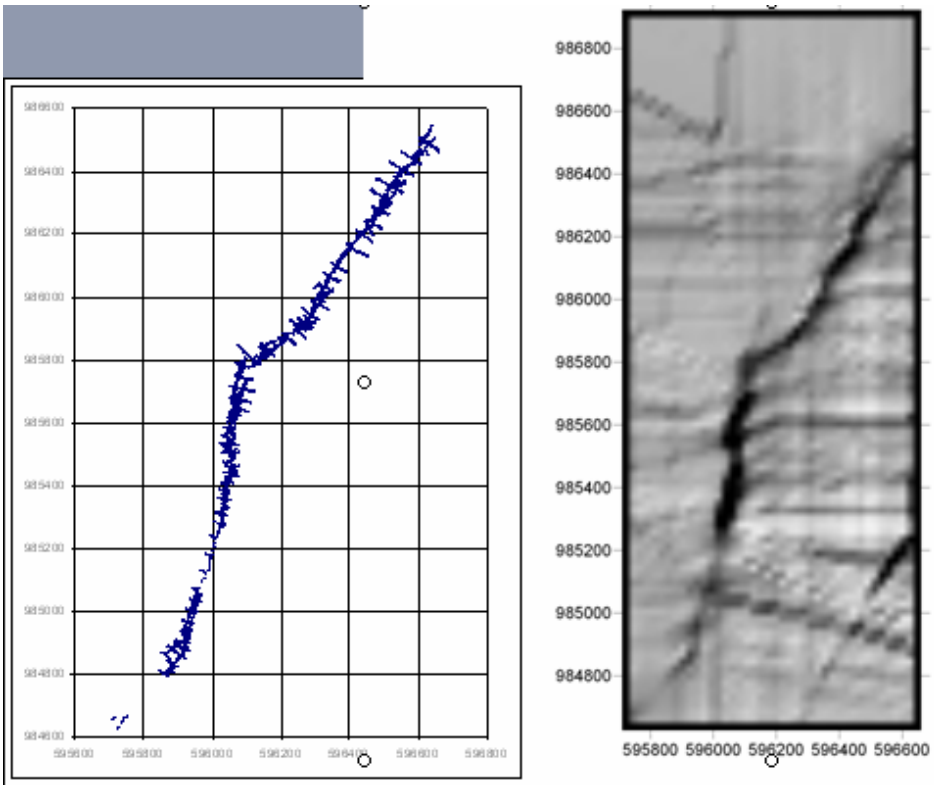


Fig.4.12 Along and across the fissure measurements: Fissure northwest of Lake Beseka

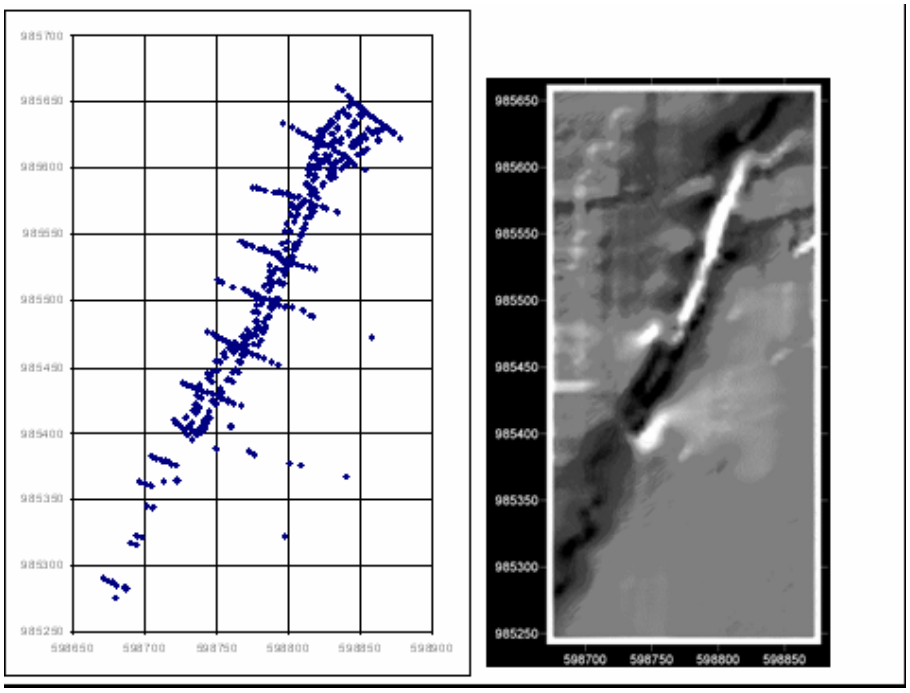


Fig.4.13 3-D of the fissure: It is the same site of the above figure; it has 16m depth and 9m width.

The NNE-SSW striking normal faults and fissures system, which are mostly determining the lake shape, can be observed at the present eastern and western shoreline of the north and south of Lake Beseka (Fig. 4.14). The open fissures reach up to 8m width and about 14m depth. The wider fissure were found northwest of Lake Beseka (Fig. 4.14A)

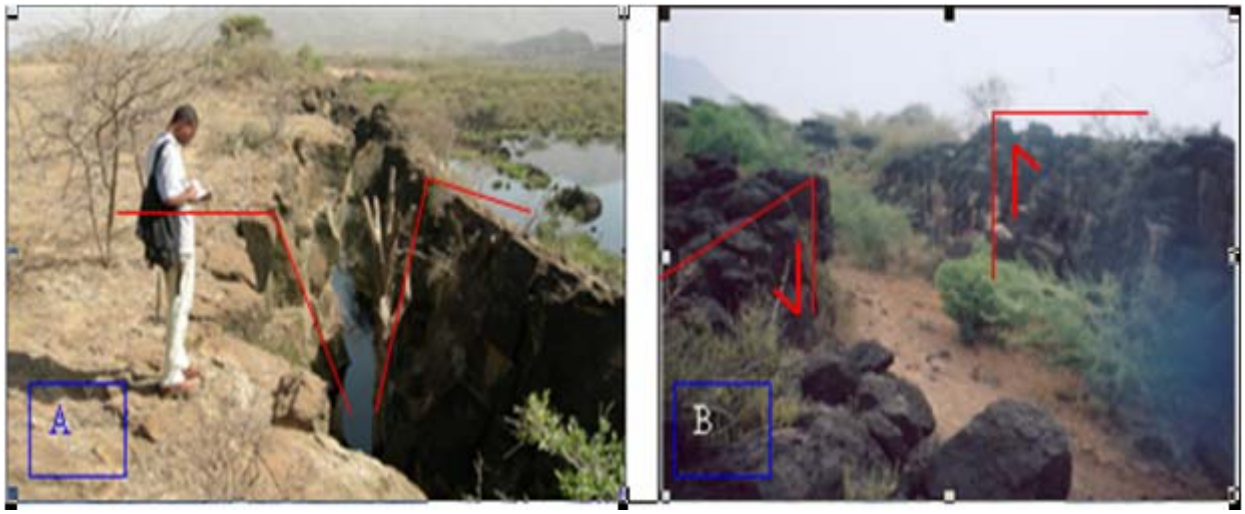


Fig.4.14 Fracture outcrops: **A**) Fissure form northwest of Beseka, hanging wall dipping to East. **B**) Fault form southeast of Beseka, hanging wall dipping to west (30^{o}) and has vertical offset of 3m.

Extension fractures of the atypical faults in the field have vertical offset shown by faults (Fig.4.14A). But to wards the end of the total length these fractures, at north, they are characterized by vertical extension fracture (Fig.4.15) which is the termination of the normal faulting.



Fig.4.15 Vertical extension fracture

4.2.2.2 Formation of Fault-Fisure-Monoclinal-System (FFMS)

The fault/ fissure often alternate with or occur in combination with monoclinal folds. The observed structures appear to be generated in a process beginning with slight monoclinal folding and fissure formation which is followed by faulting when the displacement is growing. A schematic diagram for the evolution such structures is shown in figure 4.16 below (After Buchwitz, 2006) and Field observations give a clear understanding of the formation FFMS (Fig.4.17)

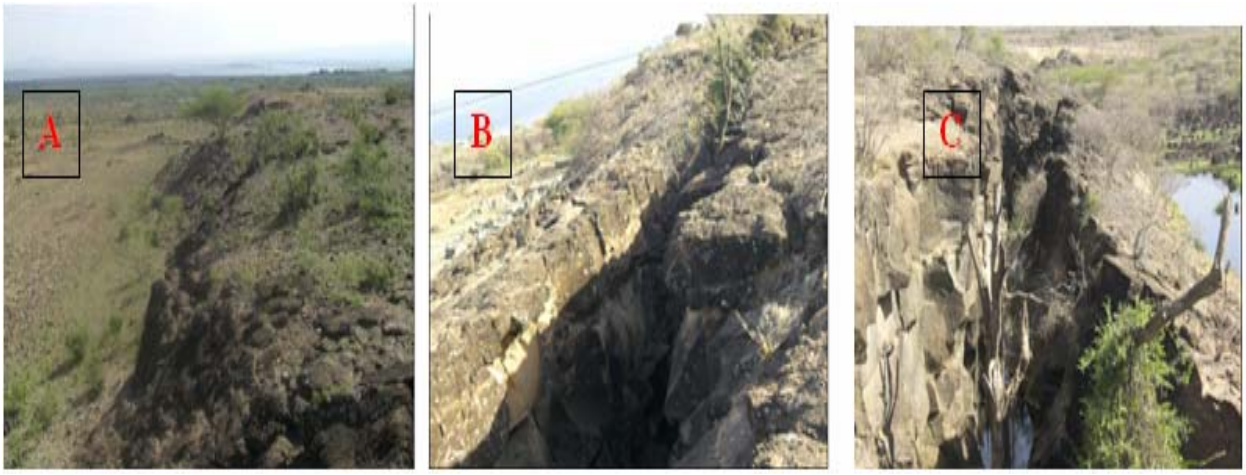


Fig.4.16 Dyke induced faulting (photos): **A**, **B** and **C** represent for **B**, **C** and **D** in fig 4.17 below respectively.

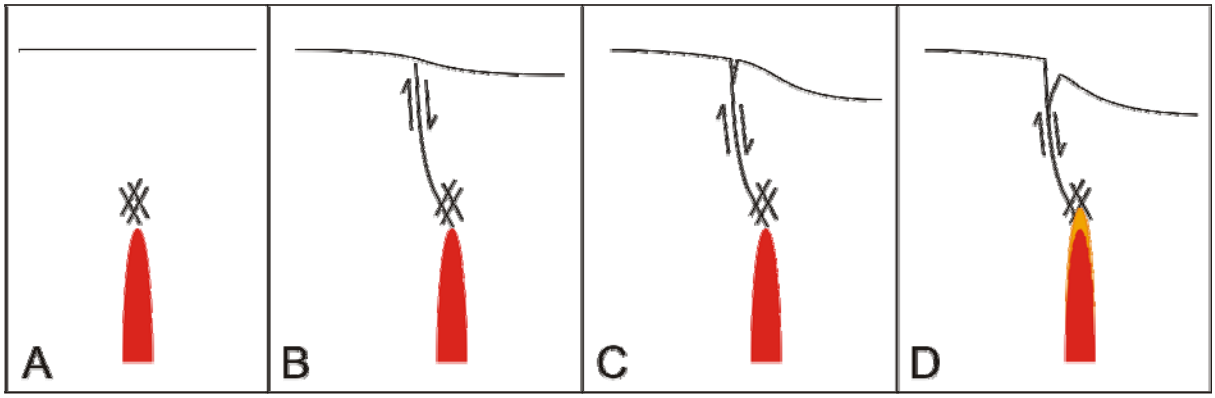


Fig.4.17 Dyke-induced faulting (Model): In stage (**A)** vertical stress above an upward-propagating dyke (red) is enlarged and leads to fracturing. **B:** The fissure propagates to the surface. Vertical displacement grows leading to the formation of monocline. **C:** After reaching the surface on the upper side of the monocline as a nearly vertical fracture, vertical and horizontal spacing grows resulting in a normal fault with atypical profile (**D**). Meanwhile the dyke may propagate further to the surface (orange).

4.2.2.3 Interpretation from aerial photograph

Besides field observations, aerial photographs also help us to understand the Wonji Fault Belt (WFB), which is constituted by a number of sigmoidal, overlapping, right-stepping en-echelon fault/fissure arrangements as shown in (Fig.4.18B) and also the presence of left-steeping segments (Fig.4.18A).

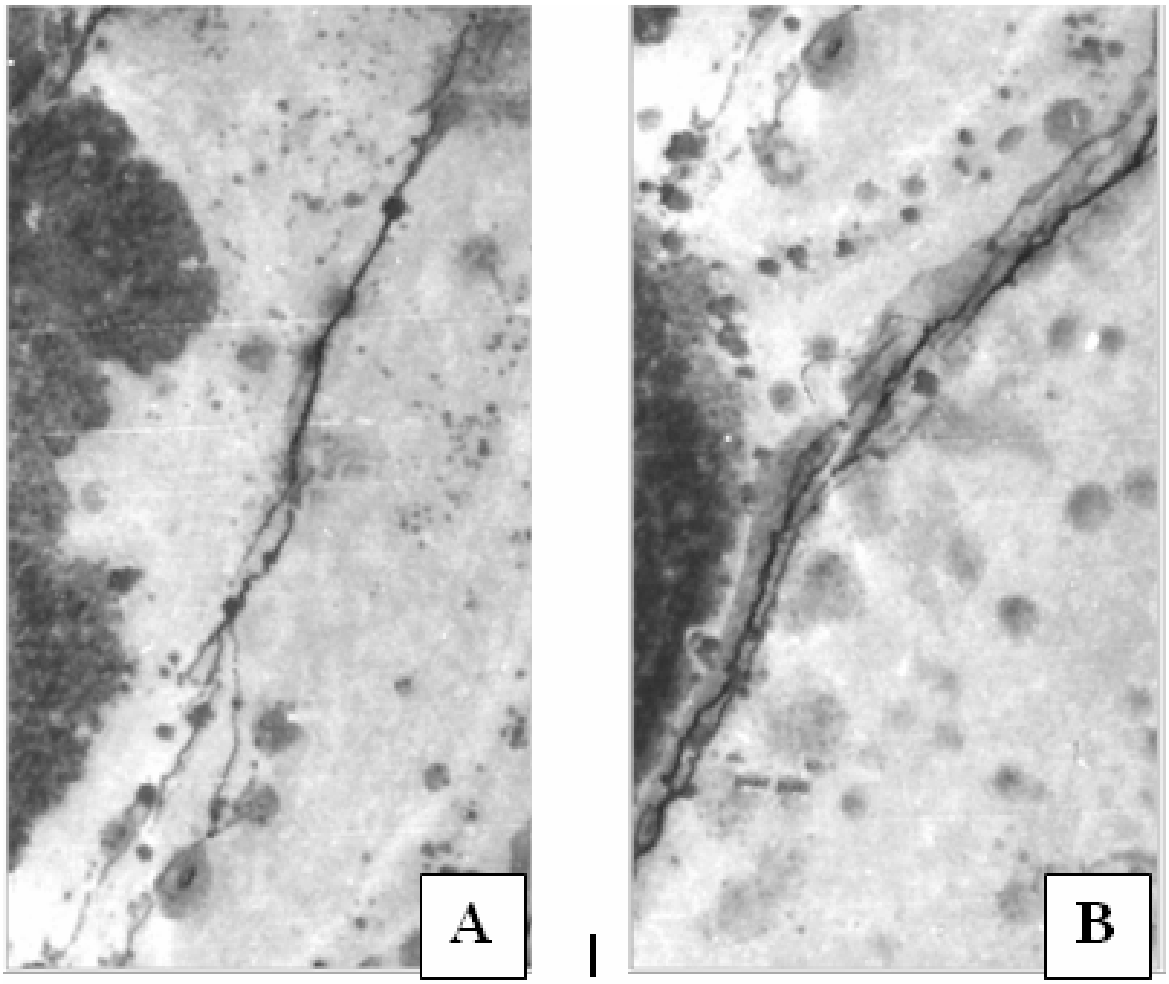


Fig.4.18 Sections from aerial photograph (1975) showing two fault/ fissure systems to the northeastern of Lake Beseka. (A) Left-stepping segments in fault/ fissure system, (B) Right-stepping segments in fault/ fissure system

From the structural map of the study area there are also right-steeping fault arrangements within the faults found at the south western edge of Lake Beseka.

4.2.2.4 Extension direction

The extension direction along the EARS has been a matter of debate over the last decades. The proposed extension direction is either mainly E-W (roughly perpendicular to the EARS trend (Morley, 1988;Ebinger,1989a; Morley, 1989; Morley et al., 1992;Nelson et al., 1992;Foster and Jackson,1998 Boccaletti et al., 1998, 1999; Chu and Gordon,1999) or NW-SE, i.e. oblique to the EARS trend(Tiercelin et al.,1988; Scott et al., 1989 Strecker et al., 1990; Chorowicz and Sorlien, 1992; Ring et al., 1992).

The extension direction of specific portions of the EARS is also debated. Among these, the MER is possibly one of the most controversial segments. Early works (McKenzie et al., 1970; Le Pichon and Francheteau, 1978), based on plate kinematics observation at Afar triple junction, proposed a NW-SE extension direction for the MER since the Late Miocene, which is the inferred age of the onset of rifting (WeldeGabrieal et al., 1990). These results have been supported in part by subsequent field surveys and remote sensing studies on Quaternary structures (Chorowicz et al., 1994; Korme et al., 1997), geodetic surveys (Mohr et al., 1978; Bilham et al., 1999) and focal mechanism solutions (Kebede and Kulhanek, 1991).

Nevertheless, an increasing number of studies, especially in the last decade, have suggested an overall E-W extension direction for the MER. These studies are based on plate kinematics calculations (Miocene-Quaternary extension, Chu and Gordon, 1999), remote sensing analysis on Quaternary structures and analogue models (Quaternary extension; Bonini et al., 1997; Boccaletti et al., 1998, 1999), focal mechanism studies (present day extension; Foster and Jackson, 1998), bore hole breakout data (present day extension; Bosworth et al., 1992) and numerical models (present day extension; Coblentz and Sandiford, 1994; Jestin et al., 1994). On the basis of both the general fault pattern and structural analysis, the recent evolution of the Ethiopian Rift has

been related to a nearly E-W oriented extension direction, which trends about 50^{o} to the rift axis (Boccaletti et al., 1992,; Abebe, 1993). Such stretching direction is consistent with the occurrence of both the diffuse horizontal left lateral shear component along some WFB faults (Boccaletti et al., 1992, Abebe, 1993).

Other works, based on structural considerations on Quaternary faults (Mohr, 1968; Gibson, 1969; Abbate et al., 1995) and focal mechanism interpretation (Ayele, 2000), suggest a Quaternary left-lateral component of shear along the MER. This component is kinematically consistent with an E-W extension direction.

In this study the opening direction of structure in the study area is based on field survey. It is done by taking the matching edges of the fissures (Fig.4.19). The measurements are taken from north of Lake Beseka which is between Fentale and the lake. There are also measurements from north west Beseka fissures which bound the lake. Generally 487 data were taken and weighted according to their horizontal displacement (eq.4.5) to gave the total opening direction 113.4^{o}, which is in agreement with the overall E-W direction. Here, for all wider fissure (eg. 9 m) and some fissures, the opening direction, total separation, vertical and horizontal offset are determined by equations 4.1-4.4 below, reading from the Trimble GPS at the two sides of matching edges. The values of both opening direction and horizontal offsets are shown in Fig.4.20 and 4.21, respectively. Most of the data show opening direction is between 110 and 120 (Fig.4.22).

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \quad \text{.....eq. 4.1}$$

Where, d – Total separation between two edge matching points

X, y, z – latitude, longitude and elevation.

$H_{os} = X_2 - X_1$ ..... eq. 4.2

Where, Hos - horizontal offset

$V_{os} = Z_2 - Z_1$ ..... eq. 4.3

Where, Vos - Vertical offset

$$O_{ds} = 90^{o} - \arctan(\frac{y_2 - y_1}{x_2 - x_1}) \text{ ..... eq. 4.4}$$

Where, O_{ds} – Opening direction Opening for a single edge matching point

$$W_{od} = \frac{\sum_{i=1}^{n=487} Od_i * Hos_i}{\sum_{i=1}^{n=487} Hos_i} \text{ ..... eq. 4.5}$$

Where, W_{od}- weighted opening direction,

O_d –opening direction,

H_{os} – horizontal offset between edge matching

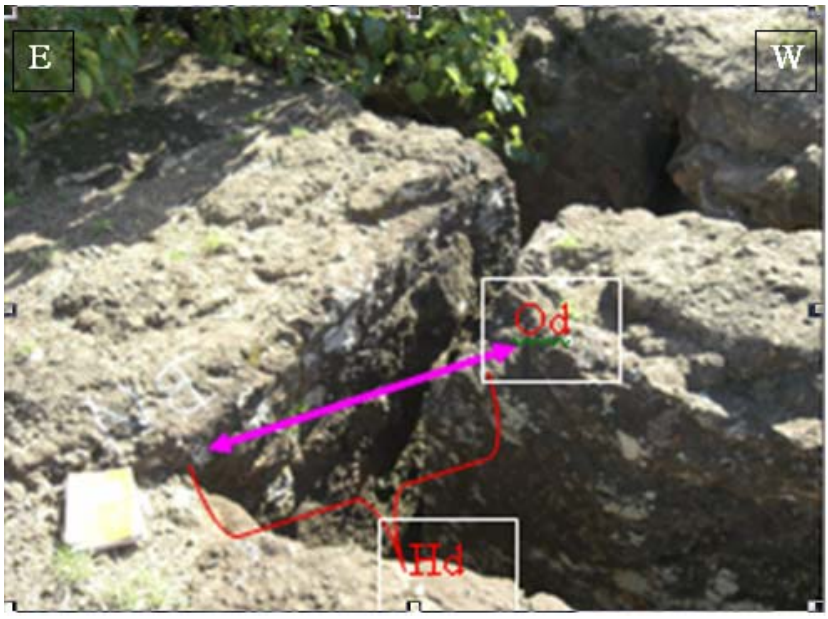


Fig.4.19 Edge matching of opened fissure

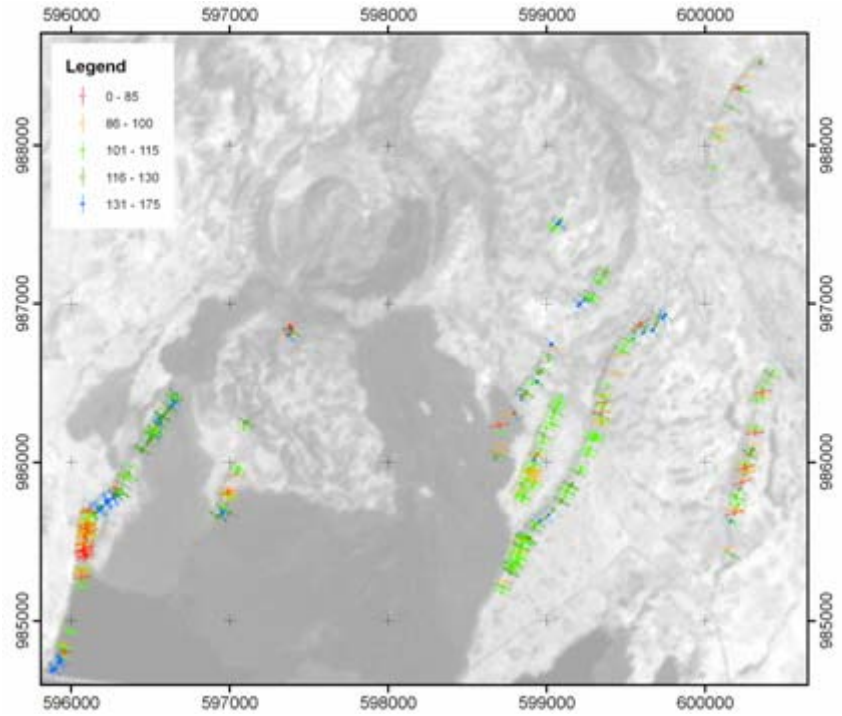


Fig.4.20 Measurements on opening Direction of Fissures their values

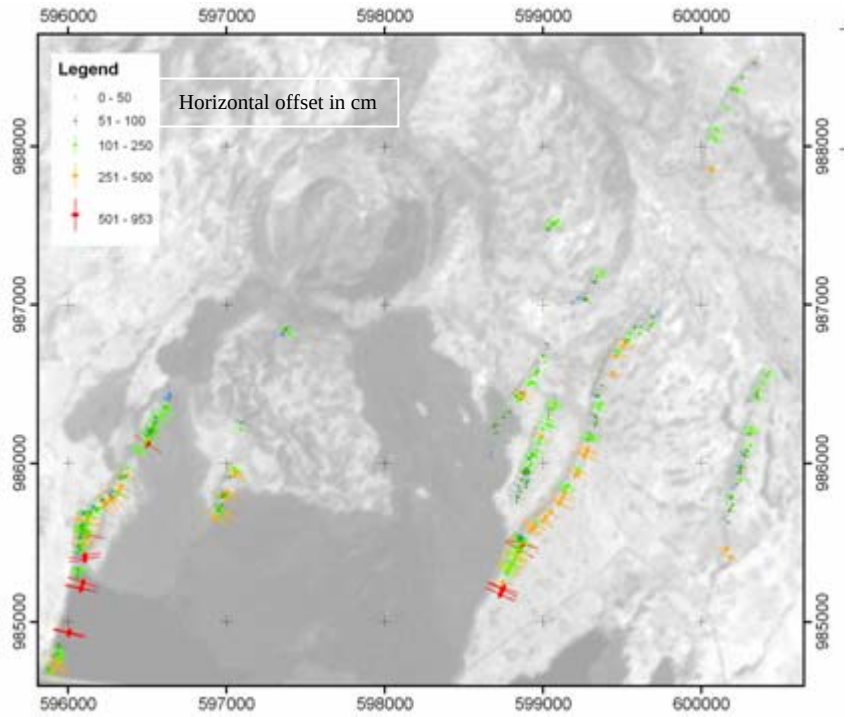


Fig.4.21 Measurements on Horizontal offset of Fissures their values

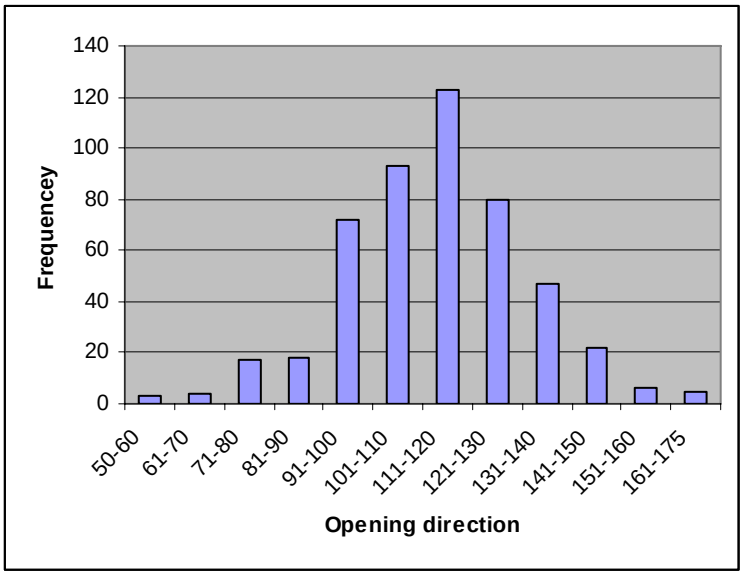


Fig.4.22 Frequency of values of opening direction

4.2.2.5 Geometric features of interacting fractures

In the investigation area, especially north of Lake Beseka, we find examples of development of interaction between fractures at different stages (Fig.4.23). At the beginning stage, the fracture segments are propagating to wards each other and this is characterized by underlapping configuration. In the next stage, the fracture segments are curving/ bending to ward each to other to form an overlap zone (Fig.4.24). The last stage is constituted by further propagation of one of the fractures and linkage with the other. This leads to the abandonment of the less propagating segment and to the development of a single continuous structure.

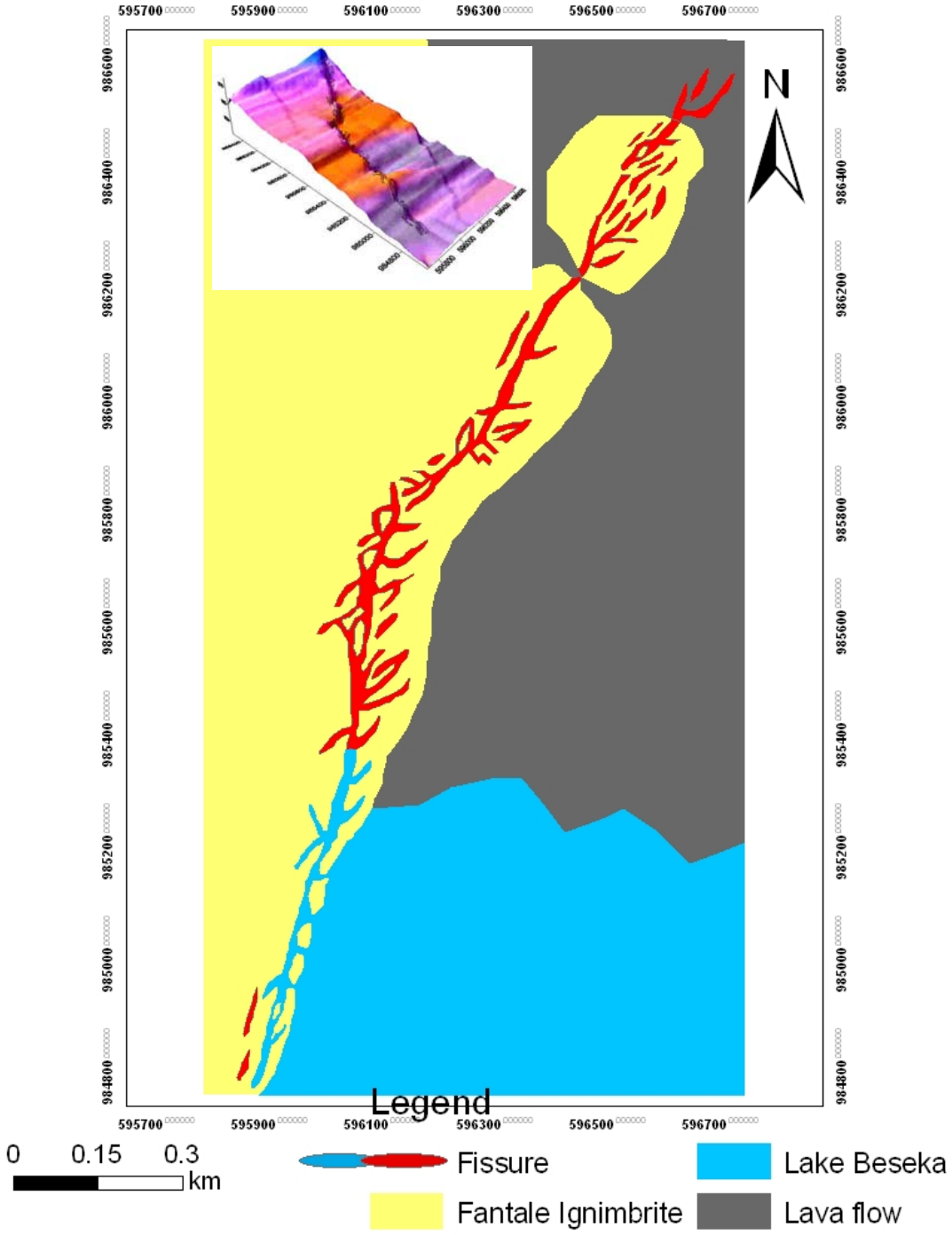


Fig.4.23 Geometry of Fissures (North West of the Lake): Inset shows 3-D of the whole fissure

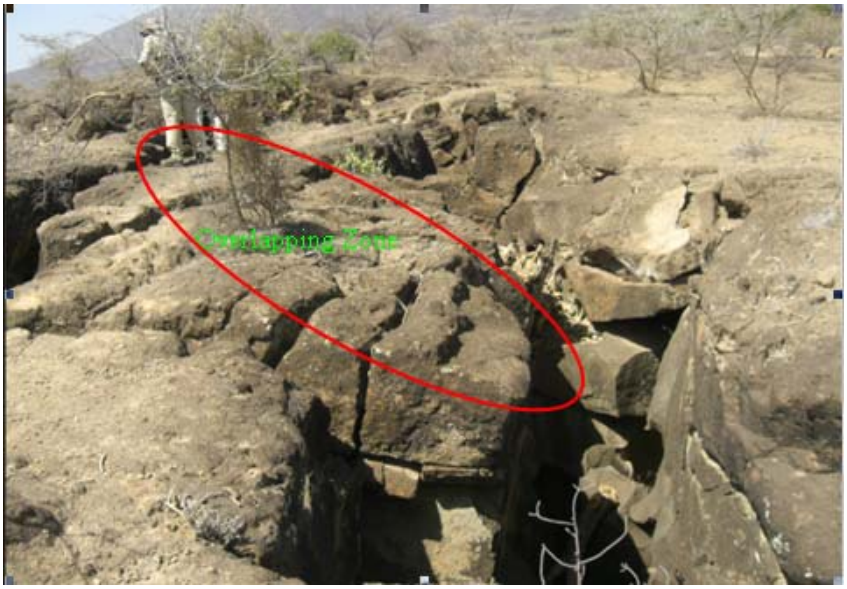


Fig. 4.24 Fracture interaction

In combination with the tectonic fissures there are also cooling fractures (Fig.4.25). They occur as conjugate sets which have completely different orientation from the tectonic fissures. These structures are formed by cooling at the time of formation of the tectonic fissures and are very small compared to the fissures.

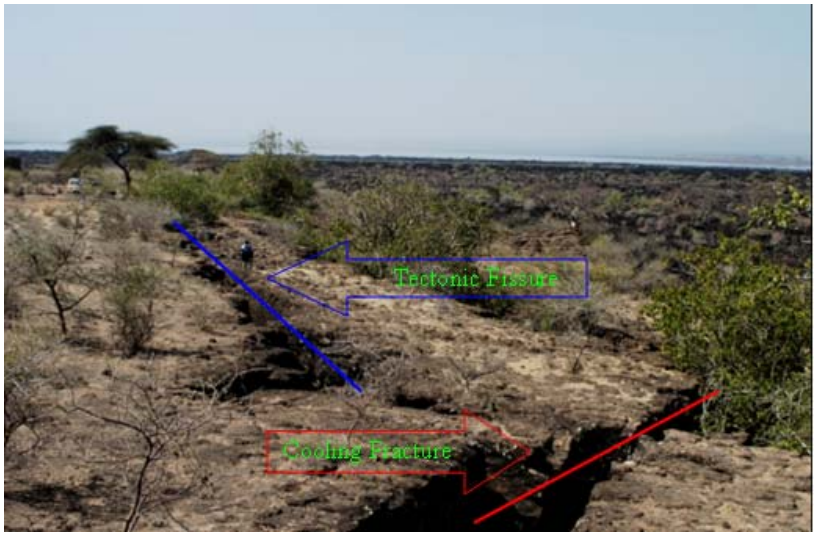


Fig.4.25 Combination of Tectonic Fissure and Cooling Fracture

5. Tectonics and Volcanism

The EARS is a Miocene- Quaternary intracontinental extensional system composed of several interacting rift segments, from Mozambique to Afar (Davidson and Rex, 1980; Rosendahl, 1987; Ebinger, 1989b; Bosworth and Strecker, 1997). At the Afar, the EARS joins with the Gulf of Aden and Red Sea Rift, both characterized by a more advanced extensional stage (Mc Kenzi et al., 1970; Ebinger and Hayward, 1996; Manigetti et al., 2001).

The MER constitutes the northern most part of the EARS, connecting the EARS with the Afar triple junction. The MER started to develop during Miocene time (Davidson and Rex, 1980; WoldeGabriel et al., 1990; Chernet et al., 1998), following a broad doming centered on the present Afar Depression (Almond, 1986; Ebinger et al., 1989;Colle et al., 2000). The MER progressively deepened during Plieocene and Quaternary, evolving through a sequence of interacting half-graben segments, marking the boundary between the Nubia and Somalia plates (Ebinger and Hayward, 1996).

The youngest part of the MER is the axial zone, which coincides with the so-called Wonji Fault Belt, mainly formed during the Quaternary (WFB; Mohr, 1967; Mohr, 1987; Boccaletti et al., 1998, 1999). Despite the overall NE-SW trend of the MER, the WFB is characterized by active NNE-SSW trending extension fractures and normal faults. These are often set in a right-stepping en-echelon arrangement and are associated with volcanic activity. The slightly different trend of the MER margins suggests a change in the extension direction during Quaternary (Bonini et al., 1997; Boccaletti et al., 1998).

The present day widening rate of MER as estimated using GPS measurements as the central MER over the last 20 years indicate an extension rate of 4.5 ±1mm/yr in approximately 1.1±2.2 mm/yr (Asfaw et al., 1992). More recent

GPS measurements show N72^{o} W extension direction, perpendicular to the trend of the WFB (Bilham et al., 1999).

Volcanism is mainly a bimodal basalt-rhyolite association (Peccerillo et. al., 2003), with a distinct lack of lavas of intermediate composition. Rhyolites are usually associated with regularly-spaced central volcanoes, usually characterized by a summit caldera, with a diameter exceeding 10km (Ebinger and Casey, 2001; Acocella et al., 2003). The proportion of rhyolite was formerly estimated to be reaching about 90% of the total volume of the erupted products in the central MER (Trua et al., 1999), but recent field investigations reveal that the basalts may constitute up to 60% of the total volume at least in the northern MER (Wolfenden et al., 2004).

Basalts are usually associated with monogenetic vents and/or fissure eruptions, at the side of the main central volcanoes (Ebinger and Casey, 2001). The MER is, therefore, mostly floored by several basaltic fields, silicic pyroclastic flows & domes and calderas. These are interlayer with and covered by Plio-Quaternary fluvio-lacustrine sediments (Le Turdu et al., 1999; WoldeGabriel, 2002). However, the genetic relationships between the basalts and the rhyolites are still debatable (Peccerillo et al., 2003).

Interaction among the major faults systems have induced formation of complex fault patterns on the most active systems (Wonji Fault Belt) and facilitated the formation of secondary fault-related open structures. These secondary structures have served as the eruption sites for some of monogenetic volcanoes (e.g., scoria cones) in the rift valley (Korme et al. 2003), with chains of scoria cones having developed along the fracture of traces (Fig. 5.1).

Close interaction between faulting and recent magmatism can be defined by the presence of alignment of cones along the orientation of faulting direction (Fig.5.2). In addition to the linear alignment scoria cones along those fissures,

which helps to understand the interaction of faulting and magmatism, cone shape is also affected by the orientation of the structure, and is elongated along the fault direction (Fig.5.2B). South of Tinish Sabober, three scoria cones aligned along and cutting the fault/fissure, are good example of the relationship between faulting and volcanism. This fault/fissure continues through the center of Tinish Sabober caldera which is the main source of the lava flows in the study area (Fig.5.3). This lava flows in to the fissure which can help us to understand the age of the fault (Fig.5.4). This leads to easily constrain the relative age of the fault as exactly between the age of the ignimbrite which is already cut by the fault and age of the lava flow that covers it.

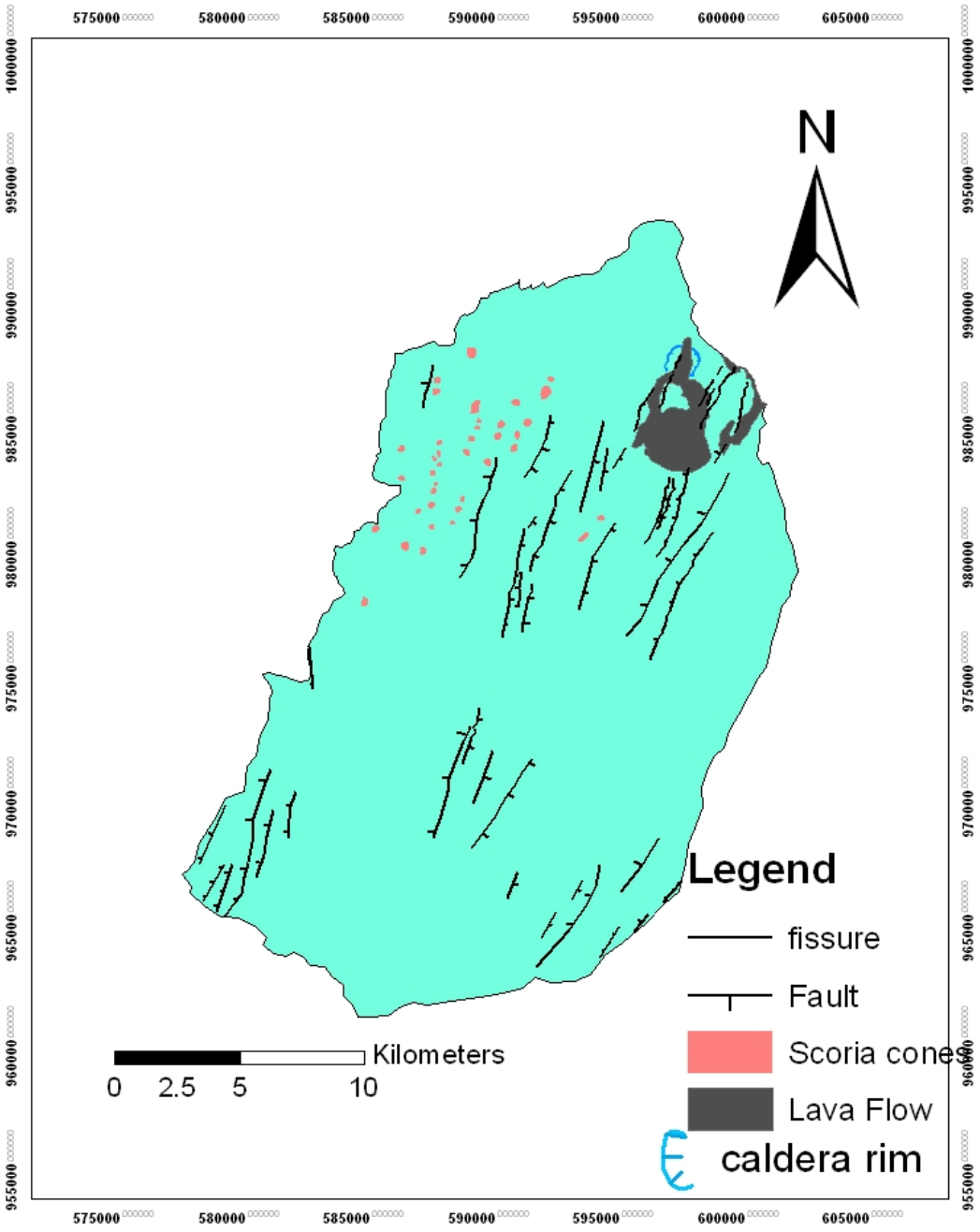


Fig.5.1 Structures and Volcanism relationship map**.**



Fig.5.2 Alignment of Scoria cones along the fissure



Fig. 5.3 Lava flow from Tinish Sabober.



Fig.5.4 Lava flows in to fissure of Young ignimbrite of Fantale

6. Result and Discussion

6.1 Interpretation of Climatic data and lake level

Lake level data for Lake Beseka are recorded since 1976 (Table 6.1) by Upper Awash Authority under Ministry of Water Resource (MWR).From the data, the gauge height was about 0.71 m in 1976 and 5.6 m in 2006. The lake level at present is almost about 8 times that of 30 years ago (Fig 6.1). The curve of the lake level fluctuation shows an increment with time while climatic data, for example, rainfall and average temperature of 1986 -2006 doesn't show any anomalies (Fig.6.2) and also wind speed, sunshine hours, relative humidity and Piche Evaporation of 1986-2005 (Fig.6.3). Hence, climate has not to have any impact/influence on the lake level rise.

Table 6.1 Lake Level in meter (1976 – 2006)

Year	Apr-76	May-77	Jun-78	Jul-79	Aug-80	Sep-81	Oct-82	Nov-83	Dec-84	Jan-85	Feb-86	Mar-87	Apr-88	May-89	Jun-90	Jul-91
Lake level (m)	0.71	1.21	1.46	1.48	1.4	1.76	2.03	2.05	1.91	1.9	2.13	2.07	2.09	2.44	2.66	2.776

Aug-92	Sep-93	Oct-94	Nov-95	Dec-96	Jan-97	Feb-98	Mar-99	Apr-00	May-01	Jun-02	Jul-03	Aug-04	Sep-05	Oct-06
3	3.18	3.45	3.55	3.89	3.91	4.27	4.36	4.55	4.74	4.93	5.19	5.72	5.78	5.65

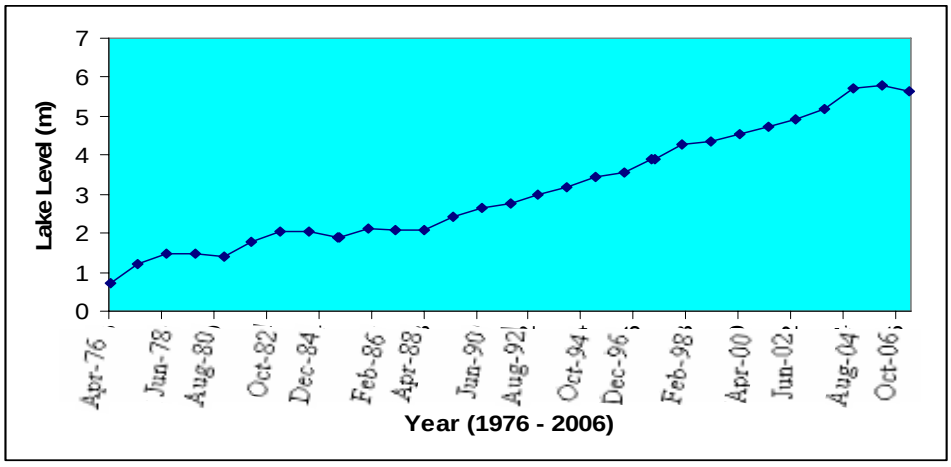


Fig.6.1 Lake level change of Beseka (1976 - 2006)

Table 6.2 Rainfall, Average temperature and Lake Level (1986-2006)

Year	Feb-86	Mar-87	Apr-88	May-89	Jun-90	Jul-91	Aug-92	Sep-93	Oct-94	Nov-95	Dec-96	Jan-97
Rainfall (mm)	41.6	71.6	23.7	7.5	0.9	137	157.6	41.6	0.1	0	0	29.7
Ave.T (Oc)	26	26.25	27.7	25.9	30.15	26.35	25.4	27.4	24.45	23.1	21.4	23.65
Lake Level (m)	2.13	2.07	2.09	2.44	2.66	2.776	3	3.18	3.45	3.55	3.89	3.91

Feb-98	Mar-99	Apr-00	May-01	Jun-02	Jul-03	Aug-04	Sep-05	Oct-06
18.1	73.6	20.7	12.7	10.2	118.9	123.9	21.6	37.50
26.25	25.85	27.5	29.4	29.4	29.4	26.85	27.9	26.6
4.27	4.36	4.55	4.74	4.93	5.19	5.72	5.78	5.65

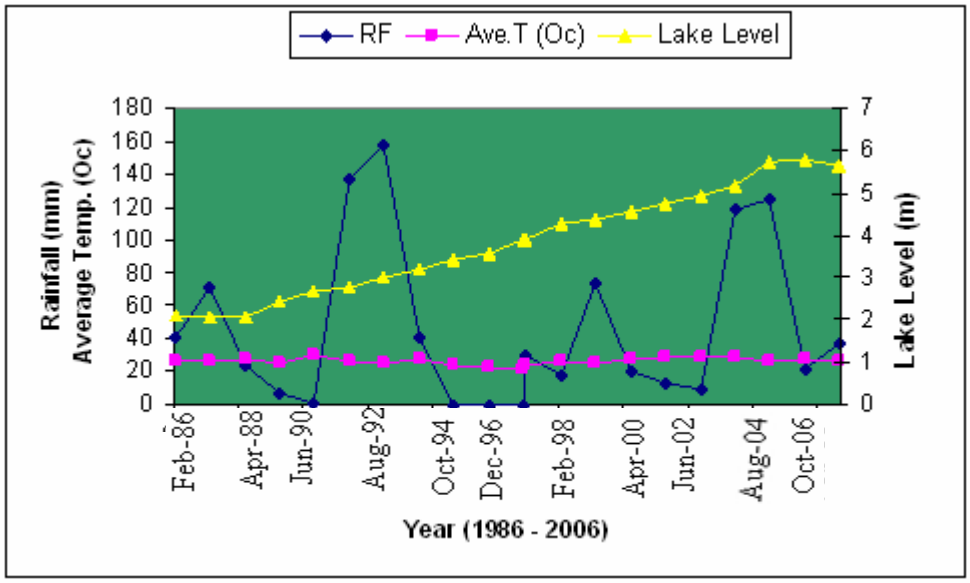


Fig. 6.2 Climate (rainfall & temperature) and Lake Level change

Table 6.3 Sunshine, Wind Speed, Relative Humidity, Pitche Evaporation and Lake Level (1986-2005)

Year	Feb-86	Mar-87	Apr-88	May-89	Jun-90	Jul-91	Aug-92	Sep-93	Oct-94	Nov-95	Dec-96
Sunshine hours (hrs)	8.8	7.5	8.6	9.8	9.5	7	5.6	7.1	9.6	10.3	10.1
Wind Speed (m/s)	2.3	2.1	2.0	1.6	2.6	2.9	2	2	1.5	1.4	1.3
Relative Humidity (%)	54.66	57.66	50.66	34.33	41.67	58.67	60.4	55.33	32.33	51.33	50.67
Piche Evaporation(mm)	285.6	306.9	270	306.9	435	244.9	161.2	231	291.4	291	306.9
Lake Level (m)	2.13	2.07	2.09	2.44	2.66	2.776	3	3.18	3.45	3.55	3.89

Jan-97	Feb-98	Mar-99	Apr-00	May-01	Jun-02	Jul-03	Aug-04	Sep-05
8.3	9.3	8.3	8.4	9.1	8.7	6.8	8.1	7.5
1.5	1.7	1.5	1.7	1.6	2	2.3	1.7	1.4
59.33	67	58.33	47	53	43	58	58.67	55
220.1	142.8	182.9	255	244.9	234	198.4	204.6	198
3.91	4.27	4.36	4.55	4.74	4.93	5.19	5.72	5.78

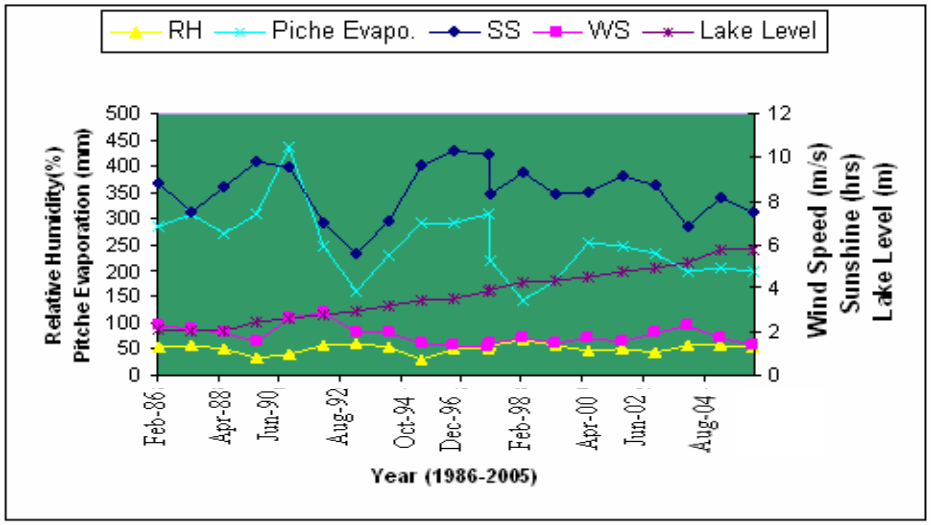


Fig. 6.3 Climate (Relative humidity, sunshine, and wind speed and pitche evaporation) and Lake Level change.

6.2 Groundwater flow and structures

Groundwater usually flows toward, and eventually drains into, streams, rivers, and lakes. Groundwater flows from higher elevations to lower elevations in the direction of maximum change in elevation. The line perpendicular to the straight lines which connect the elevation increments indicate the direction that the groundwater flows. This direction of flow is indicated by the slope of the water table which is called the hydraulic gradient.

6.2.1 Groundwater and streams

The interaction between streams and groundwater takes place in two basic ways:

a) Streams gain water from ground water through the streambed when the elevation of the water table adjacent to the streambed is greater than the water level in the stream.

b) Streams lose water to groundwater by outflow through the streambed when the elevation of the water table is lower than the water level in the stream.

In the study area, in the Abadir farm, there are wells with water table is lower than the elevation of the Awash River. Therefore, there should be groundwater flow from Awash River to wells.

6.2.2 Groundwater and Lake

The type of interactions between groundwater and lakes are generally similar to the interactions with streams. The main difference is that lakes have a much larger surface water and bed area. Furthermore, the slower through flow rates in a lake often result in accumulation of low permeability sediments in the lake floor which can affect the distribution of seepage. As a result, the rate of seepage is often greatest around the lake margin where wave action may restrict the deposition of finer sediments.

Lake Beseka is known for its rising lake level from year to year. The elevation of water level of Lake Beseka is lower than the elevation of the water table of wells in the Abadir farm as well as the elevation of Awash River. Hence, the flow is towards the Lake Beseka in the direction of faults, which is SSW - NNE.

Lake Beseka's expansion is reflected in long-term hydrochemical observations. Previous chemical analyses indicate the dilution of lake water in the course of lake level rise by a factor of 10 (Table.6.4) is due the flow of ground water. Discrepancies caused by various analytical methods and different, partially irreproducible, sampling sites do not allow differentiated statements for the last past 13 years (Gorner et. al., 2005).

Table.6.4 Chemical analysis, including only parameters given in many studies (Taken from Gorner and Jolie, 2005).

Reference	Talling & Talling, 1965*	Kebede et al., 1994*	Gizaw, 1996*	Tessema, 1998	Reimann et al., 2002*	Klemperer & Cash, 2005*	Görner & Jolie
Date sampled	May-61	Mar-91	Feb-93	1997	2000	Jan-03	Sep/Oct-2004
Li [ppm]					0.04	4.92E-02	<0.8
Na [ppm]	17800	1810	1900	1721.53	1740	1492	1775.99
K [ppm]	406	67	60	52.55	64	79.1	65.9
Ca [ppm]	<3	2.2	1	5.31	3.15	2.23	3.26
Mg [ppm]	<7.5	0.49	0.4	0.91	0.7	0.4	1.31
Cl [ppm]	5480	450	572	542.99	542	414	583
SO4 [ppm]	4680	600	540	981.84	494	603	538.02
pH	9.94	9.4	9.55	9.5	9.71	9.54	9.69

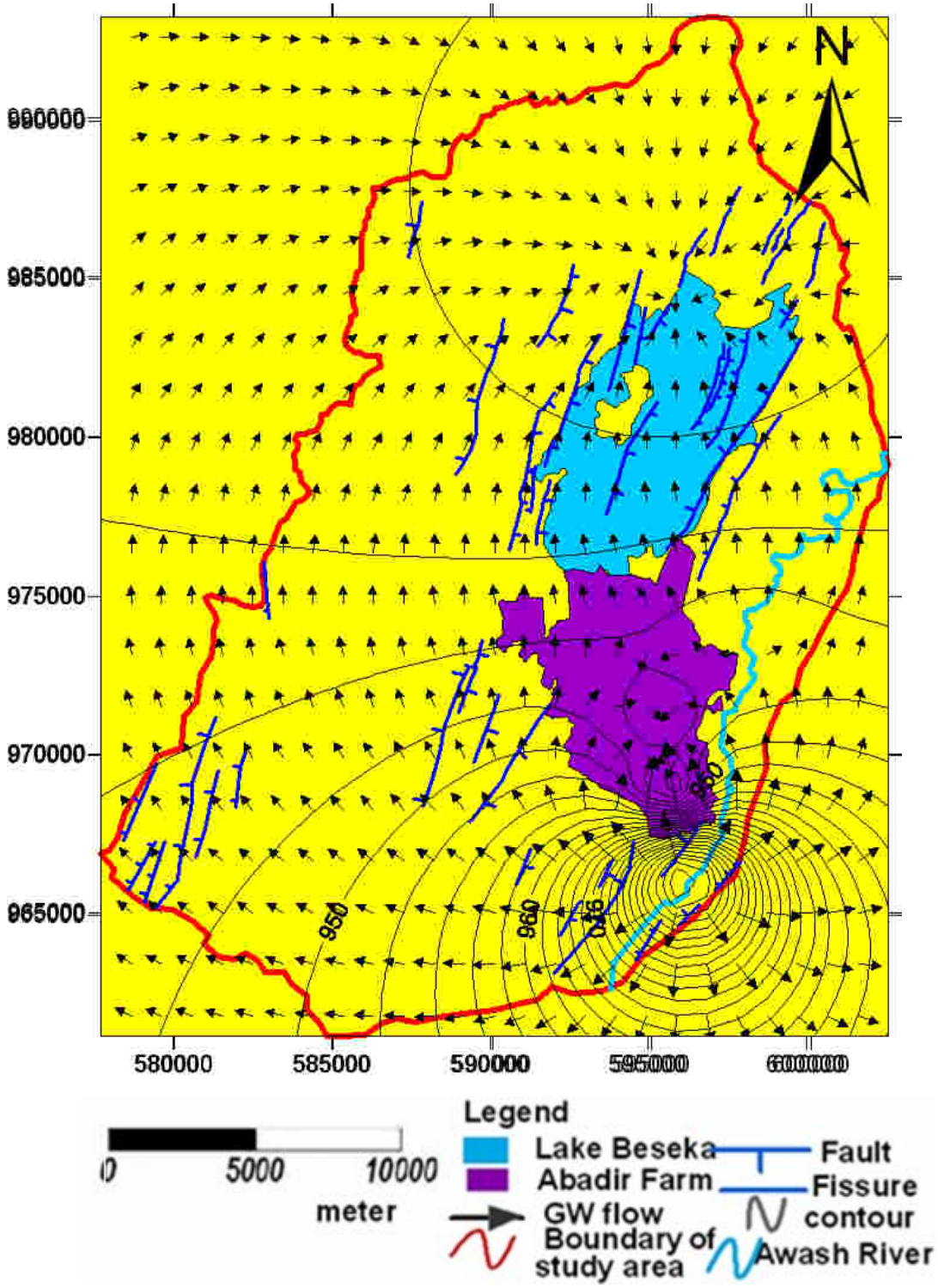


Fig.6.4 Ground water flow map

6.3 Spring and structure

In the Ethiopian Rift, more than 500 hydrothermal features were indicated in UNDP (1973). The expansion of Lake Beseka is attributed to numerous underwater and shore springs that feed the lake (Tamiru, 2006). The presence of active open fissures as well as the normal faults shows progressive expansion of the lake as they serve as open channel and /or conduits for regional and local transfer of ground water flow to the lake. In addition to the flow of ground water, the tectonic hot springs as well as cold springs, which are also important factors to the expansion of the lake, come through these structures.

The open fissures and fractures of the southwest side of lake drain the ground water in to the lake as 'Tone' springs and other submerged springs. According to MWR (1999), the 'Tone' spring discharges hot water in to the lake linearly along the fault escarpment, at a discharging rate 500l/s (Jan. 1998). This spring has a great impact on the lake level rise.

6.4 Ground crack

Ground cracks, also known as earth fissures in most manuscripts or ground fissures, sinkholes, or collapsing surface elsewhere in literature, are defined as long, linear tensile structures that occur at the land surface with or without vertical offsets (Carpenter, 1993). Ground cracks were developed in central portion of the Ethiopian Rift Valley when an anomalous heavy rainfall was soaking the region in1996, 1997 and 1998 (Ayalew et al., 2004). The cracks were observed in a small village called Muleti, around Lake Awasa and Adamitulu. With a width of 1-3 m a depth of 6-12 m and a length of up to 5 km, the cracks were the first major structures observed in the rift floor with no record of seismicity.

Deep-rooted ground cracks are formed in Abadir farm. These cracks are visible and increase their size especially during the rainy season and when there is excess water from irrigation. Very wide and long cracks formed many times in the irrigation area with a strike of N10^{o}E that is in the direction of the local faults. For example, in May 2006, a ground crack formed in the Abadir farm broke the concrete canals as well as the night storage reservoirs causing the loss of a lot of water. Abadir farm is also a cause for the rising of lake level. Some of the water used for irrigation goes through deep-rooted ground cracks.

6.5 Lake Beseka Graben

Lake Beseka is located within 5 to 6 kms wide local graben that is elongated in about NNE-SSW direction (Fig.6.5). It is developed within highly fractured vesicular and aphyric basalts on south eastern and western sides and on fissured Fantale ignimbrites on northern eastern and western sides of the lake

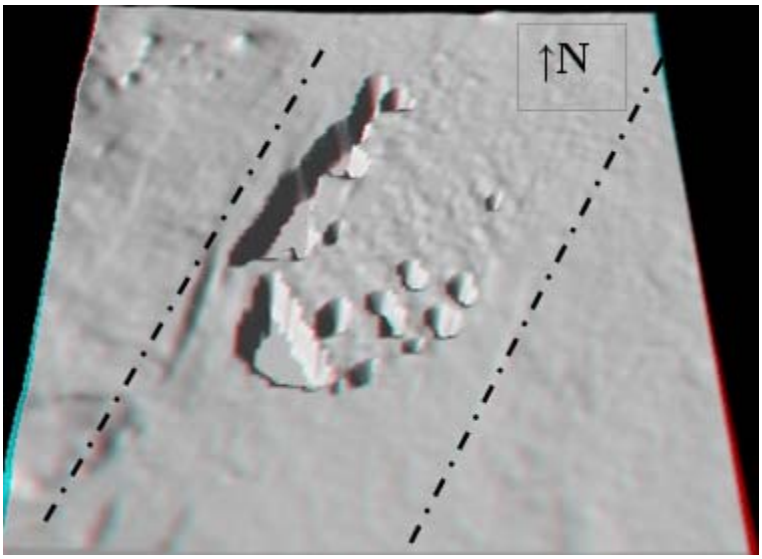


Fig.6.5 Lake Beseka Graben

Faults on the southeastern and western side of the lake face each other and have about 30^{o} dip angles (Fig.6.6). Likewise, open fissures along this zone

having NNE-SSW strike are observed immediately northwest and east of the lake and these also face each other (Fig.6.7). At both locations, the hanging wall is tilted away from the almost flat foot wall.

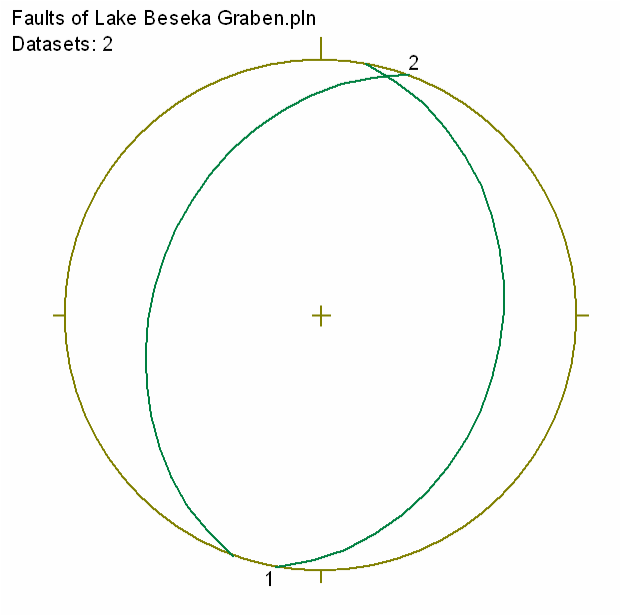


Fig.6.6 Great circles for the faults east (2) and west (1) of Lake Beseka graben

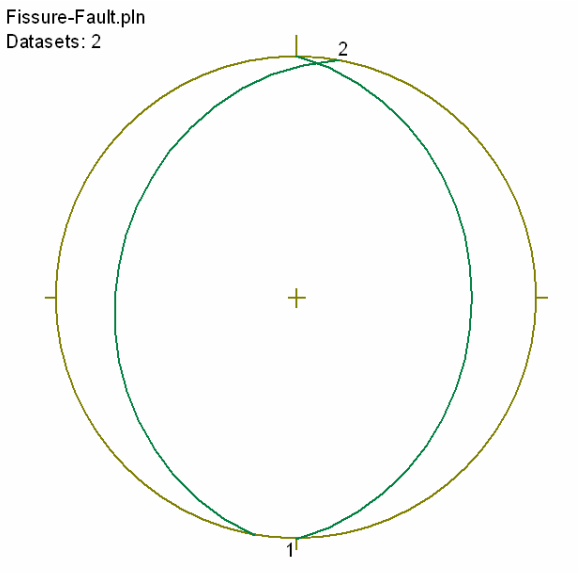


Fig.6.7 Great circles for the fissure/faults northeast (2) and northwest (1) of Lake Beseka graben

These fractures control the lake shape, which is expanded more along the orientation of the structures than the other side (Fig.6.8)

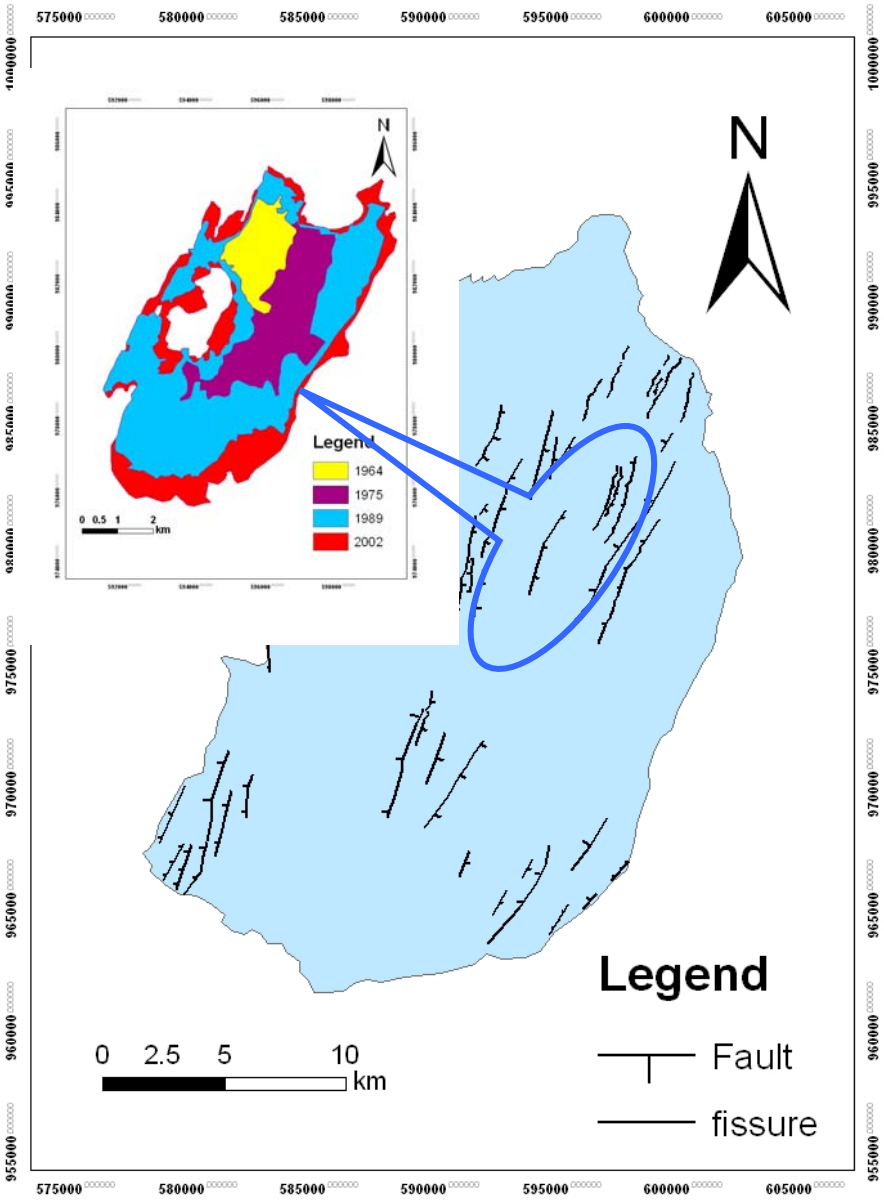


Fig. 6.8 Extend of Lake Beseka's expansion recorded from 1964 -2002 and relation with the orientation of structures.

6.6 Remedial Measure

Controlled amount of water is allowed to be blended in to Awash. The amount is determined from the environmental impact point of view (MWR, 1999). The quality of Awash water is used as yardstick such that the quality of water will be within the standard range for irrigation and drinking. The amount to be blended is 2% of Awash River run off. In figure 6.1, lake level seems to be constant for the last three years. This is due to the release of about 13 MCM and 17 MCM water in 2004 and 2005 (Table 6.4) to be blended with the Awash River.

Table 6.5 Amount of water blended in to Awash River from Lake Beseka

year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2004	V.water(m3)								1107247.32	993861.28	515189.52	175535.56	288408.72	3080242.4
	Time(hr)								1541.9	1354.5	790.2	380	375.4	4442
2005	V.water(m3)	806582.12	410478.46	742392.61	581707.75	595389.92	432700.78	1323784.36	2766048.14	3054077.74	1088333.9	1091960.6	805160.81	13698617.19
	Time(hr)	1259.8	731.3	1166.93	941.8	918.68	623.51	2055.4	3429.73	3908.39	1577.56	1519.44	1166.5	19299.04
2006	V.water(m3)	850516.5	1141494.98	1827682.28	1649735.9	1042371.848	1205104.13	1554804.592	3686203.728	2559471.74	720305.4	908344.68	825140.82	17971176.6
	Time(hr)	1069.9	1606.6	2489.8	1978.11	1557.18	1721.4	2029.28	4260.88	4082.5	1090.8	1334.8	1423.3	24644.55
2007	V.water(m3)	1215451.06	1068353.48	1081391.64										3365196.18
	Time(hr)	1437.5	1483.8	1573.6										4494.9

7. Conclusion and Recommendation

7.1 Conclusion

Lakes in the MER are generally located in three basins: Awash basin, central Main Ethiopian Rift and southern basin. Lake Beseka is one of the lakes found within the volcanically active rift floor at the northern end of the MER in the Awash basin.

The principal rock units in the study area are two types: volcanic rocks mainly basalts and ignimbrites of different ages and different mineralogical composition and sedimentary rocks of fluvio-lacustrine are located at the southern part of the study area (Abadir farm) and at the floor of Lake Beseka.

The structures of the study area are atypical faults and fissures. Profile across the fissure was done and field observation of faults shows that, they do not show the morphology of typical faults. The footwall remains flat and the concave hanging wall curves up to ward the fault plane at angle of 25-30°.

In the field, extension fractures appear as valleys and are several meters to some kilometers long and reach up to 9m wide and 16m deep. Generally 487 data of edge matching of the opening direction are taken and weighted according their horizontal displacement to gave the total opening direction 113.4°, which is in agreement with the overall E-W direction.

Recent faults seem to be affected by dyking. The fault/ fissure often alternate with or occur in combination with monoclininal folds. The observed structures appear to be generated in a process beginning with slight monoclinal folding and fissure formation which is followed by faulting when the displacement is growing.

The open structures have served as the eruption sites for some of monogenetic volcanoes (e.g., scoria cones) in the rift valley, with chains of scoria cones developed along the fracture of traces.

From aerial photograph interpretation, there are both right- and left-steeping segments of faults/fissures in the study area.

Interaction between fractures can be seen by the propagation one of the fractures and linkage with the other. This leads to the abandonment of the less propagated segment and to the development of a single continuous structure.

Lake Beseka is located within 5 to 6 kms wide local graben that is elongated in about NNE-SSW direction of fractures. These fractures control the lake shape, and the lake's expansion is more along the orientation of the structures than the other direction.

The curve of the lake level fluctuation shows an increment with time while climatic data doesn't show any anomalies. Therefore, climate probably has no any impact/influence on the fluctuation of lake level.

The elevation of water level of Lake Beseka is lower than the elevation of water table of wells in the Abadir farm as well as the elevation of Awash River. Hence, the flow of groundwater is towards the Lake Beseka.

The Abadir Farm- a sugar cane plantation south of Beseka-is mainly placed within the lake's catchment area, which is affected by ground cracks is also a cause to recharge the groundwater that affects the lake level to rise.

Generally, flow of ground water from south of the study area (Awash River and Abadir Farm) and tectonic hot springs as well as cold springs are the main

factors to the expansion of the lake come through the structures. Hence, structures play the main role in the expansion of the lake.

7.2 Recommendation

Even though most of the catchment's if almost flat, there is runoff from the slope of Mt. Fantale in the north and Hada Mountain in southwest of the study afforestation of the sloppy areas and contour bounding to reduce the amount of water added by runoff are recommended.

Any remedial measures taken for the lake should take in consideration the effect of the structures in the study area.

Detailed structural map of subsurface of the Abadir farm must be done because there are ground cracks in that area. Therefore, if there are more deep fractures which are covered by the thickness of the alluvial deposits, the Metehara Sugar Estate (MSE) must reduce the area or completely remove using Abadir farm.

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Annexes

Annex 1. Mean Monthly Maximum Temperature (°C)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1986	30.9	33.6	34.4	34.4	36.5	34.9	32.8	33.6	34.5	33.9	33.1	31.1	33.64
1987	30.3	33.6	33.2	33.6	33.7	36.9	36.4	33.3	35.7	34.7	33.1	31.8	33.86
1988	31	33.8	35.6	35.4	37.3	37	32.1	31.7	32.7	33.2	31.6	30.3	33.48
1989	29.7	30.7	33.4	31.1	35.8	36.1	32.7	32.13	33.8	34.2	32.4	30.1	32.68
1990	31.2	29.6	30.9	32.7	37	37.7	32.7	32.7	33.6	34.1	32.7	30.8	32.98
1991	32.6	32.2	34.6	34.1	35	36.7	32.3	31.3	33.9	33.8	31.8	31	33.28
1992	30.4	29.8	35.1	35.3	35.9	36.6	32.8	30.9	32.3	32.7	31.8	31.5	32.93
1993	30.2	28.9	34.9	33.5	33.6	36.8	33.1	33.1	34.2	33.9	32.7	31.4	33.03
1994	31.4	33	35.3	36.5	36.3	36.3	32.1	31.7	32.3	33.5	31	30.1	33.29
1995	31.1	33.4	32.4	34.8	36.9	37.7	33.2	32.5	33.5	34.3	33	32.5	33.78
1996	31.6	34.2	34.4	34.4	34.3	34.7	32.3	32.4	34.1	34.3	31.9	31.1	33.31
1997	31.3	32.1	35.3	34.1	36.8	36.3	33.1	33.3	36	31.6	30.3	30.4	33.38
1998	30.1	32.9	33.9	36.9	37.2	38.1	34.3	31.5	33.8	32.9	32.3	31	33.74
1999	32	34.8	32.8	36.3	37.2	36.8	31.9	32	33.7	31.9	31.3	30.4	33.43
2000	31.8	33.2	35.1	35.7	36.8	37.3	33.2	31.5	33.7	32.7	32	30.9	33.66
2001	30.1	32.8	33.7	35.9	37.8	36.4	33	31.3	34.9	34.8	32.7	31.7	33.76
2002	30.9	33.9	34.5	36.3	38.3	37.8	36.6	33.6	35.4	35.3	33.5	31.4	34.79
2003	31.3	34.8	35.6	35.8	38.1	36.8	32	31.6	32.6	35.2	33.1	30.9	33.98
2004	32.3	32.4	34.1	33.4	37.8	36.9	33	33.1	34.7	33.4	32.5	31.2	33.73
2005	31.6	35	33.7	35.8	34.5	36.5	32.2	33.4	35	34.9	33.2	31.7	33.96
2006	32.7	34	34.3	34.9	37.3	37.9	33.7	36.9	37.4	34.4	31.4	28.3	34.44
Ave.	**31.2**	**32.8**	**34.15**	**34.8**	**36.4**	**36.8**	**33.1**	**32.5**	**34.2**	**33.8**	**32.2**	**30.9**	**33.58**

Annex 2. Mean Monthly Minimum Temperature (°C)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1986	9.8	18.4	17.6	19.9	19.8	20.9	19.4	19.7	18.6	15.6	13.8	13.6	17.26
1987	13.6	15	19.3	17.2	18.7	22.9	22.1	20.2	20.2	17.8	12.7	13.6	17.78
1988	16.7	18.8	17.9	20	19.1	22.3	20.6	19.4	19.4	16.7	10	12.1	17.75
1989	13	15.9	17.8	18.7	16	19.7	19.9	19.54	19	15.2	14.5	18	17.27
1990	14.7	18.8	17.6	16.9	20.8	22.6	19.4	19.9	19.9	15.1	14.7	12.2	17.72
1991	16.4	18.2	19.5	18.7	19.2	21.7	20.4	19.8	19.5	15.7	12.8	13.6	17.96
1992	16.9	19.1	20.5	20.3	19.8	21.5	20.3	19.9	18.6	16.8	15	16.8	18.79
1993	13.4	16.3	15.5	19.7	19.4	21.9	20.3	20.3	20.6	18.3	14.3	12.4	17.70
1994	11.9	14.8	20.1	20.8	19.9	21.8	19.6	19.5	18.5	15.4	14.3	13	17.47
1995	15.97	17.4	18.6	19.7	19.8	21.1	21.2	20	19	17	13.2	17.1	18.34
1996	17.7	15.2	20.1	19.36	19.7	21.4	20.2	20.1	20	15.4	13.4	11.7	17.86
1997	16	12.8	19.1	19.5	19.5	20.6	20.1	20.4	20.1	18.7	18.6	14.4	18.32
1998	18.1	19.6	20.1	20.4	21.1	23.2	21.4	20	20.3	17.8	12.6	10	18.72
1999	14.1	14.5	18.9	18.7	19.5	21.1	18.9	19.2	19.6	17.6	12.6	12.1	17.23
2000	12.1	12.1	16.5	19.3	20.7	22.4	19.8	19.7	19.7	15.9	14.7	13	17.16
2001	13.4	14.8	18.9	18.2	21	22.3	20	20.1	18.6	17.9	13.9	14.3	17.78
2002	16.6	15.7	20.1	19.9	20.5	22.3	21.8	20	19.1	17.7	14.3	18	18.83
2003	16	17.1	19.2	20.5	19.2	21.2	20.4	19.6	20	16.3	16	14.3	18.32
2004	18.2	15.4	16.1	19.3	18.3	21.9	19.6	20.6	19.9	16.7	15.5	15.8	18.11
2005	15.4	15.6	19.3	18.6	20.2	21.7	20.3	20	20.8	16.2	14.5	10.5	17.76
2006	15.7	18.2	17.8	19.3	20.35	21.39	20.6	19.81	19.02	18.8	18.58	18.36	18.99
Ave.	**14.9**	**16.3**	**18.6**	**19.3**	**19.6**	**21.7**	**20.3**	**19.9**	**15.6**	**19.7**	**14.1**	**13.8**	**17.82**

Annex 3. Mean Monthly Air Temperature (°C)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1986	20.35	26	26	27.15	28.15	27.9	26.1	26.65	26.55	24.75	23.45	22.35	25.45
1987	21.95	24.3	26.25	25.4	26.2	29.9	29.25	26.75	27.95	26.25	22.9	22.7	25.82
1988	23.85	26.3	26.75	27.7	28.2	29.65	26.35	25.55	26.05	24.95	20.8	21.2	25.61
1989	21.35	23.3	25.6	24.9	25.9	27.9	26.3	26.01	26.4	24.7	23.45	24.05	24.99
1990	22.95	24.2	24.25	24.8	28.9	30.15	26.05	26.3	26.75	24.6	23.7	21.5	25.35
1991	24.5	25.2	27.05	26.4	27.1	29.2	26.35	25.55	26.7	24.75	22.3	22.3	25.62
1992	23.65	24.45	27.8	27.8	27.85	29.05	26.55	25.4	25.45	24.75	23.4	24.15	25.86
1993	21.8	22.6	25.2	26.6	26.5	29.35	26.7	26.7	27.4	26.1	23.5	21.9	25.36
1994	21.65	23.9	27.7	28.65	28.1	29.05	25.85	25.6	25.4	24.45	22.65	21.55	25.38
1995	23.53	25.4	25.5	27.25	28.35	29.8	27.2	26.25	26.25	25.65	23.1	24.8	26.09
1996	24.65	24.7	27.25	26.88	27	28.05	26.25	26.25	27.05	24.85	22.65	21.4	25.58
1997	23.65	22.45	27.2	26.8	28.15	28.45	26.6	26.85	28.05	25.15	24.45	22.4	25.85
1998	24.1	26.25	27	28.65	29.15	30.65	27.85	25.75	27.05	25.35	22.45	20.5	26.23
1999	23.05	24.65	25.85	27.5	28.35	28.95	25.4	25.6	26.65	24.75	21.95	21.25	25.33
2000	21.95	22.65	25.8	27.5	28.75	29.85	26.5	25.6	26.7	24.3	23.35	21.95	25.41
2001	21.75	23.8	26.3	27.5	29.4	29.35	26.5	25.7	26.75	26.35	23.3	23	25.81
2002	23.75	24.8	27.3	26.1	29.4	29.4	29.2	26.8	27.25	26.5	23.9	24.7	26.59
2003	23.65	25.95	27.4	28.15	28.65	29	29.4	25.6	26.3	25.75	24.55	22.6	26.42
2004	25.25	23.9	25.1	26.35	28.05	29.4	26.3	26.85	27.3	25.05	24	23.5	25.92
2005	23.5	25.3	26.5	27.2	27.35	29.1	26.25	26.7	27.9	25.55	23.85	21.1	25.86
2006	24.2	26.1	26.05	27.1	28.83	29.65	27.15	28.38	28.23	26.6	24.97	23.34	26.72
Ave	**23.09**	**24.58**	**26.37**	**26.97**	**28.01**	**29.23**	**26.86**	**26.23**	**26.86**	**25.29**	**23.27**	**22.48**	**25.77**

Annex 4. Mean Relative Humidity at 1800 LST

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	33	34	36	41	x	39	39	35	39	30	26	x
1987	34	28	42	40	40	34	30	41	38	26	27	30
1988	41	36	28	34	28	28	44	46	49	32	25	30
1989	34	41	45	52	35	39	49	46	50	34	35	48
1990	37	56	53	43	30	28	42	43	51	33	31	27
1991	31	40	38	37	45	26	45	51	45	31	29	32
1992	42	52	38	53	x	x	x	x	x	x	x	40
1993	48	52	30	45	44	29	38	43	43	40	30	29
1994	24	25	29	35	35	32	x	52	48	29	43	34
1995	30	35	47	44	36	32	44	48	44	36	36	45
1996	39	28	45	46	47	48	50	51	46	36	37	33
1997	42	35	38	48	39	47	49	47	44	57	52	41
1998	49	52	46	39	x	29	43	50	48	43	32	26
1999	30	20	39	36	36	33	48	46	46	48	32	33
2000	27	27	26	34	31	29	42	50	48	x	43	40
2001	43	41	41	37	37	34	42	51	42	30	26	34
2002	41	28	37	34	29	30	30	44	38	26	25	48
2003	40	31	29	39	27	30	44	55	51	30	31	33
2004	42	31	33	46	28	33	40	44	45	35	33	43
2005	39	30	45	37	47	33	47	53	44	27	27	26

Annex 5. Mean Relative Humidity at 1200 LST

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	40	47	40	40	x	46	44	44	39	30	33	x
1987	42	35	46	43	46	38	36	54	37	33	31	37
1988	51	46	36	40	27	33	53	54	48	35	31	39
1989	41	54	52	60	33	37	56	51	46	38	43	54
1990	46	68	55	48	35	33	53	51	47	30	35	34
1991	42	51	43	41	41	32	51	58	45	32	35	38
1992	55	61	45	54	x	x	x	x	x	x	x	43
1993	56	60	35	49	46	33	48	46	42	39	35	36
1994	33	32	38	38	33	43	x	59	52	34	45	43
1995	40	46	55	44	37	36	55	56	50	36	40	51
1996	49	38	50	52	50	54	60	57	46	37	39	38
1997	51	42	46	49	36	44	58	54	40	55	55	46
1998	49	64	60	39	x	29	43	50	48	43	32	52
1999	39	30	52	36	35	35	57	55	46	47	36	38
2000	36	37	34	34	34	38	52	57	49	x	46	47
2001	49	49	51	37	38	36	53	57	39	31	31	40
2002	49	37	46	36	31	33	39	51	41	28	29	55
2003	48	40	38	40	26	36	51	61	49	32	35	42
2004	53	40	35	52	31	35	48	52	43	38	39	46
2005	47	39	46	41	49	36	56	53	42	28	30	32

Annex 6. Mean Relative Humidity at 0600 LST

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	81	83	87	83	x	74	81	67	86	75	72	x
1987	77	71	85	85	81	67	69	82	76	73	72	75
1988	81	84	69	78	64	65	76	86	82	81	89	78
1989	34	41	45	52	35	39	49	46	50	34	35	84
1990	80	92	93	91	75	64	81	83	85	77	73	73
1991	78	82	81	86	84	64	80	84	84	80	77	81
1992	84	90	76	86	x	x	x	x	x	x	x	40
1993	83	93	80	86	87	69	81	80	81	85	80	82
1994	82	73	73	78	77	74		85	52	34	45	43
1995	80	81	91	87	80	73	79	84	86	77	78	87
1996	87	77	85	89	89	78	84	85	83	81	85	81
1997	85	79	79	85	78	83	85	83	81	92	92	86
1998	88	85	87	81	x	63	77	85	83	88	80	78
1999	78	70	84	73	72	69	85	88	83	92	84	81
2000	78	77	72	73	72	65	82	81	96		88	89
2001	83	84	86	81	81	69	82	84	86	77	74	78
2002	80	75	80	79	67	66	69	79	86	78	71	81
2003	82	74	73	77	74	76	79	82	83	78	75	83
2004	88	77	76	88	71	69	80	80	81	83	79	82
2005	86	83	86	83	86	74	82	83	79	74	78	83

Annex 7. Mean Monthly Sunshine hours

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	10.2	8.8	9.1	7.5	9.2	6.7	7.7	7.8	8.5	8.6	10.2	9.5
1987	9.6	9.1	7.5	8.9	8.2	8.3	8.9	7	8.7	9.1	9.7	9.7
1988	8.9	9.4	9.4	x	9.6	8.4	4.9		7.4	8	10.5	9.8
1989	8.7	8.6	8.4	7.2	9.8	9.3	6.4	x	4.9	8.7	9.6	
1990	9.4	6.4	8.3	8.6	9.9	9.5	7.4	6.9	7.8	9.2	9.8	9.7
1991	9.3	8.8	8.1	8.7	8.1	8.6	7	6.8	8.3	8.9	9.4	8.7
1992	6.8	x	9.3	8.4	9.2	8.6	7.1	5.6	7.6	8.8	8.9	8.6
1993	7.2	7.1	10.1	8.2	9.3	9.3	7.5	8.2	7.1	8.6	10	10
1994	10.2	9.7	8.8	8.4	9.2	8.1	7.1	7.4	8.1	9.6	8.5	9.7
1995	10.1	9.3	7.8	8.7	9.8	9.4	9.6		8.4	9.2	10.3	9.5
1996	9.2	10.4	8.4	9.1	x	x	x	x	8.1	9.5	9.4	10.1
1997	8.3	10.7	9.1	7.6	9.7	8.4	8.1	8	8.2	7.9	8.2	9.4
1998	6.9	x	8.5	9.9	9.4	9.5	7	7.3	7.7	8.7	10.3	10.5
1999	9.6	10.8	8.3	10.5	x	7.9	7.3	8.2	8.4	8.1	9.3	10.1
2000	10.2	10.3	9.9	8.4	x	9.9	x	x	x	x	10.4	9.7
2001	8.9	9.8	7.4	9.3	9.1	8.9	x	6.6	x	8.6	10.5	x
2002	x	x	x	x	x	x	x	x	x	x	x	x
2003	9	9.3	9.8	7.9	9.1	8.5	6.8	6.5	7.8	9.6	9.7	9.3
2004	8.9	10	8.6	8.3	9.9	8.5	7.9	8.1	7.6	8.4	9.8	8.6
2005	8.5	10.4	9.2	8.6	8.2	9.1	6.5	6.5	7.5	9.6	9.4	10.4
Ave.	**8.94**	**9.35**	**8.74**	**8.57**	**9.23**	**8.72**	**7.33**	**7.21**	**7.77**	**8.84**	**9.68**	**9.61**

Annex 8. Mean Monthly Wind Speed at 2m in m/s

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	1.7	2.3	1.9	2.4	2.2	3	2.7	2.5	2	2	2.3	2.5
1987	2.4	2.2	2.1	1.8	2.1	2.5	2.6	2.3	1.9	2.1	1.9	2.1
1988	2	2.1	2.2	2	2	2.8	3	1.9	1.4	1.5	1.6	1.9
1989	2	2.3	2	1.5	1.6	2.4	2.89	2.6	1.7	1.6	2.1	2.2
1990	2.3	1.8	1.6	1.4	1.8	2.6	2.6	2.4	1.7	1.6	1.9	1.8
1991	2.2	2	2	1.6	1.6	2.2	2.9	2	1.6	1.6	1.8	1.7
1992	2	2.1	2.4	1.9	1.5	2	2.4	2	1.5	1.3	1.5	1.8
1993	2.1	1.8	1.6	1.7	1.4	2	2.5	2.2	2	1.7	1.7	1.7
1994	1.6	2	2.2	1.8	1.8	2.6	x	1.7	1.4	1.5	1.5	1.7
1995	1.5	1.8	1.5	1.4	1.6	1.8	2.5	2.1	1.4	1.7	1.4	1.7
1996	1.7	1.7	1.8	1.4	1.4	2.4	2.2	2	1.5	1.4	1.3	1.3
1997	1.5	1.7	1.7	1.4	1.6	1.8	2	1.9	1.6	1.6	1.4	1.4
1998	1.6	1.7	1.6	1.6	x	2.3	2.3	1.8	1.3	1.1	1.5	1.4
1999	1.6	1.7	1.5	1.7	1.6	1.8	1.9	1.5	1.3	1.1	1.3	1.5
2000	1.6	1.7	1.9	1.7	1.5	2.2	2.2	1.8	1.3	1	1.3	1.3
2001	1.5	1.6	1.8	1.3	1.6	2.1	1.8	1.4	1.2	1.5	1.6	1.6
2002	1.8	2.3	1.6	1.7	1.5	2	2.1	1.9	1.3	1.5	1.5	1.8
2003	1.5	1.6	1.9	1.6	1.6	2	2.3	1.5	1.3	1.4	1.6	1.4
2004	1.5	1.7	1.4	1.1	1.2	1.8	3	1.7	1.3	1.4	1.5	1.6
2005	1.4	1.5	1.6	1.6	1.2	1.7	1.7	1.4	1.4	1.3	1.3	1.3
Ave.	**1.78**	**1.88**	**1.82**	**1.63**	**1.62**	**2.2**	**2.4**	**1.93**	**1.51**	**1.50**	**1.6**	**1.69**

Annex 9. Mean Monthly Rain fall (mm)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	sum
1986	0	41.6	43.2	27.8	14	55	64.3	67.1	51.1	4	0	7	375.1
1987	0	24.1	71.6	78.2	74.8	0	53.6	110	8	2.8	0	0	423.5
1988	13.6	29.6	11.9	23.7	7.8	12.1	157	136	104.3	18	0	11.9	525.5
1989	0	28	105	120	7.5	82.1	48.7	92.7	28.2	5.6	0	12.7	530.2
1990	0.5	221	58.1	62.9	1.8	0.9	146	76.9	82.4	2.1	0	0	652.8
1991	0	54.3	56.1	46.7	53.3	15.4	137	132	49.6	11.7	0	0	556.1
1992	25.8	50.3	0	75.8	16.8	62.4	90	158	62.2	49.6	5.7	2.3	598.5
1993	43.8	59.5	0	140	57.3	23.7	101	104	41.6	21.9	0	56.9	649.4
1994	0	0	6.5	21.4	55.4	38.6	248	132	39.6	0.1	12.7	1.9	556.2
1995	0	43.5	81.9	44	10.5	28.5	47.3	144	57.7	0.5	0	0	458
1996	27.6	0	97.3	35.1	80.5	26.5	205	101	52.6	1.6	7.5	0	634.3
1997	29.7	0	12.6	44.3	11.5	35.1	140	53.8	20.4	112.4	14.6	0	474.1
1998	0.8	18.1	76.6	34.2	14.9	4.7	78.2	136	54	78	0	0	495.1
1999	0	0	73.6	6.2	15.9	16.7	136	151	16.4	76.2	2.2	0	494.5
2000	0	0	1.8	20.7	36.9	29.6	136	153	46.8	47.3	11.9	9.4	493
2001	0	13.6	92.7	20.4	12.7	20.2	155	82.8	15.3	7.1	0	1.6	421.2
2002	2.6	0	73.3	19.3	9.3	10.2	43	80.8	16.8	0	0	21.2	276.5
2003	4.6	17.5	33.6	13.7	0	29.5	119	186	31	0	3.2	15.7	453.7
2004	35.1	3.2	80.6	142	0	21.2	85.3	124	39.3	15.9	4.5	0	551.4
2005	19.3	0	48	51.6	75.5	35.7	146	138	21.6	0	5.2	0	541.7
2006	0.9	29.3	33.9	33.4	10	26.8	142	x	x	37.50	x	x	313.9
Ave.	**9.73**	**30.2**	**50.4**	**50.5**	**27**	**27.38**	**118**	**118**	**41.95**	**23.44**	**3.375**	**7.03**	**498.79**

Annex 10.Mean Monthly Pitche Evaporation (mm)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	sum
1986	341	285.6	334.8	342	393.7	285	232.5	254.2	270	390.6	453	337.9	3920.3
1987	390.6	414.4	306.9	294	294.5	363	347.2	269.7	336	446.4	429	319.3	4211
1988	229.4	266	372	270	523.9	354	260.4	161.2	156	263.5	291	260.4	3407.8
1989	288.3	243.6	279	150	306.9	330	233.6	183.9	225	306.9	369	244.9	3161.12
1990	322.4	137.2	189.1	231	375.1	435	269.7	251.1	225	344.1	327	303.8	3410.5
1991	313.1	218.4	272.8	240	279	312	244.9	161.2	183	297.6	297	263.5	3082.5
1992	220.1	165.2	334.8	207	285.2	321	260.4	161.2	177	238.7	252	235.6	2858.2
1993	210.8	148.4	331.7	228	204.6	315	254.2	223.2	231	263.5	288	282.1	2980.5
1994	275.9	266	294.5	282	313.1	330	186	173.6	174	291.4	222	235.6	3044.1
1995	260.4	246.4	207.7	213	337.9	333	269.7	201.5	183	341	291	254.2	3138.8
1996	220.1	277.2	229.4	216	226.3	276	226.3	192.2	198	279	234	306.9	2881.4
1997	220.1	271.6	279	228	313.1	276	204.6	179.8	213	167.4	123	164.3	2639.9
1998	136.4	142.8	182.9	258	297.6	297	266.6	151.9	141	151.9	204	210.8	2440.9
1999	248	274.4	182.9	279	279	225	170.5	136.4	150	167.4	186	235.6	2534.2
2000	257.3	240.8	300.7	255	244.9	264	223.2	155	147	136.4	168	176.7	2569
2001	161.2	198.8	173.6	207	244.9	243	164.3	133.3	156	244.9	237	210.8	2374.8
2002	170.5	221.2	201.5	249	282.1	234	257.3	207.7	231	269.7	270.3	248.62	2842.92
2003	244.2	236.5	261.2	240.8	297.6	285	198.4	130.2	129	251.1	228	164.3	2666.38
2004	148.8	204.4	235.6	156	272.8	267	244.9	204.6	201	248	273	238.7	2694.8
2005	226.3	271.6	254.2	270	179.8	255	158.1	145.7	198	294.5	261	275.9	2790.1
Ave.	**244.25**	**236.53**	**261.22**	**240.79**	**297.6**	**300**	**233.64**	**183.88**	**196.2**	**269.7**	**270.17**	**248.50**	**2982.46**

Annex 11. Gauge height of Lake Beseka (m)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1976	0.47	x	0.66	x	x	x	0.47	0.66	0.81	0.83	0.88	0.91
1977	0.99	1.07	1.04	1.07	1.21	1.27	1.33	1.44	1.45	1.50	1.55	1.48
1978	1.44	1.44	1.68	1.60	1.54	1.46	1.48	1.56	1.58	1.60	1.55	1.56
1979	1.61	1.67	1.61	1.55	1.49	1.46	1.48	1.55	1.55	1.50	1.44	1.40
1980	1.40	1.39	1.35	1.30	1.26	1.20	1.24	1.40	1.48	1.42	1.34	1.30
1981	1.29	1.27	1.32	1.49	1.48	1.37	1.35	1.64	1.76	1.71	1.62	1.55
1982	1.66	1.70	1.73	1.76	1.71	1.67	1.65	1.94	2.03	2.03	1.98	1.95
1983	1.92	1.94	1.95	1.96	1.96	2.00	1.97	2.04	2.08	2.08	2.05	2.02
1984	2.02	2.01	1.99	1.94	1.90	1.96	1.99	2.00	2.02	1.99	1.95	1.91
1985	1.9	1.76	1.85	1.9	1.99	1.96	2.02	2.26	2.33	2.26	2.17	2.14
1986	2.12	2.13	2.18	2.14	2.11	2.08	2.18	2.2	2.18	2.14	2.08	2.05
1987	2.04	2.04	2.07	2.13	2.11	2.13	2.1	2.19	2.253	2.18	2.13	2.11
1988	2.13	2.13	2.11	2.09	2.06	2.03	2.07	2.37	2.45	2.37	2.28	2.26
1989	2.24	2.26	2.27	2.44	2.44	2.41	2.45	2.51	2.54	2.48	2.45	2.39
1990	2.39	2.64	2.87	2.82	2.78	2.66	2.65	2.77	2.76	2.72	2.67	2.63
1991	2.62	2.64	2.66	2.79	2.75	2.74	2.78	2.90	2.96	2.91	2.85	2.82
1992	2.82	2.96	2.93	2.81	2.92	2.89	2.92	3.00	3.03	3.03	3.02	3.01
1993	3.01	3.04	3.04	3.04	3.12	3.13	3.11	3.18	3.18	3.19	3.17	3.16
1994	3.19	3.18	3.17	3.17	3.18	3.17	3.27	3.39	3.48	3.45	3.37	3.36
1995	3.34	3.38	3.5	3.54	3.56	3.52	3.52	3.63	3.75	3.69	3.55	3.50
1996	3.54	3.53	3.53	3.62	3.63	3.75	3.77	3.8	3.82	3.84	3.86	3.89
1997	3.91	3.94	3.97	3.99	4.02	4.05	4.07	4.1	4.13	4.15	4.18	4.20
1998	4.24	4.27	4.3	4.33	4.36	4.38	4.42	4.45	4.53	4.55	4.54	4.52
1999	x	x	x	x	x	x	x	x	x	x	x	x
2000	x	x	x	x	x	x	x	x	x	x	x	x
2001	x	x	x	x	x	x	x	x	x	x	x	x
2002	x	x	x	x	x	x	x	x	x	x	x	x
2003	x	x	x	x	x	5.14	5.19	5.41	5.6	5.54	5.54	5.43
2004	5.45	5.49	5.45	5.62	5.63	5.62	5.59	5.72	5.7	5.64	5.59	5.55
2005	5.55	5.59	5.58	5.57	5.61	5.61	5.66	5.8	5.78	5.66	5.59	5.55
2006	5.55	5.57	5.61	5.65	5.6	5.54	5.57	5.7	5.51	5.65	5.65	5.59
2007	5.68	5.69										

Annex 12. Location matching edge of the extensional fractures and their measured values

No.	Easting	Northing	Opening Direction	dip angle	dip to	vertical offset(cm)	horizontal offset(cm)	total [cm]
1	598778	986428	153	0		0	100	100
2	598752	986417	98	66	E	110	49	120
3	598730	986382	87	51	E	93	76	120
4	598679	986330	86	0		0	85	85
5	598669	986316	78	30		32.5	56	65
6	598682	986290	113	0		0	55	55
7	598665	986199	95	60		43	25	50
8	598666	986155	92	0		0	35	35
9	598664	986153	116	0		0	50	50
10	598651	986132	122	0		0	50	50
11	598817	986500	92	33	E	160	242	290
12	598816	986508	132	19	E	50	147	155
13	598830	986525	124	24	E	195	439	480
14	598816	986528	133	62	E	159	85	180
15	598839	986550	118	26	E	125	262	290
16	598840	986543	121	21	W	30	79	85
17	598877	986593	106	25	W	85	181	200
18	598892	986615	116	11	W	40	206	210
19	598915	986617	133	6	E	20	179	180
20	598933	986667	122	11	W	45	226	230
21	598919	986679	125	30	E	110	191	220
22	598951	986686	121	0		0	80	80
23	598985	986750	127	0		0	160	160
24	598983	986775	121	9	E	15	99	100
25	599016	986814	97	44	W	42	43	60
26	599009	986854	140	0		0	58	58
27	599179	987102	137	0		0	50	50
28	599188	987113	136	0		0	33	33
29	599211	987134	131	0		0	45	45
30	599219	987138	125	0		0	45	45
31	599237	987136	106	21	E	32	83	89
32	599245	987132	131	0		0	90	90
33	599253	987132	110	7	E	7	60	60
34	599260	987131	130	6	E	5	52	52
35	599261	987161	117	0		0	40	40
36	599301	987240	128	10	E	10	54	55
37	599306	987240	105	0		0	58	58
38	599310	987244	108	0		0	80	80
39	599322	987275	118	7	E	10	87	88
40	599336	987297	121	27	E	75	150	168
41	599344	987315	117	5	E	10	110	110
42	599046	987613	131	6	E	10	89	90
43	599061	987629	138	15	E	40	145	150

44	599062	987633	122	0		0	104	104
45	599045	987616	131	0		0	138	138
46	599017	987597	115	8	E	20	144	145
47	599016	987578	115	0		0	55	55
48	599009	987573	127	11	E	10	51	52
49	599060	986509	104	0		0	15	15
50	599049	986481	109	10	W	20	113	115
51	599044	986471	107	0		0	110	110
52	599038	986460	112	0		0	160	160
53	599029	986445	108	0		0	160	160
54	599021	986436	121	0		0	70	70
55	599017	986338	110	0		0	155	155
56	599017	986404	107	0		0	75	75
57	599000	986380	108	0		0	135	135
58	598992	986344	108	5	W	20	209	210
59	598970	986315	109	0		0	180	180
60	598952	986277	120	11	W	50	255	260
61	598947	986252	113	6	W	20	189	190
62	598941	986229	113	18	W	76	233	245
63	598926	986176	103	0		0	125	125
64	598890	986133	100	14	W	40	165	170
65	598740.6	985404.7	118	0		0	205	205
66	598744.5	985412.7	119	0		0	220	220
67	598750.8	985427.7	108	0		0	210	210
68	598770.1	985462.5	115	0		0	205	205
69	598763.2	985447	111	0		0	215	215
70	598767.9	985458.9	115	0		0	210	210
71	598775.2	985467.2	118	0		0	172	172
72	598781.9	985476.7	127	0		0	30	30
73	598786.7	985494.4	110	0		0	180	180
74	598789.8	985498.5	108	0		0	172	172
75	598796.1	985523.4	102	0		0	183	183
76	598801.4	985529.3	98	0		0	170	170
77	598793.3	985531.4	115	0		0	360	360
78	598787.8	985521.2	114	0		0	310	310
79	598786.3	985512.1	114	3	W	20	379	380
80	598780	985503	113	6	W	30	288	290
81	598769.2	985472.3	109	0		0	320	320
82	598762.6	985465.4	113	0		0	300	300
83	598750.2	985454.7	116	24	W	134	301	330
84	598743.6	985443.6	119	25	W	139	299	330
85	598737.6	985427.2	117	23		140	325	354
86	598802.8	985564.5	117	52	E	539	416	681
87	598816.5	985607.8	96	6	W	16.3	155	156
88	598816.3	985594.4	105	24	E	246	565	617
89	598818.5	985611	125	0		0	110	110
90	598820	985620.4	122	0		0	120	120
91	598825.9	985607	110	0		0	255	255

92	598838.2	985609.5	112	33	W	82	126	150
93	598833	985605.2	114	37	W	72	96	120
94	598816.1	985572.8	119	0		0	117	118
95	598803.2	985571.1	119	42	E	478	538	720
96	598807.7	985548.9	102	0		0	145	145
97	598810.1	985554.9	104	0		0	115	115
98	598815.5	985568.4	110	0		0	100	100
99	598851.5	985612.9	127	0		0	50	50
100	598862.7	985621	120	0		0	42	42
101	598864.4	985629.1	128	0		0	40	40
102	598852.5	985624.1	124	0		0	200	200
103	598844.4	985617	123	10	W	30	167	170
104	598860.8	985628	132	27	E	115	227	255
105	598846.5	985634.8	144	0		0	70	70
106	598844.5	985632.1	134	0		0	60	60
107	598840.8	985626.3	136	0		0	120	120
108	598833.2	985630.4	136	0		0	70	70
109	598841.1	985639.8	128	0		0	55	55
110	598821.1	985623.6	118	0		0	80	80
111	598829	985634	101	12	W	21	98	100
112	598882	985685	116	8	E	50	357	360
113	598900	985703	123	20	W	116	319	340
114	598907	985713	112	26	W	158	324	360
115	598912	985719	118	14	W	80	320	330
116	598936	985741	133	19	W	62	180	190
117	598966	985756	128	12	W	80	371	380
118	598993	985783	145	0		0	410	410
119	599013	985806	124	24	W	199	448	490
120	599060	985855	120	3	W	18	350	350
121	599067	985866	121	6		40	398	400
122	599084	985888	113	11	W	65	334	340
123	599098	985921	120	2	W	10	270	270
124	599100	985921	112	0		0	35	35
125	599100	985928	107	0		0	103	103
126	599112	985953	118	0		0	150	150
127	599126	985962	119	0		0	155	155
128	599131	985961	123	0		0	130	130
129	599169	986034	119	2	W	10	370	370
130	599183	986047	113	0		0	390	390
131	599186	986070	115	60	W	299	173	345
132	599221	986146	111	0		0	310	310
133	599224	986160	114	0		0	310	310
134	599237	986178	110	0		0	335	335
135	599240	986197	112	0		0	320	320
136	599245	986248	113	0		0	135	135
137	599265	986245	105	0		0	60	60
138	599267	986244	107	0		0	50	50
139	599277	986248	102	0		0	115	115

140	599724	987042	138	0		0	50	50
141	599719	987026	156	0		0	40	40
142	599679	987024	124	0		0	70	70
143	599668	986993	127	0		0	105	105
144	599663	986970	129	0		0	80	80
145	599649	986948	142	0		0	75	75
146	599595	986963	127	0		0	60	60
147	599560	986957	118	21	E	22	56	60
148	599525	986927	124	0		0	205	205
149	599567	986946	61	51	W	47	38	60
150	599587	986932	138	9	W	20	123	125
151	599520	986890	133	0		0	160	160
152	599504	986868	103	40	W	74	88	115
153	599487	986868	117	10	E	50	296	300
154	599460	986838	109	11	W	60	314	320
155	599448	986808	118	23	W	70	166	180
156	599449	986805	108	0		0	50	50
157	599418	986768	91	40	W	330	400	519
158	599396	986655	95	17	W	150	500	522
159	599350	986584	108	0		0	85	85
160	599330	986519	103	0		0	100	100
161	599324	986518	96	0		0	50	50
162	599318	986525	112	0		0	45	45
163	599316	986519	117	14	W	20	77	80
164	599337	986467	85	12	E	35	161	165
165	599324	986461	107	15	W	60	227	235
166	599324	986443	110	0		0	170	170
167	599311	986399	116	0		0	60	60
168	599309	986402	84	0		0	30	30
169	599318	986380	112	0		0	70	70
170	599317	986349	102	24	W	40	92	100
171	599306	986357	88	0		0	40	40
172	599304	986330	100	20	W	20	55	59
173	599280	986264	101	0		0	115	115
174	599270	986279	108	0		0	90	90
175	599265	986272	112	5	W	10	127	127
176	598703	985344.3	100	45	W	457	461	649
177	598696	985321.6	110	49	W	574	507	766
178	598691.6	985316.2	116	46	W	522	510	729
179	598682.2	985284.9	115	28	W	359	672	762
180	596092	985787	120	34	E	69	102	123
181	596089	985775	130	0		0	23	23
182	596087	985775	120	18	E	53	162	170
183	596078	985777	66	0		0	33	33
184	596090	985769	106	0		0	220	220
185	596080	985760	105	14	E	72	289	298
186	596077	985759	94	26	E	13	27	30
187	596082	985742	113	10	E	64	360	366

188	596073	985728	110	22	E	129	319	344
189	596068	985712	90	10	E	28	158	160
190	596060	985697	92	0		0	55	55
191	596066	985695	94	0		0	100	100
192	596062	985689	80	0		0	100	100
193	596068	985681	96	0		0	90	90
194	596070	985676	132	0		0	110	110
195	596069	985676	116	0		0	200	200
196	596066	985673	121	0		0	180	180
197	596060	985664	100	0		0	160	160
198	596066	985667	75	0		0	200	200
199	596059	985661	113	0		0	158	158
200	596062	985650	128	0		0	176	176
201	596061	985643	98	0		0	90	90
202	595866.8	984802	164	0		0	130	130
203	595874.6	984811.1	142	0		0	240	240
204	595877.6	984811.9	144	10	E	44	251	255
205	595899	984846.6	144	0		0	351	351
206	595907.6	984857	142	10	E	52	295	300
207	595915.4	984863.1	140	0		0	260	260
208	595920.2	984879.8	90	47	E	182	169	248
209	595917.8	984886.1	83	0		0	70	70
210	595918.9	984919.6	118	0		0	140	140
211	595919.2	984932.1	102	0		0	75	75
212	595920.2	984936.8	104	0		0	80	80
213	595920.9	984949.7	99	0		0	75	75
214	595923.6	984877.6	160	0		0	130	130
215	595925.1	984878.5	140	0		0	130	130
216	595922.2	984875.5	110	0		0	113	113
217	595863.7	984804.4	138	0		0	70	70
218	595899	984891.9	146	0		0	90	90
219	595949.7	985030.6	101	19	W	289	856	903
220	595950.7	985032.4	106	15	W	234	847	878
221	595952.5	985034.9	103	14	W	204	845	869
222	596027.5	985309.6	101	38	E	498	633	805
223	596027.9	985314.3	103	39	E	463	577	740
224	596038.5	985355.6	108	44	E	580	609	841
225	596032	985358.4	84	0		0	60	60
226	596033.4	985370.2	99	0		0	70	70
227	596036.2	985385.3	90	0		0	80	80
228	596038.2	985393.4	91	0		0	154	154
229	596039.1	985405.2	100	0		0	230	230
230	596045.7	985422.7	91	0		0	220	220
231	596039	985420.6	128	0		0	60	60
232	596041.1	985428.5	101	0		0	60	60
233	596050.7	985474	80	7	W	61	513	517
234	596052.3	985497.4	80	0		0	691	691
235	596040.9	985530.5	85	0		0	190	190

236	596038.1	985517.6	76	0		0	50	50
237	596039	985526.4	98	0		0	60	60
238	596061.6	985489	93	18	E	11	33	35
239	596060.3	985495.5	60	30	E	19	32	37
240	596060.6	985501	83	0		0	38	38
241	596053.9	985527.5	62	10	E	31	177	180
242	596052.6	985539.3	76	10	E	14	79	80
243	596050	985583.1	102	47	E	418	394	574
244	596051.7	985588.2	99	49	E	454	400	605
245	596057.5	985613.3	92	52	E	537	422	683
246	596065.1	985631.3	107	51	E	491	394	629
247	596070.6	985652.2	104	23	E	231	543	591
248	596081.7	985663.5	95	0		0	85	85
249	596074.5	985645.1	74	0		0	22	22
250	596071.3	985627.6	93	0		0	50	50
251	596066.5	985603	56	0		0	50	50
252	596067.8	985608.8	140	0		0	110	110
253	596043.8	985555.6	98	0		0	50	50
254	596045.4	985564.5	95	0		0	70	70
255	596048.4	985568.2	92	0		0	65	65
256	596047.7	985569.6	94	0		0	61	61
257	596045.4	985569.8	78	0		0	68	68
258	596054.8	985628.5	102	0		0	65	65
259	596059.7	985645.9	98	54	E	132.3	96	164
260	596053.5	985621.2	96	0		0	88	88
261	596049.3	985616.7	98	0		0	65	65
262	596061.4	985659.6	92	18	E	39.7	126	132
263	596084.5	985704.6	110	0		0	49	49
264	596064.3	985672.4	117	0		0	236	236
265	596063.1	985677.6	101	13	E	60.7	271	278
266	596067.8	985692.8	86	29	W	91.8	169	192
267	596060	985681.4	99	26	E	46.4	95	106
268	597078	986357	120	0		0	80	80
269	597072	986356	130	0		0	50	50
270	597059	986317	114	0		0	160	160
271	597024	986067	106	0		0	215	215
272	597012	986045	101	0		0	250	250
273	597033	986060	130	0		0	300	300
274	597018	986035	125	35	E	283	404	493
275	597002	986005	92	0		0	80	80
276	596962	985930	99	0		0	50	50
277	596962	985909	96	20	E	140	385	410
278	596959	985893	75	0		0	70	70
279	596954	985888	94	0		0	105	105
280	596949	985876	94	0		0	70	70
281	596955	985884	102	0		0	65	65
282	596959	985878	111	12	E	96	450	460
283	596953	985890	91	20	E	113	310	330

284	596933	985821	110	0		0	200	200
285	596927	985809	128	0		0	190	190
286	596946	985829	97	0		0	70	70
287	596936	985815	135	0		0	90	90
288	596933	985807	139	0		0	93	93
289	596970	985791	121	9		58	365	370
290	596899	985766	117	20		109	301	320
291	596893	985761	121	21		108	280	300
292	596937	985794	154	27		86	169	190
293	596954	985839	137	0		0	55	55
294	596970	985896	107	0		0	80	80
295	600146	985517	120	0		0	353	353
296	600116	985552	96	0		0	254	254
297	600140	985741	134	0		0	24	24
298	600149	985759	76	0		0	27	27
299	600152	985726	114	0		0	65	65
300	600157	985787	100	0		0	92	92
301	600159	985796	91	0		0	93	93
302	600162	985816	117	0		0	75	75
303	600175	985831	103	0		0	83	83
304	600167	985870	105	0		0	60	60
305	600163	985885	110	0		0	73	73
306	600167	985892	123	26	W	53	108	120
307	600193	985938	130	0		0	15	15
308	600202	985953	74	0		0	77	77
309	600212	985987	92	0		0	110	110
310	600225	986029	89	0		0	50	50
311	600228	986039	92	0		0	90	90
312	600223	986046	70	0		0	55	55
313	600218	986036	128	0		0	55	55
314	600225	986066	99	0		0	82	82
315	600231	986074	96	0		0	80	80
316	600230	986100	112	46	W	14	14	20
317	600215	986078	101	50	E	29	24	38
318	600255	986137	90	38	E	70	90	114
319	600255	986153	117	0		0	88	88
320	600257	986158	127	0		0	80	80
321	600253	986156	131	0		0	37	37
322	600265	986182	125	0		0	120	120
323	600273	986183	125	0		0	60	60
324	600274	986206	95	20	W	50	135	144
325	600280	986271	83	30	W	61	106	122
326	600278	986278	93	25	W	34	73	80
327	600282	986308	108	7	W	28	228	230
328	600286	986320	104	10	W	30	167	170
329	600294	986483	106	0		0	40	40
330	600325	986504	103	0		0	130	130
331	600331	986513	89	46	W	100	98	140

332	600331	986527	81	0		0	100	100
333	600335	986570	111	0		0	120	120
334	600354	986610	115	0		0	220	220
335	600385	986658	119	0		0	160	160
336	600398	986678	114	0		0	110	110
337	598812	985859	115	0		0	80	80
338	598811	985875	107	0		0	75	75
339	598824	985888	118	0		0	65	65
340	598823	985890	109	0		0	45	45
341	598837	985914	106	0		0	55	55
342	598874	985946	114	0		0	85	85
343	598889	985961	107	0		0	28	28
344	598897	985980	113	0		0	20	20
345	598873	985966	92	0		0	100	100
346	598883	985986	97	0		0	70	70
347	598887	985999	93	0		0	45	45
348	598889	986033	90	0		0	75	75
349	598885	986048	92	0		0	55	55
350	598876	986061	109	0		0	70	70
351	598870	986045	100	0		0	50	50
352	598863	986033	112	0		0	80	80
353	598780	985889	107	0		0	30	30
354	598798	985915	96	0		0	45	45
355	598826	985948	113	0		0	54	54
356	598814	985968	123	0		0	40	40
357	598841	985990	110	0		0	70	70
358	598848	985998	115	0		0	65	65
359	598866	986020	98	0		0	60	60
360	598875	986033	95	0		0	55	55
361	598864	986035	110	0		0	70	70
362	598856	986030	107	0		0	60	60
363	598859	986052	122	51	W	85	70	110
364	598871	986065	123	25	W	40	86	95
365	598885	986086	111	36	W	140	195	240
366	598892	986102	112	23	W	96	226	245
367	598917	986141	91	19	W	45	133	140
368	598915	986160	129	36	W	70	97	120
369	598905	986150	123	24	W	53	119	130
370	598898	986133	137	17	W	30	95	100
371	598899	986127	136	19	W	10	28	30
372	596090.3	985719	139	12	E	10	49	50
373	596096.2	985725.5	150	10	E	20	115	117
374	596069.2	985718.2	95	23	W	173.9	403	439
375	596069.5	985724.7	100	0		0	399	400
376	596071.1	985730.7	106	0		0	407	407
377	596085.7	985765.9	102	20	E	137.1	379	403
378	596089.5	985784.1	131	16	E	46.4	161	168
379	596091.8	985795	136	44	E	81.9	85	118

380	596077.8	985785.1	89	9	W	6.3	41	41
381	596079.5	985775.6	87	17	E	19.6	63	66
382	596124.4	985806.1	154	10	E	10	54	55
383	596125.7	985807.1	163	0		0	68	68
384	596123.1	985783.4	130	0		0	57	57
385	596136.7	985794.4	131	0		0	55	55
386	596156.4	985807.5	132	0		0	140	140
387	596165.5	985820.3	140	0		0	80	80
388	596175.7	985829.7	146	0		0	110	110
389	596164.8	985828.2	146	0		0	160	160
390	596160.7	985825.1	143	0		0	160	160
391	596146.6	985815.5	135	0		0	20	20
392	596143.2	985819.5	144	0		0	90	90
393	596154.9	985823.5	125	0		0	35	35
394	596150.5	985822.9	135	0		0	24	24
395	596200.9	985854.7	143	13	E	83.9	372	381
396	596217.7	985872.2	142	0		0	380	381
397	596215.7	985879.9	154	0		0	65	65
398	596209.5	985873.6	151	0		0	70	70
399	596196.1	985869.9	137	0		0	85	85
400	596242.4	985893	144	16	W	110.1	385	400
401	596259.1	985901.7	132	0		0	270	270
402	596251.8	985903.4	125	0		0	50	50
403	596248.3	985904.8	136	0		0	43	43
404	596248.8	985895.3	117	0		0	70	70
405	596273.4	985919.1	114	0		0	260	260
406	596281.6	985936.2	126	0		0	330	330
407	596298.2	985961.4	118	0		0	350	350
408	596316.8	986007.9	115	0		0	230	230
409	596332.9	986036	122	0		0	270	270
410	596313	986013.2	108	0		0	100	100
411	596305.6	986003	119	0		0	75	75
412	596257.1	985922.3	119	0		0	40	40
413	596262.8	985896.6	165	0		0	55	55
414	596285.8	985911.4	120	0		0	50	50
415	596289.1	985914.5	121	0		0	140	140
416	596278.5	985910.2	148	0		0	35	35
417	596337.8	986014.4	117	0		0	90	90
418	596251.3	985893.1	150	13	E	96	414	425
419	596416.1	986177.2	119	25	E	55	118	130
420	596343	986071	113	28	E	77	146	165
421	596419.6	986182.8	122	45	E	106	106	150
422	596423	986187.4	119	34	E	78	116	140
423	596456.6	986222.8	123	13	E	50	210	216
424	596459.3	986238.2	123	18	E	305	953	1000
425	596469.8	986251.7	126	13	E	40	180	184
426	596475.9	986276.3	116	0		0	100	100
427	596479	986261.3	123	0		0	125	125

428	596506.7	986295.4	105	10	E	10	54	55
429	596490.7	986281.3	103	13	W	43	191	196
430	596506.3	986288.4	142	28	E	35	66	75
431	596500.8	986291	142	0		0	80	80
432	596477.1	986281.6	118	0		0	150	150
433	596491.4	986288.8	120	0		0	27	27
434	596500.1	986303.2	125	0		0	80	80
435	596503.4	986310.6	131	0		0	70	70
436	596505.4	986315.6	129	0		0	68	68
437	596491.8	986308.9	121	0		0	132	132
438	596512.8	986342.6	124	0		0	200	200
439	596525.4	986355.8	130	0		0	145	145
440	596531.7	986369.1	136	0		0	130	130
441	596542.5	986383.2	130	0		0	44	44
442	596543.9	986390.1	120	6	E	15	134	135
443	596547.9	986396.4	120	0		0	150	150
444	596570.6	986418.3	125	0		0	240	240
445	596551.3	986399.1	121	0		0	160	160
446	596589	986435	127	0		0	160	160
447	596596.6	986447.2	129	0		0	180	180
448	596605.5	986454.7	140	0		0	170	170
449	596614.8	986464.3	133	0		0	120	120
450	596536.7	986394.5	145	0		0	75	75
451	596553.9	986364.1	175	33	E	25	38	45
452	596539.9	986356.2	174	29	E	34	61	70
453	596512.7	986309.9	101	0		0	77	77
454	596509.9	986301.9	93	8		10	69	70
455	596528.6	986331.4	150	0		0	110	110
456	596533.3	986333.5	154	35	E	77	111	135
457	596540.1	986362.8	145	0		0	58	58
458	596630.9	986527.1	126	0		0	47	47
459	596633	986533.2	126	0		0	29	29
460	596636.4	986541.7	151	0		0	23	23
461	596625.2	986515.4	119	0		0	60	60
462	596620.9	986508.5	101	0		0	29	29
463	596615.1	986507	128	0		0	38	38
464	596610.6	986498.4	128	0		0	40	40
465	596591.6	986456.8	120	0		0	70	70
466	596633.1	986492.1	138	0		0	20	20
467	597324	986896	100	0		0	40	40
468	597346	986909	141	0		0	46	46
469	597348	986911	133	29		24	44	50
470	597348	986917	141	0		0	40	40
471	597367	986929	120	0		0	221	221
472	597365	986923	118	0		0	224	224
473	597359	986930	55	46		86	83	120
474	597358	986915	51	73		200	60	209
475	600021	987952	101	7		50	417	420

476	600057	988126	97	8		31	218	220
477	600049	988148	101	33		117	180	215
478	600067	988189	95	0		0	185	185
479	600059	988202	95	4		13	180	180
480	600133	988340	116	5		14	154	155
481	600180	988444	74	25		25	54	60
482	600201	988445	105	35		105	150	183
483	600193	988462	118	26		67	137	152
484	600237	988524	91	0		0	80	80
485	600319	988626	125	0		0	98	98
486	596992	986184	113	0		0	50	50

Annex 13. Elevation Measurements Lake Beseka, well and Awash River

Easting	Northing	Elevation	Place	Description
594442.7	984401.7	941.774	Lake Beseka	
594443.3	984403.8	941.64	Lake Beseka	
595934.7	984926.8	941.526	Lake Beseka	
595935.4	984926.9	941.182	Lake Beseka	
595931.6	984913.7	941.982	Lake Beseka	
595932.4	984913.7	941.568	Lake Beseka	
595933	984913.8	941.032	Lake Beseka	
595933.1	984913.9	941.112	Lake Beseka	
595928.3	984876.6	941.873	Lake Beseka	
595929.5	984875.8	941.588	Lake Beseka	
595931.1	984875	941.41	Lake Beseka	
595931.9	984875	941.274	Lake Beseka	
595929.7	984884.9	941.868	Lake Beseka	
595930.2	984884.8	941.798	Lake Beseka	
595917.3	984850.3	941.178	Lake Beseka	
595713.9	984657.8	941.284	Lake Beseka	
596049.3	985352.6	941.717	Lake Beseka	
596043.9	985329.4	941.182	Lake Beseka	
596039	985307.4	941.375	Lake Beseka	
596036.9	985278.9	941.663	Lake Beseka	
596034.2	985270.4	941.523	Lake Beseka	
595696.7	984565.7	941.213	Lake Beseka	
595695.1	984558.9	941.185	Lake Beseka	
595688.7	984538.5	941.401	Lake Beseka	
595686	984526.9	941.463	Lake Beseka	
595684.5	984511.3	941.382	Lake Beseka	
595684.5	984489.2	941.415	Lake Beseka	
595681.2	984474	941.508	Lake Beseka	
595676.3	984454.1	941.607	Lake Beseka	
595630.3	984350.1	941.091	Lake Beseka	
595615.1	984326.3	941.027	Lake Beseka	
595601.5	984295.7	941	Lake Beseka	
595735	984648.7	941.425	Lake Beseka	
599505.6	984142.9	941.449	Lake Beseka	
596705.6	973907.5	946.157	Abadir camp4 well	SW = 16.54m
595462	971243.7	943.525	Abadir camp3 well	SW = 28.1m
595625	969051.3	942.052	Abadir camp2 well	SW = 39.2m
598208.8	973192.6	947.785	Awash River	Wthin plantation
598216	973170.7	947.267	Awash River	Wthin plantation
596168.6	966006.1	994.669	Awash River	Before entering plantation
596155.6	965977.5	993.585	Awash River	Before entering plantation

SW – Static Water level

Declaration

I, the undersigned declare that this thesis work is my original work, has not been presented for a degree in any other University and that all sources of material used for the thesis have been duly acknowledged.

Name	Date	Signature
Berihu Abadi	_____	_____