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ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES

NEOTECTONICS OF NAZRET-DERA AREA

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## ABSTRACT

The Nazret-Dera area forms a segment of the northern part of the Main Ethiopian Rift. The region is characterized by a complicated morphology which is a result of several episodes of volcanism and tectonism.

The volcanic rock units outcropping in the area are principally bimodal in nature and it is possible to subdivide them into 6 groups according to their spatial distribution. The groups include; the stratoid Eastern Margin and Dera-Nazret group mainly formed by a series of flood basalts interlayered with ignimbrites and Rhyolites; Keleta group, representing the oldest rift floor product and constituted by Ash flows and Ignimbrites; Boku and Gedemsa group, which are results of central type volcanic activity evidenced by preserved caldera of Gedemsa and destructed caldera of Boku, giving rise to Pantellerites, Rhyolites and pumice fall deposits and Melkasa group which is constituted by basaltic spatter cones and associated 'AA' type lava flow. The age of the rocks vary from 1.7 my to 0.06 my.

The large volume of acidic product as compared to the basaltic one and the lack of transitional rock units suggest that there is a partial melting of the lower crust probably induced by intrusion of large bodies of basaltic magma.

From Tectonic point of view, the area is characterized by right stepping, "an echelon" half grabens, grabens and faults which affect even the youngest rock outcropping in the region. The geometry of these structures i.e. an overstepping towards the right suggest a left lateral motion along this part of the rift. The theory is substantiated by meso-scale structural data which has been collected from, small faults with slicklines, extensional fractures and joints which show that the area is undergoing an east-northeast, west-southwest extension. Thus strike-slip system and oblique extension is the major mode of deformation for this part of the Rift System and possibly may extend across the whole length of the Main Ethiopian Rift.

TABLE OF CONTENT

	<u>Page</u>
Abstract .....	i
Contents .....	iii
Illustrations	
Figures .....	v
Plates .....	vii
Tables .....	viii
Acknowledgements .....	ix
I. Introduction .....	1
II. Geological Review .....	8
III. Stratigraphic Sections .....	25
Section 1 (Sire) .....	25
Section 2 (Kara) .....	27
Section 3 (Chefeko) .....	28
Section 4 (Keleta) .....	29
Section 5 ((Feyiso) .....	31
Section 6 (Bodore) .....	32
Section 7 (Wagillo) .....	33
Section 8 (Kimbibit ridge) .....	34
Section 9 (Kimbibit river) .....	37
Section 10 (Nazret city dump) .....	38
Section 11 (Jogo) .....	38
Section 12 (Gedemsa) .....	39

	<u>Page</u>
IV. Lithostratigraphy .....	41
- Eastern Margin Group .....	42
- Dera-Nazret Group .....	45
- Keleta Group .....	48
- Boku Group .....	52
- Gedemsa Group .....	54
- Melkasa Group .....	55
V. Structural Geology .....	60
Meso-scale structural data .....	70
VI. Conclusion .....	112
References .....	118

FIGURES

	<u>Page</u>
1 East African Rift System Redrawn from Mohr (1962) .....	5
2 Physiographic map of Ethiopia .....	6
3 Location map of study area .....	7
4 Residual gravity map of Ethiopia, Somalia and the Southern Red Sea after Makris and Ginzburg (1987) .....	21
5 Contact between basalt and ignimbrite of Eastern Margin Group .....	42
6 The lower pyroclastic flow deposit of Keleta Group .....	50
7 A basaltic boulder included within yellow ignimbrite of Lower Keleta sequence .....	50
8 Brown ash flow of upper Keleta sequence interlayered between ignimbrite of Gedemsa and a basaltic spatter cone of Melkasa Group .....	51
9 A quarry of pumice fall deposit of Boku Group resting on a basaltic spatter cone..	58

	<u>Page</u>
10	A basaltic spatter cone at Kurfa and associated lava flow ..... 59
11	The large boundary faults of Eastern Margin at Sire ..... 62
12	A fault showing sinistral component of motion on the eastern shoulder of Gedemsa Caldera ..... 63
13	A close up of Figure 12 ..... 63
14	Normal fault plane affecting spatter cone located near Wonji ..... 68
15	Normal faults within a quarry of scoria found along the road to Melkasa ..... 68
16-30	Stereoplots of meso-scale structural data ..... 72-109
31	Kinematics of all fault planes with slicklines showing also the extension direction ..... 111
32	Modeling of formation of acidic volcanism in rift development of intrusion of large bodies of basaltic magmas according to Kazmin (1987) and Huppert and Sparks (1988) ..... 117

PLATES

1. Geological map of Nazret-Dera area with 1:50,000 scale and two geological cross-sections
2. Stratigraphic sections of selected sites with correlated composite stratigraphic column
3. Structural map of Nazret-Dera area with 1:50,000 scale showing extension direction from meso-scale data.

T A B L E S

	<u>Page</u>
1. The stratigraphy of the northern part of the Main Ethiopian rift according to Di Paola (1972) .....	22
2. Absolute age determination of some of the volcanic units outcropping in the study area according to Morton et al, (1979)	23
3. Absolute age determination of units outcropping in the study area according to Bigazzi et al (1981)	24
4. Stratigraphy of the northern wall of Gedemsa caldera	55

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## I. INTRODUCTION

The East African Rift System (Fig. 1) forms part of a complex tectonic feature, represented by a system of down-faulted troughs extending from Mozambique, in the south, northward through East Africa, the Horn of Africa, Red Sea and into Israel, Jordan and Syria (Mc Connell, 1980). This remarkable feature of the Earth's crust is thus observed to extend for about 5000 km in a generally north-south direction.

The Ethiopian Rift system, which is a segment of the East African Rift system, is a structure of great interest to understand the early stages of ocean-basin evolution. The unique association of abundant volcanic products and variable structures provide an ideal exercise for volcanologists, structural geologists and geophysicists. In spite of the large interest regarding the various aspects of rift development, detailed geological mapping in the Ethiopian Rift system are very rare. The study of the tectonics has mostly been based on aerial photograph and satellite image interpretation, while detailed structural analyses are completely lacking.

The principal aim of this work is to study an area where volcanic and tectonic features are well exposed and to understand the process which has led to the occurrence of the volcanotectonic features.

The main objectives of this thesis are:-

1. to recognize and describe the general geometry of the fault pattern and the related kinematics;
2. to arrive at a neotectonic stress field geometry responsible for the faulting process;
3. to relate the observed tectonic pattern with the volcanological process affecting the area.

Among several suitable locations for such kind of study one of them is the Nazret region. This area is located in the northern part of the Main Ethiopian Rift which is a northeast elongated depression dividing Ethiopia into two main physiographic regions (Fig. 2).

The northwestern part, named the Ethiopian plateau takes up almost half of the country. Although it contains peripheral lowlands near the Sudan boarder, most of its regions have an altitude higher than 2500 m. It also contains a poorly defined, at places simply embayed western margin to the rift system and a well defined, north-south oriented border to the Afar, a tectonically complex triangular depression marking a site of triple junction (Ethiopian, Red Sea, Gulf of Aden rifts) including one of the lowest areas in the World (Dallol -125 m b.s.l.). The southeastern region, named Somalian plateau, is constituted by a north-east elongated highland along its margin with the rift,

having an average altitude of 2000 m and an extensive flat region that gently slopes towards southeast to the Indian Ocean. It also forms a well marked eastern margin to the Main Ethiopian Rift and turning east-west marks the southern border of the Afar.

The study area in particular extends from the town of Mojo, in the west, to the town of Sire in the east. In the south it starts in the vicinity of Wonji Sugar Plantation continuing north upto Wekera River (Fig. 3) covering an area of approximately 300 sq.km.

The rift segment at the latitude of the study area has a poorly defined western margin that gently slopes from an elevation of 2000 m to an elevation of 1500 m at Nazret and a well marked stepped eastern margin rising to 2500 m altitude. The depression takes up almost 90% of the area under investigation and is characterized by flat plains, arcuate ridges, large and small volcanic centers and linear north-northeast oriented escarpments. Two large rivers, Awash flowing due east and Keleta due north cross the area.

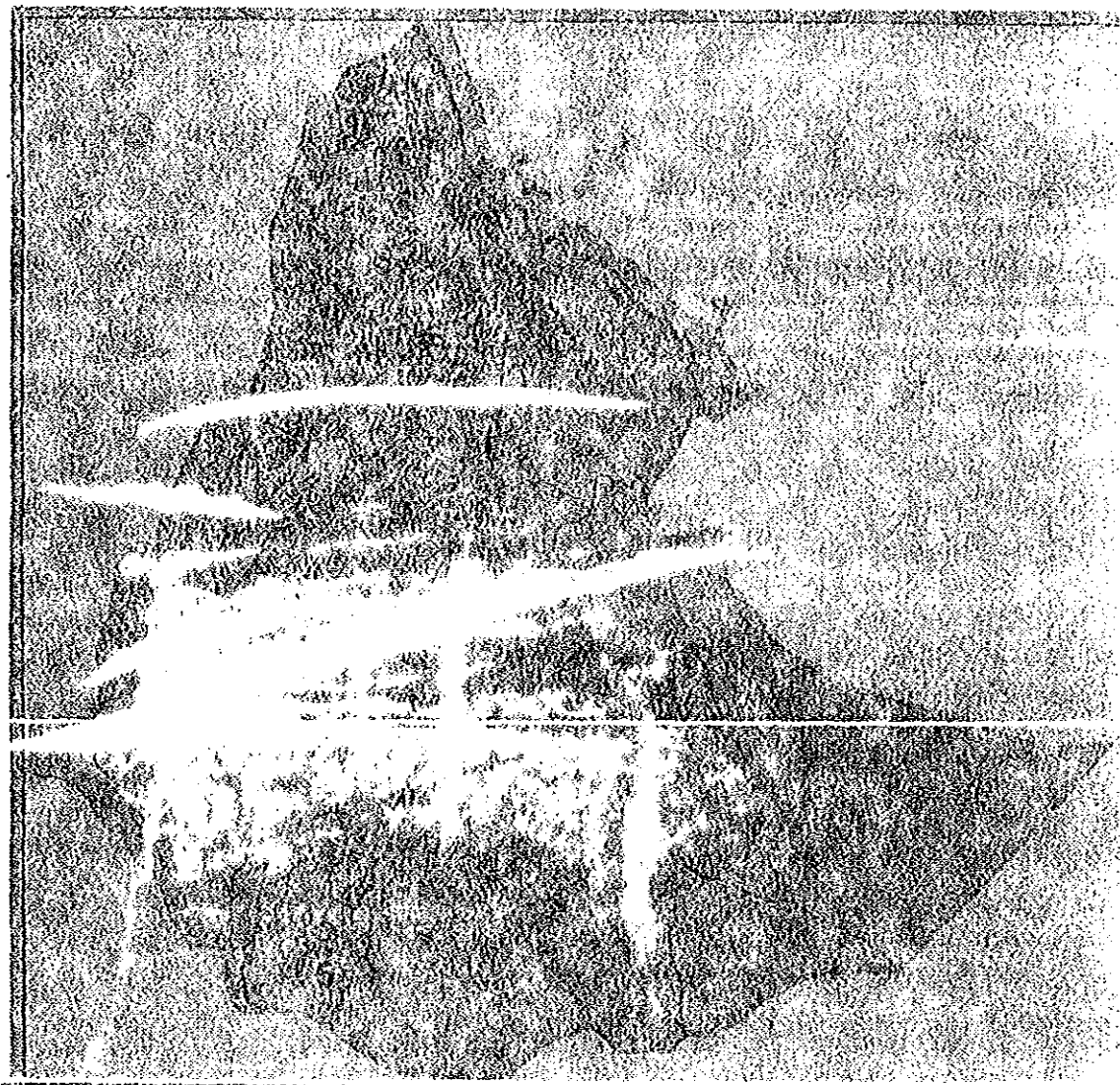
As many parts of the rift system, the Nazret region has a rather hot, average annual temperature of 28 C, and dry average annual rainfall 400 mm/yr climate (Mesfin, 1970). Eventhough most of the area is covered by pyroclastic deposit, large patches of arable black soil

are present that are farmed using irrigation techniques by water obtained from the Awash river. The Wonji Sugar Plantation and Melka Wooba are examples of such large farms based on irrigation. The natural vegetation, when present is dominated by Acacia trees, thorny bushes and grassland.

A total of two months of field work was carried out to complete the work. In general the area is well accessible. Two major roads: Addis Ababa - Awash and Nazret - Asela together with secondary Melkasa - Sodore and numerous dirt roads are available for vehicles.

Mapping was done using 1:50,000 scale topographic maps and aerial photographs as base maps. Detailed stratigraphic sections were described at specific localities to understand the temporal evolution of the different magmatic units. Along these sections several representative samples from different lithological units were collected for petrographic study. Similarly, numerous structural data including meso-scale measurements of slicklines on the major and minor fault planes, joints and extensional fractures were collected. The analyses of such data enabled to determine the geometry of the stress field responsible for the faulting process affecting the area.





**Fig. 2** Physiographic division of Ethiopia showing

- 1.** Ethiopian plateau;
- 2.** Somali plateau;
- 3.** Afar;
- 4.** Main Ethiopian Rift;
- 5.** South Western rift zone.

Redrawn from relief map of Ethiopia.



## II. GEOLOGICAL REVIEW

In Ethiopia, the rift system runs in a north-northeast direction and extends into the Red Sea-Afar-Gulf of Aden System. It is possible to divide it into: the southwestern Rift Zone, the Main Ethiopian Rift and the Afar.

The southwestern Rift Zone is a broad structurally disturbed area containing four rift valleys which are, the northwesterly trending Kibish rift, the north south striking Omo, Usno and Chew Bahir (Stephanie) rifts. The area with its bimodal volcanism is believed to be a region where the oldest Tertiary volcanics in East Africa (Eocene) occur (Wole Gabriel, 1937).

The Main Ethiopian Rift (MER) represent a structural depression with an average width of 80 km. It starts in the north from an arbitrary Yerer-Gugu cross-rift lineament and extends in the south where it bifurcate into Ganjuli and Galana graben.

The MER subdivides Ethiopia into a northwestern Ethiopian plateau and southeastern Somalian plateau. These plateaus are composed of extremely folded and foliated basement of Precambrian age overlain by sub-horizontal Mesozoic transgressive and regressive sedimentary strata separated by a marked Paleozoic unconformity, and covered by Tertiary volcanics. The whole series has been uplifted

since Eocene as part of the Afro-Arabian swell across which large scale faulting has later taken place to form the eastern and western margins of the rift.

The eastern margin is morphologically well expressed as compared to the western one, which at places is so subdued that the boundary between the rift floor and the plateau is hard to define.

The floor of the MER is marked by a persistent belt of intense fresh faulting which has been termed as the Wonji Fault Belt (WFB) (Mohr, 1960). The faults are short, normal type and are oriented in north - northeast, south - southwest direction.

From magmatic point of view the area is characterized by the occurrence of many volcanotectonic features like calderas, composite volcanoes, spatter cones and fissures which gave rise to huge volumes of ignimbrites and subordinate basaltic lava flows ranging in age from 5 to 0.06 my (Morbidelli et al., 1975; Morton et al., 1979; Bigazzi et al., 1981).

In general the MER registers large geophysical anomalies. Heat flow data values range from  $75 \text{ mWm}^{-2}$  in the southern part to  $100-150 \text{ mWm}^{-2}$  in the central and northern sectors (Lyask, 1987). The gravity values are strongly negative ( $-200$  to  $-260 \text{ m Gals}$ ) with a gravity low of  $-260 \text{ m Gals}$

located along the eastern border fault on the Somali block; the main gradient being more or less coincident with the eastern escarpment (Fig. 4) (Makris and Ginzburg, 1987). Despite these anomalies gravimetric and seismic refraction data suggest that the continental crust of the MER has a thickness ranging from 30 km in the northern most sector to 40 km in the southern one (Makris and Ginzburg 1987).

The Afar is a roughly triangular shaped depression of about 110,000 sq km, where three important tectonic structures meet, namely Red Sea, Gulf of Aden and East African rifts, to form a triple junction. The major phases in the development of Afar region is summarized by Barberi et al, (1975b) as an initial Oligocene (25 m y) subsidence and formation of continental rifts and a final period of 4 m y to present where oceanic crust was generated. On the other hand Makris and Ginzburg (1987) argue that in spite of the fact that extensive basic volcanism is dominant in the Afar region, it presents a stretched continental crust, except in the region of Tadjura where a wedge of oceanic crust propagating from the Gulf of Aden has been emplaced. They explain that the crust has been thinned by tensional stresses caused by an updoming of high temperature low density upper mantle material and has a thickness between a true oceanic crust and a continental one (20 - 14 km).

Several works concerning the volcanism and tectonics have been published which bear direct relevance to the study area. Mohr (1960, 1962a, 1967) was the first to give a comprehensive summary of the rift system. In general he considers the rift to be divided into sectors which are dextrally offset along cross-rift lineaments. He also successfully identified and described what he calls the Wonji Fault Belt, which are a north - northeast oriented fault systems running across the whole length of the MER upto the Red Sea associated with extensive bimodal volcanism.

Later, Gibson (1969) described the outline of the WFB as having a northeast trend at a near junction with the eastern margin and then curving gently back towards a north-north east trend near the western margin. These sigmoidal faults, he noted, are 100 km long, and are best developed on the Gedemsa and Bosseti segments of the WFB. The theory was further developed in Gibson and Tazief (1970) in which the tectonics of the WFB was described as tensional faulting along a north - northeast trend. The faulting clearly varies in age and is in general younger along the medial line of the rift valley, becoming progressively older as one approaches the rift margins. One of the most striking feature of the WFB, they noted, is that it is not a continu-

ous line of faulting but in fact, it is a whole series of fracture swarms arranged in "en echelon" fashion. The "en echelon" arrangement of the swarms emphasize that the most important direction of faulting is not parallel to the rift margin but run obliquely at an angle of 20°. Furthermore the cross-rift lineaments of Mohr (1960, 1967a, 1967b) are not substantiated in the field and the manner of dying out of the fault belt suggest otherwise. Finally they concluded by stating that the MER is a zone of a left lateral shear as a whole and the WFB do not continue upto Red Sea but abruptly terminates at Tendaho graben.

In subsequent publications, Mohr (1981) declines in accepting the sinistral theory by giving two reasons: the first he argues, is that the sigmoidal pattern is not developed across the whole length of the Ethiopian rift and second plate tectonic analyses (Le pichon and Fracheteau, 1978) suggest a dextral component of shear along the Ethiopian rift. In giving justification for the observed features he states that the sigmoidal pattern could possibly result from modification of the regional extensional stress field on approaching an obliquely trending boundary against thicker lithosphere. The dextral shear, he stated, is very minor and can as well be considered as result of local accident of crustal strength and thickness. Therefore, he

concluded, the rift in general can be viewed in terms of pure extension.

The volcanotectonic aspect of the northern part of the MER has been topic of argument for several earth scientists. Di Paola (1972) mapped the area and stated that it is affected by a set of north - northeast, south-southwest oriented normal faults in "en echelon" arrangement which correspond to the WFB. Another similar set was identified by the author in the Silti-Butajira area.

The successive periods of volcanic activity, according to Di Paola (1972), include fissure eruptions with emplacement of explosive, dominantly ignimbritic products followed by volcanotectonic collapses. The youngest volcanic cycle include the building up of silicic central volcanoes on the ignimbrites followed by basaltic fissure eruptions and edification of recent mostly pantelleritic centers with associated "sub-historical" basaltic fissure eruptions. The composite stratigraphic column of the author is summarized in table 1.

Meyer et al. (1975) in the northern part of the rift system distinguish two main volcanotectonic units. An older Nazret series with age of 5-2 my and a younger Wonji series with Pleistocene - Holocene age. The two units are divided

by a Nazret faulting phase which came into activity 1.6 to 1.8 my ago.

The Nazret series form a stratoid trachytes, rhyolites, ignimbrites and pumice. In the region of Nazret, the succession, according to the authors, consist of light rhyolites and ignimbrites. Light pumice on top of Nazret series has in some places greater thickness than normal because it accumulated in previously formed basins and grabens. Beds of tuff and yellow loam alternate in the pumice beccias. Eruptions of this phase is considered to be mainly through fissures and vents, but local centers also occur.

The younger Wonji series, the authors consider, is built up mainly from large basaltic flows resulting from complex fissures. Trachytes, rhyolites, ignimbrites, pumice and tuffaceous material are also found. The volcanics of this series is observed to strongly follow north - north-east, south - southwest running faults or are erupted from fissures and vents in this direction.

From tectonic point of view the two phases are summarized as:-

- 1) In the first phase during the deposition of stratoid Nazret series with an age of 5 - 2 my a tensional stress caused the tectonic pattern within the MER,

with fractures fissures and dykes running north-east - southwest and north - northeast - south - southeast. The tectonic activity came to an end with the Nazret faulting phase. The pattern during the Nazret phase can be referred to as a tectonics perpendicular to the direction of the MER.

- 2) In the second and main part of the Nazret faulting phase a fundamental and completely different evolution began with the Wonji Fault Belt. Groups of fractures, open fissures and dykes show a north-northeast, south - southwest and north - south direction. The north - northeast direction of the WFB is oblique to the direction of the MER and makes an angle of 10 - 25.

Siefe M.D. and Kazmin V. (1978) presented a geological map of Nazret sheet. Later Kazmin et al (1980) summarized the development of the Ethiopian Rift System especially the northern part as follows.

- 1) The rift developed in stages of which the main events occur at 15 to 14, 10, 4 to 4.5 and 1.6 to 1.8 my;
- 2) at least the northern part of the Ethiopian Rift was formed simultaneously with the Afar (15 to 14 my);

- 3) In the northern part of the Ethiopian Rift and Afar initial downwarping (14 my) was followed by intensive faulting and subsidence (10 and 4.5 my);
- 4) the slow rate of attenuation in the Ethiopian Rift provides favourable condition for the partial melting of the crust and the effusion of large volume of silicic volcanic rocks.

Absolute age determinations of some of the rock units outcropping in the vicinity of the study area (Table 2) are reported by Morton et al (1979) and Bigazzi et al (1981). According to Morton et al (1979) there is an overall south-eastern dip of volcanic units at the latitude of Addis Ababa where disconnected older volcanic rocks outcrop and this gentle downwarping is not associated with faulting (major escarpment) leaving a gap in the line of western margin. Absolute age determination of volcanic rock units from different localities at this latitude show riftward younging trend. The age of the rocks in the vicinity of the study area range from Pliocene to Holocene.

A summary of the youngest phase of volcanotectonic development within the study area is given by Bigazzi et al (1980). He stated that the collapse of Gedemsa caldera is younger than 0.2 my and the post caldera perlites and pumice inside Gedemsa were erupted between 0.2 and 0.1 my.

The ages, he presumed, of the great number of faults which affect these products are younger than 0.1 my and the aphyric Basaltic and mildly alkali-basaltic flows and spatter cones have age of 0.06 my. Absolute age determination of some of the rock units within the study area, according to the author, is reported in Table 3.

The fact that volcanic and tectonic episodes occur in a sequential order of a specific length of time have been noted by several geologists.

According to Mohr (1986):

- 18 - 21 my Broad crustal downwarping and fissure basalt in northern part of the rift, local rifting developed in the south.
- 15 - 13.5 my Warping and initial faulting of northern rift margins.
- 10 - 7 my Faulting and fissure basalt extrusion.
- 5 - 3.5 my Faulting and massive silicic eruptions especially in the north.
- 1.8 - 1.5 my Margin and floor faulting.
- 1.0 - 0.9 my Eastern margin faulting and plateau uplift.
- 0.25 - 0 Wonji fault belt.

According to Woldegabriel (1987) from magmatological point of view:-

- 32 - 26 my Thick (500 m) widespread basalt.

- 17 - 12 my Intermediate to felsic rocks.
- 11 - 8 my Bimodal and confined close to the present day rift and its margins.
- 4.2 - 3 my Widespread crystal rich ignimbrite.
- 3 - 1.6 my Trachytic shield volcanoes and ranges confined to the rift shoulders.
- 1.6 my Bimodal volcanism has become virtually rift bound.

In addition he states that each volcanic episode was accompanied by faulting and downwarping. Fluvial sediments of the first and second episodes imply embryonic downwarping preceded rifting.

The complexity of the results of crustal extension occurring in the MER is discussed by Mohr (1987). He describes the following patterns of rifting; arcuate faults convex in plan towards the downthrown part, lines of obliquely tilted faulted blocks, lip horsts, horizontally stratified rhomb horsts, athwart tilted strata, faults whose polarity switches in conjunction with development of small horsts, intersecting faults and re-entrant and semi-circular faults.

Part of the study area has been mapped by the author. He named the depression of the Nazret town the Adama graben and described it as a north - northeast, 5 km wide and 30 km

long graben structure which abuts west against the intensely eroded southeastern flank of a Late Miocene - early Pliocene volcanic massif and in the east bounded by a narrow, Delesha, horst.

The general stratigraphy of this area is summarized as:

- 1) strongly welded tuff base not exposed (55 m) 1.7 my;
- 2) massive pumiceous sediments with occasional well bedded subunits;
- 3) Weakly welded tuff thickening and more crystal rich eastwards (2 - 4 m) (0.51 my).

This succession, he further stated that, is complicated by interbedded feldspar phyric basalt commencing near the termination of unit 2, continued after deposition of unit 3, and yielded a maximum thickness exceeding 50 m.

Finally the tectonics of the rift system is analyzed by Bocalletti et al. (in press) and states that strike-slip tectonics has played a major role in the development of the rift and oblique extension along major northeast-southwest trending strike-slip faults is responsible for the upwelling and differentiation of most of the acidic volcanic products known to occur, whereas basaltic lava flows and associated volcanotectonic features are derived from a development of north-south trending extensional features.

According to the authors north of Asela, close to the study area, the belt runs toward Afer through regional splays which give rise to several north-northeast south-southwest trending grabens arranged in "en echelon" manner, most important being Nazret and Melka Jilo depression and the Awash half graben. The geometry of these structures (an overstepping towards the right) suggest a left lateral motion along a northeast-southwest blind fault. Meso-Scale structural data collected along the northern branch of the MER between Melka Jilo and Nazret show that both minor and major extensional fissures are oriented roughly north-south whereas minor fault planes trending northeast-southwest and northwest-southeast are left and right oblique normal faults respectively and suggest a roughly east-west extension. The authors conclude that strike-slip system play a major role in the development and evolution of the post ignimbritic tectonic history of the MER while it is a possibility that this mode of deformation might have also been important for the earlier tectonic phases.

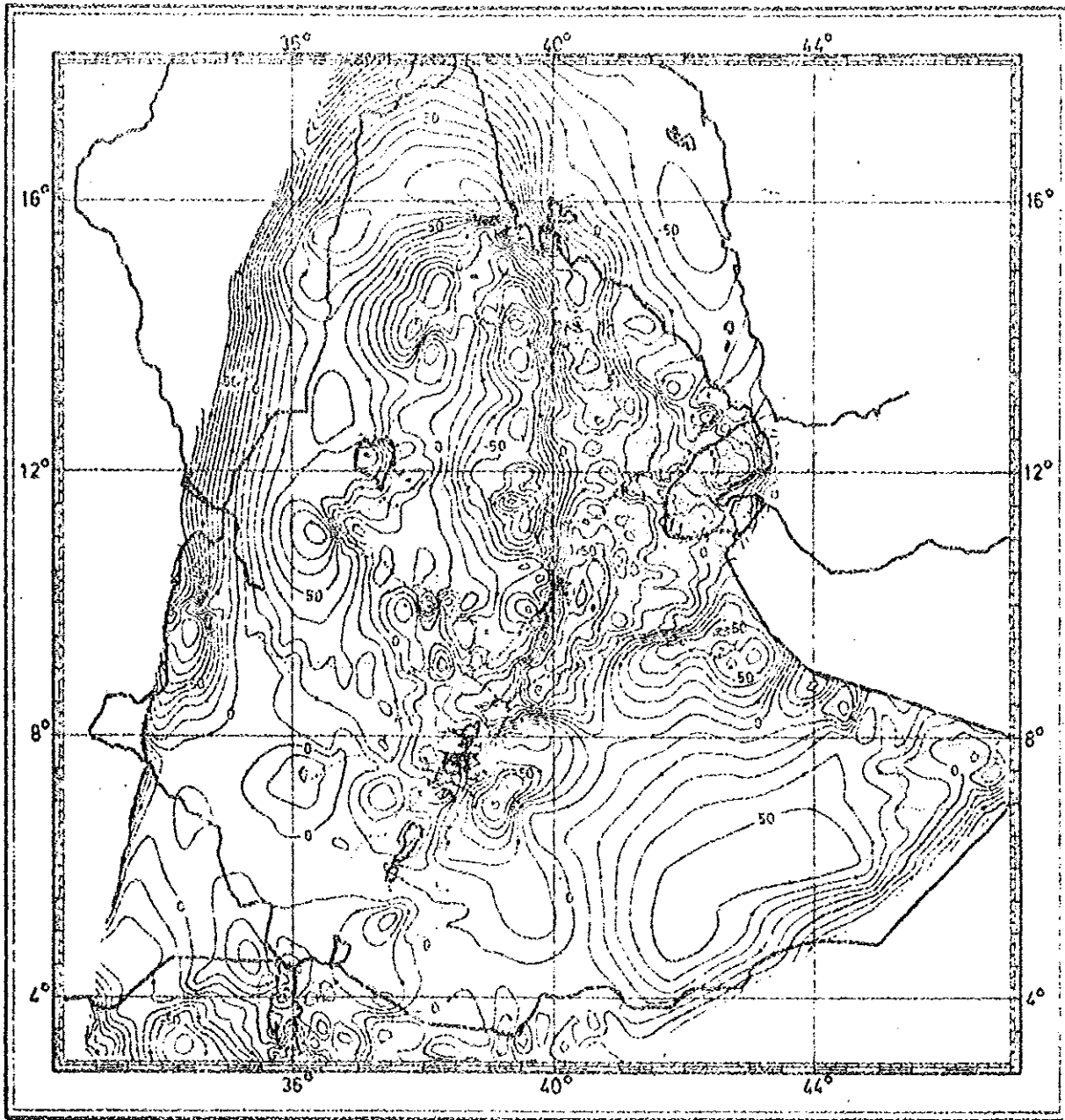


Fig. 4. Residual gravity map of Ethiopia, Somalia and the southern Red Sea.  
After Makris and Ginzburg (1967).

Table 1

Age	Stratigraphy
Recent to Pleistocene Holocene	Alluvium, lacustrine deposit recent alkaline and peralkaline rhyolites pumice, ashes and obsidian lava flow.
Recent to Pliocene	alkali trachytes lava flows and domes.
Recent to Pleistocene	recent basaltic lava flows and spatter cones.
Recent to Pleistocene	basaltic hyaloclastites
Early Pleistocene to Late Pliocene	old alkaline and peralkaline rhyolites lava flows and domes associated with pumice and ashes.
Pliocene	alkaline and peralkaline Ignimbrite associated to pumice, ashes and lahars.
Pliocene to early Eocene	tertiary basalts and ignimbrites of the plateau trapp series.

Summary of age and stratigraphy of volcanic products  
outcropping in the northern part of the Main Ethiopian Rift  
Di Paola (1972).

Table 2

Age	Location
3.32 - 0.06 my	Gara Mariam Tedi
3.11 - 0.06 my	Gara Mariam Tedi
1.71 - 0.04 my	3 km south-east of Tedi
0.51 - 0.03 my	Kimbibit Horst 4 km west of Adama
0.61 - 0.03 my	Scarp 2 km west of Adama
0.85 - 0.07 my	Northern rion Gadamsa caldera
0.41 - 0.04 my	Nagow cone, Gadamsa caldera
0.61 - 0.04 my	Northeastern flanks Gara Boku
0.44 - 0.05 my	2 km south-west of Bofa

Absolute age determination of volcanic rocks outcropping within the area under investigation after MORTON et al (1979) unless stated otherwise absolute age determination are K/Ar.

Table 3

Sample No.	Rock Type	Location	Age
Rv 1A	pantellerite	eastern margin	1.77±0.44
Rv 22	pantellerite	eastern margin	1.80±0.09
Rv 46	pantellerite	eastern margin	1.49±0.07
Rv 108	pantellerite	eastern margin	1.41±0.07
Rv 359	pantellerite	precaldera lava flow on the SE rim of Gadamsa caldera	0.082±0.021
Rv 359*	pantellerite	"	0.267±0.040
Rv 365*	pantellerite	precaldera lava flow on the NE rim of Gadamsa caldera	0.212±0.032

Absolute age determination of volcanic rocks outcropping within the area under investigation after Bigazzi et al. (1981).

\* Age determination data are from fission tracks.

### III. STRATIGRAPHIC SECTIONS

In order to correlate and arrive at a composite stratigraphic sequence of the volcanic products outcropping in the study area (Plate 2) twelve stratigraphic sections are chosen. These sections are exposed along river cuts and excarpments. Along each of the sections the thickness of the different units were measured and samples from the main lithological units were collected. When present, absolute age determination of some of the rock units is included.

#### Section 1 (SIRE)

The section is located along the boundary fault of the eastern margin near the town of Sire. The escarpment expose a base of 15 m thick, dark grey, porphyritic, highly fractured basalt followed by 25 m thick acidic lava flow containing levels of obsidian and considerable amount of scoria fragment. A 10 m thick whitish ignimbrite unit, containing numerous pumice clast, rest on the acidic lava flow unit with a 1.5 m thick, brown, crusted paleosol separation. At the top 12 m thick, dark aphyric basaltic lava flow occur.

Samples for petrographic study were collected from: the lower basaltic unit (E6), acidic lava flow (E-5), ignimbrite (E4) and upper basaltic unit (E-0).

#### E-6 Hawiitic Lava Flow

Under microscope the rock exhibit porphyritic texture with phenocryst of plagioclase (An 60-64%), olivine and very few clinopyroxene set in a fine groundmass. Olivine is quite abundant as pheno and microphenocryst. The clinopyroxene is found mainly in the groundmass which is composed of olivine, plagioclase and abundant opaques mostly of magnetite. In general phenocryst enrichment of plagioclase observed in this section suggest evolution of the magma.

#### E-5 Rhyolite

The thin section of this rock show a porphyritic texture with phenocryst of plagioclase (An 15-20%) set in a felsic to glassy groundmass which is made up of scarce needles of plagioclase and abundant opaques. Flow structures are also evident.

#### E-4 Ignimbrite

The ignimbrite show eutaxitic texture with abundant crystals of plagioclase, alkali feldspar and quartz. The matrix is composed of glass shards interbedded with bands of recrystallized glass that could originally be collapsed pumice clasts.

#### E-0 Basalt

This basaltic rock exhibit aphyric texture with very few microphenocryst of plagioclase (An 68-70%) and olivine. The groundmass is made up of extensive olivine, plagioclase, opaques and few pyroxene.

## Section 2 (KARA)

This section is located along a north-northeast south-southwest elongated curvilinear ridge in the vicinity of Kara. At the central part of this ridge, where it attains its maximum height, a base of 15 m thick strongly welded, greyish, lithic fragment rich ignimbrite capped by a dark fine grained basalt is exposed.

Thin section study of samples collected from the ignimbrite (D9) and basalt (D8) shows the following character.

### D9 Commendite

This rock shows an eutaxitic texture with crystals of quartz, plagioclase, alkaline amphibole, aegirine and K-feldspar. Basaltic and trachytic lithics are also present. The basaltic fragments are composed of calcic-plagioclase pyroxene, idingstized olivine and opaque minerals. The matrix is characterized by bands of recrystallized glass, glass shards and collapsed pumice.

### D8 Basalt

The rock shows aphyric texture with microcrystals represented by plagioclase, pyroxene, olivine and abundant grains of opaques; secondary calcite is formed along fractures and in the vesicles of the rock.

### Section 3 (CHEFEKO)

The section is located along a large fault escarpment near Chefeko. It forms the last boundary fault which is grouped as eastern margin faults. It exposes a base of greyish well welded, highly jointed 20 m thick ignimbrite covered by a dark grey, spheroidally weathered, 30 m thick porphyritic basalt. The two units are separated by a 20 cm thick light yellow fine ash flow and by 20 cm thick brown, crusted paleosol.

Samples were collected from the ignimbrite (D12) and basalt (D10) for thin section study.

#### D12 Alkaline Ignimbrite

This rock is represented by scarcely welded ignimbrite containing crystals of plagioclase (An-36%), K-feldspar, alkaline amphibole and very scarce aegirine. Mainly trachytic and few basaltic rock fragments are also present. The glass which the matrix is made up of has a brownish colour.

#### D10 Basalt

It shows porphyritic texture with microgranular ground-mass is composed of titaniferous pyroxene, calcic plagioclase, idingsitized olivine and opaque minerals. The opaques are basically of two kinds: spine like ilmenite and cubic magnetite.

#### Section 4 (KELETA)

This section was taken along a flank of a river near the junction of Boru and Kelets. It is possible to subdivide the pyroclastic flow deposit of this section into a lower prevalently proximal unit and an upper distant unit.

This lower pyroclastic unit is composed of a 2.5 m thick grey ash flow unit overlain, with 1 m thick brown paleosol separation, by a well welded dark 2.5 m thick ignimbrite with "fiammae" of dark glass. This unit is black horizontally sheeted at the base and grades into a lighter conchoidally fractured upper part without any significant break. The main unit of the lower pyroclastic sequence is a 10-15 m thick columnarly jointed, yellow ignimbrite which is rich in pumice clast of variable flattening and carries also basaltic and dark ignimbritic boulders. The last two units are separated by a 20 cm thick brown coarse grained, crusted paleosol containing chips of glass, quartz grains and fragments of underlying rock. The upper pyroclastic series has a total thickness of 10-15 m. and is constituted by fine, loose right brown to grey ash flows separated by thin layers of paleosol.

Several samples were collected from the lower pyroclastic unit for thin section study including: basal dark ignimbrite (D32), top grey ignimbrite (D31), yellow ignimbrite (D1) and (D1-1) from the basaltic boulder.

#### D3-2 Glassy Ignimbrite

This rock is represented by an ignimbrite showing an eutaxitic texture containing crystals of quartz and oligoclase and lithic fragments of basalts and trachytes. The matrix is made of fine crystals of aegirine, amphibole, thinly collapsed pumice and irregular spots of brown glass. These spots apart from having different colour from the glass of which the matrix is made up of, they also have different refractive index. Thus they could represent drops of a liquid with different composition.

#### D3-1 Glassy Ignimbrite

It is a lithic and crystal bearing eutaxitic ignimbrite. The crystals include quartz, few plagioclase, very scarce aegirine and amphibole. The lithics are composed of oxidized basaltic fragments and trachytic fragments too. The matrix is constituted by extensive glass shards and thinly collapsed pumices.

#### D-1 Yellow Ignimbrite

It is composed of a scarcely welded ignimbrite containing crystals of oligoclase, alkali feldspar alkaline-amphibole and aegirine and mainly basaltic lithic fragments. The matrix is made up of uniformly altered glass with few droplets of brown glass of different composition signifying magma mixing.

## D1-2 Basalt

The boulder basalt shows aphyric texture with microphenocryst of plagioclase (An 58%). The general mineralogical assemblage is represented by plagioclase, euhedral, partially idingsitized olivine, titaniferous pyroxene and opaques.

## Section 5 (FEYISO)

Similar pyroclastic deposit to the Keleta section is present along the Feyiso river. It presents a base of 20 m thick yellow ignimbrite which is rich in pumice clasts and other lithic fragments followed by an 8 m thick, horizontally bedded, fine brown ash deposit then comes an unusually thick (8m) alluvium deposit carrying stone lines of rounded pumice and pebbles. The last unit of this section is a well welded "fiammae" rich ignimbrite characterized by a basal black colour which grades into a light grey colour towards the top. In between the alluvium and the ignimbrite a fine grey ash flow, having a maximum thickness of 20 cm is present.

Sample was collected only from the well welded ignimbrite both from the basal one (D21) and top one (D23), for thin section study.

## D21 Glassy Ignimbrite

This ignimbrite exhibit an eutaxitic texture containing scarce and few crystals of oligoclase, aegirine, quartz, K-

feldspar and amphibole together with mainly trachytic lithic fragments. The matrix is mainly composed of collapsed pumice and glass shards set in an oxidized glass.

#### D23 Ignimbrite

This rock is formed by crystals and lithics set in a glassy matrix. The crystals are scarce and small and include plagioclase, quartz while the lithic fragments are mainly of basaltic composition. In the matrix rare collapsed pumice and droplets of brown glass are present.

#### Section 6 (SODORE)

This section is taken along an escarpment located half way between Melkasa and Sodore. It presents a base of 20-25 m thick grey, banded "flammae" rich ignimbrite unit followed by a 1.5 m thick scarcely welded ignimbrite containing abundant fragments of obsidian and lithics; then 2 m thick light yellow scarcely welded ignimbrite carrying fragments of obsidian and boulder from underlying rock and centimetric levels of pumice rich horizons follow. On top of this unit 5 m thick fine depleted, weakly stratified subangular pumice fall deposit carrying fragments of obsidian and pieces of lava is present. The youngest unit of this section is the youngest rock unit of the study area and it is represented by 5 m thick 'AA' type scoracious basaltic lava flow. Absolute age determination of this basalt gives subhistorical age.

Samples were collected from the base ignimbrite (D28) unit and the top basaltic unit (D29).

#### D28 Ignimbrite

It is represented by eutaxitic ignimbrite carrying lithics and abundant and large crystals of oligoclase, quartz, augite and magnetite. The lithics are constituted by abundant basaltic and few trachytic rock fragments. The matrix is characterized by collapsed in part re-crystalized, pumices and glass shards. Secondary calcite is also present.

#### D29 Basalt

It is porphyritic basalt carrying phenocryst of plagioclase (An 74%) and olivine set in a microgranular groundmass constituted by abundant plagioclase, olivine, clusters of pyroxene and opaques. In general the section shows enrichment in olivine.

#### Section 7 (WAGILLO)

The section is located along a fault scarp near Wagillo area where numerous ridges with curved outlines are present. It is principally made up of two unit: a base, 25 m thick rhyolitic lava flow exhibiting evident flow structure and a top 10 m thick pumice fall deposit. The pumice fall deposit is constituted by fine depleted, coarse, angular pumice clasts, 1 m thick grey ignimbrite, large patches of dark glass and centimetric levels of grey fine ash.

Samples were taken from the base rhyolite (W-4) and ignimbrite (W-4) and ignimbrite (W-2), obsidian (W-3) intercalated with the pumice fall deposit.

#### W-4 Rhyolite

Under thin section the sample shows porphyritic texture with felsic groundmass. The mineral association include, oligoclase, alkali-feldspar, quartz and relatively abundant hornblende. The groundmass is felsic containing very scarce microcrystals of aegirine and amphibole.

#### W-2 Ignimbrite

The rock is constituted by crystal and lithic bearing ignimbrite set in a glassy matrix. The crystals are quartz, aegirine and small plagioclase; the lithics are very scarce and mostly basaltic in nature. The matrix at places carry glass shards.

#### W-3 Obsidian

It presents virtually a section of recrystallized glass containing plagioclase, aegirine, amphibole and sanidine crystals. The groundmass show spherulitic texture with stretched glass. It resembles an ignimbrite texture which could be attributed to the flowing structure of the obsidian.

#### Section 8 (KIMBIBIT RIDGE)

The section is taken along the two western scarps of Nazret town. It starts with a dark, highly fractured basalt

unit followed by a 2 m thick fine brown ash and a total of 5 m thick grey "fiammae" rich ignimbrite which is coarse and less welded towards the top, finally a fine grained dark basaltic unit rest on top. In the vicinity of this sequence, feldspar phyric basaltic lava flow outcrops which takes up a stratigraphic position on top of the basalt at the Kimbibit ridge. Absolute age determination of the "fiammae" rich ignimbrite yields an age of 1.7 my (Mohr, 1987).

Petrographic study was performed on samples collected from the base basalt (N-2), lower part of "fiammae" ignimbrite (N-3), top part of "fiammae" ignimbrite (N-9), top basalt on Kimbibit (N-10 and finally from the feldspar phyric basalt (N-4).

#### N-2 Basalt

The rock shows a fine grained texture with microphenocrysts of zoned plagioclase (An 54-68%) and olivine. Some crystals of olivine are observed to be completely idingsitized while others appear completely fresh. Agglomerate of crystals made up of plagioclase and olivine are also present. The groundmass has the same mineralogical assemblage with few pyroxene and abundant opaques. The appearance of some of the crystals suggest that they may be xenocrysts.

#### N-3 Ignimbrite

The rock shows abundant crystals of k-feldspar, quartz,

horablende, few plagioclase and pyroxene together with trachytic rock fragments which are set in eutaxitic matrix composed of collapsed, partially recrystallized pumice and glass shards.

#### N-9 Ignimbrite

It has coarsely crystalline eutaxitic texture. The crystals are plagioclase, k-feldspar, small altered amphibole and pyroxene. Lithics in this section include both trachytic and basaltic rock fragments. The matrix is made up of glass shards, fine grained crystals and collapsed pumice clasts.

#### N-10 Basalt

It is represented by microcrystalline basalt carrying few phenocrysts of plagioclase (An 60-70%) and poikilitic pyroxene, including plagioclase crystals. The groundmass is constituted by plagioclase lath, partly idingsitized olivine and abundant opaques. Secondary precipitate of calcite filling vesicles is also present.

#### N-4 Coarsely Porphyritic Basalt

Porphyritic basaltic lava with phenocrysts of unusually large and abundant plagioclase (An 68%), smaller euhedral olivine with multiple idingsite rim and zoned alkali-feldspar set in a microcrystalline groundmass. The groundmass is composed of plagioclase, olivine, very scarce augite and opaques.

## Section 9 (KIMBIBIT RIVER)

The section is taken along the Kimbibit river. The sequence starts at the floor of the river where a dark highly jointed 2.5 m thick basaltic lava flow is exposed and it dips under a 1.5 m thick black well consolidated conchoidally fractured ignimbrite followed by a total of 7 m thick grey to brown ash flow; finally 6 m thick scarcely welded, lithic rich grey ignimbrite occur. Absolute age determination of the top lithic rich ignimbrite has given an age of 0.51 my (Mohr, 1987).

Samples for thin section study were collected from the floor basalt (N-11) and the dark ignimbrite (N-17).

### N-11 Basalt

The rock is represented by porphyritic basalt with phenocyst of plagioclase (An 60-64%). The groundmass is composed of mainly plagioclase, idingsitized olivine, very small pyroxene and fine grained opaques. Secondary calcite precipitate is also present in the vesicles.

### N-17 Glassy Ignimbrite

It is a crystal and lithic bearing ignimbrite set in a glassy matrix. The crystals include quartz, plagioclase and amphibole; lithic fragments are basaltic in nature containing plagioclase, olivine and aegirine.

#### Section 10 (NAZRET CITY DUMP)

The section is taken in the vicinity of the Nazret city dump. It presents a base of 3 m thick weakly stratified angular, fine depleted pumice fall deposit carrying thin levels of paleosol followed by 60 cm thick grey well consolidated ignimbrite. The top of this section is a whitish 3-4 m thick, scarcely welded coarse ignimbrite rich in pumice clasts and lithic fragments.

A sample was taken from the ignimbrite (Ge-9) immediately on top of the pumice fall deposit for thin section study.

#### Ge-9 Ignimbrite

It shows an eutaxitic texture containing abundant crystals of k-feldspar, alkali-amphibole, corroded quartz and micro-crystals of plagioclase. The lithics are represented by trachytic rock fragments. The matrix carries collapsed pumice clasts and intricately contorted glass shards.

#### Section 11 (JOGO)

The section is taken in a quarry located approximately half way along the north-northeast elongated Jogo ridge. The sequence starts with 48 m thick grey "flammae" rich ignimbrite followed by 12 m thick coarse, angular, fine depleted pumice fall deposit.

Sample of the ignimbrite unit (W-5) under microscope show crystal and lithic bearing set in a glassy matrix. The crystals

are represented by plagioclase, quartz, alkali-feldspar, hornblende and very scarce aegirine. Lithics are represented by both trachytic and basaltic rock fragments. The matrix is glassy and at places glass shards are observed.

#### Section 12 (GEDEMSA)

In order to complete the stratigraphic column of the study area, a very generalized stratigraphy of the young acidic phase of Gedemsa activity is presented here (see Table 4 for complete precaldera stratigraphy).

The pre-caldera Gedemsa volcanic products is constituted by a series of grey to brown ash flow intercalated with green ignimbrites, surge deposit and pumice rich horizons. The post caldera activity is dominated by rhyolite and obsidian lava flows rich in fragments of glass and pieces of lava. The last phase of volcanism is represented by a basaltic activity as observed from the spatter cones on the flank and floor of Gedemsa caldera. Absolute age determination of rocks of Gedemsa caldera spans from 0.8 m y to 0.2 m y (Di Paola, 1972, Bigazzi et al. 1981).

Samples were collected from the pre-caldera, green ignimbrites (G-7, G-9). In hand specimen it is well welded, green in colour and contains large fragments of acidic lava and basaltic scoria.

#### G-7 Ignimbrite

It is a crystal and lithic bearing ignimbrite set in a partially crystallized glassy matrix. The crystals include calcic plagioclase, aegirine and resorbed olivine probably representing xenocrysts. The lithics are mainly trachytic ones. The matrix is made up of dark oxidized glass with a very intense recrystallization upto the extent where ignimbritic texture is almost obliterated. It also contains fragments of juvenile magma more basic than the glass of which the matrix is constituted.

#### G-9 Ignimbrite

In thin section presents light sialic bands of partially recrystallized glassy particles containing crystals of quartz, plagioclase, alkali-feldspar and aegirine followed by darker bands made up of dark glass and crystals of plagioclase, k-feldspar and abundant riebeckite. In general an almost complete recrystallization has nearly obliterated the eutaxitic texture.

#### IV. LITHOSTRATIGRAPHY

The area under investigation exposes various types of volcanic rocks which were the results of volcanism from Pliocene to recent (Mohr, 1987 and others). Several volcanoes were active contemporaneously evidenced by the interfingering of their products.

The exposures are limited to river and road cuts and along escarpments. Large flat plains and depressions, which take up considerable amount of the study area, are covered by either reworked volcanoclastic deposits or extensive ash flow units. The products associated with centers can easily be traced if the volcanic edifice is preserved as in the case of the Gedemsa caldera but several other collapse structures, like the Boku ridge, suggest that there were a lot more volcanic centres than previously thought.

The lack of proper marker horizon, extreme lateral and vertical variations of rock units together with the fact that the exposure of the volcanic rocks are limited to a certain area, presented great difficulty in constructing a composite stratigraphic column.

The composite stratigraphic column (plate 2) is constructed mainly by the use of the lithologic identity of the rock units and incorporating the few absolute age determination data (see chapter 3 for complete discussion).

The rock units along the sections are the result of several phases of volcanism which lasted for a fixed span of time evidenced by the presence of interlayered paleosols. It is possible to subdivide these rock units into groups according to their lithological identity and spatial distribution.

Six such kind of groups have been identified: the stratoid Eastern Margin and Dera-Nazret group prevalently acidic Keleta, Boku and Gedemsa group and Melkasa group constituted by basaltic spatter cones and associated lava flows.

The subsequent subdivision of the rock units is informal and don't follow the proper stratigraphic rank. The lithological character of each unit is summarized hereunder according to the suggested stratigraphic position from bottom to top.

#### Eastern Margin Group

The stratoid rocks of the eastern margin are exposed in the southeastern region of the study area along the large boundary faults and are composed of basaltic units interlayered with ignimbrites. The composite stratigraphy has been reconstructed by the correlation of the rock types along the stepped faults. It includes the rocks along the large faults east of Keleta (fault 1) and the first major fault scarp of the rift margin at Sire (fault 2).

Fault 1 exposes a base of ignimbrite (1) followed by a basaltic unit (1). This basalt is considered to be of the same type as the basalts exposed at the base of fault (2).

Fault 2 scarp section continues by a unit composed of acidic lava flow and ignimbrite (2). This acidic unit is further capped by another basaltic unit (2) found just east of Sire town.

#### **Ignimbrite (1)**

The ignimbrite is exposed along the Dera-Sire road at the base of fault 1. It has exposure thickness of 20 m. In general it is grey in colour, well welded and highly jointed. In hand-specimen it carries fragments of pumice clasts, lithics and dark glass. Petrographically the ignimbrite show an eutaxitic texture with flattened pumice and glass shards containing numerous plagioclase, alkali feldspar, pyroxene and amphibole crystals together with lithics of trachytic and basaltic nature.

#### **Basalt (1)**

The basalt (1) is found along the same scarp and covers the ignimbrite (1) unit. It has a thickness of 30 m and continues across the whole length of the scarp. It is porphyritic, dark grey and at places is highly fractured. Spheroidal weathering features are also observed. Under microscope the rock presents typical basaltic texture with intertwined plagioclase associated with pyroxene and olivine. The texture is porphyritic with phenocrysts of only plagioclase.

The two units are separated by a 20 cm thick brown, crusted paleosol, and a thin 20 cm thick fine yellowish ash flow unit (Fig. 5).

## Acidic Lava Flow and Ignimbrite (2)

This rock unit is exposed along the first major fault (2) scarp at Sire. The base of this scarp exposes a highly fractured spheroidally weathered basaltic lava flows which are considered to be equivalent to basalt (1) unit. The acidic lava flow and ignimbrite (2) unit rest on basalt (1) with a 30 cm brown paleosol separation. The units are grouped together for the convenience of mapping but in the field, they present two distinct rock units separated by 1.5 m thick brown crusted paleosol.

The acidic lava flow, which overlies basalt (1), show clear flow structures typical of viscous lavas with approximate flow orientation towards the downthrown side of the fault. It has an average thickness of 10 m and contains considerable amount of scoria fragment ranging in size from 20 to 50 cm and levels of obsidian. Under thin section it presents a porphyritic texture with phenocrysts of plagioclase set on felsic groundmass containing needles of plagioclase.

The ignimbrite (2) unit which is well exposed at the town of Sire is characterized by whitish colour and show a thickness of about 10 m. At the exposure level it carries numerous pumice fragments and is well welded. Petrographically it has eutaxitic texture with wholly and partly collapsed pumice clasts and contains quartz, alkali-feldspar and plagioclase crystals.

## Basalt (2)

The last unit for this group is formed by basalt (2) which is exposed just east of Sire town. It has 10-15 m total thickness and is composed of a series of flows separated by lines of baked brown paleosol. It is dark coloured, fine grained and is highly fractured. This rock exhibits an aphyric texture with very few microphenocryst of plagioclase and olivine set on a groundmass made up of plagioclase olivine, few pyroxene and opaques.

There is a 6 km wide flat plain separating fault 1 and 2. Principally it is covered by thick alluvium deposit but there is a northeast elongated ridge near the locality of Kara. The view of the ridge from the town of Sire shows a gentle dip of the flanks uniformly in both north-northeast and south-southwest direction which gradually merge with the floor. The rocks exposed along this ridge include a base of strongly welded greyish lithic bearing ignimbrite of 15 m exposed thickness covered by a dark fine grained basalt having a maximum thickness of 10 m. This ridge is here considered to be a collapse remnant exposing rocks equivalent to basalt and ignimbrite which outcrop along fault 1.

## DERA - NAZRET GROUP

The stratoid Dera-Nazret group rocks are exposed along a northeast-southwest elongated belt starting from Dera to Sedore and near Nazret. In general the rocks of this group are composed

of acidic lava flows and domes followed by an ignimbrite unit and two basaltic units, one of which is interlayered between lava dome and ignimbrite.

#### Acidic Lava Domes and Flows

This rock unit is exposed along either northeast elongated ridges or in a form of a typical domal structure. The main part of this unit is exposed in the Dera-Sodore area. It's exposed as a typical domal structure at Dera and Bodecha where as at Sodore it forms north-northeast elongated ridge. Similarly oriented ridge is found in the vicinity of Nazret town at Dibibia.

The rocks are composed of rhyolites, light in colour interlayered with dark obsidian levels. They show clear flow structures and at places are columnarly jointed. In this section the rocks are generally porphyritic with felsic to glassy ground-mass including phenocrysts of plagioclase, quartz, pyroxene and alkali feldspar.

#### Ignimbrite

This ignimbrite unit mostly outcrop along north-northeast oriented fault escarpments exposed west of Nazret (scarp west of Nazret, Jogo, Didimtu and Germama areas). It is represented by pale green, well welded ignimbrite characterized by the occurrence of several lenses of dark glass (fiammae) ranging in size from 3 to 20 cm. The thickness of the unit varies from 2 to 40 m, where towards the top, the ignimbrite becomes less welded and includes larger amount of lithic fragments.

Similar ignimbrite unit has also been found along the road to Sodore having an exposure thickness ranging from 20-25 m. It is characterized by a base of grey well welded ignimbrite with "fiammae" of dark glass, while the top 1.5 m is formed by an ignimbrite containing patches of glass, pumice clasts and abundant lithics. From petrographic point of view, these rocks exhibit eutaxitic texture with collapsed partially crystallized pumice, crystals of quartz, plagioclase, amphibole and pyroxene and lithic fragments of basalts and trachytes.

#### **Basalt (n)**

This basalt (n) unit is only exposed along the scarp west of Nazret under the ignimbrite previously described, separated by a 30 cm thick red brown paleosol and 1 m thick fine grained brown ash flow deposit. This rock is 2.5 m thick, mostly fine grained, dark in colour and show flow lamination. Under thin section it presents a fine grained texture containing microphenocryst of plagioclase and olivine. The groundmass is formed by microcrystals of olivines, plagioclase pyroxenes and abundant opaques.

#### **Basalt**

The last unit of this group, a basalt unit, is exposed along the ridge of Kimbibit, at the base of Tadecha cone and along a ridge on the road to Sodore near the junction of Melka Woba. These rocks are represented by vesicular, dark generally fine grained basalts carrying few phenocrysts of plagioclase.

Petrographically it presents sparsely porphyritic texture set on microgranular groundmass formed by olivine plagioclase and pyroxene. The phenocrysts are of zoned plagioclase and pyroxene only.

#### KELETA GROUP

The Keleta group is an extensive pyroclastic flow deposit which can be considered as the oldest true rift floor deposit outcropping in the study area. The type locality is located along the Keleta river, in this area, it is possible to subdivide the whole pyroclastic section into a lower unit of proximal facies and an upper unit of distant facies.

The lower pyroclastic flow deposit (Fig. 6) starts with grey ash flow covered by glassy ignimbrite and a thick yellow ignimbrite.

#### Grey Ash

This unit, which outcrop at the base of the river, is composed of 2.5 m thick, fine grained, grey ash flow, containing several pumice clasts ranging in size from 1 to 5 cm. Very rare lithic fragments have also been found.

#### Glassy Ignimbrite

The Grey Ash unit is covered by a Glassy Ignimbrite with a 1 m thick brown paleosol separation, containing chips of glassy material. The ignimbrite is 2.5 m thick, dark in colour and contains levels of dark glass and stretched pumice. The base of this unit show clear horizontal flow lamination. Under thin section it has eutaxitic texture with collapsed pumice

and glass shards, quartz and plagioclase crystals with lithics of oxidized basaltic fragments and trachytes are also present.

#### Yellow Ignimbrite

The main unit of this lower pyroclastic flow is represented by 12-15 m thick yellow ignimbrite. It carries abundant pumice fragments which show variable flattening. It is columnarly jointed and contain large basaltic boulder and ignimbrite fragments reaching in size 80 cm in diameter (Fig. 7).

Petrographically the basalt is fine grained containing microphenocryst of plagioclase with groundmass of plagioclase olivine and scarce pyroxene.

Separating the yellow tuff unit from the underlying ignimbrite there is a 20 cm thick coarse grained sandy paleosol containing chips of glass, fragments of pumice and the underlying rock.

The upper pyroclastic flow deposit is exposed on the top part of the Keleta river. It is composed of loose unconsolidated units of brown and grey ash flow deposit with intercalation of several levels of paleosols. The total thickness is approximately 10 m. The ash units are fine grained and carrying small pumice fragments, especially in the grey ash unit, silicified fossil plants and gas escape routs characterized by fine depleted coarse lenses of pumice are present. The upper most unit of this group is represented by a fine grained brown ash flow deposit which is seen to cover large areas, including Dera domes, Nazret area and Gedemsa Caldera (Fig. 8).

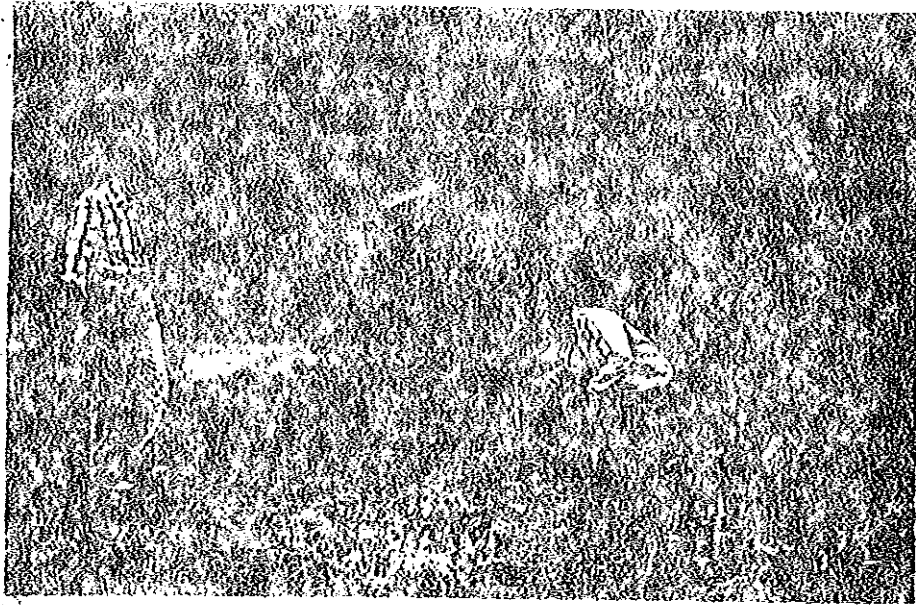


Fig.5 Fractured basalt (1)unit resting on ignimbrite (of Eastern Margin Group. It is possible to observe 40 cm of ash and paleosol between the units. Road to Sire.



Fig.6 The lower pyroclastic flow unit showing the base glassy ash, glassy ignimbrite and the main yellow ignimbrite. Ke river.

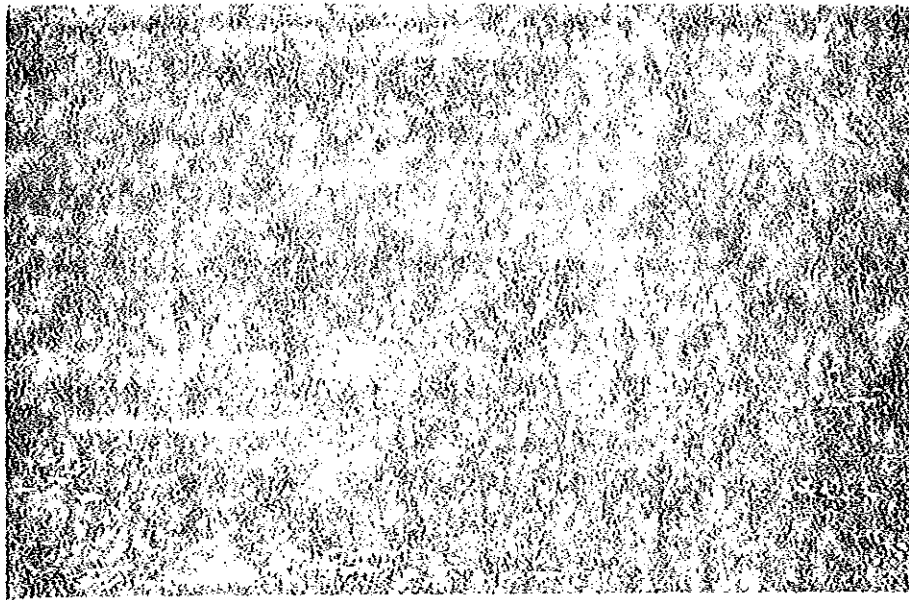


Fig.7 A basaltic boulder measuring 80 cm diameter within the yellow ignimbrite unit Keleta river.



Fig.8 Brown ash deposit intercalated between a basaltic spatter cone and a green ignimbrite of Gedemsa group. Northern shoulder of Gedemsa caldera.

The products of the Keleta group are also well exposed at Feyiso river. Here the section starts with a yellow ignimbrite unit carrying large pumice clasts and lithic fragments followed by 8 m thick brown ash flow deposit which show weak stratification and in turn overlain by 10 m thick reworked volcanoclastic deposits showing a crude stratification marked by stone lines of rounded pebbles. At the top 2-3 m thick well welded ignimbrite carrying large lenses of dark glass is found. The base of this unit is glassy and is separated from the underlying reworked volcanoclastic unit by a thin layer (20 cm) of fine grained ash flow deposit. Petrographically the ignimbrite shows an eutaxitic texture with glass shards and collapsed pumice containing crystals of plagioclase, quartz, pyroxene and lithics of trachytic nature. Eventhough the unit of this section are similar to the ones exposed at Keleta river linear correlation between them is not possible.

#### BOKU GROUP

The rocks of this group are associated with a large central volcano and several smaller centers outcropping near Wagillo. The volcanic products connected with the activity of these centers, are observed to extend as far as Jojo ridge and fill all the depressions found in the western part of the study area.

These rocks are constituted by a base of acidic lava flow

unit covered by a pyroclastic flow unit characterized by pumice fall deposits, ignimbrites and ash flow.

#### Acidic Lava Flow

These rocks are constituted by light rhyolites having thickness which vary from 100 m at Boku to 20 m at Wagillo and show clear flow structure with interlayers of obsidian lava. From petrographic point of view, the rhyolites show porphyritic texture with felsic groundmass containing phenocrysts of quartz and amphibole; needles of plagioclase are also present.

#### Pyroclastic Flow and Fall

The rocks of this group are exposed at Wagillo, Boku, near Nazret city dump, at Kimbibit river and in a quarry located along the Koka-Nazret road.

At Wagillo, this unit is constituted by 10 m thick, weakly stratified, coarse, fine depleted pumice fall deposit. The pumice clasts are sub-angular and are interlayered with 1 m thick grey well welded ignimbrite, patches of dark glass and grey, fine ash flow deposit.

Near Boku ridge, in a small quarry, a 5 m thick very coarse pumice fall deposit carrying large lenses of obsidian occur.

At the Nazret city dump, this unit is made up by a base

of coarse, angular, fine depleted pumice fall deposit carrying levels of grey and brown ash giving an overall appearance of weak stratification. On top of this section, separated by 20 cm thick brown paleosol, 60 cm, thick, well welded grey ignimbrite occur. Finally a whitish, 3-4 thick scarcely welded coarse ignimbrite rich in pumice clasts and lithic fragments cap all the unit.

At Kimbibit river, rocks of this group cover a basalt unit of Dera-Nazret group. This section starts with a base of 1.5 m thick, black, fine grained, glassy ignimbrite followed by a total of 6 m thick, brown to grey ash flows separated by thin horizons of paleosol.

The best outcrop of this unit is located in a quarry found along Kika-Nazret road. The deposit is constituted almost entirely by weakly stratified coarse grained pumice fall containing layers of grey to brown fine grained ash flow deposits and centimetric levels of paleosol.

#### GEDEMSA GROUP

The Gedemsa group rocks are related to the youngest acidic event occurring in the study area, connected with a large central volcano which later collapsed to give rise to a 7 km wide caldera bounded by vertical wall of 150-200 m height. The floor of the structure is characterized by an east-west elongated ridge formed by several domes connected

with post caldera activity. Pumice fall and surge deposits representing products of later activity are also found.

Within the limit of the area studied, the stratigraphy of this group starts with a base of very thick pyroclastic flow and ignimbrites followed by rhyolites and obsidian lava flows of post caldera activity capped finally by a pumice fall deposit.

Stratigraphic description of whole products of this group except the pumice fall deposit, described hereunder, is given in Table 4.

#### Pumice Fall

The fall deposit is exposed within Gedemsa, and along the Wonji road near the bridge on the Awash river.

In Gedemsa, the unit is characterized by 20 m thick greyish, very coarse grained pumice fall deposit. The clasts are usually angular and contain fragments of obsidian red and green lava and levels of 2.5cm thick grey fine ash deposit.

At the bridge of Awash the fall deposit is 3 m thick and show intercalation of fine grained grey ash flow deposit. The pumice clasts have smaller size as compared to the outcrop within Gedemsa.

#### MELKASA GROUP

The Melkasa group rocks are results of basaltic volcanic activity represented by numerous north-northeast aligned

spatter cones and associated lava flows. In the field it has been established that spatter cone activity began earlier than the pumiceous phase of the Boku cycle and continued upto later times (Fig. 9). The youngest phase of volcanism is of fissural type and is closely associated with the spatter cones (Fig. 10). It gave rise to a scoracious basaltic 'aa' type of flow. This unit is exposed along Tadecha area where it flows down the fault scarps and at places into river channels.

Petrographically the basalt show porphyritic texture with a microgranular groundmass. Phenocrysts are of olivine and zoned plagioclase.

Table 4

Thickness (m)	Field Description
3	fine grained brown ash flow unit.
4	light yellow welded tuff unit carrying 2-3 cm thick levels of green tuff and obsidian. The top is characterized by 70 cm-1 m thick, very fine grained light yellow tuff. The unit, in general, contain, blocks of 40 cm size of red rhyolite and oxidized lavas.
2-3	aphyric lava flow containing few phenocrysts of feldspar. The top of

- 2 this unit carries large obsidian blocks  
light brown lithic tuff. The matrix is  
fine grained carrying 1-5 cm size  
fragments of the underlying rock and  
rarely small pieces of obsidian
- 1 brown tuff of medium grained matrix  
including several fragments of 5-7 cm  
size of red and green lava. Lenses of  
10 cm thick fragment concentrated  
horizon is also present
- 4-5 very coarse grained tuff rich in  
fragments of obsidian and lavas of  
different kinds showing size varying  
from 1-2 cm upto 50 cm. Pumaceous clast  
are very common, in fact the top 2 m  
of this unit is a coarse grained  
pumaceous tuff
- 4 well welded green ignimbrite
- 6 mainly aphyric scoriaceous lava flow  
carrying few feldspar phenocryst very  
coarse grained welded tuff unit rich  
in lithic fragments. Large, 1.5 m red  
lava and obsidian blocks are present.
- 3 light brown, fine grained, pumaceous

	tuff containing blocks of 10-20 cm size obsidian and different kinds of lava. Beds of 10 cm thick of very coarse pumice are interlayered
15	well stratified green tuff. Singular beds are 10 cm thick having medium to coarse grained matrix. It contains centimetric levels of fine depleted pumice.
3-4	a base surge deposit of dark brown colour and containing cross-bedding marks. Basaltic lapilli, pisolites, and lenses of coarse matrix are also present.
4-5	brecciated ignimbrite containing blocks of red rhyolite, aphyric lava and obsidian ranging in size from 1-1.5 m.

Table 4 A stratigraphic section along the northern boarder of Gedemsa caldera.

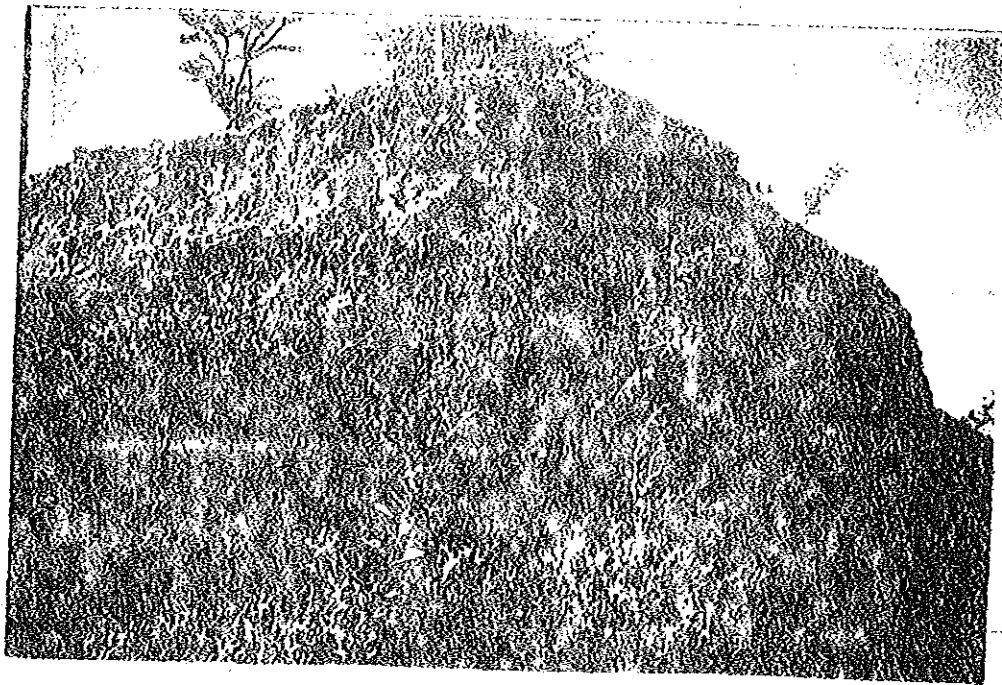


Fig.9 Contact between the underlying basaltic spatter cone and overlying pumice fall deposit of Boku Group. Quarry along Koka road.



Fig.10 Kurfa spatter cone and associated 'aa' type basaltic lava flow. Awash Melkasa.

## V. STRUCTURAL GEOLOGY

The area under investigation, located in the northern part of the Main Ethiopian Rift, is characterized by a well marked eastern and poorly defined western margin bounding a 45 km wide depression. The depression, which is part of the rift floor, is affected by several tectonic and volcanotectonic features such as "en echelon" arrays of faults and grabens, partly destructed and preserved calderas, elongated domes and aligned spatter cones.

The marginal faults are located in the southeastern and northwestern part of the study area. The southeastern faults (Fig. 11) trend N30 E and are arranged in "en echelon" arrays. They have throws ranging from 200-250 m and at the tip of each segment there are splays which are concave towards the downthrown side of the fault. These escarpments cut all the volcanic products belonging to the eastern plateau which has an age of approximately 1.7 m y (Bigazzi et al. 1981).

The western marginal faults, located in the northwestern part of the study area, are constituted by several N20 E oriented faults and a large curved volcanotectonic structure. The throw of the faults range from 50 m to 120 m and cut the rocks of the Dera-Nazret group which date approximately 1.7 m y (Mohr, 1987).

The faults of the floor, considered to be part of the Wonji Fault Belt (Mohr, 1960), are generally linear and run in north - northeast direction. They are arranged in "en echelon" arrays and form several tectonic depressions like the ones found in the area of Boku, Wagillo,

Dera, eastern side of Koka and also at Gedemsa caldera. They show throws ranging from 5 to 60 m and cut the whole sequence of rocks outcropping in the area i.e. they are seen to cut rocks ranging in age from 1.7 m y (ignimbrites of Dera-Nazret group) to 0.06 m y (Basaltic spatter cones of Melkasa group Bigazzi, et al. 1981).

Well developed fault scarps are observed in the western part of the study area and in particular along the eastern border of Koka lake. The faults are arranged in right stepping "en echelon" overlap and extend upto the Nazret area. They are characterized by a nicely developed escarpment ranging in height from 60 m in the southern part to 5 m in the northern one. The throw of these structures, which displace the rocks of Dera-Nazret group is difficult to measure but, field consideration suggest that the maximum throw does not exceed the height of the entire fault scarp.

Similar well developed fault system is present along the eastern rim of Gedemsa caldera, immediately south of Wonji Sugar Plantation. In this locality, a complex fault pattern trending north-northeast, south-southwest give rise to a graben-in-graben structure which extend for a about 15 km. The western border of this structure is formed by a fault set which cut and dismember the eastern rim of Gedemsa caldera. These faults, at places, seem to have a left component motion; in fact along the eastern flank of Gedemsa caldera, in the vicinity of Cheka village, the crest of a cone and a nearby river channel are seen to be offset in a sinistral way (Figs. 12, 13).

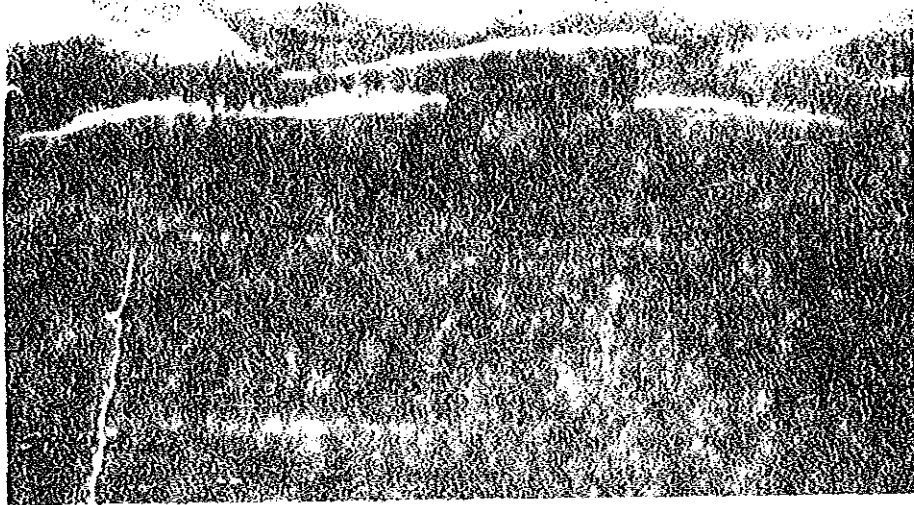


Fig.11 The fault scarps of the Eastern margin of the Rift at Sire. View towards east.

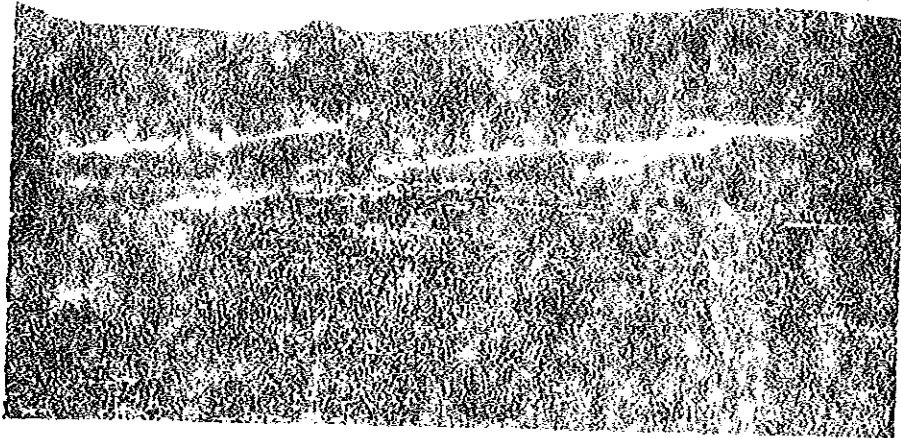


Fig. 12 Normal fault scarp cutting ignimbrites of Gedemsa Group. Crest and river show left slip component along fault. Eastern side of Gedemsa caldera. View towards west.



Fig. 13 Close up of Fig. 12.

From volcanotectonic point of view, the area is characterized by; preserved caldera (Gedemsa), partly preserved caldera rims (Boku, Wagillo), other volcanotectonic collapse structure like Jogo, elongated rhyolitic domes including Sodore, Dibibisa, Tedemariam, and aligned spatter cones.

The Gedemsa structure is a completely preserved caldera with an average diameter of 7 km. The rim is constituted by a near vertical wall rising from a floor having an average altitude of 1640 m to a maximum height of 1850 m. The floor of the caldera is dominated by several approximately east-west aligned rhyolitic domes of post caldera activity.

In Boku and Wagillo area several remnants of caldera rims, evidenced by their curved outline and constituted by rhyolitic lava flow are present. The largest one, Boku ridge is facing northeast and has 160 m height. Its flank is cut by north-south oriented faults forming a 1 km wide graben along which strong hydrothermal activity occurs. Similar but less curved ridge is present in the Jogo area which is constituted by composite curved ridges facing west.

Most of the rhyolitic domes within the study area, have ellipsoidal outline with their long axes oriented in north-northeast direction. Marked examples include, a pair of domes found in Tedemariam and Sodore areas and the Dibibisa dome found in the eastern part of Nazret.

The basaltic spatter cones, one of the last phases of volcanic activity, are concentrated along a north-northeast aligned belt which starts from the eastern side of Gedema and continues with a right "en echelon" displacement at Boku area. Some of the spatter cones have later been disrupted to give rise to fresh 'AA' type of lava flow as observed near Melkasa area.

To evaluate the kinematics of the major structures which affected the area, a study on the meso structures was carried out. In particular this study was undertaken through careful measurements of mesofaults with slicklines, extensional fractures and joints excluding those meso structures which could have been genetically linked with volcanic phenomena; such as flow surfaces, cooling fractures and collapsed pumices. Such meso-scale structural data were collected from 15 selected stations.

#### Station 1

The station is taken along a graben located 4 km west of Nazret. Mesofaults run in northeast-southwest direction and show pitch of slicklines ranging from 5 to 45, indicating an east-northeast west-southwest extension direction (Fig.16).

#### Station 2

The station is located within the campus of Sodore Hotel where a brown tuff of upper Keleta series is affected by

mesofaults which are oriented from N175 E to N30 E and having pitch of striae ranging from 46 to 90 suggesting northeast-southwest extension direction (Fig. 17).

#### Station 3

In a quarry of pumice fall deposit of Gedemsa group along the road to Koka, faults, mostly trending north-south direction showing pitches ranging from 30 to 77 are present. Data from several other fault planes without clear kinematic indicators are also collected. Extension inferred from striated fault planes show an east-northeast-west-southwest direction (Fig. 18).

#### Station 4

On a lacustrine deposit found on the eastern side of the Awash bridge, along the road to Wonji, faults oriented in east-west direction with sub-horizontal (less than 10) slicklines indicating right - slip and north-south oriented faults with sub-vertical slicklines are present. The average extension is oriented roughly in northeast-southwest direction (Fig. 19).

#### Station 5

Along Keleta river, on the main unit of the lower pyroclastic sequence, two fault planes measuring N05 E and N45 E and having pitches of slicklines 82 and 12 respectively are present. Extension direction from this data gives N40 E.

Numerous joints in northeast-southwest direction related to the faults are also observed (Fig. 20).

#### Station 6

At Shewa estate, a basaltic spatter cone (Fig. 14) shows normal faults trending north-northeast, south-southwest. On a single fault plane slickline with pitch of 74 was recorded (Fig. 21)

#### Station 7

5 km along Nazret-Melkasa road, within a quarry of basaltic spatter cone (Fig. 15) normal faults with orientation ranging from north-south upto northeast-southwest are present (Fig. 22).

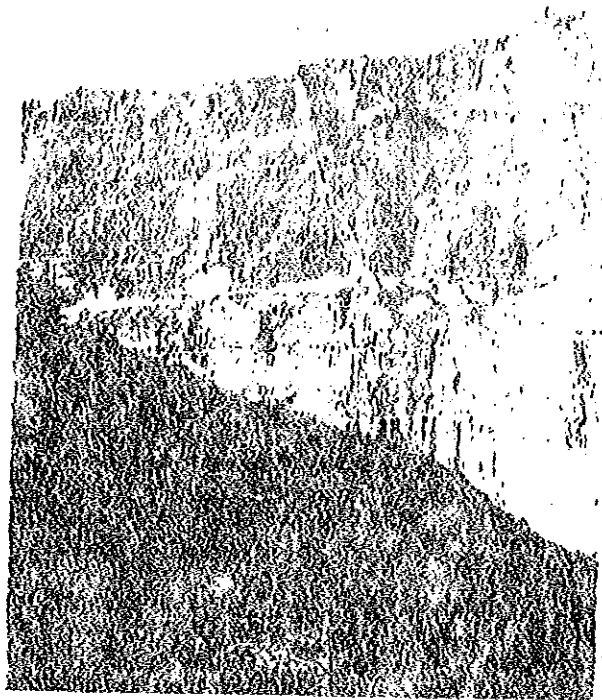


Fig.14 Normal faults affecting basaltic spatter cone located along Nazret-Melkasa road. Roadside near junction to Wagillo. View towards northeast.

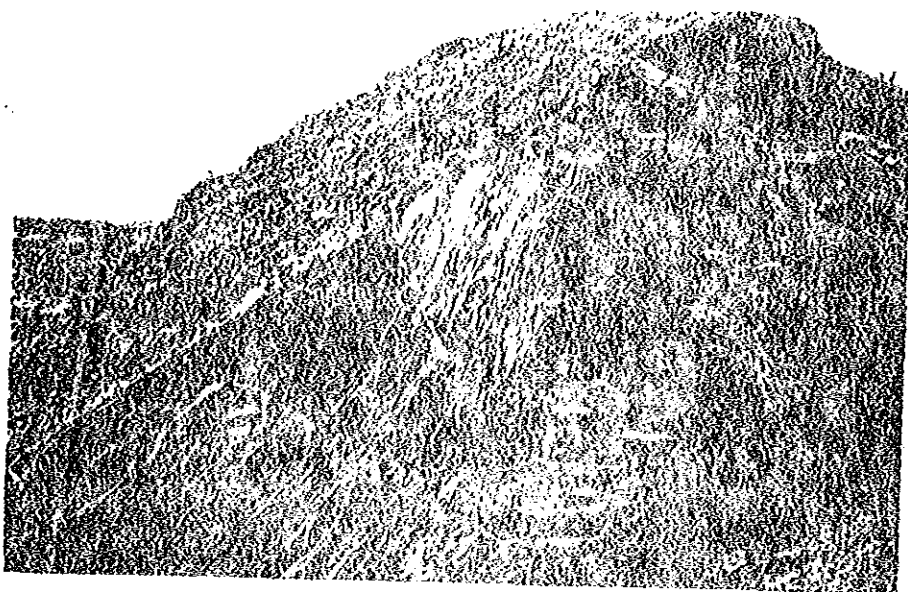


Fig.15 Normal faults near Gedemsa caldera within a quarry of basaltic scoria. Near Shewa estate. View towards south.

#### Station 8

The quarry of pumice fall deposit of Boku group located along the city dump near Nazret is affected by meso-scale normal faults whose orientation range from north-northeast to east-northeast direction (Fig. 23).

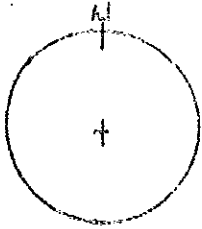
#### Station 9 - 12

At these 4 stations data of extensional fractures were collected. The sites are located, within campus of EELPA (Station 9), along the road to Sodore (Station 10), near Wonji (Station 11) and in the vicinity of Kimbibit ridge (Station 12). The extensional fractures at Stations 9, 10 and 12 affect the lithic ignimbrite unit of Boku group whereas at Station 11 the extensional fractures are found within the pumice fall deposit of Gedemsa group. The fractures display "en echelon" pattern and are oriented in a roughly north-northeast, south-southwest direction having openings in the order of few centimeters. The openings are filled with fine grained material of the host-rock material which have been affected by strong hydrothermal activity (Fig. 24-27).

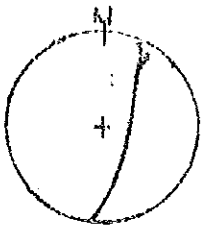
#### Station 13 - 15

Numerous data of joints were collected at the three stations. On average, the joints have north-northeast, south-southwest direction and affect the lithic ignimbrite of Boku group at; the floor of Luma river (Station 13), 5 km west of Nazret (Station 14) and 3 km west of Nazret (Station 15) (Fig. 28-30).

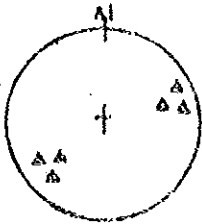
MESOSCALE STRUCTURAL DATA



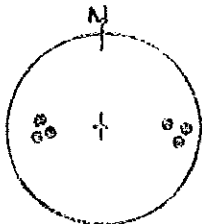
Lambert equal area projection



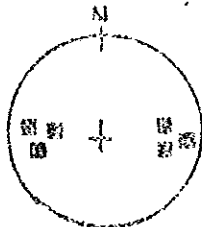
Fault with striae



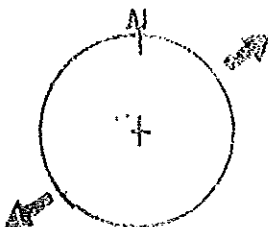
Normal fault



Joint



Extensional fractures



Extension direction

Station Number 1

Locality 4 km from Nazret towards Addis along a graben.

Type of Structure normal fault

Lithology Ignimbrite with "fiammae" of Dera-Nazret group

Structural Data

<u>Dip Direction</u>	<u>Dip</u>	<u>Pitch</u>
165	75	5W
150	80	45
122	75	188
143	85	20SW

Fig. 16 stereoplot of data of station 1, with extension direction.

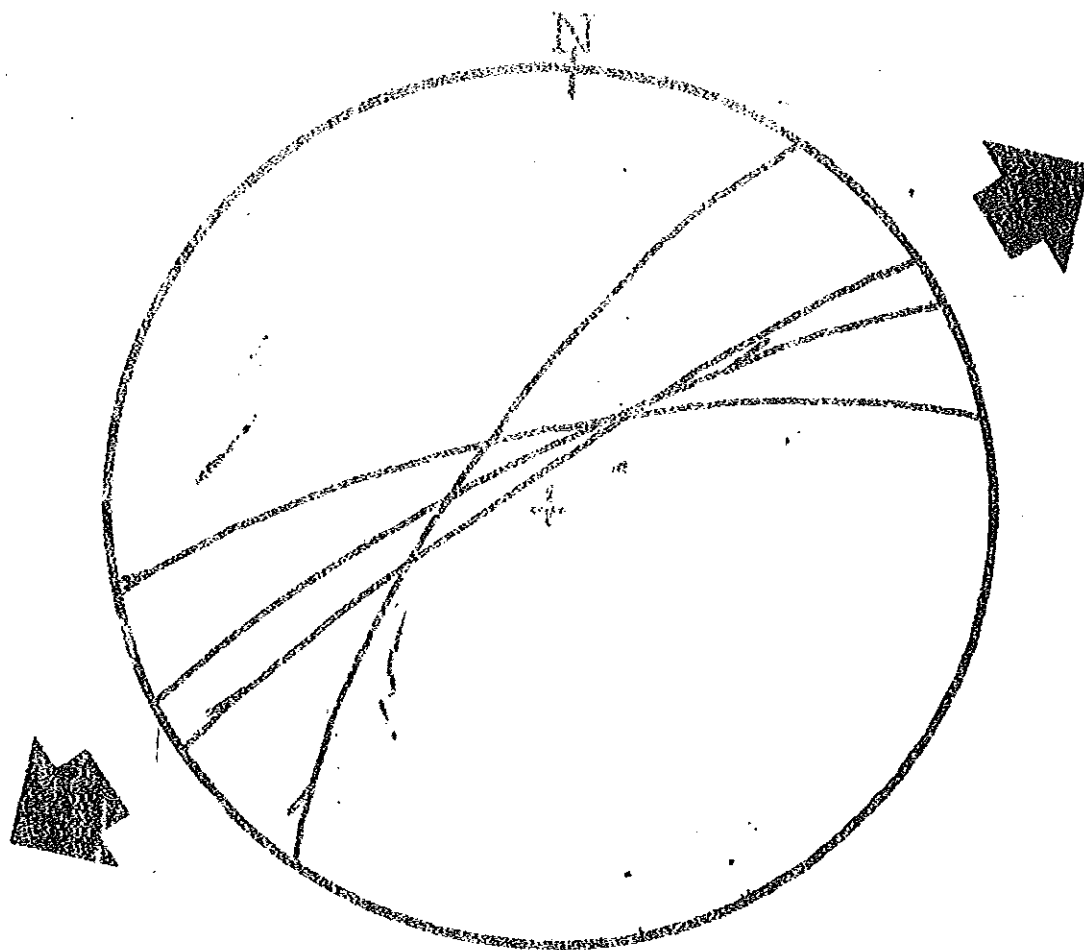


FIG 16.

Station Number 2

Locality Sodore within campus of hotel

Type of Structure Normal faults

Lithology Brown tuff of Upper Keleta Unit

Structural data

<u>Dip Direction</u>	<u>Dip</u>	<u>Pitch</u>
266	74	90
110	80	46N
120	82	80N

Fig. 17 Stereoplot of data of station 2, with extension direction.

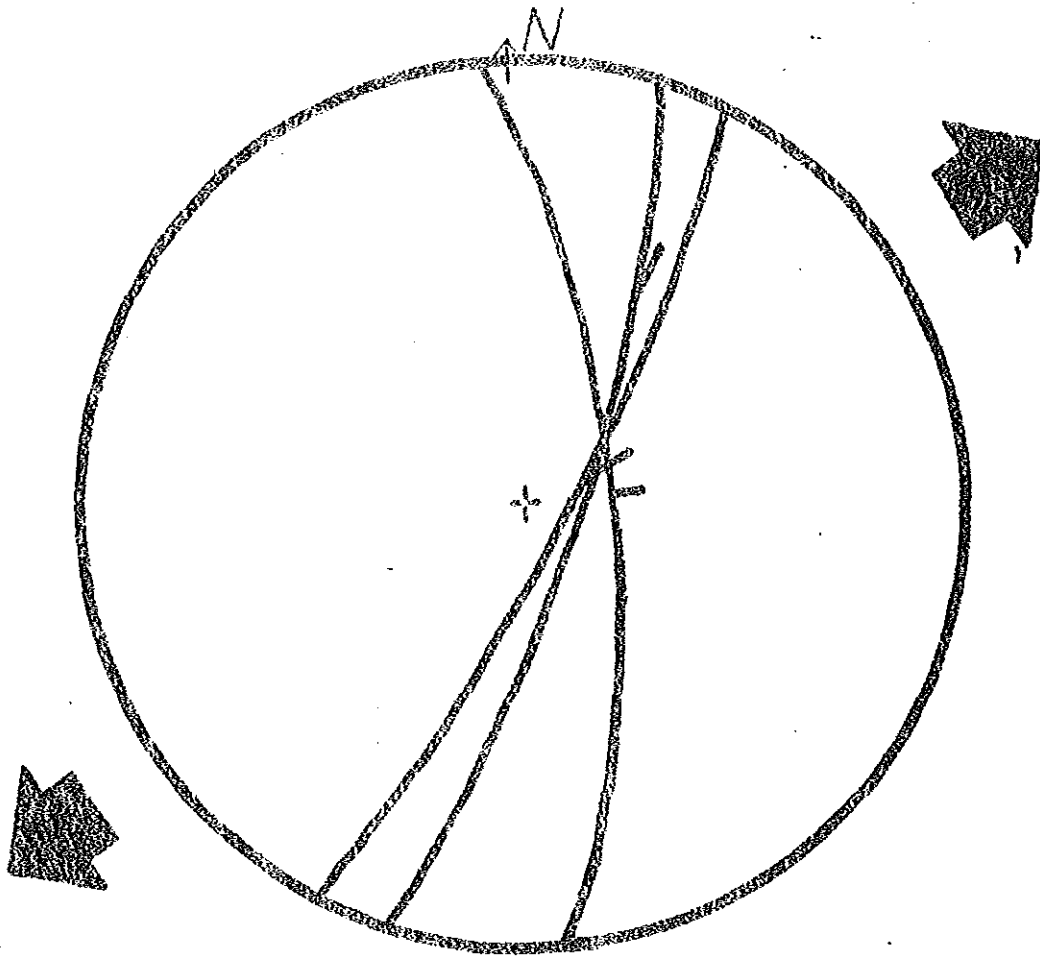


FIG 17

Station Number 3

Locality Quarry along road to Koka  
Type of Structure Normal faults  
Lithology Pumice fall deposit of Boku group  
Structural Data

<u>Dip Direction</u>	<u>Dip</u>	<u>Pitch</u>
90	70	30 S
260	85	77 S
220	80	60 W
255	68	74 N
265	80	-
136	55	-
275	85	-
176	90	-
264	90	-
145	65	-
342	85	-
225	65	-
72	85	-
237	80	-
295	60	-
70	90	-
295	80	-
107	80	-

<u>Dip Direction</u>	<u>Dip</u>	<u>Pitch</u>
330	60	-
315	60	-
155	75	-
270	65	-
68	90	-
192	60	-
295	65	-
310	55	-
100	70	-
310	80	-
105	80	-
265	70	-
105	90	-
260	70	-
98	60	-
345	85	-
300	65	-
145	90	-
100	65	-
162	80	-
115	80	-
80	72	-
95	80	-

<u>Dip Direction</u>	<u>Dip</u>	<u>Pitch</u>
115	89	-
280	70	-
100	90	-
260	80	-
215	60	-
255	65	-
248	60	-
262	80	-
258	83	-
124	60	-
105	68	-
265	60	-
97	83	-
245	62	-
242	58	-

Fig. 18 stereoplot of data of station 3 with extension direction.

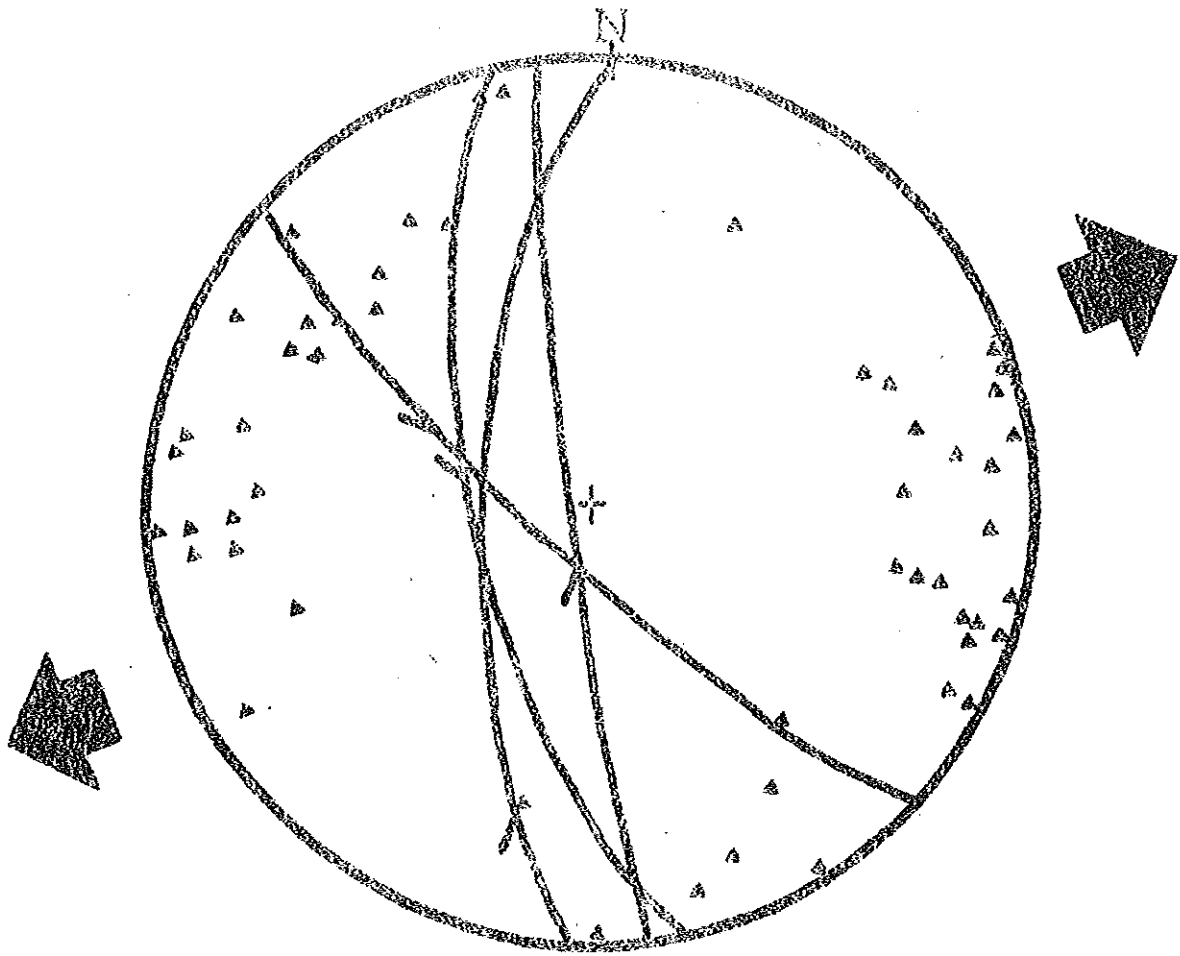


FIG 18

Station Number 4

Locality Roadside, along road to Wonji before  
Awash bridge.

Type of Structure Normal faults, joints and open fractures

Lithology Lacustrine deposit

Structural Data

<u>Dip</u>	<u>Direction</u>	<u>Dip</u>	<u>Pitch</u>	<u>Type of Structure</u>
100		60	10 S	Normal fault
95		70	90	" "
190		90	50 E	" "
180		82	30 W	" "
95		90	-	Open fracture
170		90	-	Joints
260		90	-	"
240		90	-	"
135		90	-	"

Fig. 19 stereoplot of data of station 4, with extension  
direction.

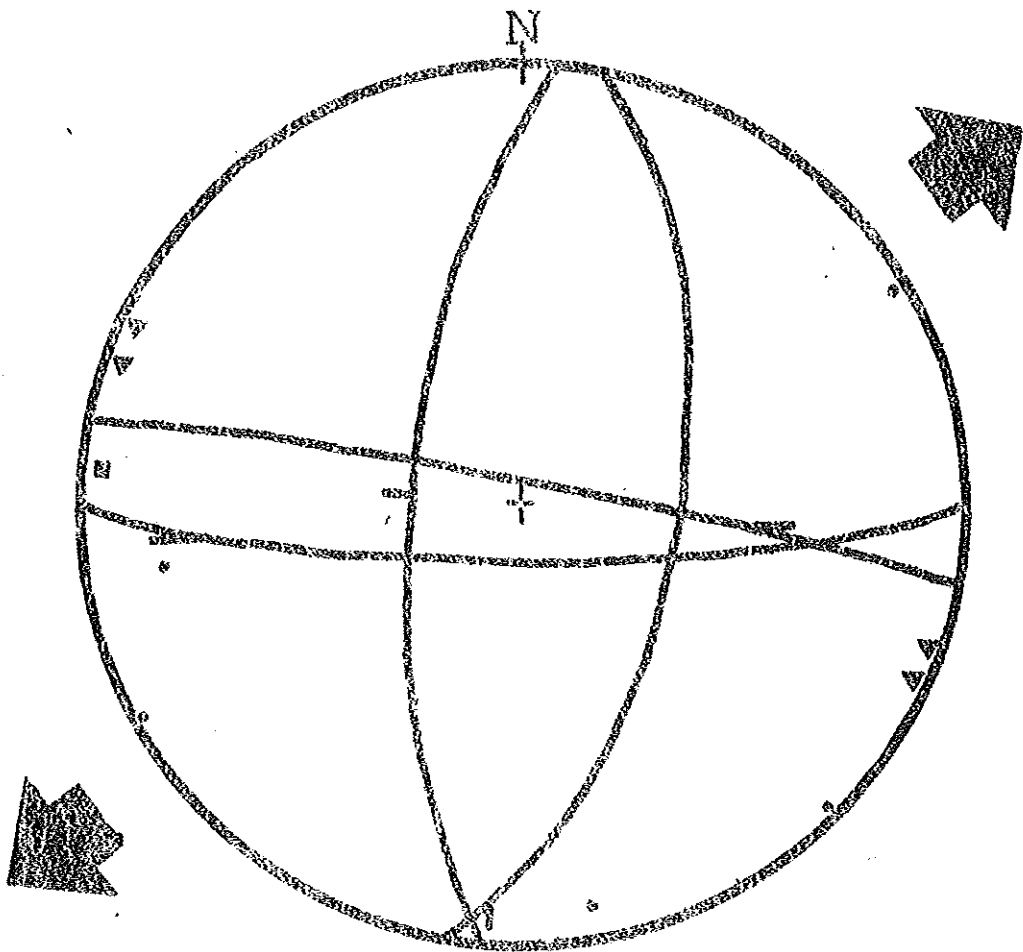


FIG 19

Station Number 5

Locality Keleta river

Type of Structure Joints, faults

Lithology Yellow ignimbrite of Lower Keleta unit

Structural Data

<u>Dip direction</u>	<u>Dip</u>	<u>Pitch</u>	<u>Type of Structure</u>
95	86	82 N	Normal fault
130	86	12 SW	" "
319	60	-	Joints
305	90	-	"
125	85	-	"
133	65	-	"
135	56	-	"
310	85	-	"
126	90	-	"
292	75	-	"
309	85	-	"
123	85	-	"
313	90	-	"
300	90	-	"
132	85	-	"
320	85	-	"
133	85	-	"
303	90	-	"

<u>Dip Direction</u>	<u>Dip</u>	<u>Pitch</u>	<u>Type of Structure</u>
305	85	-	Joints
132	90	-	"
120	80	-	"
312	85	-	"
310	80	-	"
320	85	-	"
140	82	-	"
320	85	-	"
306	90	-	"
314	85	-	"
125	80	-	"
309	90	-	"
295	85	-	"
125	85	-	"
310	85	-	"
310	80	-	"

Fig. 20 stereoplot of data of station 3, with extension direction.

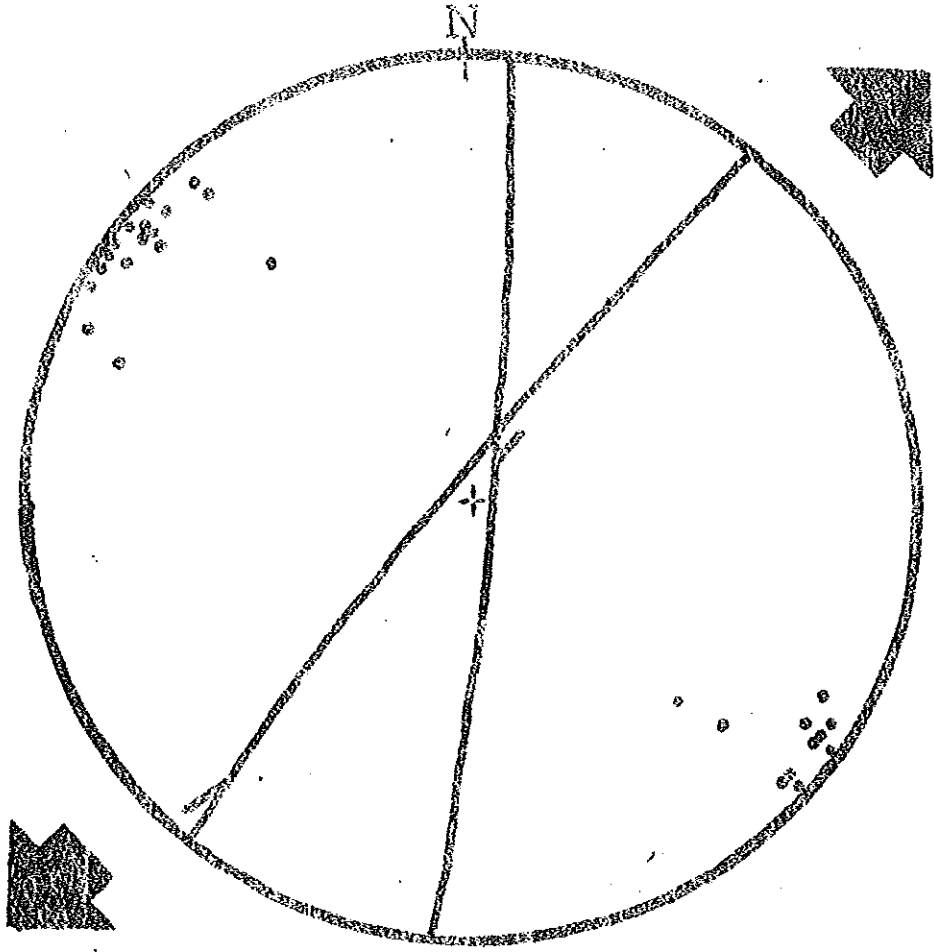


FIG 20

Station Number 6

Locality Quarry near Shewa estate

Type of Structure Normal faults

Lithology Basaltic spatter cone

Structural Data

<u>Dip Direction</u>	<u>Dip</u>	<u>Pitch</u>
115	72	74 N
90	75	-
100	60	-
96	70	-
130	65	-
105	50	-
165	50	-
195	60	-
253	80	-
110	70	-
120	80	-
120	65	-

Fig. 21 stereoplot of data of station 6.

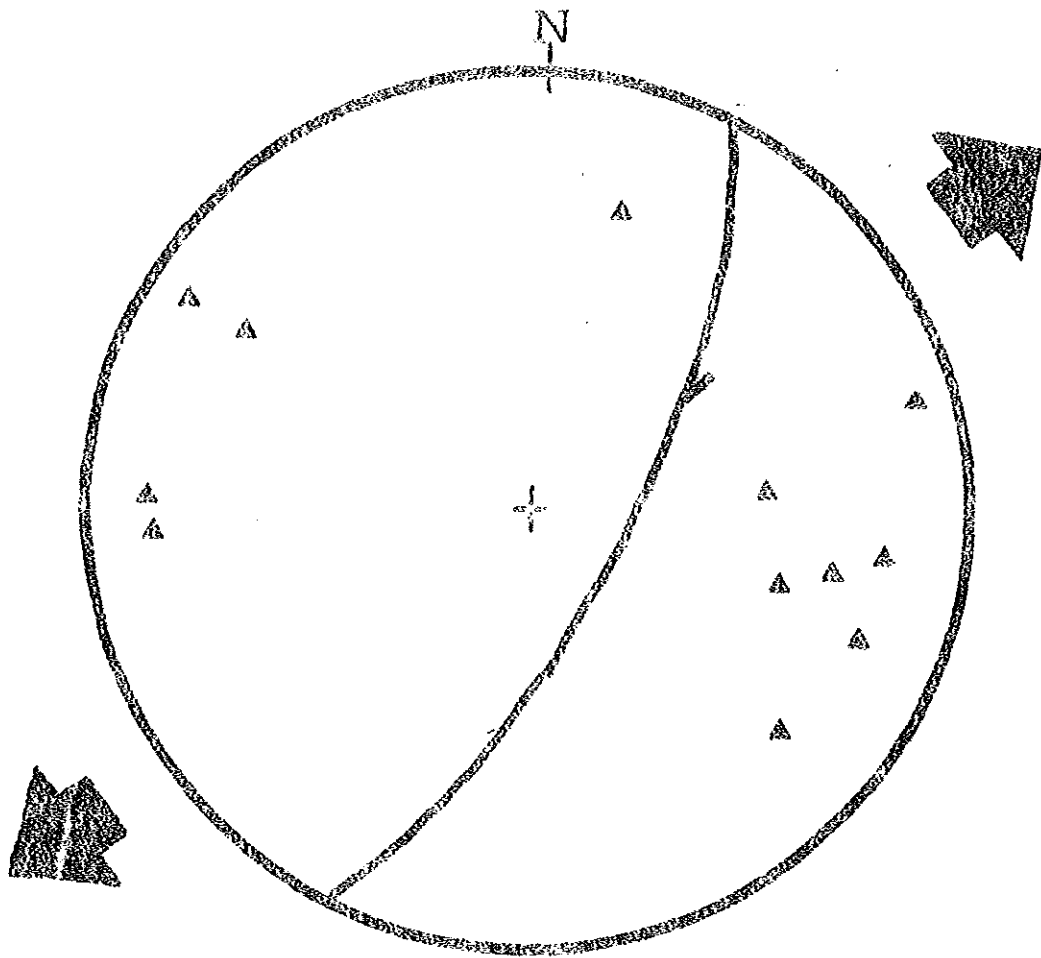


FIG 21

Station Number 7

Locality 5 km along Nazret-Melkasa road

Type of Structure Normal faults

Lithology Basaltic spatter cone

Structural Data

<u>Dip Direction</u>	<u>Dip</u>	<u>Pitch</u>
90	50	-
92	54	-
100	60	-
140	54	-
148	56	-
318	30	-

Fig. 22 stereoplot of data of station 7.

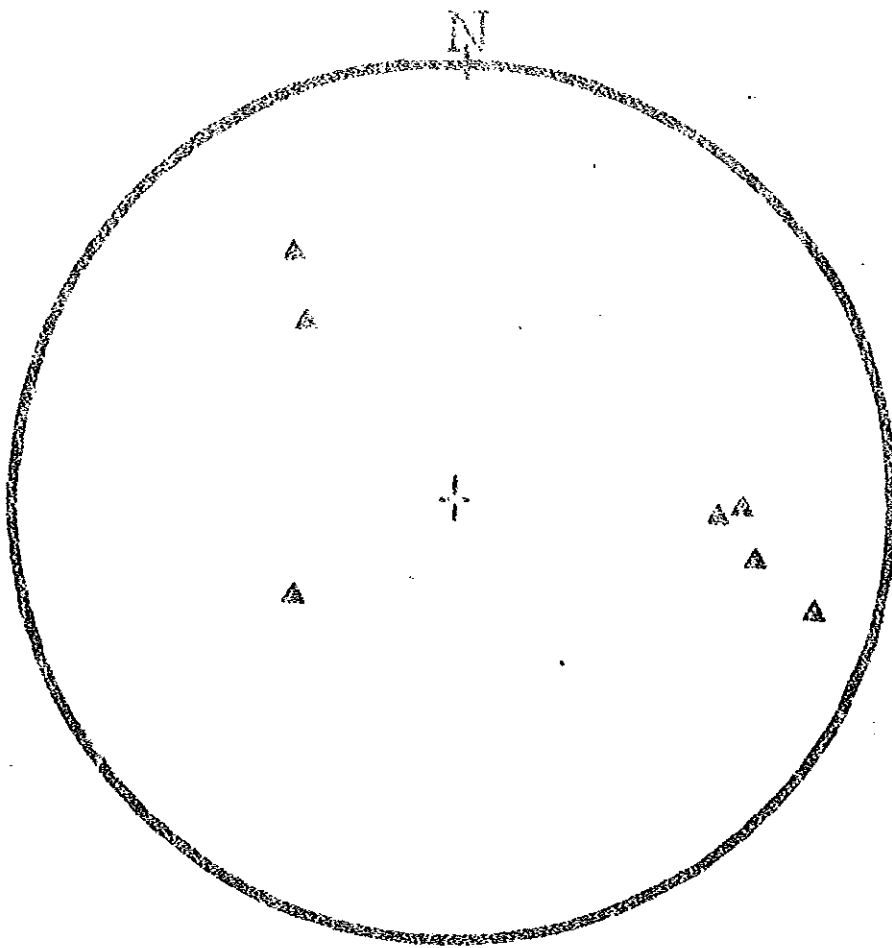


FIG 22

Station Number 8

Locality Near the Nazret city dump  
Type of Structure Normal faults  
Lithology Pumice fall deposit of Boku Group  
Structural Data

<u>Dip Direction</u>	<u>Dip</u>	<u>Pitch</u>
321	79	-
344	70	-
286	85	-
145	90	-
280	87	-
115	75	-
310	70	-
345	80	-
282	60	-
307	75	-
322	70	-
82	80	-
702	75	-
245	60	-
294	80	-
255	70	-

Fig. 23 Stereoplot of data of station 8.

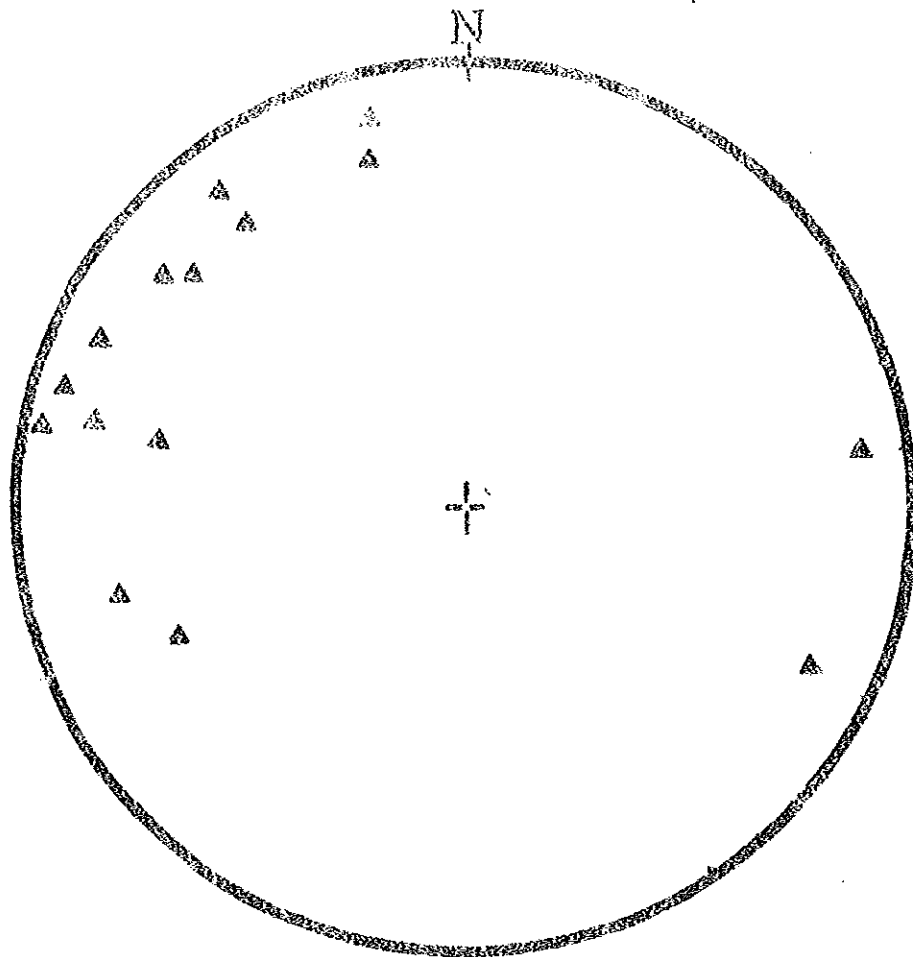


FIG 23

Station Number 9

Locality Within the campus of EELPA at Melkasa  
Type of Structure Extensional fractures  
Lithology Fiammae ignimbrite of Dera-Nazret group  
Structural Data

<u>Dip Direction</u>	<u>Dip</u>
350	80
275	88
268	88
265	88
285	85
282	84
290	86
282	88
278	86
275	85
303	85
300	85
275	82
278	82
357	80
350	82
320	88
309	86
310	80

Fig. 24 stereoplot of data of station 9.

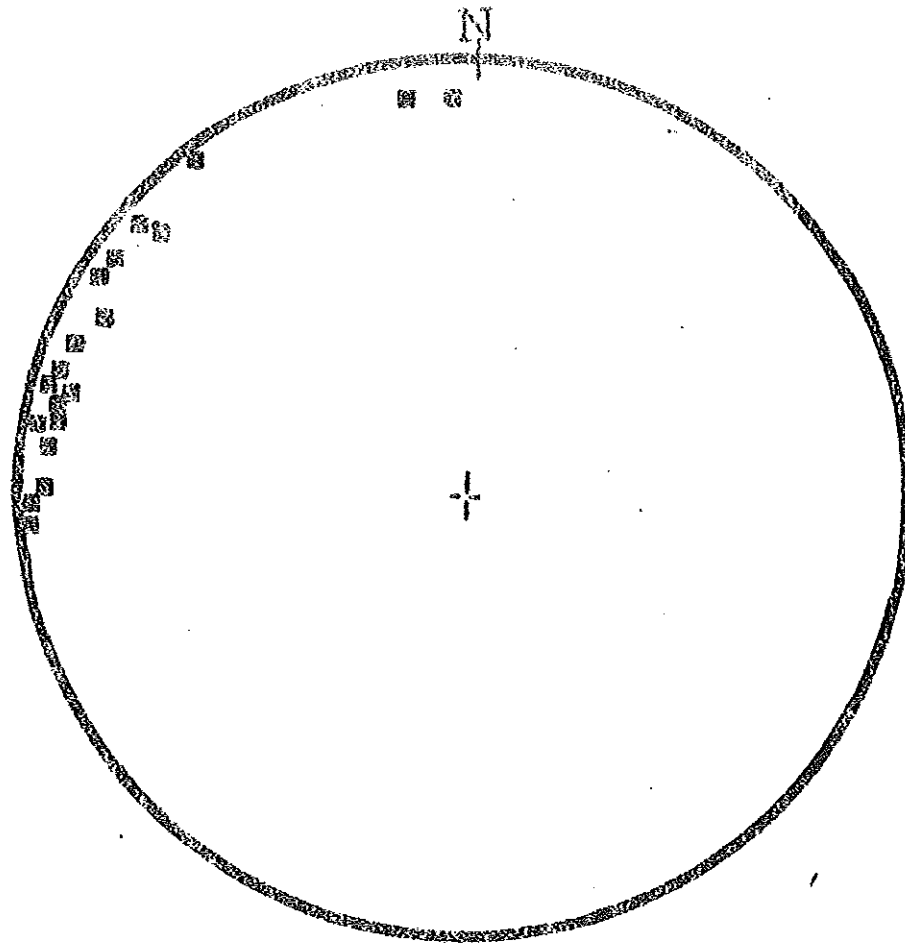


FIG 24

Station Number 10

Locality Roadside, along Sodore road at junction  
of Melka Wooba

Type of Structure Extensional fractures

Lithology Coarse Ignimbrite of Boku group

Structural Data

<u>Dip Direction</u>	<u>Dip</u>
285	82
290	80
282	86
108	86
272	88
280	86
284	82
283	88
105	88
288	82
300	88
292	88
287	88

Fig. 25 stereoplot of data of station 10.

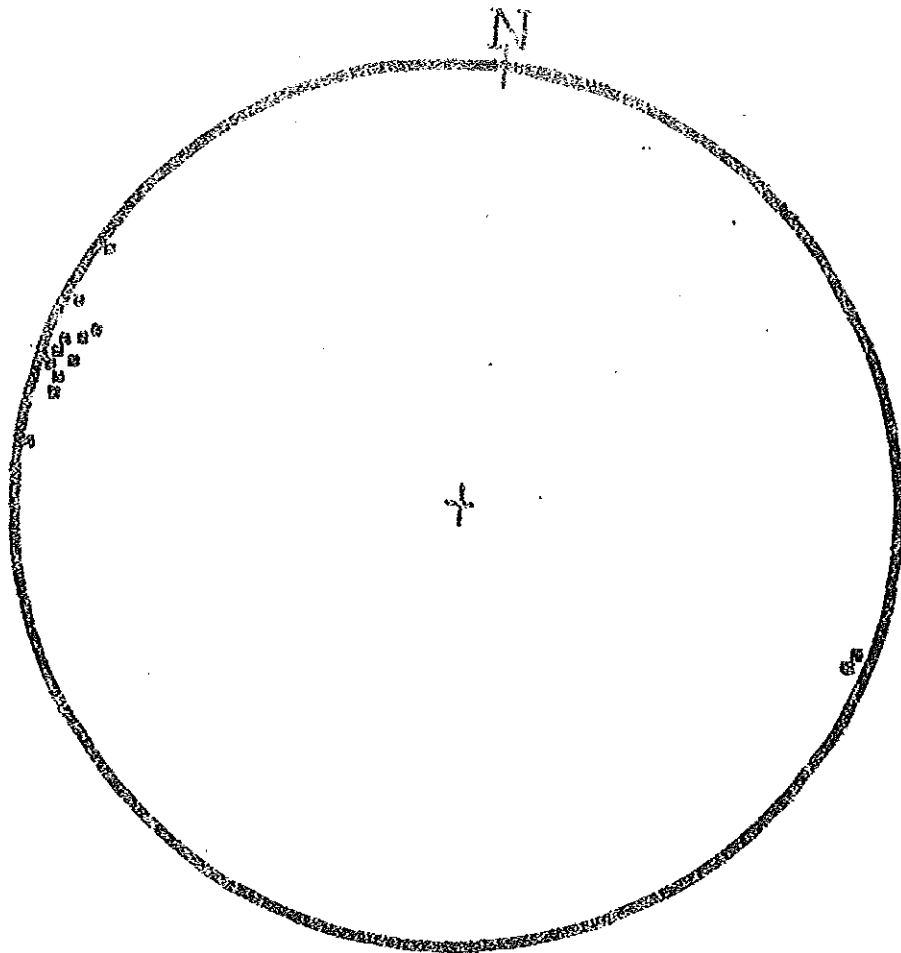


FIG 25

Station Number 11

Locality Roadside along road to Wonji after  
Awash bridge

Type of Structure Extensional Fracture

Lithology Pumice fall deposit of Gedemsa group

Structural Data

<u>Dip Direction</u>	<u>Dip</u>
90	85
95	88
92	87
105	80
100	89
102	87
100	85
120	87
140	85
100	82
105	85
129	81
127	84
125	86
129	88

Fig. 26 stereoplot of data of station 11.

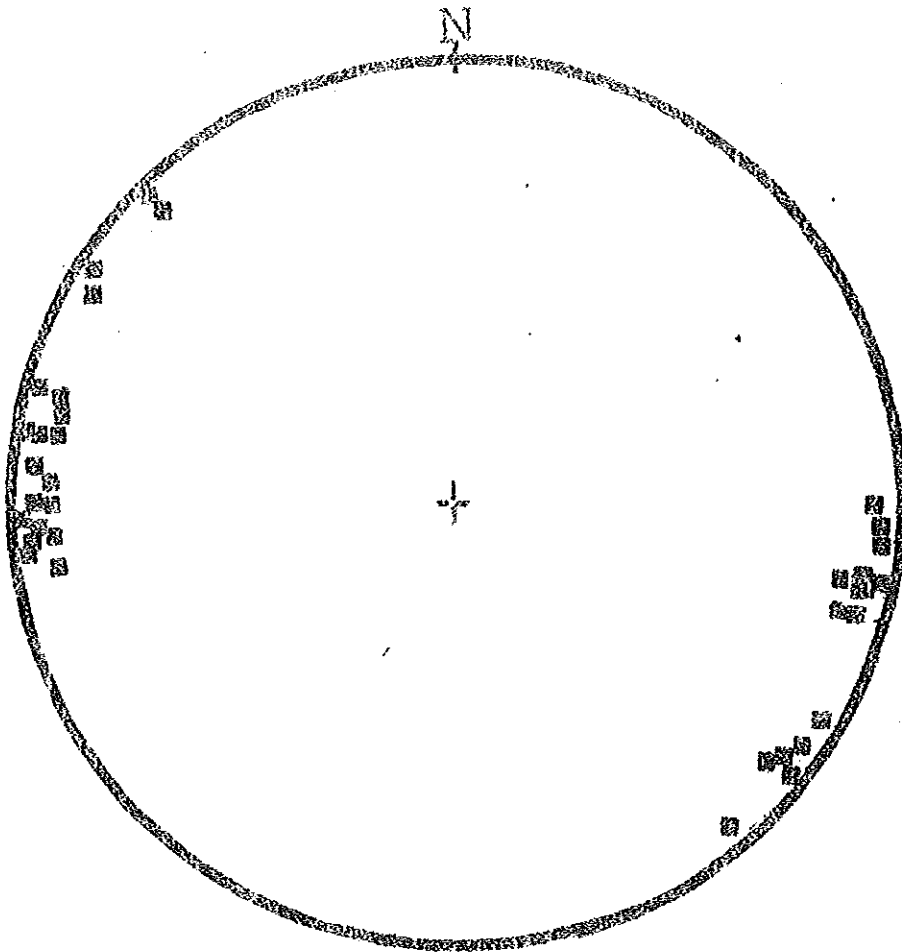


FIG 26

Station Number 12

Locality Roadside base of Kimbibit ridge  
Type of Structure Open fracture  
Lithology Coarse Ignimbrite of Boku Group  
Structural Data

<u>Dip Direction</u>	<u>Dip</u>
137	82
150	85
135	85
280	80
115	87
112	85
110	88
120	87
160	88
140	80
120	82
115	80
285	84
130	81
110	80
122	84
121	85
315	87

<u>Dip Direction</u>	<u>Dip</u>
323	86
125	86
128	80
110	82
145	85
305	85
255	89
140	87
320	80
345	82
145	85
115	82
120	84
280	80
302	82
320	80
315	82
328	87
170	86
300	87
155	80
330	85
140	88
152	82

<u>Dip Direction</u>	<u>Dip</u>
175	80
330	80
160	81
332	83
295	86
340	84
145	83
130	82
128	83
130	84

Fig. 27      stereoplot of data of station 12.

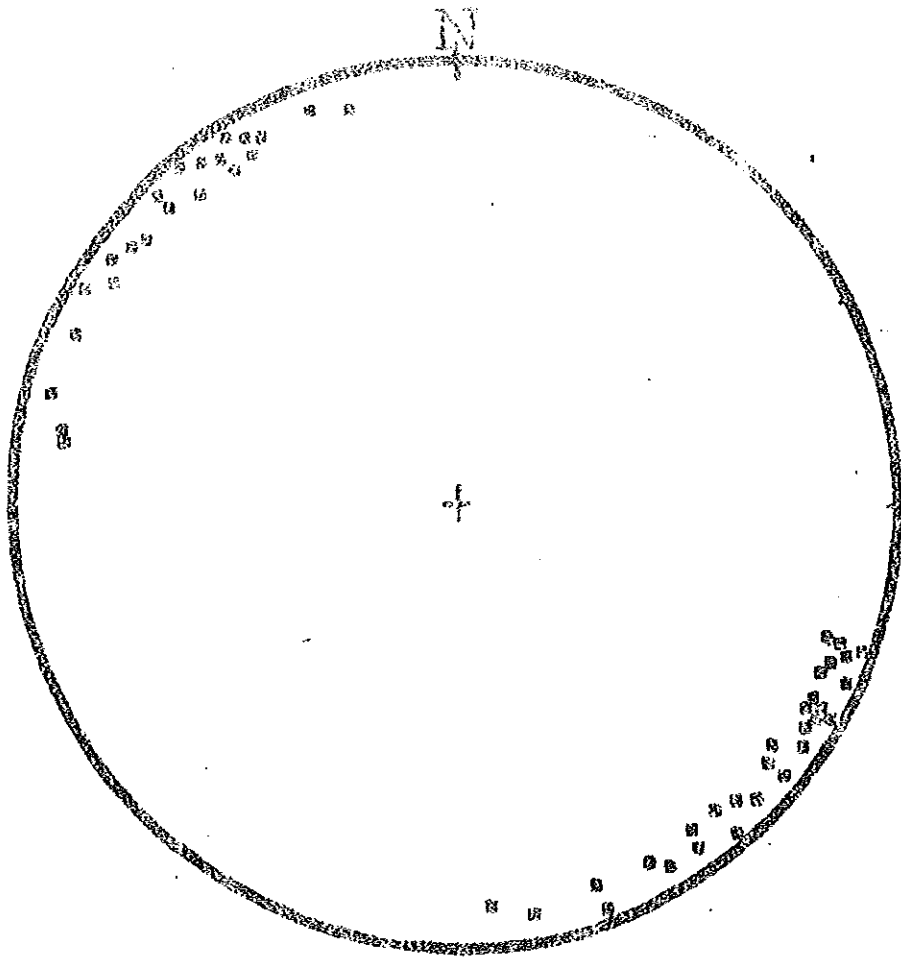


FIG 27

Station Number 13

Locality On floor of Luma river  
Type of Structure Joints  
Lithology Coarse Ignimbrite of Boku Group  
Structural Data

<u>Dip Direction</u>	<u>Dip</u>
114	87
105	85
109	80
296	85
300	85
121	90
125	82
289	75
297	80
117	90
128	80
130	85
297	85
119	87
120	89
128	86
301	89
123	90

<u>Dip Direction</u>	<u>Dip</u>
299	90
115	85
300	88
116	90
114	83
276	70

Fig. 28 stereoplot of data of station 12.

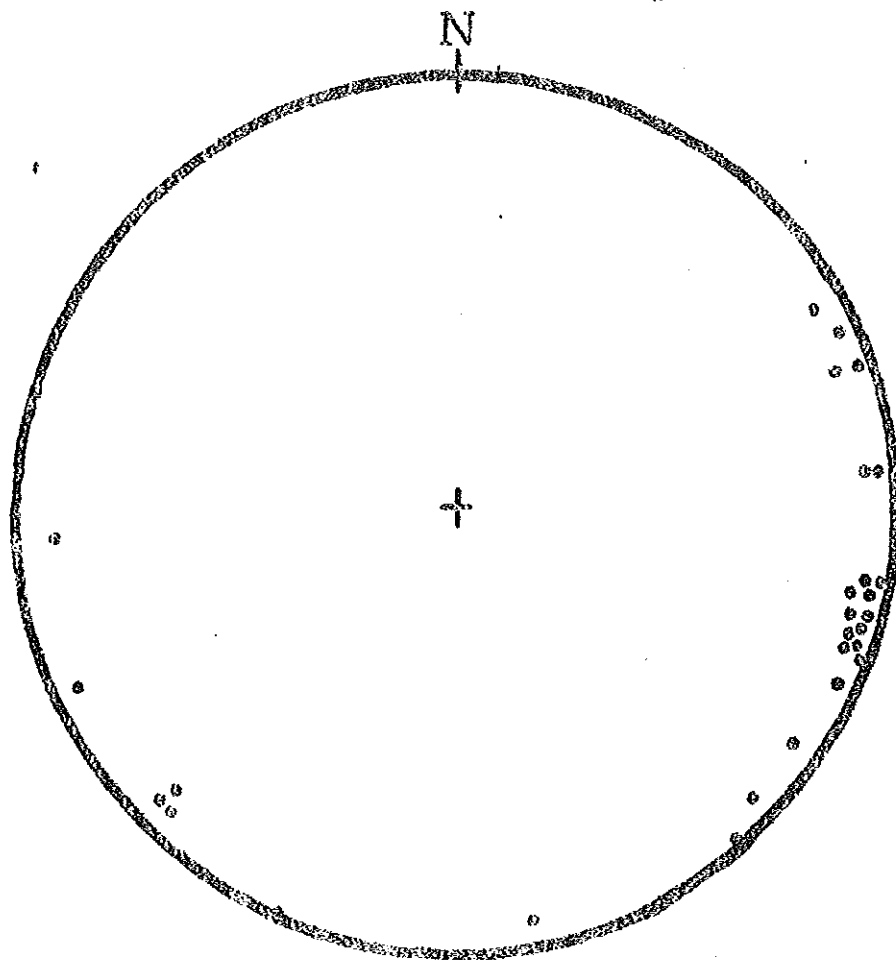


FIG 28

Station Number 14



Locality Roadside 5 km from Nazret along the Addis Ababa-Nazret main road.

Type of Structure Joints

Lithology Coarse Ignimbrite of Boku Group

Structural Data

<u>Dip Direction</u>	<u>Dip</u>
90	85
100	87
105	86
65	85
125	82
90	89
110	87
70	80
108	82
107	85
110	82
105	81
102	80
100	83
85	82
115	84
245	84

<u>Dip Direction</u>	<u>Dip</u>
170	86
140	88
104	85
102	84
124	89
135	83
215	84
265	80
70	86
60	82
215	80
216	86

Fig. 29 stereoplot of data of station 14.

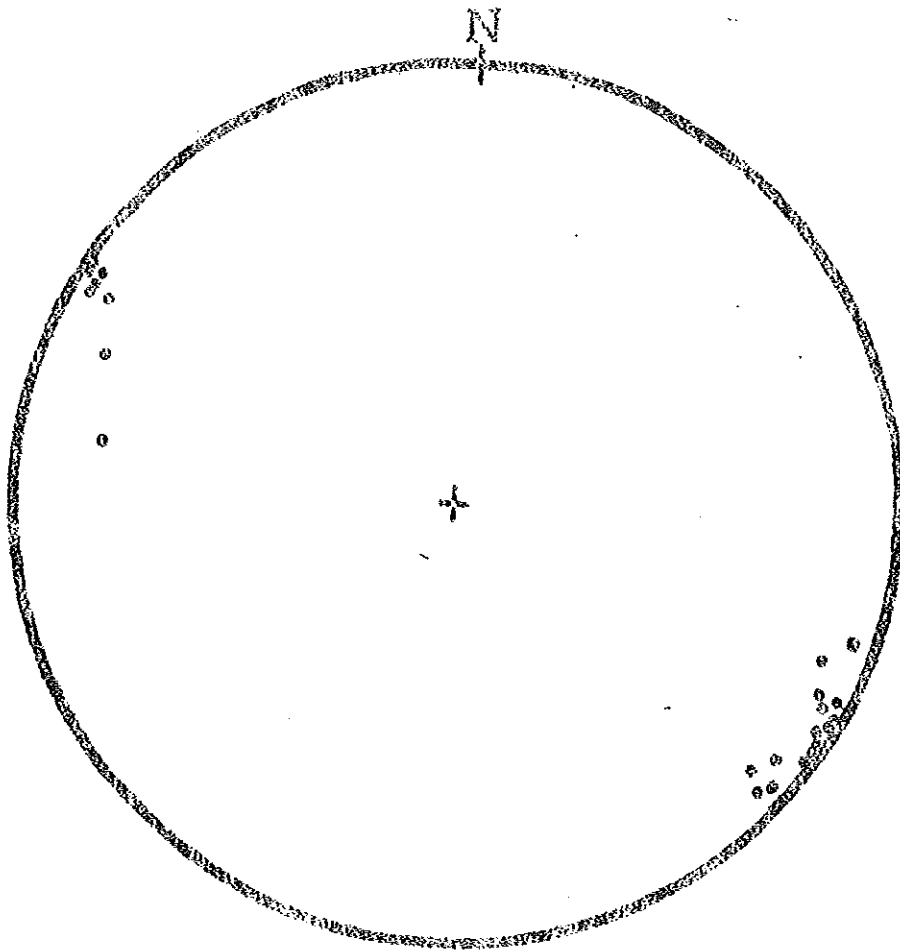


FIG 29

Station Number 15

Locality 3 km from Nazret towards Addis Ababa  
under railway bridge.

Type of Structure Joints

Lithology Coarse Ignimbrite of Boku Group

Structural Data

<u>Dip Direction</u>	<u>Dip</u>
270	85
275	88
170	82
122	89
105	80
115	86
115	82
118	84
98	86
120	88
97	83
129	85
280	80
290	89
285	85
245	86
180	85

<u>Dip Direction</u>	<u>Dip</u>
105	87
225	80
107	85
130	80
130	86
100	80
106	84
124	88
119	86
120	84
92	80
93	88
105	88
275	85
295	89
265	87
292	80
109	82
120	82
105	83
104	82
125	85
140	86

<u>Dip Direction</u>	<u>Dip</u>
95	82
116	88
88	84
104	86
110	80
284	82
270	80
283	85
270	80
283	85
282	87
96	86
96	80
100	84
100	88
110	86
130	83
120	80
112	84
116	85

Fig. 30 stereoplot of data of station 15.

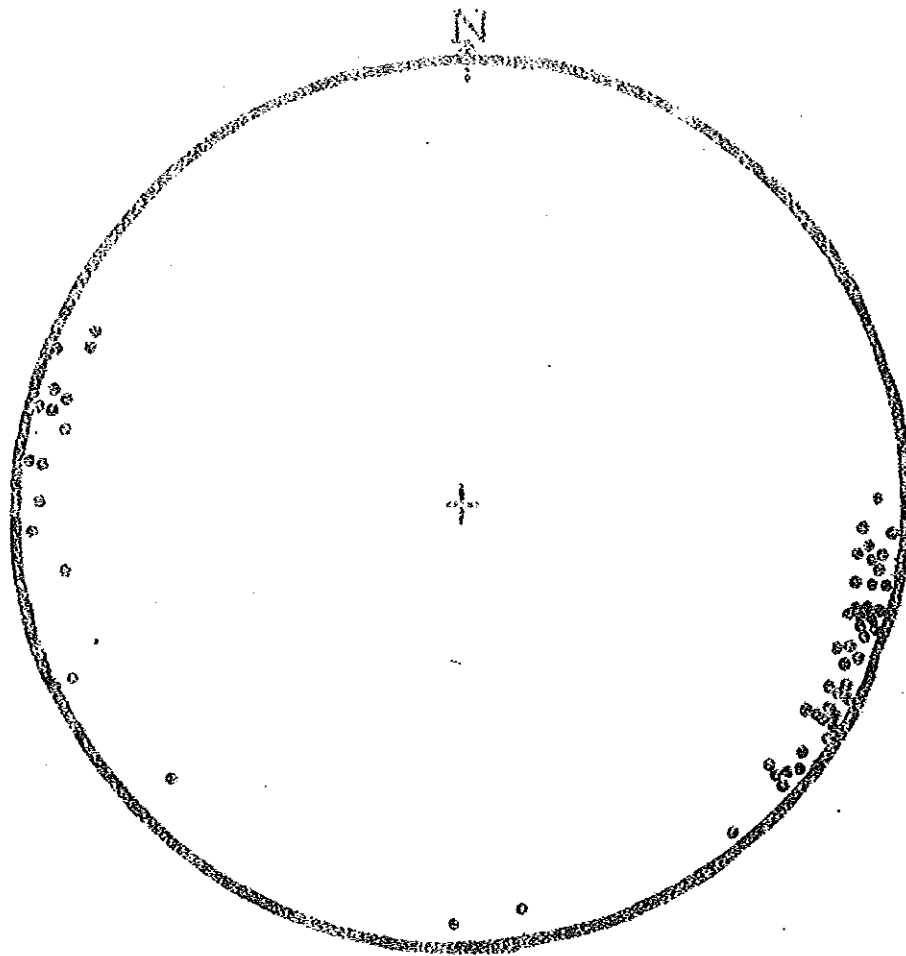


FIG 30

The regional pattern of the major structures which affected the area show that the main faults trend in north-northeast, south-southwest direction and have clear right stepping "en echelon" geometry suggesting that a left lateral component of movement has taken place.

Mesoscale structural data collected from faults show oblique slicklines which are indicative of oblique extension direction with respect to the main displacement zone.

Data processing of all planes bearing slicklines (ANGELIER, 1979) indicates that the area is undergoing extension in east-northeast, west-southwest direction. Kinematics derived from the above data confirms that the main structures are characterized by a left lateral component of movement and that extensional strike slip tectonics affect this part of the Main Ethiopian Rift (Fig. 31).

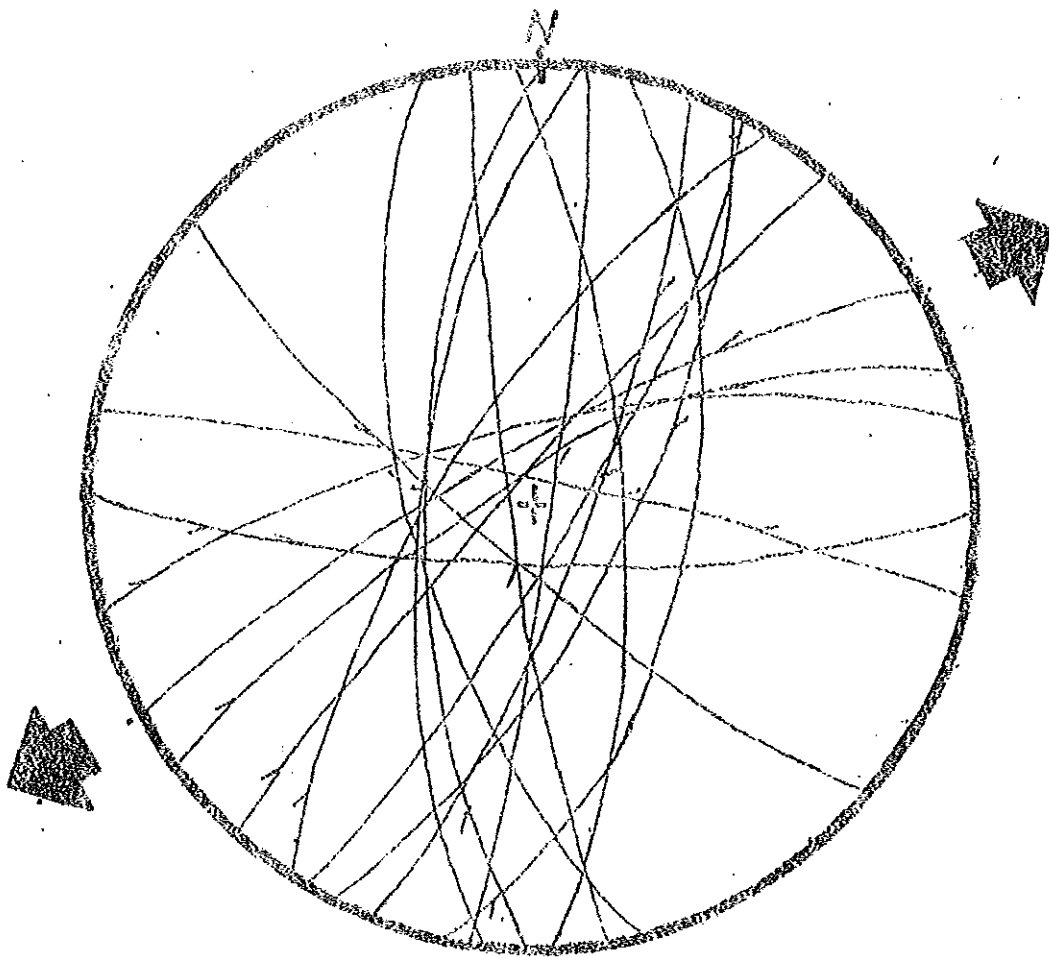


Fig.31 Stereoplot of all data normal faults with slicklines. Extension direction calculated using Angelier (1979) method.

## VI. CONCLUSION

The study carried out in the Dera-Hazret region allows to define a new, detailed, stratigraphy and structural pattern which affect the area and to characterize the relationships between tectonism and magmatism.

In this region, which is limited mostly to the floor of the rift and partially includes also the Somalian plateau, six main groups of volcanic rocks have been recognized.

The oldest group crops out mostly along the eastern escarpment and is composed of ignimbrite units interbedded with flood basalts. This sequence shows an age ranging from 1.4 m y to 1.8 m y (Morton, et al., 1979; Bigazzi, et al., 1981).

The other groups are found only in the floor and their characteristics can be summarized, from bottom to top, as follows:-

- ( 1) DERA-NAZRET GROUP: this sequence is composed of rhyolitic lava flows and domes followed by strongly welded, "fiammæ" rich ignimbrites interlayered with basaltic lava flows. This group, which may represent an uplifted portion of the rift shoulder, has an age of 1.7 m y (Mohr, 1987). On top of this sequence a feldspar rich basaltic lava flows are found;

- (ii) KELETA GROUP: this sequence, which may represent a product of the rift floor, is composed of a series of ignimbrites and ash flows probably derived from fissural activity;
- (iii) BOKU AND GEDEMSA GROUP: the products of these groups are connected with collapse of huge calderas and are formed by ignimbrites, pumice fall deposits and ash flows. The age of the products related to Boku range from 0.8 m y to 0.5 m y while Gedemsa products show an age ranging from 0.8 m y to 0.2 m y (Bigazzi et al. 1981), the later age referring to the last products prior to caldera collapse;
- (iv) MELKASA GROUP: to this group belong rocks of the last phase of volcanic activity of the study area. They are represented by basaltic spatter cones associated with lava flows which show an age younger than 0.06 m y (Bigazzi, et al., 1981).

The stratigraphic data indicate that the volumes of the acidic products are markedly greater than the basic ones; in fact it is possible to observe that they represent 90% by volume of all the rocks outcropping on the floor. Furthermore from a petrographic point of view, it should be stressed that, the intermediate products are extremely scarce.

From a tectonic point of view, the area is affected by north-northeast, south-southwest trending faults, known as the Wonji Fault Belt (Mohr, 1960). The faults show a

right stepping "en echelon" arrangement and cut all products outcropping in the area. The very recent activity of the faulting process is also well documented by the morphotectonic features including a clearly visible fault controlled topography and by the antecedent drainage pattern of established rivers like Awash. The fault structures also include several seismogenic fault segments which are thought to be responsible for the occurrence of several earthquakes with magnitude greater than 6 (Gouin, 1979).

The general geometry of the fault pattern and the mesostructural data suggest a left lateral motion along the main structures connected with an east-northeast, west-southwest extension direction. These results show that oblique extension is a dominant mode of deformation in the study area, thus suggesting that a strike-slip system has played a major role in the development of the tectonic history of this part of the Main Ethiopian Rift.

The transtensional nature of this crustal strike-slip system may extend across the whole length of the Main Ethiopian Rift as inferred by Gibson and Tazieff (1970) and by seismological (focal mechanisms) from Afar depression and Djibouti area (Mc Kenzie, 1972; Abdallah, et al., 1979) and from southern sector of the East African Rift system (Maaaha and Molnar, 1972; Fairhead and Stuart 1982; Bungam and Nako,

1985; Shudofsky, 1985) which show that there too, an oblique extension is the prominent mode of deformation.

The stratigraphy, petrography and structural pattern which characterize the Nazret-Dera region, allow to suggest a new model for a rift segment undergoing strike-slip motion.

Large volumes of the acidic rocks, high rates of uplift and high thickness of continental crust which characterize the region under study suggest that this portion of the Main Ethiopian Rift can't be related to a model which takes in account lateral free dispersion of lithospheric plates.

In fact, if one takes into account this model (Mc Kenzie, 1978; Le pichon and Sibuet, 1981; Beaumont, et al., 1982; Kazmin, 1987), large amount of basaltic products, very rapid subsidence, pure extensional regime and thin continental crust, connected with a rapid extension and attenuation of the lithosphere should be expected.

Instead, a better model would be the one proposed by Kazmin (1987) which implies an opening related to the main forces connected with the Africa-Eurasia collision. This model explains:

- 1) The occurrence of strike-slip tectonics as demonstrated by Molnar and Tapponier (1978) and Tapponier et al., (1982) in Asia;

- 2) Step by step evolution of the rift system, separated by long quiet periods in relation to different stages (Kazmin, 1987).
  
- 3) The large amount of acidic products could be connected with a crustal melting process. This phenomenon, also suggested by Huppert and Sparks (1988) considers the acidic magmas as being generated by partial melting of continental crust caused by intrusion of basaltic magmas, linked to an uprising of asthenospheric material (Fig. 32) as large horizontal lenses at mantle-crust boundary.

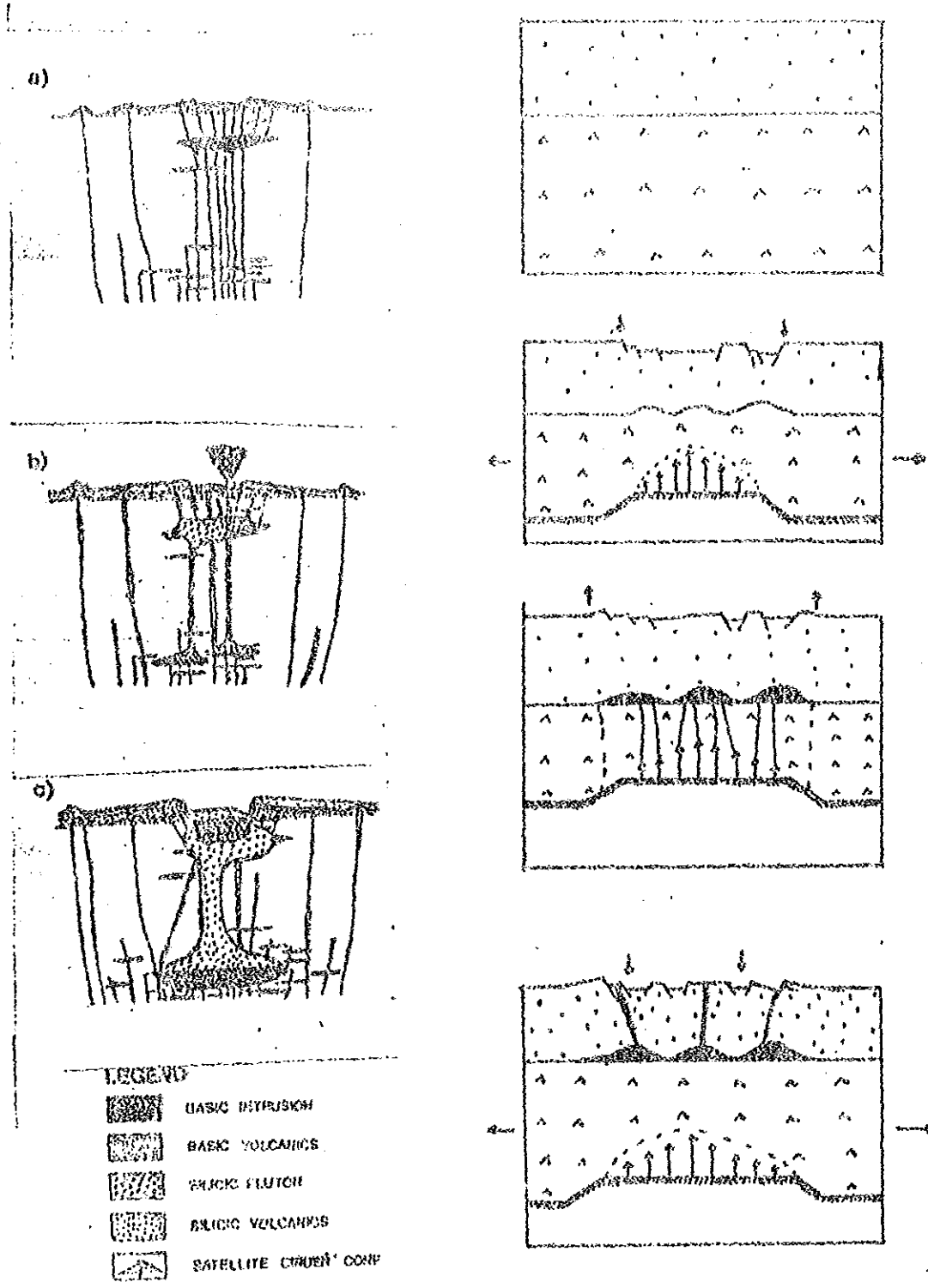


Fig. 32. A) Evolutionary scheme for a silicic magma system formed by emplacement of basalt into the crust after Huppert and Sparks (1988).

B) Extension in pulses during collision after Kazmin (1987).

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DECLARATION

I, the undersigned, declare that this thesis is my work and that all sources of material used for the thesis have been duly acknowledged.

Alula Damte



Addis Ababa, June 1990