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1.INTRODUCTION

The Ethiopian Institute of Geological Surveys is at present conducting different exploration and mapping activities throughout the country. On due course, the mapping of Yabelo map sheet at a scale of 1: 250000 has undertaken by Regional Geology and Geochemistry Department since 1991 E.C. to 1992 E.C. fiscal year. The sum of the money was allocated by the Ethiopian Government to run the project. This work is part of the Yabelo sheet mapping - project.

1.1. Objective and scope the work

The objective of this work is to produce a geological map of subsheet O (Kenchero) and U (Arbele) at a scale of 1: 50000 with its accompanying geological report for a compilation at a scale of 1: 250,000.

The scope of the work is to know the arial distribution, composition, metamorphism and deformation history of the rock. The construction of the geologic history of the area used as a basis for feature planning of land use, exploration activities and environmental protection.

1.2. Location

The mapped area (Fig. 1) is located within Diree and Yabelo worda, Borena zone Oromiya region, Southern Ethiopia.

Geographically, it is bounded between latitudes 37^0 45’ 00’’ to 38 ^{0} 00’ 00’’ E and longitudes 4^0 00’ 00’’ to 4^0 30’ 00’’ N. The area covers about 1500 sq. km of the Yabelo sheet (NB36 – 14).

1.3. Accessibility

The area can be reached from Addis Ababa through Awasa, Dila, Yabelo, Dubluk and Dilo towns. It is about 750 km from Addis Ababa of which 650 Km is asphalted and 100 km is dry weather road.

Within the mapped area, there are dry weather roads connecting Dilo to Elweya, Dubluk, Haro-Legurbu, Megado and Sarittie Ranch and many foot trials. Most of the foot trials are accessible by 4WD vehicle (fig. 1).

1.4. Climate and Vegetation

The area is characterized by dry and hot climate. The rainy season lasts from February to the end of April with mean annual rainfall ranges between 700 – 800 mm. The average daily temperature is 25^0 C (Ethiopian mapping agency).

Vegetation varies from scrub to woodland on the flat terrains and equatorial rainforest on the highlands of Arbele ridge (fig.2).

1.5. Topography and Drainage

Topographically, the mapped area is characterizes by NNW running chain of ridges extending from Arbele to Gobbso with different forms and elevated hills like Kulkule (Dika and Guda) , Gara Arba , Bufe (Dika and Guda) , Kenchero , Adole , Obboda etc. The rest of the area is characterizes by extremely flat lowlands. The highest elevation reaches 2210 mt above mean sea level at Arbele and the lowest elevation is 820 mt at southern part of subsheet U .For simplicity, the area is grouped into three main topographic region based on elevation (fig. 2).

The drainage pattern of the area varies from place to place. Mostly dendritic to parallel on the flat land and radial drainage pattern on the elevated surface characterize the drainage pattern of the area. Most of the streams are immature and all are dry throughout the year except the rainy season. There is only one spring at the bottom of Arbele ridge.

1.6. Population

The mapped area is inhabited by the Oromo people of Borena trib. They speak Oromigna and are nomadic people. The population density in the area is very low. They depend on mostly animal raising.

1.7. Methodology

Prior to the fieldwork; Photogeological interpretation, planning of traverse routes and previous date acquisition were done in the office.

The mapping was conducted on 1:50,000 scaled topographic maps and 1:60000 aerial photographs with the help of 12XL Garmin GPS for navigation and positioning. Based on the general strike of the terrains 3 to 4 kms apart traverse lines were planned.

The actual field data were collected from 206 observation points (fig.3) and the collected data were transferred to the base map at a scale of 1: 50,000. From this observation points 0.07 rock samples/ sq. Km were collected and 56 % of this samples were selected for thin sections (Tab.1). The petrographic description of these thin sections are supplemented the results obtained in the field (for rock naming).

Generally, the collected field data, petrographic description and aerial photograph interpretation are used for producing the final geological map of the area. The fieldwork was conducted from November 1999 to February 2000 by four geologist, two driver and 4 to 5 daily laborers.

Table. 1. Volume of work

Liothology	Number of observation points	Number of rock samples	Number of thin sections	Number of thin sections examined
Biotite gneiss	11	9	5	5
Granitic gneiss	44	23	16	12
Foliated granite	57	32	17	13
Synite	4	3	3	3
Amphibole schist	1	1	1	1
Actinolite - trimolite schist	1	1	1	1
Marble	1	1	1	1
Quartzite	1	2	2	
Vesicular to non vesicular basalt	10	4	2	2
Scoriaceous basalt	1	1	1	1
Vesicular basalt	6	3	2	2
Aphanatic basalt	2	2	1	1
Pyroclastic rock	1			
Scoria	12	7	4	2
Total	152	98	55	42

1.8. Previous work

The Geological Map of Ethiopia (1:2000000) of Kazmin (1972) and the Revised Version of Mengesha etal (1996) show that, the area is covered by Quaternary sediments and Quaternary – Tertiary volcanics (fig.4).

On structural mapping of Mega area, Balemwal etal (1991) noted that the elongated and massif ridge trending to the NW extends from south of Mega into the present area as quartzo- feldspatic rocks while the lowland is covered by post- Miocene deposits.

2. Regional Geology

The Precambrian geology of Ethiopia is represented by the combination of two prominent orogenic belts.

1) Mozambique belt (MB)

This is a N-S trending orogenic belt extending for the entire length of East Africa (Holmes, 1951) and have meridional structural trend (Mosley, 1992). The belt consists of high - grade gneisses and migmatites, schists, marbles and amphibolite with the intrusions of granites and pegmatites (Almond, 1983). It generally consists of rocks ranging in age from 1300 to 480ma.

2) Arabian – Nubian Shield (ANS)

The belt extends from western Arabian Peninsula to Ethiopia. It consists of greenschist facies volcano – sedimentary rocks and ultramafics with intrusive rocks.

The southern Ethiopia represent a zone in which the southern extension of ANS and the northern extension of MB belts are interfingering to each other (vail etal 1983) .

According to Gilboy (1970), Chater (1971) and Amenti (1996), the middle to upper amphibolite facies and polydeformed basement rocks of southern Ethiopia is equated to be part of and equivalent to some lithologies of the MB.

The mafic – ultramafic and volcanosedimentary rocks of the southern Ethiopia is the southern extension of ANS (Kazmin 1978, Vail 1983, and Beraki etal, 1989). This association is also considered as an ophiolite complex (Shacklton 1986, Berhe 1990). Beraki etal (1989) and Mulugata (1992) conformed that the Adola and Moyale belts as part of the shield.

Kazmin (1972) subdivided the Precambrian basement rocks of southern Ethiopia into three main complexes that were intruded by Syn – Post tectonic granite (fig.5). These are

A) Lower complex (high - grade gneisses) - Burji gneiss
- Konso gneiss and
- Arrero group- Yabelo gneiss
  - Awata gneiss
  - Alghe gneiss

B) Middle complex (clastic sediments) - Wadera group

C) Upper complexes (Low grade rocks; ophiolitic rock, andesitic metavolcanic and associated metasediments)
- Adola group

The rocks of the study area belong to lower and upper complexes (see later).

The Tertiary volcanic rocks of Ethiopia are mainly distributed on Ethiopian and Somalia plateau, main Ethiopian Rift and Afar region (fig. 6). Blanford (1869) classified these volcanic rocks into two main series, the Trap and the Aden series. Intern the Trap series was subdivided into Ashangi and Magdala Groups. Later Mohr (1967a) introduce the term shield group instead of subdividing the monotonous Trap series.

Kazmin (1972) adopted the same classification for basaltic flow and different group of volcanic units of Ethiopia. The eruption is either fissure or central type volcanism. The later one is the dominant type in southern Ethiopia (Balmwal etal, 1991). South of Teltele including the present area, volcanic cones and flow of scoriaceous basalt are described as late volcanoes and associated flows of Pleistocene to recent age (Davidson etal, 1973) and also the presence of aligned spatter cones and maars shows a late Pleistocene age (Balmwal etal, 1991).

3. Local Lithology

3.1. Introduction

In the mapped area, various lithologies were identified. They are grouped into three main lithological units with different sub units. These are

1. Precambrian rocks
2. Tertiary – Quaternary rocks
3. Quaternary sediments

1. The Precambrian rocks

The Precambrian rocks cover about 19.8 % of the mapped area. It forms continuos exposure on rugged ridge and hills (fig.7). Based on metamorphic grade and mineral composition, it is divided into different subunits. These include: -

1. High grade metamorphic rocks
    1. Biotite gneiss (Pbtgn)
    2. Granitic gneiss (Pgtgn)
2. Low grade metamorphic rocks
    1. Mafic – ultramafic rocks
        1. Amphibole schist (Pamst)
        2. Actinolite – Trimolite schist (Patst)
    2. Metasediment
        1. Marble (Pmb)

2. And Intrusive rocks which are identified as

1.Foliated granite (gt_1)

2. Synite (sy_2)

the Foliated granite is exemplified by

1.Adole foliated granite

2.Medera foliated granite

3.Gara Arba foliated granite

4.Bisika foliated granite

5.Oboda foliated granite

and the synite is exemplified by Bufe Guda synite

2. Tertiary – Quaternary rocks

The rocks of Tertiary – Quaternary age covers about 9.4 % of the mapped area (fig.7). Based on mode of occurrence, mineral composition and texture it is divided into different subunits. It shows a broadly varying textural and physical appearance. These include:-

1. Volcanic flow that includes varities of Vesicular to Non Vesicular basalt (Tbv_n), Scoriaceous basalt (Tbs), Vesicular basalt (Tbv) and Aphanetic basalt (Tba)

2. Volcanic fall which intern include Pyroclastic falls (Tpy) and Scoria (Ts)

3. The Quaternary sediments

   1. Alluvial soil (Qa)
   2. Sandy soil (Qs)

3.2. Precambrian rocks

3.2.1 High grade metamorphic rocks

3.2.1.1. Biotite gneiss (Pbtgn)

The biotite gneiss crops out at the northern part of subsheet O, central and northeastern corner of subsheet U of Yabelo sheet (fig.7). It covers 2.5 % of the mapped area. It mainly makes up the Bule Kersa Dika, Kulkule (Guda & Dika) and western escarpment of Arbele ridge.

It is dark to light gray in color and have coarse grain size with well-developed gneissosity. The gneissosity is defined by the segregation of biotite grains with felsic minerals (feldspars and quartz). At Arbele, the mafic layer is discontinues and it is highly silicified.

The unit is highly migmatized. The migmatitic banding is characterized by ptygmatitic and disharmonic folds of variable orientations.

The occurrence of pegmatite veins parallel to the foliation plane is a pecular feature of the biotite gneiss at Kulkule (Guda &Diko) ridges. The pegmatites are pink in color and have coarse grain size with 2 to 25 cm widths. It is trending to N300. It is affected by simple folds of different orientation and at southern part of Kulkule Guda and shows asymmetric S- folds that may indicate sinistral sense of movement.

The biotite gneiss, at Bule Kersa Dika shows a crenulation cleavage and consists of boudined and pinch-swell structures.

At Kulkule Diko and Bule Kersa Dika, there is an intrafolial fold with a plunge of 10 degree to SE (170^0).

The foliation is defined by planar orientation of biotite and stretched quartz and feldspar grains. The foliation of the unit has NNE-SSW strike and dips towards either direction (east or west) with dip angles ranges between 30 to 55 degree.

Petrographically, it is on average consists (tab.2) of 32 % quartz, 23 % microcline, 21% plagioclase, 15.5 % biotite, 6 % hornblende, 1 % opaque and sericite, 0.6 % zocite, 0.1 % epidote with trace amount of apatite. It is mainly characterized by lepidoblastic texture (fig.8). However some of the thinsection show nematoblastic and granoblastic texture. The feldspar altered to sericite (sercitization) and some of the biotite also altered to chlorite (fig.8). In all thinsections the quartz and feldspar grains are stretched into one direction.

3.2.2.2. Granitic gneiss (Pgtgn)

The granitic gneiss crops out at the eastern most part of subsheet O and the northeastern corner of subsheet U of the Yabelo sheet (fig.7). It covers about 9.2 % of the mapped area. It mainly occurs as an elongated ridge extending about 27km from Arbele to Gobso localities.

It is pink to light gray in color and weathers to reddish brown color and have medium to coarse grain size. But at Bule Kersa Guda, it has very fine grain size. At the eastern part of Gobso ridge, the metamorphic banding is defined by the grain size variations where the coarse and fine grain sized bands alternate each other with thickness of 2 to 5 cm. West of Dikole village, a well developed banded gneiss is observed. Here the banding is defined by the alternation of mafic and felsic layers of different thickness and some of the bands are affected by minor fault with sinsitral sense of movement. The amount of biotite varies in concentration from place to place but in general it decreases to the top of the ridge. It also contains minor hornblende at Arbele locality.

This unit also contains dessiminated magnetite throughout the area. However at bule kersa guda, the magnetite forms a thin bands parallel to the foliation plane. The top most part of the ridge is highly silicified and forms a cliff resistance to erosion.

At Someso hill and Sulula river, the granitic gneiss grades to biotite gneiss, due to the local increase in biotite contents. It is light gray in color and has medium grain size. The gneissosity is defined by the segregation of biotite grain with the feldspar minerals. It is intruded by differently oriented pegmatite veins and the veins are affected by simple folding. At west of Gobso ridge, there is a pegmatite dyke. It is pink in color and have coarse grain size with 0.5mm to 1mm sized porphyroblastic k-feldspar grains that exhibit graphic texture. The width of pegmatite dyke is 0.5mt to 5mt.

The granitic gneiss, as a whole, is affected by two sets of joint and differently oriented fractures. The two sets are E-W and NNW- SSE trending. At west of Kobo, the E-W joint displaced by the NNW-SSE joints. And also in the gneiss at bule kersa guda and west of Gobso, there is a striation lineation with a plunge of 60 degree to 140 degree and 25 degree to 330 degree, respectively.

The intensity of foliation varies from place to place but at Gubal and bottom of Gobso, it grades to massive varieties. The foliation of the unit has mainly NNW and NW strike and locally it forms doming structure. It dips towards the west and the east with dip angle ranges between 15 to 70 degrees.

Petrographically, it is on average consists (tab.3) of 46.9 % microcline, 27.8 % quartz, 15.5 % plagioclase, 3.8 % biotite, 2.1 % hornblende, 1.1 % opaque and a total 2.8 % sericite, garnet, apatite, sphene and epidote. The QAP plots show that most of them fall in the granite field (fig.9). The texture of this granitic gneiss is mainly granoblastic. However due to a local increment of biotite and hornblende, it attain a lepidoblastic and nematoblastic texture respectively (tab.3). In some of the thin section, the feldspar shows piokiloblastic, myrmekitic and graphic texture (fig.10). In thin section DM-836, there is a perthite intergrowth of microcline. Some of the feldspar is altered to sericite while the biotite and hornblende are altered to epidote. But thin section DM-861B some of the biotite altered to hornblende.

3.2.2. Low grade metamorphic rocks

3.2.2.1. Mafic- Ultramafic

3.2.2.1.1. Amphibole Schist (Pamst)

The amphibole schist crops out at northeastern corner of subsheet O of the Yabelo sheet. It covers about 0.1 % of the mapped area (fig.7). The contact with the Marble and Actinolite – Tremolite schist is sharp.

The rock is light green to dark green in color and has fine to medium grain size with well-developed schistosity. The schistosity is defined by the preferred alignment of amphibole and feldspar minerals.

The foliation of the rock have strike direction of NNW- SSW and dip towards east with dip angle between 60 – 85 degree.

Petrographically, it is consists of 70 % hornblende, 15 % plagioclase, 10 % quartz, 5 % epidote. The amphibole schist is nematoblastic in texture.

3.2.2.1.2. Actinolite – Tremolite schist (Patst)

The Actinolite – Tremolite schist crops out at northeastern corner of subsheet O of the Yabelo sheet (fig.7). It is mainly exposed at Kersa Buruka hill. The contact with the marble and the amphibole schist is sharp.

The Actinolite – Tremolite schist is light green in color and has coarse grain size with schistosed texture. It is well foliated but at the southern bottom of the hill it is massive. The foliation of the unit has E-W strike and dip towards north with dip angles 30 – 45 degree.

Petrographically, it is consists of 89 % tremolite- actinolite, 10 % talc and 1% opaque. There is a quartz veinlet parallel to the schistosity plane and where there is limonitized surface along the contact with the schist. And also bands of fine grain talc is formed alternately with the tremolite – actinolite grains. The unit is nematoblastic in texture (fig.11).

3.2.2.2 Metasediments

3.2.2.2.1. Marble (Pmb)

This unit crops out at the northeastern corners of subsheet O of the Yabelo sheet. It makes up a flat topography. It has a sharp contact with amphibole and tremolite-actinolite schist.

It is light to dark gray in color and have medium grain size. Karest and erosional grooving are common. It is characterized by a banded appearance with alternating layers of darker and lighter part. The band thickness ranging from 1 cm to 3 cm.

Petrographically, it is composed of 97 % calcite and 1 % opaque with trace amount of muscovite and epidote. The texture is granoblastic.

3.2.3. Intrusive rocks

3.2.3.1. Foliated granite (gt_1)

3.2.3.1.1. Adole foliated granite

The foliated granite crops out at the central part of subsheet O of the Yabelo sheet. It mainly exposed at Adole ridge and its surrounding (fig.7). It covers 1.6 % of the mapped area.

It is pink to light gray in color and have medium to fine grain size except that at Huluko ridge it has coarse grain size. It is affected by differently oriented fractures.

The occurrence of pegmatite veins parallel to the foliation plane is the main characteristic feature of this granite. However the frequency of the pegmatite veins increase upward to tip the ridge. The pegmatites are pink in color and have coarse grain size with width ranging from 0.5mt to 5mt wide with N-S orientation. The pegmatites have a clear sharp contact with the granite. Compositionally, it consists of K- feldspar and quartz exhibiting graphic intergrowth.

The Adole granite contains xenoliths of biotite gneiss. It is light gray in color and has coarse grain size with locally augened, (for example at Huluko ridge) texture. The gneissosity is defined by parallel alignments of biotite and stretched feldspar grains. The xenolth is occurring parallel to the foliation plane and discontinuous with lensoidal shape.

The Adole granite shows that the amount of biotite and disseminated magnetite increase from bottom to the top of the ridge where it is highly silicified.

The intensity of foliation varies from place to place. At places, it grades to massive varieties. The foliation is defined by slight and random orientation of the biotite grain and at places, by the segregation of magnetite. The foliation of the unit has NNE - SSW strikes and dips toward the east with dip angle ranges between 5 - 45 degrees.

Petrographically, it is on average consists (tab.4) of 40 % microcline, 31.5 % quartz, 27.5 % plagioclase, and 1 % biotite with trace amount of opaque and sericite. The texture of Adole foliated granite is granoblastic. Additionally the porphyritic feldspar shows piokiloblastic, myrmekitic and graphic texture. Some of the microcline exhibits a perthite intergrowth. The quartz grains shows a bimodal grain size distribution. The feldspar is altered to sericite and at spot the biotite is changed to opaque (magnetite) minerals.

3.2.3.1.2. Medera foliated granite

The Medera foliated granite crops out at the south-central part of subsheet O of the Yabelo sheet (fig.7). It is mainly exposed at Medera ridge and its surrounding. It covers 3 % of the mapped area. It has a gradational contact with the granitic gneiss in the east.

It is yellowish pink to light gray in color and have medium grain size. It contains magnetite and at spot veinlets of magnetite parallel to the foliation. It is affected by differently oriented fractures.

At the eastern side, the unit cut by differently oriented and sized pegmatite veins. The pegmatites are pink in color and have coarse grain size. The pegmatites have a clear sharp contact with the granite. Compositionally, it consists of K- feldspar and quartz, which exhibits graphic intergrowth.

The Medera granite contains xenoliths of amphibole schist. It is light gray in color and has medium grain size. The schistosity is defined by parallel alignments of amphibole minerals. The xenoliths is occurring parallel to the foliation plane and with lensoidal shape.

The degree of foliation the Medera granite varies from place to place. The foliation is defined by slight alignments of biotite grains.

The foliation of the unit has NW- SE strikes and dips towards west (locally to east) with dip angle ranging between 30 to 55 degrees.

Petrographically, it is on average (tab.4) consists of 28.4 % microcline, 36.8 % quartz, 28.6 % plagioclase, 5.4 % biotite, 0.4 % hornblende with trace amount of epidote. The texture of Medera foliated granite is granoblastic. Locally, it attains a lepidoblastic texture (tab.4), due to an increase of biotite contents. Additionally, the feldspar grains show piokiloblastic, myrmekitic and graphic texture. Some of the microcline exhibits a perthite intergrowth

3.2.3.1.3. Gara Arba foliated granite

The Gara Arba foliated granite at Gara Arba hill crops out at the northwest part of subsheet U of the Yabelo sheet (fig.7). It covers about 0.3 % the mapped area.

It is light gray in color with yellowish weathering color and has medium grain size. It is affected by differently oriented sets of joints.

It contains disseminated magnetite and also minor veinlets of hematite at north tip of Gara Arba. The amount of magnetite is increasing to the top of the hill. At the top part, the unit is highly silicified.

The degree of the foliation varies from place to place but the massive varity is the dominant one. The foliation is defined by the slight orientation of the biotite grains.

The foliation of the unit has NW – SE strikes and dips towards west with dip angle ranging between 20 to 30 degrees.

Petrographically, it is on average consists (tab.4) of 42 % microcline, 30 % quartz, 25 % plagioclase, 2 % opaque and 1 % hornblende, epidote, and biotite. The texture of Gara Arba foliated granite is granoblastic. Additionally the feldspar grains shows graphic texture. Some of the microcline exhibits a perthite intergrowth. The quartz grains shows a stretching in one direction and wavy extinction. At spot, there is a grain boundary discontinuities, which shows the development of neoblasts. The feldspar and hornblende is altered to epidote and at spot the biotite is changed to chlorite and opaque (magnetite) minerals.

3.2.3.1.4. Bisika foliated granite

The Bisika foliated granite crops out at the northwestern subsheet O of the Yabelo sheet (fig.7). It covers about 1.2 % of the mapped area.

It is light gray to pink in color with reddish brown weathering color and have coarse grain size with slight grain size variation going upward to the hill. It contains a disseminated magnetite. The amount of biotite decreases from bottom to the top of the ridge where it is highly silicified .

At the top of the hill, there is E – W running quartz veins. It has 1mt width and affected by N – S running fracture. It is void of any mineralization.

Subhorizontal and vertical joint affect the unit. The vertical set is the dominant one.
The intensity of foliations varies from place to place. It grades to massive varieties, at the bottom of the ridge. The foliation is defined by slight and random orientation of the biotite grain. The foliation of the unit has NNE – SSW strikes and dips toward the east with dip angle ranges between 10 - 20 degrees.

Petrographically, it is on average consists (tab.4) of 35 % microcline, 40 % quartz, 25 % plagioclase, with trace amount of hornblende and epidote. The texture of Bisika foliated granite is granoblastic and a minor perthite intergrowth is seen. Some of the hornblende is altered to chlorite and epidote. And also limonitization is seen.

3.2.3.1.5. Oboda foliated granite

The Oboda foliated granite crops out at the west central part of subsheet O of the Yabelo sheet (fig.7). It covers 1.3 % of the mapped area.

It is light gray to pink in color and have medium to coarse grain size. However, there is a slight grain size variation going up to the ridge. It contains disseminated magnetite. The amount of biotite and disseminated magnetite is decrease from bottom to the top of the ridge where it is highly silicified.

It contains xenoliths of biotite gneiss. It is light gray in color and have coarse grain. The gneissosity is defined by parallel alignments of biotite and stretched feldspar grains. The xenolth is occurring parallel to the foliation plane and discontinuous with lensoidal shape. At north of Gara Dogogiti, there is a minor banding of mafic and felsic rich unit of the granite.

There are 2 – 10 cm wide pegmatite veins parallel to the foliation plane. It is pink in color and have coarse grain size with sharp contact to the granite.

The intensity of foliations varies from place to place. At places, it grades to massive varieties. The foliation is defined by slight and random orientation of the biotite grain and at places by the segregation of magnetite. The foliation of the unit has NNE - SSW strikes and dips toward the east with dip angle ranges between 10 - 20 degrees.

Petrographically, it is on average consists (tab.4) of 52.2 % microcline, 37 % quartz, 10 % plagioclase, 0.5 % biotite with trace amount of opaque. The texture of Oboda foliated granite is granoblastic. Additionally the feldspar grains shows piokiloblastic, myrmekitic and graphic texture. Some of the microcline exhibits a perthite intergrowth. And the feldspar is highly altered to sericite.

3.2.3.2. Bufe Guda Synite (sy2)

The Bufe Guda synite crops out at the west central part of subsheet O of the Yabelo sheet (fig.7). It makes up Bufe Guda hill. It covers 0.5 % of the mapped area.

It is light gray to pink in color and have fine to medium grain size. However, to the top of the hill, it is coarser. The amount of biotite and hornblende decrease from bottom to the top of the ridge and to the north it grades to quartz synite in composition.

Petrographically, it is on average consists (tab.5) of 78.3 % microcline, 10 % quartz, 5 % plagioclase, 2.8 % amphibole,1.8 % biotite, 1 % opaque, 0.3 % garnet, 0.7 % epidote with trace amount of zircon. Perthite intergrowth is common and it is porphirtic in texture (fig.14). The QAP plot (fig.13) shows that the occurrence of variation in composition from alkali feldspar synite to quartz synite.

3.3. Tertiary – Quaternary rocks

3.3.1 Volcanic flow

3.3.1.1. Vesicular to Non Vesicular basalt (Tbv_n)

This unit crops out at the southern most part of subsheet U of the Yabelo sheet (fig.7). It is mainly exposed on the flat elevated portion of the area. It covers about 5.5 % of the mapped area. It has a gradational contact with the Obru scoria and forms small fragments of various size and shape.

It is dark green to black in color and has very fine grain size (aphanetic). At north Obru, it is highly weathered and strongly laterized.

It is slightly vesicular but the non - vesicular part is the dominant one. The concentration of the vesicles varies from place to place. The vesicles have different size and shape, where the size ranges from mm to 1cm in diameter. The basalt, north of Obru hill, shows a flow banding.

Petrographically, it is on average consists (tab.6) of 47.5 % plagioclase microlites, 17.5 % olivine, 10 % pyroxene and 25 % of groundmass regardless of the void. The voids are sparsely and randomly distributed in the section. This basalt shows different textural features. Olivine, pyroxene and plagioclase are occurred as porphyritic grains. An intergrowth of plagioclase and pyroxene, ophitic texture is also seen. And in thin section Dm-936, at spot shows sub trachytic texture. However the over all texture of the unit is ranging from micro- hypocrystalline to intersertal.

3.3.1.2. Scoriaceous basalt (Tbs)

The scoriaceous basalt mainly crops out at the southwestern part of subsheet U of the Yabelo sheet (fig.7). It mainly makes up the Argemsa hill. It covers about 0.4 % of the mapped area.

It is reddish brown to dark gray in color and has a fine grain size (aphanetic). It is highly affected by differently oriented fractures.

Petrographically, it is consists of 15 % idiomorphic plagioclase, 80 % groundmass, 1.5 % calcite (secondary) with trace amount of olivine. Differently oriented and sized vesicles are observed in the sections where some of them filled with calcite (amygdules). The texture of the unit is porphyritic with minor ophitic intergrowth.

3.3.1.3. Vesicular basalt (Tbv)

The vesicular basalt crops out at the north central and west central part of subsheet O of the Yabelo sheet (fig.7). At the north central part it forms a flat topography while at west central part it forms an ox-bow shaped Bilal hill. It covers about 0.4 % of the mapped area.

The vesicular basalt is dark to light gray in color and have fine grain size (aphanetic). It is light in weight. The basalt is highly vesiculated and the vesicles are stretched in one direction to an elliptical shape.

Olivine and pyroxene nodules are randomly distributed in the basalt of Bilal hill. At the top of Bilal hill, this basalt is bracciated.

Petrographically, it is mostly consists of a groundmass and vesicles with trace amount of olivine and pyroxene. The unit is highly to almost vesiculated. The vesicles are with different shape and size. The texture of the unit is holohyline to pumiceous.

3.3.1.4. Aphanetic basalt (Tba)

The Aphanetic basalt crops out at the west and southern part of subsheet O and northern part of subsheet U of the Yabelo sheet (fig.7). It covers 0.1 % of the mapped area. It occurs as a dome shaped hill.

It is dark green to dark in color and have a fine grain size (aphanetic). At places, it is amygdaloidal where the vesicles filled by calcite.

Petrographically, it is consists of 30 % plagioclase microlites, 20 % olivine, 15 % pyroxene and 35 % groundmass. The texture of the unit is crystallite to intersertal.

3.3.2. Volcanic fall

3.3.2.1. Pyroclastic falls (Tpy)

The Pyroclastic deposit crops out at the southwestern part of subsheet O of the Yabelo sheet (fig.7). It is exposed at the flat topography of the area. It covers about 2.4 % of the mapped area.

It is light gray to gray in color and have fine to coarse grain size. It is friable and highly affected by weathering. It is laminated where the thickness varies from 0.5 to 10 cm. The contacts within the laminations are undulating (wavey). The laminations

a) Containing rounded pumice, unsorted with fine-grained ash, not consolidated, it is friable

b) Fine grained ash highly consolidated, containing amygdaloidal and vesicular grain of basalt (lappilii), and also some crystals of olivine.

It contains fragments of the country rock, granitic gneiss and biotite gneiss. It varies from sand to a bomb size fragments. There is also an Olivine nodules randomly distribute in the area. The nodules are rimed by the basalt .The source is the Dilo creater some 5km far to west of the mapped area.

3.3.2.2. Scoria (Ts)

The scoria crops out at the north central and south western part of subsheet O and U of the Yabelo sheet respectively at Bule Kerera, Molicha and Obru hills (fig.7). The unit covers about 0.7 % of the mapped area.

It is mostly reddish brown in color but at Obru hill there is a color variation from reddish brown to yellow. It has fine grain size. The unit is vesicular to fragment but at Kerera hill the vesicles are only observed on the fragmented unit. The vesicles at Obru hill show a slightly stretching to the N-S direction.

The unit is affected by many fractures oriented in different direction resulting in blocky outcrop at Kerera hill and forming a cliff on the Obru hill where there is a silica coated smoothed surface with no striation on the surface of the block.

At Molicha, there are N300 and N-S trending basaltic dykes. It is light gray to dark green in color and have fine grain size (aphanetic). It is amygdaloidal where the vesicles filled with silica and calcite. The dike at DM-826 is highly fractured and laminated. The contact with the scoria is gradational from pure basalt to scoriaceous basalt and scoria.

At top central part of Molicha hill, it varies from scoria to scoriacious basalt and even to pure basalt and such variation also observed at kerera hill. The basalt is massive and fine-grained. Sometime, it shows flow banding structure. The kerera scoria is also altered to white carbonaceous material.

Petrographically, the scoria is consists of about 97 % groundmass (opaque + glass) with an average 2 % pyroxene and olivine (tab.6). At some of the thin section the groundmass is highly limonitized. The texture of the scoria is holohyline to pumiceous and some of the crystal shows ophitic intergrowth (fig.15a).

The basaltic dykes at Molicha hill, Petrographically is composed of 82% grounmass with plagioclase microlites, 15% idiomorphic plagioclase, 2 % olivine and 1 % pyroxene. The texture varies from porphiritc to trachytic.

3.4. Quaternary sediments

3.4.1. Alluvial soil (Qa)

The alluvial soil is mostly covering the northern and southern part of subsheet O and U respectively (fig.7). It covers marshy places and some streambeds of the area. It is black in color and have fine (clay and silty) grain size. The soil is mainly associated with the volcanic rocks hence it contains fragments of the volcanic rocks.

3.4.2. Sandy soil (Qs)

It covers mostly the flat topography, ridge slopes and some elevated plane of the mapped area. It is reddish brown to yellowish red in color and have fine to medium (clay to sandy) grain size. It is soft and friable. It is mainly composed of clay material with ferromagnesian and ironoxides which gave the soil reddish brown color. At places the low concentration of ironoxides in the soil result in brownish to yellowish color. The soil represents the C – horizon of the area.

4. Structure

4.1 Introduction

The mapped area comprises of a limited Precambrian rocks and Tertiary - Quaternary deposits. The Precambrian rocks are polydeformed and metamorphosed, forming higher topographic features in the area. However due to the competency problem of the rocks and luck of exposure, there is a scarcity of structural data in the area. Despite the scarcity, the available planar and linear structural features are categorized into different deformational events designated as D_1, D_2 and D_3.

The Tertiary - Quaternary deposits; spatter cone, lava and pyroclastic materials are covered most of the structures in the area. However, there should be tectonic activities before the eruption of the volcanic materials, which is responsible for the formation of open fissures or faults, a path for the volcanic materials.

4.2 First phase of deformation (D1)

The development of maridonal N – S running foliation (S_1) is the most prominent planar feature in the area. It is formed by the transposition of the primary bedding (S_0) of the metasediment (marble & quartzite) and metamorphic segregation (mafic & felsic) minerals during the D1 deformational event. The intensity of the foliation (S_1) varies from place to place due to the compositional variation of the rock units and the effect of later deformations.

The general trend of the foliation (S_1) is NNE – SSW and NNW – SSE. The dip of the foliation is ranging from subhorizontal to vertical at a places (10 – 80 degree), however the NNW – SSE foliation is the dominant one (fig.17). At the eastern most part of the area, the foliation dips towards the east and at the southwestern part, it dips to the west (fig.20). In the granitic gneiss and foliated granite, the segregation and slight alignments of biotite and felsic (quartz & feldspar) minerals define the S_1 foliation plane. The granitic gneiss, shows a banding structure at west of Dikole village. Each band varies in thickness from 2 to 5 cms. At Gubal and Bule Kersa Guda, there is a strike change of the foliation. While in the amphibole gneiss, the foliation is defined by the parallel alignment of the amphibole minerals.

An intrafolial fold, remnant of first phase of folding (F_1) plunging 10 degree to north 170 degree was also formed during D_1 deformation event at Kulkule diko hill (fig.16c). The axial surface of the fold is parallel to the S_1 surface.

4.3. Second phase of deformation (D2)

The second phase of deformation is explained by the presence of crenulation cleavage. It is resulted by the folding (crenulating) of the regional foliation (S_1). This cranulation cleavage represents the local axial planar surface (trace of S_2 surface) along the hinge zone of F2 folds.

Stereoplot of poles of the foliation (S_1) define a great circle girdle whose axis plunge to NW direction (fig.18 &19). The concentration of the poles shows cylindrical fold. This fold is F_2 fold due to D_2 deformation.

4.4. Third phase of deformation (D3)

The third phase of deformation in the area is a shearing event. The structural elements of this phase of deformation are not common in the area. Among which the mesoscopic shear sense indicators observed at some places include

a) Asymmetric S folds at Kulkule Guda in the biotite gneiss with sinistral sense of movement (fig.16c).

b) Z folds in the marble with dextral sense of movement (fig.16a).

c) Small scale fault at west of Dikole village in granitic gneiss with sinistral sense of movement (fig.16b).

This local observation might represent a N – S running ductile – brittle shear zone (D3) affected by later deformation.

4.5. Fourth phase of deformation (D4)

The regional antiform and synform in the area are interpreted from opposing dips might be the result of D_4 deformation (fig.20).

The lineation plots close to great circle girdle axis (fig18). The plot shows the existence of open fold of D_4 deformation whose axis is shallowly plunging to NW direction. The plot of lineation show two different points which may be associated with doubly plunging axis of the fold (fig.18) to NW and SE direction.

4.6. Lineament

Two prominent lineament directions, NW - SE and NE – SW is observed in the mapped area. The NW - SE lineaments are the dominant one. Most of the lineaments have length ranging from 1 Km to 10 Km and are shown up well in arial photos. Some of these lineaments are possibly concealed faults.

5.Metamorphism

5.1.Introduction

The basement rocks in the mapped area are mainly affected by regional metamorphism. The mineral assemblage (paragenesis) of the respective rocks is used to identify the metamorphic grade of the area. The P- T stability fields of individual minerals are mainly used for the determination of the facies because of the absence of any index minerals.

Based on the metamorphism in the area is grouped into two stages of prograde metamorphic events with local retrograde metamorphism. The metamorphic events are designated as M_1 and M_2 respectively.

5.2.The First metamorphic event (M1)

This phase of metamorphism is displayed in the gneissic terrains and in the metagranitoids. The mineral assemblage are stable over the complete P- T ranges of amphibolite facies.

A) Biotite gneiss

biotite + plagioclase + microcline + quartz + opaque ± hornblende

B) Granitic gneiss

quartz + plagioclase (oligoclase or above) + microcline + biotite ± hornblende

The stability fields for individual minerals, according to Winkler (1979) is as follows

Biotite ----- greenschist facies to amphibolite facies

Microcline ----- greenschist facies to amphibolite facies

Plagioclase (oligoclase or above)----- upper epidote – amphibolite to granulite facies

Hornblende ----- upper epidote – amphibolite to amphibolite

Such wide range of stability field for each mineral type actually depends on the type of co-exists mineral. However the average stability fields for the above assemblage falls in the amphibolite facies. The occurrence of hornblende and plagioclase together in the assemblage indicate that it belongs to amphibolite facies (Hyndman, 1985). The appearance of oligoclase also exhibits the lower temperature limits of amphibolite facies. The presence of some perthite intergrowth of the microcline shows the temperature range below 660^0 C (Kerr, 1975) which is well in the amphibolite facies field.

The biotite grains define the gneissosity of the rock, but at higher grades the gneissosity became rough and more irregular. In the absence of flaky minerals, the gneissosity defined by flattened quartz grains. This quartz grains at highly strained cases show wavy extinction. The occurrence of abundant granitc veins are also an indicator of amphibolite facies (Hyndman, 1985). However the absence of penetrative deformation in granitoids indicate that they retain the original igneous texture (Frey, 1994) regardless of the metamorphic grade.

5.3. The second metamorphic event (M2)

The second metamorphic event is displayed in ultramafic (Tremolite- actinolite schist).It is a lower grade of metamorphism under greenschist facies conditions. The characteristic mineral assemblage is as follow

tremolite + actinolite + talc ± opaque depicts the fact

The stability fields for individual mineral depends on the assemblage. However, in general

Tremolite is thought to be stable under wide range of metamorphic condition ranges from

upper prehenite-pumphlite to lower amphibolite facies

Actinolite is also stable from upper prehenite-pumphlite to lower greenschist facies

Talc on the other hand, is stable from zeolite to middle greenschist facies depends on the type of co-existing minerals.

Therefor the over all stability field for the above assemblage is the greenschist facies.

5.4. Retrograde metamorphism

The presence of retrograde metamorphism is noted by the break down of some minerals (tab.7)

Table. 7 Alteration product of some minerals

Rock type	Source mineral	Secondary mineral	process
Biotite gneiss	plagioclase	sericite	sericitization
	biotite	chlorite	chloritization
Granitic gneiss	hornblende	epidote	epidotization
	plagioclase		propylitic
	biotite	chlorite	chloritization
		limonite	limonitization
Foliated granite	biotite	Opaque (magnetite)	
		chlorite	chloritization
	plagioclase	epidote	propylitic
	hornblende	chlorite	chloritization

6. Discussion and conclusion

Kenchero and Arbele localities of Southwestern Ethiopia comprises Precambrian metamorphic rocks, Tertiary – Quaternary volcanic rocks and Quaternary sediments.

The polydeformed and metamorphsed Precambrian rocks are grouped into different sub units, based on their metamorphic grade and mineral composition. These include gneisses (biotite and granitic gneiss) and deformed granite with patchy outcrops of mafic – ultramafic rocks. The mineral composition is estimated by averaging the approximate modal percentage of minerals from each thin section while the metamorphic grade is interpreted from the metamorphic mineral assemblages and P – T stability fields of individual minerals following (Winkler. 1979) method.

The Precambrian rocks are affected by four phases of deformations. The prominent and intense D_1 deformation has produced dominantly maridonal trending and subhorzontal to vertical dipping regional foliation (S_1) in the gneissic terrain. This event is coevial with peak amphibolite facies (M_1) metamorphism as is the case within the Mozambique Belt in the south (Mosley, 1992). The event is termed as Baragoian event (age 620 ma) of Northern Kenya in the Mozambique Belt, which is equated as D_1 event of Mulugata (1992) and D_2 event of Amenti (1996). The occurrence of xenoliths of biotite gneiss in the granitic gneiss and foliated granite proved that the granitoids were probably intruded during Syn – Post D_1 deformation.

The second and third phases of deformation in the mapped area are less intense than D_1 deformation. These phases of deformation produced minor crenulation cleavages and shear zones, respectively with greenschist facies (M_2) metamorphic event in the ultramafic schist and a local retrogressive effect in the gneissic rocks. Finally the D_4 event produces a regional folding with NW- SE, subhorzontal axis.

The post D1 deformation events D2 - D_4 mainly interpreted as Barsaloin event of Mozambique Belt of Northern Kenya (Mulugata, 1992 and Amenti, 1996). Pegmatization is common through out the deformation history.

The mafic – ultramafic schists mainly contain melanocratic amphibole schist and tremolite – actinolite schist in association with marble. These are probably part of the Low -grade Arbian – Nubian Shield rocks which are more extensively exposed in the north (Kazmin, 1978 and Vail, 1983).Due to poor exposure and soil cover, it is impossible to deduce any tangible relationships between the high-grade rocks and the Low - grade rocks. However, this slice might be a remnant of allochthonous (Beraki etal, 1989), fragmented ophiolitic complexes which is tectonically transported either directions or might be a remnant of oceanic crust during continent – continent or arc- arc collision.

Based on composition, metamorphism and certain structural elements, there is a lithlogical similarity of the study area with Kazmin's 3 – fold classification of southern Ethiopia (Kazmin, 1972). The high – grade rocks of the present area is more or less lithologically similar to the lower complex granite and gneisses (Kazmin, 1972) of southern Ethiopia while the patchy mafic – ultramafic unit is correlable with the upper complex (Kazmin, 1972) of the Precambrian succession of southern Ethiopia (Table. 8).

Tertiary to Quaternary rocks of the study area is comprised of volcanic flow and volcanic pyroclastic falls. The volcanic flows mainly cover the lower topography of the mapped area. While the volcanic fall forms a spatter cone (scoria cone) aligned in NNE direction probably following major structural weak zone such as fault.

The eruption of these volcanic materials is closely related to certain tectonic activities. These tectonic activities are responsible for the formation of fissural opening for the volcanic flow and a conduit for the central type or volcanic fall eruption (Balmwal etal, 1991).

The presences of mantle drived nodules show the extent of the fractures (opening) deep to the mantle. While, the alignment of scoria cone in NNE direction might indicate the presence of lineament which is probably the result of propagation of the main Ethiopian rift system from the west or Anza graben of Northern Kenya from the south. Chronologically, Balemwal (1991) adopted two periods of volcanic activities for Southern Ethiopia. 6 – 4.5 ma and 2.5 – 0.9 ma (upper Miocene to recent) for fissural and central type volcanisms respectively. Later, the volcanic cones and flows of scoriaceous basalt (analogous with the present area) were categorized under pleistocence to recent age (Devidson, 1973). This age is also considered as localization of volcanism (Kazmin, 1979) within and out side the rift system.

7. ECONOMIC GEOLOGY

7.1 INTRODUCTION

Previously, no systematic exploration activities were undertaken in the area under consideration. Even though some salt mining and minor collection of gemstone by the local people are under taken in the surrounding subsheet. However in the mapped area, some disseminated metallic minerals, industrial mineral and construction materials are observed.

7.2 Metallic minerals

During the mapping activities, magnetite and hematite at places are observed in granitic gneiss and foliated granite. This mineralization is commonly occurring in disseminated forms. Rarely the hematite and magnetite (at bule kersa guda) concentrated as thin layer parallel to the foliation plane.

7.3 Industrial mineral

Gemstone (olivine nodules, peridote) and is found in the area .The nodules are dark green, rounded and bomb sized which is mostly found with the vesicular basalt and pyroclastic falls.

7.4 Construction materials

The study area contains basalt, red scoria, marble and granitoids are potential for construction row materials in the area.

7.5 Agricultural potential of the area

In the area, there are wide, thick and fertile soil covers that can be used for mechanized farming especially in the raining season.

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