Geology of the Shar and Bulen areas, northwestern Ethiopia: Preliminary result

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Abstract

Geological assessment of Shar and Bulen areas, northwestern Ethiopia indicates distinctive rock associations consisting of pelitic and pssamitic sediments that are interbedded with volcanic rocks and linear belt of mafic-ultramafic rocks. These volcano-sedimentary associations signify interchanges of sedimentary process and volcanic activity. Deposition is interpreted to have occurred within a marginal to shallower marine setting. The rocks were subjected to different phases of deformation and were metamorphosed to greenschist facies. Structural investigation indicates that the area underwent at least three phases of deformation (D_1-D_3) with pre-, syn- and post- kinematic granitic intrusions. The volcano-sedimentary association together with mafic-ultramafic rocks can be interpreted as an arc/continent suture zone.

1. Introduction

An interfingering of two prominent orogenic belts i.e. the Mozambique Belt (Holmes, 1951) to the south and Arabian-Nubian Shield (Gass, 1981) to the north defines the Precambrian geology of western Ethiopia (Fig. 1). The Arabian-Nubian Shield comprises extensive low-grade Neoproterozoic volcano-sedimentary sequences, associated with dismembered ophiolites aligned along suture zones (Vail, 1983; Berhe, 1990; Ayalew et al., 1990; Stern, 1994; Abdelsalam and Stern, 1996). The two belts are developed in structural and metamorphic continuity during the 950-500 Ma pan African orogenic event (Chewaka et al., 1981; Almond, 1983) and intensely deformed during the Neoproterozoic tectonic evolution of the East African Orogen (Stern, 1993; 1994). The low-grade volcano-sedimentary rocks of western Ethiopia are bounded between high-grade gneissic terrains to the west and east. It extends from 6° N to 12° N before it disappears under Cenozoic

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cover (Fig. 1). It forms wedge shaped linear belt narrows to the south and widened (about 150km) in the north. The Shar and Bulen areas are located at the western part of northwestern Ethiopia (Fig. 1), where Neoproterozoic rocks are widely distributed. Although very limited works were reported south and west (Terji, 1997; Braathen et al., 2001) of these areas, there is no previous geological map with such details for the Shar and Bulen basement rocks. In this paper, we present the results of field investigations of the lithologies and structures of the Shar and Bulen areas. Based on previous works for the east Africa and different part of western Ethiopia (e.g., Kazmin et al., 1978; Chewaka et al., 1981; Shacklton, 1986; Berhe, 1990; Ayalew et al., 1990; Stern, 1993; 1994; Tefera et al., 1996; Abdelsalam and Stern, 1996; Tefera, 1997; Terje, 1997; Gerra et al., 2000; Alemu et al., 2000; Braathen et al., 2001; Allen et al., 2003), we discuss about the evolution of the volcano-sedimentary and mafic-ultramafic associations in the area.

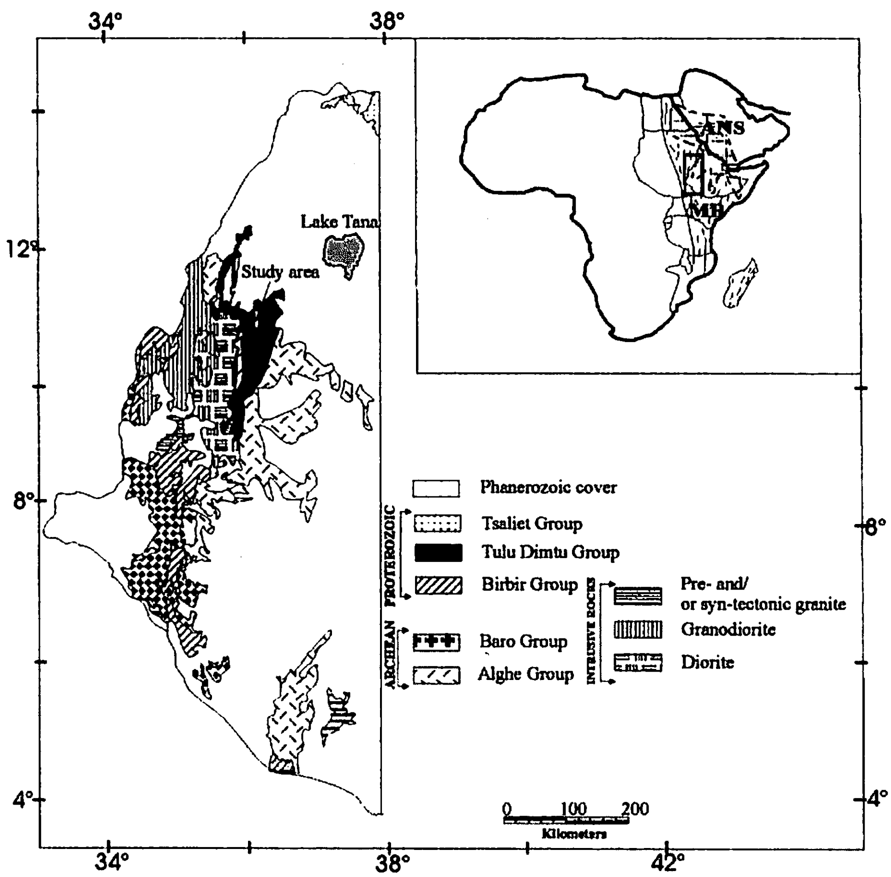

Fig. 1 Simplified geological map of western Ethiopia. Inset: - Generalized map showing the spatial distribution of the Arabian-Nubian Shield (ANS) and Mozambique Belt (MB) in east Africa (after Gichile, 1991). The location of Ethiopia and the study area also shown.

2. Regional geology and Geological setting

In western Ethiopia (Fig. 1), the high-grade gneissic terrains comprise various gneisses and migmatites, which are usually coarse-grained, well foliated and gray colored, often banded due to the injection of granitic material. Transitions from foliated and banded rocks to massive varieties are common, reflecting the variations in degree of granitization and mobilization (Kazmin, 1972). Whereas the low-grade volcano-sedimentary rocks are assumed to be the southern extension of Arabian-Nubian Shield (Ayalew et al., 1990; Berhe, 1990), and it belongs to the Upper Complex defined by Kazmin (1972; 1975). The Upper Complex constitutes low-grade mafic-ultramafic rocks and volcano-sedimentary rocks of island arc-ophiolite association of Neoproterozioc age (Shacklton, 1986; Berhe, 1990; Kazmin et al., 1978). It is metamorphosed to greenschist facies and at places to amphibolite facies with restricted granitization (Kazmin, 1975). It was formed between 830 and 650 Ma and was followed by deformation, metamorphism and intensive plutonism that continued until 520 Ma (Ayalew et al., 1990; Teklay et al., 1993). The complex composed of Birbir (Kazmin, 1975) and Tulu-Dimtu (Kazmin, 1972; 1978; Tefera et al., 1996; de Wit et al., 1977) Groups (Fig. 1). The Birbir Group is developing in the marginal and shallower part of the sedimentation basin. It consists of chlorite and sericite schists (phyllite) with interbedded quartzites, graphitic rocks, acidic to intermediate volcanics and siliceous rocks (Kazmin, 1975). The Tulu-Dimtu Group is low-grade metavolcanics and metasedimentary unit with abundant intrusive bodies of mafic, intermediate and granitic composition (Tefera et al., 1996). It also contains ultramafic bodies and forms the Tulu-Dimtu-Dalati-Yubdo ophiolite suture zone (Kazmin, 1978; Kazmin et al., 1979) and merged with the Tsaliet Group (Kazmin, 1972; 1978). These groups, together with the ophiolite and intrusives, are of pan African age (Tefera et al., 1996) and developed as island arc-oceanic basin complexes (Tefera et al., 1996). However, the relatively narrow linear belts can be interpreted as convergent boundaries or suture between continental and island terrains (de Wit et al., 1977; Vail, 1983). This group closely resembles the Boji and the Soka series of southeastern Ethiopia, the Tsaliet and Tembien Groups of north Ethiopia (Kazmin, 1975) and the Adola-Moyale belts of southern Ethiopia (Worku et al., 1996; Worku, 1996; Tefera et al., 1996; Yibas et al., 2002).

3. Methods of investigation

Following to the field survey conducted in 2003, Landsat imagery, aerial photo and topographic data were interpreted in order to determine major lithologic and structural trends in the study area. The combined data has been summarized in the geological map and is described below.

4. Lithology and Petrography

The basement rocks of the study area consist of high-grade gneiss, low-grade volcano-sedimentary rocks and Ganzi melange (Fig. 2). They are metamorphosed to amphibolite and greenschist facies respectively and subjected to polyphases of deformation. The metasedimentary rocks are intercalated with mafic to intermediate metavolcanic rocks. Contacts between the successions were generally gradational, except where it is sheared. Granitic intrusives have intruded them, which lastly followed by volcanic covers (Fig. 2).

4.1 High-grade rock

The high-grade rock is mainly consists of migmatized biotite gneiss. It forms the rugged topography of east Donben locality (Fig. 2). It is coarse-grained, gray to dark gray. It is characterized by the mineral assemblage of quartz + biotite + plagioclase + K-feldspar + hypersthene ± calcite ± opaque (Fe-Ti oxides). The quartz grains are anhedral, show wavy (undulated) extinction and they are elongated and stretched parallel to the foliation plane. Alteration of K-feldspar and plagioclase to sericite; biotite and plagioclase to epidote and chlorite is common. The biotite grains define the major foliation plane. It is intruded with metagabbro-diorite complex and metatonalites. Swarms of undeformed, boudined, folded pegmatite and granitic veins are also hosted in the migmatized gneisses.

4.2 Volcano-sedimentary rocks

The volcano-sedimentary rocks are the principal lithologies of the study area. They are generally deformed and intercalated slice of metasediments and metavolcanics. The volcano-sedimentary rocks are mainly composed of marble, undifferentiated metasediments, sheared quartz-hornblende schist and metavolcanic rocks (Fig. 2).

Marble

It makes up rugged topographies of southern Mora and Bapuri and west of Emanji localities (Fig. 2). It is also found as mega xenolith within Kidoh-Badore granite. It is highly deformed, medium- to coarse-grained, dark gray to milky white with mineral assemblage of calcite ± quartz ± opaque (graphite) ± muscovite. Usually the trace minerals are concentrated in some spots. The calcite shows equigranular grains with well-developed triple junctions and granoblastic texture. The mega xenolith is affected by concordant and discordant pegmatite veins and veinlets.

Undifferentiated metasediments

It forms relatively flat topography of Dach Weseb, Wubgish, Berber and very rugged topography of Benosh and Moch localities (Fig. 2). It has sheared contact with metavolcanic, Ganzi melange and weakly deformed granite (Fig. 2) and sharp contact with the other intrusives. It comprises an intercalation of sericite quartz schist, quartz mica schist, quartz graphite schist, graphite schist, graphitic quartzite, marble and metavolcanics. The sericite quartz schist is fine- to medium-grained, light gray, dark to reddish gray. It is highly affected by concordant and discordant quartz veins and veinlets. The concordant veins are boudined and form pinch and swell structure. The mineral assemblage of the sericite quartz schist is quartz + sericite + biotite + plagioclase ± opaque ± k-feldspar ± chlorite ± calcite. The marble is usually found as patches and intercalates with the sericite quartz schist. It occupies a flat to gentle topography. The quartzite is found as a minor intercalating unit within the mica quartz schist. It is medium-grained, dark gray to reddish brown. It is composed of quartz + biotite + sericite ± plagioclase. The amphibole schist also intercalates with the sericite quartz schist. It is medium-grained, dark green to dark gray with assemblage of hornblende + quartz + calcite + biotite ± opaque (Fe-Ti oxides) ± muscovite ± plagioclase ± K-feldspar. Quartz grains are anhedral, equigranular and sometimes elongated and show wavy (undulated) extinction.

Sheared quartz hornblende schists

The sheared quartz hornblende schist crops out in the northwestern part of Shar area and forms an elongated, low lying and rugged topography (Fig. 2). It has a gradational contact with the metavolcanics. This unit constitutes minor intercalation of metasediments at different spots. The quartz hornblende schist is fine to very fine grained, light green to dark green. It is highly deformed (sheared) and schistosed. Sometimes, it show banding structure. Near the shear contact it is frequently intercalated with granite seals (Fig. 3a). Epidotization is very common. Granite mylonite and pegmatoidal gabbros are also encountered. The mineral assemblage is hornblende + quartz + opaque (Fe-Ti oxides) ± epidote ± chlorite. The quartz grain is equigranular and has sutured boundaries. The hornblende is strongly aligned, showing nematoblastic texture.

Metavolcanic rocks

Metavolcanic rock forms very rugged topography of Defli locality (Fig. 2). It is bounded by major shear contacts at the east (Fig. 2) and intruded by post-tectonic granite. The metavolcanics mainly comprise amphibole schist and chlorite schist with a few intercalations of mica quartz schist, quartzite, mylonitic granite and gabbro. The amphibole schist is medium- to coarse-grained, dark green to gray. It is composed of hornblende + quartz + calcite + opaque (Fe-Ti oxides) + chlorite ± epidote. It exhibits mostly equigranular fabric with hornblende grains are weakly to strongly align with nematoblatic texture and also shows alteration to chlorite and rarely develop zone of epidotization. Silicification and chloritization are the common alterations. The chlorite schist intercalates with the amphibole schist and found dominantly at the northern part.

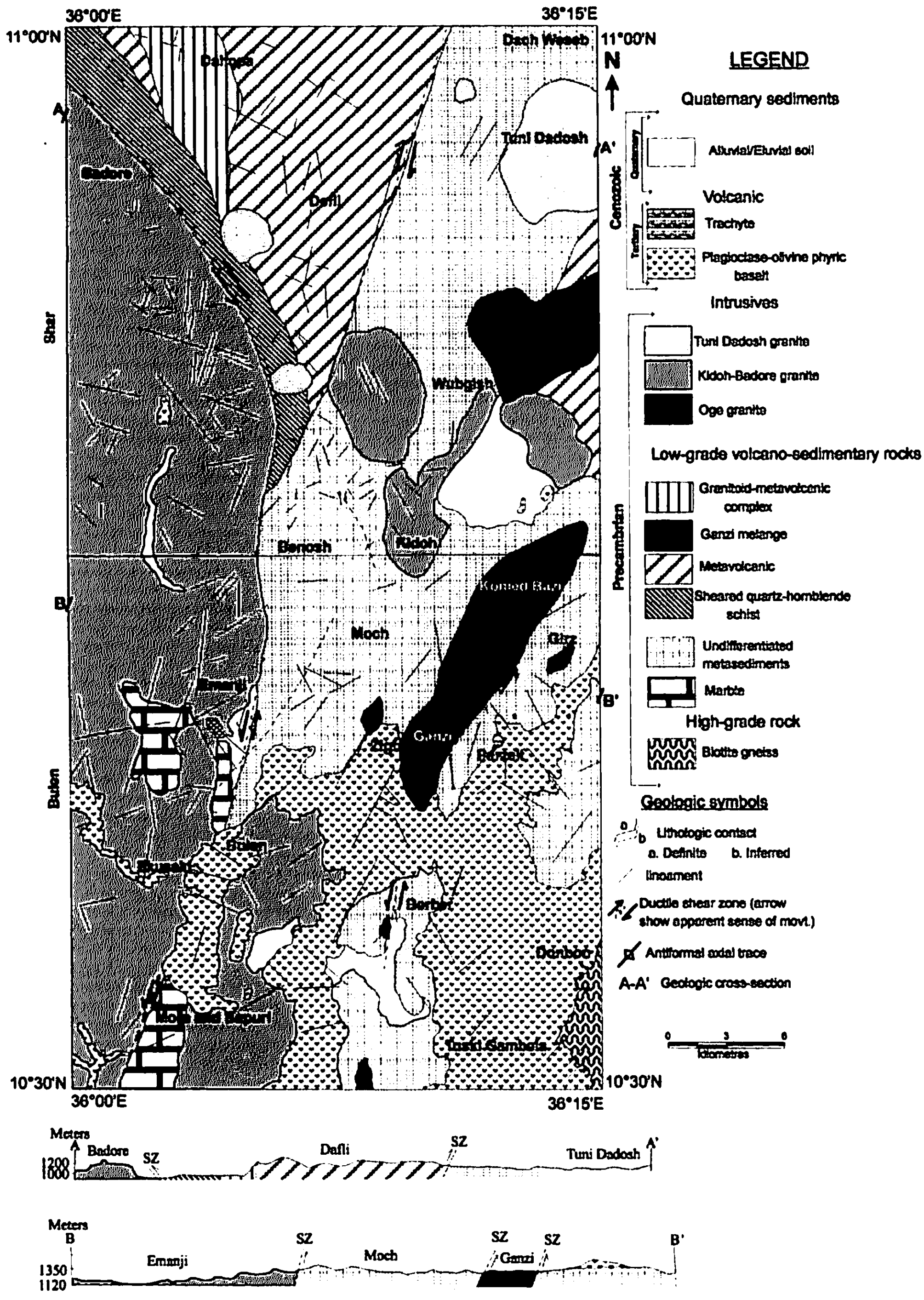

Fig. 2 Geological map of the study area and schematic cross sections across A-A' and B-B' with the shear zones (SZ).

It is highly schistosed and develops strong fabrics. It is fine to medium grained, greenish to reddish green (buff color). Sometimes it contains sericite and rarely very thin magnetite rich layer. Occasionally both rocks are associated with mylonitized granite. Pods of undeformed granitoids are very common. Highly shattered concordant and discordant quartz and pegmatite veins and veinlets are also associated. As well, at the northwestern part of Shar area, there is an injection of granite seals into the metavolcanics and it is mapped separately as granitoid-metavolcanic complex (Figs. 2 and 3b). It forms very rugged topography southwest of Dahopa locality. It can be considered as zone of hybridization or injected migmatization. The granite is injected through foliation plane of the metavolcanics.

4.3 Ganzi mélange

It forms flat to gentle topography of Komed Bazi locality and Ganzi hill (Fig. 2). The Ganzi melange comprised of tectonically mixed rock associations. These are serpentinite, serpentine schist, silicified serpentinite, talc chlorite schist, talc tremolite schist, serpentine talc schist, marble, mica quartz schist, quartzite and pods of hornblendite. The central part of the melange is massive but the margins are invariably sheared (Fig. 2). The serpentinite shows massive to highly deformed nature. It usually occupies the central and top part of the hills. It is fine to medium grained, greenish to greenish gray. It is composed of serpentine + talc + opaque (Fe-Ti oxides). It is highly brecciated and silicified. It is affected by plenty of concordant and discordant quartz veins and veinlets. Moreover, veinlets of chromites and magnesite are also common. The serpentine talc schist usually occupies the lower (basal) part of the hills. It is highly deformed and schistosed, fine grained, greenish to greenish gray with mineral assemblage of talc + serpentine + opaque (Fe-Ti oxides). The opaque minerals are very fine, randomly oriented and rarely concentrated following schistosity plane. The hornblendite is usually

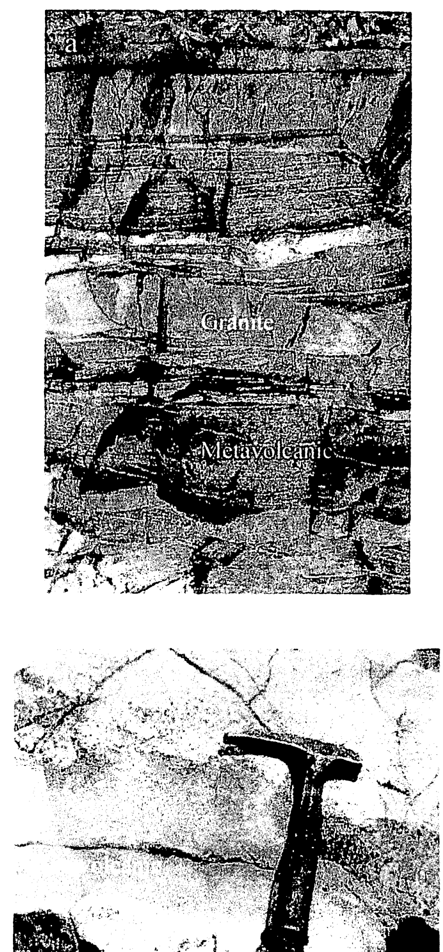

Fig. 3 An injection of granite into the foliation plane of metavolcanic rocks.

found as pods. It is massive, coarse-grained, deep green to green. It is composed of hornblende ± pyroxene ± chlorite ± epidote ± calcite. The associated marble mostly found at the lower topography. The marble shows banding fabrics and contains boudined, lensoid and contorted silicified serpentinite and quartzite.

4.4 Intrusives

It is exposed as prominent elevated mountain range and ridges intruding the undifferentiated metasediments and metavolcanics. The intrusives are classified into three subgroups Oge, Kidoh-Badore and Tuni Dadosh granites (Fig. 2).

Oge granite

It forms Oge and Gesses ridges (Fig. 2). It is foliated, where the foliations are characterized by the flattening of the constituent minerals, and at places gneissosed. The intensity of deformation varies from place to place. It ranges from massive to strongly deformed pre to syn tectonic granite. It is medium- to coarse-grained, pinkish to dark gray and leucocratic to mesocratic, sometimes lineated. It is affected by series of joint systems and pegmatite veins. The average composition is quartz - K-feldspar + plagioclase ± sericite ± opaque (Fe-Ti oxides) ± epidote with granoblastic texture. The modal plot mainly falls in the granitic field with higher percentage of quartz (Fig. 4).

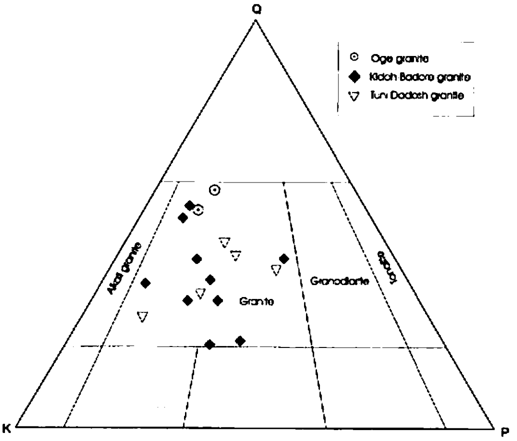

Fig. 4 Modal plot of the granites (after Streckeisen, 1976). Q=quartz; P=plagioclase; K= alkali feldspar.

Kidoh-Badore granite

It mainly defines syn to post tectonic Kidoh ridges and Badore batholith (Fig. 2). It is medium- to coarse-grained (pegmatoidal), pinkish gray to dark gray and leucocratic to mesocratic. The intensity of deformation increases towards the shear zone. Moreover, the deformation is slightly reflected on the textural variation of the rocks. It is massive to marginally foliated and variably affected by major shear zones even to an ultramylonite stage, the augene feldspar crystals show sinistral sense of movement. Concordant and discordant pegmatite veins and xenoliths of marble and metavolcanics are distinguished. Most of the veins are highly shattered and jointed. The average composition is K-feldspar + quartz + plagioclase + biotite + sericite ± epidote ± sphene ± calcite. The modal compositions straddle towards alkali granite and granodiorite (Fig. 4).

Tuni Dadosh granite

Tuni Dadosh granite crops out at Tuni Dadosh and west of Defli locality (Fig. 2). It forms a gentle to moderately steep topography. It is massive (not foliated), coarse-grained, pinkish to dark gray and leucocratic post tectonic granite. Exfoliation is very common. It is composed of quartz + k-feldspar + plagioclase + biotite + sericite + muscovite ± opaque (Fe-Ti oxides) ± epidote ± chlorite ± sphene. The modal compositions mainly fall in granitic field (Fig. 4).

4.5 Volcanic rocks

The volcanic rocks mostly covered the low-lying topographies (Fig. 2). The rocks are comprised of plagioclase olivine phyric basalt and trachyte. The basalt is fine grained (aphanitic), dark to dark green. The mineral assemblage of the groundmass is olivine + plagioclase + augite – opaque (Fe-Ti oxides) ± glass ± chlorite ± epidote. The trachyte makes up the Parzeit hill. It is light gray to yellowish white and has aphanitic texture with groundmass of sanidine + quartz ± pyroxene ± apatite.

5. Structure and deformation

The area is affected by at least three phases of deformations with progressive sequences of deformational events designated as D_1, D_2 and D_3. Consequently the intense shearing obliterates some of the pre-sheared primary structures. The description of these structures with their respective deformation event is given below.

5.1 D_1 deformation event

It is the earliest deformational event in charge of the development of regional foliation and folds (F_1). Tight to isoclinal intrafolial folds, remnant of the first phase of folding (F_1) is noted frequently in the metasediments (Fig. 5). Relatively with thickened and rounded hinge zones. The axial surfaces of these folds are parallel to S_1-foliation surface. However the plunge amount and directions of the axis is uncertain (Fig. 5). The S_1 planar fabric developed regionally throughout the area (Fig. 6a). It is penetrative, well preserved and documented in all volcano-sedimentary rocks and marginal part of the plutons.

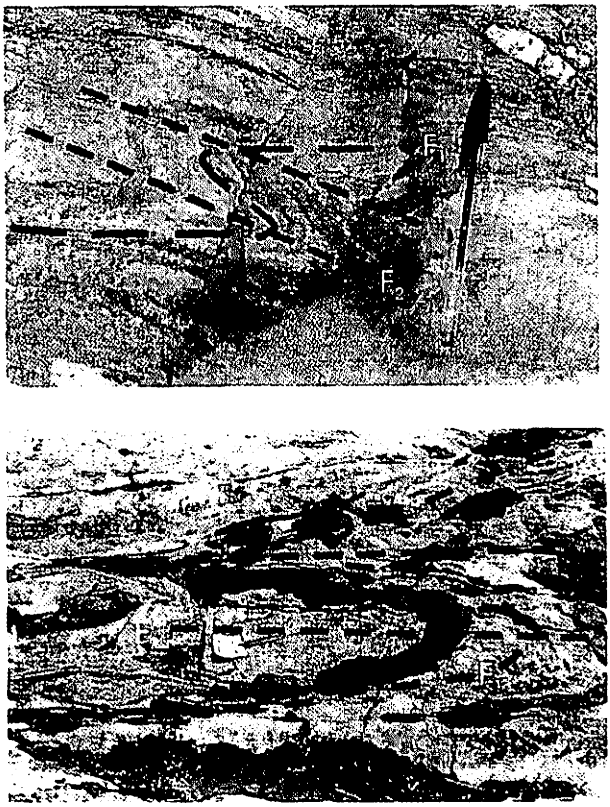

Fig. 5 Isoclinal F_1 folds and tight to open upright F_2 folds in metasediments.

Generally it is characterized by NNE-SSW and NNW-SSE trending foliations, dipping steeply inclined to subvertical towards east. The intensity of S_1-foliation surface is non-uniform, due to the effect of later orogenic events occurred in the area. The stereographic projection of S_1-foliation shows the variation of planar direction and the average surface of S_1-foliation, revealing the presence of east dipping N-S running regional foliations (Fig. 6b).

5.2 D_2 deformation event

The crenulations of S_1-foliations which lead to new generation of foliation planes (S_2) and the refolding of F_1 folds to tight to open upright folds (F_2) are the result of D_2 deformation. Tight to open upright folds (F_2) are observed in different part of the area. Minor tight upright folds (F_2) are mainly encountered in the metasediments (Fig. 5). The fold axis show shallow plunge angle toward SW direction. The Gesses hill is defined by megascopic regional open upright fold (F_2). The plots of the foliations illustrate upright F_2 fold plunging 40° /230° (Fig. 6c). The axial trace of this fold is nearly parallel to the trend of S_2 fabric.

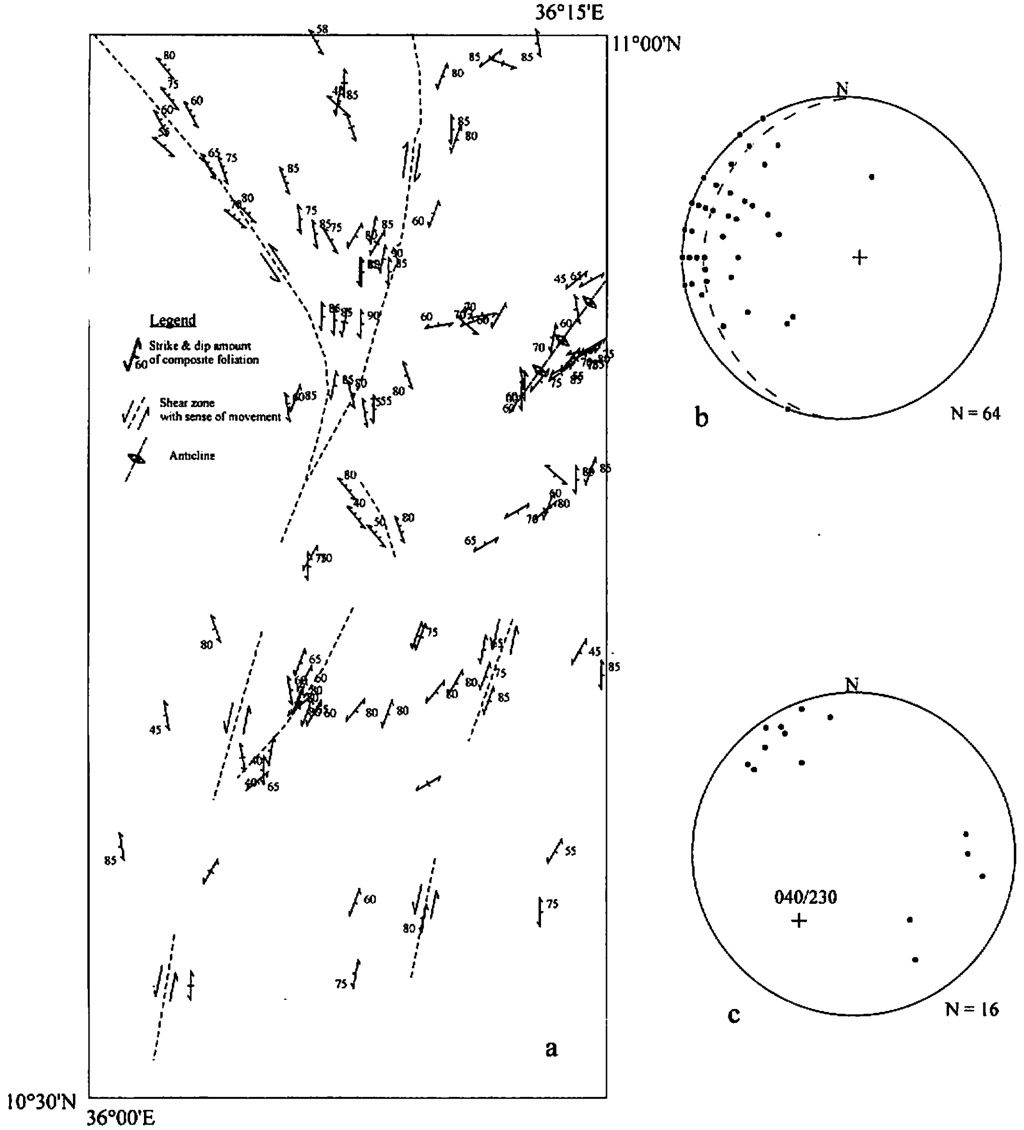

Fig. 6 Structural map and data from Shar and Bulen area, plotted in equal area lower hemisphere stereonet. a) Structural map. b) Poles of S_1 foliation (dot) and average foliation plane (dash line). c) Poles of (S_1/S_2) foliation indicating a SW plunging F_2 fold axis (cross).

5.3 D_3 deformation event

The D_3 deformation is associated with the development of a series of NNE to NNW trending shear zones (Fig. 6a). It is an extensive zone display by steep to subvertical dipping foliations (enhancement of S_1 foliation planes). Outcrop to regional scale shear splays that merge to the major sinistral shear zone are abundant. These shear splays produced antithetic and synthetic shear fractures. The main sinistral shear zone can be traced in length north to south out of the mapped area (Fig. 6a). The kinematic shear indicators associated with these shears are drag related folds, asymmetric S-folds, sigmoidal quartz veins or rotated porphyroclasts (Fig. 7c and d), boudines and pinch-swell structures (Figs. 7a and b).

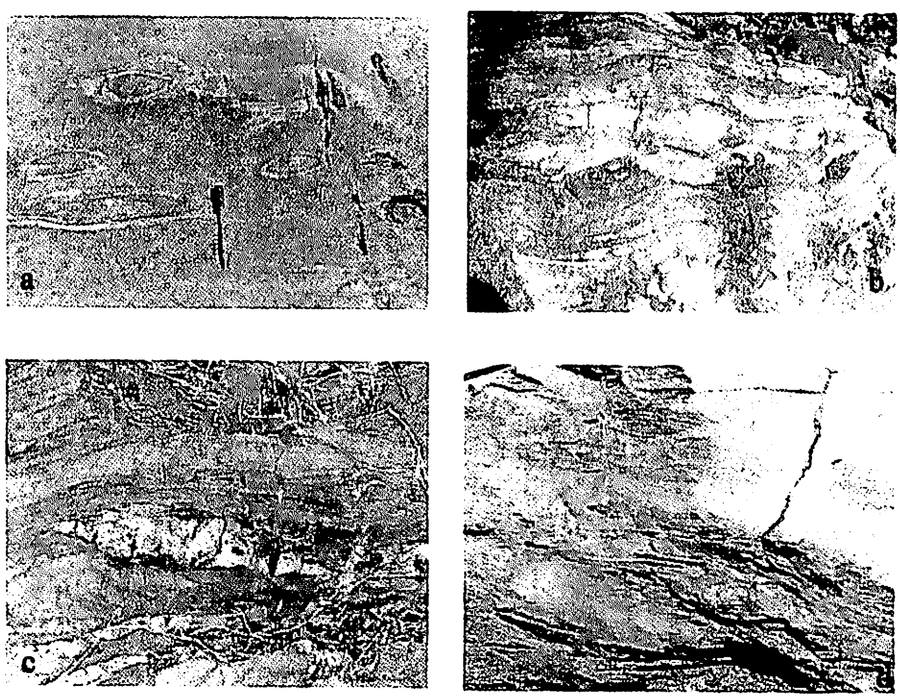

Fig. 7 Shear kinematic indicators in metasediments and metavolcanics.

6. Metamorphism

Though metamorphic history of the area is complicated, at least two major events could be perceived. These are amphibolite facies and low to upper greenschist facies in the migmatized biotite gneiss and the volcano-sedimentary associations, respectively. Later, both rocks were affected by retrograde metamorphism, revealed by chloritization of hornblende and biotite. The metamorphic mineral assemblages of the two facies are neither in mineral nor textural equilibrium. Field observation and petrographic study of representative rock samples do not show any indication or tendency of progressive or retrogressive metamorphic mineral assemblages towards each other. Therefore the rocks were metamorphosed in different P-T condition and tectonically juxtaposed together. The mafic-ultramafic rocks in Ganzi melange includes relict of high temperature minerals such as olivine and pyroxene pseudomorphs, which indicate that dunite and/or peridotite protolith has been weakly metamorphosed under low P-T conditions.

7. Discussion

The volcano-sedimentary rocks of Shar and Bulen areas are part of the NS-trending low-grade sequence of the western Ethiopia. It is bounded to the east and west by amphibolite facies gneissic blocks (outside the mapped area). The lithologies of the area record deposition of sedimentary and volcanic succession. The succession indicates a variable interplay between sedimentary process and volcanic activity. The deposition occurred in marginal to shallow marine environment close to certain volcanic centers or island/back arc setting that followed by pre- to post-tectonic intrusions. The intrusions are granitic (Fig. 5) and similar to the Tulu Dimtu Group (Tefera et al., 1996) and granitoids of Gore Gambella of Neoproterozoic ages (Ayalew et al., 1990). All the rocks are later affected by regional compressional deformation with greenschist facies metamorphism. This gave rise to a penetrative NNW-SSE to NNE-SSW striking foliations (Fig. 6a) in the supracrustal rocks and the granite, the N-S trending pan African fabrics (Allen et al., 2003) and designated as D_1 in Abraham (1989) and Braathen et al. (2001). Then followed by the refolding of F_1 folds to tight upright F_2 folds with its axial traces nearly parallel to S_2 foliations and associated with intrusions of syn- to post-tectonic Kidoh-Badore granite. It is also described as the D_2 deformation in Abraham (1989). The strike-slip sinistral shear zone (D_3) associated with the regional shear splays represents the eastern boundary of Baruda shear zone (Terje, 1997), which belongs to the N-S trending Barka-Tulu Dimtu zone and known as D_2 deformation event in Baruda area (Braathen et al., 2001). Moreover, almost all the shear splays except east of Defli (Fig. 2) have sinistral sense. The exception is the dextral shear splay east of Defli, which is accommodated by post-tectonic Tuni Dadosh granitic intrusions. The composite movements show an imbrication structure (Fig. 2) with the enhancement of S_1 foliations. The linear mafic-ultrmafic assemblage (Ganzi melange) represents an arc-continental suture zone, which is previously considered as deformed ophiolite fragments (Kazmin et al., 1978) or as intrusions (Braathen et al., 2001). It follows the shear zone or the major fracture zone (Terje, 1997) and known as Ganzi and Komed Bazi belt (Braathen et al., 2001) with the major strike-slip movement (Fig. 2). In broad-spectrum, the lithological associations, metamorphic facies and style of deformations of Shar and Bulen area are closely similar to part of the Tulu Dimtu belts (Kazmin 1978; Tefera et al., 1996; de Wit et al., 1977) and Barka-Tulu Dimtu zones (Berhe 1990; Braathens et al., 2001).

8. Conclusion

The continental collision during the Neoproterozoic tectonic evolution of the East African Orogen is verified by several shear belts or suture zones and most of them are associated with mafic-ultramafic complexes. The Shar and Bulen area is a major structure of this type, which is mainly characterized by greenschist facies volcano-sedimentary associations and mafic-ultramafic melange. The rocks are invaded by pre-, syn- and post-tectonic granitic intrusions. Thus, the associations represent an ophiolitic terrane that interpreted to represent an arc/ continent suture zones during the Pan African orogeny.

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