Shear Zone-Hosted Base Metal Mineralization near Abraha Weatsebaha-Adidesta and Hawzein, Tigray Region, Northern Ethiopia

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ABSTRACT

Low-grade basement rocks of Neoproterozoic age with well developed shear zones and post-tectonic granitic intrusives from Hawzien area of northern Ethiopia were studied for field characteristics, mineralogy, textures, alteration assemblages and geochemistry to explore their potential for base metal mineralization. The basement rocks includes metavolcanic (mafic to felsic), metavolcaniclastic and metasedimentary rocks. The intrusive post-tectonic granitoids mark the end of Proterozoic. Field observation and petrographic data indicate the presence of N-S, NE-SW trending shear zones; hydrothermal quartz (±calcite) veins of different generations; malachite stains; alterations like chloritisation, kaolinization, epidotization, sericitization; and presence of base metal sulfides in association with quartz and calcite veins. Geochemistry of surface and drill core samples indicate enrichment of zinc in shear zones with low concentrations of copper, lead, gold, arsenic and silver. Zn-rich base metal mineralization with Pb-Cu-Fe (±Ag-As-Au) is related to D_2 deformation. Barite veins are although common, conspicuously occurring in E-W trending veins. Post-tectonic granitoids are facilitating the hydrothermal activity and the source rock compositions controlling the nature of the mineralization. A paragenetic scheme is suggested on the basis of texture, mineral association, alteration and deformation.

Keywords: Abraha-Weatsebaha, Tigray, Ethiopia, Neoproterozoic, Shear zones, Paragenesis, Sulfide mineralization

1. INTRODUCTION

Ethiopia is endowed with a wide variety of minerals and rocks of which, some are in large quantities with excellent qualities. Minerals such as potash, bentonite, kyanite, diatomite and graphite occur in large quantities and warrant medium to large scale mining. The discovery of primary gold deposit at LegaDembi and tantalum at Kenticha, south Ethiopia, which have reached production stage, can be cited as the best examples of the significance of systematic exploration conducted in the recent past. Furthermore, some of the good indications of the mineral potential of the country include the recent discoveries of eluvial-diluvial gold in western Tigray (Adi Daro, Asgede and Daro Techi), the Weri gold and base metal mineralization by Weri Gold Project (NMIC), the discoveries of gold and base metals at Galesa, Repar, Aware, Egambo (Bulen, Beishangul, Gumuz), Boseti (Adola), and gold deposit at Okote (Dawa Digati area, currently under intensive by drilling) by Midroc LegaDembi Mineral Exploration Project.

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Copper as well as gold occurrences at Wachile and Gewale in Arero Woreda, Borena zone (southern Ethiopia) by the Ethiopian Mineral Development Share Company.

All the mentioned discoveries in different parts of the Ethiopia suggest the need to undertake mineralization-related studies in geologically potential areas.

Mineral exploration activities have been limited in Tigray region of northern Ethiopia particularly due to civil war which ended in 1991. Nowadays exploration activities are intensively being conducted in the region by companies such as Ezana Mining Development PLC, United Geomineral Association and Donia among others. Many areas in Tigray are explored for base metals and gold and some of them are successful in delineating mineralized zones for further detailed studies at Workamba, Terer, Meli, Adi Daro, Asegede, Daro, Techi and Werri. In tune with the ongoing exploration activities, many areas are also been studied by Universities in collaboration with companies to understand the nature of mineralizations, their genesis with respect to the intrusives, alterations and host rocks. In this light, Abrha-Astebha and Hawzein areas potential for mineralization were chosen for study and the results are presented in the paper. Previous workers have undertaken geological investigation in and around the study area (Beyth, 1971, Tadesse, 2000, Alene et al., 2000) but with little emphasis on mineralization. The present paper deals with the mineralization and tries to understand the nature of the deposit based on geological, petrographical and geochemical data.

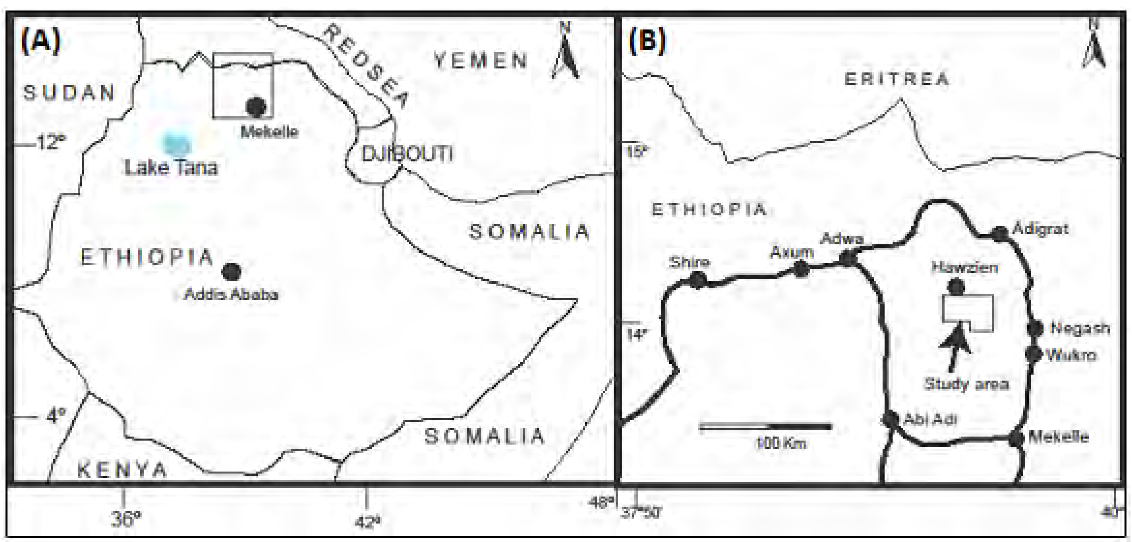

Figure.1. Location map of the study area, A) map of Ethiopia and northeastern Africa and some portions of Arabia; B) Plan view of northern Ethiopia showing the roads and position of the study area along with the major towns in Tigray.

1.1. Study Area

The study area lies to the east of Negash in the central part of Tigray, northern Ethiopia (Fig.1). Geographically, the study area is bounded by 1530000N-1545000N and 542000E-560000E and covers an area of about 200 km^2. The area has rugged topography with elevation varying from 2430 to 2320m. Presence of scant bushes and stunted trees indicate the existing semi-arid climate. The area is characterized by the dendritic drainage system and with gentle to sub-gentle slopes. Suluh is the main river in the area that flows from north to south. The areas Negash, Abrha-Weastbha and Workamba are reported to have NE-SW trending shear zones hosting base metals and gold mineralizations (Gebresilassie, 2009; Bheemalingeswara and Nata, 2009; Mufta, 2011; Berhane, 2011). It is situated adjacent to Abraha-Weatsbaha village in the south and Hawzein town in the north, approximately 15 kms northwest of Wukro town, eastern zone of Tigray, Ethiopia (Fig. 1). It lies north of Mekelle outlier and E-W trending major fault related to Wukro fault and east of Negash pluton.

1.2. Previous Work

Geological mapping of Mekelle sheet in the scale of 1:250,000 conducted by the Ethiopian Geological Survey has revealed geochemical anomalies for copper in the metavolcanics around Negash area and believed to be related to the post-tectonic Negash intrusive granitoid (Beyth, 1971). Asrat (2002) on the basis of his study concluded that the Negash intrusive did not contribute to the enrichment of copper but has facilitated the hydrothermal activity. Bheemalingeswara and Nata (2009) have conducted petrographic and geochemical study in the same Negash area, which is about 5 km east to the study area and reported presence of malachite stains, well developed sericite alterations and shear zone-hosted copper anomalies in the basement rocks of Tsaliet Group. Atkilty and Kebede (1999) has conducted stream sediment and rock chip sampling around Abrha Astbha and found anomalous values for zinc followed by moderate values for lead and silver. The study conducted by Amaha (2011) in Digum area about 2 km south west of the study area has releaved presence of vermiculite-hosted igneous intrusive, within NE trending shear zone in the basement rocks with well developed alterations chloritization, sericitization and ferrugenization. In another study near Workamba, about 20km west of the present study Gebreselassie (2009) has reported presence of orogenic gold mineralization in quatz veins as well as in wall rocks of Tambien Group associated with shear zones and with well developed alterations chloritization, sericitization and carbonatization.

2. GEOLOGICAL OUTLINE

The geology of northern Ethiopia is characterized by the low-grade metavolcano-sedimentary rock assemblage belonging to the Tsaliet and Tambien Groups of Neoproterozoic Pan-African Arabian-Nubian Shield (Kazmin, 1971, De Wit and Chaweka, 1981). These are intruded by the syn- (~800 to 735 Ma) and post-tectonic (620 to ~520 Ma) granitoids (Taddese et al., 1999, Gebresillassie, 2009). Tsaliet Group is older among the two and covers major part of the region. It represents calc-alkaline, island arc metavolcanic rocks and sericite-chlorite schist, slate, greywacke, calcareous siltstone, well-bedded tuffs and agglomerates (Beyth, 1971; Tadesse et al., 1999; Alene et al., 2000; Beyth et al., 2003). Tambien Group on the other hand is mainly exposed in a series of synclinal inliers overlying the Tsaliet Group with gradational contact from west to east Maikenetal, Tsedia, Chehmit, and Negash (Alene et al., 2006, Garland, 1980). It consists of only metasedimentary rocks of argillite and carbonate composition but predominantly argillaceous. The rock types present are slate, phyllite, graphitic schist and metalimestone. The Group is further subdivided from the oldest to the youngest, into Weri Slate, Assem Limestone, Tsedia Slate, and Maikenetal Limestone. The lithologies suggest shallow marine environment and a regional low-grade metamorphism. NE-SW trending shear zones with a sinistral strike- slip sense of movement affect these rocks and predominantly of calc-alkaline variety of Tsaliet Group (De Wit and Chewaka, 1981; Tadesse et al., 1999).

2.1. Geology of the Study Area

The rocks belong to Tsaliet Group and consist of slate, phyllite, metabasalt, metaandesite and metarhyolite. In addition, metavolcaniclastic rocks are also present which are characterized by the presence of clasts of different size and show variation in composition from felsic to mafic. The basement rocks are intruded by two granitoids, namely Negash Igneous Complex (mainly granodiorite) to the east and Megab granite to the west. Quartz, aplitic and granitic dikes of different generations cut across both the basement and granitoid rocks. The basement rocks are Neoproterozoic in age and follow the regional trend N-S to NE-NW (Gerra, 2000; Ayalew et al., 1990; Teklay et al., 1998). Details of the rock types and overlying younger Phanerozoic cover rocks are shown in figure 2 and subsurface geology in figure 3 and disussed below.

2.1.1. Metavolcanic rocks

The rock varies in composition from mafic to intermediate to felsic and is predominant in the area. It is fine grained, massive, foliated at places and shows shearing. It generally follows the regional N-S trend and varies from 5-30º NE with 50-70º westward dip. Among the metavolcanic rocks; metabasalt, metaandesite and metarhyolite are noted in the area. Metabasalt is green, mainly massive, and strongly foliated at places. Epidotization, chloritisation, ferrugenisation is common in these rocks and shear zones are prominent. Metaandesite is dark grey, massive and indicate carbonatization. Metarhyolite is pink, massive, compact, jointed and kaolinised at places. Silicification and brecciation is also common in this rock.

2.1.2. Metavolcaniclastic rock

It shows a gradational contact with phyllite and at places shows shearing. It is less foliated and shows similar trend with metavolcanics. It is fine-grained with grey and light green color with clasts, which vary in shape, size and composition. The clasts vary in size from medium to coarse; consist of minerals like feldspar, quartz and lithic fragments; and sub-rounded to elongate in shape. The elongated nature of the clasts indicates the effect of deformation and is common in the shear zones. At places the metavolcaniclastics show intercalation with phyllite.

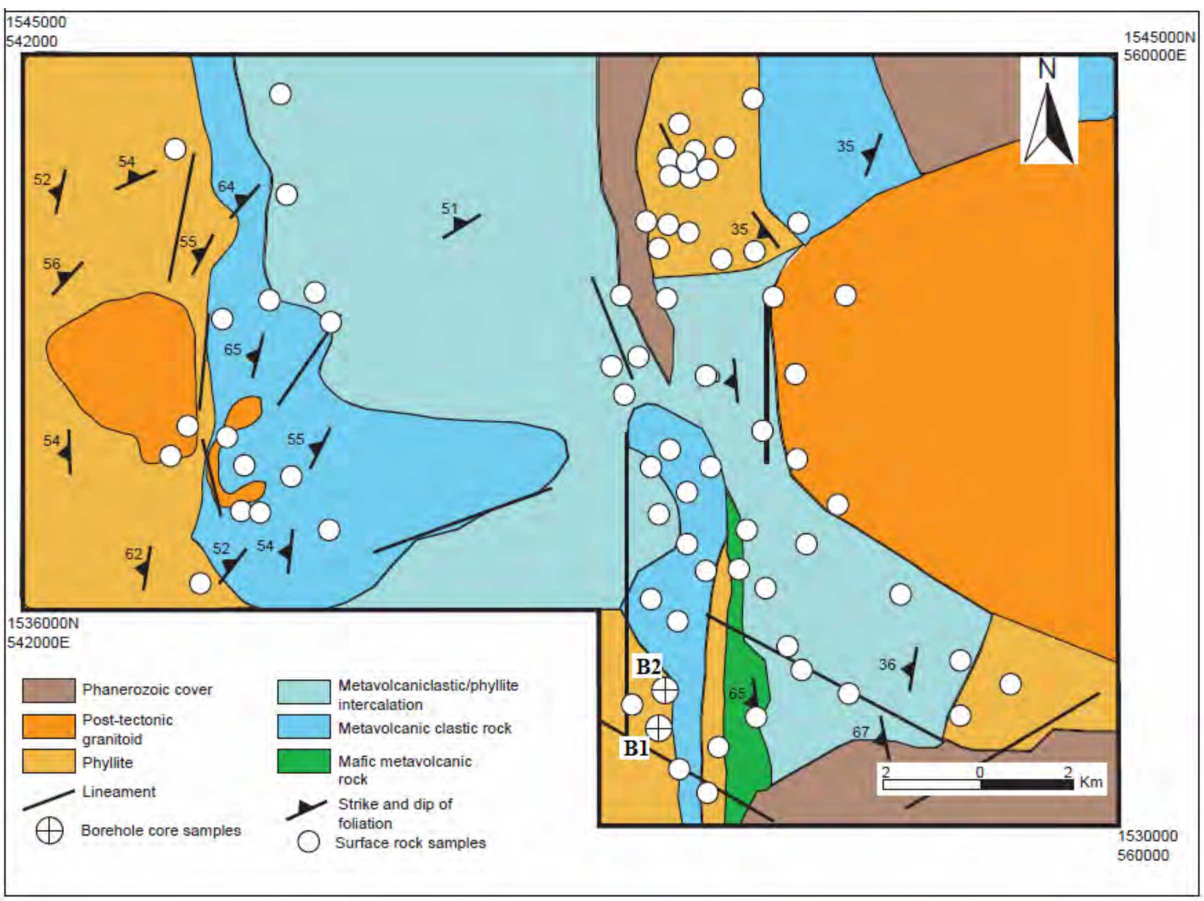

Figure 2. Geological map of Abraha- Watsbaha, Hawzein areas, Tigray.

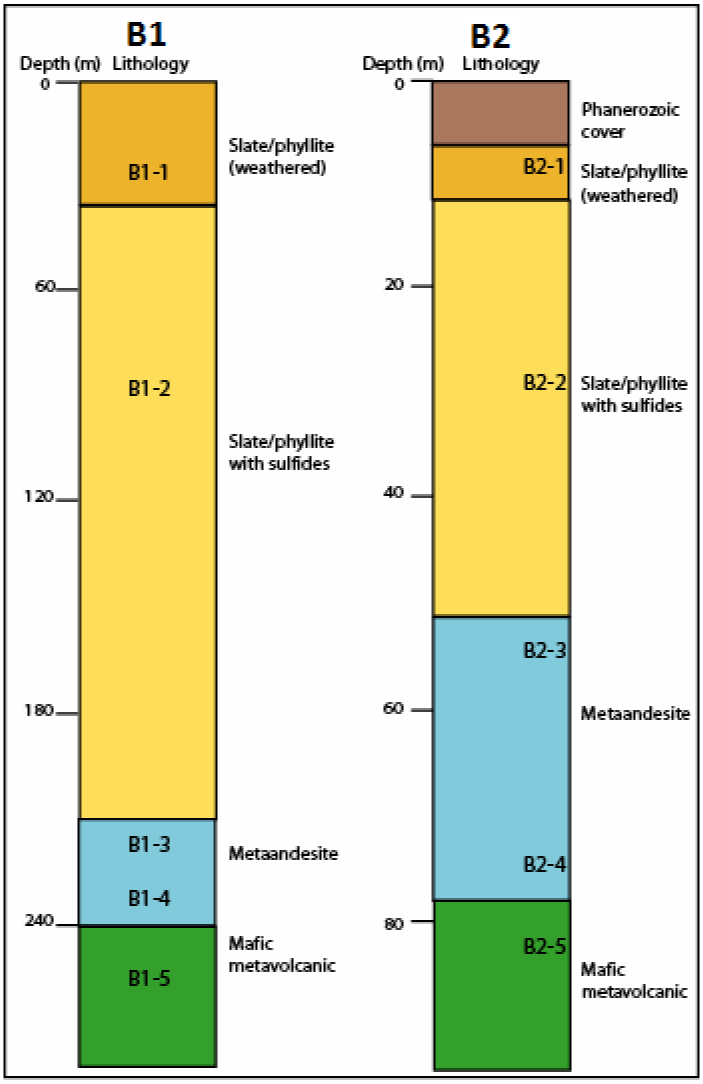

Figure 3. Lithologs of two borehole sections, Abraha- Watsbaha, Tigray (data from Ezana).

2.1.3. Metasediments

Metasediments are represented by phyllite/ slate. They show grey, red, green colors though grey is common and mainly present in the western part of the study area. Phyllite being incompetent rock is highly sheared and shows well developed foliation. The foliations and shear-zones though show N-S regional trend, locally varies from N10-15°E and dipping 50°-70° west. Both aplitic and quartz dikes are represent this rock unit. Slates are compact and show slaty cleavage. They are in contact with both metabasalt in the east and metaandesite/metarhyolite in the west.

2.1.4. Granitoids

Two granitoids known as Negash and Megab granitoids are present in the northern part of the area. The Negash granitoid is exposed in the east and is a granodiorite. Megab is granitic in composition and exposed in the west (Fig. 2). The pink coarse-grained granodiorite shows presence of coarse-grained mafic xenoliths. The mineralogy is dominated by orthoclase feldspar, quartz, plagioclase feldspar. Biotite and hornblende form the minor phases. Talc as skarn is developed along the contact with the dolomitic limestone, which forms part of the metasediments and occur as small lenses. Contact with phyllite shows thermal effect and inicipient development of biotite which is uncommon in phyllite in the area. The granitoid do not show any deformation and shows sharp contact with metavolcanic rocks. However, later it is affected by the tectonic effects as indicated by the movement of part of the granitoid parallel to the Suluh River, which is the major river in the area. Megab granite consists of medium to coarse-grained albite, K-feldspar, quartz, muscovite and biotite. It is muscovite granite and at places shows presence of pegmatite bodies. Alterations like kaolinization are common in both the granitoids. Both the granitoids do not indicate any effect of deformation suggesting their post-tectonic character.

2.1.5. Phanerozoic cover rocks

These rocks comprise Paleozoic rocks of Enticho sandstone, Edaga-Arbi tillite and Mesozoic rocks of Adigrat sandstone. All these rock units are overlying the low-grade metamorphic and post-tectonic intrusive granitiods and occupy the highest elevation in the area. On the basis of the disposition of the lithologies, metavolcanics are the oldest followed by metavolcaniclastics and metasediments. Among metavolcanics, mafic variety (metabasalt) is the oldest and is followed by metaandesite and metarhyolite.

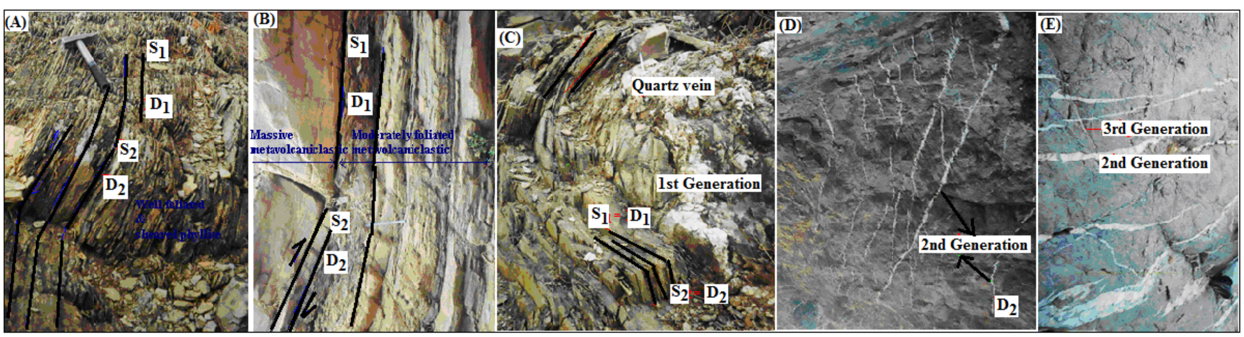

Figure 4. Field photographs showing D_1 & D_2 in phyllite (A); in metavolcaniclastic rock (B); pre-shearing quartz dike/vein in phyllite (C); 2^{nd} generation quartz veins during shearing in metavolcaniclastic (D); and 3^{rd} generation quartz veins of post-shearing in metavolcaniclastic (E).

2.2. Geological Structures

Based on the field observation, three phases of deformation have been identified, which resulted in the development of different folds and shear zones. The early deformation event (D_1) gave rise to NE-SW trending folds (F_1) and penetrative metamorphic foliation (S_1). It is recognized by its planar features and foliation. The folds are asymmetric and their axes are generally parallel to the planar fabric S_1 of the rock which is prominent in slates/phyllites and less in metavolcaniclastic rocks. It shows NNE-SSW trend dipping to 50-70^0 due west.

The second event of deformation (D_2) produced large scale upright sub-horizontal northerly or southerly plunging (F_2) folds. The second deformation (D_2) is coaxial with (F_1) and is locally developed. It is not intense enough to deform totally the attitude of early formed rocks. The D_2 features are better developed than D_1 features. Development of macro-, meso-, and micro scale structures related to the dextral shear whose trend is parallel to the foliation of the rock is common in phyllite. It is ductile type deformation with dextral sense of shearing. This deformation also produced senistral-dextral sense of shearing on the pre-shearing quartz veins. In addition to the shear zone, the deformation has produced cleavage fabrics (S_2) trending NE-SW.

Third phase of deformation (D_3) is the last deformational event in the area and is a brittle deformation that has produced one major normal fault and many other minor faults. The strike of the major fault is NE-SW while that of the minor faults is variable.

The NE-SW and NW-SE trending lineaments are also pronounced in the highly sheared parts of the metavolcanic and metasedimentary rocks and correspond with the trends of major faults in the area. The NE-SW lineaments are offset by younger E-W lineaments. The NE-SW lineaments are parallel to the regional lineaments of Negash, Maikinetal and Chihmit syncline, which have been suggested as the major synclinoria surrounding the study area (Beyth, 1971; Alene et al., 2006). The rocks are also affected by a series of normal faults with two major orientations. NNE-SSW trending faults are almost parallel to the foliation direction of the country rocks and the WNW-ESE trending faults are common in southern part of the study area and sub-parallel to the prominent younger Wukro fault. A major N-S trending sinstral stike slip fault which has displaced the metaandesites and parallel to Suluh River is quite prominent in the area. In addition, there are also minor structures like crenulation cleavage in phyllite and brittle-ductile shearing in the granite dike demarcated by folding of quartz veins within it.

3. METHODOLGY

70 surface rock samples, and core samples from two boreholes about 1 kg each were collected and their locations are given in the figures 2 and 3. The surface rock samples were collected in such a way that all the rocks are represented properly. 20 surface rock samples were chosen for

processing. They were cut using rock cutter into 5 x 2 cm size rock slabs and were sent to Ethiopian Geological Survey for thin section preparation. About half a kilogram of each of 20 surface rock samples together with 10 drill core samples from two boreholes were sent to Ezana Mining Development plc, Mekelle for making fine rock powders about minus 200 mesh size. 15 surface rock and drill core samples indicating mineralization were selected for preparing polished sections. In addition, petrography study was carried on thin sections at the Department of Earth Science, Mekelle University (Figs. 5 to 9).

All the 30 rock powders were submitted to Geological Survey of Ethiopia central laboratory for major, minor and trace geochemical analysis using X-ray Fluorescence Spectrometer in Addis Ababa. The analyses were carried out on pressed pellets using rock standards as reference and control the accuracy of the data and given in tables 1 and 2. In addition, 150 surface rock samples data for Cu, Pb, Zn, Ag and As elements obtained from Ezana Mining Company (Table 3) are also used in the study.

4. RESULTS

4.1. Petrography

4.1.1. Petrography of rocks

The thin section in figure 5 (A & B) is mainly composed of fine-grained quartz (30%), plagioclase (20%), orthoclase (15%). They are intruded by coarse-grained quartz and calcite (10%) veins. Opaque minerals (10%) are randomly distributed and also are in association with the less prominent calcite veins (bornite? as indicated in megascopic observation). Two generations of quartz veins are noted. The rock is massive metaandesite with development of fine-grained sericite (10%). It is followed by silicification and chloritization which manifested by the presence of secondary quartz and chlorite (5%). Carbonatisation is indicated by calcite.

In figure 6 (A & B), the thin section is composed of quartz (30%), muscovite (30%), biotite (15%), chlorite (10%), sericite (5%) and opaque minerals (10%). Fine-grained muscovite, biotite, chlorite and sericite dominate the section; form the groundmass; being flaky shows well developed foliation; and compositional banding. Quartz is mostly equigranular, fine-grained and aligned. The rock is phyllite and it not only shows well developed foliation but also crenulation cleavage producing S_1 and S_2 rock fabric, respectively. Opaque minerals are medium size and randomly distributed. Sericitization is prominent among others like silicification and carbonatisation.

The thin sections in figure 7, (A) & (B) are of Merab granitoid and (C) & (D) of Negash granitoid. Megab granitoid consists of quartz (30%), plagioclase (10%), orthoclase (20%), muscovite (20%), sericite (10%), biotite (5%) and opaque minerals (5%).

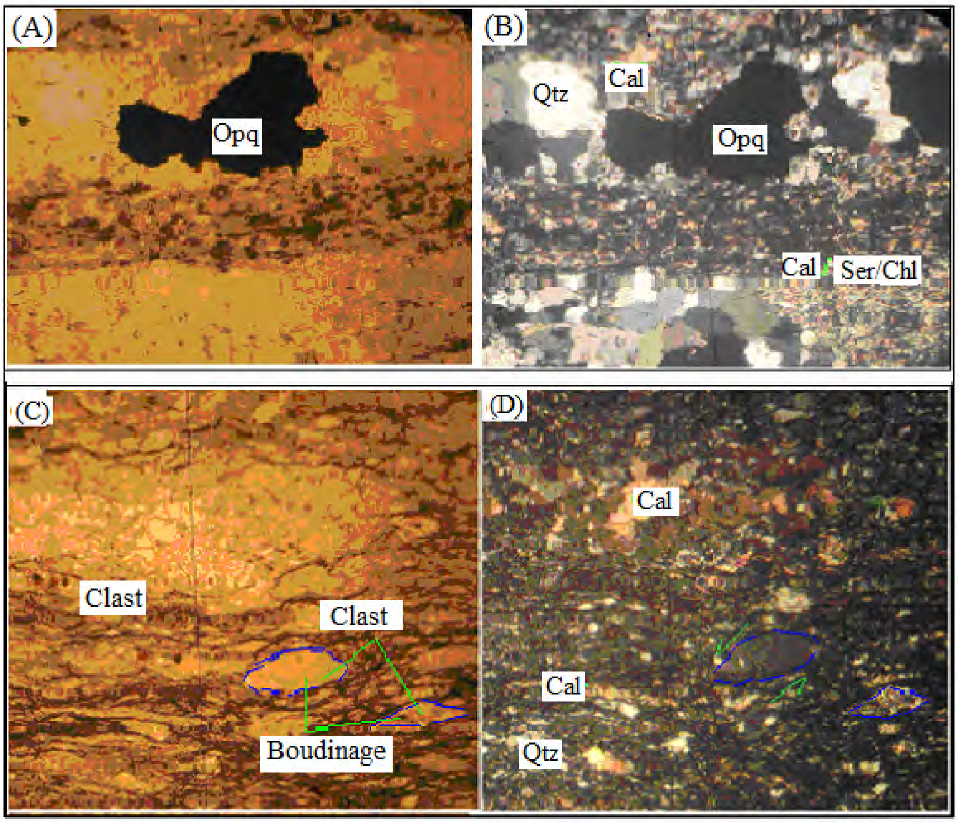

Figure 5. Photomicrographs of (A) & (B) metavolcanic rock (metaandesite) showing fine grained groundmass with quartz and calcite veins and opaque; and (C) & (D) development of incipient foliation and alignment of clasts in metavolaniclastic rock (A &C, PPL & B &D, XPL, 40x).

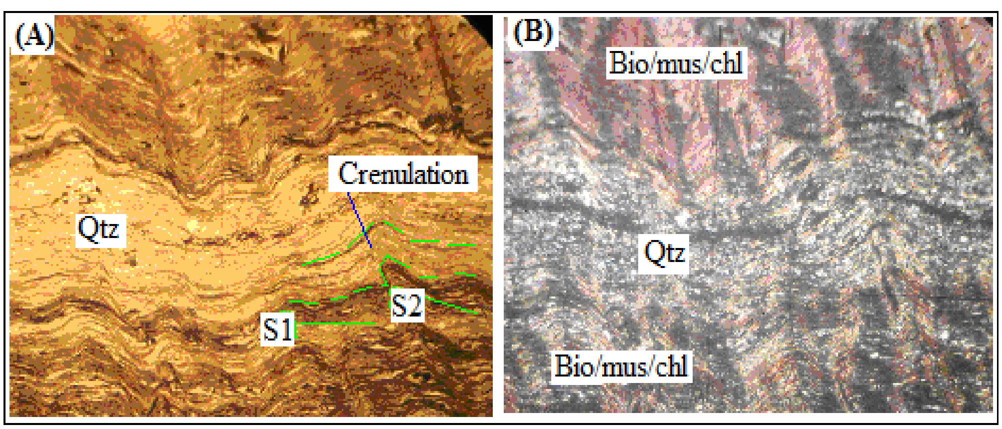

Figure 6. Photomicrographs of phyllite, (A) PPL & (B) XPL (40x).

Majority of the minerals are medium- to coarse-grained, randomly distributed and do not show any effect of deformation and metamorphism. The rock is muscovite granite and is post-tectonic.

Among alterations, sericitization is prominent followed by kaolinization. Negash granitoid is comprised of orthoclase (30%), quartz (25%), plagioclase (20%), biotite (10%), hornblende (5%), calcite (5%), sericite and kaoline (5%). Majority of the minerals are coarse to very coarse in size, randomly distributed and do not show any effect of deformation and metamorphism. Biotite shows green color in addition to brown due to alteration together with hornblende it shows alteration to sericite, calcite, kaoline etc. Few grains also show replacement by feldspars. The rock is granodiorite and is post-tectonic. Euhedral high relief, high birefringence, rhombic cleavage mineral, calcite (?) is present in both the rocks. It is an accessory and seems the youngest cutting across biotite, hornblende and feldspars.

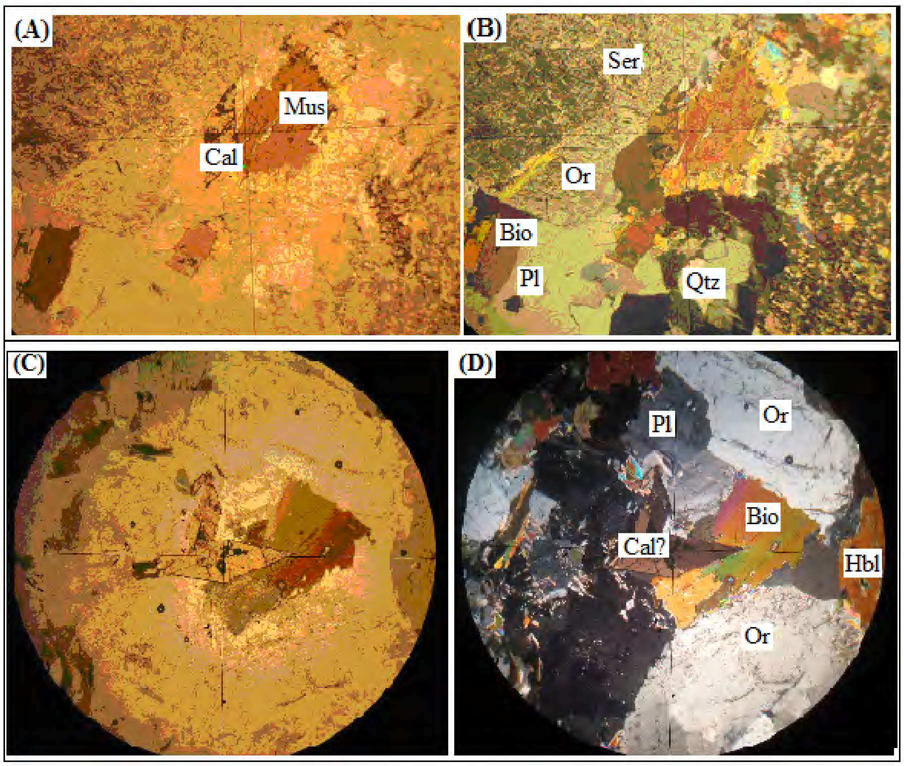

Figure 7. Photomicrographs of Megab granite ((A) PPL & (B) XPL (40x); and Negash granodiorite ((C) PPL, (D) XPL, 40x) times magnification) (Note: Plagioclase (PL), orthoclase (Or), quartz (Qtz), muscovite (Ms), biotite (Bio), hornblende (Hbl), calcite (Cal).

Different types of alteration patterns are observed in the field. Prominent among them are sericitization, which is mostly confined to shear zones and is indicated by the formation of fine-grained, white mica mineral, sericite; chloritization is manifested by the development of chlorite from the mafic minerals and is common in metavolcanic and metavolcaniclastic rocks; epidotization is indicated by the presence of epidote and often in the form of veins cutting across the metavolcanic rocks; and kaolinization revealed by fine-grained, white clay mineral (kaolin) due to weathering of feldspars, within metarhyolite and aplitic dikes; silicification manifested by the presence of secondary quartz, carbonatiation indicated by the presence of calcite; and ferrugenization by the presence of iron hydroxide (limonite).

4.1.2. Ore petrography

The polished sections from drill core samples (B1 & B2 sections) in figure 8 shows presence of coarse, irregular pyrite and sphalerite. There minerals show interlocking texture and alignment with host rock fabric (stratiform) and trend of the shear zone.

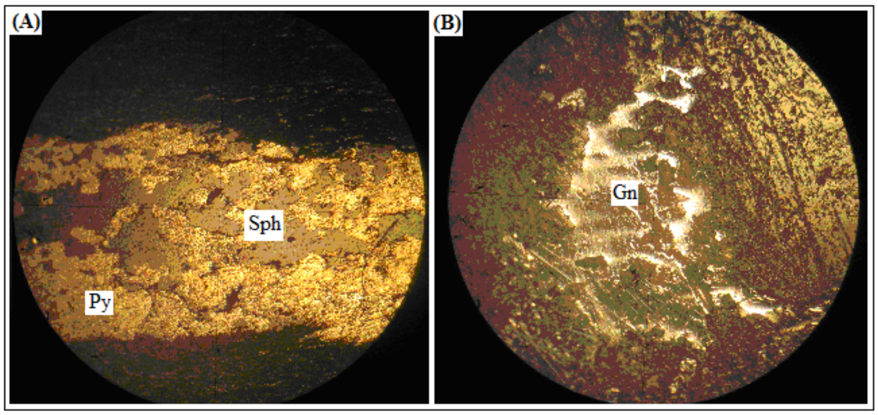

Figure 8. A) Alignment of yellow color pyrite (Py) and grey color sphalerite (Sph); and B) irregular cream color galena (Gn) in drill core sample (PPL, 40x).

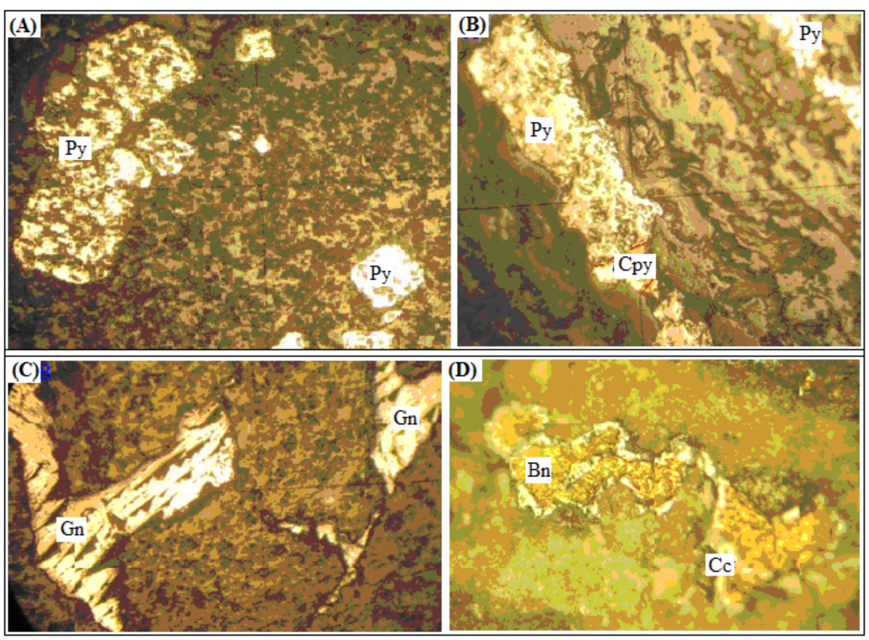

Figure 9. Ore minerals in surface rock samples, (A) pyrite in metavocaniclastic; (B) vein filling pyrite being replaced by chalcopyrite in metavolcanic; (C) galena with triangular pits in quartz reef; and (D) bornite in calcite veins in metaandesite and chalcocite replacing bornite along boundary (all in PPL; A, B, C are 40x and D is 100x).

The thin section (Fig. 9A) is from surface sample (metavolcanic rock). It consists of pyrite with high polishing hardness. They are disseminated and some of them are coarse, euhedral (cubic). The thin section (metavolcanic rock from shear zone) in figure 9B consists of pyrite and chalcopyrite associated with quartz veins. Pyrite is coarse and major mineral, whereas chalcopyrite is minor with typical brass yellow color and younger as it replaces pyrite.

Polished section shown in figure 9C shows presence of cream colored galena in quartz reef. It is coarse, irregular with well developed and oriented triangular pits. Interestingly, the sample is from the same place where gold was identified in the same reef. The section in figure 9D shows presence of bornite in association with calcite veins in massive metaandesite. Bornite is fine to medium-grained , irregular with strong pink color. It is altered to green color chalcocite due to oxidation along grain boundaries showing replacement texture. Though gold was observed in the field, none of the polished sections show gold. Small scale panning activity for placer gold by local people also indicates the presence of gold in the area.

4.2. Geochemistry

Harker variation diagrams between SiO_2 and major oxides were prepared to understand the trends of major oxides and to evaluate their mobility during fractional crystallization and differentiation process of magma (Fig. 10). Discrimination diagram using metavolcanic rocks data (Zr versus TiO_2) is prepared as suggested by Pearce (1980) to discriminate between MORB, within the plate and volcanic-arc tectonic setting. Relation between silica and trace elements, between trace elements and zirconium (Green, 1980) in terms of mobility is discussed. Correlation matrix is prepared for Cu, Pb, Zn, Ag and As to understand inter relationship between them (Table 4).

4.2.1. Metavolcanic rocks

Oxides also show significant variation in their composition e.g. Fe_2O_3 (6.94-18.1%), CaO (1.04-8.88%), MgO (1.23-8.12%), TiO2 (0.7-4.77%) in tune with the crystallization trend and variation in the rock types (basaltic, andesitic and rhyolitic). Variation may also be attributed to derivation from different melts or alteration effects. Figure 10 shows as expected negative correlation between TiO_2 & Fe_2O_3 and SiO_2; and positive between MgO & Al_2O_3 and SiO_2 indicating the normal magma crystallization trends (Thornton and Tuttle, 1960) and common magma source. Scattered points for K_2O, Na_2O and P_2O indicate substantial mobility of these oxides during alteration and metamorphism (Alene et al., 2000).

In terms of trace elements, Co, Ni, V, Cr and Cr show negative and Zr positive relation with SiO_2. Other elements like Zn and Pb do not show any significant trend. The trends are quite expected and tally well with the data reported for Negash area (Bheemalingeswara and Nata, 2009). Zirconium being an incompatible element is used to evaluate the mobility patterns of other elements. Zr variation diagrams indicate negative relation with Ni, Sr, Co, V and Y indicating their compatible nature and fractionation during magma crystallization. Concentration of these elements is too low for parental liquids derived from a periodotitic mantle source (e.g. mantle values for Cr, Ni, and Co are 3000, 2000 and 110 ppm respectively (Green, 1980; Gill, 1981) and thus reflect differentiation.

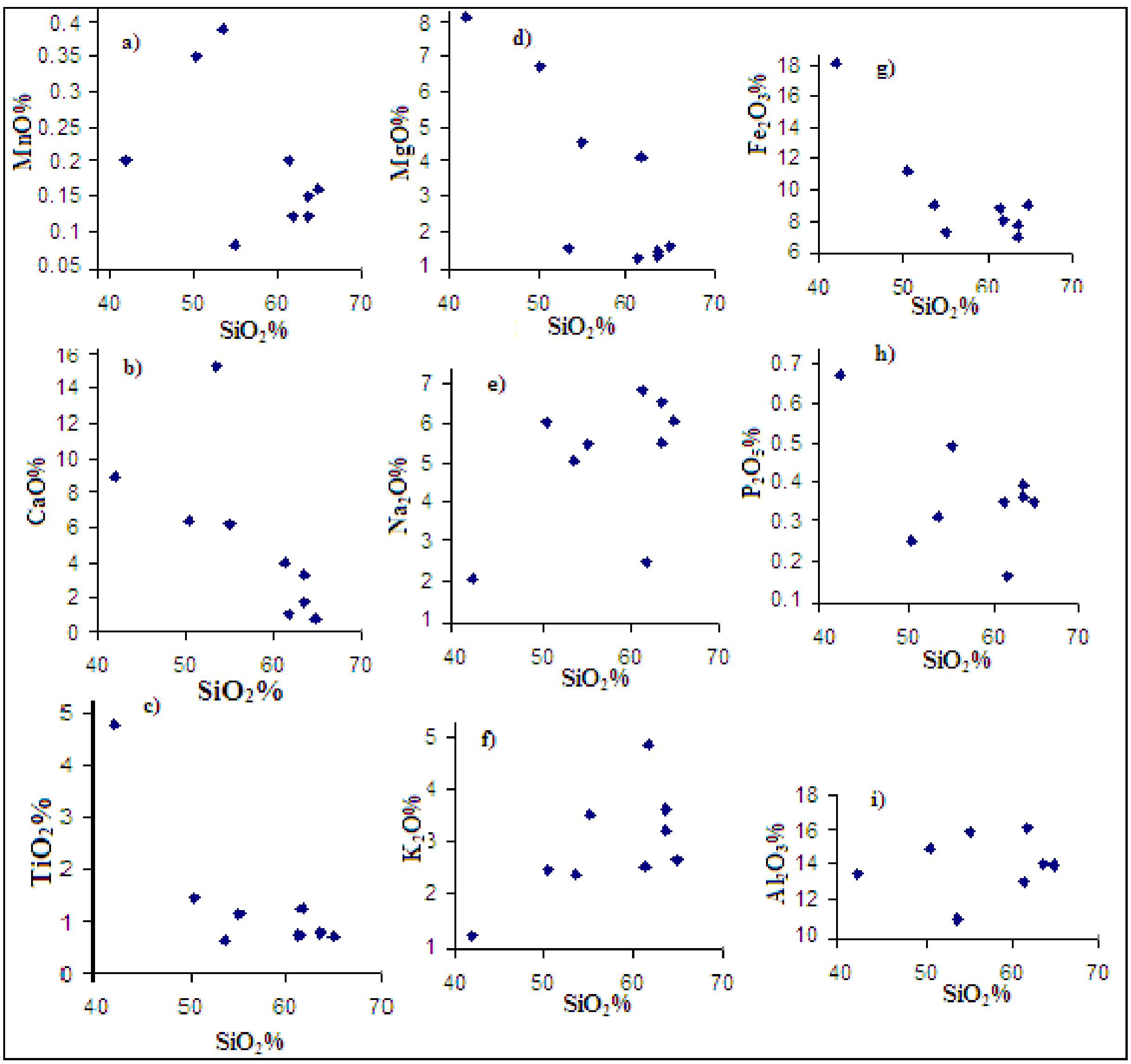

Figure 10. SiO_2 vs major oxides (wt%) variation diagrams, metavolcanic rocks (Mufta, 2011).

4.2.2. Metavolcaniclastic rocks

Megascopic observation indicates that the metavolcaniclastic rocks vary significantly in terms of composition of the clasts, their size and the fine grained groundmass. This is well reflected in the major, minor oxides and trace element geochemical data (Table 1). Among oxides SiO_2 shows significant variation from 57 to 75 wt%; Al_2O_3, 11 to 15.5%; CaO, 0.7 to 4.1%; Fe_2O_3, 2.5 to 9%; MgO, 0.2 to 5.2%; Na_2O, 3 to 6%; K_2O, 0.5 to 2.6% and TiO_2, 0.5 to 0.7%. Except SiO_2, other oxides like MgO, Fe_2O_3, CaO, TiO_2 are relatively lower in concentration (maximum values) compared to metavolcanic rocks. Among trace elements, V, Cr, Co, Ni, Ga are slightly lower compared to Rb, Zr, Ba with relation to metavolcanic rocks.

Table 1. Major oxides, minor oxides (in wt%) and trace elements (ppm) data from two boreholes (B1 & B2), basement rocks, Abrha Astbha. (Note: MA= Metaandesite; MB = Metabasalt; SL = Slate/phyllite; W = weathered)

Sample no.	***MA (B1-03)***	***MA (B2-03)***	***MA (B1-04)***	***MA (B2-04)***	***MB (B1-05)***	***MB (B2-05)***	***SL (W) (B1-01)***	***Slate (W) (B2-01)***	***SL (B1-02)***	***SL (B2-02)***
Oxides/Trace elements	Metavolcanics						Metasediments			
SiO_2	63.5	63.5	66.9	61.3	41.9	53.5	65.1	61.7	65.6	63.5
MnO	0.15	0.12	0.06	0.2	0.2	0.39	0.05	0.12	0.09	0.1
CaO	3.31	1.77	0.43	3.98	8.88	15.3	0.5	1.04	3.97	0.58
SO_3	0.84	0.31	1.66	1.12	0.58	1.15	0.28	0.12	1.53	2.39
TiO_2	0.8	0.79	0.84	0.73	4.77	0.66	0.96	1.26	0.8	1.01
MgO	1.38	1.28	3.43	1.23	8.12	1.49	3.2	4.1	3.68	3.22
Na_2O	5.52	6.53	2.26	6.83	2.04	5.02	0.79	2.47	1.28	2.44
K_2O	3.2	3.61	3.29	2.53	1.19	2.37	4.98	4.84	3.33	4.3
Fe_2O_3	6.94	7.75	5.62	8.77	18.1	9.05	7.07	8.03	5.77	6.55
P_2O_5	0.36	0.39	0.21	0.35	0.67	0.31	0.17	0.16	0.21	0.23
Al_2O_3	14	14	15.3	13	13.5	10.8	16.9	16.1	13.7	15.7
Sum	100	100	100	100	100	100	100	100	100	100
LOI	2.7	1.1	2.7	1.9	9.1	6.5	5.5	4.1	3.6	3.2
Zr	137	134	86	123	121	101	79	71	51	76
V	55	42	124	35	223	<20	190	182	150	181
Cr	53	25	50	52	45	66	55	64	188	99
Co	18	10	8	13	55	20	15	17	15	12
Ni	5	5	7	<5	20	<5	7	14	10	10
Zn	188	97	500	85	202	97	97	100	135	101
Ga	20	20	16	15	22	21	13	20	11	18
Rb	42	56	58	33	16	37	122	74	52	79
Sr	87	57	53	203	767	150	48	43	74	38
Y	40	26	40	35	17	43	44	32	16	48
Pb	52	<10	315	<10	43	10	<10	<10	70	13
Ba	379	512	431	265	<30	258	5198	1732	535	739

Table 2. Major, minor oxides (wt%) and trace elements (ppm) data, basement rocks.

Sample	***North***	***East***	SiO_2	Al_2O_3	Fe_2O_3	***CaO***	***MgO***	Na_2O	K_2O	TiO_2	***MnO***	P_2O_5	SO_3	***LOI***
Metavolcaniclastics														
HW8	1536375	543732	71.27	12.52	5.42	0.96	1.87	5.28	0.83	0.48	0.06	0.22	0.217	1.92
HW9	1536471	544591	66.56	13.05	4.88	3.96	1.4	3.29	2.22	0.48	0.10	0.22	0.23	3.46
HW21	1536881	544220	75.46	11.8	3.52	0.92	0.86	5.49	1.11	0.45	0.13	0.19	0.01	1
HW24	1538921	544375	59.83	15.04	9.11	1.51	5.24	4.96	0.5	0.7	0.04	0.25	0.02	3.37
HW25	1536899	544029	70.52	12.52	4.30	1.61	1.09	4.10	2.48	0.51	0.06	0.22	0.02	2.43
HW29	1543691	544518	71.53	12.67	4.38	0.99	1.85	3.46	2.15	0.65	0.09	0.26	<0.01	5.37
HW43	1544650	544747	57.27	15.47	8.46	4.1	2.16	4.01	1.87	0.56	0.05	0.15	0.6	1.64
HW63	1536293	545827	64.32	13.15	7.1	3.01	3.04	3.54	1.95	0.55	0.10	0.20	0.76	2.19
HW66	1536582	545679	73.77	11.28	2.52	3.59	0.17	3.96	2.30	0.17	0.05	0.01	0.01	2.37
SR-02	1533816	553148	64.8	13.9	9.01	0.73	1.56	6.08	2.63	0.7	0.16	0.35	0.08	1.90
Metavolcanics														
HW2	1540423	545747	72.76	1.71	4.32	1.13	1.42	4.21	2.23	0.52	0.06	0.19	0.12	1.42
HW26	1538467	543023	55.89	16.08	9.3	3..65	4.29	5.52	0.96	0.72	0.12	0.28	0.45	2.97
SR-01	1535681	554533	50.3	14.9	11.2	6.38	6.71	6.04	2.46	1.45	0.35	0.25	0.01	1.70
SR-05	1541360	553204	55	15.9	7.35	6.23	4.57	5.46	3.52	1.16	0.08	0.49	0.18	0.74
Phyllite/Slate														
HW61	1535536	543350	63.57	18.41	4.32	0.56	1.72	1.53	3.39	0.07	0.02	0.08	1.51	3.3
SR-03	1532968	558377	64.9	13.80	4.83	4.24	0.76	4.06	6.18	0.84	0.20	0.18	0.06	2.3
Intrusives														
HW13	1537839	545591	69.13	12.61	5.58	2.03	1.15	4.59	2.97	0.52	0.05	0.19	0.01	0.66
HW27	1538297	543810	67.15	14.6	3.39	3..5	0.89	5.15	2.84	0.41	0.05	0.24	0.02	1.28
HW32	1543657	542799	71.69	14.3	1.69	1.74	0.39	5.80	2.75	0.15	0.02	0.06	0.01	1.05
SR-04	1540571	556257	76.6	11.8	2.44	0.06	0.04	0.09	8.70	0.18	0.03	0	0.12	0.12

Sample	North	East	V	Cr	Co	Ni	Ga	Rb	Zr	Ba	Pb	Zn	Sr	Y
Metavolcaniclastics														
HW8	1536375	543732	86	166	13	9	22	22	184	396	7	101	92	31
HW9	1536471	544591	102	130	12	11	21	55	181	852	<5	88	66	29
HW21	1536881	544220	72	144	8	9	12	18	200	584	<5	97	76	31
HW24	1538921	544375	246	134	21	14	26	12	107	184	<5	98	184	22
HW25	1536899	544029	66	152	10	10	29	58	219	739	11	104	172	20
HW29	1543691	544518	203	170	2	14	24	44	113	605	<5	104	172	20
HW43	1544650	544747	118	135	8	11	23	44	193	803	8	99	109	27
HW63	1536293	545827	160	112	11	7	27	37	133	772	<5	96	352	26
HW66	1536582	545679	<10	149	5	5	32	50	324	699	<5	92	67	65
SR-02	1533816	553148	31	31	18	5	13	33	141	1562	<10	102	41	44
Metavolcanics														
HW2	1540423	545747	85	109	9	7	29	44	207	739	<5	97	97	30
HW26	1538467	543023	232	155	20	10	35	27	113	261	<5	88	372	23
SR-01	1535681	554533	254	15	31	9	21	44	59	215	15	102	163	42
SR-05	1541360	553204	116	96	23	19	21	38	77	981	10	93	1690	48
Phyllite														
HW61	1535536	543350	148	69	<5	6	36	81	273	646	9	96	64	34
SR-03	1532968	558377	75	101	14	8	23	158	130	1143	<10	10	31	68
Intrusives														
HW13	1537839	545591	76	163	8	5	22	69	331	1151	5	84	88	47
HW27	1538297	543810	66	195	<5	6	22	77	160	843	14	93	555	13
HW32	1543657	542799	62	246	<5	6	29	87	91	1322	<5	93	567	<5
SR-04	1540571	556257	59	188	6	7	20	222	148	645	<10	94	8	11

Table 3. Surface rock sample data (ppm), Abrha Astbha, Tigray (data from Ezana Company).

S. No	Ag	Pb	Zn	Cu	As	S. No	Ag	Pb	Zn	Cu	As	S. No	Ag	Pb	Zn	Cu	As
1	1.3	2	5	5	27	51	0.6	9	66	33	2	101	0.3	30	67	42	60
2	0.08	6	1240	44	100	52	0.5	3	1050	14	61	102	0.5	4	210	26	22
3	0.2	0	12	41	100	53	0.7	4	937	31	26	103	0.2	55	361	12	28
4	0.7	380	1800	26	80	54	0.2	3	67	21	45	104	1.6	133	428	30	80
5	0.7	164	2105	52	120	55	0.3	59	49	23	94	105	0.8	2	348	14	37
6	0.2	6	49	43	60	56	0.6	15	59	43	36	106	0.5	2	174	14	45
7	1.3	2	6	14	29	57	0.6	14	49	46	80	107	0.2	2	41	14	62
8	1.1	2	76	11	2	58	0.5	10	127	54	87	108	0.2	7	222	26	41
9	0.2	2	9	7	40	59	0.5	14	76	46	2	109	0.6	340	509	44	56
10	0.2	2	9	4	60	60	0.8	9	62	25	92	110	0.5	22	357	25	45
11	0.2	2	9	3	140	61	0.6	23	190	42	163	111	1.6	183	435	30	84
12	0.2	26	240	41	40	62	0.6	16	181	31	143	112	1.6	195	486	31	85
13	0.2	2	6	5	60	63	0.4	225	716	24	67	113	0.9	14	357	28	41
14	0.2	2	4	5	80	64	0.4	85	359	24	108	114	1.7	205	577	33	90
15	0.2	2	240	16	80	65	1.4	59	205	27	57	115	1.7	209	593	34	90
16	1.3	4	6	15	30	66	0.7	73	234	12	81	116	1	2	173	33	2
17	0.2	2	82	4	2	67	1.5	65	269	28	58	117	0.7	2	223	30	118
18	1.3	5	8	16	31	68	0.8	38	437	19	132	118	0.9	2	247	22	190
19	0.7	2	220	3	100	69	1.5	71	300	29	59	119	0.8	3	293	25	112
20	1.3	8	29	16	37	70	0.7	95	132	75	83	120	1	2	650	17	83
21	0.9	3	280	61	80	71	0.7	7	145	28	196	121	0.8	22	544	66	49
22	1.3	8	75	19	40	72	0.9	2	214	40	127	122	0.5	2	323	18	59
23	1.3	8	80	21	40	73	0.2	2	13	7	80	123	0.8	2	253	15	490
24	1.3	10	88	21	46	74	0.9	160	960	37	218	124	1	2	211	58	173
25	1	2	108	4	120	75	0.8	67	766	17	153	125	1	2	185	20	316
26	0.3	3	10	6	160	76	1.5	82	315	30	61	126	1.1	2	323	28	409
27	0.2	0	12	37	160	77	1.2	7	256	15	88	127	0.9	5	217	17	40
28	1	2	420	6	120	78	1.2	3	238	13	50	128	0.4	2	43	14	66
29	1.1	6	88	44	110	79	0.5	6	125	20	119	129	0.3	2	25	21	67
30	0.9	8	88	43	33	80	0.7	31	252	31	200	130	1.7	212	636	35	91
31	0.8	3	72	30	86	81	0.5	30	118	9	157	131	1.7	214	639	35	96
32	1	22	79	44	28	82	1.2	3	126	41	61	132	1.8	215	643	35	110
33	0.9	32	116	41	29	83	1.5	114	320	30	78	133	1.1	96	2045	30	99
34	0.2	14	10	13	51	84	1.6	122	411	30	80	134	0.9	28	852	24	63
35	1.3	10	89	22	46	85	1.2	3	33	73	88	135	1.8	220	673	37	115
36	1.3	11	91	22	46	86	1.6	130	415	30	80	136	1.9	228	688	39	117
37	1.4	14	102	22	47	87	0.4	2	163	21	48	137	1	27	975	32	2
38	1.4	14	130	22	47	88	2	16	40	11	27	138	2	240	697	42	119
39	1	105	936	37	82	89	0.6	2	10	3	52	139	0.8	93	757	27	76
40	0.3	22	104	8	2	90	0.8	2	17	4	68	140	0.8	166	751	25	76
41	0.4	15	73	9	2	91	0.4	15	260	33	105	141	0.2	435	589	72	113
42	1	107	939	28	34	92	0.4	6	432	18	73	142	2.1	245	720	42	119
43	1.4	17	169	22	51	93	0.2	25	334	15	71	143	1.1	33	597	17	80
44	1.4	28	175	24	52	94	0.5	29	367	56	69	144	1	197	2430	20	97
45	1.4	28	180	24	52	95	0.6	49	311	76	80	145	2.1	251	755	43	120
46	1.4	33	196	24	53	96	1.1	243	538	49	83	146	2.2	264	756	44	120
47	1.4	40	202	24	54	97	0.7	419	343	53	45	147	1.2	133	1960	17	88
48	0.8	2	88	24	80	98	0.8	338	358	51	111	148	2.2	271	10200	46	123
49	0.6	29	62	49	42	99	0.2	13	16	15	66	149	2.3	289	848	47	124
50	0.7	6	74	36	2	100	0.2	11	147	90	33	150	2.3	331	984	47	133

4.2.3. Metasedimentary rocks

Major and minor oxides show minor variation in concentration. Weight percentages for SiO_2 vary from 63.5-65; Al_2O_3, 13.8 to 18.4; CaO, 0.5 to 4.24; Fe_2O_3, 4.3 to 4.8; MgO, 0.7 to 1.7; Na_2O, 1.5 to 4; K_2O, 3.4 to 6; and TiO_2, 0.07 to 0.8. Metasedimentary rock as expected shows much higher values for Al_2O_3, K_2O and lower values for Fe_2O_3 and MgO (Table 1). These values distinctly vary from metavolcanic and metavolcaniclstic rock data. Among trace elements, V, Cr, Co, Ni and Sr values are lower compared to those of metavolcaniclastic and metavolcanic rocks and higher in Rb and do not show much variation in Zr and Zn. The major and trace element contents are fairly similar to those of Weri (Sifeta, 2003), Workamba (Gebressilassie, 2009) and Negash (Bheemalingeswara and Nata, 2009). MgO and K_2O concentration are about two times higher than median values of Weri metasediments. Ba and Y contents are about 2 and 8 times lower than that of the median values of Weri metasediments. Except SiO_2 and MgO, other oxides are higher compared to Weri metasedimentary.

4.2.4. Surface rock trace element geochemistry

150 rock samples from metavolcanic, metavolcaniclastic and metasedimentary lithologies collected mainly from the shear zones are analysed for basemetals, Ag and As. Copper values range from 3 to 90 ppm with mean of 29; zinc range from 4 to 1000 ppm with a mean of 420 (in one sample the value is as high as 1%); lead from 1 to 435 ppm with 65 as mean; silver range from 0.8 to 2.3 ppm with a mean of 0.91; and arsenic 2 to 490 with a mean of 83 ppm. Three samples near Hawzein collected from quartz veins and reef analysed for gold shows values in ppb ranging from 20 to 40 ppb (Berhane, 2011).

Table 4. Pearson correlation matrix, surface rock sample data (N=150).

	Ag	***Pb***	***Zn***	***Cu***	***As***
Ag	1				
Pb	0.440	1			
Zn	0.282	0.397	1		
Cu	0.142	0.381	0.153	1	
As	0.082	0.114	0.109	0.054	1

5. DISCUSSION

5.1. Mineralization

Different generations of quartz veins in metavolcanic, metavolcaniclastic and metasedimentary rocks and calcite veins mainly in metavolcanic rocks show presence of sulfide minerals like pyrite, galena, sphalerite, and chalcopyrite. Native gold is noted in some of the quartz veins. Intensity of the quartz veins is more in the sheared zones and particularly in phyllite and metavolcaniclasic rocks. The drill core samples clearly show the presence of base metal sulfides. The drilling cuts across and pass through weathered metasedimentary rock (slate), fresh slate, metavolcaniclastic and mafic metavolcanic rock (Fig.3). This is in tune with the stratigraphic position of the litho-units within the Tsaliet Group where mafic metavolcanic forms the oldest among others.

5.1.1. Nature of mineralization

Petrographic data indicate presence of sulfides like pyrite, chalcopyrite, sphalerite, galena, bornite, and native gold. Chalcocite and limonite are present as alteration minerals from bornite and pyrite respectively and show replacement textures. The ore minerals are associated with the hydrothermal fluids. The introduction of these fluids has resulted in the development of new mineralogy in the basement rocks due to alteration. However, the role of meteoric waters in the alteration patterns can not be ruled out. Chlorite and sericite are the major alteration minerals while calcite, kaoline and epidote are minor constituents. Kaolinisation is more prominent in rhyolite and granitoids possibly due to meteoric waters. Though the ore minerals are associated with quartz and calcite veins, pyrite also occurs as disseminated primary mineral in all the rock types (Figs 7, 8 & 9). It forms part of the primary mineralogy crystallized from the magmatic process or produced due to break down of mafic minerals in volcanic rocks and during diagenesis in the case of sedimentary rocks, which form protolith for metasediments. The other variety of pyrite together with other sulfides is related to hydrothermal quartz veins (Figs. 8 & 9) produced from hydrothermal precipitation particularly in shears/fractures along the lithological contacts. Fractures being more intense in shear zones have acted as channels for metal rich hydrothermal fluids circulation and precipitation of ore minerals pyrite, chalcopyrite, bornite, gold and galena and gangue minerals such as barite, calcite and quartz.

The intrusives have facilitated the generation of hydrothermal solutions which have leached the metals from the country rocks and transported to the sites of deposition i.e. structural weak zones. In the present case, N-NE trending shear zones have developed and facilitated deposition of sphalerite particularly along the contacts between metavolcanics, metasediments and metavolcaniclastics. Zinc anomalies noted in the surface rock samples (Table 3) tally well with the presence of sphalerite together with pyrite in drill core samples.

The type and content of the metal in the mineralization depends on many factors like nature of the source rock, depth of hydrothermal activity, favourable structures etc. Enrichment of zinc in drill core (Table 2) and surface rock samples (Table 3) are expected to be from intermediate to felsic variety of the metavolcanic rocks rather than mafic variety of metavolcanic rocks. Because the average concentration of zinc is higher in intermediate to felsic rocks compared to mafic rocks and the area is dominated by intermediate to felsic variety of metavolcanic rocks. This trend (Zn/Pb enrichment) is also observed in the nearby Dugum area (Amaha, 2011) which is dominated by metarhyolite, and in the nearby Negash area which is dominated by mafic metavolcanics and shows enrichment in copper (Bheemalingeswara and Nata, 2009). This is a clear indication that the role of source rock is playing a dominant role in the nature of mineralization.

The correlation matrix for five elements in table 5 shows significant positive relation between Pb & Ag; Pb & Zn; Pb & Cu. It is interesting to note that lead is showing positive correlation with copper and zinc. Zinc and silver do not show positive relation with copper which is generally expected on the basis of their average concentration in mafic and felsic rocks and geochemical mobility. Mean value for arsenic in surface rock samples though is relatively high (83 ppm) compared to its average crustal concentration, which is in ppb do not show any significant relation with base metals. Presence of higher values for arsenic and pyrite as a major sulfide indicate possibility of gold as an important by product. Gold though is not found in the ore petrographic study, it was identified in the megascopic observation in the field in quartz reef sample and in chemical analysis of three samples showing 30ppb (Berhane, 2011). In general, the correlation values are considered significant if they are above 0.5. In the present case all are below 0.5. So, the correlation matrix does not show strong positive correlation between the base metals, Ag and As. This indicates that the metals though being mobilized by hydrothermal fluids and confined to shear zones, do not suggest a common source. So, the source for the fluids being common, it is the source rock and the structures that are important factors controlling the nature and composition of the mineralization. The granitoids have facilitated hydrothermal activity in the area but do not seem to have contributed to the mineralization (Asrat, 2002).

5.2. Geology, Geochemistry and Tectonics of the Basement rocks

The Neoproterozoic basement rocks are the oldest rocks exposed in the study area. Available age data for the basement rocks of the region indicate that the metavolcanic/meta-volcanoclastic rocks form the oldest, followed by phyllite, slate, and carbonate and the associated syn- to post-tectonic intrusives of granite to granodioritic composition (Alene et al., 2000; Garland, 1980) and sedimentary cover rocks. The presence of chlorite, muscovite and biotite, development of foliation and presence of primary compositional banding of minerals in the metamorphic rocks indicates the rocks in the study area have experienced low grade greenschist facies metamorphism. Furthermore, the development of crenulation cleavage in phyllite, at places, is observed due to the localized effects of quartz intrusion or intensive shearing (Fig 6C). Among accessories, sphene is conspicuous in both the granitoids. Both the granitoids are clearly post-tectonic as they do not indicate any effect of deformation (Fig.7). Among the two, Megab granitoid is granitic in compostion while Negash granitoid is granodiorite and seems to be younger in age. As both have initiated hydrothermal activity in the area, it seems that the Negash granite is related to the first phase of ore minerals- sphalerite, pyrite, chalcopyrite, galena, gold which forms the part of mineralization and the Megab granitoid represents the second phase indicated by bornite, chalcopyrite, pyrite, gold, galena. However this observation needs further investigation. Deformation episodes are represented by different generations of quartz veins. Calcite veins are relatively younger, conspicuous in metavolcanic rocks and consist of bornite.

Slates show high sillica values with marginally increased Al_2O_3 (Table 1). Significant variation in trace element content in slates is well reflected by the colors they display. Higher values for iron in slate/phyllites are ascribed to the presence of pyrite. Sericitization is quite conspicuous along the shear zones in all rock types. Chloritization is common in mafic metavolcanics which also show relatively higher values for MgO and Fe_2O_3. Silicification is also common but pronounced in metasedimentary rocks. Chemical data suggest that MnO, CaO, Na_2O, Ba, Rb and Y seems to have variably added to the slates, where as MgO and Sr were removed.

On the basis of the present and published petrological, geochemical and structural data, it is possible to construct a sequence of events that have taken place in the area. Sedimentation and development of linear sedimentary belts in intra-oceanic basins (Tadesse et al., 1999) was accompanied by bimodal volcanism during Middle to Late Proterozoic. The sediments together with volcanics have undergone low-grade regional metamorphism. The younger plutonic intrusives mark the end of the tectonic activity and Proterozoic Era. Based on the discrimination diagram (Fig.5.10) drawn between TiO_2 (wt%) and Zr (ppm) for metavolcanic/ metavolcaniclastic rocks (Pearce, 1980) it is suggested that the rocks are produced in an island arc-tectonic setting. Tectonic discrimination diagram (Fig. 11) drawn between TiO_2 and Zr for metavolcanic rocks suggest an island arc-tectonic setting.

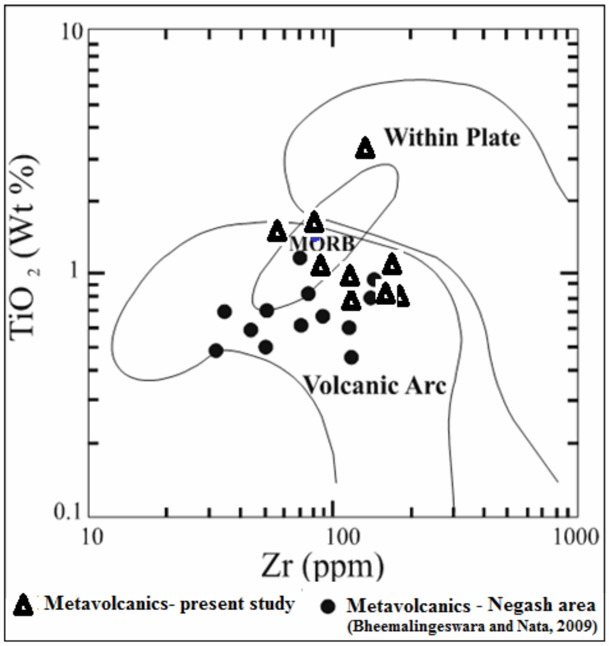

Figure 11. Tectonic setting discrimination diagram (Pearce, 1980)

5.3. Mineral Paragenesis

Three main paragenetic sequences are found/observed/identified/recognized/noted based on mineral relationships and associations, textures, and alteration products. On the basis of cross-cutting relationship three generations of quartz veins were noted related to pre- shearing (N80° W), syn-shearing (N40°W) and post-shearing respectively (Fig. 4). Pre- shearing intrusives include aplitic dykes, quartz dykes, quartz veins and veinlets mostly without any indication of mineralization. The second generation quartz veins are related to ore minerals like pyrite, galena, gold and chalcopyrite, and the syn-shearing veins present in the basement rocks trending N30°W. Quartz and carbonate veins and veinlets present in massive metavolcanic rock (andesitic) and others, typically associated with bornite is related to 3^{nd} generation. So, the paragenetic sequence of the sulfide minerals may be related to three distinct stages.

Stage 1 represents disseminated type pyrite present in almost all basement rocks in the area. Stage 2 is an ore mineral phase in which majority of the ore minerals have precipitated from metal- rich hydrothermal fluids filling the fractures predominantly within the shear zones and related to 2^{nd} generation quartz veins and barite. The minerals in this stage include pyrite, sphalerite, galena and gold. Stage 3 includes chalcopyrite replacing pyrite in quartz veins and bornite in calcite veins. Bornite has not been found in association with other sulfides to suggest its position in the paragenetic sequence. However, based on the relation with quartz veins, calcite and barite veins are compared with the third generation quartz veins, which are not intensive like 2nd generation. But keeping chalcopyrite and bornite relationship, the chalcopyrite can be formed as a reaction product of the pyrite with the bornite depositing fluids (Craig and Vaughan, 1981). Thus the chalcopyrite may be related to the stage three with bornite because bornite seems to have facilitated the development of chalcopyrite in the presence of pyrite. This is indicated in the development of chalcopyrite by replacing pyrite (Fig 9B). The last phase of paragenetic sequence is represented by chalcocite produced due to supergene alteration of bornite and shows replacement along the grain boundary. Another secondary mineral limonite, alteration product of pyrite has been observed in the field. On the basis of the above discussion a tentative paragenetic scheme has been proposed for the basemetal mineralization (Fig.12).

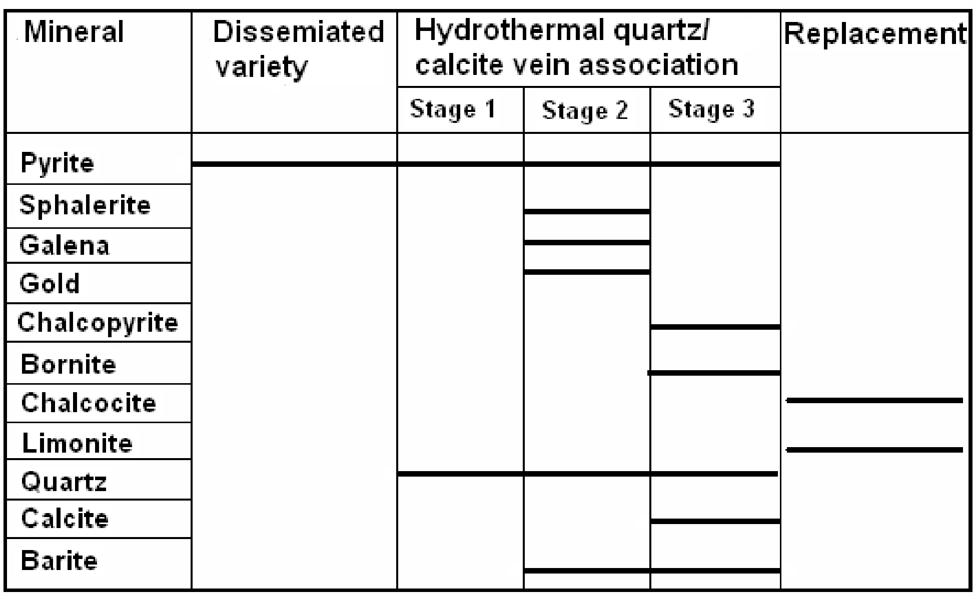

Figure 12. Paragenetic sequence of ore minerals related to the base metal mineralization.

6. CONCLUSION

The study area forms part of the Neoproterozoic basement rocks formed in an island arc tectonic setting. The rocks from older to younger include - metavolcanics (metabasalt, metaandesite, and metarhyolite), metavolcaniclastics, metasediments (phyllite/ slate), granitoids and Phanerozoic sedimentary cover rocks. Metavolcaniclastic rocks and phyllites show gradational contact and sharp contacts with metavocanics. Mineral assemblage and related textural properties suggest that a) the rocks have experienced low grade regional metamorphism, b) affected by shearing as indicated by dextral sense of shearing and c) the intrusive granitoids are post-tectonic.

Alterations like chloritisation, sericitisation, kaolinization, silicification, carbonatization, epidotisation are common in the area.

Three generations of quartz veins are noted in the area. They are prominent in shear zones and compared to quartz, calcite veins are less prominent and mainly confined to metaandesite.

Zinc enriched sulfide mineralization is related to D_2 deformation and the ore forming minerals, pyrite, sphalerite, chalcopyrite, bornite, galena present in quartz and calcite veins show a variety of textures like replacement, disseminated, fracture filling, stratiform etc.

Zinc enrichment is confined to shear zones and the nature of mineralization is controlled by the source rock (intermediate to felsic dominanted country rock) and the metal-rich hydrothermal fluids facilitated by the intrusive granitoids.

Based on the results, the mineralization is defined by a complex paragenesis of zinc in association with Pb-Cu-Fe (±Au-As-Ag) in quartz veins, hosted by slate, phyllite, metavolcaniclastic and metavolcanic and is structurally controlled.

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