International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-3, Issue-11, November 2016

Study on geological and structural characterization around Mai Kenetal, Central Tigray in Northern Ethiopia.

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***Abstract*— the present research is aims to study geological and structural characterization around Mai Kenetal, central Tigray, in northern Ethiopia. Topographic difference of the Mai Kenetal area helped in identifying the rock units in the north-western and south-eastern parts of the study area. So that metavolcanic, metavolcaniclastic formations are located in the north and northeast sides whereas slate and phyllite are situated in the south, central and eastern side. Also intrusive granite and dikes are recognized in the central part of the study area. The results shows that the basement rocks are prominently NE-SW trending and shows parallel to the regional lineaments of Mai Kenetal is syncline inliers structure. In study area, the dominant structures such as foliation, shear zone, fold, and fractures like fault, joints, and slickenside are appears. Structural data suggests that the study area has been experienced in three phases of deformation and it also indicated presence of hydrothermal alterations like chloritization, epidotization, sericitization. Based on the lithology study and the non-development of foliation or schistosity suggest that the study area is experienced in low grade metamorphic conditions.**

***Index Terms*— Deformation, Geological, GIS mapping, Hydrothermal alterations.**

I. INTRODUCTION

The geology of Ethiopia lies at the unique position of the northern part of the Mozambique belt and southern tip of the Arabian Nubian shield [1]. The Precambrian metamorphic rocks are dominated in Ethiopia in which comprises of: (1) litho-tectonic low-grade volcano-sedimentary assemblages with associated mafic to felsic intrusives and (2) high grade orthogenesis and parageneses assemblages. These crystalline basement rocks have undergone poly phase deformations and metamorphism. Low-grade metavolcano-sedimentary assemblages (island arc, ophiolites) are commonly termed as Upper complex of the Precambrian basement. The geology of Mai Kenetal, central Tigray, northern Ethiopia is further complicated by the abundance of Neoproterozoic to Neotectonic structures such as folds, faults, shear zones and lineaments. Hence, it is believed that geology of the central Tigray, which encompasses all types of geological units and the major geological structures of the region, will be of -paramount importance for any kind of natural resources investigation. Regional geological mapping of northern Ethiopia by [2,3] and compilation work by [1], are standard references for the geology of the region. These works describe the occurrence of widespread meta-volcanic and meta-sedimentary rocks and mafic to felsic intrusions in the area, as part of the Upper Complex of Ethiopia [1]. Within the Upper Complex, there are two major litho-stratigraphic groups, namely the Tsaliet and Tamben Groups [2,3]. With this background this study is proposed to carry out a study around Mia Kenetal in Werei Lehe district, central Tigray. The area was chosen for study because (a) it forms the northern extension of the gold bearing shear zones of Workamba [4] and parallel to the nearby areas like Negash [5] and (b) it is intensively traversed by different generations of hydrothermal quartz veins. This research is mainly intended to provide basic information on the geological and structural characterization in the study area.

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II. DESCRIPTION OF THE STUDY AREA

The study area is around Mai Kenetal town in Werie Lehe Woreda, central Tigray of northern Ethiopia. It is bounded between 496000E to 506000E easting and 1530000N to 1542000N northing and covers an area of 120km^2 (Fig.1). Also it is situated with reference to 950 km north of Addis Ababa, capital city of Ethiopia, and 160 km towards N - NW from Mekelle.

A. Physiographic, climate and drainage

The study area is mainly characterized by rugged, hill and dissected topography. It seems undulating structures. Topographically the highest elevation is 1938m and the lowest is 1319m above sea level (Fig.2). The climatic parameter in the study area, Werei Lehe district is categorized under arid to semiarid, and register the mean annual temperature ranges between 11°C and 33°C, with an annual rainfall range of about 678 – 1286 mm (Tigray Meteorological Agency, 2010). The drainage pattern is mainly accomplished by the perennial Werei, Tsadei, Tsalit, Melka and Garo river, which is used by the local people for domestic purposes and to pan placer gold (Werei).

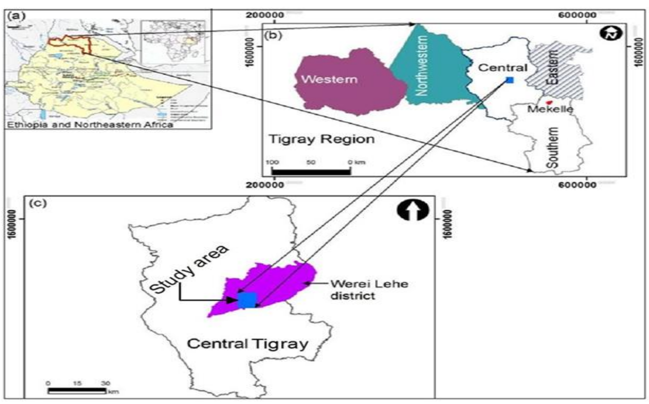

Fig. 1. Map of Ethiopia, northeast Africa and Arabia showing, (a) position of Ethiopia with respect to East Africa and Arabia, and portions of northern Ethiopia, Tigray (inset bold reddish boundary), (b) position of Werei Lehe (part of central Tigray) with respect to Tigray (inset rectangle), (c) position of study site (inset rectangle) with respect to Werei Lehe district.

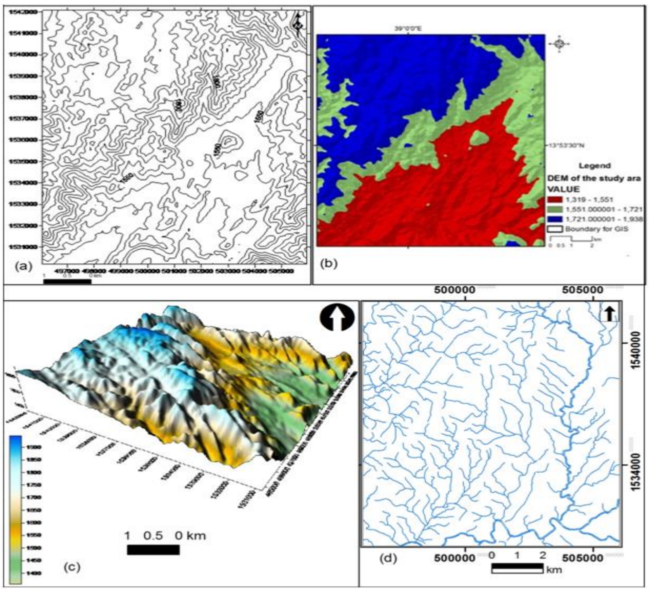

Fig.2. (a) Topo sheet, (b) digital elevation model (2D), (c) digital elevation model (3D) and (d) drainage map of the study area, Mai Kenetal, central Tigray, northern Ethiopia.

B. *Fieldwork surveys*

Field work was carried out from 2nd of March to 23th, 2012, through direct observation of units in the studied area with the help of enlarged and merged two top sheets (No.1338B2 and 1339A1) at 1:50,000 scale.

III. GEOLOGY OF TIGRAY (NORTHERN ETHIOPIA)

The basement rocks of the northern Ethiopia belong to the southern part of the Arabian-Nubian Shield which constitutes predominantly low grade metavolcano-sedimentary assemblages of island arc and ophiolite [1]. Low grade metavolcanic, metavolcanclastic and metasedimentary rocks are intruded by syn-to late-tectonic granitoids [6, 7, 8].

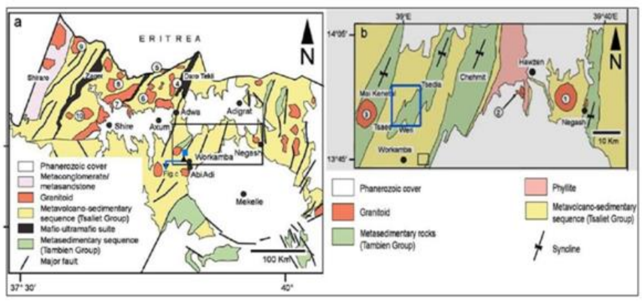

Fig. 3. a) Geologic map of the Tigray region, northern Ethiopia and the inset rectangle (Fig. c) in the rectangle shows the study area, b) Close-up of the area between Mai Kenetal and Negash shows the occurrences of Tambien Group in four synclinoria inliers [modified by 4 from7,8,9,10].

IV. TECTONOSTRATIGRAPHIC SETTING

Tigray lies entirely within the southern extension of the Nakfa Terrane of Eritrea. The Nakfa terrane is characterized by calc-alkaline volcanics and volcaniclastic sediments, which overlie a deformed and possibly coeval plutonic complex [11]. Whereas in Tigray, metavolcano-sedimentary blocks are delineated within the Tsaliet Group (Shiraro, Adi Hageray, Adi Nebrid, Chila, Adwa and Mai Kenetal) and Tambien Group formed by deformation (D2) and occur in lowlands of the western Shiraro area, as well as in several en echelon synclinoria to the east (Mai Kenetal, Tsedia, Chemit, and Negash), and the Red Sea escarpment area east of Adigrat [6]. The Tambien Group in this area includes slates, phyllites and black slate and occur on top of the Tsaliet Group and may correlate with the lower Werei slate of the Tambien Group [6], the latter is the base of the Tsedia inliers. Generally, the stratigraphic section of Tigray basement, Mai Kenetal and Tsedia rocks are shown below (Fig. 4).

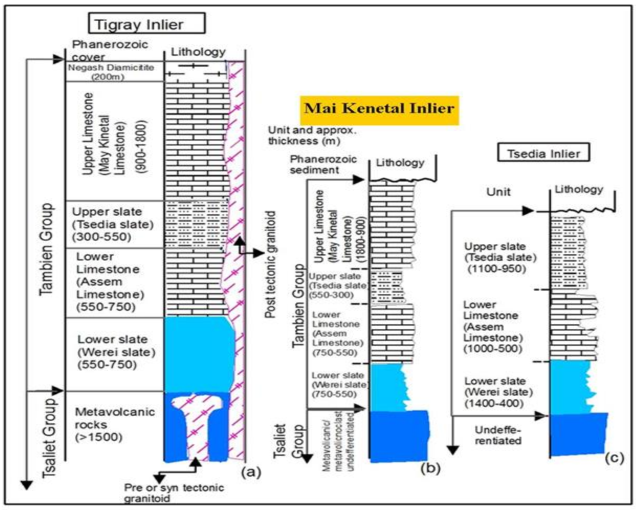

Fig.4.a) The pre- or syn-tectonic granitoids intruded the Tsaliet Group at about ~800 to ~735 Ma, and the post-tectonic granitoids intruded both the Tambien and Tsaliet Groups as well as the diamictites between ~620 and ~520 Ma.Stratigraphic sequences of the Tambien Group metasediments in the Mai Kenetal (Fig. b) and Tsedia sections (Fig. c), northern Ethiopia. Unit names given in parentheses are those used by [6]. The range of thickness of units in each inlier is given; the thicknesses plotted are those in the area in which samples were taken [6,9].

V. RESULT AND DISCUSSION

A. *Mapping of geology in 1:20000 scale.*

The geology of the study area is characterized by the rocks of variable compositions from mafic to felsic. It is mainly composed of metavolcanic, metavolcanclastic, metasedimentary rocks which intruded by dike and granitic rocks. The classifications of rocks in the study area are based on age relationship, mode of formations, lithologic characteristics and stratigraphy. Also these rocks have experienced low grade metamorphic conditions. They are Neoproterozoic in age [12,13] and also form part of the Mai Kenetal and Tsedia inliers [4] (Fig.3). Within the study area, metavolcanic and metavolcanclastic rocks (Tsaliet group) occupy the northeast, north, northwest, west, and southern part which show NE-SW trend. Metasedimentary rocks

(Tambien group) occupy central, eastern and southern part. Intercalations of metavolcanic and metasedimentary rocks occupy to the north central part, whereas intrusive rocks (aplitic dike, granite, massive metavolcanic dikes and quartz vein) intrude both metavolcanic and metasedimentary in the NNE to SSW direction parallel to sub parallel to the foliation. Further, there are many younger mafic dikes are also present in the study area which are not common in Hawzein area. So, in the study area rocks belonging to both Tsaliet and Tambien groups are present.

The area seems to have experienced three phases of deformations. The lithological units are highly affected by brittle ductile shear structures of mainly NE-SW trend. The NE-trending foliations and shear zones that are common in the area are related to D1 deformation. The folded structures which are common in metasedimentary rocks mostly isoclinals folds are related D2 deformation. Later developed fractures which cut across the foliation and folded structures are related to D3 deformation. The slates and not well developed schistocity in metavolcnic rocks indicate that the rocks have experienced low grade metamorphic conditions.

The details of these lithologies are mapped in (Fig. 5). Bedding, foliation, fold, shear zone and fractures are the geological structures whereas chloritization, epidotization, kaolinization, carbonitization, ferruginazation and sercitization are the alterations which were observed in the study area.

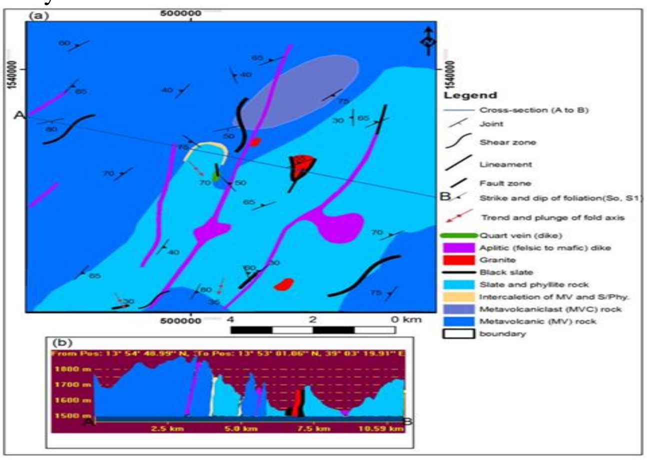

Fig. 5. a) Geological and structural map of the study area (inset rectangle in the rectangle of Fig. 3b), b) a cross-section along the line A-B. mafic to intermediate metavolcanic rocks of the Tsaliet group covered in the northeast, north, northwest, west and southern part; vesiculated metavolcaniclastic rock occur near central to north; slate/phyllite and thin layers of black slate of the Tambien Group are exposed in the east, central to the southern part and dikes intrusion occur in the Tsaliet and Tembien group in the NE to SW trend of the area.

B. Tsaliet group.

Metavolcanic and metavolcanclastic rock units are mainly exposed in the northern, western, northeastern, northwestern, and southern parts of the study area (Fig. 5). Metavolcanic is characterized by dark black, green to gray color, is massive, non-foliated and at some places shows presence of relicts of sub rounded to elongated plagioclase feldspar, amphibole and spherical cavity with a fine grained matrix (Fig.6a and b) respectively.

Fig. 6, a) Dark black massive and non-foliated metavolcanic rock; b) metavolcanic rock which shows sub rounded to elongated plagioclase feldspar, pyroxenes and spherical cavity within a fine grained matrix.

Metavolcaniclastic rock shows dark gray to green color and contains quartz, chlorite, and lithic fragments. The fragments vary in size and shapes from sub-rounded to rounded and even elliptical are being wrapped by the sheet silicates. These orientations of fragments indicate flow structure, elongation due to shearing (Fig.7).

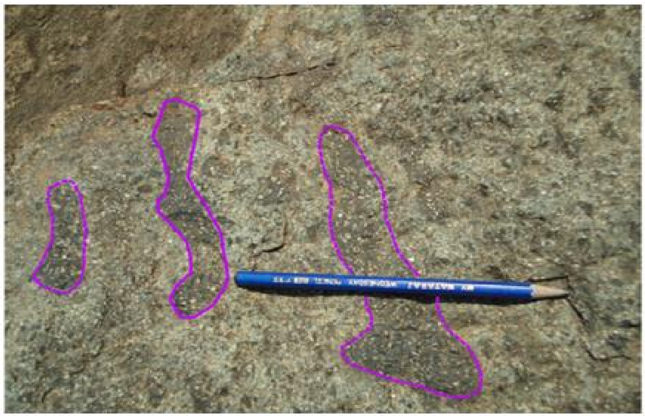

Fig.7. Dark gray to green color, presence of clast set (semi circular pink line) in a fine grained meta volcaniclastics rock.

C. Tambien group.

Phyllite and slate rock units are exposed in the east, central to the southern part of the study area (Fig.5). Phyllite and slate are the predominant litho units of metasedimentary rocks which are characterized by gray to pinkish color, fine-grained, highly to moderately foliate and at some places well developed harmonic fold (Fig. 8a and b). This unit is intercalated with compact black slate layer of 20 to 30 m thick of graphite (Fig.5). The graphite is characterized by black color, weakly foliated and shows cleavable structures (Fig. 8c).

D. Intrusive rocks.

Granite was found in the central part, west of Melka and north of Werie River (Fig. 5). It is characterized by light gray to pinkish color, medium to coarse-grained size texture and comprises of feldspar, biotite and shows boulder shapes of structures (Fig. 9 a and b). Since granite intrudes the basement rocks along the weak zone it serve as a conduit for hydrothermal solutions to carry minerals and transport, deposit probably the base metal mineralization in the favorable environment.

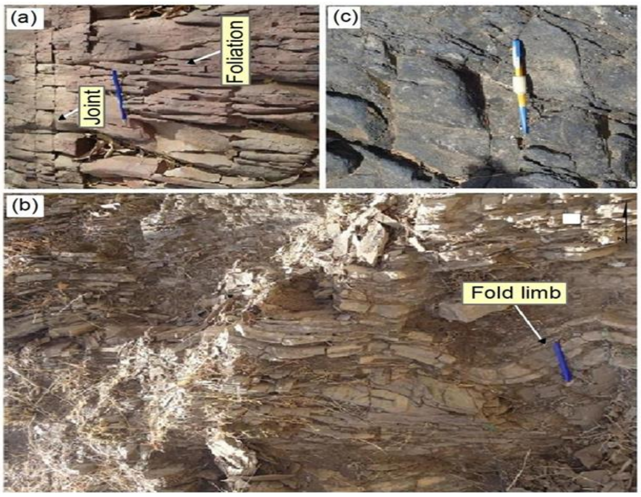

Fig. 8 a) Gray to pinkish color, fine grained, highly to moderately foliate slate/phyllite rock; b) slate shows harmonic fold structure; c) black color, smooth, moderately foliated black slate rock (graphite schist).

Aplitic dikes are felsic to intermediate in compositions which are exposed in the central part of the study area. It is characterized by light to dark color, fine to medium grained and comprises of silica and quartz. It shows N-S and NE to NW trend, and slightly to moderately weathered (Fig. 9c). Its usually suffered more intense hydrothermal alteration and therefore, contain alteration like kaolinazation.

Fig. 9 a) Pinkish color, medium to coarse grained granite rock; b) boulder shapes structure and moderately weathered granite rock; c) Light dark color, fine to medium grained aplitic dike.

E. Structural geology of the study area

The basement rocks of the mapped area are mainly affected by different phases of deformation. It is NE-SW and NW-SE trending and shows parallel to the regional lineaments of Mai Kenetal, Tsedia, Chehmit, and Negash syncline inliers [4,6,9]. The dominant structures of the study are includes: foliation, shear zone, fault, fold, fractures and slickenslide. (Fig.10).The general strike direction of the foliation is NE-SW and NW-SE trend. The dip amount of the foliation varies from 30^0-80^0 towards northeast and northwest. This foliation is correlated- with the regional D1 deformation, which was caused as a result of N-S compression [9].

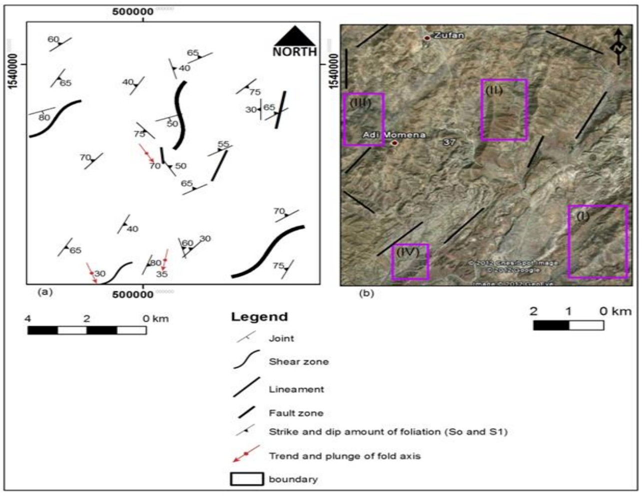

Fig. 10 a) Structural map, b) Satellite images showing shear zone (Pink rectangular (I, II, III, and IV)), lineament (Black line) and orientation trend of the study area (Image: Google Earth, visited on March 2012).

Brittle-ductile shears occured in both metavolcanic and metasedimentary rocks in the area. Two major and a minor shear zones are encountered in the area. The two major structures are predominantly trending towards NE-SW and NW-SE (Fig.10). The stress applied on the basement rocks causes shear, fractures, fold and cracks at a variety of size scales formed due to stretching and rotation (Fig. 11). Therefore, the NE oriented brittle-ductile shear zones are correlated to deformation (D1) [9]. Manifestations of a weakly developed, second shear deformation phase are observed at various places (Fig. 11). Perhaps the formed open cavities are later filled hydrothermal solutions. Presence of quartz vein, kaolinazation, chloritization and sericitisation alteration stains are some of the common features demonstrating the hydrothermal activity in the study area.

Harmonic folds were observed on the metasedimentary rock, at the central and southern part of the study area (Fig. 10). It is characterized by fold axis plunging 30° and 70° SE and south in the pure and black slate (Fig. 12). The orientation of the fold is compatible with N-S oriented D1 fold [9] and may be related to D2 deformation.

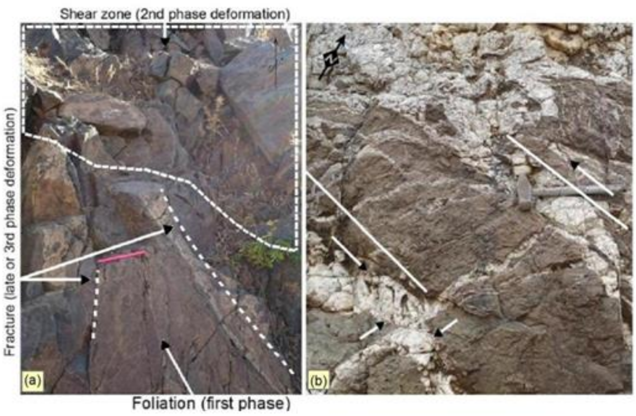

Fig. 11 a) Plan view on a rock domain showing relationships between foliation, weakly developed second shear deformation and later fracture (fault, joint) in basement rock, b) view on a small scale NNW trending dextral ductile shear correlated with D2 deformation.

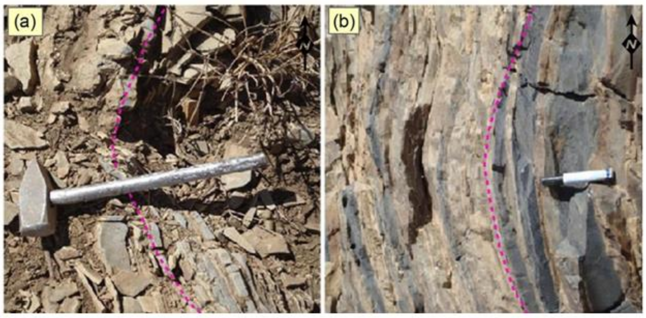

Fig. 12 a) View to the SSE on a NWW-SEE trending fold which folded the layers of the slate unit (Tambien Group) and is correlated with D2 deformation; b) view to the W on a W-E trending fold axis which folded the layers of of intercalation of slate with black slate.

Joints, cracks, faults and lineaments are other structural features identified in the study area (Fig. 10). There are also north-south trending strike slip faults displacing the basement rocks at the central part of the study area and cut across the shear zone (Fig.13). A set of NE-SW and NW-SE trending vertical to sub-vertical joints and fractures were developed on the basement rocks (Fig. 14a, b). Since these faults displace the shear zone, they are interpreted to be younger than the shear zone and related to D3 deformation. Locally, right-lateral strike-slip fault are common on metavolcanic, aplitic and quartz dike in the central, southern and western part of the study area (Fig. 14c, d).

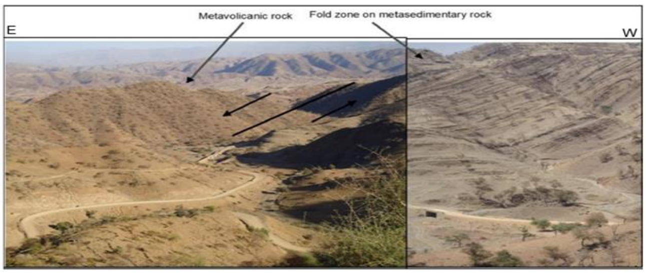

Fig.13 Side veiw of fold and fault zone in the central part of the study area, around Mai Kenetal.

Fig.14 a) An example of N-S and NW-SE trending joints and fracture cutting metavolcanic, b) left-lateral strike slip fault on metavolcanic, c) right-lateral strike slip fault of aplitic dike on metasediment and d) right-lateral slip fault of quartz dike on metavolcanic rock.

Quartz veins occur near to the shear-zone and at the contact between the metavolcanic and the metasedimentary rocks. Locally, quartz vein generations were detected based on their intersection relationship and their occurrence with respect to the foliation of the host rocks. These are concordant N-S trending quartz veins (qv_1) of gashes shape of NE striking discordant quartz veins (qv_2) (Fig. 15 a and b). The qv_2 veins are intensely deformed in many places due to progressive deformation affects the basement rocks in the study area.

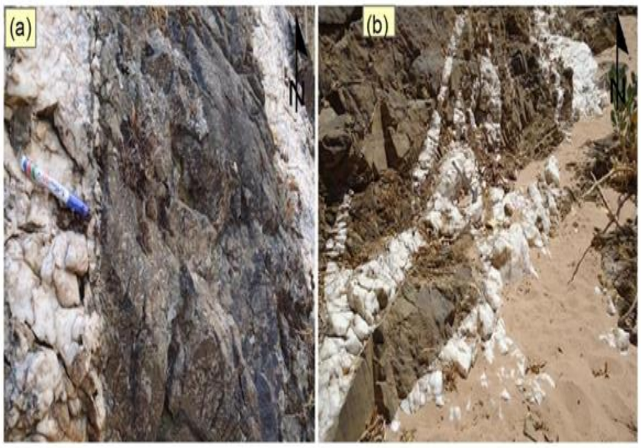

Fig. 15. a) An example of N-S trending concordant quartz vein (qv_1) in the central part of metavolcanic rock, and b) NE-SW trending en-echelon tension gashes quartz veins (qv_2) in SSE part of the metavolcanic rock of the study area.

F. Alteration and mineralization of the study area

Most of the alterations were generated as a result of fluid-rock interactions in hydrothermal systems related to mineralization and can be used as a tool for discerning the temperature of crystallization [14]. Based on field observations and petrographic information alterations occur in the study area include: chloritization, epidotization, kaolinazation, sercitization and ferruginouzation. The intensity of alteration increases along the shear zone, foliation and intrusions to the northeast, east and southeast.

Chloritization is characterized by the presence of chlorite on the surface of the metavolcanic rocks giving the rocks a distinct greenish color. It also occurs in the form of foliation parallel anastomosing bands mainly in the northeast of metavolcanic/metavolcanclastics units (Fig. 16a).
Epidotization is represents partial rock alteration that produces epidote group minerals. The mineral was formed either from alteration of feldspars, biotite and shows rounded to sub-rounded grain shapes occurred within the metavolcanic and along the drainage of the study area (Fig.16b)
Ferruginization alteration is characterized mainly by reddish brown color in quartz vein. This is probable due to the occurrences of iron during the hydrothermal fluid interaction with iron rich rocks (Fig.16c).
Sericitization alteration is prominently responsible for the formation of fine-grained white mica minerals. Complete or partial replacement of feldspars by sericite is common. This development of alteration is thin and placed in the central to southeast along the intrusion in the research area.
Kaolinization alteration is occurres in the central part of the study area producing a fine grained, white clay mineral and shows friable due to alterations. It is predominantly generated as a result of alteration and weathering of intrusve rocks mainly along the aplitic dikes (Fig.16d).

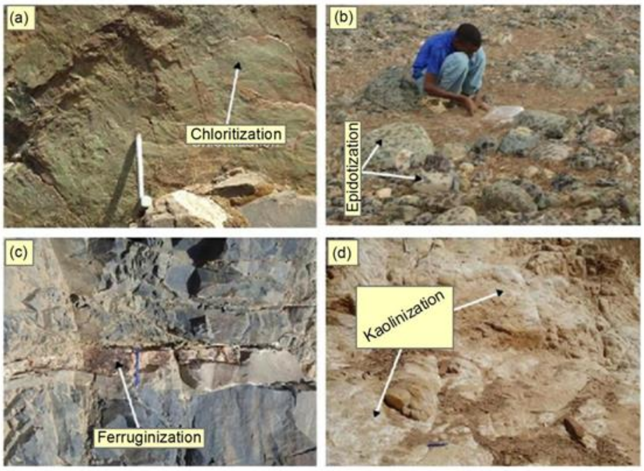

Fig.16 Chloritization, epidotization of sub-rounded grains, ferruginous alteration on the metavolcanic and metavolcanclastic rock (a – c) and d) kaolinization on slate/phyllite rocks.

VI. Conclusion

Geological map with structural data have been prepared at 1: 20000 scales in the study area using ArcGIS 10 software. Based on field observations bedding, foliation, fold, shear zone, fractures and geological alterations occur in the study area which include: chloritization, epidotization, kaolinazation, sercitization and ferruginouzation. The intensity of alteration increases along the shear zone, foliation and intrusions towards the east, northeast and southeast sides of the study area. In the basement rock, a set of NE-SW and NW-SE trending towards vertical to sub-vertical joints and fractures were developed. Based on the structural data, three phases of deformation have been identified specifically foliation and related shearing is linked to D1 deformation and folding, mineralization related hydrothermal activity is interrelated to D2 deformation. Also, later developed fractures such as cutting across the shears and folded structures are related to D3 deformation. The study area is belonging to both Tsaliet and Tambien groups in which Tambien group in this area includes slates, phyllites, black slate and occur on top of the Tsaliet group and may correlate with the lower Werei slate of the Tambien group. The results of geological and structural mapping suggests that the study area has been experienced in presence of low grade metamorphic conditions, propylitic alteration in mafic metavolcanic rocks and proximity to favourable structures are the most important recognition criteria for gold and base metal concentrations in the study area.

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