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GEOLOGICAL STUDIES ON THE ABU FANNANI MYLONITIC AMPHIBOLITES AND RELATED AMPHIBOLITE XENOLITHS IN THE JUVENILE NEOPROTEROZOIC MEATIQ DOME AREA, CENTRAL EASTERN DESERT, EGYPT.

Mohamed E. Habib[1]; Mohamed Abdel-Moneim[2]; Salwa M. Abdel-Sattar[3]
1,2,3 Geology Department, Faculty of Science, Assiut University,71516Assiut, Egypt

***E-mail:** geo.moh2015@gmail.com*

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The Neoproterozoic crustal rocks exposed in the Meatiq dome area, Central Eastern Desert of Egypt, comprise medium - to high - grade mylonites. They form strongly foliated and folded mappable units, including (in the core): Um Baanib granite-gneiss, followed structurally upward by Fiadiya augen schists, Gabal Meatiq phyllonitic mylonites, Abu Zohleiqa augen gneisses, Um Esh El-hamra quartzofeldspathic mylonites, and Abu Fannani mylonitic amphibolites. These appear to have been largely derived from granitic, pelitic to semipelitic, and basaltic to basaltic andesite rocks. The present work is focused only on the Abu Fannani mylonitic amphibolites which occur mainly in the shear zone constituting the frame of the Meatiq Dome. The amphibolite xenoliths hosted by the Um Baanib granite-gneiss are supposed to be originally belonging to the Abu Fannani unit. Field and petrographic characteristics of both amphibolitic types indicate that they were undergone a complex evolution of repeated deformations and metamorphisms. These were genetically connected with three major events, including subduction, obduction and updoming processes. Due to subduction, the original basaltic to basaltic andesites, together with the pelitic to semipelitic sediments formed a strongly folded and highly metamorphosed (M_1) orogenic belt. The lower part of this belt was migmatized and intruded by a synkinematic granite (i.e., Um Baanib granite-gneiss). During obduction, thick nappes overrode the highly metamorphosed belt leading to its transformation into high-to medium-grade mylonites having the amphibolite facies grade metamorphism (M_2). Thereafter, updoming processes originally linked with the Najd Fault System took place where brittle-ductile shear zones accompanied with greenschist facies metamorphism (M_3) were achieved. Regarding geochemistry of the amphibolites, major elements refer to their derivation from tholeiitic basalt to basaltic andesites. In Harker variation diagrams, immobile and incompatible elements (Zr,Ti,Y, and P) show good linear correlation relative to the mobile elements. Tectonic discrimination diagrams suggest the presence of two tectonic settings for both amphibolites, i.e., within-plate and MORB environments.

Keywords: Neoproterozoic, Meatiq Dome, polydeformation, polymetamorphism, shear zone, Geochemistry, Within-plate, MORB.

INTRODUCTION

The area of the Meatiq Dome is located in the Pan-African basement of the Central Eastern Desert of Egypt, west of Quseir town on the Red Sea coast. This area covers about 500 km^2, bounded by latitudes: 26^0 00' 00" and 26^0 10' 44"N, and longitudes: 33^{0}41' 00" and 33^0 56' 14" E (Fig.1). It is formed mainly of mylonitic rocks, previously described as infrastructure, constituting part of Pre - Neoproterozoic continental crust, overthrust by juvenile Pan-African supracrustal rocks (e.g. Habib et al., 1982; El Gaby et al., 1983; Habib et al., 1985; El Gaby et al., 1988; Khudeir et al., 2008). However, other authors considered these infrastructure rocks to represent juvenile Neoproterozoic crust (e.g. Harris et al., 1983; Ries et al., 1983; Sturchio et al., 1983a, b; kroner et al., 1993, 1994; Liegeois et al., 2010).

Habib et al. (op.cit.) referred to the infrastructure rocks of the Meatiq dome as variably cataclastic granite-gneisses, mylonites, augen schists, phyllonites and cataclastic amphibolites. The granite - gneisses are represented mainly by the Um Baanib orthogneiss, which crops out in the core of the dome, covering c.140 km^2, and forming a doubly plunging antiform facing ENE. The NNW-SSE hinge zone is gently folded where the plunge of the axis varies between 10^0 S and 25^0 N. Thickness of this unit is unknown, where its lower boundary is unexposed. It is structurally followed upward by the mylonitic and other several cataclastic rocks constituting five further mappable units including: the Fiadiya (up to 230 m thick), Gabal Meatiq (200 m thick), Abu Zohleiqa (400m thick), Um Esh El - Hamra (280 m thick), and Abu Fannani (600-1600 m thick) thrust sheets. The major development of these thrust sheets is in the western sector of the dome; in the east only the Fiadiya and Abu Fannani units are represented. Habib et al. (1985) noted that the contacts between the different units are flat-lying thrust faults along which the rocks are intensely sheared and mylonitized, and that the intensity of shearing and mylonitization decreases away from the main thrusts where the pre-mylonite features can be easily observed. They also noticed that relics of the parental coarse – grained rocks such as migmatites, granite-gneisses, pegmatites, tonalites and diorites are still preserved, and that the Um Baanib granite-gneiss is the least sheared unit, compared with the thrust sheets.

Liegeois et al. (2010) noted that the age of the Um Baanib orthogneiss is controversial. Andresen et al., (2009) obtained a concordant TIMS U-Pb zircon age of 631 ± 2 Ma, which agrees reasonably well with a five - point Rb-Sr whole rock isochron of 626 ± 2 Ma (intial^{87}Sr/^{86}Sr = (0.7030±0.0001) reported by Sturchio et al., (1983) for the orthogneiss.

The main aim of the present study is to spot the light upon the geology and geochemistry of the Abu Fannani mylonitic amphibolites, together with the amphibolite xenoliths within the Um Baanib granite-gneiss.

Abu Fannani mylonitic amphibolites

Andresen et al. (2009) believed that Habib et al. (op.cit.) used the heading "Abu Fannani thrust sheet" to include all the five mylonitic units overlying the Um Baanib orthogneiss, and not only the mylonitic amphibolites, which form the outer frame of Meatiq dome (Fig.1). The term Abu Fannani mylonitic amphibolites is used here, instead of the Abu Fannani thrust sheet of Habib et al. (1985). Field, petrographic and geochemical studies carried out on this unit indicate that it mainly represents originally an old oceanic crust, whereas a minor part of it possesses a sedimentary origin.

This unit is locally migmatized and intercalated with pelitic to semipelitic gneisses and schists, and intruded conformably by synkinematic diorite lenses having crystallization ages of 609 ± 1 and 606.4 ± 1Ma (see Andresen et al., 2009). It constitutes the frame of the Meatiq dome, specially from the eastern, southern and western sides. This frame varies in thickness between 600 and 1600 m. It is missing from the northern side, yet it builds up a thick outcrop in the northwestern corner of the Meatiq dome, forming an anticline, whose axis plunging NW. The Abu Fannani mylonitic amphibolites occur also along Wadi Abu Ziran west, which are bounded from the north by the Abu Zohleiqa augen gneisses and from the south by the synkinematic granitoids. Along the eastern bank of this wadi, a northwest - trending outcrop (2000 × 800 m) of mylonitic amphibolites is recorded. This outcrop is intruded by Arieki postkinematic granite which has a crystallization age of 590 ± 3.1 Ma (Andresen et al., 2009).

In the southwestern sector of the Meatiq dome, the Abu Fannani mylonitic amphibolites constitute with the synkinematic granitoids doubly plunging syncline and anticline, whose axes trending sigmoidally WNW-ESE (Fig. 2).

In the eastern side of the Meatiq dome, the present unit lies along Wadi Murr left-hand shear zone which trends NW and dips 60^{o} NE. It is bounded from the western side by the Fiadiya augen schist, and from the eastern one by a tectonic mélange. The contact Abu Fannani and Fiadiya units represents a shear zone of highly complicated deformational and metamorphic history. The present contacts between the three units are not thrust faults, as described by Habib et al. (1985), but represent brittle-ductile shear zones. The zone between the mylonitic amphibolites and

Fiadiya augen schists shows a complex deformational and metamorphic history (Fig.2).

In the western side of the Meatiq dome, the Abu Fannani mylonitic amphibolites lie along the Um Esh El-Hamra left-hand shear zone, which trends NW and dips at 60^o SW. This shear zone faces from the west the eastern desert ophiolitic mélange and is bounded from the east by the Um Esh El-Hamra quartzofeldspathic mylonites.

In the northwestern corner of the dome, the NW-ward plunging anticline of the Abu Fannani mylonitic amphibolites are bounded from the west by the northern extension of Um Esh El-Hamra left-hand shear zone but bounded from the north and east by a thrust fault where the southern part of El-Rubshi serpentinite sheet overrides the present amphibolites. This thrusting appears to be responsible for development of a series of synclines and anticlines, whose axes running parallel to the main axis of the plunging anticline (Fig. 2).

Amphibolite xenoliths

The migmatitic amphibolite xenoliths in the Um Baanib granite-gneiss are recorded by many authors (e.g. El Nady 1983; Sturchio et al., 1983; El Gaby et al., 1984; Habib et al., 1985;Asran 1992; Neumayr et al., 1996, 1998; Loisenbauer et al., 2001; Khudeir et al., 2008; Andresen et al., 2009; Liegeois et al., 2010). Neumayr et al. (1996) noted that amphibolitic and dioritic enclaves or xenoliths occur locally within the Um Baanib orthogneiss or as mafic dykes. The latter are altered to biotite schist, where its schistosity is oriented sub-parallel to that of the enclosing host. In view of the geochemical characteristics (present study), these amphibolitic xenoliths are supposed to be related to the Abu Fannani mylonitic amphibolites, which appear to represent the oldest rock unit in the mylonitic rocks of the Meatiq dome.

Neumayr et al. (op.cit.) stated that the amphibolite inclusions in the Um Baanib orthogneiss record different geologic settings - from the formation of oceanic crust to within - plate basaltic magmatism – prior to the intrusion of the Um Baanib granitoid. Neumayr et al. (1998) noted that the M_1 metamorphic event ($T \geq 750°C$) is restricted to the migmatized amphibolite xenoliths and mentioned that this metamorphic event occurred at about 780 Ma, namely prior to the intrusion of the Um Baanib granite protolith.

The amphibolite xenoliths occur in the Um Baanib granite-gneiss as lensoidal bodies of varying dimensions (Fig. 3A). They are randomly distributed in the eastern and western parts, with their major lengths running parallel or subparallel to the regional foliation. These xenoliths are characterized by tight isoclinal folding, penetrative foliation and migmatization. Ptygmatic and convolute folds indicative of high plasticity are well represented (Fig. 3B). Some of them show assimilative reaction along their boundaries. Also, mechanical assimilation is observed, where numerous crystals of k-feldspar are dispersed in the xenoliths.

At Wadi Murr left-hand shear, angular fragments of amphibolites are tectonically embedded in a cataclasite shear zone (Fig. 3C). Such xenoliths still possess internally tight folding indicating that they came from a ductile shear zone, which was later reactivated at a lower temperature, in the brittle regime.

Petrography

The Abu Fannani mylonitic amphibolites and amphibolite xenoliths within the Um Baanib granite – gneiss are generally dark grey and green in color, fine-to medium- grained and possess conspicuous schistosity. Migmatization of these amphibolites had taken place along their schistosity planes. Neumayr et al. (1996) noted that this migmatization represents the only record of the M_1 metamorphic event at minimum temperature estimated to be > 750 °C. The variations in mineral assemblages, textures and deformations, particularly in the Abu Fannani mylonitic amphibolites reflect a complex tectonic and metamorphic history. The continuous development of shear surfaces (or zones) was accompanied by increase in the degree of foliation and reduction of grain size.

Generally, the migmatized amphibolites are medium-grained (1000-2000 µm), characterized by a banded structure arising from the veining of the original amphibolites with leucocratic quartzofeldspathic veins. The paleosome is characterized by a clear foliation, and consists mainly of hornblende and plagioclase, with subordinate quartz. The leucosome, on the other hand is composed mainly of plagioclase and quartz with minor amounts of hornblende. Titanite is present as accessory mineral. As a result of high temperature of deformation produced during development of high- to medium- grade mylonites, the presumably previous euhedral shapes of plagioclase and hornblende in the leucosome bands migmatized amphibolies are nearly absent due to lobate grain boundaries (Fig. 4A). The large grain size of plagioclase (up to 2000 µm long), suggests that the older grain boundaries have migrated extensively. Lobate interphase boundaries of the mineral phases in the amphibolites were resulted from deformation and/or chemical exchange and transport during syndeformational metamorphism. The chemical reaction was responsible for the change in plagioclase composition as indicated from zoning and recrystallization (Fig. 4B). Such reaction led also to precipitation of quartz grains at its boundaries forming a core-mantle structure (Fig. 4C). Therefore, we can suggest that the diffusive processes (dissolution and reprecipitation) at the interphase boundaries accommodated part of the deformation at the highest temperatures (≤ 670°C, Rosenberg C. L., and Stünitz. H., 2003). At higher strain, bands of garnet-mica schists intercalating the Abu Fannani mylonitic amphibolites (Fig. 4D) consist mainly of feldspar, biotite, quartz and porphroblasts of garnet. Inclusions of biotite are observed within the garnet porphyroblasts (Fig. 4E). Carbonates are also present as thin veinlets (Fig. 4F).

Intra-crystalline cataclasis of hornblende crystals in the form of partings and fragmentation along cleavage planes is common. Large crystals of plagioclase prophyroclasts are also bent and fractured. Some of these fractures are filled with biotite which may show mismatching. Recrystallization of the plagioclase porphyroclasts (Fig. 4G and H) along their crystal margins indicates high temperature of deformation. The latter is also evidenced from the garnet-biotite schist bands intercalating the Abu Fannani mylonitic amphibolites. The mineral assemblage of such bands appears to have taken place during M_2 metamorphic event at temperature between 620^{o} to 690°C, and medium pressure between 6 and 8.5 k bar (Neumayr et al. 1996).

In the southern and western parts of the study area, namely along the E-W and NW-SE left – hand shear zones, respectively, higher strain deformation had taken place. The amphibolites are highly schistose, fine-grained (30 to 70 μm), and composed mainly of actinolite, quartz and plagioclase, together with epidote and chlorite. Iron oxides are arranged parallel to the schistosity planes, which show symmetrical folding. These schistose amphibolites are of greenschist facies grade, and are thought to have been developed during the M_3 metamorphic event at temperature < 550°C, and pressure < 4 kbar (Neumayr et al. 1996).

Evolution of deformations and metamorphisms

An early ductile deformation, followed by brittle-ductile, brittle-viscous transition and brittle shear zones can be recognized.

The ductile deformation was represented by ptygmatic and tight isoclinal folds, originated in the lower level of the folded orogenic belt, that genetically connected with the subduction event. This type of deformation was accompanied by penetrative foliation, higher grade amphibolite-facies metamorphism (M_1), and migmatization. It is recorded in both: the amphibolite xenoliths, and the Abu Fannani mylonitic amphibolites.

The brittle-ductile shear zones occurred in two main phases; the first (and older) phase was related to the obduction event, whereas the second (and younger) one was connected with the updoming processes.

During obduction, thick thrust nappes of ophiolitic mélange overrode the orogenic belt causing the first brittle-ductile shear zones which led to transformation of the amphibolites and gneisses into high- to medium -grade mylonites. These are characterized by overturned and recumbent folds, together with amphibolite-facies metamorphism (M_2).

The updomig processes were genetically linked with the Najd Fault System (see Stern,1985). In the early stage of updoming, the second brittle-ductile shear zones were expressed in the form of left-and right-hand shears accompanied with transpression and transtension zones. Overturned folds, whose axial planes dipping steeply, together with greenschist facies metamorphism (M_3), were achieved. This is retrogressive metamorphism,

In a progressive stage of updoming, brittle-viscous transition involving brittle fracturing, followed by invasion of quartz veins, was formed. This phenomenon indicates that the fracturing process became inactive at a certain time, and a high strain condition was predominant at another. Later on, however, such case was reversed where the quartz viens were fractured and displaced. Moreover, cataclasite zones were developed, due to lower temperature, in the brittle regime.

Geochemistry

Methods of analyses

Five samples (Table 1) from the Abu Fannani mylonitic amphibolites, that constitute the frame of the Meatiq dome, are selected for major and trace elements chemical analyses. These are carried out in the mineral laboratories, Canada, using ICP/ES method. SiO_2 is analysed in the geochemistry lab., Geology Department, Assiut cvniversity, Egypt, using gravimetric method. Other five samples (Table 1) representing the amphibolite xenoliths within the Um Baanib granite-gneiss are choosen from the published work of Neumayr et al. (1996) in order to throw the light upon the genetic interrelation between the two amphibolitic types.

Results

The chemical analyses for the present amphibolites show that they are typically mafic to intermediate in composition with SiO_2 varying between 48 and 56 wt%. Major and trace elements distribution illustrate that the mylonitic amphibolites are enriched in FeO, and depleted in CaO, MgO, Ba and Sc relative to the amphibolite xenoliths within the Um Baanib granite - gneiss.

In the total alkali- silica classification diagram (Fig. 5, after Le Bas et al. 1986), the present amphibolites are plotted in the basalt and basaltic andesite fields except two samples lie in the trachy basalt field. Their lower values of L.O.I suggest less alteration when compared with other mylonitic rocks in the area. However, the presence of secondary minerals such as chlorite, muscovite and epidote indicate that these rocks were affected by alteration processes.

In the Harker variation diagrams (Fig. 6) between Zr versus some major and trace elements, incompatible elements like TiO_2, Y and P_2O_5 show a good linear relation indicating that such elements were not influenced by a high-grade metamorphism affecting the Meatiq rocks as suggested by some authors (Habib et al., 1985; Neumayr et al., 1996; Sturchio et al., 1983). This trend of relatively immobile elements can be explained as due to fractional crystallization of basaltic magma (see Kakar et al., 2015; Munyanyiwa et al., 1997). On the other hand, elements such as Ba, Nb and K_2O exhibit random distribution, indicating that they were affected by high-grade metamorphism like some Meatiq rocks**.**

Origin and petrogenesis

In Niggli c-mg plot (after Leake, 1964) the present amphibolite samples lie along the Karoo dolerite trend (Fig.7a). In Na_2O+K_2O versus $100*K_2O/Na_2O+K_2O$ diagram (after Honkamo, 1987), most of these amphibolites lie in the igneous field (Fig. 8B), indicating that these rocks include ortho-and para amphibolites (Fig.7b).

In the FeO-Alk-MgO (AFM) diagram (after Irvine and Baragar, 1971), all of the amphibolites plot in the calc-alkaline field, except for one sample from the mylonitic amphibolites lying in the tholeiitic field (Fig. 8). In SiO_2 versus FeO/MgO discrimination diagram (after Miyashiro, 1974), some of the samples lie in the tholeiitic field and the others lie in the calc – alkaline field, but most samples are clustered around the separation line between both fields (Fig. 9).

In general, the previous results must be treated with caution, because of the possible mobility of major elements during metamorphism. A better approach is to examine the contents of high field strength elements (HFSE), which are believed in many cases to be relatively immobile during alterations and metamorphism. We used tectonic discrimination diagrams based on the HFSE to evaluate the magmatic affinity of the basaltic protoliths of the present amphibolites.

In the TiO_2 versus Zr tectonic discrimination diagram (after Pearce and Cann, 1973), the amphibolites under consideration lie on MORB and Arc lava fields; only one sample lies on within-plate lava field (Fig. 10). Both types of basalts are interpreted by Owona et al. (2013) as high Fe-andesite basalt. In Ti/100 - Zr- Y*3 and Ti/100 - Zr-Sr/2 triangular diagrams (after Pearce and Cann, op.cit.), the present samples plot in the island arc and calc-alkaline fields (Fig. 11A), and in the island arc, MORB and within-plate basalts (Fig. 11 B). Wang and Glover (1992) have shown that great caution must be taken into account in applying these diagrams to continental basalts, because many of them fall in the MORB field.

In the Ti/1000 versus V tectonic discrimination diagram (after Shervais, 1982), the present amphibolites plot mostly in the fields of MORB and those of oceanic island and alkali basalt (Fig. 12). The Ti/V ratio appears to be increasing systematically from island arc theoleiitic basalt (IATB), to mid- oceanic ridge basalt (MORB), and to intraplate volcanics. Hodder (1985) stated that the depth of origin of basalts can be inferred from Ti/V ratios. The order of magma depth origin (island arc > MORB > plume) is the reverse of Ti/V ratios of the basalt in Shervais (1982) discrimination. In the amphibolites under consideration Ti/V ratios show wide spam from 9 to 67 (Table1) which is consistent with different tectonic setting and origin.

In spider diagram (Fig.13), the large ion lithophile elements (LILE) exhibit linear distribution characterized by decreasing abundances from LILE (Ba, Sr) down to HFSE similar to oceanic island basalt (see Owona et al., 2013).

Plotting of the amphibolites from the Meatiq dome area in two or more different tectonic settings was discussed by Neumayr et at. (1996). They interpreted this phenomenon as due to a complex geological history prior to the intrusion of the Um Baanib granite- gneiss protolith.

From the foregoing discussion, the different tectonic settings of the present amphibolites from the formation of oceanic crust to within-plate basaltic magmatism, may refer to the complicated geological history of the Meatiq rocks.

Engel et al. (1980) studied REE of selected pillow basalts, arc andesites and late tectonic granites from the Central Eastern Desert of Egypt. They concluded that, the shape of REE pattern indicates a MORB setting for the pillow basalts and an island – arc setting for the calc-alkaline andesites. Also, they noted that the Afro – Arabian oceanic arcs were consolidated from island – arc to continental crust within 300 Ma. The shape of REE pattern presented by these authors is the same obtained for the Meatiq amphibolites by Neumayr et al. (1996). But Engel et al.

(op.cit.) determined crustal consolidation in the Central Eastern Desert (CED) depending on basalts and andesites, (between 750 and 550 Ma in age). Andresen et al. (2009) noted that the amphibolite xenoliths are enclosed in the Um Baanib granite-gneiss which possesses a crystallization age of 631±2 Ma. Thus, the Meatiq amphibolites record the tectonic evolution of the present area at, or prior to 631 Ma.

Based on the geochemical study of the amphibolites from Hafafit metamorphic complex (HMC), Abd El-Naby and Frisch (2006) stated that these amphibolites belong to a back- arc geotectonic setting.

Conclusion

The Abu Fannani mylonitic amphibolites forming the frame of the Neoproterozoic crustal rocks of the Meatiq dome, together with the migmatitic amphibolite xenoliths within the Um Baanib granite-gneiss are treated. Field, petrographic and geochemical studies revealed that the area under consideration was suffered from complex tectonic and metamorphic history. The major tectonic events are represented by subduction, obduction and updoming processes. The subduction led to the development of a highly folded and metamorphosed belt. In the deeper levels of this belt, the metamorphism(M_1) reached a temperature up to > 750^oC (see Neumayr et al. 1996). Also, the migmatitic amphibolites were formed. These were captured as xenoliths within the Um Baanib granite-gneiss, which was synkinematically intruded into the folded belt at 631 Ma (see Andresen et al. 2009). During the obduction event, thick ophiolitic nappes overrode the folded belt which was affected by brittle-ductile deformation, together with initiation of high- to medium- grade mylonites. In this stage, metamorphism(M_2) attained a temperature between $620\text{-}690^oC$ (after Neumayr et al. 1996). The updoming processes were genetically connected with the Najd Fault System which was resulted in brittle-ductile shear zones accompanied with the (M_3) metamorphism at a temperature < 550^oC. Two major left-hand shears along Wadis Murr and Um Esh El-Hamra can be easily recognized. Both are trending NW-SE; the former bounds the Meatiq dome from the east, whereas the second bounds it from the west. Wadi Murr left-hand shear shows a right-hand bend (transpression). Um Esh El- Hamra left-hand shear possesses a left-hand bend (transtension) in the south, and right-hand bend (transpression) in the north.

The geochemical studies indicate that, the present amphibolites were derived from tholeiitic to calc-alkaline magma (basaltic – basaltic andesite) via magmatic crystallization. Tectonic discrimination diagrams refer to different tectonic settings ranging from within - plate basalt to mid-oceanic ridge basalt (MORB). Their enrichment in MgO, FeO*, Al2O3 and TiO2, leads to the assumption that they can be considered as high – Fe basaltic andesite overlapped by crustal contaminated basaltic-andesite. This model is consistent with a back – arc tectonic setting.

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Table (1): Major oxides and trace elements from Abu Fannani mylonitic amphibolites and amphibolite xenoliths in Um Baanib granite-gneiss.

Serial No.	1	2	3	4	5	6	7	8	9	10
						Um Baanib east margin			Um Baanib west margin	
Sample	10B	3B	10A	7	52A	NM2/1	NM6	NM85	NM3	NM4
SiO2	51.78	51.28	52.52	55.4	54.44	54.3	51.4	48.9	49.2	50.4
TiO2	2.09	2.91	2.03	0.58	0.45	0.94	1.45	1.96	0.78	1.08
Al2O3	16.59	15.42	15.35	15.74	15.27	11.3	13.8	16.4	15.6	14.8
FeO	8.22	12.76	9.12	6.59	10.09	4.664	6.468	5.412	5.236	5.896
MgO	3.66	2.35	4.56	6.05	6.11	8.95	5	3.66	8.19	5.67
MnO	0.13	0.04	0.15	0.15	0.18	0.16	0.25	0.16	0.19	0.22
CaO	13.57	7.67	12.18	10.68	9.5	8.64	7.75	8.95	9.6	9.86
Na2O	1.86	4.7	2.28	4.04	2.47	2.58	3.54	4.04	3.1	2.28
K2O	0.85	0.92	0.47	0.75	0.49	0.74	0.87	1.26	0.77	0.76
P2O5	0.05	0.09	0.05	0.01	0.01	0.13	0.12	0.44	0.06	0.08
LOI	1.2	1.86	1.29	0.01	0.99	7.596	9.442	8.818	7.304	9.014
Cu	87	7	52	5	135	12.1	15	76.7	20.4	171
Zn	107	156	89	86	79	106	156	121	89.9	105
Ni	54	37	57	59	60	95	13	62	53	20
Co	34	49	33	30	36	51	30	40	44	44
Th	2	2	2	2	2	0.8	0.4	1	0.2	0.2
Sr	313	431	294	362	131	251	199	265	226	202
V	229	270	225	234	304	247	421	263	313	411
La	17	28	16	8	4	8.4	4.2	11.2	0.8	1.1
Cr	64	21	59	210	116	100	13	180	120	10
Ba	1062	226	523	101	94	106	113	190	136	176
Zr	69	21	69	17	18	92	85	186	33	42
Y	42	46	42	15	14	16	35	30	10	20
Nb	7	40	7	7	2	36	10	24	10	10
Sc	27	28	26	35	39	33.3	37.1	35.3	51.4	46.2
mg	0.25	0.12	0.27	0.41	0.31	45	25	23	41	30
Ti/V	55	67	56	15	9	23	21	45	15	16

1-5 Abu Fannani mylonitic amphibolites
6-10 Amphibolite xenoliths in Um Baanib granite-gneiss (from Neumayr et al.,1996).

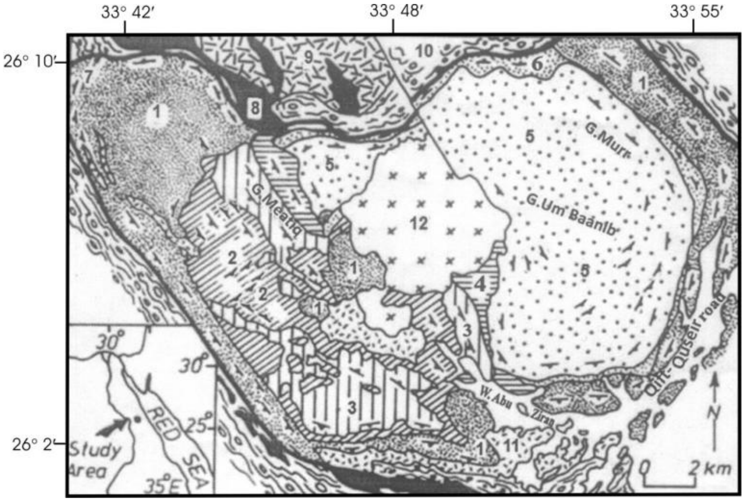

Fig.1. Geological Map of the Meatiq Dome Area (modified after Hahib et al., 1985). 1, Abu Fannani Mylonitic Amphibolites; 2, Abu Zohleiqa Augen Gneisses; 3, Um Esh El Hamra Quartzofwldspathic Mylonites; 4, Gabal Meatiq Phylonitic Mylonites; 5, Um Baanib Granite- Gneiss; 6, Fiadiya Augen Schists; 7, Meatiq Dome Boundary; 8, Serpentinites; 9, Metagabbros; 10, Eastern Desert Ophiolitic Melange; 11, Synkinematic Granites; 12, Postkinematic Granites.

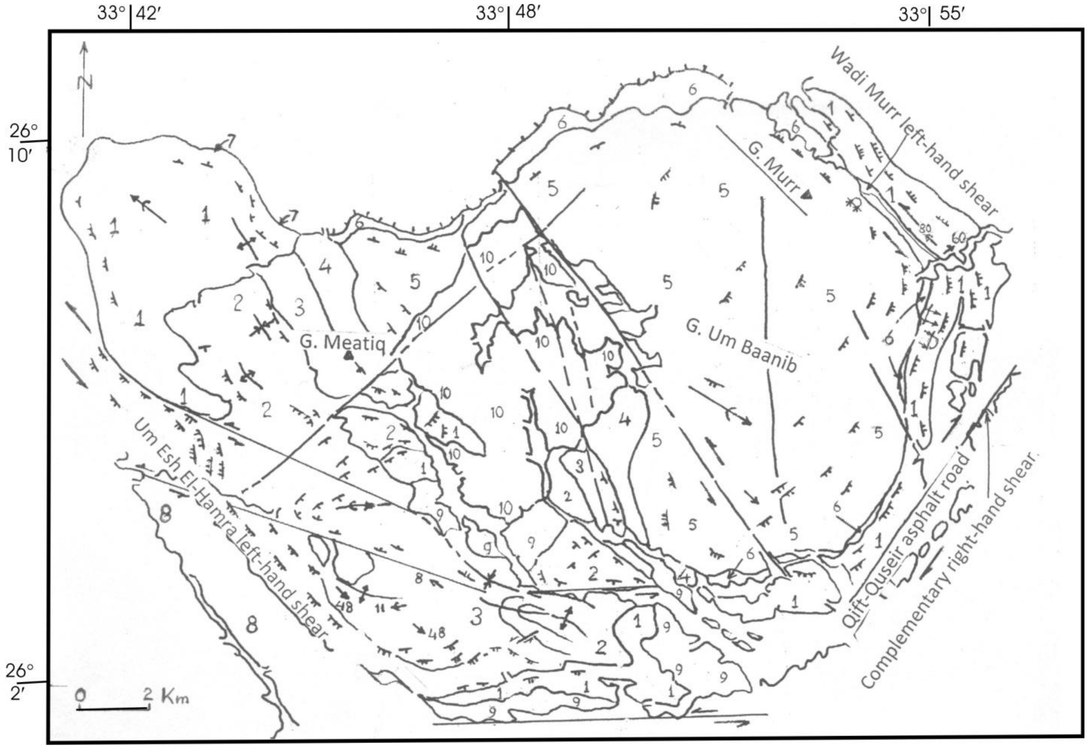

Fig.2. Structural Map of the Meatiq Dome Area. 1, 1, Abu Fannani Mylonitic Amphibolites; 2, Abu Zohleiqa Augen Gneisses; 3, Um Esh El Hamra Quartzofwldspathic Mylonites; 4, Gabal Meatiq Phylonitic Mylonites; 5, Um Baanib Granite- Gneiss; 6, Fiadiya Augen Schists; 7, Meatiq Dome Boundary; 8, Eastern Desert Ophiolitic Melange; 9, Synkinematic Granites; 10, Postkinematic Granites.

Foliation dip ≤ 20°; Foliation dip 20°-40°; Foliation dip 40°-60°; Foliation dip ≥ 60°; Strike – slip fault; Normal fault; 80° Axis and plunge of minor fold; Axis of anticline; Axis of syncline;

Isoclinal overturned anticline and syncline.

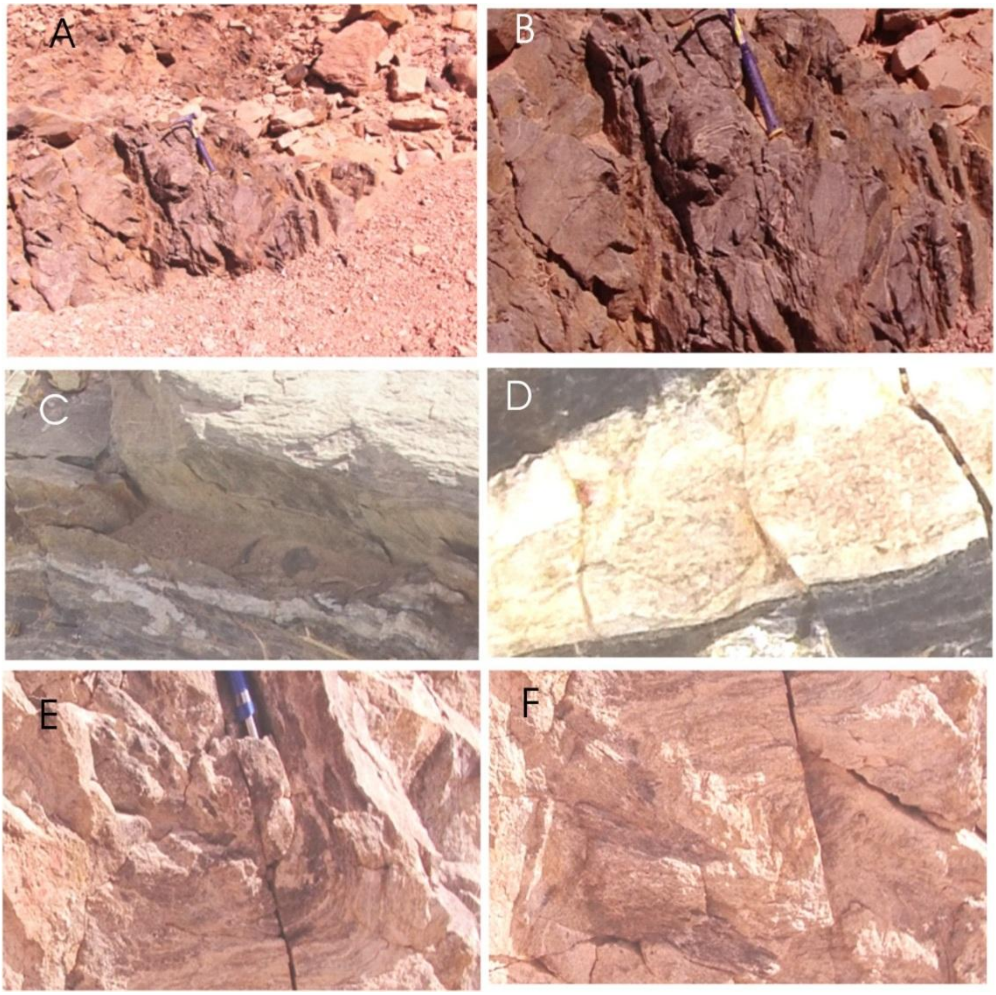

Figure 3: A) Photograph of lensoidal migmatitic amphibolites xenoliths hosted by the southern margin of Um Baabib granite-gneiss.

B) Close-up view for the same xenoliths showing ptygmatic and highly plastic folds representing the early ductile deformation in the Meatiq dome area.

C) A close - up view for structurally complicated deformations in amphibolites xenoliths tectonically embedded in Fiadiya augen schists. In the upper part of the photograph, a sinistral sense of shear is recognized. In the central part, angular fragments of amphibolites are embedded in a cataclasite shear zone consisting of quartz, feldspars, chlorite and epidote. The orientation of the fragments indicates a dextral sense of shear. In the lower third of the photograph, a brittle-viscous deformation can be easily observed. In the lower left side, ductile asymmetric microfolds showing a sinistral sense of shear are detected. (In a tributary from Wadi Murr left – hand shear zone).

D) A close-up view of a leucosome in migmatitic amphibolite slice detatched from the Abu Fannani mylonitic amphibolites and incorporated in the Fiadiya augen schist. The leucosome shows C/S fabric and C’ – type shear bands. The latter appears to be developed later than the former. Notice that both indicate dextral sense of shear. (Wadi Murr left-hand shear zone).

E and F) Close–up views of a cataclasite shear zone showing a complex deformational history. It includes highly folded migmatitic amphibolites fragments belonging to the Abu Fannani mylonitic amphibolites. Such fragments are embedded in a matrix formed of quartz, iron oxide, chlorite and other minerals that probably precipitated from a fluid.

3

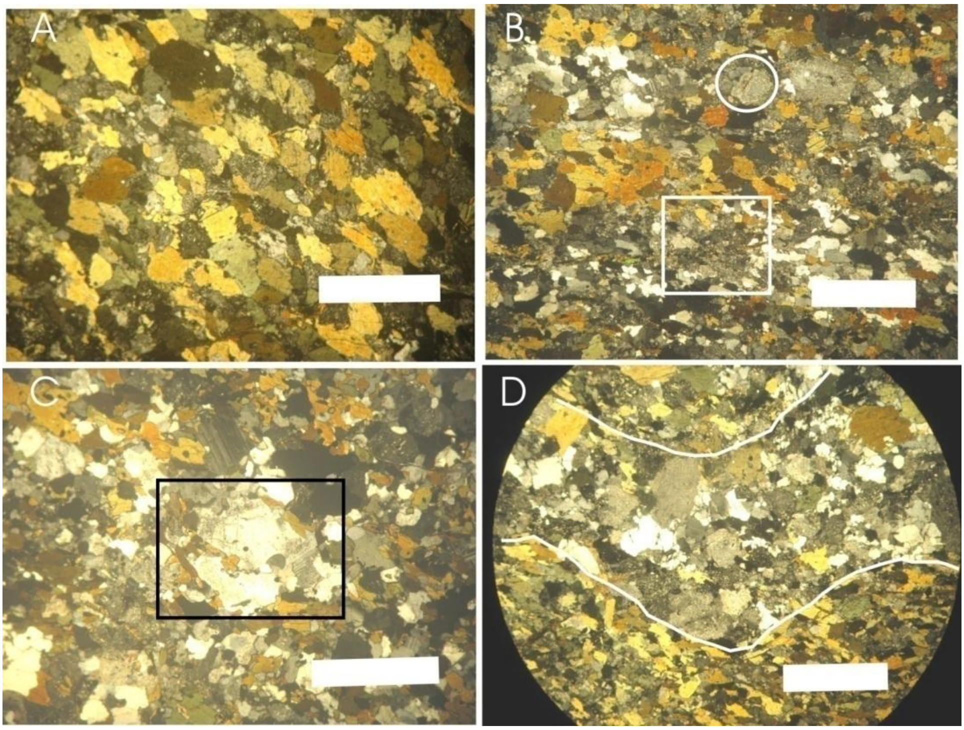

Figure 4: (A-D):

A) Photomicrograph showing lobate grain boundaries of the plagioclase, hornblende and quartz.

B) Photomicrograph showing compositional zoning in plagioclase (marked by circle), and recrystallization of its margins which are replaced by quartz and albite (marked by square).

C) Recrystallized large plagioclase porphyroclast forming a core-mantle structure.

D) Garnet- mica schist bands within the Abu –Fannani amphibolites.

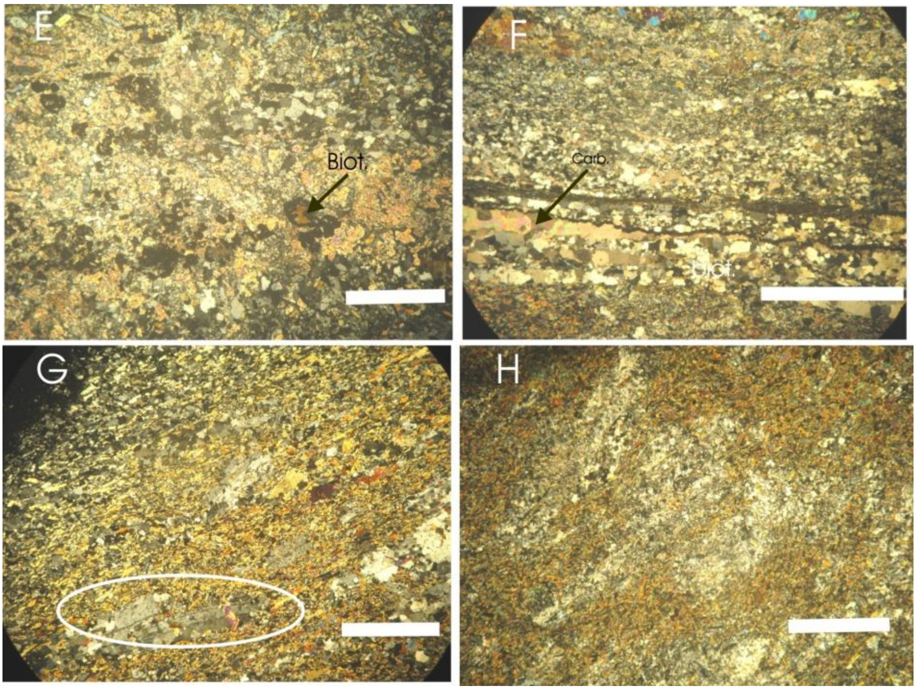

Figure 4: (E-H):
E) Inclusions of biotite (Biot.) within the porphyroblastic garnet.
F) Thin band of carbonates (carb.) within the Abu-Fannani mylonitic amphibolites
G and H) highly deformed and recrystalized plagioclase porphyroclasts in a highly schistose mylonitic amphibolite from the southern and western area of the Meatiq dome.

Bar = 900 µm

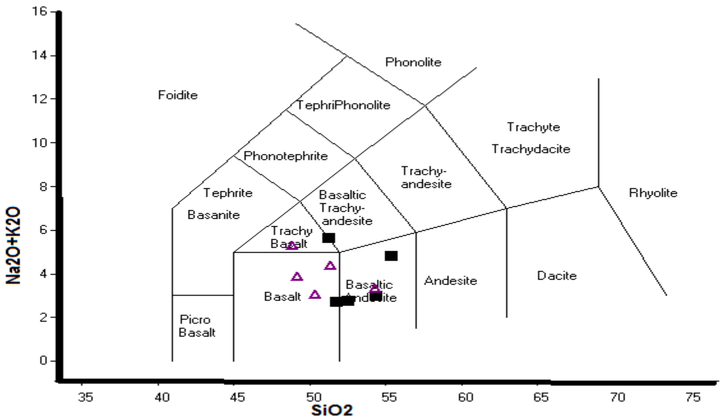

Figure 5: Meatiq amphibolite plotted in the total alkali-silica classification of volcanic rocks (after Le Bas et al.,1986).

■ : Amphibolite from the mylonitic belt, Δ : Amphibolite xenoliths within the Um Baanib granite-gneiss.

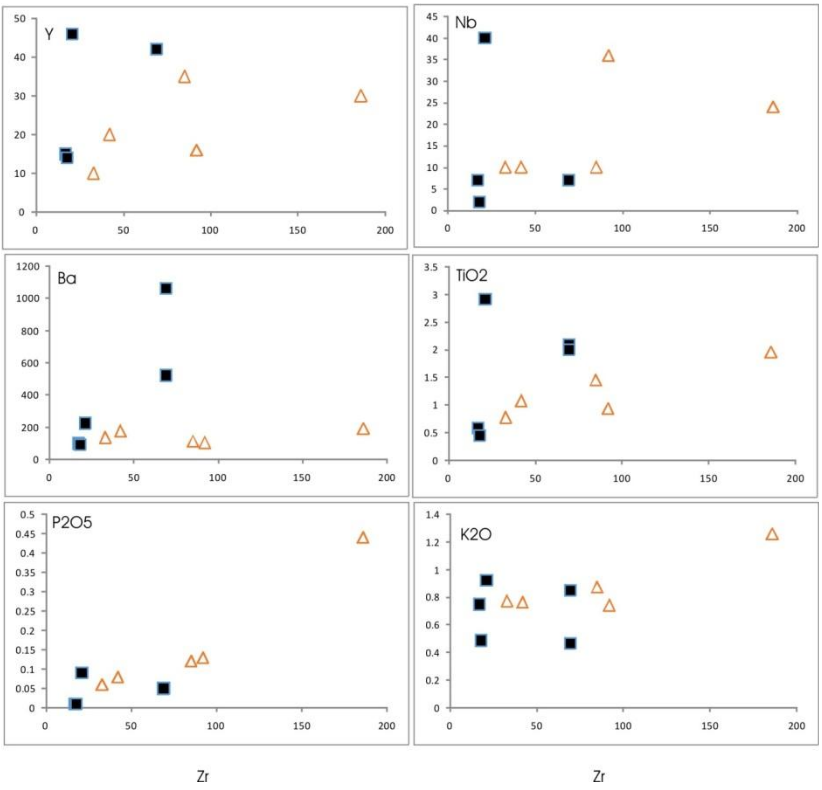

Figure 6: Variation diagrams for selected major and trace elements of the amphibolites in the Meatiq Dome to test element mobility during high-grade metamorphism, (symbols as in Figure5.).

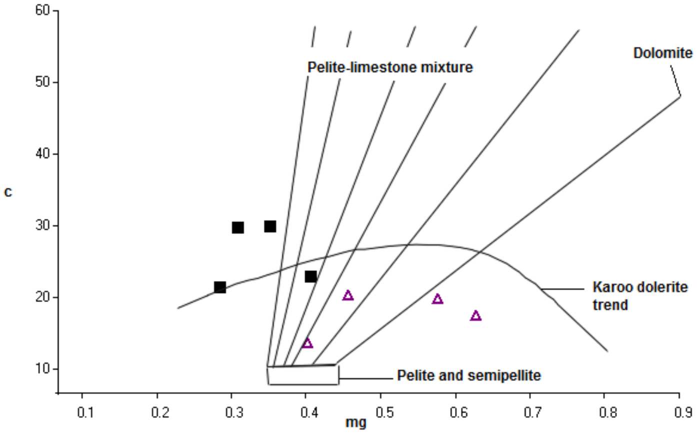

Figure 7 (a): Niggli c-mg plot (after Leake,1964) for amphibolite from Meatiq dome, (symbols as in Figure 5.).

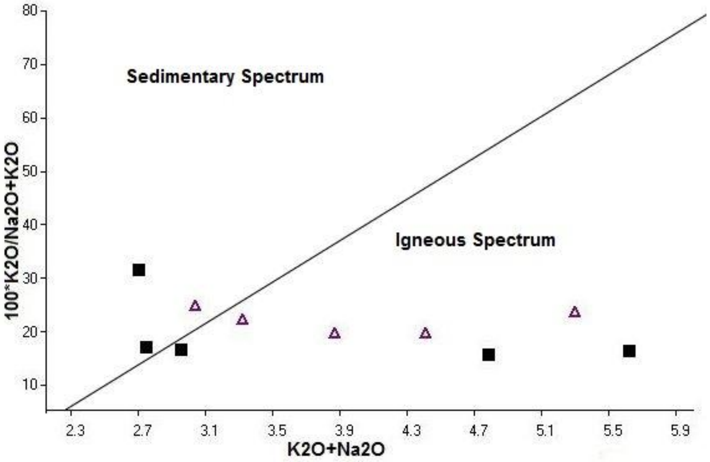

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Figure 7 (b): Na_2O + K_2O versus 100x K_2O / Na_2O + K_2O of the amphibolite xenoliths within the Um Baanib granite – gneiss and the Abu Fannani mylonitic amphibolites (after Honkamo, 1987), (symbols as in Figure5.).

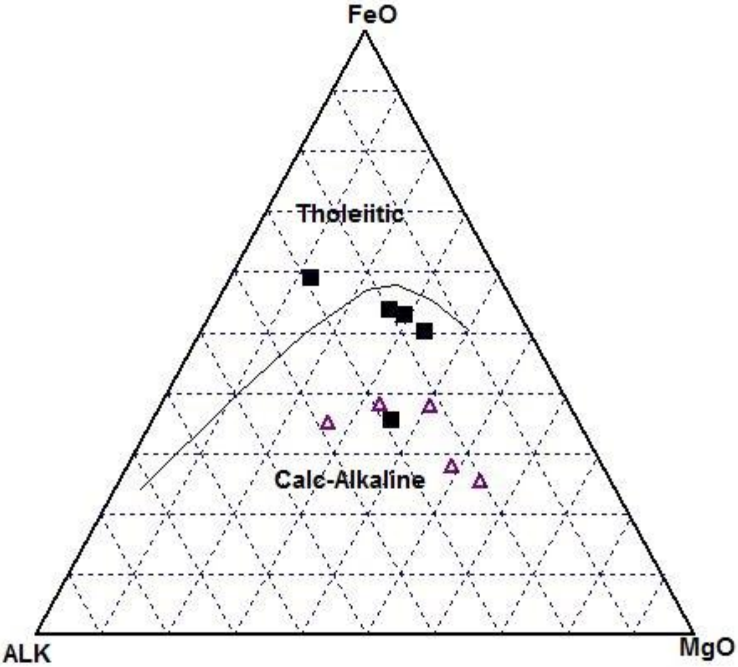

Figure 8: FeO-Alklis-MgO plot (after Irvine and Bargar, 1971), (symbols as in Figure 5.).

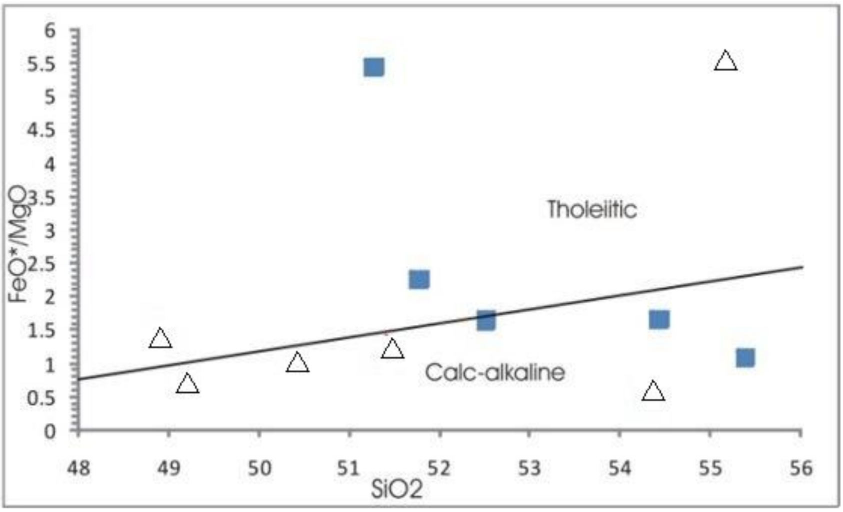

Figure 9: SiO_2 versus FeO*/MgO (after Miyashiro, 1974), (symbols as in Fig. 5.).

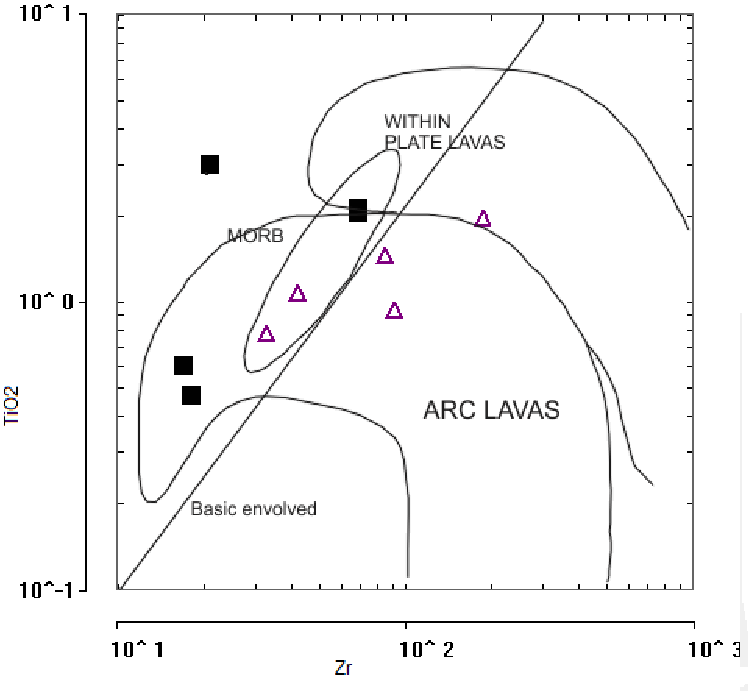

Figure 10: TiO_2 -Zr tectonic discrimination diagram (after Pearce and Cann, 1973), (symbols as in Figure 5.).

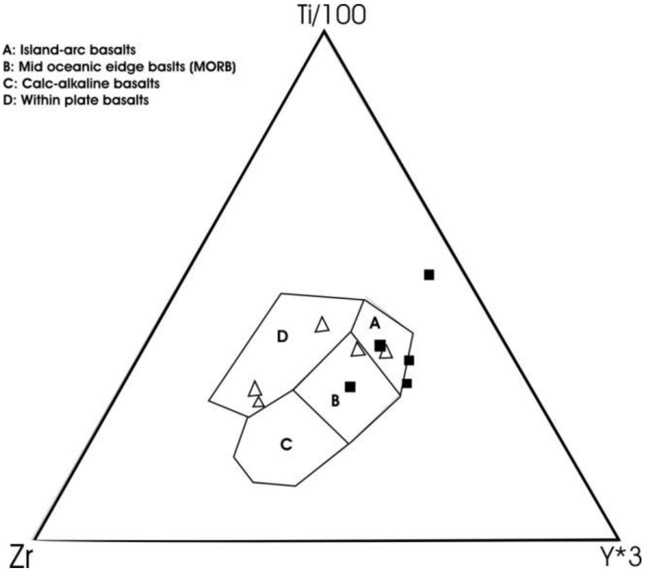

Figure 11(a): Ti/100-Zr-Y*3 plot (after Pearce and Cann,1973), (symbols as in Figure 5.).

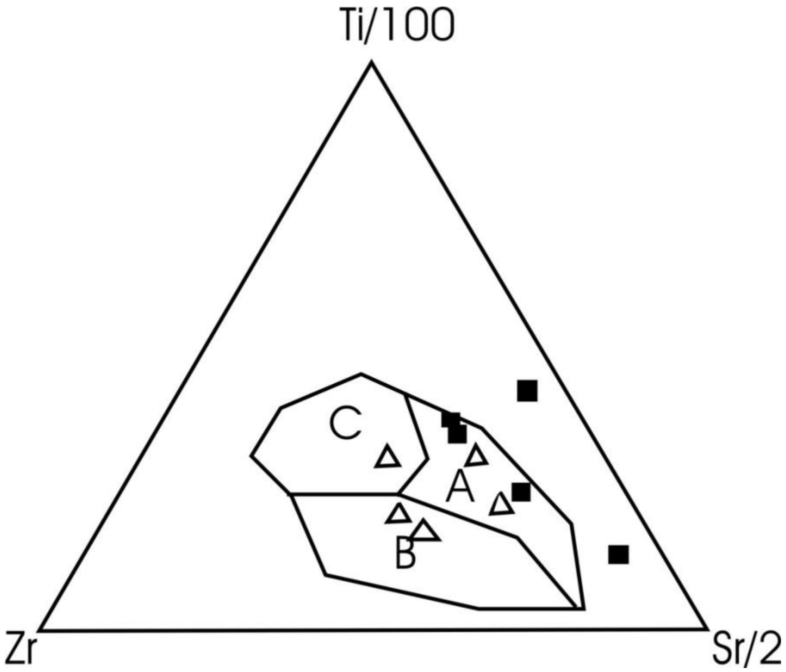

Figure 11(b): (Ti/100-Zr-Sr/2) plot (after Pearce and Cann 1973). A: Island-arc tholeiite, B: Calc-alkaline basalt and C: MOBR, (symbols as in Figure 5.).

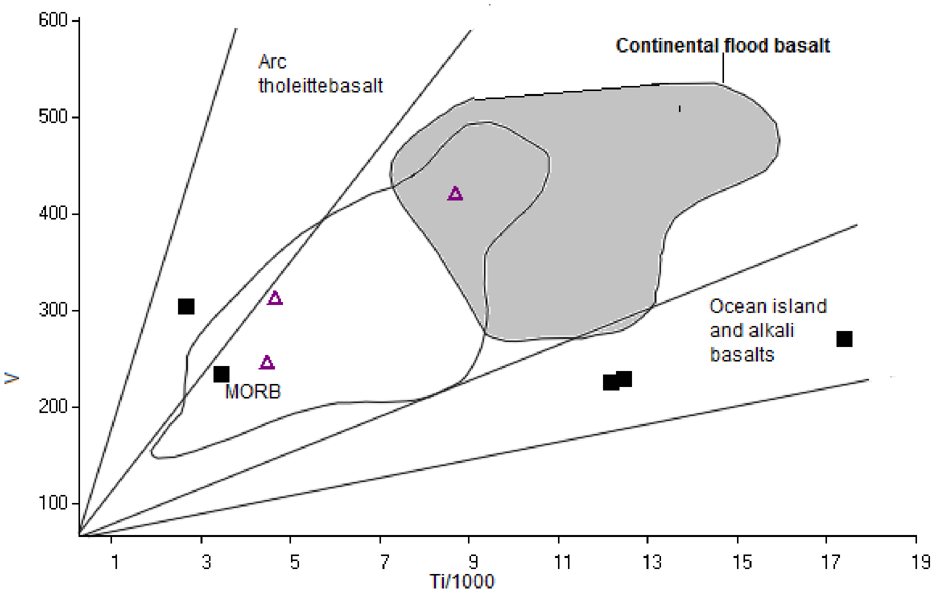

Figure 12: V - Ti/1000 (after Shervais ,1982), (symbols as in Figure 5.).

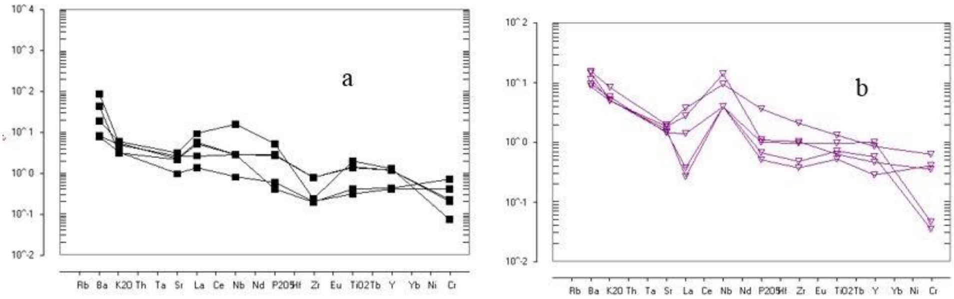

Figure 13: MORB normalized trace element patterns (after Pearce, 1982).
a) amphibolites from the Abu Fannani mylonitic belt;
b) amphibolite xenoliths within the Um Baanib granite-gneiss (symbols as in Figure 5.).

دراسات جيولوجية على الامفيبولايت المايلونايتى ل "ابو فنانى" ومكتنفات الامفيبولايت المرتبطة بها فى منطقة قبة المعيتق التابعة للنيوبروتيروزويك بواسط الصحراء الشرقيه، مصر.

محمد السيد حبيب، محمد عبد المنعم وسلوى محمود عبد الستار
قسم الجيولوجيا – كلية العلوم – جامعة أسيوط

يختص هذا البحث بدراسة الامفيبولايت المايلونايتى ل "ابو فنانى" التى تشكل الاطار الخارجى للصخور القشرية لحقبة النيوبروتيروزويك لقبة المعيتق، بوسط الصحراء الشرقية لمصر، بالاضافه الى الامفيبولايت الميجماتايتى الذى يوجد كمكتنفات داخل ام بعانيب جرانيت-نايس. وقد كشفت الدراسات الحقلية والميكروسكوبية والكميائية للمنطقه انها قاست من تاريخ جيولوجى وتحولى معقد، تمثل فى احداث رئيسية اشتملت على عمليات اندساس، اعتلاء، وتقبب. وقد ادت عمليه الاندساس الى نشوء حزام مطوى بعنف، فضلا عن تحوله العالى . وقد وصلت درجة هذا التحول الاول(M_1) عند المستويات الاعمق لهذ الحزام الى ما فوق ٧٥٠°م . وقد تمت عندها ايضا العملية الميجماتاتية لصخور الامفيبولايت، التى تم اثرها كمكتنفات فى متداخله ام بعانيب الجرانيتية عند ٦٣١ مليون سنه. اثناء حدث الاعتلاء الكبير، جرى تحرك الواح سميكه من الاوفيولايت فوق الحزام المطوى والمتحول. مما سبب فى الاخير نطاقات جز تقصى-لدن، مع نشؤ صخور المايلونايت ذات الدرجه العالية والمتوسطة. فى هذه المرحلة، كان التحول الثانى(M_2) الذى تراوحت درجة حرارته بين ٦٣٠° م و٦٩٠° م . اما عملية التقبب، فقد ارتبطت ب "نظام صدع نجد" الذى نتج عنه ايضا نطاقات جز تقصى-لدن، صاحبه التحول الثالث(M_3) عند درجة حرارة اقل من ٥٥٠° م . وقد تكون نطاقا جز كبير يساريى الزحزحة، على طول واديى مر و ام عش الحمراء. و يمتد كلا النطاقين فى اتجاه شمال غرب-جنوب شرق، حيث يحد النطاق الاول قبة المعيتق من الشرق ، بينما يحدها النطاق الثانى من الغرب. ويوضح نطاق جز وادى مر انثناء يمينى(transpression)، بينما يمتلك نطاق جز ام عش الحمراء انثناء يسارى (transtension) فى الجنوب، وانثناء يمينى (transpression) فى الشمال.

تدل الدراسات الجيوكيميائية على ارتباط مكتنفات الامفيبولايت الميجماتاتية داخل جرانيت-نايس ام بعانيب بالامفيبولايت المايلونايتى ل "ابو فنانى" ، الذى اشتق من صهير ثولييتى الى كلسى-قلوى(بازلتى-انديزايت بازلتى) خلال عملية تبلور الصهير. وتشير الرسوم البيانية للتميز التكتونى الى اوضاع تكتونية مختلفة متراوحة من بازلت داخل-اللوح الى بازلت منتصف العرف المحيطى (MORB).

كما ادى غنى هذه الصخور فى اكاسيد الماغنسيوم و الحديد والالمنيوم والتيتانيوم الى افتراض امكانية اعتبارها انديزايت بازلتى غنى بالحديد، علاه انديزايت بازلتى ذو تلوث قشرى. هذا النموذج متطابق مع الوضع التكتونى لخلف الاقواس.