Sohag Journal of Sciences
An International Journal

A sheared Ophiolitic Mélange: Occurrence, Petrographical And Geochemical Studies, Around Wadi Fatira, North Eastern Desert, Egypt.

*Bekir, R.Kh., El sheikh, A.A., Saber, E. A., Shalaby, O.R.**

Department of Geology, Faculty of Science, Sohag University, Egypt.

Received: 3 Feb. 2022, Revised: 22 Mar. 2022, Accepted: 29 Mar. 2022.
Published online: 1 May. 2022

Abstract: The present study provides a new perspective on the nature and deformational development of the basement rocks in the Fatira area. The goal of the project is to characterise the mélange rocks in the area from a petrographic and geochemical standpoint. Field, petrographic and geochemical studies of the Neoproterozoic rocks in the Wadi Fatira area indicate that these rocks are sheared part of an ophiolitic suite. These rocks comprise serpentinites and their related rocks of talc carbonates and quartz carbonates, sheeted metadolerite, and pillowed metabasalts. The original ophiolitic suite has been deformed and suffered different degrees of shearing, leading to the formation of an ophiolitic mélange that is composed of fragments of the ophiolitic rocks set in a highly sheared mylonitized matrix. The geochemical data revealed that ophiolitic metavolcanics and their mylonites are mainly of basaltic and basaltic andesite composition. They are tholeiitic in nature and originated in an oceanic floor setting. These rocks were mylonitized by the effect of a NE–SW trending dextral shear zone in Wadi Fatira that may represent the second-order shear of the Najd fault system (NFS).

Keywords: Wadi Fatira – Ophiolitic mélange – mylonite – ultramylonite.

1 Introduction

The study area is traversed by Wadi Fatira that located at about 80 km west of Safaga city and about 170 km east of Sohag city (Fig.1.1). The area is limited by Latitudes 26˚ 36´36"-26˚ 44´27" N and Longitudes 33˚10´-33˚ 20´E covering an area of about 116 Km² (Fig.1.2). The area attracted the attention of many workers [**1**, **2**, **3**, **4**, **5**, **6**].

The basement rocks in the area and surrounded environments were described as geosynclinal metasediments and associated metavolcanics, intruded by a group of granitoid intrusive varieties. [**1**]

The metavolcanic association at Fatira area were distinguished into mantle-derived meta-basalts and island arc metavolcanics separated by a schist belt with a tectonic contact [**2**, **3**, **7**].

This association was described as tholeiitic basalts and turbiditic volcaniclastics, which were deposited in an extensional back-arc basin. [**4**]

The metavolcanoclastics were further separated into a lower member of highly schistose metaandesite tuff which is structurally overlain by a member of banded metarhyolite tuff associated with the BIF, and they are deposited in a marine environment. [**5**]

Despite the abovementioned studies, the nature of the rock units in the study area and their tectonic setting are still under discussion. The work aims to provide the petrographic and geochemical characterization for the mélange rocks in the area, with some emphasize on the mineralogical changes associating the alteration and the effect of low-grade metamorphism.

Fig.1.1: Location map of the study area.

* Corresponding author E-mail: omarshalaby95@yahoo.com

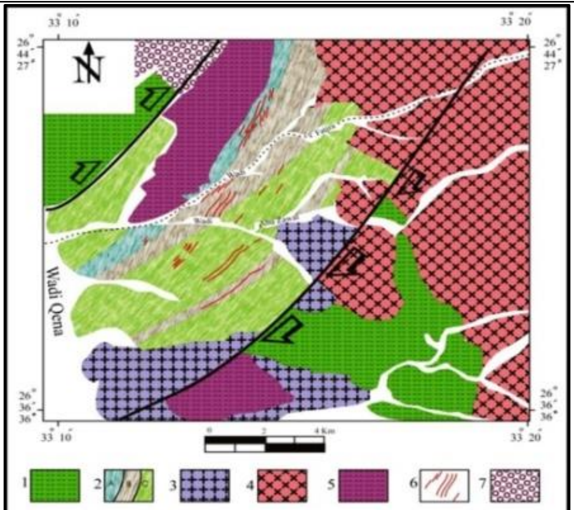

Fig.1.2: Geological map of the study area; 1) massive metavolcanics, 2) sheared (mylonitized) ophiolitic mélange (a-serpentinites, b-metadolerite, c-pillowed metabasalt), 3) older granite, 4) younger granite, 5) Dokhan Volcanics, 6) BIF bands, 7) Hammamat sediments

2 Material and methods

The study is based on detailed field work, as well as landsat images and the geologic map of the study area (scale 1:50000). More than 30 thin polished sections of represented samples of the melange rocks and their sheared mylonites, were prepared for petrographic investigation. The petrographic study was achieved using a transmitted and reflected light Polarizing Microscopes. Chemical analyses for 16 samples were also carried out at the Central Laboratories of the Geological Survey of Egypt. The chemical composition of both major (in wt %) and trace elements (in ppm) was performed by using a Philips x-ray fluorescence technique model PW/2404, with Rh radiation tube. Detection limits for major oxides are between 0.001 and 0.03%, and detection limits for trace elements are between 0.01 and 0.5 ppm. Loss on ignition (L.O.I) of samples were obtained by heating 0.5 gm. of powdered samples at 1000 °C.

3 Geological Setting

Detailed field work on the area revealed the occurrence of a mélange of dismembered ophiolitic blocks and their sheared mylonitized derivatives. The main components of the mélange comprise remnants of serpentinites and their related rocks, metadolerites and pillowed metabasalts together with mylonites; all set in a sheared matrix (Fig.2A). Serpentinites and related rocks occur in the northwestern part of the belt as continuous subparallel sheets and ridges extending in the same direction of the belt.

Talc carbonates and quartz carbonate rocks are more common than their precursor serpentinites. Serpentinites appear as soft and cavernous grayish green relics, pockets and aprons associated with the talc carbonate and quartz carbonates. The latter stand up as hard resistant ridges extending in the NNE- SSW direction. These rocks are creamy brown in colour and frequently associated with iron oxide pockets and veinlets. These ultramafic derivatives are overlain and followed northeastward by metadolerite rocks and their sheared equivalents.

The metadolerites occur as elongated and oriented remnant fragments and blocks of metadolerite dispersed in a sheared and mylonitized matrix. They are invaded by numerous sill-swarms of rhyolitic composition. The massive remnant metadolerite blocks together with their rhyolite sills show a dextral sense of shear (Fig. 2B). Metadolerite rocks and their mylonites are overlain and followed northeastward by differentially sheared and mylonitized pillowed metabasalts. The intact undeformed pillowed rocks are represented by a minor amount of arranged blocks and by fragments floating within thickly stacked units of sheared and mylonitized metabasalts. Intact pillows consist of bulbous, spherical to oval shaped bodies, with an average diameter of about 35 cm. They are massive, greenish to brownish grey in color, highly compacted and characterized by radial and irregular cracks and amoeboid vesicles (Fig. 2 C).

The metabasaltic rocks seem to have been subjected to a variety of shear intensities and consequently produced different types of sheared rocks ranging from protomylonites through mylonites to ultramylonites (Fig. 2 D).

In the protomylonites, a limited matrix starts to form, while the pillow structure is still recognized (Fig. 3A). In the mylonite rocks however, the pillow structure is completely obliterated, with development of wide ranges in both fragments/matrix ratio and fragment grain size (Fig. 3B).

Ultramylonite rocks are the most common type among the sheared metavolcanic rocks in Fatira area. They are steeply foliated forming moderate to high relief peaked terrains (Fig. 3C). They are generally fine-grained and characterized by banding, where light and dark bands are alternated in a ribbon – shaped patterns (Fig. 3D). The ultramylonite rocks have been mistaken for laminated tuff in the previous studies. The ultramylonite in Fatira area is considered the main host rock of the BIF although the latter is also hosted in both mylonites and protomylonites. The different mélange rocks are generally steeply dipping to the southeast. They are intruded in the central and southern parts of the area by grey granites (GI). The latter and the mélange are both intruded by late orogenic (pink) granites (GII) (Fig. 3E). In the northwestern side of the area, the mélange rocks are unconformably extruded by a belt of Dokhan volcanic rocks elongated in the NNE-SSW direction (Fig.2A).

4 Petrography

1. **Serpentinite and related rocks**

Serpentinite relics and pockets are composed mainly of fibrolamellar antigorite with mesh texture and minor crystals of talc, magnesite, calcite, chromite and pyrite. Talc-carbonate is composed mostly of anhedral to subhedral crystals or patches of magnesite and wavy flakes of talc with relict antigorite in addition to chromite and disseminated pyrite. Talc carbonate rocks are variably silicified through replacement of talc and magnesite by quartz producing the hard quartz carbonate rock (Fig.4A). Shearing of the relatively soft talc-carbonate rocks produced banded quartz-carbonate mylonite, which is composed of alternated bands of oriented magnesite fragments and fine-grained chert (Fig.4B). The chert bands have been produced via silicification of the finely sheared carbonate bands. The rock as a whole is frequently transformed into banded chert. In this ultramafic-derived mylonite, the chert bands are streaked with sheared chromite crystals along closely spaced fractured planes in the micrometer scale (Fig. 4C).

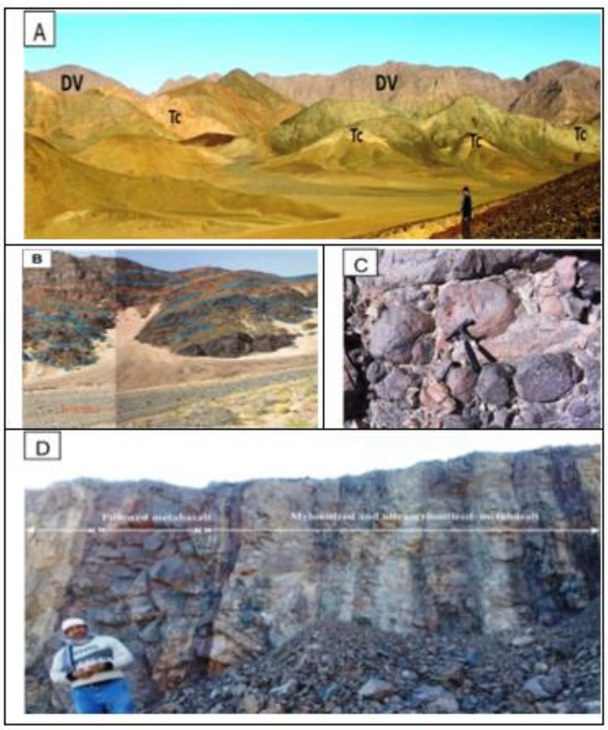

Fig.2: (A) Talc-carbonate- quartz carbonate ridges and serpentinite relics, (B) The metadolerite rocks occur as elongated and oriented fragments and blocks of metadolerite in a sheared and mylonitized matrix, with dextral sense of shear, (C) Intact pillows consist of bulbous, spherical to oval shaped bodies, with an average individual diameter of about 35 cm, (D) The metabasaltic rocks, seem to have been subjected to a variety of shear intensities and consequently produced different types of sheared rocks ranging from protomylonites through mylonites to ultramylonites.

Moreover, it is observed that the banded talc carbonate rocks contain scattered trails of sulfide fragments and granules (Fig.4D). In addition, some of these sulfide grains and granules are oxidized into pseudomorphic iron oxides. Shearing of the more brittle quartz-carbonate rocks produced porous quartz carbonate cataclasite. The latter is built up of coarse fragments of quartz carbonate rocks in a crushed and banded matrix of fine-grained quartz, magnesite, dolomite and siderite bands.

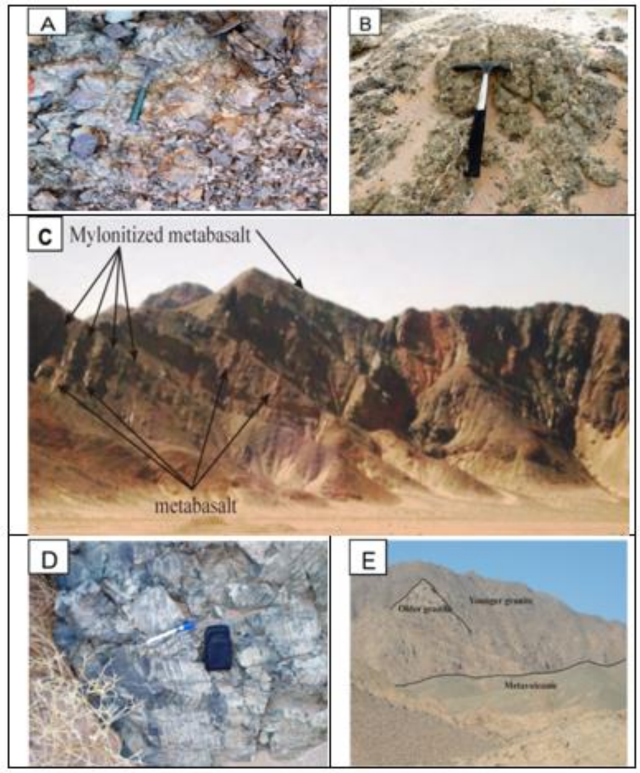

Fig.3: (A) Slightly deformed pillow basalt (Protomylonite) with common cement of matrix formation, (B) Mylonite rocks with oriented rock fragments (porphyroclasts)with dextral sense of shear) in a crushed matrix, (C) The metabasaltic rocks seem to have been subjected to a variety of shear intensities and produced different types of sheared rocks ranging from protomylonites through mylonites to ultramylonites, (D) Ultramylonite with characteristic banding, (E) Metavolcanics intruded by older and younger granitoids.

2. Metadolerite rocks

They comprise olivine metadolerite, sassuritized metadolerite and porpheritic serpentinized metadolerite (Pillow lava). Metadolerite rocks are composed mainly of phenocrysts of plagioclase (An48–62) and augite and scarce olivine phenocrysts, all set in a groundmass of altered plagioclase, augite, hornblende, actinolite, actinolitic hornblende, talc, calcite and opaque oxides.

Augite is occasionally altered into an aggregate of serpentine minerals, or chlorite, calcite, zoisite, epidote, and/or opaques. Hornblende occasionally makes coronas around and peripheral to augite crystals. Serpentine minerals include mainly the bastite and chrysotile cross fibers and less commonly the fibrolamellar antigorite. Quartz occurs as minor anhedral to subhedral crystals filling the empty parts among the triangular spaces within the groundmass. Porphyritic, glomeroporpheritic, ophitic, subophitic, diabasic textures are common, while corona texture is less common.

Opaque minerals under reflected light microscope are composed mainly of titanomagnetite, ferrian ilmenite, and magnetite forming crystals up to 10 % by volume of the rock. Titanomagnetite occurs as subhedral to euhedral crystals up to 0.5 mm across. It contains ilmenite bands as intergrowths in perpendicular pattern. Ilmenite occurs as subhedral to euhedral crystals up to 0.3 mm across. It contains slight exsolution of lamellae hematite. Magnetite present as elongated pseudomorphic crystals that occasionally develops on expense of chlorite plates (Fig. 4E, F). The elongated magnetite grains attain up to 1.5 mm in length and 0.1 mm in width. They show slight martitization and anomalous anisotropism which is possibly due to deformation [8]. It seems generally that formation of pseudomorphic magnetite has been taken place in a late stage relative to alteration processes (including serpentinization), where chlorite plates are selectively oxidized into magnetite leaving serpentine fibers inside the formed magnetite.

Sulphides are represented mainly by disseminated fine grained anhedral chalcopyrite crystals. They are variably altered into covellite and iron oxides.

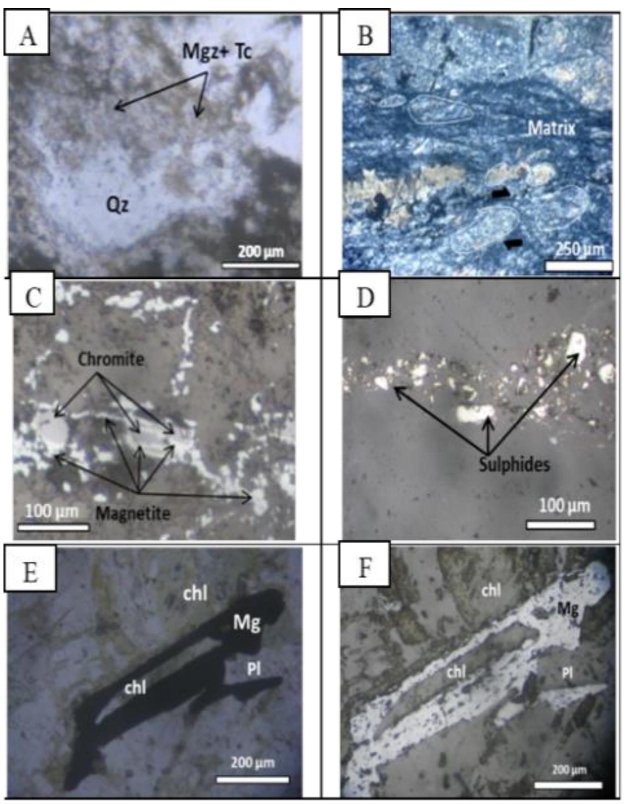

Fig.4: (A) Talc carbonate rocks are variably silicified through replacement of talc (Tc) and magnesite (Mgz) by quartz (Qz), (B) Talc- and quartz-carbonate rocks have been further sheared and mylonitized developing porphyroclasts in a finer grained crushed matrix of the same components, (C) Fractured chromite replaced to martite along sheared planes parallel to banding that shows micrometer scale of shearing effect, (D) Scattered trails of sulfide fragments and granules, (E) Elongated pseudomorphic magnetite crystals develop on expense of chlorite plates, (F) The same description at (Fig. E) but under reflected light microscope.

3. Metabasalt rocks

They composed essentially of phenocrysts of plagioclase, altered pyroxene and hornblende set in a finer grained groundmass of plagioclase, hornblende and quartz. Secondary minerals include chlorite, calcite, epidote actinolite and iron oxides. Porphyritic, glomeroporpheritic and intergranular textures are common.

Hornblende is altered into aggregates of chlorite, actinolite, epidote, calcite, and stilpnomelane. Stilpnomelane is frequently encountered replacing chlorite in the form of elongated plates parallel to its cleavage. Opaque minerals are up to 1 % by volume of the whole rock. Magnetite occurs as elongate, jagged skeletal, crystals up to 0.3×0.1 mm across. It develops on the expense of chlorite directly or through a transition stage of stilpnomelane.

4. Mylonites

Under the microscope, mylonite rocks are built up of elongate oriented rock fragments of variably altered metadolerite or metabasalt in a finer grained crushed and foliated matrix. The metabasalt rock fragments are gradational in grain size and show further alteration into aggregates of epidote, chlorite, actinolite, calcite and opaques. These rock fragments are variably ferriginated and replaced by magnetite. They also show obvious dextral sense of shear. The foliated matrix is fine grained and built up of albite, quartz, chlorite, epidote, calcite and iron oxides.

5. Ultramylonite

Under the microscope, the ultramylonite is generally fine-grained and composed of alternated light and dark colored bands. The light-colored bands are composed of fine- grained quartz, albite, epidote, zoisite, calcite with minor amounts of chlorite actinolite and opaque oxides. On the other hand, dark-colored bands are composed mainly of fine-grained chlorite, actinolite and opaque oxides with less amount of epidote, zoisite, and albite.

5 Geochemistry of metavolcanics

Plotting of the major oxides against SiO2 on Harker diagrams revealed that, MgO, Fe_2O_3, CaO, TiO_2 and P_2O_5 oxides decrease with increasing SiO2 (Fig. 5).

Chemical classification

Using total alkalis versus silica (TAS) diagrams of [9] and [10] shows that the studied metavolcanic samples are predominated by basalt, basaltic-andesite and much less andesite (Fig. 6).

Magma Type

The chemically analyzed samples of Metavolcanics and others of sheared metavolcanics are plotted on the diagrams of SiO_2-FeOt/MgO and FeOt/MgO-TiO_2 of [**11**], point to a tholeiitic nature (Fig. 7).

The total alkali content of the studied metavolcanic rocks is low with K_2O (average 0.84 of metavolcnic and 0.76 of sheared metavolcanic) is lower than Na2O (average 2.47 of the metavolcanic and 2.17 of the sheared metavolcanics) (Table.1). The low-K and Fe-rich of a tholeiitic nature of the metavolcanics, is also shown by plotting samples on (Fe_2O_3+FeO+TiO_2-Al_2O_3-MgO) and AFM diagrams of [**12**], (Fig. 8A, B).

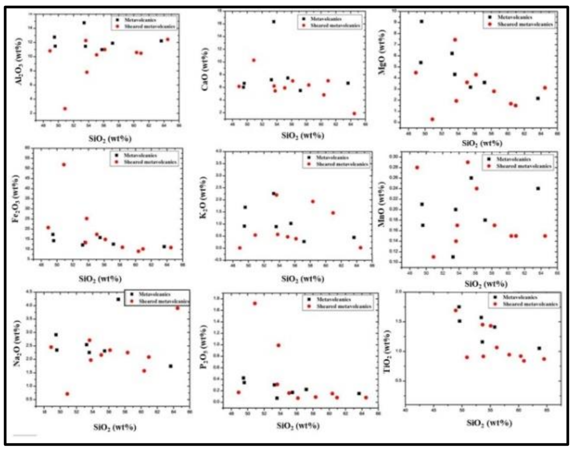

Fig. 5: Harkers variation diagram of SiO_2 vs. major oxides.

Tectonic setting

Based on the tectonic discrimination diagrams of [**13**], the studied metavolcanic rocks are mainly fall within the oceanic floor basaltic field (Fig. 9A, B). Sheravais (1982) [**14**] used Ti-V discrimination diagram to differentiate between volcanic-arc tholeiites, MORB, and alkali basalts. The relation of Ti/V is higher in oceanic-island and in alkali basalts compared to the other types of basalts. The samples are plotted near or in the overlapping area are of arc tholeiite, MORB and of calc-alkaline basaltic nature (Fig. 10A). A plot of Ti versus Zr [**15**] for metavolcanic rocks of the Fatira area revealed that most of samples lie within the field of MORB (Fig.10B).

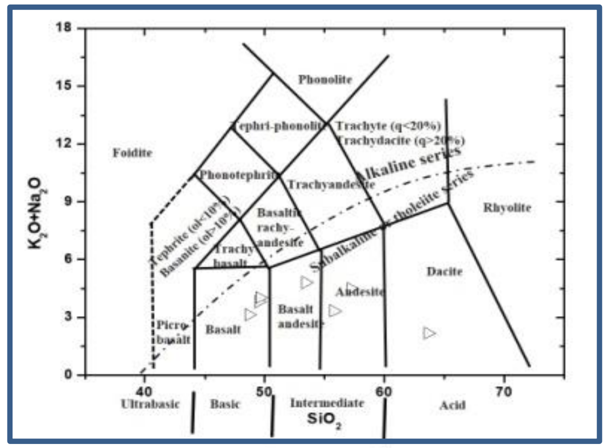

Fig. 6: (TAS) diagrams of [9] and [10].

Table (1): Major oxides and trace elements of the studied metavolcanic and their sheared derivatives (mylonites).

	Metavolcanics							Sheared metavolcanics									
	Major elements in wt%																
No	S4	S17	S15C	S24	S26	S30P	S30L	X13	X9	X7	S15A	M3	T3	S25	C1	C11
SiO_2	49.49	49.59	57.19	48.66	63.66	53.42	55.79	52.04	60.95	48.88	64.5	55.08	53.65	53.64	60.38	59.22
TiO_2	1.75	1.51	1.88	0.76	1.05	1.57	1.41	0.67	0.84	1.69	0.87	1.43	0.81	1.45	0.92	0.82
Al_2O_3	12.75	11.47	11.89	11.45	12.21	14.77	10.98	7.8	10.48	10.81	12.43	10.25	11	12.27	10.59	13.98
Fe_2O_3	17.3	14.24	12.52	13.36	11.25	11.25	16.64	25.2	10.16	20.72	10.85	17.37	14.84	13.24	9.02	10.95
MnO	0.21	0.17	0.18	0.2	0.24	0.11	0.26	0.17	0.15	0.28	0.15	0.29	0.24	0.14	0.15	0.17
MgO	5.38	9.08	3.58	4.31	2.15	6.2	3.16	1.93	1.52	4.48	3.11	3.6	4.3	7.44	1.68	2.8
CaO	6	6.61	5.48	16.33	6.64	7.18	7.45	5.43	7.02	6.14	1.86	5.9	7	6.2	4.79	6.35
Na_2O	2.91	2.34	3.23	2.25	1.74	2.54	2.31	1.97	2.08	2.45	3.5	2.16	2.34	2.71	1.57	2.25
K_2O	0.91	1.09	0.27	0.89	0.44	1.26	1.02	0.57	1.46	0.11	0.12	0.47	0.39	1.2	1.9	0.93
P_2O_5	0.42	0.34	0.22	0.07	0.15	0.3	0.17	0.99	0.08	0.17	0.08	0.16	0.07	0.31	0.15	0.09
LOI	2.58	2.66	2.55	1.41	0.17	0.1	0.52	2.92	4.25	4.07	1.93	3	5.06	0.1	6.97	1.13
	Trace elements in ppm															
V	213	244	269	165	156	217	251	126	117	351	129	214	152	215	134	152
Cr	10	287	2	41	2	175	14	18	14	15	7	4	71	254	5	14
Ni	16	152	2	9	2	122	2	2	9	2	4	2	20	106	1	3
Cu	22	43	21	90	31	27	51	72	57	112	46	45	45	36	33	31
Zn	84	88	78	62	105	92	94	65	79	92	103	103	98	80	104	63
Y	20	8	20	7	36	2	21	7	35	17	22	23	42	5	37	22
Rb	21	28	8	15	12	35	14	16	34	10	7	12	14	42	57	31
Sr	496	606	263	305	277	496	248	117	136	332	242	275	215	538	183	474
Zr	137	113	120	57	98	110	68	40	99	76	106	76	81	111	83	96
Nb	6	6	9	1	1	6	1	1	1	1	10	1	1	6	1	5
Ba	270	405	201	420	336	700	669	172	637	301	192	339	316	765	611	565
La	17	24	15	23	20	35	34	14	34	19	15	20	20	39	32	30
Co	62	66	51	45	38	61	51	19	44	55	41	44	57	58	38	35
Pb	10	6	6	10	7	11	7	10	7	10	9	7	12	14	7	7
Th	2	2	2	1	1	3	1	1	1	1	15	1	1	1	1	2
Sn	4	2	5	1	1	5	1	1	1	1	6	1	1	5	1	4

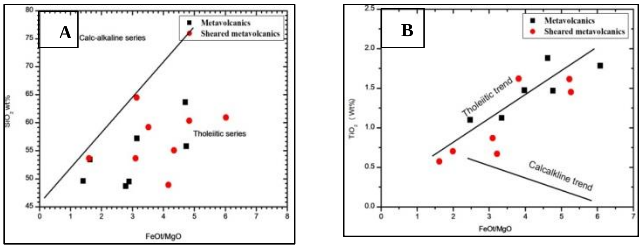

Fig.7: (A) SiO_2-FeOt/MgO and (B) FeOt/MgO-TiO_2 of [**11**].

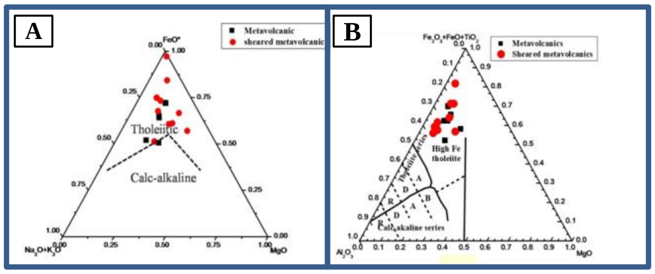

Fig. 8: A) AFM diagram showing wholerock composition in terms of $Na_2O + K_2O$, total iron as FeO and MgO, (B) (Fe_2O_3+ FeO+TiO_2 - Al_2O_3- MgO) diagram after Jensen 1976. [**12**]

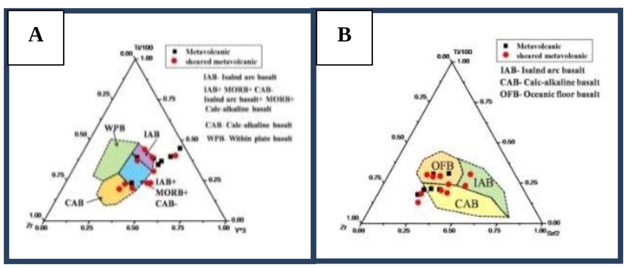

Fig. 9: (A)Discrimination diagram using Ti, Zr and Y & (B) using Ti, Zr and Sr [**13**].

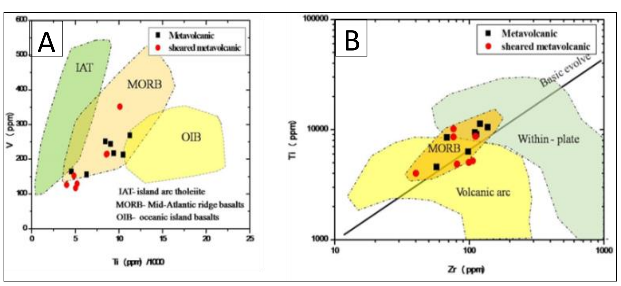

Fig. 10: (A) Ti - V [**14**], (B) Ti versus Zr [**15**].

6 Discussion

Field, petrographic and geochemical studies indicate that, the central part of the studied area is remarked by the occurrence of tectonic mélange rocks. These mélange rocks are formed through two main stages. The first stage of ophiolitic suite obduction, followed by a second stage of shearing and mylonitization. The First stage includes the accretion-related obduction and overthrusting of dismembered ophiolitic sheets in the NW direction. These ophiolitic sheets comprised serpentinites and their related rocks, metadolerites and pillowed metabasalts. Evidence of ophiolitic origin of the Fatira mélange are verified from field and petrographic studies, which are coincided with the geochemical relationships. The occurrencs of serpentinite and their derivatives of talc carbonates and quartz carbonate ridges, the pillow structure of the associated metavolcanics are the main field criteria. Moreover, the structural relations of SE-dipping thrusts and their related foliation are important criteria, where the mélange in the Central Eastern Desert suffered top-to-the-NW displacement and low dipping shears [**16**, **17**, **18**, **19**, **20**].

Again, the serpentinites and their characteristic associated ore minerals particularly chromite and some sulfides, are diagnostic of ophiolitic stage. Moreover, the spilitic nature of most pillowed metabasalts and some metadolerite (albitic plagioclase + enrichment in chlorite) are also conclusive of ophiolitic stage. The serpentinization of numerous pyroxene phenocrysts in the massive metadolerite is typical evidence of the ophiolitic mélange rocks. Formation of metadolerite and metabasalt in this stage is also indicated by their euhedral primary oxides of titanomagnetite and ilmenite.

The geochemical tholeiitic character and the MORB tectonic environment are consistent with the field observations and petrographic investigation results. The second stage comprises the subjection of the central part of the ophiolitic mélange rocks to NE–SW trending dextral strike slip faulting and shearing. These faulting and shearing movements modified the nature of the mélange rocks and produced a NNE–SSW to NE-SW trending belt of ophiolitic mélange-related mylonites. The remarked diagnostic evidences for shearing and mylonitization are; a) Formation of banded talc carbonates and chert on the expense of the talc carbonate rocks, b) Presence of fine-grained cherty aggregates streaked with trains of chromite granules is a strong evidence for ultramafic mylonites [**21**], c) Presence of scattered trails of sulfide fragments and granules and their partial to complete oxidation into pseudomorphic iron oxides is also indicative of shearing and mylonitization and d) The closely spaced and subparallel fractures recorded in the chromite trains down to the micrometer scale (see Fig.4C), indicative of the corresponding closely spaced planes of effective shear stresses and accordingly, high shear intensity.

The oriented massive remnants of the metadolerite rocks, the associated rhyolitic sills in the NE-SW direction and their dextral sense of shear (see Fig. 2B) inside a sheared matrix are all diagnostic of shearing in that direction. The same condition is true for the pillowed metabasalt rocks. The main indicative mineralogical changes are the formation of the platy pseudomorphic magnetite on the expense of chlorite. The common ultramylonite rocks stand as evidence for the intensive shearing of the mélange rocks. The evidence of the intensive shear that able to modify these thick piles of metavolcanic

* Corresponding author E-mail: omarshalaby95@yahoo.com

rocks has been previously referred to in the closely spaced planes of effective shear stresses which caused fracturing of the minute chromite trains. Formation of banding in ultramylonite may have been taken place by metamorphic differentiation due to different response of different minerals to the shearing stress [**22**]. Accordingly, the more ductile minerals respond to stress by translation and formation of slip surfaces and by recrystallization, eventually being smeared out in particular bands of intensive shear motion, while the more brittle minerals are rotated and segregated together into layers.

Structurally, the NE–SW dextral strike–slip faults and shear zones in wadi Fatira may represent the second-order shear of the Najd fault system (NFS) that may have been rejuvenated during the Red Sea rifting [**23**]. The NFS and the other NW-trending strike-slip faults in the ANS are post-accretionary structures formed by squeezing of the ANS between E- and W-Gondwana [**19, 24**]. The same mechanism is adopted for subordinate NE–SW trending ones [**25, 26**].

7 Conclusions

Wadi Fatira area is occupied by sheared tectonic mélange rocks. These rocks comprise serpentinites and their derivatives, metadolerites and pillowed metabasalts together with their sheared products including protomylonites, mylonites and ultramylonites. These rocks are thought to be formed on two different stages. The first one is represented by top-to-the-NW displacement of dismembered ophiolitic sheets with low dipping successive and dissected shears. This stage is evident by many field, petrographic and geochemistry studies. The second stage comprises the development of a NE-SW trending dextral shear zone that modified the nature of the original ophiolitic rocks forming a mylonite dominated mélange. Mylonite and particularly the ultramylonites are the most common rocks among the sheared rocks in Fatira area. The ultramylonite represents the main host rock of the banded iron formation (BIF) in Wadi Fatira area. The main results of the present work can provide useful information about the banding nature of the banded chert and the associated BIF, which are mainly hosted in the ultramylonite and mylonite rocks in the study area.

8 References

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