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THE OPHIOLITE MELANGE OF WADI DUNQASH AND ARAYIS, EASTERN DESERT OF EGYPT: PETROGENESIS AND TECTONIC EVOLUTION

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ABSTRACT

Wadi Dunqash and Wadi Arayis in the central and southern Eastern Desert of Egypt are characterized by the presence of metamorphosed dismembered ophiolite sequence. This sequence consists of harzburgite-serpentinite, pyroxenite-chlorite schist; normal and sheared metagabbros; metabasalt and meta-andesite and their schists.

Major and trace element studies indicate that the present sequence can be comparable with the ophiolitic ultramafic-mafic cumulates. The metagabbros and metavolcanics pertain to a high-Ti ophiolite, exhibit tholeiitic and minor calc-alkaline nature, derived from ocean floor-island arc transitional basalts, suggest their probable back-arc environment.

INTRODUCTION

The ultramafic-mafic rocks constitute one of the distinctive rock group in the late Precambrian of Egypt. Recently, many authors have attempted to identify the mafic-ultramafic assemblage in the Eastern Desert of Egypt as ophiolite complexes and hence as fragment of oceanic crust. Ophiolites in the Eastern Desert always occur as allochthonous and commonly dismembered ultrabasic to basic bodies frequently interlayered with highly foliated peilitc layers (SHACKLETON et al. 1980, RIES et al. 1983, BASTA et al. 1983, ABU EL ELA 1985). More or less complete ophiolite sections are described from Wadi Ghadir (EL SHARKAWI and EL BAYOUMI 1979), Qift-Quesir road near Fawakhir (NASSEEF et al. 1980), Wadi Mubarak (HASSANEIN 1984) and Wadi Esel (ABU EL ELA and ALY 1990).

Only very few previous studies carried out on the ophiolite melange of Wadi Dunquash (ABU EL ELA 1985) and Wadi Arayis (ABDEL-KHALEK et al. 1992). The studies concentrated on the regional geology, geodynamic evolution and tectonic specularities.

This study presents the mode of occurrences and new whole-rock chemical data for the mafic-ultramafic assemblage of Wadi Dunquash and Arayis in the central and southern Eastern Desert of Egypt, in an attempt to clarify the magmatic history and the past tectonic environment.

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GEOLOGIC SETTING

The ophiolite melange of Wadi Dunqash and Arayis occupy the extremely westernmost parts of the Precambrian rocks of the Eastern Desert of Egypt (*Fig. 1*). The geology of the present ophiolite melange distributed in the two areas were treated elsewhere (ABU EL ELA 1985 and ABDEL-KHALEK et al. 1992). The following is a synopsis of the geology of the areas in question starting with the oldest rock unit (*Fig. 1*).

I) *Gneisses* represent the oldest rock unit in Wadi Arayis area. They include muscovite biotite granodiorite gneisses and biotite granodiorite gneisses. Both types are foliated, lineated and folded. They are sometimes graded to hornblende-biotite- and garnet-biotite gneisses. The present gneisses are overthrusted by the ophiolite melange.

II) *Ophiolite melange* forms hanging wall of the major thrust in Wadi Arayis. The trends of the major thursts run, more or less, in NW-SE in Wadi Arayis. In Wadi Dunqash the trend of the major thrust is NEN-SWS and EN-SW direction. The ophiolite melange includes allochthonous dismembered blocks and fragments of ultramafics, metagabbros and metavolcanics with a matrix of low grade metamorphosed metasediments and metapyroclastics.

a) *The ultramafic rocks* are the most widespread being represented by serpentinite and chlorite schist with relics of harzburgites in Wadi Arayis and harzburgites and pyroxenites in Wadi Dunqash. They crop out in variable size and range from small blocks and lenses of low relief to huge steeply inclined sheets forming mountains of moderately high relief (814 m a.s.l. in G. Dunqash and 630 m a.s.l. in Arayis) thrusted over the melange matrix. The present serpentinite and its derivatives have not sign of thermal contact on the enveloping rocks, emphasizing that these rock bodies are allochthonous (ASHMAWY 1987). The contact is mostly marked by veins of asbestos and magnesite and black-walls of talc and chlorite schists. The present ultramafics are charged with lenses mostly of chromite and minor talc and magnesite. The serpentinite sheets of Dunqash are structrally either overlain by or overthrusted on the metasediments. The thrust zones are regular and dip 50°–60°N. The present rocks are mostly intruded by syntectonic older granites in Wadi Dunqash and late tectonic younger granites in Wadi Arayis.

b) *The metagabbros*, in the two area under study, occur as variable size masses of low to moderate to relief. They show tectonic contact against the metasediment matrix as well as other melange blocks. The present metagabbros are strongly sheared, being foliated and display minor folds. They range from fine grained to pegmatitic and from normal gabbros to leucogabbros. The pegmatitic gabbros occurs as pockets and irregular masses and veins within the normal gabbros, possess tectonic contacts with them.

c) *The metavolcanics* form small elongated blocks and fragments inside the melange matrix of Wadi Dunqash and Wadi Arayis. They are frequently medium to fine grained, massive or sheared and displaying well developed lineation. These rocks are represented by metabasalts and meta-andesites or their equivalent schists. In Dunqash area, the metavolcanics are mostly exhibited pillow structure. The pillows are aphanitic, ovoidal to elongate shapes and range in size from 10–65 cm. Pillow breccias are also common. They are highly sheared particularly along fault contact with the serpentinites. In Arayis area, the pillow structure is not observed probably due to the strong deformation and metamorphism of the metavolcanics which converted mostly into amphibolite schists.

d) *The volcanoclastic metasediments* are widely distributed rock unit in both studied areas, mostly form the matrix enclosing the ophiolite fragments. They are slightly to strongly sheared, folded and lineated. Wide development of albitization, chloritization,

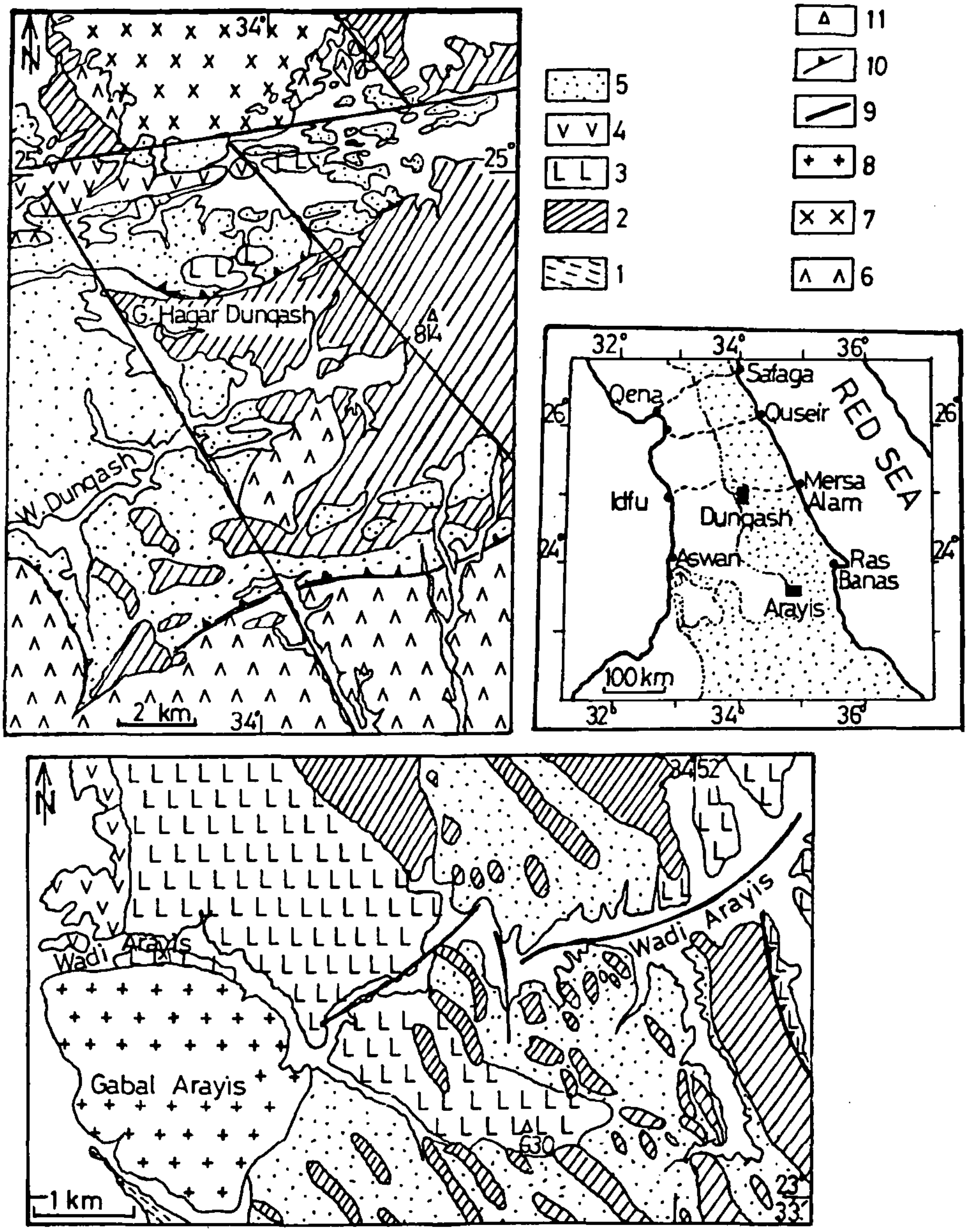

Fig. 1. Geologic map of the studied ophiolite melange of Wadi Dunqash (after ABU EL ELA 1985) and Wadi Arayis (After ABDEL-KHALEK et al. 1992) with some modifications.
1 = Pre-Pan African gneisses, Ophiolite melange, 2 = peridotite and its derivatives, 3 = metagabbros, 4 = metavolcanics, 5 = volcanoclastic metasediments (matrix), 6 = island arc metavolcanics, granitoid rocks, 7 = syntectonic granites, 8 = late tectonic granites, 9 = major tectonic lines, 10 = thrust with direction of dip, 11 = triangulation point.

sericitization and sometimes epidotization are common alteration products of the present rocks. They are represented by metagreywackes, metasiltstones, phyllites and schists, all are within the zone of greenschist regional metamorphism. The different beds usually grade into each other without sharp boundaries. The metagreywackes include feldspathic and volcanic varieties, the latter contain andesitic rock fragments beside quartz and feldspar crystal fragments. Tuffaceous meta-andesite and metadacite intercalated with metamudstones are common in Dunqash area.

III) *Island arc metavolcanics* are recorded only in Dungash area as elongated belt overthrusted on the metasediments and intruded by the syntectonic older granites. The thrust zone dips 50°–60° N. These rocks include basic and intermediate composition are volcanics with subordinate metapyroclastics.

IV) *Granitoid rocks* comprise syntectonic granites (Wadi Dunqash), and late tectonic granites (Wadi Arayis). The contact of these rocks with the enveloping ophiolite melange are sharp and distinct. The Dunqash granites are represented by calc alkaline foliated quartz diorite to granodiorite rocks, meanwhile the Arayis granites are perthitic leucocratic granites.

PETROGRAPHY OF THE OPHIOLITE MELANGE

The petrographic description of the ultramafics and their derivatives, metagabbros, and metavolcanics of Wadi Dunqash and Arayis are briefly discussed in the followings:

I) Ultramafic rocks

Peridotites and their derivatives include primary rocks such as peridotites and pyroxenites as well as their alteration products, namely serpentinites which comprise antigoritite, lizardite-antigorite serpentinite and magnesite-antigorite serpentinite. Meanwhile, the derivatives include chlorite schists, talc schists and talc-quartz carbonate rocks.

Harzburgite-serpentinite is recorded in Wadi Dunqash and Arayis area. It consists of primary olivine and minor pyroxene variably altered to serpentine minerals. Talc and carbonate are accessory minerals. Olivine forms fine granules mostly altered to antigorite. Pyroxene relics are represented by enstatite. They are subjected to different degree of serpentinization. Lizardite occurs as interpenetrating blades and is slightly replaced by talc and carbonates.

Pyroxenite-serpentinite is recorded in Wadi Dunqash area. It consists of primary enstatite and augite variably altered to serpentine or chlorite. Tremolite and magnetite are accessory minerals. Orthopyroxene commonly is in exsolution lamellae within the clinopyroxene.

Serpentinites are recorded in Wadi Dunqash and Arayis areas. They are made up mainly of antigorite or lizardite admixed with chrysotile. In this rocks, the primary minerals are completely obliterated. Carbonate, talc, chlorite, chromite and iron oxide are accessories. Antigorite forms xenoblastic blades resulting in interlocking texture. Lizardite occurs as extremely fine grained flakes and scales showing hourglass texture and scarce mesh texture. Chrysotile forms cross-fibrous veinlets within the shear zone. Iron oxide is concentrated along the mesh rim-core boundaries. Chromite occurs as disseminated grains, lenses and veins.

The ultramafic schists comprise the chlorite, and talc schists. In the *clorite schist*, chlorite (clinochlore) mostly occurs as the main mineral constituent. Chlorite occurs in the form of pseudospherulitic blades. In the *talc schist*, radial, fibrous and granular aggregates of talc is the dominant mineral.

In *talc, and quartz carbonate rocks*, carbonates constitute the varieties. Magnesite is the most predominant carbonate minerals, calcite, talc and quartz are less common.

II) **Metagabbros**

The metagabbros display rapid grain-size variations from fine to pegmatoid varieties, with either normal or sheared structure. In normal metagabbros, the primary minerals (pyroxene) and textures (ophitic and subophitic) are still partly preserved, while the original textures are obliterated and tectonized and mylonitized ones are common in the sheared metagabbros. The normal and sheared metagabbros are recognized in the studied two areas.

The *normal metagabbros* range from mesocratic to leucrocratic, quartz injected metagabbros and from pyroxene-hornblende to and hornblende metagabbros. They are composed of pyroxene and/or hornblende and plagioclase. Tremolite-actinolite, zoisite and titanite are the accessory minerals. Pyroxene relic is represented by enstatite and augite. Enstatite is mostly altered to antigorite or chlorite while augite is either rimmed by uralite indicating the oceanic metamorphism or transformed into tremolite-actinolite ± chlorite. Plagioclase (An_{35-40}) is partly altered to saussurite, albite and kaolinite ± calcite.

The *sheared metagabbros* are composed mainly of strongly deformed clinopyroxene, amphibole and plagioclase ± quartz with minor epidote and apatite. The clinopyroxene exhibits kink-bands and is either altered to tremolite-actinolite aggregates or recrystallized to fine grained ones of the same mineral. The plagioclase (An_{32-37}) is intensively altered to albite, epidote and carbonate.

III) **Metavolcanics**

The metavolcanics consist mostly of metabasalts and meta-andesites and their alteration products (e. g. chorite-tremolite-actinolite and tremolite-actinolite schists). The primary minerals and even the primary textures are still partly preserved in metabasalts and meta-andesites, while they are completely obliterated in the schists.

Metabasalts consist of pyroxene relic, plagioclase and hornblende together with secondary tremolite-actinolite. Quartz, epidote, apatite and iron oxide are the main accessory minerals. They display ophitic and subophitic textures. Variolitic, intersertal and porphyritic textures are sometimes observed. Augite occurs as anhedral prismatic crystals, slightly altered to tremolite-actinolite aggregates or replaced by hornblende. Plagioclase (An_{8-12}) forms fine laths, variolites and rarely phenocrysts altered to kaolinite and sericite. The meta-andesites consist of plagioclase, hornblende and chlorite with subodinate amounts of calcite, quartz, titanite, apatite and iron oxide. They exhibit porphyritic and fluidal textures.

The schists consist mainly of tremolite-actinolite, strongly altered plagioclase ± chlorite, epidote and carbonate. The accessory minerals include apatite and iron oxide. Albite forms fine grained metablasts and rarely porphyroblasts containing acicular grains of actinolite. Relic augite and saussuritized plagioclase are sometimes seen. Iron oxide (Ti-rich) is mostly transformed into titanite ± rutile.

On the basis of the mineral assemblage and textures, as well as the alteration products, the present serpentinites, metagabbros and metavolcanics have been metamorphosed up to the greenschist facies.

Chemical analyses were carried out on 27 rock samples (Table 1) representing the ophiolite suite of Wadi Dunqash and Wadi Arayis areas (nine from the ultramafics, eleven from the metagabbros and seven from the metavolcanics). Major and trace element analyses were carried out by computerized XRF Spectrometer system "Philips PW 1400" using pressed pellets in Institute of Mineralogy, Salzburg University, Austria. The major elements of the ultramafics are recalculated on a water-free basis.

Petrochemical classification:

I) *Ultramafic rocks*

On the normative Opx-Ol-Cpx diagram of STRECKEISEN (1976); *Fig. 2a*, the present ultramafic from Wadi Dunqash fall within the fields of orthopyroxenite and harzburgite, while those from Wadi Arayis fall within the harzburgite field.

II) *Metagabbros*

On the normative Px-Pl-Ol diagram of STRECKEISEN (1976); *Fig. 2b*, Wadi Dunqash metagabbros fall with in the fields of olivine gabbro-norite and gabbro-norite, while Wadi Arayis metagabbros fall within the fields of olivine gabbro-norite, gabbro-norite and leucogabbro. COLOMBI (1988) proposed the use of SiO_2 variations with increasing $FeO_t/(FeO_t+MgO)$ to classify the ophiolitic gabbros. The present metagabbros from Wadi Dunqash fall within the clinopyroxene (cpx) gabbro, while those from Wadi Arayis fall within or around the fields of cpx-gabbro and ferro-gabbro (*Fig. 2c*).

III) *Metavolcanics*

WINCHESTER and FLOYD (1977) inferred the discrimination of altered and metamorphosed volcanic suites of different magma series and their differentiation products in terms of SiO_2 content and Zr/TiO_2 ratio (*Fig. 2d*). All the analyses of the present rocks have Zr/TiO_2 ratios < 0.03, suggesting that these metavolcanics are indeed basaltic composition with minor andesite.

Magma Type:

Identification of the magma type helps to elucidate past tectonic setting of the unknown magmatic belts (MIYASHIRO 1974, 1975; WINCHESTER and FLOYD 1977).

MIYASHIRO's diagrams (*Fig. 3a, b* and *c*) and the AFM diagram (*Fig. 4a*) show a diverse in magma type of the present rocks which range from tholeiitic (TH) to calc alkaline (CA) series. The chemical data on MIYASHIRO's diagrams indicate that the majority of the metavolcanics and metagabbros are TH with a few CA type and fall within or around the field of basalts from the Alp ophiolite (DAL PIAZ et al., 1981; BECCULUVA et al. 1984; ABDEL-KARIM 1992) (*Fig. 3a* and *b*). On the AFM diagram, the analyses of metavolcanics are TH, while the metagabbros are mainly TH with a few samples showing CA affinity.

Ophiolitic Affinity and Tectonic Setting

STRONG and MALPAS (1975) and COLEMAN (1977) drew the composition fields of ultramafic and mafic cumulates (ophiolitic cumulates) using AFM diagram (*Fig. 4a*) and CaO-Al_2O_3-MgO diagram (*Fig. 4b*). In these figures, the ultramafic rocks from Wadi Dunqash fall within ultramafic-mafic cumulate field except a few samples of the metapyroxenites which enriched in FeO_t and Al_2O_3 and depleted in CaO probably due to the enrichment of these samples in Fe-rich chlorite. Wadi Arayis ultramafics fall within the field of metamorphic peridotite and ultramafic-mafic cumulate.

The metagabbros from both areas fall within the field of oceanic gabbros from Mid Cayman Ridge (CAYTROUGH 1979) and Egyptian metagabbros (GHONEIM et al. 1992),

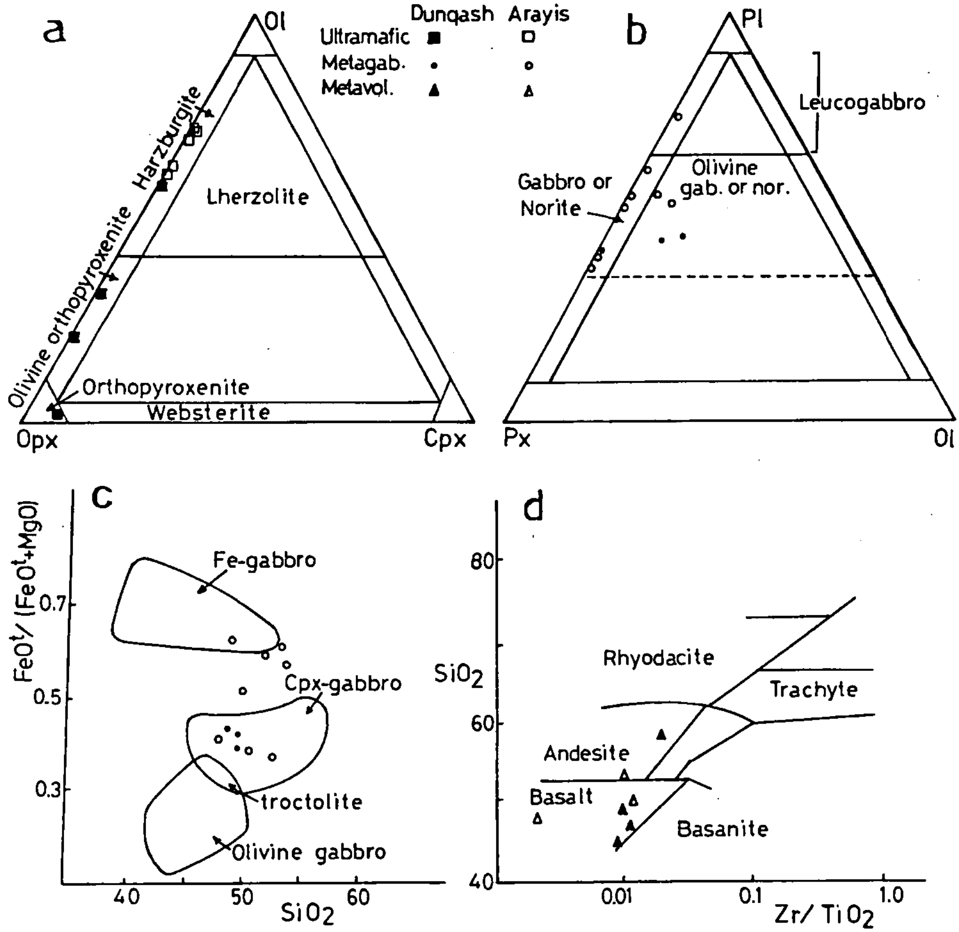

Fig. 2. Plots show the chemical classifications of the studied ophiolites:
a) normative Opx-Ol-Cpx diagram for the ultramafics and after STRECKEISEN (1976),
b) normative Px-Pl-Ol diagram for the metagabbros after STRECKEISEN (1976),
c) FeOt/(FeOt+MgO) versus SiO_2 diagram for the metagabbros after COLOMBI (1988),
d) SiO_2 versus Zr/TiO_2 diagram for the metavolcanics after WINCHESTER and FLOYD (1977).

Fig. 4a. Moreover, the present metagabbros together with the metavolcanics fall mostly within the mafic cumulate field of COLEMAN (1977), *Fig. 4b.*

The ophiolites are generally classified into high-Ti, low-Ti and very low-Ti (BECCALUVE et al. 1983). SERRI (1981) and DECCALUVA et al. (1983) used the variation diagram of TiO_2 versus $FeO_t/(FeO_t+MgO)$ ratio in gabbroic complex and basaltic rocks to discriminate between high- and low-Ti ophiolites. *Fig. 5a* reveals that the present metagabbros and metavolcanics from the both areas under studied belong to a high-Ti ophiolites.

The present ophiolite suite can be comparable with the high-Ti ophiolite of transitional MOR for the following:

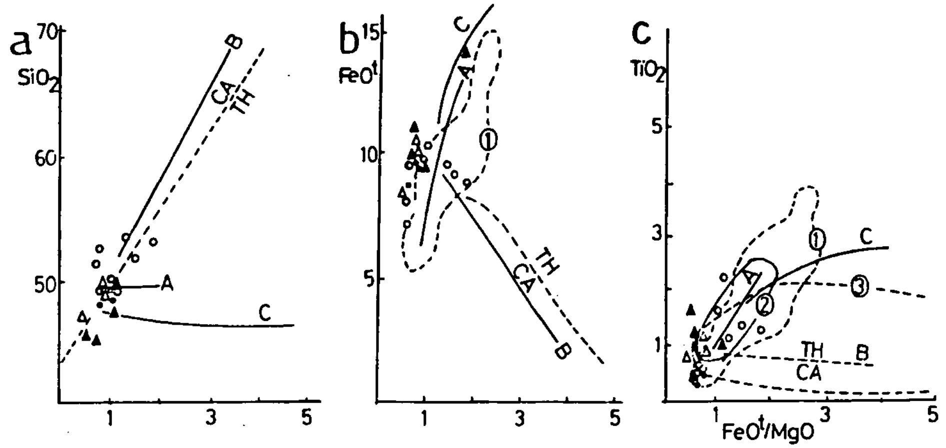

Fig. 3. SiO_2-, FeO_t- and TiO_2 versus $FeO_t/(FeOt+MgO)$ variation diagrams for the studied metagabbros and metavolcanics. The dashed line separating the tholeiitic (TH) and calc-alkaline (CA) series, and the solid trend lines for abyssal tholeiites (A), the Asama calc-alkaline volcano (B) and Skaergaard intrusions (C) are after MIYASHIRO (1975a). Fields: 1 = Basalts from Western Alps ophiolite after DEL PIAZ et al. (1981), BECCALUVA et al. (1984), ABDEL KARIM (1991); 2 = Abyssal tholeiites and 3 = Island arc volcanics after MIYASHIRO (1975b).

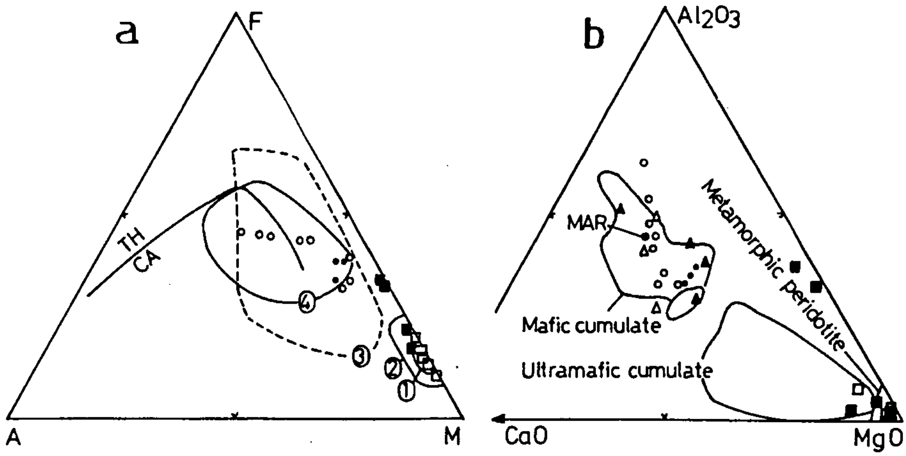

Fig. 4. Plots show the ophiolitic affinities and magma type of the studied rocks. a) AFM diagram after IRVINE and BARAGAR (1971), Fields: 1 = metamorphic peridotites and 2 = mafic-ultrmafic cumulates after STRONG and MAPLAS (1975), 3 = oceanic gabbros (CAYTROUGH, 1979), 4 = Egyptian metagabbros (GHONEIM et al., 1992) b) CaO-Al_2O_3-MgO diagram after COLEMAN (1977).

Plots of metagabbros and metavolcanics on TiO_2-FeO_t/MgO diagram (*Fig. 5a*) after MIYASHIRO (1975) indicate their abyssal tholeiite with a few samples showing island arc affinity.

Plots of the present metagabbros and metavolcanics on Ti-Cr diagram (*Fig. 5b*) after PEARCE et al. (1975) reveal their ocean floor and island arc setting.

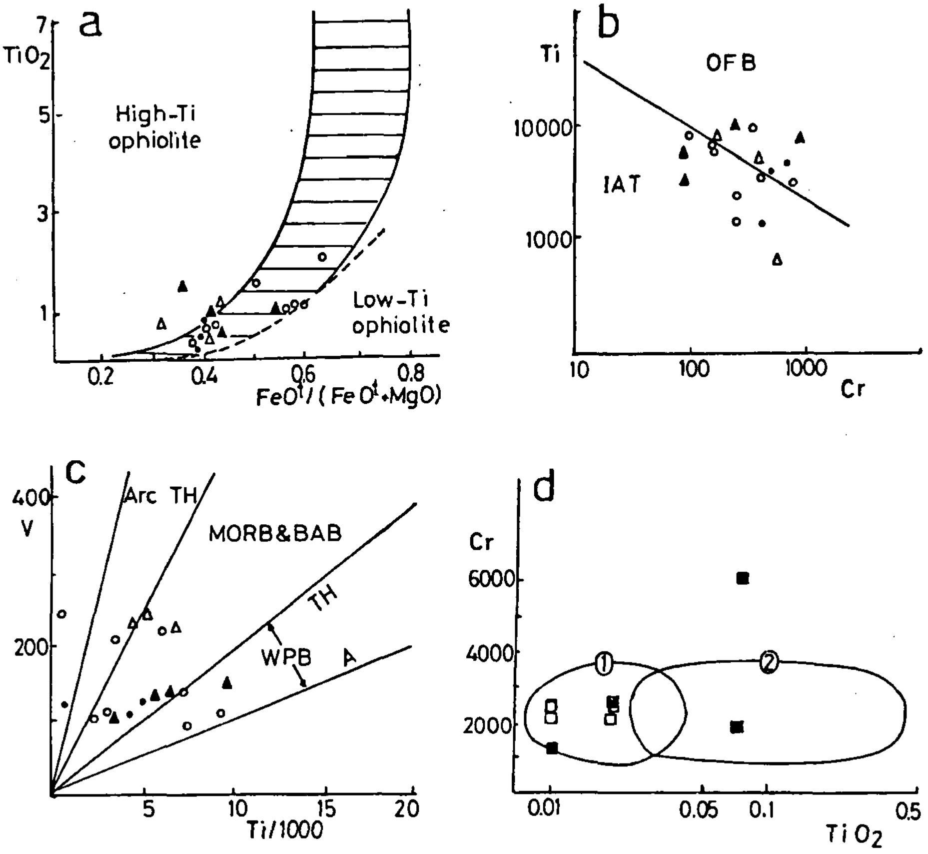

Fig. 5. Plots show the magma type and tectonic setting of the studied metagabbros and metavolcanics.
a) TiO_2-$FeO_t/(FeO_t+MgO)$ diagram after SERRI (1981). Shaded field denotes gabbroic rocks from Atlantic and Indian oceans.
b) Ti-Cr diagram after PEARCE (1975). OFB = Ocean floor basalts, IAT = Island arc tholeiites.
c) V-Ti/1000 diagram after SHARVAIS (1982). BAB = Back-arc basin, WPB = Within plate basalts, TH = Tholeiite, A = Alkaline.
d) Cr-TiO_2 diagram after PEARCE et al. (1984). Fields: 1 = Supra-subduction zone ophiolite, 2 = MORB ophiolite.

Plots of the metagabbros and metavolcanics on V-Ti diagram (*Fig. 5c*) after SHERVAIS (1982) indicate that the present rocks fall mostly within or around the field of mid-ocean ridge and back-arc basin basalt with a few samples showing TH of arc and within plate.

Plots of the ultramafic rocks on the simple discrimination diagram of Cr-TiO_2 (*Fig. 5d*) of PEARCE et al. (1984) which differentiate between the ophiolites of the supra-subduction zone (SSZ) and mid-ocean ridge (MOR) show that most of the present ultramafics fall within the field of supra-subduction zone ophiolite (SSZ).

TABLE 1

Results of chemical composition of the ophiolite of Wadi Dunqash and Wadi Arayis, Eastern Desert, Egypt

	Metaultramafics Wadi Dunqash				*Wadi Arayis*					*Metagabbros Wadi Dunqash*			*Wadi Arayis*							*Metavolcanics Wadi Dunqash*				*Wadi Arayis*		
	109	*109/1*	*109/2*	*102/3*	*96/3*	*96/3*	*99/1*	*101/3*	*96/1*	*111*	*112'*	*112*	*111/2*	*95*	*97*	*97/1*	*94/2*	*93*	*101/1*	*101/2*	*105/1*	*105/5*	*107/1*	*106/1*	*99/4*	*99/5*	*98*
SiO_2	40.10	32.07	33.55	64.14	42.36	44.12	43.23	41.22	31.38	49.63	48.50	49.57	48.84	51.10	52.24	52.53	53.12	53.34	48.74	50.09	45.21	47.46	45.07	58.02	47.05	49.40	52.53
TiO_2	0.02	2.86	0.07	0.01	0.01	0.02	0.01	0.02	0.08	0.73	0.52	0.21	0.56	0.38	1.26	0.51	1.17	1.09	2.22	1.54	1.17	1.06	1.63	0.54	0.75	1.16	0.77
Al_2O_3	4.25	15.36	14.48	1.22	1.14	1.12	1.03	4.11	14.50	11.96	12.50	12.25	11.68	13.34	16.42	12.22	18.74	14.06	13.84	16.05	13.10	12.92	10.21	14.60	9.64	18.77	13.62
Fe_2O_3	8.50	15.23	13.79	5.09	8.78	7.18	8.10	9.53	4.58	1.58	1.32	1.42	1.59	1.31	1.62	1.20	1.39	1.55	1.70	1.62	1.80	2.39	1.62	1.25	1.29	1.80	1.77
FeO	1.81	3.05	2.76	1.02	1.76	1.44	1.02	1.91	0.92	7.88	8.11	7.12	7.94	6.55	7.58	6.01	6.94	7.76	8.50	8.07	8.98	44.93	8.06	8.26	6.93	9.28	8.83
MnO	0.15	0.15	0.21	0.06	0.16	0.10	0.14	0.15	0.05	0.15	0.16	0.15	0.14	0.14	0.14	0.13	0.12	0.17	0.12	0.14	0.16	0.16	0.22	0.17	0.16	0.18	0.17
MgO	41.33	24.55	28.39	24.35	44.21	45.77	44.21	39.49	34.24	13.49	13.70	14.17	14.11	12.84	6.27	12.49	4.57	7.10	9.17	9.38	15.55	11.61	17.16	6.53	18.08	9.49	10.45
CaO	0.88	0.70	0.10	2.68	0.87	0.12	0.34	2.61	0.07	8.60	8.88	9.83	9.53	11.08	8.03	11.18	7.11	8.61	10.78	10.19	7.90	7.99	12.27	6.83	13.57	6.48	10.03
Na_2O	–	0.06	–	–	–	0.05	–	–	–	1.61	1.91	2.42	0.48	1.28	3.29	1.99	4.56	3.23	2.81	2.50	0.41	1.78	1.30	2.46	0.69	1.74	1.36
K_2O	–	0.04	–	–	–	–	–	–	–	0.24	0.20	0.05	0.87	0.41	1.21	0.20	0.75	1.03	0.22	0.13	1.54	0.82	1.05	0.83	0.14	0.64	0.14
P_2O_5	0.04	0.55	0.05	0.02	0.02	0.03	0.02	–	0.02	0.15	0.10	0.02	0.13	0.09	0.38	0.10	0.53	0.28	0.07	0.11	0.26	0.27	0.17	0.17	0.02	0.23	0.11
LOI	2.90	5.37	6.50	1.32	0.63	–	1.80	1.92	13.50	2.95	3.60	2.97	4.11	2.32	2.51	2.43	0.95	1.74	1.73	0.17	2.52	2.05	1.30	0.27	2.10	0.80	0.12
Total	99.98	99.99	99.90	99.91	99.93	99.93	99.87	98.98	98.98	99.50	99.98	99.06	99.98	99.84	99.85	99.99	99.95	99.96	99.80	99.99	99.80	99.14	99.07	99.96	99.98	99.97	99.90
Ba	125	11	40	41	39	32	48	31	22	150	120	47	190	133	266	67	361	300	71	66	242	431	111	281	66	746	68
Zn	–	4	4	–	–	–	–	–	4	95	85	23	69	97	140	102	333	149	86	76	103	85	104	118	49	102	43
Y	–	–	–	–	–	–	–	–	–	3	2	–	2	–	6	–	8	14	–	–	14	10	11	12	10	17	12
Sr	2	36	4	43	3	3	2	6	1	262	188	150	160	517	504	427	537	350	444	414	159	570	120	321	100	137	145
Rb	–	–	–	–	–	–	–	–	–	2	2	–	6	–	14	–	3	10	–	–	11	22	–	10	–	83	–
Th	3	4	3	5	2	7	–	4	–	–	–	–	1	–	3	6	–	2	–	5	1	–	2	2	5	–	–
Pb	4	–	4	6	3	4	7	10	–	–	10	–	2	–	6	4	11	11	–	19	–	–	–	1	9	–	7
Ga	10	18	25	10	11	10	9	10	16	16	12	13	16	17	20	17	24	19	17	18	16	18	16	19	13	19	15
Zn	35	115	109	59	36	39	27	35	102	55	43	38	6	63	76	54	111	90	50	76	64	84	97	81	38	58	62
Hf	–	–	–	–	–	–	–	–	–	2	2	1	2	2	2	2	6	3	1	1	3	3	2	2	–	3	1
Co	150	83	77	79	151	142	149	145	63	40	35	36	50	41	31	43	18	30	35	36	53	22	33	7	53	42	33
Cr	2350	2050	2031	1615	2565	2460	2219	2258	9987	705	520	421	883	258	103	398	118	159	250	331	969	194	246	102	577	187	395
V	105	50	56	17	47	148	40	107	725	101	105	120	216	102	91	107	133	95	239	114	114	115	135	95	232	216	248
Ce	–	–	–	–	1	–	–	–	–	47	32	28	26	2	18	9	56	34	–	50	17	55	14	32	–	92	–
La	–	15	–	12	–	–	48	–	–	–	10	17	–	–	16	–	9	–	–	–	33	20	11	–	13	–	–
Cl	150	137	122	94	213	448	105	131	66	109	93	78	125	55	138	163	25	172	104	175	54	108	159	138	160	47	130
S	118	327	60	117	296	195	67	291	29	890	88	161	276	44	658	1070	227	297	75	71	528	84	197	132	47	507	68
Ni	2350	1256	1190	1666	2414	2408	2588	1413	1350	109	102	95	140	104	45	208	33	29	79	78	346	19	84	22	113	188	96
Nb	8	19	–	11	11	13	10	–	–	5	–	–	7	–	–	3	11	–	–	–	7	8	–	–	–	–	–

DISCUSSION AND CONCLUSION

The field investigation of the mafic-ultramafic assemblage of Wadi Dunqash and Wadi Arayis, Eastern Desert of Egypt, reveal that the occurrence of harzburgite serpentinite and pyroxenite-chlorite schists followed by metagabbros (normal and sheared) and metavolcanics (metabasalts and meta-andesites and their alteration products). The present assemblage were emplaced into volcanoclastic metasediments with no sign of thermal contact. This sequence may be classified as a dismembered ophiolite suite in the sense of the GSA Penrose Conference (1972). The general extention trends of the present ophiolite melange are NW-SE direction in Wadi Arayis and ENE-WSW in Wadi Dungash. The presence of volcanoclastic materials in the metasediments (as well as the island arc calc-alkaline metavolcanics in Dungash) probably indicate the presence of nearby island arc. The major elements geochemistry confirms this conclusion.

The high-Ti ophiolite are generated in a number of transitional tectonic settings, related to an incipient or more mature stage of MORB and marginal basin magmatism (BECCALUVA et al. 1983). The present mafic-ultramafic sequence show a similarity with high-Ti ophiolite of transitional-MORB. This features reveal from discrimination diagrams (*Fig. 5*) which show ocean floor- or abyssal tholeiite-island arc trends for the metagabbros and metavolcanics and supra-subduction zone (SSZ) for the ultramafic rocks.

The present-day SSZ ophiolites lie in fore-arc and parts of some back-arc basins; whereas MORB ophiolites lie in incipient oceans, major oceans, "leacky" transform faults and most back-arc basins. Moreover, compositional fields for some marginal basins fall into two groups. Those from back-arc basins which fall entirely within the MORB field, and from back-arc and fore-arc basins plot within or to the left of the island arc tholeiite. Subsequently, the present mafic-ultramafic sequence probably represent the best analogues for transitional MORB, attribute to their transitional setting between ocean floor basalt and island arc.

The following facts probably suggest a similarity of the present mafic-ultramafic assemblage with the ophiolite suite:

1. The metagabbros and metavolcanics are derived from tholeiitic with minor calc-alkaline magma.
2. Both the metagabbros and metavolcanics are transitional between ocean floor and island arc.
3. Both the metagabbros and metavolcanics exhibit a back-arc basin-MORB affinity.
4. The ultramafics are similar to that associated with the SSZ ophiolite, support that they are not typical MORB (i. e., transitional).

Therefore, the variation of both magma type and tectonic setting of the present rocks can be interpreted if the present ophiolites are implicated in back-arc system. Similar results are given by KRONER et al. (1987), ABU EL-ELA and ALY (1990) and others. The view is consistent with the presence of studied ophiolite assemblage within the volcanoclastic metasediments.

REFERENCES

ABDEL-KARIM, A. M. (1991): Comparative petrological and geochemical study of some ophiolite occurrences in the Alps-Carpathian system, Ph. D. Thesis, Eötvös Lorand Univ., Budapest, 223p.

ABDEL-KHALEK, M. L., TAKLA, M. A., SEHIM, A., HAMIMI, Z. and EL MANAWI, A. W. (1992): Geology and tectonic evolution of Wadi Beitan area, Southeastern Desert, Egypt. Geology of the Arab World. Cairo Univ., 369–394.

ABU EL ELA, A. M. and ALY, S. M. (1990): The ophiolite suite of Wadi Esel, Eastern Desert, Egypt. Proc. Egypt. Acad. Sci. **40**, 27–39.

ABU EL ELA, F. F. (1985): Ophiolitic melange of the Abu Mireiwa district, central Eastern Desert, Egypt. Ph. D. Thesis, Assiut Univ.

ASHAWY, M. H. (1987): The ophiolitic melange of the south Eastern Desert of Egypt; remote sensing field work and petrographic investigation. Ph. D. Thesis, Berliner Geowiss. Abh., Berlin, (A), **84**, 134 p.

BASTA, E. Z., CHURCH, W. R., HAFEZ, A. M. A. and BASTA, F. F. (1983): Proterozoic ophiolitic melange and associated rocks of Gabal Ghadirarea, Eastern Desert, Egypt. 5th Intern. Conf. on Basement Tectonics, Cairo Univ. Abstract vol.

BECCALUVA, L., GIROLAMO, P., MACCIOTTA, G. and MORRA, V. (1983): Magma affinities and fractionation trends in ophiolites. Ophioliti. 8, 3, 307–324.

BECCALUVA, L., DAL PIAZ, G. V. and MACCIOTA, G. (1984): Transtonial to norma MORB affinities in ophiolitic metabasites from the Zermatt-Saas, Combin and Antrona units, Western Alps: Implication for the paleogeographic evolution of the Western Tethyan basin. Geol. Mijnbouw. **63**, 165–177.

CAYTROUGH, P. (1979): Geological and geophysical investigation of the Mid-Cayman Ridge spreading center. In Talwani, M., Harrison, G. E. and Hayes, D. E. (eds.): Maurice Ewig Series, 2, Am. Geophys. Union, 66–95.

COLEMAN, R. G. (1977): Ophiolites. Springer Verlag, New York, 299p.

COLOMBI, O. A. (1988): Metamorphisme et geochimie des roches mafiques des Alpes. Duest-centrales (geoprofil Viege-Domodossala-Locarno). Ph. D. thesis, Lausanne Univ., 195p.

DAL PIAZ, G. V., VENTURELLI, G., SPEDEA, P. and DI BASTTISTILNI G. (1981): Geochemical features of metabasalts and metagabbros from the Piedmont ophiolite nappe. Italian Western Alps. N. Jb. Min. Abh, **142**, 248–269.

EL SHARKAWI M. A. and R. M. EL BAYOUMI (1979): The ophiolites of Wadi Ghadir area, Eastern Desert, Egypt. Ann. Geol. Surv. Egypt. **9**, 125–135.

GHONEIM, M. F., TAKLA, M. A. and LEBDA, E. M. (1992): The gabbroic rocks of the Central Eastern Desert, Egypt: A geochemical approach. Annals Geol. Surv. Egypt. **XVIII**, 1–21.

HASSANEIN, S. M. (1984): Ophiolite-melange complex of Wadi Mubarak area, Eastern Desert, Egypt. Ph. D. Thesis, Cairo Univ.

IRVINE, T. N. and BARAGAR, W. R. (1971): A guide to the chemical classification of the common volcanic rocks. Can. J. Earth Sci. **8**, 523–548.

KRONER, A., GREILING, R., REISCHMANN, T. HUSSEIN, I. M., STERN, R. J., DURR, S., KRUGER, J. and ZIMMER, M. (1987): The Pan-African crustal evolution in the Nubian segment of northeast Africa. In KRONER, A. (ed.): Proterozoic Lithospheric Evolution. Geodyn. Ser., Am. Geophys. Union. **17**, 235–257.

LE MAITRE, R. W., BATERMAN, P., DUDEK, A., KELLER, J., LAMEYRE, M. J., SABINE, P. A., SCHMID, R., SØRENSEN, H., STRECKEISEN, A., WOOLEY, A. R. and ZANETTIN, B. (1989): A classificiation of igneous rocks and glossary of terms. Blackwell, Oxford.

MIYASHIRO, A. (1974): Volcanic rock series in island arc and active continental margins. Am. J. Sci. **274**, 331–355.

MIYASHIRO, A. (1975a): Classification, characteristic and origin of ophiolites. J. Geol. **83**, 249–281.

MIYASHIRO, A. (1975b): Volcanic rock series and tectonic setting. Annual Rev. Earth Planet. Sci. **3**, 251–269.

NASSEEF A. O., BAKOR, A. R. and A. H. HASHAD (1980): Petrography of possible ophiolitic rocks along the Qift-Quesir road, E. D., Egypt. Bull. Inst. Applied Geol., King Abdul-Aziz Univ. Jaddah **3**, (4), 157–168.

PEARCE, J. A. (1975): Basalt geochemistry used to investigate post-tectonic environments on Cyprus. Tectonphysics. **25**, 41–67.

PEARCE, J. A., LIPPARD, S. J. and S. ROBERTS (1984): Characteristics and tectonic significance of supra-subduction zone (ssz) ophiolites. In B. P. KOKELAAR and M. F. HOWELLS (eds.). Spec. Publ. Geol. Soc. **16**, 77–94.

Penrose Conference (1972): Ophiolite. Geotimes. **17**, No. 12, 24–25.

RIES, A. C., SHACKLETON, R. M., GRAHAM, R. H. and W. R. FITCHES (1983): Pan-African structures, ophiolites and melange in the Eastern Desert of Egypt: a traverse at 26° N. J. Geol. Soc. London. **140**, 75–95.

SERRI, G. (1981): The petrochemistry of ophiolitic gabbroic complexes: a key for the classificaton of ophiolities into low-Ti and high-Ti types. Earth Planet. Sci. Lett. **52**, 203–212.
SHACKLETON, R. M., RIES, A. C., GRAHAM, R. H. and W. R. FITCHES (1980): Late Precambrian ophiolite melange in the Eastern Desert of Egypt. Nature **285**, 472–474.
SHAERVAIS, J. W. (1982): Ti-V plots and the petrogenesis of modern and ophiolitic lavas. Earth Planet. Sci. Lett. **58**, 101–118.
STRONG, D. and MALPAS, J. G. (1975): The sheeted dykes layer of the Betts Core Ophiolite Complex does not represent spreading – Further discussion. Can. J. Earth Sci. **12**, 844–896.
WINCHESTER, J. A. and FLOYD, P. A. (1977): Geochemical discrimination of the different magma series and their differentiation products using immobile elements. Chem. Geol. **20**, 325–343.

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