

Geology and Geochemistry of the Metagabbros and Metavolcanics Rocks at El Igla Area Central Eastern Desert, Egypt

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Abstract

The Precambrian rocks of El Igla area, Central Eastern Desert, Egypt are consisting of metagabbros and metavolcanics cutting by syn-tectonic granites. El Igla metagabbros occurring as small to big outcrops, they are medium to coarse-grained and greenish grey to pale green in color, composed. They are showing ophitic to subophitic texture with calcic pyroxenes and plagioclase as well as amphibole and pockets of hornblende as the major components. The alteration of El Igla metagabbros led to formation pyroxene, amphibole and actinolite.

El Igla metavolcanics are exposed and comprise a heterogeneous of grey to green assemblages. They are coarse to medium grained and they are frequently interleaved with variably altered ultramafics (serpentinites) in the form of wedges and slices, with sharp tectonic contacts. El Igla metavolcanics are classified into meta-andesite, meta-basalt and meta-dacite rocks. Meta-andesite is composed essentially of plagioclase, hornblende and pseudomorphs chlorite. Accessory and secondary minerals are iron oxides, calcite, epidote and interstitial quartz. Meta-basalt is mainly composed of micro-phenocrysts of plagioclase, pyroxene and quartz set in a fine-grained groundmass exhibiting intersertal texture. Meta-Dacite is composed predominantly of plagioclase, quartz and biotite. They have a fine grained aphanitic to porphyritic texture.

The original magma of El Igla metagabbros was primitive and tholeiitic to calc-alkaline in nature. They are fall in MORB type field and formed as a result of partial melting of mantle spinel peridotite that has been metasomatized by fluids dehydrated from a subducted slab. They are characterized by relatively parallel REE patterns with depletion of heavy rare earth elements ($\Sigma HREE = 7.91$) and enrichment in light rare earth elements ($LREE = 49.79$) with $[(La/Yb)_n = 1.17-2.06]$.

In El Igla metavolcanics, some major elements have wide compositional range of MgO (4.2-8.8 wt%) and MnO (0.11-0.18 wt%) with narrow compositional range of SiO₂ (49.3–52.1 wt %), suggesting diverse protolith. The La/Sc ratios (0.03-6.57 with an average 0.97 ppm), the ratios of Y/Nb, and Nb/Y fall in the range between 1.91-15.63 ppm with an average 5.90 ppm and 0.06 – 0.53 ppm with an average 0.27 ppm, respectively. The Nb/Y and La/Sc ratios are mostly < 1.0 and La/Y ratio is ranged from (0.05-0.56) with an average 0.22), implying possible approach to calc-alkaline and alkaline affinities with island arc setting.

Keyword: El Igla, Metagabbros, Metavolcanics, Geochemistry, Calc-alkaline, Central Eastern Desert

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I. Introduction

The Egyptian gabbroic rocks are widely distributed in all tectonic environments from ophiolitic to continental settings [1, 2, 3]. Based on chronologic data, field relations, and tectonic settings, four groups of gabbroic rocks are distinguished [2]: (a) ophiolitic metagabbro, (b) island arc intrusive metagabbro–diorite complex, (c) intrusive fresh gabbros±ultramafic associations, and (d) gabbroic rocks associated with Phanerozoic ring complexes. In the Egyptian basement sequence, the gabbroic rocks post-date the calc–alkaline older granitoids and pre-date the calc–alkaline younger granitoids [4, 5, 6].

The Pan-African basement history of Wadi Abu Ghusun-Wadi Chatter district began with the arc volcanics (Ranga metavolcanics) passing through arc continent collision accompanied by the distribution of the oceanic lithosphere flooring the volcanic-arc and overthrusting of an oceanic slice (Atshan ophiolitic metabasalts) followed by emplacement of the Mahara and Abu Ghalaga metagabbros-diorite complexes [7].

The aim of the present paper is to shed more light on the geology and geochemical characteristics of El Igla metagabbros and metavolcanics.. El Igla area is located in the Central Eastern Desert of Egypt.

II. Location of the Study Area

El Igla area is located in the central Eastern Desert between longitudes 34° 42' 54" E and 34° 39' 54" E and latitudes 25° 08' 06" N and 25° 03' 54" N. It is easily accessible through Marsa Alam-Idfu asphaltic road at the entrance about 19km west of Marsa Alam city with track about 12km (Fig. 1A).

III. Geologic Setting and Petrography

The Precambrian basement rocks exposed in El Igla area represent a part of the Pan-African belt of the Arabian Nubian Shield [8]. El Igla area has a moderately to low topographic features.

El Igla area was studied in detailed and mapped on the scale 1:50,000 (Fig. 1B) using aerial photographs scale 1:40,000, photomosaic scale 1: 50,000 and Landsat image scale 1:100,000.

3.1- Geology and Petrography of El Igla Metagabbros

El Igla metagabbros are found from small to big outcrops (Fig. 2) on the east and west side of the mapped area (Fig. 1B). They are medium to coarse-grained and greenish grey to pale green in color (Fig. 3). They form low and moderate relief and composed of plagioclase and amphibole as well as contain pockets of hornblende. The ophiolitic metagabbros are found as small fragments and blocks associated with serpentinites.

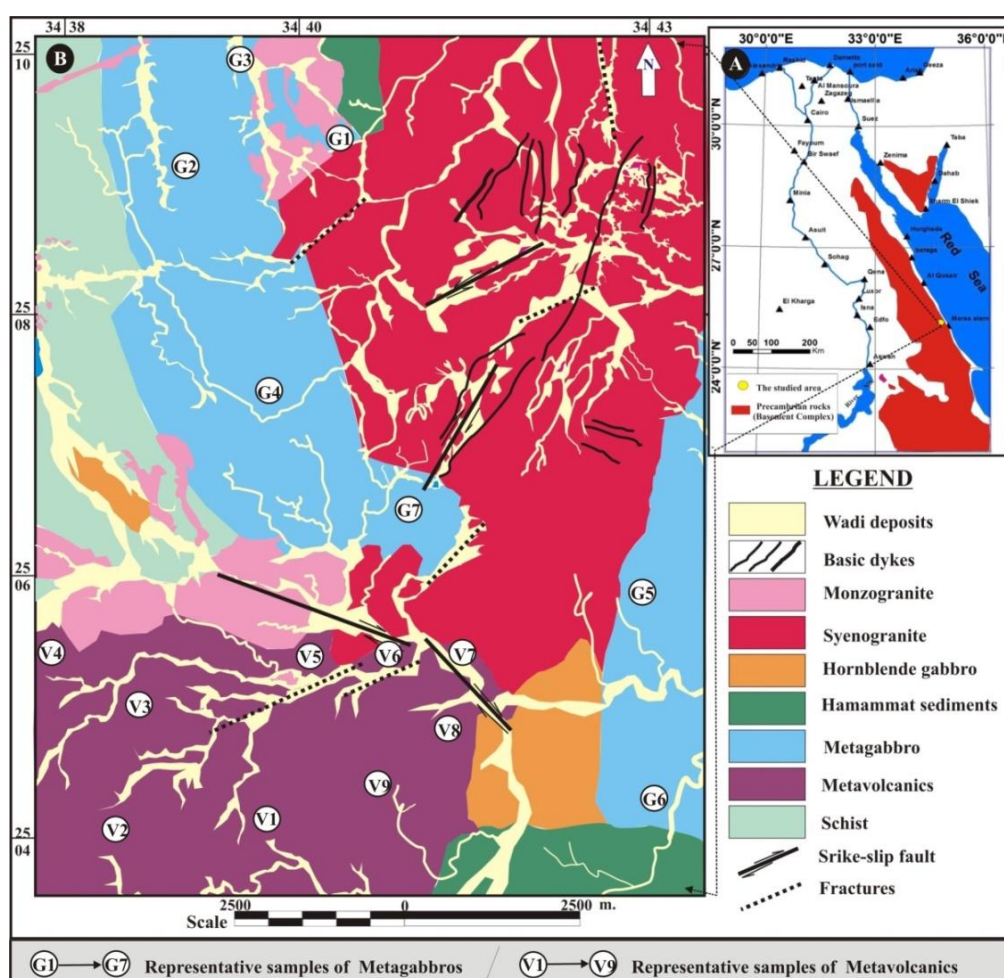


Fig. (1): A) location map and B) Detailed geologic map of El Igla area, Central Eastern Desert, Egypt



Fig. (2): The outcrop of El Igla metagabbros, Central Eastern Desert



Fig. (3): Greenish grey to pale green metagabbros at El Igla area

Petrographically, El Igla metagabbros are medium-sized grain and exhibit a hypidiomorphic texture. They are constituents of hornblende, plagioclase, calcic pyroxene, biotite and quartz. The accessory and secondary phases are magnetite, ilmenite, apatite, chlorite, epidote, iron oxides, actinolite and opaques.

Hornblende occurs either as subhedral to euhedral prismatic crystals, ranging in size from 0.2 to 0.6mm in width and from 0.5 to 1.0mm in length, sometimes, they show ophitic to subophitic texture (Fig. 4A), or as alteration products of olivine (Fig. 4B). It is slightly altered to chlorite and epidote along its cleavages. In some samples the hornblende partially serpentinized composed mainly of actinolite, chrysotile and antigorite associating carbonate. **Actinolite** occurs as fibrous aggregates showing faint pleochroic colors. **Chrysotile** is present as pale green foliated crystals associating talc (Fig. 4C). **Antigorite** is the main constituent occurring as platy crystals with colorless to gray colors and low relief. It occurs as aggregates of associated with carbonate (Fig. 4D).

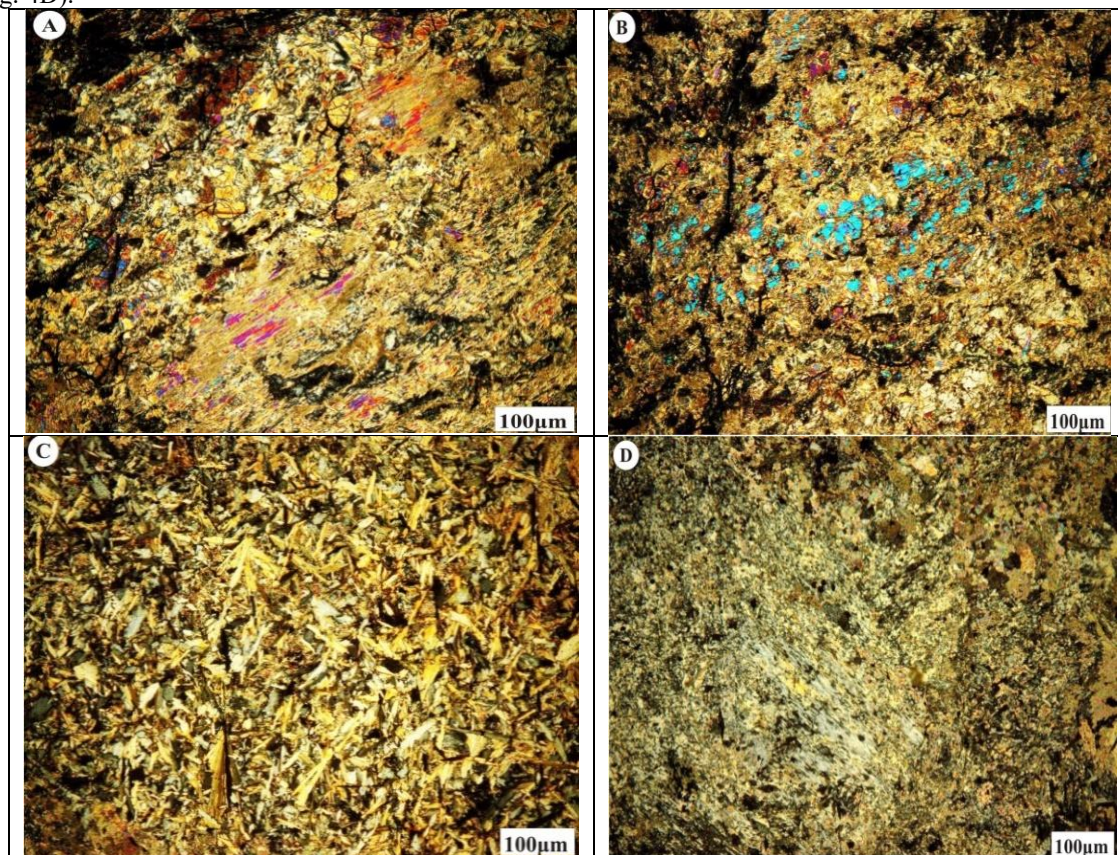


Fig. (4): Photomicrographs of El Igla Metagabbros showing; A) Hornblende crystals association with olivine and carbonate, notice ophitic to subophitic texture, B) Olivine crystals altered to hornblende, C) Fibrous crystals of actinolite and chrysotile, D) Fibrous crystals of antigorite associating carbonate.

3.2- Geology and Petrography of El Igla Metavolcanics

El Igla metavolcanics are exposed and comprise a heterogeneous of grey to green assemblage. They are coarse to medium grained and are abundant in southern parts of the mapped area (Fig. 1B). El Igla metavolcanics are frequently interleaved with variably altered ultramafics (serpentinites) in the form of wedges and slices, with sharp tectonic contacts (Fig. 5). Serpentinites locally contain patches of magnesite. Metavolcanics are intruded by monzogranite (Fig. 6).

Petrographically, El Igla metavolcanics classified into meta-andesite, meta-basalt and meta-dacite rocks. **Meta-andesite** rocks are composed essentially of plagioclase, hornblende and pseudomorphs chlorite. The accessory and secondary minerals are iron oxides, calcite, epidote and interstitial quartz.

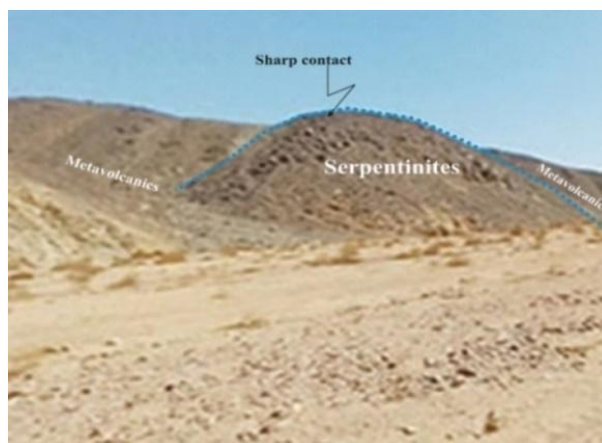


Fig. (5): Sharp contact between metavolcanics and serpentinite rocks at El Igla area.



Fig. (6): Metavolcanics intrude by monzogranite rocks at El Igla area.

Plagioclase megacrysts vary from 1.2 to 2.2mm long and from 0.4mm to 0.7mm width. They have andesine and labradorite compositions (An. 34-54). Zoning is quite common and twinning is according to albite and albite carlsbad laws. 1.2 to 2.2mm long and from 0.4mm to 0.7mm width. They have andesine and labradorite compositions (An. 34-54). Zoning is quite common and twinning is according to albite and albite carlsbad laws. Plagioclase phenocrysts show partial to complete cloudiness due to alteration and associated with chlorite of penninite type (Fig. 7A). They usually elongate euhedral to subhedral crystals. Plagioclase of the groundmass form lathiform crystals (0.2 to 0.5mm long and up to 0.2mm width). It's usually andesine in composition (An. 36-40) and commonly altered. **Hornblende** is restricted to groundmass attaining 0.4mm long and showing completely altered to chlorite. **Carbonates** are always present in the form of patches or veinlets, associated with epidote, iron oxides, and sericite (Fig. 7B).

Meta-basalt rocks are mainly composed of micro-phenocrysts of plagioclase, pyroxene and quartz set in a fine-grained groundmass exhibiting intersertal texture (Fig. 7C). The groundmass of meta-basalt is formed of plagioclase, hornblende and quartz. Calcite, epidote, chlorite and opaques are secondary minerals. **Plagioclase** (An. 25-40) occurs as subhedral blasto-porphyrates, up to 3.0mm long and dense aggregates in the groundmass. It is highly cracked, saussuritized and usually corroded by the quartz. **Pyroxene** shows fine euhedral to subhedral crystals varying from 0.3 to 4.0mm in length and from 0.2 to 0.5mm in width. It is highly altered, fine flakes and including plagioclase forming subophitic texture (Fig. 7D).

Meta-Dacite rocks are composed predominantly of plagioclase, quartz and biotite. They have a fine grained aphanitic to porphyritic texture. **Plagioclase** occurs as anhedral to subhedral blocky phenocrysts up to 3.0 mm long and dense aggregates in the groundmass. It is highly cracked and usually saussuritized (Fig. 7E). Plagioclase is corroded by secondary quartz and sometimes shows wavy extinction due to strain. **Quartz** appears as rounded and corroded phenocrysts or as an element of the groundmass (Fig. 6F). The groundmass is composed essentially of cryptocrystalline aggregates of quartz, plagioclase, hornblende, chlorite, epidote and opaques.

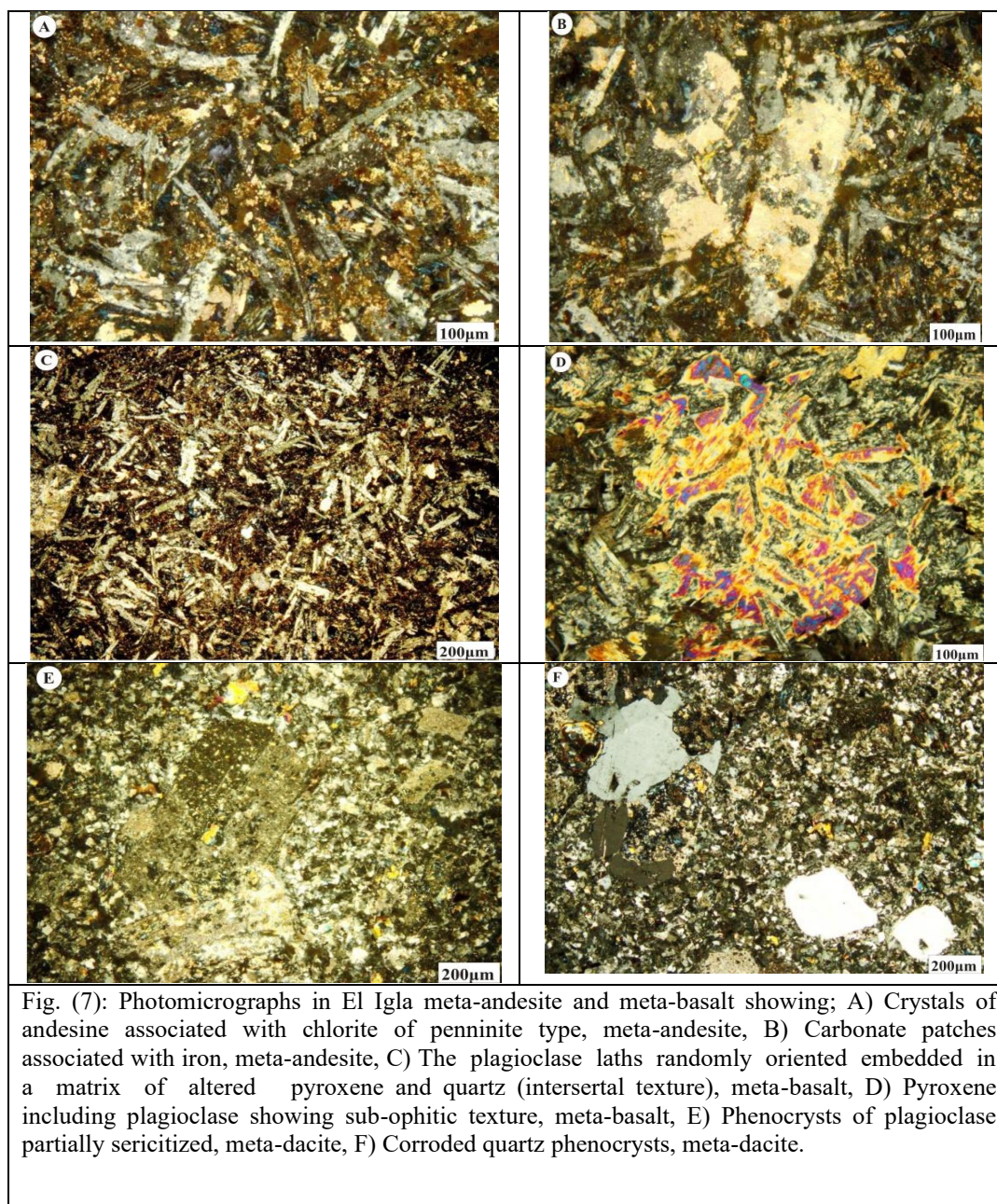


Fig. (7): Photomicrographs in El Igla meta-andesite and meta-basalt showing; A) Crystals of andesine associated with chlorite of penninite type, meta-andesite, B) Carbonate patches associated with iron, meta-andesite, C) The plagioclase laths randomly oriented embedded in a matrix of altered pyroxene and quartz (intersertal texture), meta-basalt, D) Pyroxene including plagioclase showing sub-ophitic texture, meta-basalt, E) Phenocrysts of plagioclase partially sericitized, meta-dacite, F) Corroded quartz phenocrysts, meta-dacite.

IV. Geochemistry

4.1- Geochemistry of El Igla Metagabbros

The geochemical characterization of the El Igla metagabbros are carried out through the study of the chemical composition of seven selected samples (Fig. 1B). All the selected samples were analyzed for major, trace and rare earth element contents, and their CIPW norm values are computed (Table 1).

El Igla metagabbros can be divided into olivine metagabbros and normal metagabbros. The olivine metagabbros are represented by samples (G1, G3, G5 & G6), they have a low differentiation index ($D.I=Q+Or+Ab$) [9], ranging from 20.89 to 32.63 with an average 26.92 (Table 2), this may indicate that, the original magma of these rocks was primitive and tholeiitic in nature. The normal metagabbros are represented by samples (G2, G4, & G7), they have a very low differentiation index $D.I=Q+Or+Ab$ [9], ranging from 14.75 to 28.85 with an average 23.70 (Table 2), this may indicate that, the original magma of these rocks was primitive and tholeiitic to calc-alkaline in nature.

Table (1): Geochemical analysis of El Igla metagabbros, Central Eastern Desert, Egypt

Major oxides (Wt%)								
S.No.	G1	G 2	G 3	G 4	G 5	G 6	G 7	Aver.
SiO ₂	49.73	46.91	49.31	48.00	46.95	46.43	48.22	47.94
TiO ₂	0.74	0.61	0.89	0.45	0.41	0.56	0.38	0.58
Al ₂ O ₃	16.6	19.0	17.14	18.29	19.05	18.10	16.2	17.77
Fe ₂ O ₃	3.66	6.59	4.59	5.80	3.19	4.40	5.43	4.81
FeO	4.3	4.75	3.79	3.18	4.30	4.05	3.10	3.92
MnO	0.16	0.20	0.13	0.12	0.15	0.14	0.16	0.15
MgO	8.52	4.70	6.87	7.54	8.22	9.0	8.11	7.57
CaO	11.0	10.90	10.23	9.99	11.10	12.57	13.0	11.26
Na ₂ O	2.44	2.60	2.98	1.88	2.54	2.63	2.10	2.45
K ₂ O	1.10	1.0	1.10	1.77	1.12	0.45	0.47	1.00
P ₂ O ₅	0.12	0.14	0.11	0.09	0.09	0.08	1.0	0.23
LOI	1.37	2.44	2.0	2.34	2.54	1.44	1.50	1.95
Total	99.74	99.84	99.14	99.45	99.66	99.85	99.67	-
CIPW norm								
Qz	00	0.22	0.0	0.37	0.0	0.0	1.84	0.35
Or	6.61	6.07	6.70	10.78	6.82	2.70	2.83	6.07
Ab	20.96	22.56	25.93	16.36	19.76	18.19	10.08	19.12
An	31.56	38.16	30.99	37.26	38.32	36.79	33.97	35.29
ne	0.0	0.0	0.0	0.0	1.27	2.38	0.0	0.52
Di (wo)	9.69	6.91	8.61	5.53	7.46	10.91	10.76	8.55
Di (en)	7.33	5.09	6.84	4.67	5.45	8.51	8.98	6.70
Di (fs)	1.36	1.14	0.77	0.13	1.29	1.18	0.39	0.89
Hy (en)	9.70	6.98	8.61	14.74	0.0	0.0	11.67	7.39
Hy (fs)	1.79	1.57	0.97	0.41	0.0	0.0	0.50	0.75
Ol (fo)	3.24	0.0	1.57	0.0	10.99	10.05	0.0	3.69
Ol (fa)	0.66	0.0	0.19	0.0	2.87	1.54	0.0	0.75
Mt	5.39	9.81	6.85	8.66	4.76	6.48	8.02	7.14
He	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Il	1.43	1.19	1.74	0.88	0.80	1.08	0.74	1.12
Ap	0.27	0.31	0.25	0.20	0.20	0.18	2.22	0.52
D.I	27.57	28.85	32.63	27.51	26.58	20.89	14.75	25.54
Trace elements (ppm)								
Ba	25	17	23	21	18	19	17	20
Sr	30	22	29	30	17	16	19	23.29
Rb	549	285	289	277	460	516	211	369.57
Nb	246	203	189	201	188	236	214	211
Y	49	33	50	18	43	26	19	34
Zr	4	3	3	5	4	3	2	3.43
Hf	1.5	1.2	1.5	0.9	0.8	1.2	1.1	1.17
Ga	26	25	26	21	24	20	22	23.43
Co	14	14	12	12	11	14	13	12.86
Ta	0.3	0.1	0.4	0.1	0.2	0.3	0.5	0.27
Zn	25	22	58	52	24	32	29	34.57
Ni	101	95	100	178	171	120	89	122
Cr	341	148	167	364	580	139	301	291.43
Cu	11	17	22	23	25	19	22	19.86
Sc	36	45	44	29	32	36	30	36
Au	1.14	0.12	0.13	1.12	0.17	0.12	1.15	0.56
Ag	1.08	1.2	1.1	1.1	1.7	1.3	1.09	1.22
Rare earth elements (ppm)								
La	7.8	3.3	8	4.3	3.2	5.4	3.1	5.01
Ce	25.9	18.2	22.3	22.1	18	20.1	23.2	21.4
Pr	2.11	2.32	0.43	0.75	0.22	0.30	1.6	1.10
Nd	18.1	14.2	18.2	17.2	14.5	14.3	16.2	16.1

Sm	4.5	2.4	4.2	2.8	1.9	2	3.2	3
Eu	0.8	0.5	0.7	0.5	0.7	0.9	0.6	0.67
Gd	2.9	2.3	2.5	2.3	2.2	2.8	2.5	2.5
Tb	0.5	0.4	0.3	0.5	0.2	0.4	0.2	0.36
Dy	3.2	3.3	3.6	1.6	0.93	0.95	1.1	2.1
Ho	1.1	1.3	0.9	1	0.8	1.1	1.2	1.06
Er	1.4	2.4	1.9	1.7	0.47	0.60	1.1	1.37
Tm	0.6	0.4	0.5	0.3	0.4	0.5	0.3	0.43
Yb	2.9	1.9	2.8	2.7	2	2.8	1.9	2.43
Lu	0.1	0.2	0.2	0.1	0.3	0.1	0.2	0.17
ΣLREE	62.11	43.22	56.33	49.95	40.72	45.8	50.4	49.79
ΣHREE	9.8	9.9	10.2	7.9	5.1	6.5	6	7.91

Table (2): Some parameters and ratios of the studied metagabbros of El Igla area

	G1	G2	G3	G4	G5	G6	G7	Aver.
A/CNK	1.14	1.31	1.2	1.34	1.29	1.16	1.04	1.21
A/NK	4.69	5.28	4.26	5.01	5.2	5.88	6.3	5.23
Alkalies	3.54	3.60	4.08	3.65	3.66	3.08	2.57	3.45
FeO ^t	7.96	11.34	8.38	8.98	7.49	8.45	8.53	8.73
MgO+FeO ^t	16.48	16.04	15.25	16.52	15.71	17.45	16.64	16.3
FeO ^t /MgO	0.93	2.41	1.22	1.19	0.91	0.94	1.05	1.15
FeO ^t /(MgO+FeO ^t)	0.48	0.71	0.55	0.54	0.48	0.48	0.51	0.54
DI	27.57	28.85	32.63	27.51	26.58	20.89	14.75	25.54
Y/Nb	0.2	0.16	0.26	0.09	0.23	0.11	0.09	0.16
La/Yb	2.69	1.74	2.86	1.59	1.60	1.93	1.63	2.06
Dy/Yb	1.10	1.74	1.29	0.59	0.47	0.34	0.58	0.86
(La/Yb) _n	1.94	1.25	2.06	1.14	1.15	1.39	1.17	1.44
(Dy/Yb) _n	0.74	1.17	0.87	0.40	0.32	0.23	0.39	0.59

Generally, El Igla metagabbros have a medium contents of TiO₂ (0.38-0.89 wt%), and P₂O₅ (0.08-1.0wt %), K₂O (0.45-1.77wt %) and Na₂O (1.88-2.98 wt %), with modest variations in SiO₂ (46.43-49.73 wt %), while the Al₂O₃, FeO, Fe₂O₃, and CaO have narrow ranges and high concentrations, these ranges are 16.2-19.05wt%, 3.10-4.75wt%, 3.19-6.59 wt%, and 9.99-12.57wt% respectively, except MgO has wide range is 4.70-9.0 wt %, (Table 1). El Igla metagabbros have very high total alkali concentrations, where Na₂O+K₂O values are between 2.57-4.08 wt% with the K₂O value much lower than Na₂O (Table 2).

The large ion Lithophile Elements (LILE) and the High Field Strength Elements (HFSE) have variable amounts in El Igla metagabbros, like Ba (17-25 ppm), Sr (16-30 ppm), Rb (211-549ppm), Zr (2-5 ppm), Nb (189-246 ppm), and Y (18-50 ppm) (Table 1). LIL elements (Ba, Rb, Sr, and K) are thus probable to have been remobilized during alteration and metamorphism to greenschist facies [10].

4.1.1- Geochemical Classification

The geochemical classification of the studied metagabbros is illustrated by two trends; the major oxides, and the normative minerals trend. They exhibit a slightly low degree of fractionation (DI. 14.75- 32.63 with average (25.54). On the (Na₂O+K₂O) vs. SiO₂ diagram [11], El Igla metagabbros show that the all plotted samples are fall in the gabbro field (Fig. 8). On the Al₂O₃-CaO-MgO diagram [12], this diagram has been used to differentiate between ultramafic and mafic cumulate rocks. Based on that the studied El Igla metagabbros, where they are classified as mafic cumulate rocks (Fig. 9). On the SiO₂ vs. K₂O diagram [13], El Igla metagabbros are classified largely as most medium-K rocks (Fig. 10).

4.1.2- Differentiation Index

The differentiation index (DI=Qz+Or+Ab), is calculated [9]. The differentiation index (DI) of el Igla metagabbros is plotted against some of the major oxides for illustrating the variation in the different oxides of the studied rocks (Fig. 11).

Figure (11) shows clearly that SiO₂, Na₂O, K₂O, Al₂O₃ and TiO₂ increase with increasing of the DI, while MgO, CaO and Fe₂O₃ show a marked decrease with increasing DI. It is easy to recognize on this diagram that a linear relationship is indicated no differences in the distribution of the elements argue for a single co-magmatic series.

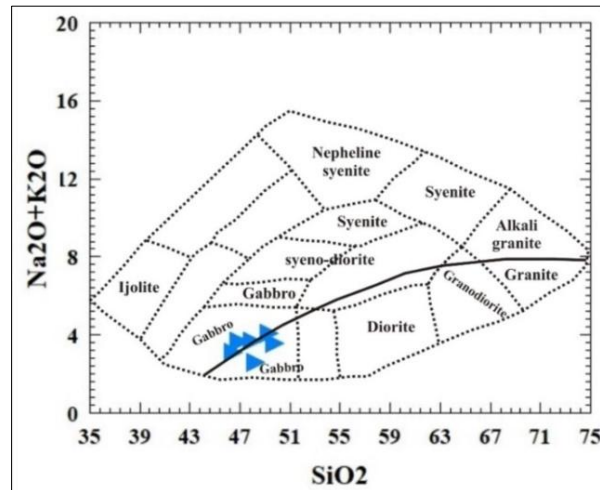


Fig. (8): Classification of the studied metagabbros, after (Cox et al., 1979)

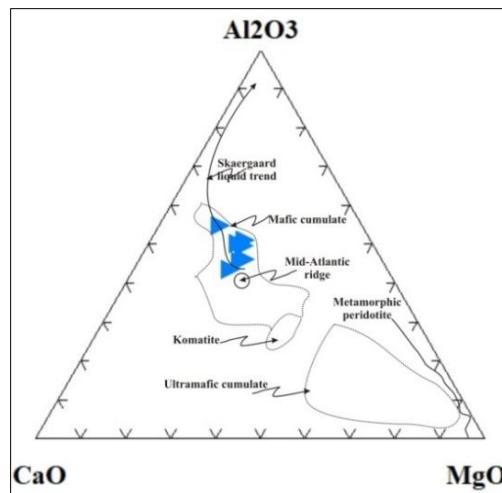


Fig. (9): Al_2O_3 - CaO - MgO diagram (Colleman, 1977)

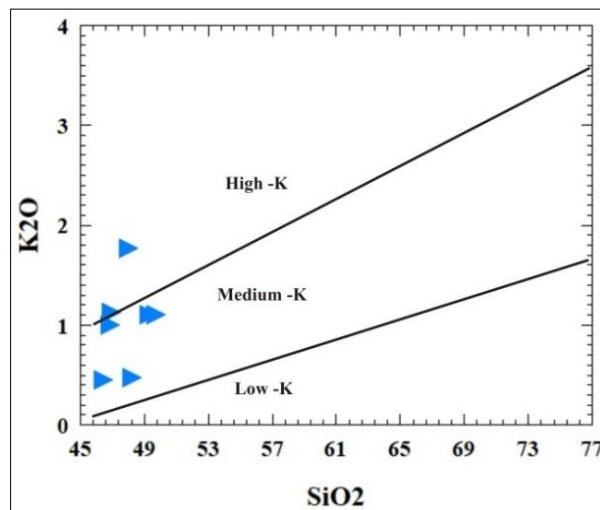
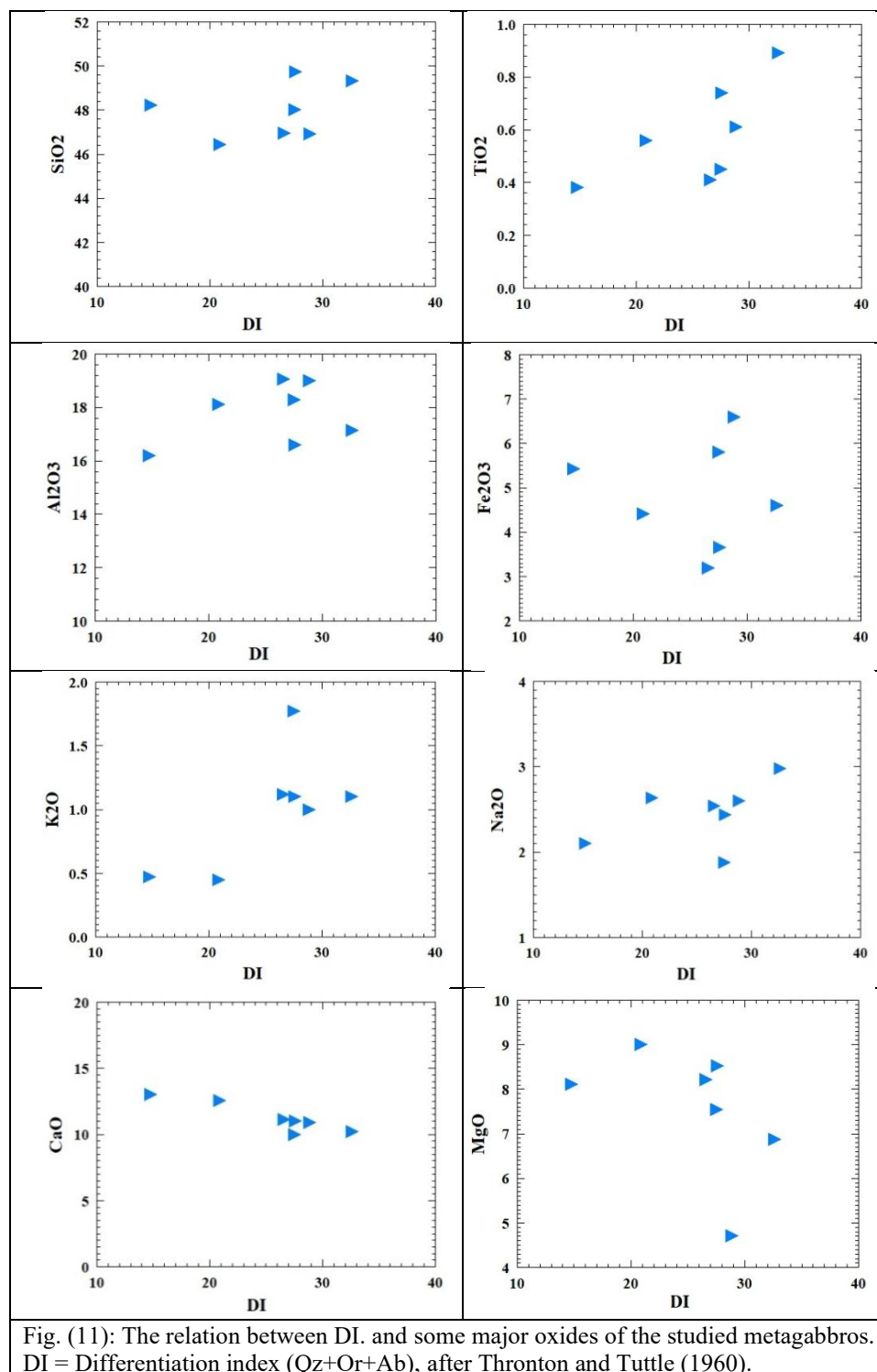


Fig. (10): SiO_2 vs. K_2O diagram (Le Maitre, 2002).



4.1.3- Magma Type

On the *AFM* diagram suggested by Irvine, and Baragar, (1971) [14] to distinguish between tholeiitic and calc-alkaline series (Fig. 12), the plotted samples are located between calc-alkaline and theoiilitic field, due to their slightly enrichment in their alkalies.

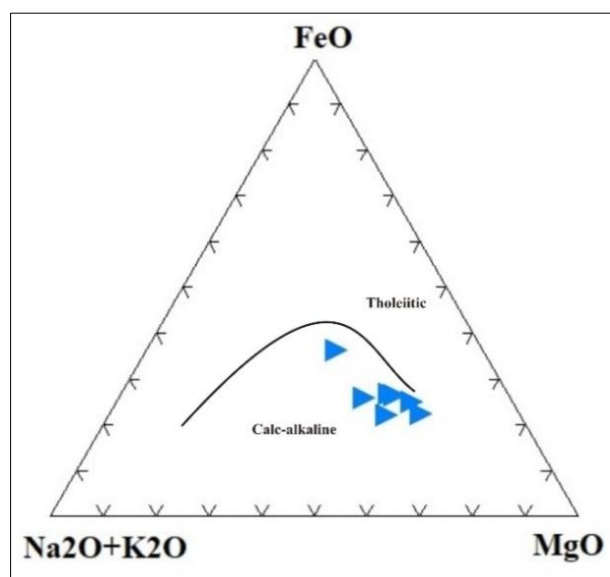


Fig. (12): Plots of the samples of the studied metagabbro on the AFM ternary diagram after (after T. N. Irvine, and W. R. A. Baragar)

4.1.4- Tectonic Setting

Major and trace elements, are used to show some light on the tectonic environments under which these rocks might have been formed. The *Ni* vs. *FeO/MgO* diagram [15] distinguishes between two different rock series MORB type and island-arc type. El Igla metagabbros fall in MORB type field (Fig. 13).

On the Al_2O_3 vs. TiO_2 diagram [16] shows El Igla metagabbros are located in the arc-related magma setting (Fig. 14).

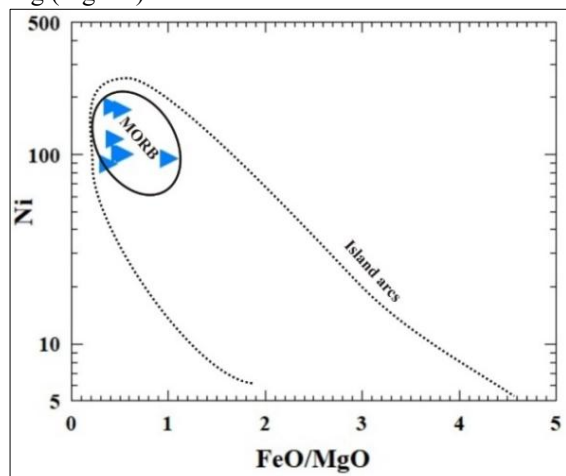


Fig. (13): Plots of Ni (ppm) vs. FeO/MgO of El Igla metagabbros (after A. Miyashiro, and F. Shido, 1975)

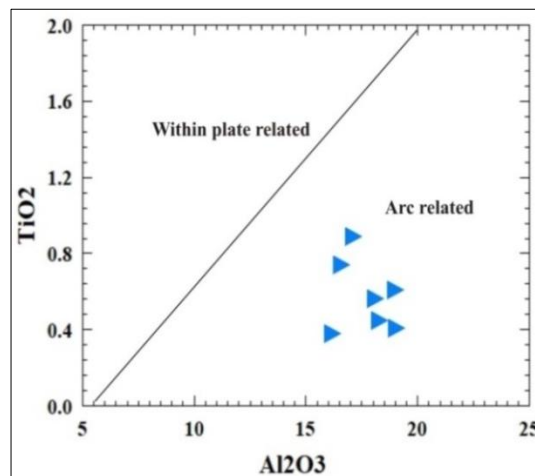


Fig. (14): Al_2O_3 vs. TiO_2 , tectono-magmatic diagram of El Igla metagabbros (Muller and Groves, 1997)

The *MgO* vs. TiO_2 diagram [17] (Fig. 15), show that El Igla metagabbros are generally low *MgO*- low TiO_2 and very low TiO_2 Island Arc, calc-alkaline, indicating that they are generated in a subduction zone. El Igla metagabbros contain low- TiO_2 (0.38-0.89%) concentrations with average value (0.58%) and were probably derived from calc-alkaline magma.

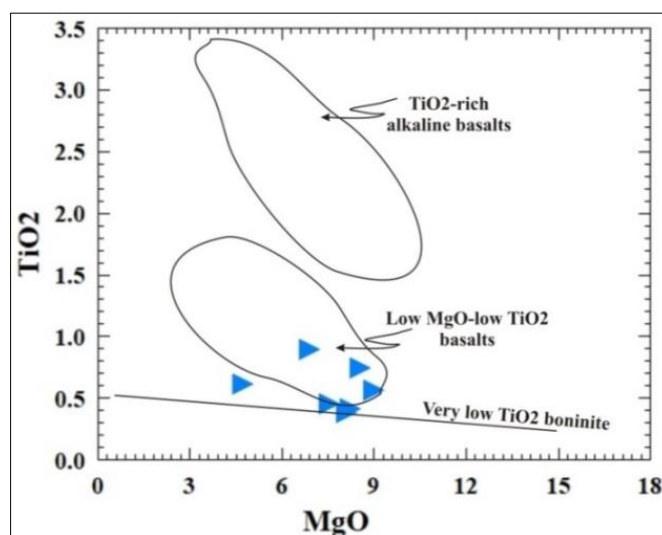


Fig. (15): MgO vs. TiO₂, tectono-magmatic diagram of El Igla metagabbros (Laurent and Hebert, 1989)

4.1.5- Petrogenesis

The REEs and HFSEs are immobile during the weathering and alteration processes. Magma origin is determined largely using the ratios and contents of HFSEs and LREEs [18]. In El Igla metagabbros, the La/Yb ratio (1.59-2.86) has a limited range, while the Dy/Yb ratio (0.34-1.74) is a wide range (Table 2 & Fig. 16), reflecting shallow source partial melting of spinel-peridotite [19]. The depletion of HFSEs like Zr, Nb, Hf, and Pb refers to the separating of LILE such as Sr, Ba, Rb, and HFSEs during subducting slab dehydration [20]. Moreover, the depletion of HFS elements may result from fractionation and metamorphism processes [21]. El Igla metagabbros are formed as a result of partial melting of mantle spinel peridotite that has been metasomatized by fluids dehydrated from a subducted slab [22]. The Ni vs. Cr diagram [23] is significant in determining ferromagnesian mineral fractionation (Fig. 17). In El Igla metagabbros, based on positive trend between Ni-Cr and the absence of olivine in some samples, this indicates that it was derived from a previous fractionated origin or a melt that was slightly fractionated by removing olivine [24].

On the Chondrite-normalized rare earth elements (REE) pattern (Fig. 18), the REE in El Igla metagabbros are generally characterized by relatively parallel REE patterns with depletion of heavy rare earth elements ($\Sigma\text{HREE}=7.91$) and enrichment in light rare earth elements (LREE=49.79) with $[(\text{La}/\text{Yb})_n=1.17-2.06]$ (Table 1 & 2).

The spider diagram for primitive mantle (Fig. 19) exhibits depletion in some (HFSEs) like Zr and Hf with enrichment in others like Nb and Y, while, there are enrichments in (LILEs) like Rb, and depletion in Sr and Ba. Pearce et al. (1984) assumed that the eclectic depletion of Ba and Sr in comparison to Zr, and Y shown by calc-alkaline rocks [25].

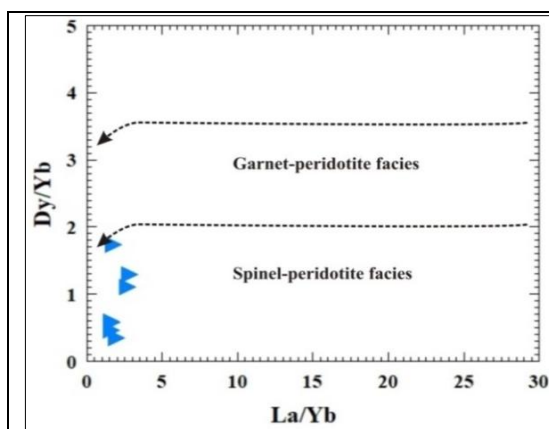


Fig. (16): La/Yb vs. Dy/Yb diagram (Jung et al., 2006).

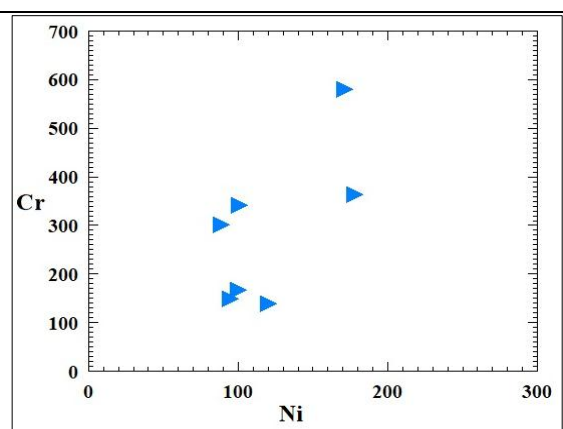


Fig. (17): Ni vs. Cr diagram (Leeman, 1976)

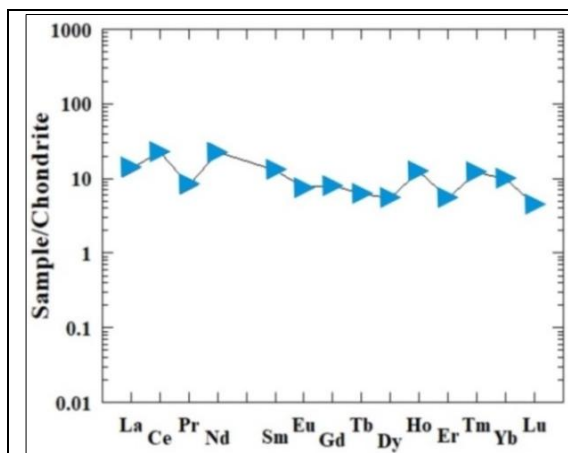


Fig. (18): Chondrite-normalized REE patterns of El Igla metagabbros (Sun and McDonough, 1989)

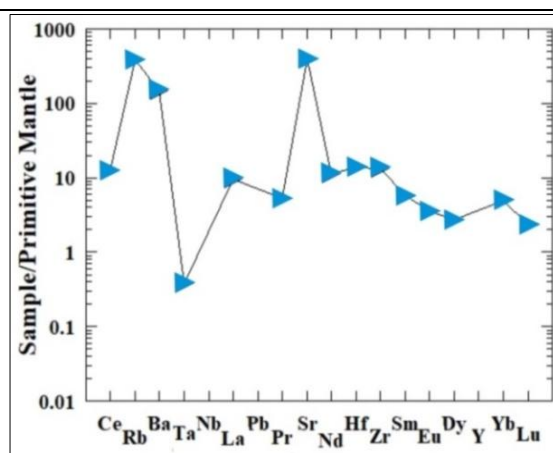


Fig. (19): Primitive mantle-normalized spider diagram of El Igla metagabbros of (Sun and McDonough, 1989).

4.2- Geochemistry of Metavolcanics

The geochemical characterization of the metavolcanic rocks at El Igla area is carried out through the study of the chemical composition of (9) selected samples representing, the outcrop of metavolcanic rocks at El Igla Iswid. All the selected samples were analyzed for their major, trace and rare earth element contents, as well as the CIPW norm values are computed (Table 3).

4.2.1- Major Element Characteristics

The studied samples (Table 3 & 4) showing high-alumina (Al_2O_3) contents ranging from 13 -15 wt% with an average 13.73, similar to those of calc-alkaline series rocks. Iron content (Fe_2O_3) seems to be relatively high ranging from 5.6- 11.2 wt%, with an average 8.97, and $\text{Fe}_2\text{O}_3/\text{MgO} = <2$ (1.53), this mean that high iron content reflect an abundant secondary opaque phase (magnetite). The studied samples show relative high abundance of CaO ranging from 5.4-13.4 wt% with an average 9.77, which may be related to the presence of epidote and non-intensive metamorphism [26]. There is abundance range of Na_2O (2.3 – 4.1 wt%), K_2O (0.15 – 0.97 wt %), and P_2O_5 (0.03–0.39 wt. %). The Cr abundances are generally high (105-496ppm)

Table (3): Major oxides, trace and rare earth elements analysis of El Igla Al Iswid metavolcanics, Central Eastern Desert, Egypt

Major oxides (Wt%)										
S.No.	V1	V 2	V 3	V 4	V 5	V 6	V 7	V 8	V 9	Aver.
SiO_2	50.2	49.5	49.3	51	50	51.1	50.4	52.1	49.3	50.32
TiO_2	2.5	1.7	1.3	0.82	0.67	0.16	0.15	2.3	2.5	1.34
Al_2O_3	14	14.1	12.5	13.4	13	13.7	15	14.9	13	13.73
Fe_2O_3	10	11.2	10.2	9.07	9.03	5.6	6.4	8	11.2	8.97
FeO	3.10	3.25	3.39	3.08	3.10	3.15	3.55	3.12	3.18	3.21
MnO	0.18	0.18	0.15	0.13	0.16	0.12	0.11	0.15	0.15	0.15
MgO	4.8	4.2	6	6.7	7.1	8.8	8.3	6.8	5.2	6.43
CaO	8.5	11	9.7	9.3	10.8	13.4	12.1	5.4	7.7	9.77
Na_2O	3.3	3.7	4.1	3.5	2.5	2.3	2.4	3.8	3.8	3.27
K_2O	0.97	0.29	0.21	0.15	0.33	0.34	0.45	0.72	0.85	0.48
P_2O_5	0.34	0.22	0.11	0.06	0.09	0.08	0.03	0.25	0.39	0.17
L.O.I	1.9	0.51	2.9	2.8	3.2	1.3	1.1	1.7	2.6	2.0
Total	99.79	99.85	99.86	100.0	99.98	100.0	99.99	99.24	99.87	-
CIPW norm										
Qz	7.18	5.28	2.25	5.93	7.33	2.90	2.64	7.16	5.14	5.09
Or	5.86	1.73	1.28	0.91	2.02	2.04	2.69	4.37	5.17	2.90
Ab	28.49	31.48	35.74	30.43	21.83	19.68	20.51	32.93	33.02	28.23
An	20.93	21.12	15.54	20.97	24.02	26.35	29.11	21.98	16.32	21.82
Di (wo)	8.40	12.26	13.96	10.92	12.87	16.91	13.12	1.67	8.60	10.97

Di (en)	7.24	10.57	12.04	9.41	11.09	14.04	10.48	1.44	7.42	9.30
Di (fs)	0.0	0.0	0.0	0.0	0.0	0.71	0.62	0.0	0.0	0.15
Hy (en)	5.02	0.0	3.43	7.82	7.25	8.24	10.14	15.99	5.95	7.09
Hy (fs)	0.0	0.0	0.0	0.0	0.0	0.42	0.58	0.0	0.0	0.11
Mt	3.40	6.17	7.88	8.20	8.85	8.22	9.38	3.97	3.58	6.63
He	7.87	7.02	5.08	3.68	3.22	0.0	0.0	5.46	9.04	4.60
Il	4.85	3.25	2.55	1.60	1.32	0.31	0.29	4.48	4.88	2.61
Ap	0.76	0.48	0.25	0.13	0.20	0.18	0.07	0.56	0.88	0.39
Trace elements (ppm)										
Ba	169	114	89	29	151	66	277	235	37	129.67
Sr	239	230	161	88	235	116	300	380	355	233.78
Rb	26	11	7	3.6	14	9	30	31	7.9	15.5
Nb	17	5.8	2.4	1.6	9.3	4.7	17	21	11.9	10.08
Y	46	35	27	25	45	13	36	40	69	37.33
Zr	214	117	75	45	69	17	241	245	278	144.56
Hf	18	10	11	9	8	5	19	18	20	13.11
Ga	17.8	17.4	14.5	15.2	3.2	12.2	9.4	3.5	6.5	11.08
Co	35.2	48.7	44.8	39	45	33	25	19	85	41.63
Ta	1.5	0.6	0.5	0.3	0.5	0.06	1	0.7	1.25	0.71
Zn	27	24	61	55	34	32	29	34	31	36.33
Ni	89	145	69	119	125	107	28	38	111	92.33
Cr	155	496	220	412	478	406	105	123	363	306.44
Cu	26	58	66	54	27	65	24	28	26	41.56
Pb	12	3.5	5.8	4.9	11	2.9	13	12	11	8.46
V	270	315	335	241	265	119	145	159	115	218.22
Sc	27	40	45	39	15	55	14	18	15	29.78
Au	1.6	1.5	1.2	0.9	2	1.5	0.9	1	0.6	1.24
Ag	0.6	1	0.9	1.1	0.8	1	0.9	1	0.7	0.89
Rare earth elements (ppm)										
La	18.3	4.8	2.5	1.4	9.2	0.6	20	12	14	9.2
Ce	44.1	17.3	9	5.2	1.4	19	30.1	102	105	37.01
Pr	5.14	2.91	1.43	0.77	0.27	0.31	4.6	4.5	5.8	2.86
Nd	25.8	14.7	9.90	5.40	4.80	6.90	19.3	18.9	13.7	13.27
Sm	5.3	3.7	2.5	1.5	0.24	0.27	0.30	4	3.5	2.37
Eu	1.22	1.40	0.98	0.55	0.15	0.19	0.15	1.98	2.65	1.03
Gd	5.74	3.92	3.80	3.18	1.37	1.44	1.98	6	4.46	3.54
Tb	1.10	0.91	0.70	0.45	0.09	0.10	0.08	1.89	0.97	0.70
Dy	5.2	5.2	4.6	2.6	0.53	0.85	1	6.11	3.98	3.34
Ho	1.31	1.20	1.13	0.98	0.13	0.19	1.11	1.09	1.54	0.96
Er	2.38	3.44	2.97	1.79	0.37	0.40	1.10	2.57	3.54	2.06
Tm	0.51	0.50	0.48	0.36	0.08	0.09	0.09	0.48	0.55	0.35
Yb	1.98	2.14	3.83	2.60	1.33	1.38	0.98	2.87	3	2.23
Lu	0.47	0.48	0.49	0.27	0.16	0.19	0.39	0.30	0.55	0.37
ΣLRE E	105.6	48.73	30.11	18	17.43	28.71	76.43	149.3 8	149.1 1	69.28
ΣHRE E	12.95	13.87	14.2	9.05	2.69	3.2	4.75	15.31	14.13	10.02

Table (4): Some parameters and ratios of the studied metavolcanics at
El Igla Al Iswid metavolcanics

	V1	V2	V3	V4	V5	V6	V7	V8	V9	Aver.
A/CNK	1.1	0.94	0.89	1.03	0.95	0.85	1	1.5	1.05	1.03
A/NK	3.28	3.53	2.9	3.67	4.59	5.19	5.26	3.3	2.8	3.84
Na ₂ O+K ₂ O Alkalies	4.27	3.99	4.31	3.65	2.83	2.64	2.85	4.52	4.65	3.75
Na ₂ O/K ₂ O	3.4	12.76	19.52	23.33	7.58	6.76	5.33	5.28	4.47	9.83
Fe ₂ O ₃ /MgO	2.08	2.67	1.7	1.3	1.27	0.64	0.77	1.18	2.15	1.53

FeO ^t	13.1	14.45	13.59	12.15	12.13	8.75	9.95	11.12	14.38	12.18
MgO+FeO ^t	17.9	18.65	19.59	18.85	19.23	17.55	18.25	17.92	19.58	18.61
FeO ^t /MgO	2.73	3.44	2.27	1.81	1.71	0.99	1.2	1.64	2.77	2.06
FeO ^t /(MgO+FeO)	1.66	1.94	1.45	1.24	1.19	0.73	0.84	1.12	1.72	1.32
DI	41.5									
	3	38.49	39.27	37.27	31.18	24.62	25.84	44.46	43.33	36.22
Y/Nb	2.71	6.03	11.25	15.63	4.84	2.77	2.12	1.91	5.8	5.90
Nb/Y	0.37	0.17	0.09	0.06	0.21	0.36	0.47	0.53	0.17	0.27
La/Ce	0.42	0.28	0.28	0.27	6.57	0.03	0.66	0.12	0.13	0.97
La/Y	0.39	0.14	0.09	0.06	0.2	0.05	0.56	0.3	0.2	0.22

4.2.2- Geochemical Classification

Silica (SiO₂) contents of El Igla metavolcanics confirm that they are dominantly andesite/basalt (SiO₂= 49.3–52.1wt %). On the Zr/TiO₂ vs. Nb/Y classification diagram (Fig. 20), the El Igla metavolcanics plot dominantly in the andesite/basalt with minor rhyolite/dacite field, whereas the two samples straddle the rhyolite/dacite boundary.

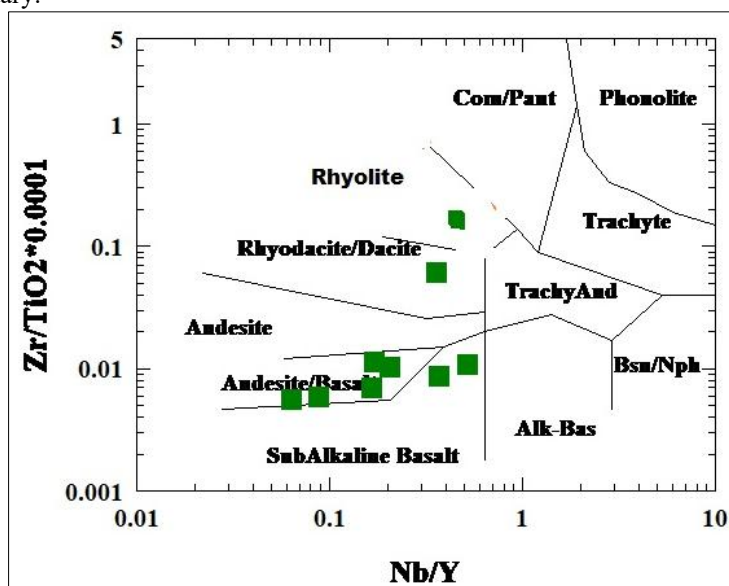


Fig. (20): Zr/TiO₂ vs. Nb/Y geochemical classifications of El Igla metavolcanics, (Winchester and Floyd, 1977).

4.2.3- Magma Type and Tectonic Setting

On the FeO^t/MgO vs. SiO₂ diagram [27] of El Igla metavolcanics occupy the tholeiitic field (Fig. 21). On the TiO₂ vs. SiO₂ diagram (Winchester and Max, 1984) and the P₂O₅/TiO₂ vs. MgO/CaO diagram [28], both discriminated diagrams showed El Igla metavolcanics as of magmatic origin, (Figs. 22 & 23).

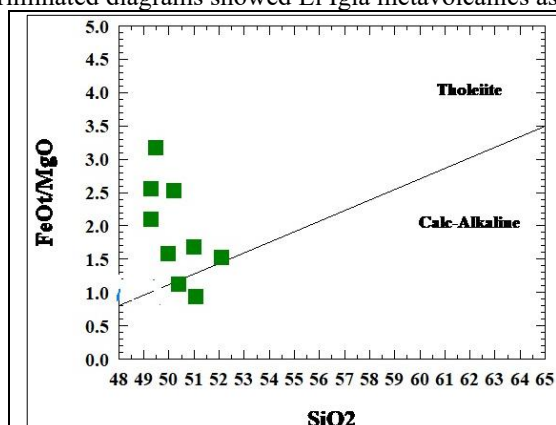


Fig. (21): FeO^{*}/MgO vs. SiO₂ diagram (Miyashiro, 1974).

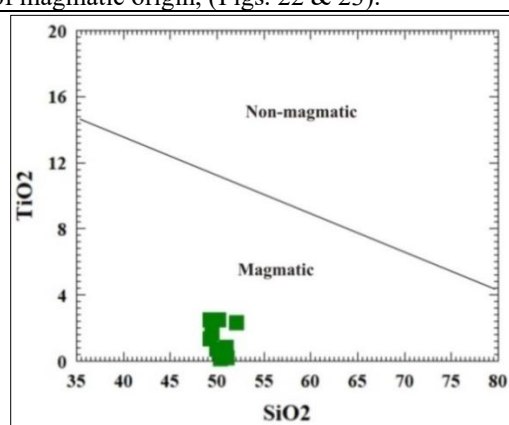


Fig. (22): SiO₂ vs. TiO₂ diagram between magmatic and non-magmatic rocks. (Winchester and Max, 1984),

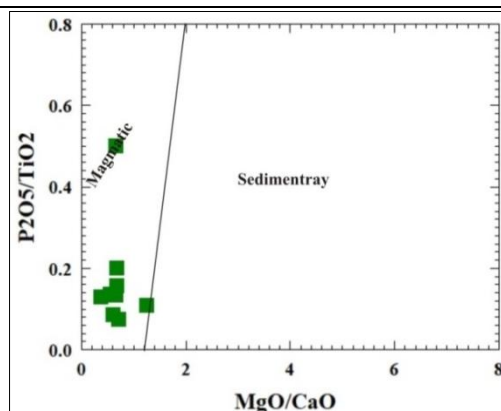


Fig. (23): MgO / CaO vs. P₂O₅ / TiO₂ diagram for discriminating between magmatic and sedimentary rocks (Werner, 1987).

4.2.4- Chemical Alteration and Element Mobility

The all selected samples of El Igla metavolcanics are altered to some extent due to the low-grade metamorphism and/or extensive deformations, reflected to the concentrations of the mobile elements and the moderate loss of ignition (LOI) values (Table 3). The present-day geochemical signature of metavolcanics may not be the same as the protoliths at the time of formation [29, 30]. Therefore, to illustrated the alteration effects of metamorphism and deformation, it can noticed element mobility through some major and trace elements against Silica (SiO₂ wt%). Harker variation diagrams [31], which show that compatible major oxides (MgO, TiO₂, FeO, MnO, Al₂O₃), P₂O₅ and CaO (Fig. 24), have a normal, correlated and continuous differentiation trends, as they tend to decrease systematically with SiO₂ increases.

From Harker diagram (Fig. 25), Sr, Ni, Zr, Y, Ba and Cr demonstrate no clear variation with SiO₂, where they remain nearly unchanged, thus they were probably immobile during metamorphism and other alteration processes.

It is evident from figures (24 & 25), that, in spite of the low-grade metamorphism and deformation, some major and trace element signatures can be used for deciphering the original protoliths and tectonic environment.

Some major element concentrations span a wide compositional range of MgO (4.2-8.8 wt%) and MnO (0.11-0.18 wt%) with narrow compositional range of SiO₂ (49.3–52.1 wt %), suggesting diverse protolith (Table 3).

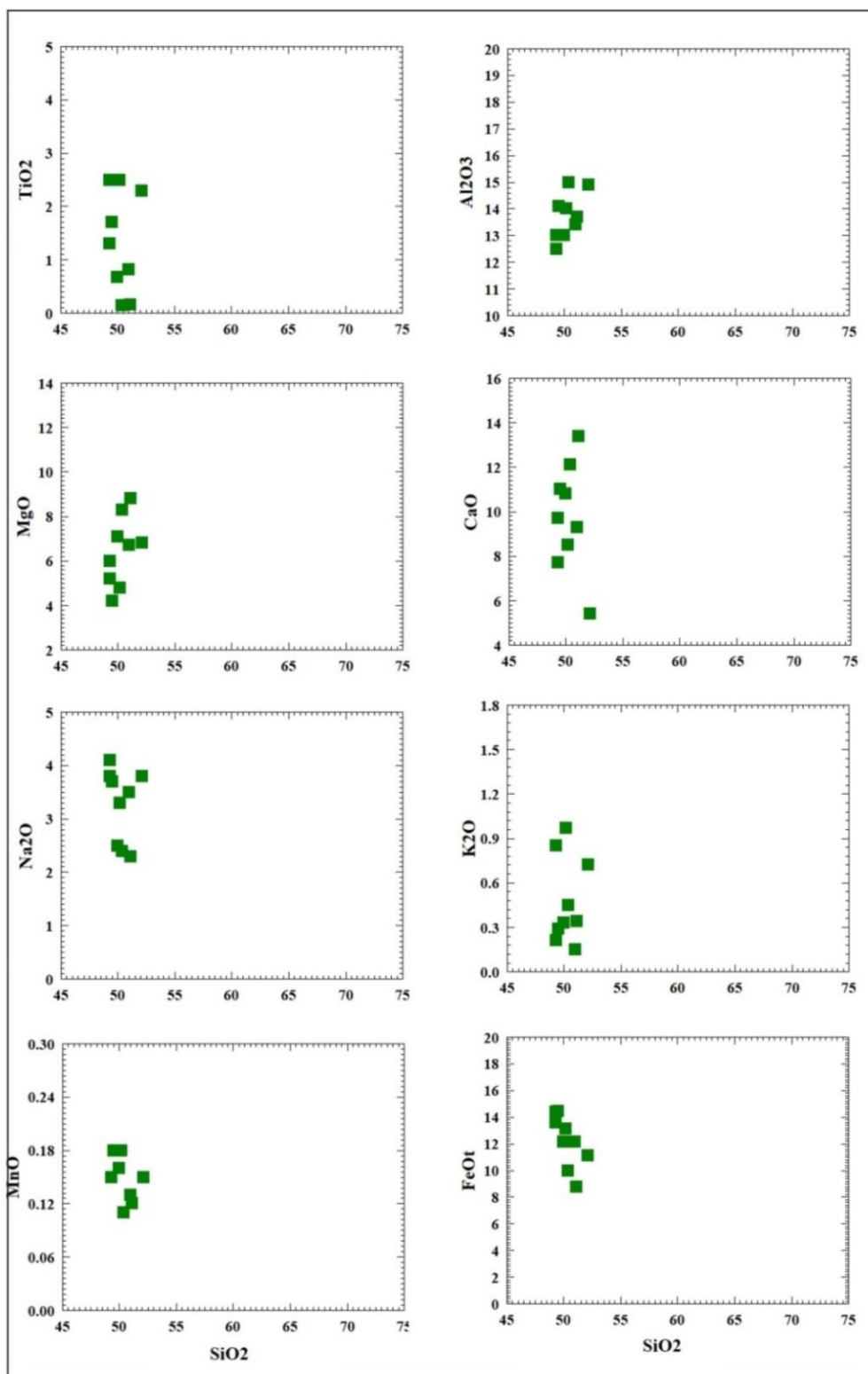


Fig. (24): Harker variation diagrams; silica (SiO₂ wt%) plotted against a range of major (wt%) of El Iгла metavolcanics.

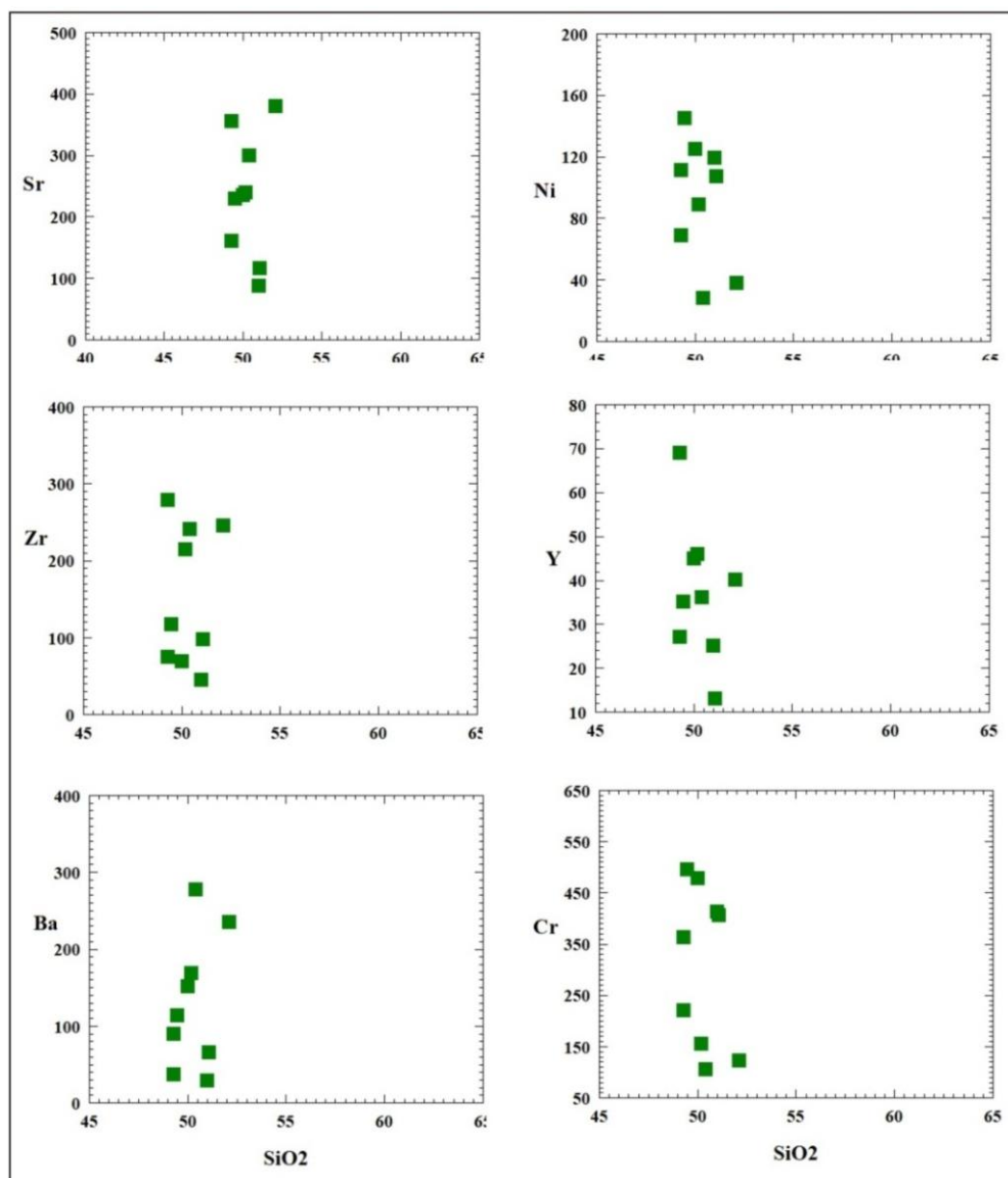


Fig. (25): Harker variation diagrams; silica (SiO₂ wt%) plotted against a range of trace elements (ppm) of El Igla metavolcanics.

4.2.5- Magma Characterization

The TiO₂ values are generally average (1.34), therefore they are in the range accepted in alkaline to calc-alkaline lavas [32, 33].

From table (5), the La/Sc ratios (0.03-6.57 with an average 0.97 ppm), the ratios of Y/Nb, and Nb/Y fall in the range between 1.91-15.63ppm with an average 5.90ppm and 0.06 – 0.53 ppm with an average 0.27ppm, respectively. The Nb/Y and La/Sc ratios are mostly < 1.0 and La/Y (0.05-0.56) with an average 0.22), implying possible approach to calc-alkaline and alkaline affinities [34].

On the SiO₂ vs. (Na₂O+K₂O) discrimination diagram [32], most plotted samples of El Igla metavolcanics fall in sub-alkaline to alkaline field (Fig. 26). K₂O vs. SiO₂ [35], which straddle the tholeiitic and calc-alkaline boundaries indicate that the petrochemical composition of metavolcanic rocks fall within the calc-alkaline field (Fig. 27).

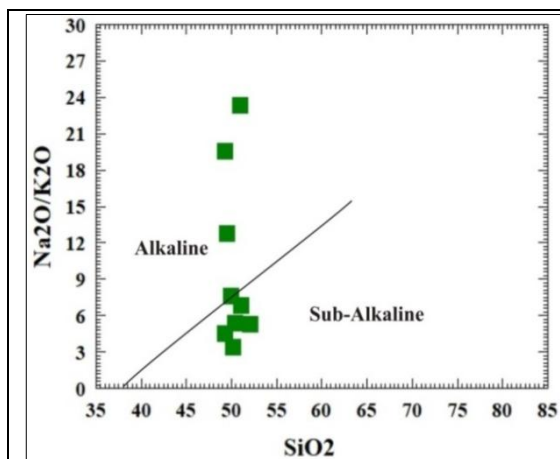


Fig. (26): SiO₂ vs. (Na₂O + K₂O) plot series boundaries (after Irvine and Baragar, 1971)

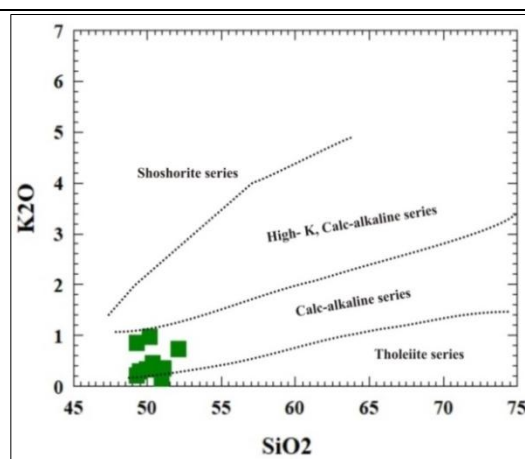


Fig. (27): SiO₂ vs. K₂O, plot series boundaries (after Peccerillo and Taylor, 1976)

4.4.6- Geotectonic Setting

In the trace and rare earth elements content (Table 5), the abundances of Sr (88-380 ppm), Y (13-69 ppm) and La (0.6-18.3 ppm), Nb (1.6-21 ppm), Ba (29-277 ppm), Ni (28- 145 ppm) and Zr (17- 278 ppm), is generally low-high, this feature suggesting the generation of these rocks arc-Island [36]. Plotting the immobile elements on the Zr vs. Y diagram [37], indicate that all samples discriminated as subduction-arc related rocks (Fig. 28).

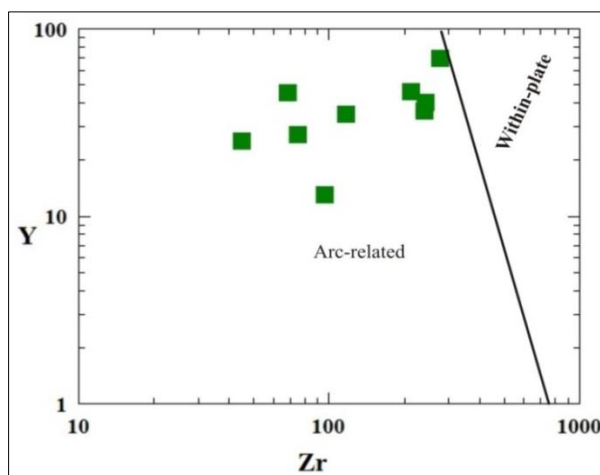


Fig. (28): Zr vs. Y Biaxial geochemical discrimination diagram indicating the subduction-arc features (Müller, et al., 2001)

In the chondrite-normalized REE pattern [38], all the analyzed El Igla metavolcanic samples display enrichment in fractionated light rare earth element (LREE: La, Ce, Pr, Nd and Sm) contents relative to heavy rare earth elements (HREE: Tb, Dy, Ho, Er, Tm, Yb and Lu) contents (Fig. 29). The Pattern is generally steep, moderately strong enrichment right-inclined type and lack Eu-anomalies similar to those from calc-alkaline to alkaline series. In the multi-element diagram normalized to primitive mantle [39], the data shows that El Igla metavolcanics possess a typical calc-alkaline island arc trace element patterns, enriched incompatible large ion lithophile elements (LILE: Sr & Ba) relative to high field strength elements (HFSE: Zr, Hf, Y, & Nb) contents, that show a negative Nb anomaly (Fig. 30).

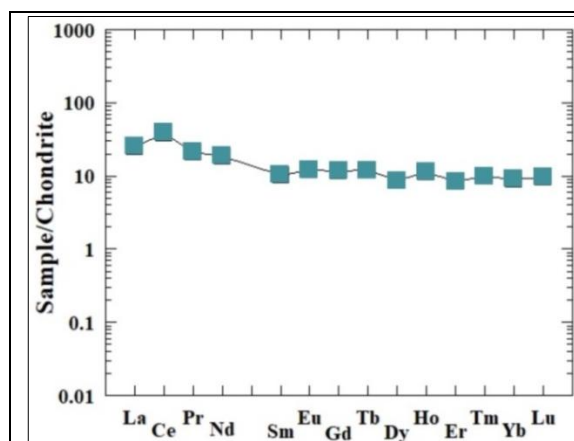


Fig. (4-48): Chondrite-normalized REE patterns of El Iгла metavolcanic (Sun and McDonough, 1989)

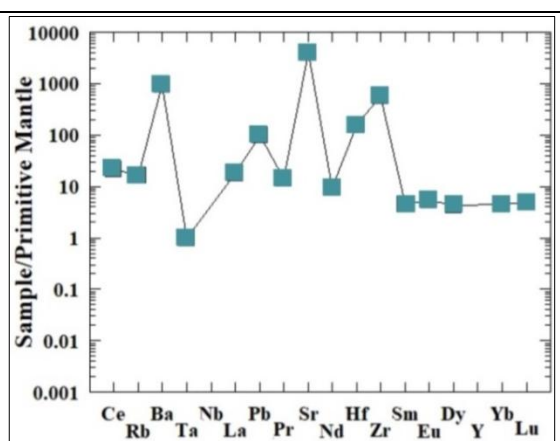


Fig. (4-49): Primitive mantle-normalized spider diagram of El Iгла metavolcanic (McDonough and Sun, 1995).

V. Discussion and Conclusion

From field observations;

- El Iгла metagabbros occurring as small to big outcrops, they are medium to coarse-grained and greenish grey to pale green in color. The ophiolitic metagabbros are found as small fragments and blocks associated with serpentinites forming low to moderately relief and composed of plagioclase, amphibole and pockets of hornblende.
- El Iгла metavolcanics are exposed and comprise a heterogeneous of grey to green assemblages. They are coarse to medium grained and they are frequently interleaved with variably altered ultramafics (serpentinites) in the form of wedges and slices, with sharp tectonic contacts. El Iгла metavolcanics are classified into meta-andesite, meta-basalt and meta-dacite rocks.

From petrographic view;

- El Iгла metagabbros show ophitic to subophitic texture with calic pyroxenes and plagioclase as the major components. The alteration of El Iгла metagabbros led to formation pyroxene, amphibole and actinolite.
- In El Iгла metavolcanics, meta-andesite is composed essentially of plagioclase, hornblende and pseudomorphs chlorite. The accessory and secondary minerals are iron oxides, calcite, epidote and interstitial quartz. Meta-basalt is mainly composed of micro-phenocrysts of plagioclase, pyroxene and quartz set in fine-grained groundmass exhibiting intersertal texture. Meta-Dacite is composed predominantly of plagioclase, quartz and biotite. They have a fine grained aphanitic to porphyritic texture.

From geochemical view;

- In El Iгла metagabbros, the original magma was primitive and tholeiitic to calc-alkaline in nature. They are fall in MORB type field and formed as a result of partial melting of mantle spinel peridotite that has been metasomatized by fluids dehydrated from a subducted slab. They are characterized by relatively parallel REE patterns with depletion of heavy rare earth elements ($\Sigma\text{HREE}=7.91$) and enrichment in light rare earth elements ($\text{LREE}=49.79$) with $[(\text{La}/\text{Yb})_n=1.17-2.06]$.
- In El Iгла metavolcanics, some major elements have wide compositional range of MgO (4.2-8.8 wt%) and MnO (0.11-0.18 wt%) with narrow compositional range of SiO_2 (49.3–52.1wt %), suggesting diverse protolith. The La/Sc ratios (0.03-6.57 with an average 0.97 ppm), the ratios of Y/Nb, and Nb/Y fall in the range between 1.91-15.63ppm with an average 5.90ppm and 0.06 – 0.53 ppm with an average 0.27ppm, respectively. The Nb/Y and La/Sc ratios are mostly < 1.0 and La/Y (0.05-0.56) with an average 0.22), implying possible approach to calc-alkaline and alkaline affinities with island arc setting.

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