

GEOCHEMISTRY, MINERAL CHEMISTRY AND TECTONIC SETTING OF THE OLDER GRANITOIDS FROM EAST OF EL-TOR, SW-SINAI, EGYPT

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ABSTRACT

The older granitoids of Wadi Hibran-Wadi Mear, East of El-Tor constitute the westernmost outcrops of the granitic intrusion of Sinai massif of Egypt. They intrude small masses of gneisses and are, in turn, invaded by huge masses of younger granites and crosscut by mafic and felsic dyke swarms.

They consist of trondjemite-granodiorite (TR-GD) suite and belong to the low- to medium K calc-alkaline series. The TR suite comprises quartz-diorite, quartz monzodiorite and tonalite, meanwhile the GD suite includes proper granodiorite.

Amphiboles are calcic-type and vary in composition from magnesio-hornblende in TR to ferroedenitic hornblende in GD. Amphiboles from more evolved rock-types contain higher values of mg [Mg/(Mg+Fe) ratio] than those of the coexisting biotites. Biotite mg-values decrease with increase Si from TR to GD rocks. Chemical parameters of amphiboles, biotites and plagioclases indicate a pressure less than 5 Kb. and temperature of about 700-850 °C for the host TR-GD suite.

Based on REE geochemistry, the older granitoids show two different types of REE patterns; A) less differentiated type represented by TR suite and B) differentiated type related to GD suite. The less differentiated type has REE distribution patterns marked by positive Eu anomaly, whereas the differentiated type has wide range of total REE abundance and displays negative Eu anomaly. Both of them have smooth concave REE distribution patterns. These patterns are fairly similar to the models involving partial melting of eclogite/quartz eclogite parents.

Tectomagmatic setting reveals that the present granitoids belong to two calc-alkaline mafic magmas emplaced through a pre-plate collision to post-collision regime. They are highly comparable with the volcanic arc granites of active continental margin.

INTRODUCTION

The Wadi Hibran-Wadi Mear area lies at the western sector of the basement rocks of the Sinai massif. It is occupied by old granitoid rocks. Old granitoids previously referred to as „Old”, „Shaitian”, „Grey” or „Syn-tectonic”. HUSSEIN et al. (1982) believe that the majority of the older granitoid plutons are subduction related granodiorite and closely associated island arc andesites. NOWEIR et al. (1990) subdivided the Egyptian Older Granites into three types namely, normal-, gneissic-, and Shaitian type older granites and closely associated with mature island arc. On the basis of the age dating the Egyptian Older Granitoids are subdivided into three events of igneous activity (HASSAN and HASHAD, 1990). These are Shaitian (800 and 850 Ma), Hafafit (670 and 710 Ma) and Meatiq event (630 and 610 Ma).

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The granitoid rocks of the present area correspond to grey/older granites of EL-RAMLY and AKAAD (1960), syn-orogenic granites of EL-GABY (1975), G 1 granites of HUSSEIN et al. (1982), and calc-alkaline, autochthonous and para-autochthonous granites of EL-GABY et al. (1988). The studied granitoids were described by El-Mezayen et al. (1994) as calc-alkaline, metaluminous, post collisional uplifting older granitoids.

Petrography are concerned with 45 samples; modal analyses were carried out on 16 selected samples (average point counts $c = 4500$). Chemical analyses for major elements (13 samples) were determined by standard wet chemical technique method. Twenty seven chemical analyses of plagioclases (6), amphiboles (9) and biotites (12) have been carried out using standard Amray-1830 I electron microprobe under operating condition of 20 Kv and 1-2 nA. In most cases core and rim composition were determined for mineral grains. The chemical analyses for the minerals and rocks were done at the Department of Petrology and Geochemistry, Eötvös University of Budapest. Also, six of these samples were analysed for the trace as well as the rare-earth elements using the standard INAA at Atomic Reactor of Technical University, Budapest, Hungary.

GENERAL GEOLOGY

The older granitoids east of El-Tor constitute the extremely western outcrops of granitic intrusion of the Sinai massif. They occupy about 55 square Km area extending from Wadi Hibran in the north to Wadi Mear in the south (*Fig. 1*). The older granitoids are medium to coarse grained equigranular to porphyritic textures. The plutons cover a compositional spectrum ranges from tonalite, trondhjemite to granodiorite. The tonalite is passing locally into trondhjemitic and granodioritic equivalents with gradational contacts. The rocks are sometimes foliated and greissose. In certain area, specially near the batholith borders, the granitoids form ragged terrains and high relief. They contain abundant xenoliths, rafts and bands of the country rocks of more mafic composition. These inclusions are variable in sizes and stages of digestion and decrease in their abundance away from the hill borders.

The older granitoid rocks intrude a small masses of gneiss with sharp and mylonitized contacts. The composition of gneiss ranges from diorite to granodiorite. The present granitoids are, in turn, intruded by huge masses of younger granites and cut by various dyke swarms ranging from basic to acidic in composition. These dykes strike NNE-SSW, NE-SW and ENE-WSW trends. The present plutons are jointed in different directions, mostly NE-SW and NW-SE trends. The main faults traversing the plutons have NNE-SSW and NNW-SSE trends.

CLASSIFICATION AND MINERAL CHEMISTRY

The trondhjemite-granodiorite suite exhibit a wide range of mineralogical and textural variations. The modal mineral percentage of 16 selected samples are given in Table 1. In STRECKEISEN's (1976) AQP diagram (*Fig. 2*) the studied rock-types are given by tonalite, quartz-diorite, granodiorite and quartz-monzodiorite. According to the evolutionary trends proposed by LAMEYER and BOWDEN (1982) the studied granitoids are calc-alkaline type and belong to (1). The trondhjemite (TR) suite (low-K): quartz diorite and tonalite and (2). The granodiorite (GD) suite (medium-K): granodiorite and quartz monzodiorite (*Fig. 2*).

TABLE I

Modal analyses of the studied granitoids

	Samp. no.	Plag.	Hornb.	Biot.	Quartz	K-feld.	Access.
Trondhjemite suite	1	54.6	1.7	14.9	26.7	2.0	0.1
	2	61.5	2.1	16.2	17.9	1.9	0.3
	3	65.0	12.6	10.1	11.7	0.1	0.6
	4	67.5	2.3	10.7	19.2	0.3	0.2
	5	73.2	2.0	10.3	14.0	0.2	0.4
	6	74.5	13.9	4.3	4.7	1.7	0.8
Granodiorite suite	7	50.0	14.2	10.8	13.3	13.0	0.7
	8	52.8	17.0	8.0	10.0	11.9	1.3
	9	52.9	5.5	8.7	15.5	15.7	1.7
	10	53.6	13.4	5.5	11.0	14.5	2.0
	11	54.5	5.3	15.2	12.5	12.0	0.5
	12	55.2	7.6	9.7	15.4	11.6	0.5
	13	55.5	2.0	4.2	23.5	13.5	1.3
	14	55.6	12.3	7.3	11.6	12.2	1.5
	15	56.5	2.5	9.0	18.0	13.0	1.0
	16	59.5	17.0	6.3	4.2	12.7	0.3

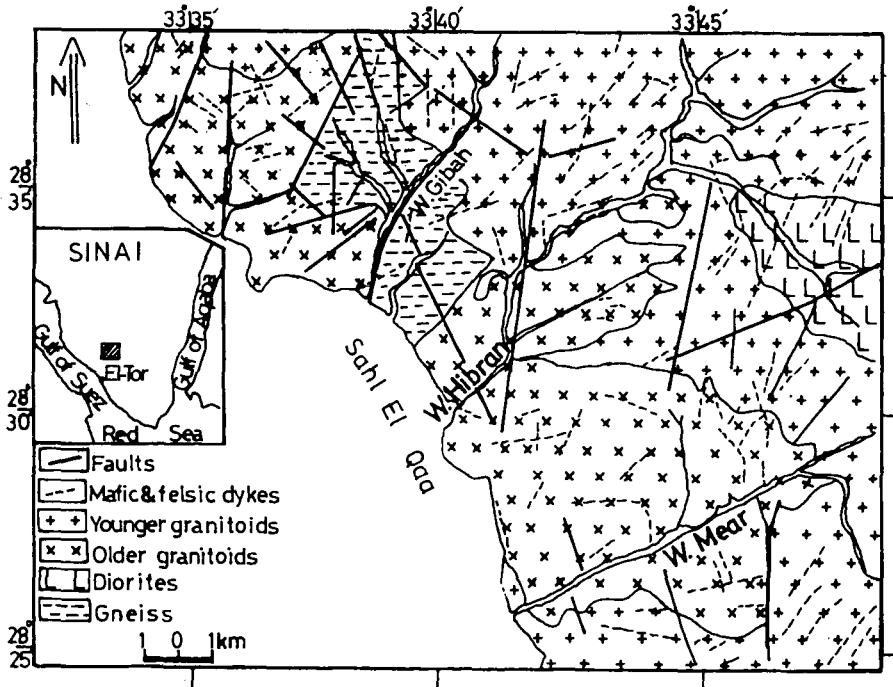


Fig. 1. Geological map of the Wadi Hibran-Wadi Mear area, East of El-Tor, Southern Sinai (modified after EL MEZHEN et al., 1994)

On the chemical classification diagram (Fig. 3) of DEBON and LA FORT (1983), the TR suite correspond to quartz diorite, quartz monzodiorite and tonalite while GD suite fall within the granodiorite field. Moreover, on the normative classification diagram (Fig. 4) of BARKER (1979), the TR suite fall in the trondhjemite and tonalite fields whereas the GD suite fall within the granodiorite field.

The TR suite is characterized by gneissic and poikilitic textures, whereas the GD is marked by perthitic, poikilitic and myrmekitic textures. Mafic mineral contents are about 22.4 vol. % and 17.3 vol. % in the TR and GD suite relatively. Accessory minerals are zircon, titanite, apatite and iron oxide minerals. Secondary minerals are chlorite and prehnite.

Plagioclase is an early-crystallized phase. It is represented by prismatic subhedral to euhedral crystals up to 3.3x4.7 mm belonging to polyphase generation as evidence by the wide difference in crystal sizes, their degree of alteration and the reaction rims between the adjacent plagioclase crystals.

The averages of microprobe analyses of 2 plagioclase grains are given in Table 2. Their composition ranges between oligoclase (Or_{3.9} Ab_{66.5} An_{29.6}) in TR suite and andesine (Or_{2.5} Ab_{65.5} An₃₂) in GD member respectively (Table 2). Plagioclase reveals both primary and secondary zonation. It is slightly sericitized probably due to hydrothermal alteration, and alkali metasomatic processes belonged to the intrusion of the adjacent younger granites.

Amphibole occur as subhedral crystals up to 0.6x1.5 mm, mostly pleochroic from yellow green to green or from greenish brown to green colour. Amphibole percentage decreases from GD to TR member. Occasionally amphibole crystals are present in cluster form and corrode the older plagioclase. The cluster in TR suite is morphologically elongated parallel to the gneissosity plains. Hydrothermal fluids partly affected amphibole. The alteration of amphibole into chlorite and epidote results in liberation of iron oxide seen scattered in amphibole. Quartz is poikilitically enclosed in amphibole crystals indicating that most amphibole crystallized under silica-saturated condition.

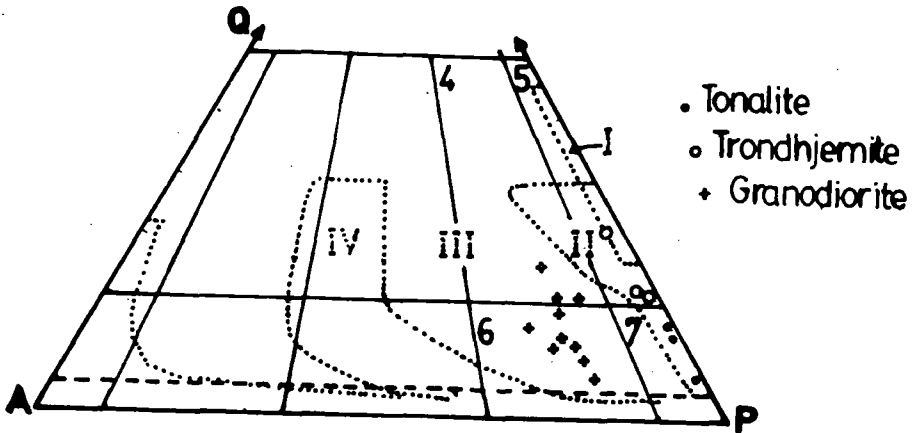


Fig. 2. Modal AQP diagram showing the classification of the studied older granitoids (after STRECKEISEN, 1976). 4 = granodiorite, 5 = tonalite, trondhjemite, 6 = quartz-monzodiorite and 7 = quartz-diorite. Fields of various granitoid suites: I = tholeiitic, II = calc-alkaline trondhjemitic (low-K), III = calc-alkaline granodioritic (medium-K) and IV = calc-alkaline monzonitic (high-K) after LAMEYER and BOWDEN (1985).

TABLE 2

Averages of microprobe analyses of the studied granitoids

Samp. no.	Plagioclases		Amphiboles			Biotites					
	2 (Av. 3) TR	3 (Av. 3) GD		1 (Av. 3) TO	2 (Av. 3) TR	3 (Av. 3) GD		4 (Av. 3) TO	1 (Av. 3) TO	2 (Av. 3) TR	3 (Av. 3) GD
Si ₂ O	61.91	59.38	SiO ₂	49.10	46.10	44.26	SiO ₂	35.36	36.12	35.77	36.37
Al ₂ O ₃	22.98	27.34	TiO ₂	0.53	0.59	1.53	TiO ₂	3.83	3.80	3.92	3.62
CaO	6.13	5.85	Al ₂ O ₃	4.57	7.42	7.89	Al ₂ O ₃	13.66	13.25	13.68	14.32
Na ₂ O	7.43	6.60	FeO ^I	18.59	20.02	20.72	FeO ^I	21.32	21.70	23.30	23.16
K ₂ O	0.68	0.39	MnO	0.80	0.47	0.54	MnO	0.26	0.29	0.25	0.21
Total	99.23	99.56	CaO	12.53	11.66	11.34	CaO	0.00	0.00	0.05	0.00
			MgO	11.72	10.39	8.90	MgO	10.05	10.66	8.92	8.91
Si	2.772	2.637	Na ₂ O	0.00	1.17	1.94	Na ₂ O	0.00	0.00	0.47	0.38
Al	0.228	0.363	K ₂ O	0.34	0.51	0.79	K ₂ O	9.50	9.31	9.76	9.11
Al	0.980	1.074	Total	98.18	98.33	97.91	Total	95.28	95.13	96.12	96.39
Ca	0.294	0.279									
Na	0.661	0.570	Si	7.204	6.818	6.710	Si	5.544	5.568	5.567	5.637
K	0.039	0.022	Al ^{iv}	0.785	1.182	1.290	Al ^{iv}	2.453	2.445	2.443	2.363
			Al ^{vi}	0.006	0.112	0.118	Al ^{vi}	0.027	0.000	0.077	0.231
Or	3.89	2.53	Ti	0.060	0.065	0.175	Ti	0.443	0.442	0.458	0.418
Ab	66.53	65.51	Fe ³⁺	0.670	0.769	0.506	Fe ³⁺	2.831	2.923	3.034	2.644
An	29.58	31.96	Fe ²⁺	1.612	1.679	2.120	Fe ²⁺	0.003	0.010	0.000	0.000
			Mn	0.100	0.057	0.071	Mn	0.034	0.039	0.032	0.028
			Ca	1.970	1.849	1.796	Ca	0.000	0.000	0.008	0.000
			Mg	2.564	2.291	2.011	Mg	2.538	2.453	2.070	2.044
			Na	0.000	0.336	0.569	Na	0.000	0.000	0.140	0.112
			K	0.064	0.151	0.153	K	1.801	1.835	1.939	1.785
			Mg	0.529	0.514	0.434	Mg	0.449	0.456	0.409	0.406

1, 2, 3, etc. = Sample numbers, TO = Tonalite, TR = Trondhjemete, GD = Granodiorite.

Plagioclase ion number on the basis of 8 oxygens.

Amphibole ion number on the basis of 23 oxygens.

Biotite ion number on the basis of 22 oxygens.

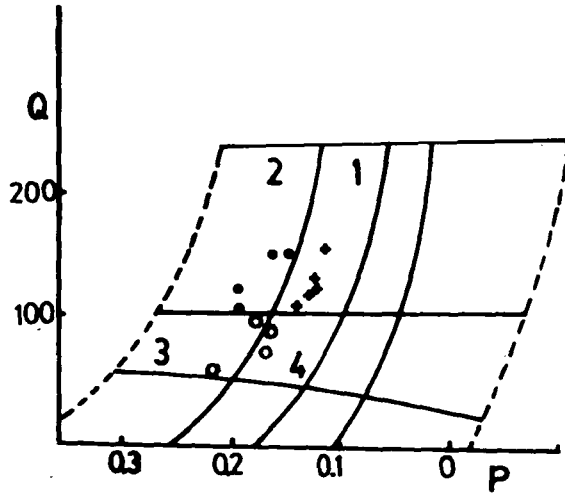


Fig. 3. Q ($\text{Si}/3 \cdot [\text{K} + \text{Na} + 2\text{Ca}/3]$)-P ($\text{K} \cdot [\text{K} + \text{Na}]$) chemical variation diagram (after DEBON and LA FORT, 1983) for the studied granitoids. 1 = granodiorite, 2 = tonalite, 3 = qz-diorite, 4 = qz-monzodiorite.

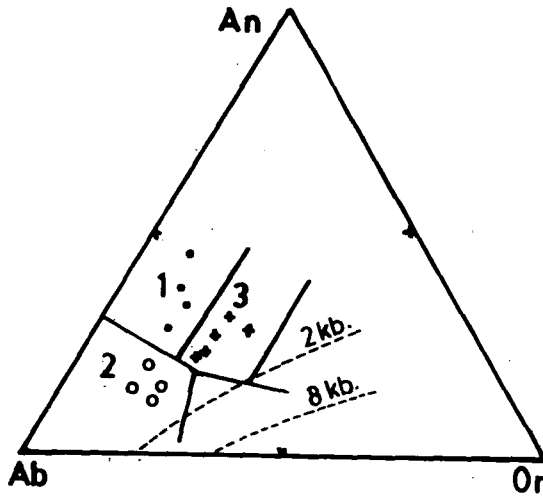


Fig. 4. Ó'Connor Ab-An-Or classification diagram (after BARKER, 1979). 1 = tonalite, 2 = trondhjemite, 3 = granodiorite. Water saturated peritectic compositions at 2 and 8 Kb are after WHITNEY (1975).

The averages of microprobe analyses of 3 amphibole grains are given in Table 2. The studied amphibole is classified according to the content of $(\text{Na} + \text{K})_{\text{A}}$, Ti, Fe^{3+} , Al^{vi} of LEAKE (1978) diagram (Fig. 5) into calcic amphibole. It is corresponded to magnesio-hornblende in TR suite (Fig. 5a) and ferro-edenitic hornblende in GD suite (Fig. 5b). The occurrence of magnesio- and edenitic hornblende possibly indicate that this amphibole was formed at about 700-750 °C (HENDERSON et al., 1989). On the Al^{vi} -Si and Ti-Al variation diagrams of RAASE (1974) and HYNES (1982), this hornblende corresponds to low-pressure amphibole (Fig. 6a and b) suggesting that it is slightly overprinted by greenschist-lower amphibolite facies. The present calcic amphibole is

probably crystallized under pressure lower than 5 Kb (RAASE, 1974). Moreover, the variation of Al^{VI} relative to Si of Ca-amphibole (Fig. 6a) revealed a negative correlation in amphibole from TR to GD suite. While a positive relation is deduced from the plot of Ti versus Al of this amphibole (Fig. 6b). The partitioning of mg-values between amphibole and biotite reveals that amphibole contains higher proportion of Mg-content than the biotite (Fig. 7). Amphibole from tonalite and trondhjemite rock types have high mg-values relative to the granodiorite rocks probably consistent with the classic progressive differentiation trend from tonalite to granodiorite.

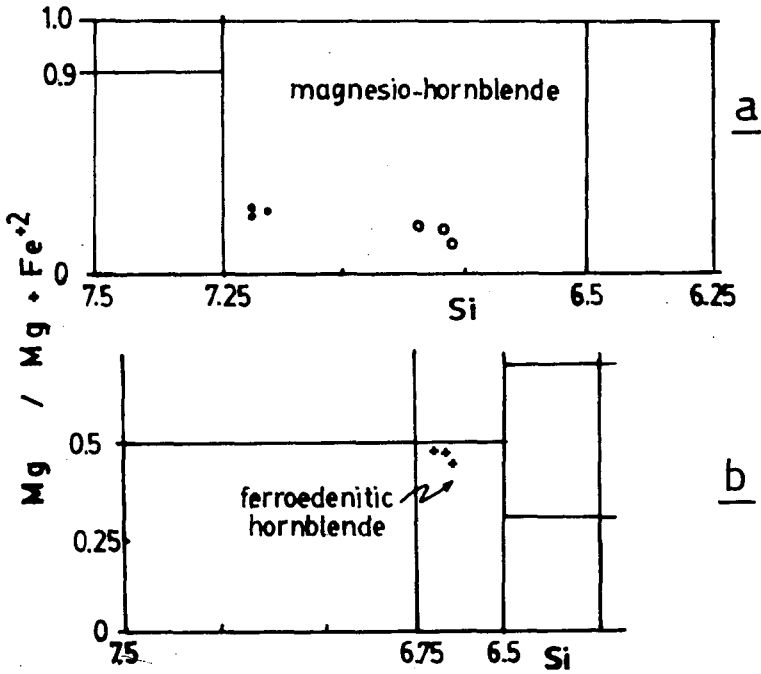


Fig. 5. Classification of the studied calcic amphiboles (after LEAKE, 1978): a) $(Na+K)_A > 0.5$, $Ti < 0.5$, $Fe^{3+} < Al^{VI}$ and b) $(Na+K)_A < 0.5$, $Ti < 0.5$.

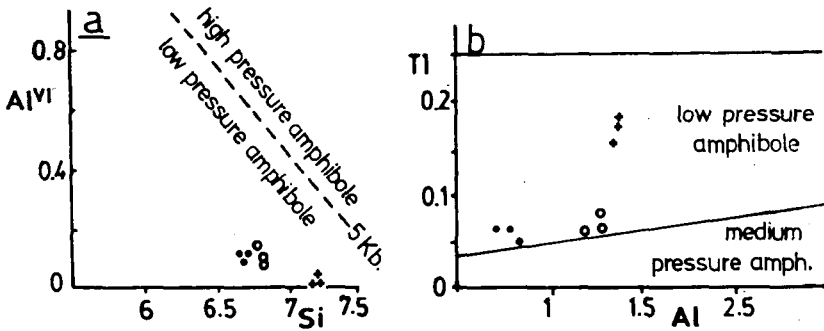


Fig. 6. Plots of hornblendes from studied granitoids in a) Al^{VI} -Si diagram (after RAASE 1974) and b) Ti-Al diagram (after HYNES, 1982) for comparison

Biotite forms fine flakes up to 2.2x1.2 mm, intergrows with amphibole and quartz, and is usually associated with apatite, iron oxide and zircon. Some biotite flakes are fresh, while others are intensively altered and interleaved by chlorite. Biotite is sometimes arranged with their long axes showing marked parallelism imparting the rock a gneissose texture as in TR suite.

The averages of microprobe analyses of 4 biotite grains are given in Table 2. The chemical data are plotted in FeO-MgO-Al₂O₃ diagram (Fig. 8). On this diagram, the biotite samples correspond to the metamorphic-metasomatic type (NOCKOLDS, 1947; GOKHALE, 1968) and belong to biotite coexisting with hornblende (NOCKOLDS, 1947). The Gd suite has higher contents of the coexisting biotite relative to that from TR suite suggest a more differentiation of the granodiorite. The plot of the mg [Mg/(Mg+Fe)] versus Si (Fig. 9) reveals two separate plots for the present granitoids. The mg-values of the coexisting biotite decrease with increase of Si for the tonalite in one hand, and constant with increase of Si for TR to GD rocks, on the other hand. Moreover, the biotite of the tonalite have enriched in mg values and depleted in Si relative to those of the granodiorite member (Fig. 9) indicate again the more differentiation trend of the granodiorite.

Figure 10 shows the plot of 100 x Fe/(Fe+Mg) ratio on the biotites stability diagram of WONES and EUGSTER (1965). It is evident that Fe/(Fe+Mg) ratio of the studied biotites ranges between 52.3 and 59.8 which corresponds to a range of temperature approximately between 700 °C–750 °C with the more Fe-rich biotites crystallizing with fall down of temperature. This result is consistent with data given by RAGAB et al. (1977) and KABESH and SHAHIN (1992).

K-feldspar consists of microcline and perthite and appears the last crystallized phase filling the interspaces between plagioclase grains. Perthite occurs as veins of albite in a microcline host.

BULK ROCK CHEMISTRY

Selected 13 rock analyses of the studied TR-GD suite are given in Table 3. The investigated rocks show a wide variation in major and trace element contents. These rocks are poor in ferro-magnesian elements, e. g. TiO₂+Fe₂O₃+MgO ranges in average from 6.5 % in TR to 4.6 % in GD suite. The studied granitoids display a wide range of differentiation index (e.g., D.I. = Qz+Or+Ab+Co) which increases from TR rocks (62 % average) to GD member (70%) (Table 3). The variation of the D.I. values versus the major elements reveals that the GD suite has relatively high D. I. values and is enriched in K₂O and depleted in TiO₂, CaO and MgO, suggest their progressively differentiated trend.

Correlation with other granites

The results of the chemical analysis of the studied granitoids compared with granites of the other localities are given in Table 3. The chemical composition of the investigated granitoids appears to be in good parallelism with that of quartz monzodiorite-granodiorite suite of Fawakhir, Eastern Desert, Egypt (EL-MAHALLAWI, 1989; EL-MAHALLAWI and BÉRCZI, 1989), oceanic volcanic arc granites of Jamaica and volcanic arc granites of active continental margins of Central Chile (PEARCE et al., 1984).

TABLE 3

Averages of microprobe analyses of the studied granitoids

	Tonalite				Trondhjemite				Granodiorite				Averages			
	187	27	206	48	202	96	296	30	131	292	45	I	26	I	II	III
SiO ₂	59.18	59.61	59.90	64.86	57.72	58.59	61.17	62.20	62.60	63.30	63.80	64.50	67.50	62.85	68.43	74.50
TiO ₂	1.30	0.50	0.95	1.25	1.87	1.16	0.85	0.78	0.72	0.70	0.84	0.73	0.60	0.91	0.33	0.16
Al ₂ O ₃	16.14	13.80	16.90	15.18	14.31	17.11	14.12	13.11	17.02	16.60	16.02	16.10	15.02	16.27	14.44	12.52
Fe ₂ O ₃	2.84	4.21	2.85	1.10	4.11	4.44	3.28	3.31	3.23	2.08	1.40	1.26	1.30	1.91	3.35	1.00
FeO	4.68	3.90	4.02	3.62	3.92	3.38	3.66	3.35	1.61	3.22	3.55	3.89	2.30	3.32	-	-
MnO	0.09	0.09	0.10	0.05	0.11	0.11	0.11	0.12	0.08	0.10	0.09	0.11	0.07	0.09	0.06	0.01
CaO	6.17	5.95	4.04	4.50	5.55	3.42	4.37	4.70	3.18	3.46	3.99	3.47	3.60	3.78	2.36	0.29
MgO	3.13	4.11	3.35	2.33	3.21	3.08	2.10	3.21	2.37	2.38	2.41	1.87	1.83	1.68	1.35	0.07
Na ₂ O	3.34	3.81	3.38	3.79	4.91	4.88	4.60	4.39	4.10	3.75	3.72	4.50	3.59	4.32	3.70	3.56
K ₂ O	1.20	1.62	1.38	1.77	1.89	2.03	2.30	2.21	2.58	2.51	2.76	2.81	2.90	2.90	3.13	5.31
H ₂ O+	1.26	1.21	1.51	0.55	1.50	1.26	1.89	0.55	1.35	1.19	1.04	0.22	0.44	1.71	3.21	0.94
H ₂ O-	0.37	0.42	0.52	0.37	0.40	0.10	0.49	0.37	0.42	0.12	0.11	0.11	0.07	-	-	-
P ₂ O ₅	0.19	0.20	0.84	0.20	0.23	0.38	0.12	0.20	0.23	0.25	0.23	0.20	0.17	0.35	0.12	0.01
Sum.	99.89	99.40	99.47	99.57	99.73	99.94	99.87	99.57	99.48	99.66	99.96	99.77	99.39	100.10	100.48	98.57
D. I.	52	56	60.3	65	61.4	66.1	67	66	71.5	68.7	66.2	70.4	72.1			

I = Qz-diorite-granodiorite suite of Fawakhir, Eastern Desert, Egypt (EL-MAHALLAWI, 1989; EL-MAHALLAWI & BERCI, 1989)

II = Oceanic volcanic arc granites, mainly calc-alkaline arcs, Jamaica, (PEARCE et al., 1984)

III = Volcanic arc granites of active continental margins, Central Chile (PEARCE et al., 1984)

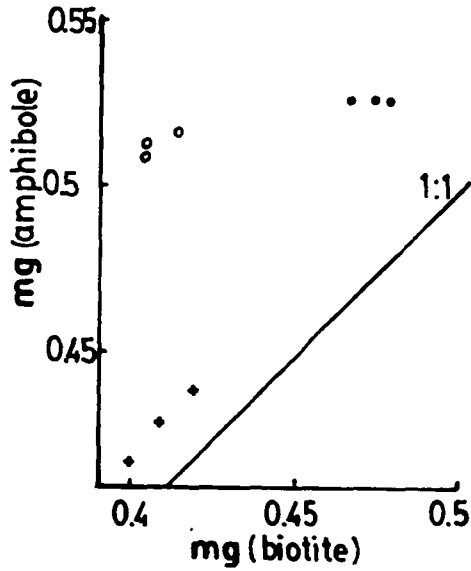


Fig. 7. Distribution of Mg and Fe between coexisting amphiboles and biotites

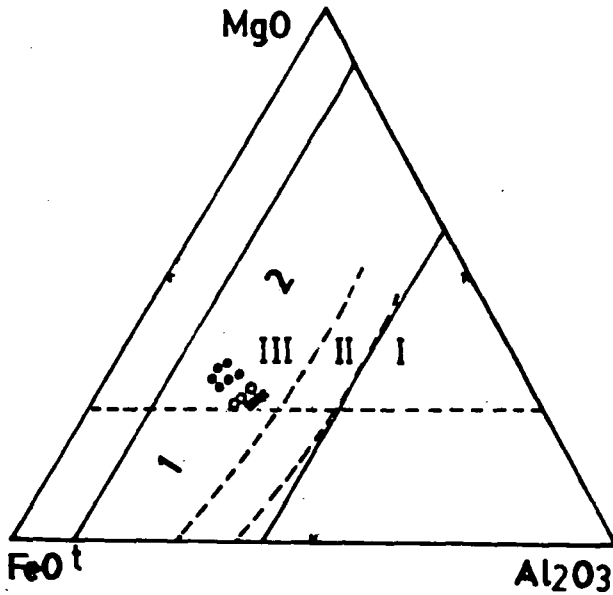


Fig. 8. Plot of FeO^t , MgO and Al_2O_3 of biotites from studied older granitoids. // zone demarked for biotites of igneous rocks and it zone separated the biotites unaccompanied with other mafic minerals (II) from those associated with muscovite (I), and hornblende (III) after NOCKOLDS (1947). --- line drawn by GOHKALE (1968) separating biotites of magmatic rocks (1) from those of metamorphic-metasomatic rocks (2).

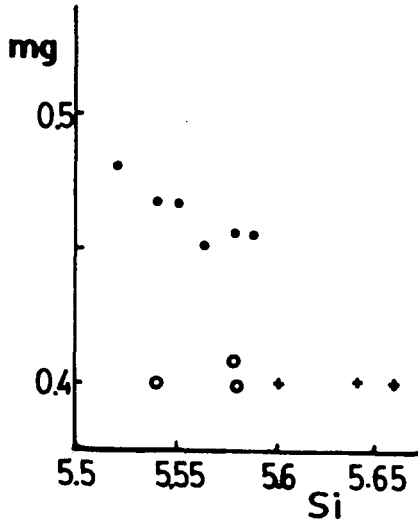


Fig. 9. mg [Mg/(Mg+Fe)] versus Si plot of biotites from the older granitoids.

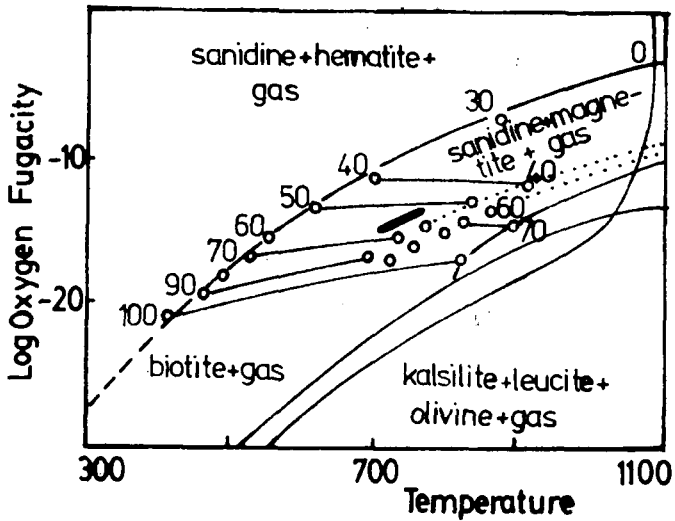


Fig. 10. Biotite stability diagram of specific Fe/(Fe+Mg) values as a function of oxygen fugacity (after WONES and EUGSTER, 1965). Heavily shaded area presents the studied biotites.

Magma type

Two generalized igneous rock trends are observed in granitic terrains (CONDIE, 1981; RAMSAY et al., 1986) (Fig. 11a). The widespread is the tonalite-trondhjemite trend which exhibits a rather constant K/Na ratio with decreasing Ca. The other, a more calc-alkaline trend, exhibits an increasing K/Na with decreasing Ca. In this figure the TO-TR samples follow the trondhjemite trend and plot in the field of typical non-ophiolitic

trondjemites. The other samples follow early stage of the calc-alkaline trend and fall within the field of granodiorite (CONDIE, 1981; RAMSAY et al. 1986). Moreover, the trondjemite affinities of the present rocks are redemonstrated using Na-Ca-K diagram (Fig. 11b). On this diagram, the samples follow the trondhjemitic trend and fall in field of I-type granitic magma (BARKER and ARTH, 1976). The calc-alkaline magma nature is revealed again on the AFM-diagram (Fig. 12). Plotting of the normative Ab-Qz-Or values on the water saturated liquidus field boundaries of TUTTLE and BOWEN (1958) and LUTH et al. (1964, Fig. 13). The TR-GD suite fall at moderate to high water vapour pressure and temperature mostly higher than 700°, suggesting that they were probably emplaced at deep levels in the crust. The same results have been proved before on the Ab-An-Or diagram (Fig. 4) which showed that the present rocks have been formed at a pressure of more than 8 kb. Further information may be drawn from Ab-Q-Or diagram (Fig. 13) leading to a distinction between the classic calc-alkaline differentiation and the trondhjemitic series (BARKER and ARTH, 1976). On this diagram the TR suite follows a trondhjemitic trend, whereas the GD rocks mostly parallel to the calc-alkaline trend. These results support the conclusions withdrawn from modal and normative analyses (Fig. 2 and 4), pointing out to the depletion to fair K₂O content calc-alkaline character of these rocks.

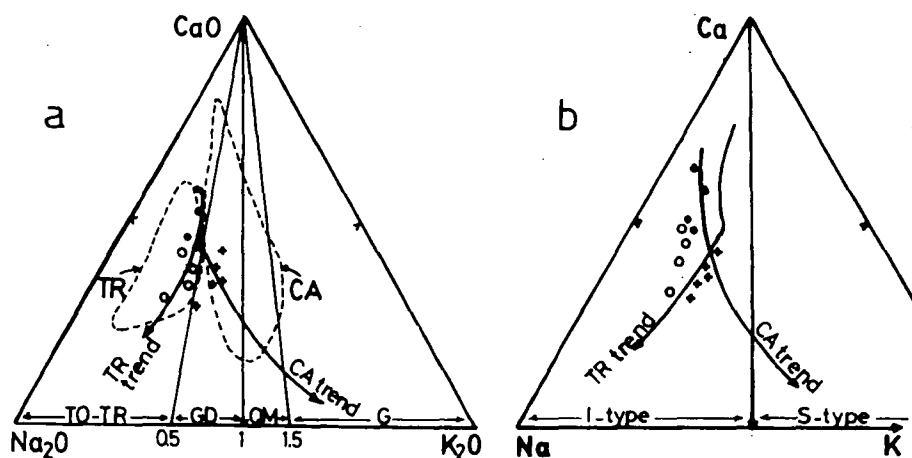


Fig. 11. Plots of studied granitoids in a) Na₂O-CaO-K₂O diagram (after CONDIE, 1981), TO-TR = tonalite-trondjemite, GD = granodiorite, QM = qz-monzonite, G = granite; b) Na-Ca-K diagram (after BARKER and ARTH, 1976), TR = trondjemite, CA = calc-alkaline. Dashed line field of TR and CA after RAMSAY et al. (1986).

Tectonic setting

Using the AFM (Fig. 12) from the tectonic aspect, the present rocks fall on the compressional suite trend of PETRO et al. (1979). Moreover, these granitoids fall in the volcanic arc field as appear in Rb versus Y+Nb diagram after PEARCE et al. (1984), and Rb-Hf-Ta diagram after HARRIS et al. (1986) (Fig. 14a and b). In the tectonomagmatic discriminate diagram (Fig. 15) after BATCHLOR and BOWDEN (1985) the studied TR-GD suite plot in the field of granitoids, particularly during the pre-plate collision to post-collision environment. Whatever preferred model (i. e. melting, fractional crystallization

or mixing) the existence of two distinctive suite in the older granitoids suggest the probability of two parental mafic magma materials with different compositions. This magma probably originated from a subduction of oceanic crust and intruded in a volcanic arc environment. Later on post-magmatic albitization processes affected on the magma before solidification.

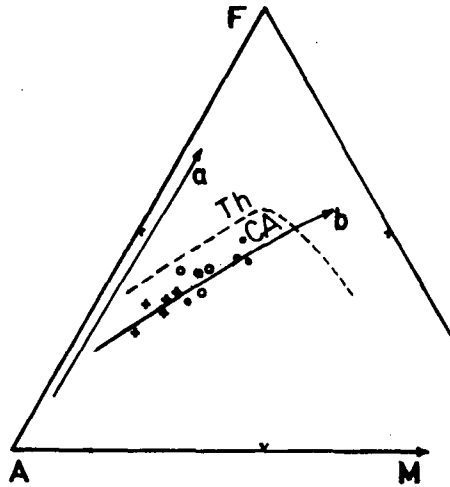


Fig. 12. AFM variation diagram. Solid lines represent the trends of extensional suite (a), and compressional suite (b) after PETRO et al. (1969).

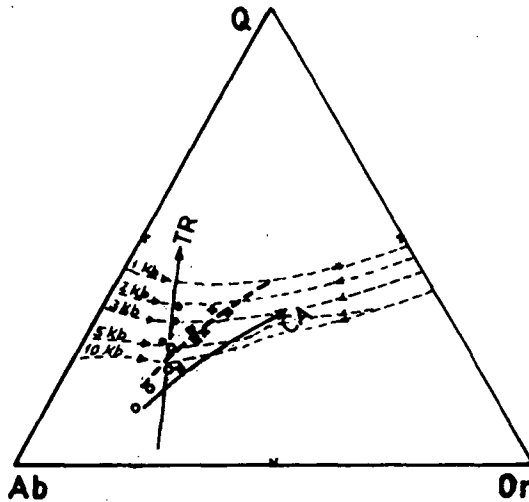


Fig. 13. Ab-Q-Or variation diagram. Dashed lines represent the H₂O saturated liquidus field boundaries in the system Ab-Q-Or-H₂O for water pressures 1, 2, 3, 5, 10 K bar (temperature of minimum eutectic: 1 Kb. = 720°, 2 Kb. = 685°, 3 Kb. = 665°, 5 Kb. = 650°, 10 Kb. = 630°) after TUTTLE and BOWEN (1958) and LUTH et al. (1964). Trends, TR = trondhjemitic, CA = calc-alkaline (b) after BARKER and ARTH (1976).

Magma source

In order to verify the nature of the source magma, a few spiderdiagrams are constructed based on the relative variations in the trace elements (Table 4).

On the ocean ridge granite (ORG)-normalized spiderdiagram (Fig. 16) adapted by PEARCE et al. (1984), the studied granitoids clearly display a pattern characteristic more akin to the volcanic arc suite. This pattern is characterized by enrichments in K, Rb, Ba and Th relative to Ta, Na, Hf, Zr, Sm, Y and Yb. A further significant feature is their high values of Ce and Sm and Y relative to the neighbouring elements as in volcanic arc calc-alkaline and shoshonite series. All these characteristics are highly comparable with the volcanic arc granites of active continental margins from Jamaica and Central Chile (PEARCE et al, 1984) (Fig. 16). Moreover, this pattern is relatively compared with that of the Fawakhir granitoids, Eastern Desert of Egypt (EL-MAHALLAWI, 1989).

TABLE 4

Chemical analysis of trace and rare earth elements of the studied granitoids

	Tonalite		Trondhjemite		Granodiorite		Averages		
	237	97	187	206	26	48	I	II	III
Sc	35.5	19.2	15.7	17.3	6.7	13.0	n. a.	n. a.	n. a.
Cr	420.0	225.0	175.0	213.0	100.0	81.0	n. a.	n. a.	n. a.
Co	38.3	25.5	22.5	23.4	8.7	12.0	n. a.	n. a.	n. a.
Zn	76.0	80.0	70.0	75.0	47.0	76.0	n. a.	n. a.	n. a.
Rb	< 10.0	25.0	< 10.0	59.0	67.0	62.0	87.0	63.0	169.0
Mo	6.0	5.0	5.4	5.2	6.0	4.2	n. a.	n. a.	n. a.
Ba	360.0	290.0	450.0	359.0	590.0	560.0	000.0	750.0	331.0
Cs	2.1	1.2	1.2	1.1	2.3	3.8	n. a.	n. a.	n. a.
Hf	1.6	3.1	3.3	3.2	3.8	5.8	6.9	2.9	5.7
Ta	0.2	0.4	0.3	0.3	0.5	0.7	1.6	0.8	1.8
Th	0.5	1.7	2.1	2.0	3.9	8.5	8.8	4.3	20.3
U	-	-	-	1.0	1.4	1.5	n. a.	n. a.	n. a.
Sr	240.0	-	595.0	-	-	430.0	-	210.0	93.0
Nb	9.0	8.5	6.0	9.0	6.0	13.0	10.6	9.0	17.0
Y	21.0	20.0	14.0	18.0	7.4	27.0	22.0	10.0	30.0
Zr	73.0	88.0	94.0	95.0	100.0	134.0	154.0	104.0	184.0
La	5.7	10.5	17.5	19.8	24.0	39.0	38.2	17.7	40.1
Ce	14.0	30.0	34.0	37.0	44.0	74.0	80.4	31.6	85.8
Nd	12.0	13.0	16.0	15.0	18.0	44.0	20.3	15.4	36.2
Sm	2.1	3.2	3.2	4.2	3.0	6.1	6.0	2.2	8.4
Eu	0.9	1.5	1.3	1.5	0.8	1.4	1.8	0.7	0.8
Tb	0.4	0.5	0.6	0.7	0.4	0.7	1.0	0.3	1.2
Yb	1.8	1.9	1.4	1.6	1.0	2.5	2.6	1.4	3.1
Lu	0.3	0.3	0.2	0.3	0.1	0.4	0.4	n. a.	n. a.
Sum	37.2	60.9	74.2	80.1	91.3	168.1	150.7	-	-

I = Qz-diorite-granodiorite suite of Fawakhir, Eastern Desert, Egypt (EL-MAHALLAWI, 1989; EL-MAHALLAWI and BÉRCZI, 1989)

II = Oceanic volcanic arc granites, mainly calc-alkaline arcs, Jamaica (PEARCE et al., 1984)

III = Volcanic arc granites of active continental margins, Central Chile (PEARCE et al, 1984)

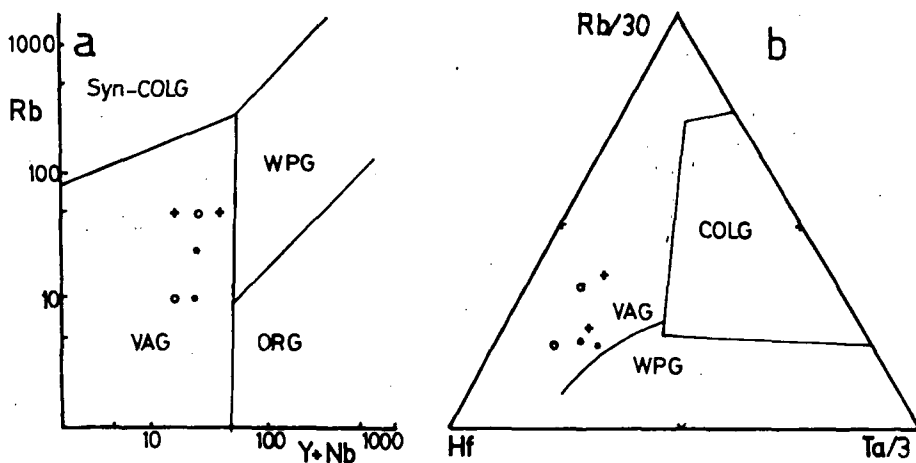


Fig. 14. Plot of the studied granitoids in a) Rb-(Y+Nb) diagram (after PEARCE et al., 1984) and b) Hf-Rb-Ta diagram (after HARRIS et al., 1986). COLG = collision, VAG = volcanic arc, WPG = within plate and ORG = oceanic ridge granites.

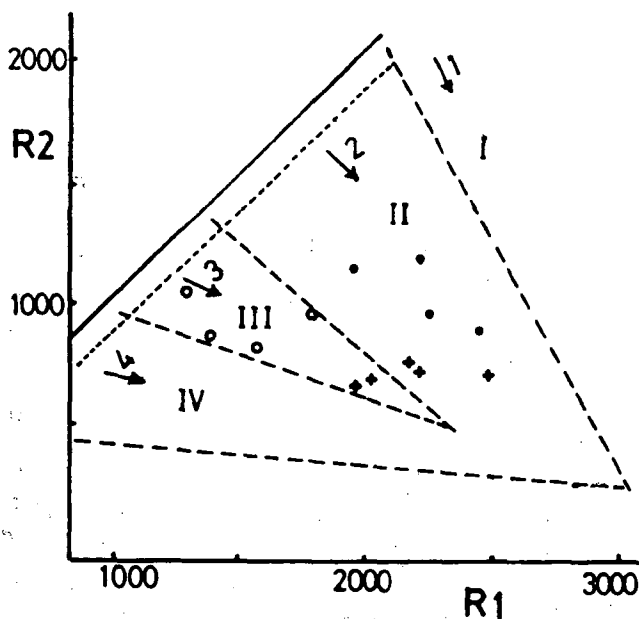


Fig. 15. DE LA ROCHE's plot and the petrographic equivalents are after LAMEYER and BOWDEN (1982): Group 1 = tholeiitic, Group 2 = calc-alkaline and trondhjemitic, Group 3 = high-K calc-alkaline, Group 4 = subalkaline monzonitic. Discrimination fields are after BATCHLOR and BOWDEN (1985): I = mantle fractionates, II = Pre-plate collision, III = Post collision uplift, IV = Late-orogenic environment.

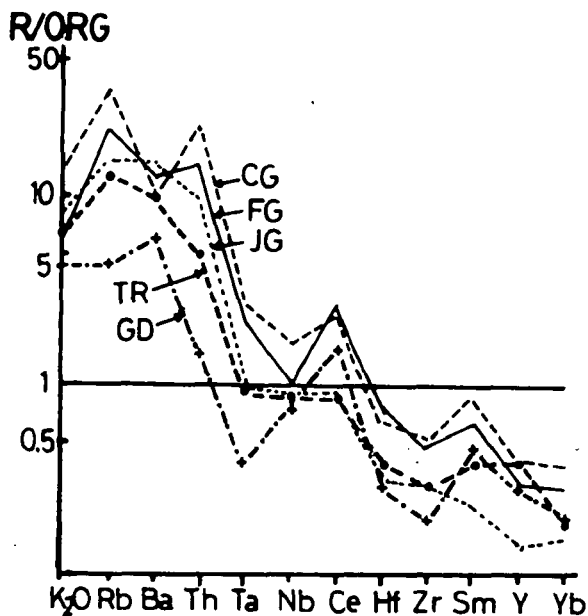


Fig. 16. Oceanic ridge granite (ORG) normalized geochemical patterns for studied trondhjemite (TR) granodiorite (GD) suite compared with Fawakhir granites (FG), Eastern Desert, Egypt (EL-MAHALLAWI, 1989); volcanic arc granites from Jamaica (JG) and from Chile (CG) (PEARCE et al., 1984). ORG values after PEARCE et al. (1984).

The REE data of the TR-GD suite (Table 4) have been normalized to the chondritic values of NAKAMURA (1974) and their patterns are illustrated in Fig. 17a and b. It is clear from this figure that the TR suite have tight REE patterns marked by positive Eu anomaly where Eu/Eu^* ratio varies from 3.5 to 4.7 and relative slight light-REE enrichment (Fig. 17a). The TR rocks are slightly fractionated and the Ce_n/Yb_n ratio gradually varies from 1.96 to 6.1. The present REE patterns of the TR rocks are quite comparable with the range of the Archean high- Al_2O_3 tonalite-trondhjemite (CONDIE, 1981) and the average of the quartz monzodiorite of Fawakhir, Eastern Desert, Egypt (EL-MAHALLAWI and BÉRCZI, 1989). Moreover, the tonalite rocks are depleted in light-REE abundance as well as the total REE, and enriched in the positively value of the Eu anomaly compared with the TD (Table 4) suggest their less fractionation trend. On the other hand, GD suite have a well tight REE pattern (Fig. 17b) characterized by negative Eu anomaly (Eu/Eu^* ratio fall from 3.18 to 2.58) and relative enrichment of light and depletion of heavy REE abundance compared with that of the TR suite. A feature indicates the more differentiation rocks ($Ce_n/Yb_n = 7.46-11.24$) of the GD suite. The present REE pattern of the GD suite is in a good parallelism with that of the Archean granodiorites given by CONDIE (1981) and Fawakhi granodiorite, Eastern Desert, Egypt (EL-MAHALLAWI and BÉRCZI, 1989)

DISCUSSION

The relationship of the mineral constituents and the major chemistry or the REE has been studied before. HASKIN et al. (1968) assumed that the increase of sum REE is associated with the increase in silica content of igneous rocks. Moreover the degree of heavy REE depletion and an increasingly positive Eu anomaly appears to accompany increasing SiO₂ (HUNTER et al., 1978). MCCARTHY and KABLE (1978) mentioned that the behaviour of REE in granitic system may be variable, as accessory minerals evidently play major part in controlling their behaviour in granitic rocks.

The studied rocks show a good relationship between sum REE and their relative age of intrusion and silica enrichment. The sum REE increase from 37 to 80 in TO-TR suite and 91 to 168 in GD suite in accordance with their pre-plate collision to post-collision uplift and with increase silica content from 57.7 to 62 in TO-TR suite and from 62.6 to 67.5 % in GD suite.

The decrease of the mg-values from amphibole to biotite and from TO-TR to GD rocks is probably consistent with increase of silica and sum REE which suggest the progressive differentiation trend from tonalite to granodiorite.

The present granitoids are probably produced by sinking of simatic lithosphere slabs and the diapiric upwelling of a succession of granitoids that commenced with early Na-rich phases but which later changed to K-rich magma types during the final stages of the crustal cratonization (ANHAEUSSER, 1981).

Two important geochemical processes in the development of magmatic granitic rocks are involved the source of the parent magma, and its differentiation between source and region of emplacement. The REE modelling is now accepted as a useful tool in evaluating the possible source and differentiation processes for granitoid rocks.

Many models have been proposed for the generation of the andesitic-dacitic melts. WILSON (1989) proposed a model for the acidic rocks by partial melting of lower crustal basic rocks of gabbro or granulite (pyroxene-garnet-plagioclase fractionation). Models involving partial melting of quartz-eclogite under hydrous conditions (e. g., 27 Kbar) produces andesitic-alkalic melts as a source granites. These models involving eclogite-quartz eclogite parents gave REE patterns with a smooth concave distribution motifs and general decrease in concentration from La to Lu, but uniformly slightly low in calculated heavy REE (LONGSTAFFE et al., 1983). STERN et al. (1975) gave non-modal melting models for eclogite/quartz eclogite parents (85 % clinopyroxene and 15 % garnet) using mantle phases equilibria with garnet and clinopyroxene entering the melt in equal contents. The equilibrium models shown in figure (18a and b) reasonably describe the REE patterns of investigated TO-TR and GD suite for 5 % and 15 % partial melting respectively. The latter model, however, still exhibits low contents of light-REE comparable with the GD suite. The light-REE abundances predicated by this model are largely controlled by garnet/clinopyroxene ratio allowed to enter the melt. Moreover, the REE pattern of the TO-TR is quite analogous to that of the andesitic granulite parent (LEAKE, 1990) (Fig. 18a).

A small positive Eu anomaly occur in some of these rocks (Fig. 18a) a feature which may reflect plagioclase accumulation (GLIKSON, 1976). The GD suite have a small negative Eu-anomaly indicating their degree of fractionation, a feature may be partly due to the feldspar fractionation or may also result from its depletion in the parent from the beginning due to fractional melting, where plagioclase is left as residual minerals. (EMMERMANN et al., 1975). Minor amounts of residual garnet are necessary to explain moderate depletion in heavy REE of the GD suite.

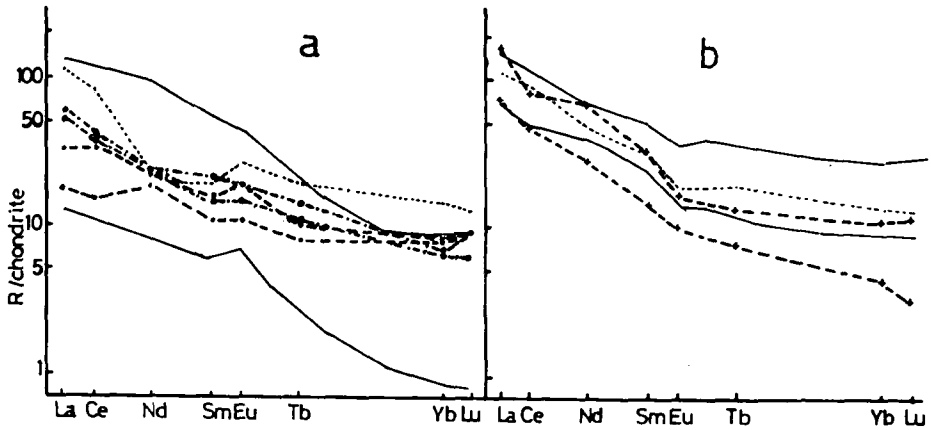


Fig. 17. Chondrite-normalized REE patterns of a) the studied trondhjemite suite (dashed lines) compared with Fawakhir qz-monzodiorite (EL-MAHALLAWI and BÉRCZI, 1989) (dotted line) and Post Archean trondhjemite-tonalite (CONDIE 1981) (solid line), b) the granodiorite suite (dashed lines) compared with Fawakhir granodiorites (EL-MAHALLAWI and BÉRCZI, 1989) (dotted line) and Post-Archean granodiorites (CONDIE 1981) (solid lines). Chondrite values after NAKAMURA.

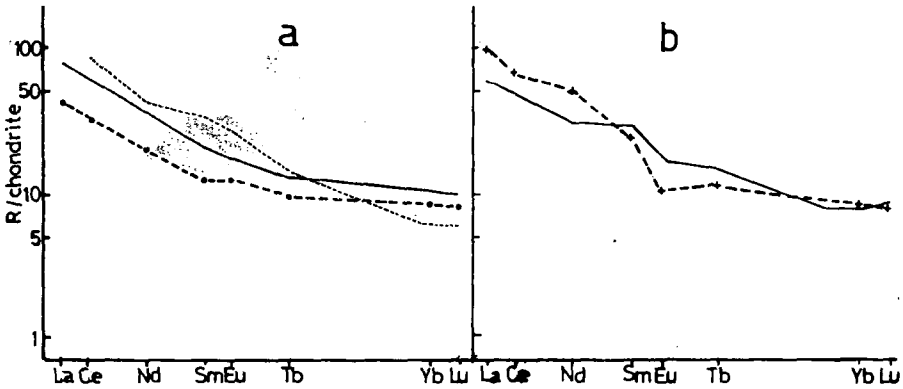


Fig. 18. Chondrite-normalized REE patterns of the averages of a) the studied trondhjemite suite. Solid line represents andesitic granulite parent (LEAKE, 1990) and dotted line represents equilibrium of non-modal melting (5 %) eclogite (85 % clinopyroxene, 15 % garnet) (LONGSTAFFE et al. (1982) b) the studied granodiorite suite. Solid line represents equilibrium of non-modal melting (15 %) eclogite (85 % clinopyroxene, 15 % garnet).

CONCLUSION

The pluton cover the compositional spectrum of tonalite, trondhjemite and granodiorite. They have a wide variation from basic to silicic varieties (57.7–67.5 % SiO_2).

The petrology, mineral chemistry and geochemistry of the studied older granites reveal the existence of two distinctive suites: 1) low-K calc-alkaline trondjemitic suite, and 2) medium-K calc-alkaline granodioritic suite.

Chemical data of amphiboles and biotites suggest that the older granites a probably during their emplacement into the volcanic arc. The existence of magnesio- and edenitic-hornblende and oligoclase-andesine suggest a temperature of about 700–850 °C and a pressure mostly <5 Kb. for the host rocks. Moreover, the proposed temperature for crystallization of biotites is about 700–770 °C.

The TR suite contains higher mg-values of hornblende and biotite compared with the GD suite suggesting a progressive crystallization trend of the evolved rocks from TR to GD. However, a more sodic plagioclase (An_{29,6}) is coexisted with TR suite relative to An₃₂ plagioclase GD suite probably indicate a late albitization effect on the TR suite.

Tectomagmatic evolution of these suites indicates that they are related to two calc-alkaline mafic magmas originated through a pre-plate collisional to post-collisional tectonic regime. They are highly comparable with the volcanic arc granites of active continental margin.

Based on REE geochemistry, the older granitoids show two different types of REE patterns; A) less differentiated type represented by tonalite-trondhjemite suite and B) differentiated type related to granodiorite. The less differentiated type has REE distribution patterns marked by positive Eu anomaly. The differentiated type has wide range of total REE abundance and displays negative Eu anomaly. Both of them have smooth concave REE distribution pattern. These patterns are fairly similar to the models involving partial melting of eclogite/quartz eclogite.

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Manuscript received: 2. September 1999.