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GEOLOGY, PETROGRAPHY, GEOCHEMISTRY AND PETROGENESIS OF THE EGYPTIAN YOUNGER GRANITES

By

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ABSTRACT

One hundred and thirty nine new chemical analyses of major and trace elements for 26 plutons and masses pertaining to the Egyptian Younger Granites are presented together with the chemical analyses of 13 biotites, 32 feldspars, 2 muscovites, 2 garnets and 4 magnetites. The present geological, petrographical and geochemical studies have subdivided the studied Younger Granites in the following four groups: Group (1) less differentiated calc-alkaline to weakly alkaline I-type granodiorite and monsogranite; Group (2) normal alkaline A-type monzogranite to syenogranite and Group (3) strongly alkaline A-type alkali feldspar granite, whereas the fourth group includes the "Apogranite" variety which is characterized by distinct enrichment in Na_20. It is believed that the magmas of the different groups may have been produced by partial fusion and refusion. It is also suggested that Group (1) granites resemble the Caledonian-type granitoids intruded during a phase of post-collsional uplift, relaxation and decompression, whereas Groups (2) and (3) appear to have been emplaced in an extensional tectonic setting.

INTRODUCTION

The Precambrian belt of the Eatern Desert of Egypt (1200-475 Ma) contain two distrinct granitoid assemblages: an older one (880-610 Ma) for which the names "Old", "Shaitian", "Grey", or "Syn-orogenic" granites were previously used and a younger one (600-475 Ma) previously referred to as "Younger". "Gattarian", "Pink", "Red", or "Late to Post-orogenic". The latter Younger Granites cover about 22.4% of the exposed total area of the Precambrian belt of the Eastern Desert. They were assigned ages between 475 and 600 Ma (Fullagar and Greenberg, 1978; Fullagar, 1980; Meneisy and Lenz, 1982; Stern and Hedge, 1985 and Abdel Rahman and Doig, 1987) which correspond to late-Proterozoic-lower Palaeozoic.

The present paper deals with the geology, petrography and geochemistry of granites from 24 younger granite plutons together with two masses of apogranites (Table 1). The work also presents the geochemistry of the separated minerals from these granitic rocks.

Table 1

Embraces the names and locations of the studied 26 granitic plutons and masses divided into the groups which the present work has recognized.

	Name of the Plutons	Longitudes							Latitudes						
Group 1	Deleihimi	34°	16′	25″	–	34°	21′	30″E	25°	39′	50″	–	25°	45′	30″N
	Fawakhir	33°	36′	10″	–	33°	38′	00″E	25°	57′	00″	–	26°	10′	30″N
	Atalla	33°	27′	00″	–	33°	38′	00″E	26°	11′	40″	–	26°	12′	25″N
	Kib Absi	33°	29′	20″	–	33°	31′	10″E	26°	13′	45″	–	26°	17′	00″N
Group 2	Hamata	35°	00′	00″	–	35°	40′	00″E	24°	00′	24″	–	24°	30′	00″N
	Kadabora	34°	20′	00″	–	34°	30′	00″E	25°	22′	00″	–	25°	32′	00″N
	Um Lasaf	34°	26′	40″	–	34°	29′	20″E	25°	34′	32″	–	25°	36′	35″N
	Um Luseifa	34°	12′	00″	–	34°	22′	00″E	25°	35′	00″	–	25°	43′	00″N
	Um Shaddad	34°	19′	30″	–	34°	24′	50″E	25°	37′	00″	–	25°	39′	00″N
	Um Hombos	33°	47′	30″	–	33°	49′	25″E	25°	56′	20″	–	25°	57′	25″N
	Um Saneyat	33°	53′	20″	–	33°	54′	30″E	25°	59′	20″	–	26°	01′	00″N
	Um Had	33°	27′	00″	–	33°	33′	30″E	26°	00′	55″	–	26°	07′	45″N
	Um Effein	33°	22′	20″	–	33°	26′	55″E	26°	10′	00″	–	26°	14′	30″N
	Eraddia	33°	22′	00″	–	33°	29′	30″E	26°	16′	50″	–	26°	25′	00″N
	Kab Amiri	33°	32′	15″	–	33°	36′	45″E	26°	20′	00″	–	26°	23′	0″N
	Abu Furad	33°	44′	40″	–	33°	46′	30″E	26°	42′	15″	–	26°	42′	45″N
	Abu Hawis	33°	34′	45″	–	33°	36′	40″E	26°	44′	00″	–	26°	26′	0″N
	Ras Barud	33°	36′	30″	–	33°	39′	30″E	26°	46′	00″	–	26°	49′	25″N
	Abu Murat	33°	43′	30″	–	33°	49′	45″E	26°	47′	45″	–	26°	51′	00″N
	Um Kibash	33°	34′	30″	–	33°	39′	35″E	26°	51′	30″	–	26°	52′	50″N
	Um Anab	33°	34′	30″	–	33°	39′	35″E	26°	51′	30″	–	26°	52′	50″N
Group 3	Sibai	34°	05′	25″	–	34°	15′	20″E	25°	35′	35″	–	25°	45′	10″N
	South eraddia	33°	26′	00″	–	33°	37′	30″E	26°	16′	05″	–	26°	17′	25″N
	Grarib	32°	50′	00″	–	32°	56′	30″E	28°	04′	30″	–	28°	11′	00″N
Apogranite	Nuweibi	34°	28′	30″	–	34°	30′	00″E	25°	11′	50″	–	25°	13′	00″N
	Abu Dabbab	34°	32′	20″	–	34°	32′	30″E	25°	20′	30″	–	25°	20′	38″N

The 26 younger granite plutons and masses possess field relations, petrographical and chemical characters which lead to their subdivision into three different groups; each has its own field, petrographic and geochemical characteristics. These three groups include: Group (1) less differentiated calc-alkaline to weakly alkaline granodiorite and monzogranite represented by 4 plutons with the Fawakhir pluton as the type member; Group (2) normal alkaline syenogranite and monzogranite represented by 17 pluton with the Kadabora pluton as the best example of this group; and Group (3) highly differentiated strongly alkaline alkali-feldspar granites represented by 3 plutons. The Sibai pluton typefies this group. Sabet *et al.,* (1976) separated the intensively metasomatic altered minor granites and considered them as the final phase of the Younger Granites and gave them the name "Apogranite".

FIELD DESCRIPTION

The 26 younger granite plutons form isolated nearly circular to elongate masses of high and rugged relief. They are emplaced not only as steep-sided plutons but also as diapirs, tack-shaped bodies, lapoliths and thick sills, and many of them are highly mineralized. They acquire pink to red colours and range in composition from granodiorite to alkali feldspar granite. The plutons are epizonal, unfoliated, posses sharp contacts, chilled margins, relatively wide contact auroles and clear magmatic characters. They were emplaced at shallow levels in the crust and their country rocks include serpentinites, metagabbros, volcano-sedimentary assemblages, Older Granites, Dokhan volcanics and Hammamat sediments.

There is a much higher concentration of younger granite plutons in the northern part of the Precambrian belt of the Eastern Desert. There, the younger granite plutons occur in clusters and sometimes they coalesce together giving rise to granite country (Fig. 1).

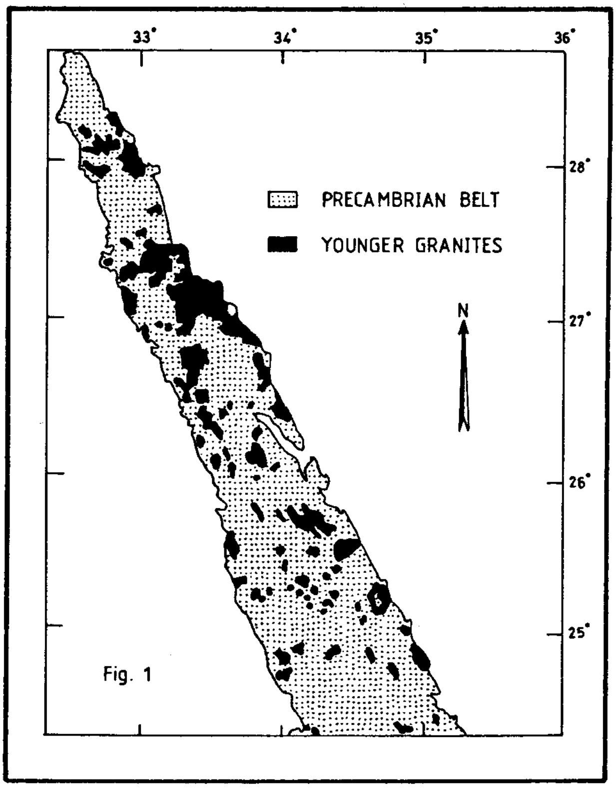

Fig. 1: Distribution of the Younger Granite in the central and northern parts of the Precambrian belt of the Eastern Desert of Egypt.

It is interesting to note that the Kib Absi pluton (Group 1) is intruded by the Eraddia pluton (Group 2) which in turn is intruded by the South Eraddia pluton (Group 3), hence the anquestionable time relation between the three granite groups (fig. 2). Age dating of many younger granite plutons in the northern Eastern Desert further support this classification. Recently Abdel Rahman and Doig(1887) obtained Rb/Sr age or 476 ± Ma with initial ^{87}Sr / ^{86}Sr ratio of 0.711 ± 0.0012 for the strongly alkaline granites of mount Ras Gharib (a member of Group 3), the latter was emplaced in granodiorite-admellite and leucogranite complex which appears to pertain to Group (2) and yield an age of 552 ± 7 Ma and initial ^{87}Sr / ^{86}Sr ration of 0.7044 ± 0.0012. Some ages, however, show contradictory time relationships. The Fawakhir pluton which represents Group (1) has an age of 574 ± 0 Ma and initial ^{87}Sr / ^{86}Sr ratio of 0.7025 ± 0.0003, where as Kadabora pluton of Group (2) has an age of 595 ± 8 Ma and initial ^{87}Sr / ^{86}Sr ratio of 0.716 ± 0.0008 (Fullagar, 1980). This may indicate synchronous emplacement.

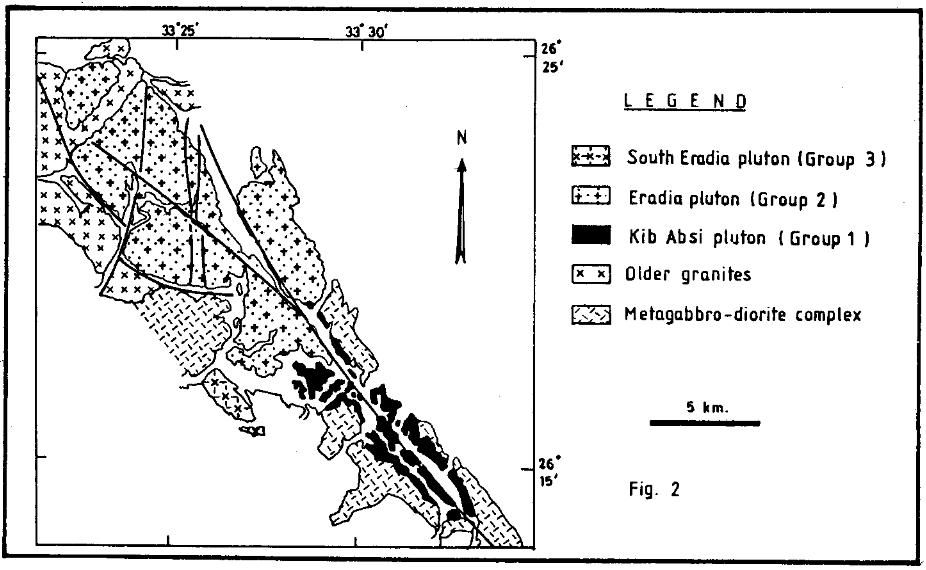

Fig. 2: A map showing the relation between the three granite groups.
The Kib Absi pluton (Group 1) is intruded by Eraddia pluton (Group 2) which is intruded by the South Eraddia pluton (Group 3).

The oustanding field characteristics of the three granite groups and the apogranites are summarized as follows:

Group granites

Group 1 includes Deleihimi, Fawakhir, Atalla and Kib Absi plutons. They possess elongated to roughtly, ovel-shped outcrops, mainly in conformity with their host rocks. The plutons usually develop moderate relief, show mild contact effect and contain abundant xenoliths and dyke swarms. The granites of these plutons are medium to coarse-grained, unfoliated, of whitish grey to pale pink colours and sometimes show spheroidal exfoliation.

El-Fawakhir pluton, representing the Group (1) granites, forms an alongated outcrops which covers about 25 km^2 with its longer axis (8 km) trending almost parallel to the regional trend of the enveloping country rocks. The pluton is sharply intruded into both the Atallla serpentinites range and the Sid metagabbros complex. Considerable assimilation reactions are clearly observed along the contact with the metagabbros. The granite contains lensoidal and rounded xenoliths of basic and ultabasic rocks. Noweir (1986) distinguished between the following two principal and mappable types of granites in the Fawakhir pluton: a) the grey granodiorite margin, and b) the main monzogranite body. He showed that the contact between these two granite types is transitional through a thin discontinuous granodiorite variety.

Group 2 granite

Group 2 includes Hamata, Kadabora, Um Lasaf, Um Luseifa, Um Shaddad, Um Hombos, Um Saneyat, Um Hadm Um Effein, Eraddia, Kab Amiri, Abu Furad, Abu Hawis, Ras Barud, Abu, Murat, Um Kibash, and Um Anab plutons. These plutons occur as high-level intrusions. They possess steep walls, oval to circular outlines and usually cut across the regional setting of the country rocks. The plutons show pronounced contact effect against their country rocks with wide contact aureoles. Xenoliths are less abundant than in Group 1. The granites of these plutons are generally medium to coarse-grained, of red to pinkish red colours, massive and devoid of any internal parallel fabric except for Um Hombos diapir pluton.

The Kadabora pluton, representing group 2 grnites, is oval in shape and covers an area of about 239 km^2. It forms bold mountaineous terrain as exemplified by Gabals Abu Itella, Kab El Rakab and Kadabora El Hamra. The pluton shows intrusive sharp contacts with the surrounding country rocks with a pronounced contact effect. It is dissected by three major Wrench faults which have distinct horizontal components and displace the boundaries of the present pluton. The granitic rocks of the pluton are generally medium to coarse-grained, leucocratic and non-xenolithic and unfoliated. The pluton is cut by a series of dykes of variable composition and distribution. The western and central parts of the pluton are cut by a swarm of granophyric dykes which are confined within the pluton boundaries. The eastern part, on the other hand, is cut by a series of dolerite dykes which extend into the country rocks.

Group 3 granites

Group 3 includes Sibai, South Eraddia and Ras Gharib plutons. These plutons form bold mountainous landmarks discordant with the host rocks. They usually possess oval outlines and some are ring-like and crescent-shape bodies (e.g. Sibai and Ras Gharib). They are free from xenoliths and dykes and have thick chilled margins.

The Sibai pluton, representing the Group 3 granites, form a huge steep sided ring-like granite body of an area of about 170 km². It is intruded into an association of amphibolites, homblende schists and subschists of basaltic and andesitic origin with sharp contacts. The granites are homogeneous and devoid of xenoliths and dykes. They are medium to coarse-grained, leucocratic and are mostly pale red, red, rosey and pale pink in colour.

Apogranites

The apogranite masses have isometrical or tack-shaped bodies of small sizes. Their contacts with the country rocks are eruptive, always steeply dipping, occasionally with gentle dip and often accompanied by eruptive breccias. Their situation is usually governed by tectonic control. They are fine to medium-grained, white in colour with some black to brownish patches of manganese minerals.

The Nuwebi and Abu Dabbab masses represent two apogranite outcrops in the Precambrian belt of the central Eastern Desert of Egypt. The Nuwebi mass is located at the upper part of Wadi El-Nabi El Atshan, some 16 km south of the Abu Dabbab mass. It forms an irregular outcrop about 1.6 km² intruding the Older Granites. The Abu dabbab mass is located at the watershed of Wadi Mubarak and Wadi Um Quraiya. It has a tack-shape, covers an area of about 5000 m² and intrudes the surrounding metasediments, metavolcanics and serpentinite rocks.

PETROGRAPHY

The modal composition of 38 representative samples of the present granites are given in Table 2 and plotted in Fig. 3. This figure shows clearly that: a) Group (1) comprises essentially granodiorite with subordinate monzogranite,

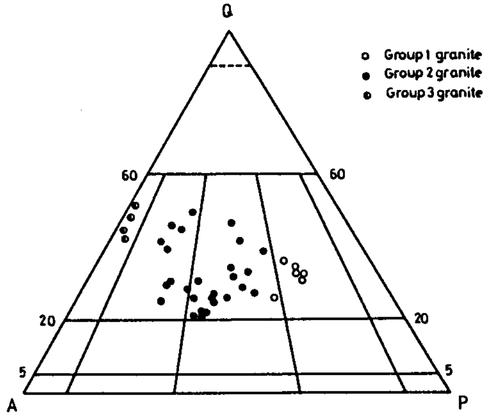

Fig. 3: QAP diagram of Streckeisen (1976).

Table 2
Modal composition of representative samples of the studied granite plutons.

Locality	Qz	Kf	Pl	Bi	Hb	Acc	Qz	Kf	Pl
Fawakhir	30.53	15.26	42.92	3.37	8.33	0.60	34.81	17.40	47.79
	29.29	15.76	46.47	5.25	2.72	0.51	32.00	17.22	50.78
Atalla	29.43	15.82	45.55	6.11	1.19	1.90	32.41	17.41	50.17
	23.62	42.32	1.91	5.13	4.22	0.80	26.29	27.07	46.64
Kib Absi	28.98	16.65	46.99	4.08	2.49	0.81	31.29	17.98	50.73
23.62	2.32	41.91	5.13	4.22	0.80	26.29	27.07	46.64	
Kadabora	32.00	28.75	35.25	3.85	–	0.15	33.33	29.95	36.72
	41.10	45.60	12.53	0.30	–	0.37	41.84	45.90	12.62
	47.00	25.70	26.95	0.35	–	–	47.17	25.79	27.04
Um Hombos	33.11	32.15	30.90	3.65	–	0.19	34.43	33.43	32.13
	43.06	38.22	15.32	2.72	–	0.68	44.58	39.57	15.86
	40.94	26.56	29.69	2.29	–	0.52	42.12	27.33	30.55
Um Had	44.47	39.53	12.35	2.47	–	1.18	46.15	41.03	12.82
Um Effein	36.45	20.69	35.47	5.91	–	1.48	39.36	22.34	38.30
	37.74	41.85	14.41	4.46	–	1.64	40.15	44.52	15.33
Eraddia	27.25	47.08	18.24	3.87	–	3.54	29.44	50.86	19.70
	28.61	41.20	24.71	2.83	–	2.65	30.27	43.59	26.14
Kab Amiri	47.05	31.86	15.08	4.22	–	1.79	50.06	33.90	16.04
Abu Furad	21.72	45.24	30.80	1.06	–	0.63	21.68	46.99	31.33
	22.11	45.32	31.60	0.62	–	0.35	22.33	45.7	31.91
	24.56	41.85	32.7	0.52	–	0.33	24.77	42.21	33.02
Abu Hawis	21.72	45.24	31.36	1.16	–	0.52	22.09	46.01	31.90
	25.17	45.86	26.70	0.42	–	1.85	25.76	46.93	27.31
	31.66	33.78	33.69	0.49	–	0.37	31.94	34.08	33.98
Ras Barud	29.93	48.79	19.76	1.14	–	0.38	30.39	49.54	20.07
	27.41	6.22	23.79	1.78	–	0.80	28.14	47.44	24.42
	24.90	54.20	19.83	0.60	–	0.47	25.17	54.78	20.05
Abu Murrat	25.34	38.10	35.06	0.53	–	0.97	25.73	38.67	35.60
	27.03	40.61	30.87	0.33	–	1.16	27.44	41.22	31.34
Um Kibash	26.00	30.74	39.78	1.26	–	2.22	26.95	31.85	41.20
	27.87	32.64	37.21	1.07	–	1.21	28.52	33.40	8.08
Um Anab	20.17	46.86	29.65	1.44	–	1.88	20.86	48.47	30.67
	24.61	40.70	31.01	1.68	–	2.00	25.55	42.26	32.19
	24.90	44.56	25.82	2.11	–	2.61	26.13	46.77	27.10
				Riebeckite					
Sibai	50.18	44.93	1.33	1.38	1.92	0.26	52.03	4.59	1.38
	48.15	47.67	2.14	0.60	1.01	0.43	49.15	48.66	2.19
South Eraddia	44.82	51.29	1.91	1.10	–	0.88	5.73	52.32	1.95
	42.94	52.49	2.62	1.55	–	0.40	43.79	53.53	2.67

Modal composition   Locality Feldspars %

b) Group (2) includes mainly monzogranite and syenogranite, c) Group (3) is essentially alkali feldspar granite. It can be also noticed from Table 2 that: a) quartz and potash feldspars are most abundant in Group (3) and least abundant in Group (1), b) plagioclase increase from group (3) to Group [1), c) hornblende is notably present in Group (1), d) biotite occur in the all three groups, e) riebekite is restricted to Group (3).

The granodiorite consists essentially of oligoclase, quartz and less abundant potash feldspar with notable biotite and hornblende. Iron oxides, apatite and sphene are accessories whereas chlorite, epidote, sericite, muscovite and kaolinite are common secondary constituents, Oligoclase (An^{15}) forms subhedral tabular and prismatic crytals, displaying varying degrees of sericitization. Quartz forms anhedal to subhedral interstitial cystals. It actively corrodes and resorbs the adjacent feldspars. Microcline-microperthite forms irregular masses which are actively replaced by quartz with marked myrmekitic texture. Biotite occurs as flakes and irregular aggregates and clots. Hornblende forms xenomorphic prismatic crystals commonly enclosing numerous plagioclase crystals.

The monzogranite and syenogranite are composed of vaiable proportions of quartz, potash feldspars and plagioclase together with subordinate biotite. Iron oxide, zircon, and apatite are accessories whereas chlorite, muscovite, sericite and kaolinite are secondary constituents. Quartz occurs mainly in the form of drops made up of one or more by clear xenomorphic crystals, and less commonly as small anhedral crystals filling the interstices between the feldspars. This is besides its occurence as worm-like myrmekitic intergrowths. Potash feldspars are represented mainly by microcline and microperthite with subordinate orthoclase microperthite. The microperthite is mainly of the exsolution type and less commonly of the replacement type. Plagioclase (An_{8-14}) forms slightly to moderately sericitized and kaolinitized tabular to equant crystals. It commonly replaces potash feldspar forming antiperthitic outgrowths, but is itself replaced by potash feldspar and corroded by quartz. Biotite forms subhedral flakes variably altered into and interleaved with chlorite.

The alkali feldspar granite consists chiefly of potash feldspar and quartz together with subordinate plagioclase, biotite, reibeckite and muscovite. Iron oxide, zircon, allanite and apatite are accesories. Potash feldspar is mainly perthite, microcline-microperthite and less commonly orthoclase microperthite. The microperthite include both exsolution replacement types. Quartz forms anhedral crystals filling the interstices between the feldspars and shows corrosive action against them. Plagioclase ($An_{8\text{-}12}$) is subordinate and occurs as tabular crystals, slightly altered to sericite. Biotite forms irregular flakes and clots. Riebeckite occeurs as subhedral prismatic crystals, or as fibrous aggregates.

The apogranite is fine to medium-grained, white in colour with few black to brownish patches of manganese minerals. It consists mainly of albite, microcline, quartz and muscovite in different proportions. Apatite, zircon, epidote and allanite are the main accesories. Albite (An_8) occurs as fine grained laths, always clean and fresh with no signs of alteration. Microcline forms anhedral crystals, highly altered to buff coloured fine granular kaolinite agregates. They enclose partly to totally fine laths of albite. Quartz occurs as anhdral crystals that fill the interstitial spaces between the albite and microcline crystals.

GEOCHEMISTRY OF THE GRANITIC ROCKS

Major and trace element analyses for 139 selected rock specimens representing the 26 granitic plutons under consideration are presented in Table 3. The chemical analyses of granitic rocks from other areas are also recorded for comparison (Table 4).

Correlation with granites of other localities

Correlation between the average chemical composition of the investigated granite and that given by Turekian and Wedepohl (1961); Abu El-Leil (1975) and Greenberg (1081) lead to the following facts:

1. The average composition of Group 1 granites appears in good parallelism with Group III of Greenberg (1981) and to some extent with the high-Ca granite of Turekian and Wedepohl (1961).
2. The average composition of Group 2 granites is similar to Group II of Greenberg (1981) in Al_2O_3, TiO_2, Na_2O and K_2O. In comparing the Group 2 and the low-Ca granite of Turekian and Wedepohl (1961), the former show decrease in SiO_2, Al_2O_3 and K_2O and enrichment in CaO and MgO.
3. Correlation between the studied Group 3 and Group I of Greenberg (1981), clearly indicate that the present Group 3 have lower values of FeO, Fe_2O_3, MgO and CaO and nearly equal amounts in SiO_2, TiO_2, Al_2O_3, MnO, K_2O and Na_2O. The chemical analyses of Group 3 appears parallel with the low-Ca granite of Turekian and Wedepohl (op. cit.).
4. By comparing average composition of the present apogranite analyses with that of the apogranite given by Abu El-Leil (1975) there appears a good parallelism between the two sets of data.

Variation in Chemical Composition

Considering the average of contents of the major and trace elements in the different granitic groups (Table 4), the following points can be noticed:

Table 3

Major and trace element analyses of the studied Younger Granites

Group	Group (1)																												
Locality	El-Deleihimi					Fawakhir						Atalla			Kib Absi														
Sample No. / Terms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
SiO_2	72.10	67.10	69.97	68.05	69.26	67.22	65.17	66.81	66.00	66.47	67.01	66.14	66.05	66.26	65.80	65.20	65.43	66.97	68.01	67.88	67.36	66.61	57.88	74.07	70.76	70.73	70.69	17.76	75.77
TiO_2	–	0.60	–	0.20	–	0.58	0.80	0.44	0.64	0.84	0.60	0.64	0.20	0.16	0.56	0.42	0.64	0.16	0.20	0.40	0.40	0.12	1.04	0.06	0.20	0.10	0.28	0.22	0.46
Al_2O_3	13.34	14.54	14.12	14.23	14.80	14.80	15.42	15.26	14.69	15.37	15.61	15.06	14.80	14.75	15.06	15.32	14.85	15.05	15.32	15.42	14.69	13.40	16.66	12.10	14.07	14.07	13.71	13.55	14.43
Fe_2O_3	0.53	3.06	0.50	0.90	2.30	1.34	1.20	0.67	1.60	1.20	0.87	1.11	0.44	1.61	1.87	1.21	1.57	1.80	1.78	0.91	1.81	1.59	4.24	0.96	0.58	2.01	1.37	1.90	2.87
FeO	2.59	3.48	2.40	3.37	0.93	2.62	3.29	3.15	2.94	2.75	3.04	3.13	3.51	3.06	2.14	2.66	2.18	2.05	2.06	2.15	1.50	2.24	5.29	1.04	1.61	1.02	1.44	1.03	2.08
MnO	0.07	0.08	0.03	0.08	0.04	0.09	0.08	0.20	0.09	0.07	0.09	0.10	0.11	0.09	0.08	0.09	0.07	0.07	0.06	0.06	0.04	0.07	0.15	0.04	0.05	0.06	0.05	0.06	0.07
MgO	0.65	1.28	0.44	1.06	0.32	0.72	1.15	1.49	0.85	1.10	1.02	1.27	1.49	1.23	2.08	1.78	0.89	0.81	1.36	0.76	1.10	0.98	2.00	0.68	0.98	0.68	0.76	0.42	1.19
CaO	2.10	3.59	2.39	3.02	2.05	3.10	2.86	2.62	2.92	2.44	2.74	3.10	3.28	3.87	3.46	3.22	3.04	2.74	2.26	2.92	2.26	2.08	4.23	1.49	2.26	2.38	2.20	2.08	2.86
Na_2O	3.50	2.97	3.57	3.70	3.57	3.91	4.31	4.08	4.58	4.38	4.18	5.05	4.51	4.92	4.18	4.24	4.85	5.32	5.19	5.39	4.24	5.05	5.46	3.91	4.58	4.38	4.24	4.24	4.38
K_O	4.51	1.93	4.51	2.89	5.90	3.98	4.85	4.25	4.33	3.49	3.86	3.03	2.53	2.41	2.89	2.77	4.04	2.89	2.41	2.77	3.19	3.37	1.32	5.12	3.71	3.19	3.61	3.37	3.19
P_2O_5	0.02	0.13	0.03	0.03	0.01	0.10	0.12	0.09	0.11	0.10	0.01	0.07	0.09	0.09	0.10	0.13	0.11	0.10	0.12	0.08	–	0.08	0.05	0.03	0.07	0.06	0.04	0.06	0.11
H_2O^+	0.52	1.20	0.38	0.83	0.56	0.56	0.75	1.01	0.38	1.72	1.22	1.17	1.98	1.39	1.65	1.92	2.00	1.27	1.11	1.19	2.31	2.27	3.32	0.45	1.04	0.65	0.92	1.04	2.39
H_2O^-	0.10	0.23	0.11	0.14	0.13	0.15	0.11	0.10	0.12	0.10	0.27	0.14	0.23	0.34	0.25	0.41	0.13	0.23	0.26	0.25	0.32	0.48	0.41	0.16	0.14	0.09	0.27	0.30	0.15
P ppm	348	2935	598	598	100	2448	2649	2156	2449	2199	250	1649	2041	2041	2202	3050	2500	2248	2649	1899	–	1750	1238	711	1537	1491	848	1399	2500
Nb	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ti	–	10016	–	3338	–	9683	13355	7345	10684	14023	10016	10684	3338	2671	9348	7012	10686	2671	3338	6677	6677	2003	17362	1002	3338	1669	4674	3673	7679
Zr	300	300	100	500	50	800	800	300	1000	500	100	500	100	800	200	500	300	300	300	300	1000	200	300	100	200	300	500	200	500
Sn	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
V	–	84	28	84	–	100	100	56	140	100	84	100	56	168	84	84	80	112	56	100	56	140	28	224	84	112	56	28	56
Cr	–	4	17	–	–	41	7	3	–	3	–	41	–	–	17	17	17	–	3	13	–	7	–	14	7	3	7	–	–
Ga	–	–	30	30	–	–	30	–	30	–	–	–	–	–	30	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mo	–	–	–	–	–	–	–	–	–	–	–	–	30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mn	904	1033	387	1033	516	1163	1033	2583	1163	904	1163	1292	1421	1162	1033	1163	904	904	775	775	516	904	1938	516	646	775	646	775	904
Co	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ni	–	30	30	30	10	–	–	10	–	–	–	20	80	10	10	–	–	30	–	10	20	–	–	–	–	–	–	–	–
Cu	30	20	20	20	10	30	50	30	20	20	10	20	50	20	20	10	20	30	10	30	10	20	20	10	10	30	20	20	10
Zn	–	–	–	–	–	–	–	–	–	–	–	–	300	–	–	–	–	–	800	–	800	–	–	–	–	–	–	–	–
Pb	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–
Sr	200	500	200	300	300	300	500	300	1000	300	200	300	100	300	1000	500	500	1000	800	800	100	1000	500	200	300	1000	500	800	100
Ba	1000	1000	1000	1000	1000	1000	3000	500	3000	800	500	500	500	500	3000	1000	1000	2000	1000	1000	800	2000	2000	800	300	1000	2000	500	500
Y	–	–	–	–	–	–	–	–	100	–	–	–	–	–	–	–	–	–	–	–	100	–	–	–	–	–	–	100	100
Be	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6	10	–	–

Table 3: Cont.

Group	Group (2)																											
Locality	Hemata					Kadabora															Umm Luseifa					Um Shaddad		
Sample No. Terms	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
SiO_2	73.36	68.99	71.02	68.94	71.21	75.82	74.57	75.60	73.49	73.74	72.77	72.99	75.55	75.56	73.83	73.79	72.40	75.15	74.06	72.38	74.00	74.10	74.10	74.16	72.99	75.83	77.50	74.10
TiO_2	0.10	0.58	0.46	0.42	0.48	0.34	0.24	0.40	0.38	0.40	0.34	0.40	0.42	0.34	0.24	0.02	–	–	–	0.08	0.24	–	–	0.14	0.04	–	–	0.14
Al_2O_3	11.99	12.20	12.30	12.62	12.04	10.53	10.89	11.35	11.35	10.78	11.35	11.66	10.89	11.66	11.96	11.78	12.62	12.82	12.88	13.29	13.24	13.66	13.40	13.14	13.39	11.16	12.99	11.89
Fe_2O_3	2.18	3.84	3.92	2.18	4.27	1.40	1.00	1.65	0.67	1.45	1.95	1.18	1.51	0.88	0.87	1.67	1.65	0.41	0.34	1.24	0.38	0.12	0.14	0.87	1.10	1.44	1.10	1.40
FeO	1.29	3.04	1.81	5.30	1.88	1.67	1.96	0.91	2.55	2.07	1.55	1.56	1.73	0.93	1.25	2.17	1.33	0.94	1.01	1.65	0.89	0.98	1.04	0.97	1.26	1.04	1.06	1.15
MnO	0.06	0.10	0.08	0.09	0.08	0.06	0.05	0.04	0.07	0.08	0.03	0.05	0.05	0.03	0.04	0.03	0.04	–	0.01	0.06	0.08	0.10	0.07	0.05	0.03	0.04	0.01	0.05
MgO	–	0.38	0.30	0.13	0.34	0.08	0.08	0.12	0.46	0.67	0.75	0.37	0.16	0.16	0.25	0.69	0.73	0.20	0.44	0.69	0.32	0.28	0.16	0.40	0.16	0.36	0.08	0.24
CaO	2.52	3.04	2.98	3.05	2.62	1.46	1.52	1.29	1.46	1.46	1.17	1.23	1.23	1.29	1.29	1.71	1.88	1.19	1.71	2.28	1.31	1.19	1.54	1.99	2.60	1.19	1.36	1.31
Na_2O	4.18	4.17	3.93	4.31	3.37	2.83	2.83	3.37	3.37	3.37	3.37	3.64	2.83	3.37	3.37	1.41	3.70	4.31	4.48	3.37	4.31	4.48	4.24	3.91	4.11	2.49	1.82	3.37
K_2O	2.71	3.19	2.83	2.47	3.37	4.34	4.82	4.94	3.98	3.97	4.82	4.82	4.34	3.97	4.34	4.94	4.50	4.51	4.51	4.51	4.74	4.39	4.76	2.11	1.38	4.82	3.61	5.64
P_2O_5	0.01	0.11	0.02	0.04	0.04	0.01	0.01	–	–	0.01	–	–	–	–	–	–	0.03	0.01	–	0.08	0.01	0.02	0.03	0.12	0.04	–	–	0.01
H_2O^+	0.33	0.39	0.27	0.35	0.21	0.46	0.70	0.76	0.30	0.35	0.33	0.55	0.59	0.23	0.46	0.63	1.04	0.25	0.46	0.26	0.41	0.43	0.33	2.10	2.67	0.50	0.39	0.67
H_2O^-	0.15	0.09	0.10	0.15	0.11	0.06	0.14	0.07	0.01	0.05	0.09	0.09	0.22	0.13	0.12	0.06	0.08	0.08	0.10	0.07	0.11	0.09	0.11	0.14	0.27	0.02	0.05	0.01
P ppm	149	2449	500	949	800	149	250	–	48	101	–	–	50	–	50	50	722	250	–	1848	99	500	750	2800	848	–	50	1000
Nb	–	100	–	100	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ti	1669	9682	7679	7011	8013	5676	4006	6677	6343	6677	5676	6677	7011	5676	4006	500	–	–	–	1335	4006	–	–	2337	667	–	–	2337
Zr	300	1000	1000	1000	200	60	40	50	50	30	30	10	50	10	20	500	500	–	200	500	–	–	–	100	100	300	200	500
Sn	–	–	–	–	–	–	4	–	4	–	–	–	–	4	6	–	–	–	–	–	–	–	–	–	–	–	–	–
V	56	56	56	56	84	–	–	28	–	–	28	–	6	–	28	112	112	140	56	56	28	28	28	28	–	–	–	–
Cr	–	3	7	–	–	10	–	–	–	–	–	–	10	–	–	3	3	–	27	17	13	3	3	13	17	–	–	–
Ga	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10	–	–	–	–	–	–	–	–	–	–	–	–	–
Mo	–	–	–	–	–	6	5	4	6	–	–	–	5	4	5	–	–	–	–	–	–	–	–	–	–	–	–	–
Mn	775	1292	1033	1162	1033	775	646	516	904	1033	387	646	646	387	516	387	516	–	129	775	1033	1292	904	646	387	516	129	646
Co	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.002
Ni	30	30	–	50	30	30	8	8	10	8	8	8	10	8	10	30	30	–	–	–	–	–	–	–	–	30	–	–
Cu	20	20	20	20	20	30	20	10	10	8	8	4	10	8	10	20	20	10	20	20	20	20	10	10	20	20	10	10
Zn	–	1000	–	–	1000	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pb	–	–	–	–	–	10	–	–	–	–	–	–	–	–	30	–	–	–	–	–	–	–	–	–	–	–	–	–
Sr	300	300	300	500	300	–	–	–	–	300	–	–	–	300	–	200	200	100	100	200	–	–	–	300	500	100	100	100
Ba	2000	2000	300	1000	1000	400	300	300	400	300	400	400	400	100	100	1000	800	200	300	1000	–	200	–	1000	500	800	800	1000
Y	100	300	100	100	300	10	20	10	20	10	10	–	10	30	10	200	100	200	100	–	–	–	–	–	–	–	–	–
Be	–	–	–	–	–	2	1	1	2	1	1	2	1	1	3	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 3: Cont.

Group	Group (1)																							
Locality	Um Hombos									Um Had										Um Effin				
Sample No. / Terms	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
SiO	72.92	72.06	71.26	71.96	71.34	71.46	72.19	69.56	69.82	73.38	73.75	72.48	67.38	72.66	71.20	68.93	74.31	73.53	68.29	70.05	71.66	68.10	74.63	62.54
TiO_2	–	0.46	–	0.20	0.08	–	0.10	0.28	0.46	0.34	0.76	0.42	0.32	–	0.20	0.22	0.20	1.16	0.40	0.48	0.08	0.32	0.12	0.66
Al_2O_3	14.02	14.38	13.60	14.64	13.97	13.60	13.60	13.50	14.75	13.24	14.46	13.86	13.97	13.97	13.45	13.40	11.73	11.68	13.08	13.34	13.19	14.18	12.93	14.80
Fe_2O_3	0.45	1.60	1.61	0.54	0.32	0.51	0.40	0.56	0.76	1.29	1.88	0.13	0.57	0.90	0.84	1.24	1.73	2.94	3.16	1.54	2.02	1.68	1.10	0.84
FeO	1.26	0.46	0.22	1.12	1.00	1.13	1.25	2.49	2.23	0.98	5.54	1.49	3.91	0.80	2.30	2.71	1.65	1.17	2.52	1.29	1.00	2.54	1.15	5.91
MnO	0.05	0.05	0.05	0.03	0.06	0.06	0.03	0.05	0.05	0.04	0.18	0.06	0.10	0.02	0.06	0.08	0.05	0.08	0.09	0.06	0.02	0.10	0.05	0.12
MgO	1.02	0.38	0.55	0.21	–	–	0.47	0.51	0.85	0.25	1.57	0.68	0.98	0.38	0.85	0.98	0.21	0.47	1.40	0.17	0.21	0.72	0.30	2.72
CaO	1.07	1.13	1.49	1.07	2.20	2.80	1.78	2.68	2.20	1.43	3.39	1.61	2.86	1.25	1.90	2.38	1.49	1.01	3.16	2.50	1.61	2.92	1.49	2.74
Na_2O	3.77	4.04	4.04	3.97	4.92	4.38	3.77	4.18	4.04	4.04	3.50	4.04	3.91	4.99	3.50	3.37	3.70	3.77	3.03	4.04	5.19	4.04	3.50	6.26
K_O	4.16	4.16	4.16	4.64	4.22	4.16	5.52	4.04	3.83	3.19	3.61	3.91	3.49	3.61	4.58	4.46	3.61	3.37	2.47	3.91	4.16	3.86	4.16	0.48
P_{O5}	0.05	0.01	0.08	0.01	–	0.01	0.02	0.07	0.04	–	0.04	0.02	0.10	0.02	0.15	0.08	–	0.04	0.06	0.03	0.03	0.07	–	0.07
H_2O^+	0.90	0.91	1.26	0.75	1.65	1.71	0.20	0.90	0.74	0.77	0.43	0.39	0.64	0.61	0.50	0.66	0.67	0.78	0.54	1.59	0.64	0.96	0.40	2.40
H_2O^-	0.36	0.09	0.22	0.06	0.26	0.14	0.03	0.20	0.11	0.10	0.34	0.08	0.10	0.12	0.06	0.22	0.06	0.25	0.22	0.12	0.31	0.18	0.13	0.13
P ppm	1147	250	1743	183	–	137	389	1536	1000	–	1009	389	2339	550	1055	1903	–	1009	1444	642	699	1651	–	1491
Nb	100	100	–	–	–	–	–	–	–	100	100	200	–	–	100	–	200	–	–	–	–	–	–	–
Ta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ti	–	7679	–	3338	1335	–	1669	5990	7679	5676	12687	7011	5342	–	3338	3673	3338	2671	6677	8013	1335	5342	2003	11018
Zr	200	500	200	100	200	300	200	500	200	500	2000	200	2000	–	500	500	1000	800	200	500	500	300	100	500
Sn	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
V	84	56	–	–	140	56	84	84	–	–	112	100	84	112	7	168	56	84	112	–	84	140	28	112
Cr	–	–	–	3	–	–	13	3	3	–	13	3	–	–	–	7	–	3	30	7–		–	–	99
Ga	–	–	–	–	–	–	–	–	–	–	–	30	–	–	–	–	–	–	–	20	–	–	–	–
Mo	–	–	–	–	–	–	100	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mn	645	645	645	387	775	775	387	645	645	516	2325	775	1292	258	775	1033	646	1033	1163	775	258	1292	646	1550
Co	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ni	–	–	–	–	–	30	10	10	–	–	30	–	30	–	–	–	–	–	–	–	–	–	–	–
Cu	10	20	10	10	30	30	30	30	10	10	50	20	30	–	20	20	20	20	10	20	30	30	10	20
Zn	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–	–	200	–	–	–	–	–	–	–
Pb	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sr	200	–	300	200	150	200	200	200	300	100	300	300	500	100	300	200	100	200	300	300	300	500	300	200
Ba	1000	500	800	500	1000	1000	1000	3000	1000	500	3000	500	200	200	800	800	300	1000	500	500	1000	800	800	300
Y	–	100	–	–	–	–	–	–	–	100	100	100	200	–	200	–	100	100	–	100	–	100	–	–
Be	10	8	8	–	–	–	–	–	–	–	–	3	–	8	–	–	3	10	–	–	–	–	–	–

Table 3: Cont.

Group	Group (1)											
Locality												
Sample No. Terms	82	83	84	85	86	87	88	89	90	91	92	93
SiO_2%	74.31	73.15	64.03	73.56	73.98	73.31	74.45	74.80	72.23	74.52	72.62	75.53
TiO_2	0.42	0.28	0.08	-	-	-	0.22	-	-	0.04	0.48	-
Al_2O_3	13.14	13.08	13.13	13.34	13.34	12.67	12.51	12.56	11.94	12.72	12.56	12.41
Fe_2O_3	0.63	0.51	0.67	1.11	0.54	0.80	0.44	1.12	1.11	1.23	1.00	0.74
FeO	0.97	1.07	1.22	0.90	1.20	0.58	1.04	1.04	2.06	0.88	1.93	1.02
MNO	0.09	0.04	0.05	0.07	0.10	0.04	0.04	0.05	0.08	0.06	0.06	0.07
MgO	0.17	0.47	0.25	0.72	0.85	0.13	0.21	0.81	0.25	0.17	0.51	0.21
CaO	1.25	1.13	1.19	0.89	0.89	2.20	1.61	1.25	2.32	1.55	1.79	1.25
Na_2O	4.44	4.62	4.04	4.51	4.04	3.64	3.91	3.50	3.77	3.37	3.84	4.18
K_2O	3.67	5.19	4.03	4.22	4.16	4.58	4.58	3.58	3.49	3.92	3.61	4.04
P_2O_5	-	0.03	-	0.04	0.01	0.01	0.07	0.03	0.02	-	0.03	0.01
H_2O^+	0.59	0.26	0.89	0.53	0.45	0.71	0.70	0.90	0.66	1.01	0.65	0.52
H_2O^-	0.08	0.20	0.17	0.15	0.11	0.17	0.23	0.12	0.21	0.14	0.10	0.08
P ppm	-	596	-	802	298	134	1598	596	500	-	688	199
Nb	80	-	-	100	-	100	-	100	-	-	-	100
Ta	-	-	-	-	-	-	-	-	-	-	-	-
Ti	4006	4674	1335	-	-	-	3672	-	-	668	8013	-
Zr	100	100	-	300	300	200	300	300	300	800	300	200
Sn	-	-	-	-	-	-	-	-	-	-	-	-
V	-	28	56	140	-	224	56	28	112	-	100	56
Cr	3	-	3	-	7	-	-	-	-	-	7	-
Ga	-	-	-	-	-	-	-	-	--	-	-	-
Mo	-	-	-	-	-	-	-	-	-	-	-	10
Mn	1162	516	646	904	1292	516	516	646	1033	775	775	904
Co	-	-	-	-	-	-	-	-	-	-	-	-
Ni	-	-	-	50	-	-	-	-	-	-	-	-
Cu	20	10	-	10	10	10	10	10	20	20	10	-
Zn	-	-	-	1000	-	-	-	-	-	-	-	-
Pb	-	-	-	-	-	-	-	-	-	-	-	-
Sr	200	200	200	300	100	200	200	200	300	500	-	-
Ba	300	1000	300	2000	200	200	200	500	800	1000	300	300
Y	-	-	-	100	-	100	-	-	200	-	100	200
Be	-	-	-	10	10	-	-	10	-	-	-	-

Group	Group (1)																	
Locality																		
Sample No. Terms	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111
SiO_2%	75.09	75.60	75.14	73.83	75.48	71.94	74.96	74.58	72.46	64.17	73.17	75.86	75.80	73.46	73.53	72.80	73.83	73.64
TiO_2	-	0.14	0.36	0.34	0.36	0.01	0.22	0.30	0.10	0.40	0.30	0.16	0.14	0.42	0.48	0.42	0.24	0.48
Al_2O_3	12.04	12.36	12.98	13.34	12.20	13.19	12.07	12.17	12.49	11.66	12.84	10.64	11.06	11.71	11.71	12.43	11.40	12.58
Fe_2O_3	0.71	0.57	0.77	0.85	1.21	1.91	0.90	0.63	2.71	0.41	1.14	2.09	2.28	1.70	0.91	0.70	1.20	1.01
FeO	0.81	0.78	0.76	0.76	0.36	1.44	1.30	1.76	0.79	1.96	0.93	1.21	1.46	1.33	1.80	2.53	1.55	1.34
MNO	0.08	0.06	0.10	0.10	0.05	0.10	0.05	0.07	0.08	0.04	0.03	0.06	0.06	0.04	0.05	0.07	0.04	0.07
MgO	0.55	0.25	0.13	0.21	0.47	0.39	0.25	0.42	0.20	0.08	0.29	0.12	0.20	0.54	0.16	0.37	0.25	1.13
CaO	1.01	0.95	1.13	1.43	1.13	2.62	1.29	1.17	2.18	1.52	1.17	2.02	1.75	1.46	1.23	1.58	1.70	1.29
Na_2O	3.91	4.17	4.04	4.04	4.18	4.72	4.31	3.37	2.83	3.37	4.04	3.10	1.75	2.83	4.04	3.91	3.37	2.83
K_2O	4.46	4.21	3.91	4.22	3.73	3.37	3.01	4.34	4.82	4.94	5.18	4.82	6.02	4.58	3.85	4.58	4.58	4.09
P_2O_5	0.01	-	-	-	-	0.07	0.01	0.01	0.01	-	-	-	-	-	0.01	-	-	-
H_2O^+	0.45	0.31	0.46	0.62	0.51	0.55	0.47	0.45	0.63	0.53	0.33	0.25	0.09	0.69	0.16	0.25	0.42	0.95
H_2O^-	0.20	0.11	0.11	0.10	0.08	0.06	0.43	0.35	0.03	0.37	0.13	0.12	0.03	0.23	0.15	0.15	0.08	0.32
P ppm	199	-	-	-	-	1649	100	100	250	-	-	-	-	-	100	-	-	-
Nb	100	200	200	-	-	-	-	-	100	100	100	100	-	200	200	100	-	-
Ta	-	-	-	-	-	-	-	-	-	-	-	-	-	300	300	-	-	-
Ti	-	2337	6010	5676	6010	1669	3672	5008	1669	6677	5008	2671	2337	7011	8013	7011	4006	8013
Zr	100	100	300	100	800	50	40	40	80	50	30	30	100	80	30	40	80	40
Sn	-	-	-	-	-	5	4	4	6	4	-	4	4	5	-	4	4	4
V	56	-	-	-	28	50	10	10	10	56	-	10	20	30	-	28	-	30
Cr	-	3	3	7	-	41	-	-	34	10	-	34	57	30	-	-	10	-
Ga	-	20		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mo	-	-	-	-	-	5	5	6	8	6	-	4	6	4	5	5	-	-
Mn	1033	775	1292	1292	645	292	646	904	1033	516	387	775	775	516	646	904	516	904
Co	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	-	-	-	-	-	8	10	10	10	10	8	8	10	10	10	8	6	20
Cu	10	10	20	10	10	10	10	10	10	10	4	6	6	8	10	10	6	6
Zn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	100	-	-	-	-	10	10	10	20	10	-	10	10	10	10	10	10	10
Sr	100	-	-	200	200	100	100	50	300	300	-	100	150	100	50	100	150	100
Ba	800	300	300	200	1000	300	300	400	300	200	200	300	600	200	200	300	400	300
Y	-	100	200	-	-	10	10	-	40	10	10	30	30	80	60	10	10	-
Be	-	-	-	10	-	1	1	1	3	1	1	2	2	2	2	1	1	1

Table 3: Cont.

Group	Group 2				Group 3								
Sample No. Terms	112	113	114	115	116	117	118	119	120	121	122	123	124
SiO_2	74.26	73.39	67.38	68.28	75.22	75.65	75.05	76.69	76.10	75.27	74.69	74.69	75.07
TiO_2	0.24	0.24	0.60	0.48	–	–	–	–	–	–	–	–	–
Al_2O_3	12.34	12.22	12.81	15.53	11.32	11.16	9.92	10.90	10.90	11.16	11.42	11.58	12.70
Fe_2O_3	1.49	1.03	3.44	2.60	1.17	2.08	4.17	1.44	1.07	1.27	2.11	1.48	1.14
FeO	1.12	1.11	1.55	1.25	1.62	1.02	1.21	1.30	1.17	1.83	1.06	1.56	1.03
MnO	0.07	0.08	0.14	0.16	0.03	0.03	0.03	0.03	0.02	0.04	0.02	0.05	0.05
MgO	0.20	0.42	0.61	0.63	0.33	0.65	0.53	0.32	0.28	0.24	0.53	0.57	0.76
CaO	1.91	1.17	2.13	2.46	1.31	1.02	1.88	1.31	1.36	1.48	0.97	0.97	1.02
Na_2O	2.83	5.37	5.39	5.16	3.50	3.23	0.03	3.23	3.77	3.77	3.37	3.50	3.10
K_2O	4.94	4.34	3.61	3.35	4.58	4.58	3.61	4.48	4.15	4.52	4.58	4.62	4.05
P_2O_5	0.03	0.01	0.01	0.07	0.02	–	0.02	–	–	–	–	0.01	0.01
H_2O	0.14	0.36	0.53	0.56	0.39	0.50	3.26	0.21	0.44	0.27	0.28	0.32	0.60
H_4O^-	0.04	0.34	0.02	0.02	0.04	0.05	0.11	0.01	0.03	0.06	0.05	0.03	0.05
P ppm	598	101	300	1550	548	–	399	50	–	–	50	199	298
Nb	–	–	–	–	100	–	–	–	–	100	100	100	–
Ta	–	–	–	–	–	–	–	–	–	–	–	–	–
Ti	4006	4006	10016	8013	–	–	–	–	–	–	–	–	–
Zr	40	40	60	40	500	500	800	500	300	200	600	800	100
Sn	4	4	3	5	–	–	–	–	–	–	–	–	–
V	10	10	10	10	56	84	140	84	112	28	94	112	24
Cr	48	10	–	20	–	3	–	–	–	–	–	–	–
Ga	–	–	–	–	–	–	–	–	–	100	–	–	–
Mo	3	6	6	4	–	–	–	–	–	–	–	–	–
Mn	904	1033	1808	2067	387	387	387	387	258	516	258	646	646
Co	–	–	3	4	–	–	–	–	–	–	–	–	–
Ni	6	10	30	40	–	–	30	–	30	30	30	30	–
Cu	8	10	6	8	30	10	20	20	30	30	50	30	30
Zn	–	–	–	–	–	–	–	–	–	100	100	–	–
Pb	10	20	10	10	–	–	–	–	–	–	–	–	–
Sr	100	150	–	300	100	100	200	100	100	100	100	100	300
Ba	300	400	400	680	800	1000	400	200	600	300	100	150	1000
Y	–	10	10	10	100	–	200	100	100	200	100	100	–
Be	1	1	1	1	10	–	–	–	–	–	–	–	–

Group	Group 3														
Sample No. Terms	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139
SiO_2	73.82	73.36	72.26	76.13	73.41	70.25	71.25	73.22	69.19	74.14	73.77	71.76	73.82	72.71	71.34
TiO_2	0.20	0.24	–	–	0.41	0.04	0.02	0.04	–	–	–	0.04	0.02	–	–
Al_2O_3	13.08	12.88	12.15	12.25	11.19	15.42	15.37	14.70	15.90	14.02	13.40	14.33	11.68	14.36	14.90
Fe_2O_3	0.48	0.37	1.57	0.27	0.34	1.17	1.04	0.51	0.87	0.50	1.30	1.27	2.80	0.41	0.74
FeO	1.10	1.20	1.03	0.98	3.16	0.48	0.21	0.68	0.44	0.77	0.21	0.54	1.84	1.60	1.38
MnO	0.03	0.04	0.05	0.03	0.05	0.08	0.12	0.13	0.08	0.11	0.43	0.62	0.14	0.04	0.02
MgO	0.21	0.34	0.31	0.34	0.48	0.17	0.13	0.08	0.21	0.17	0.47	0.93	0.25	0.08	0.36
CaO	1.49	1.31	1.19	1.00	1.62	1.31	1.31	1.00	1.19	0.71	1.13	1.19	1.43	1.31	1.45
Na_2O	3.70	3.71	3.91	4.28	3.64	6.13	6.13	6.16	5.32	5.59	5.73	5.46	3.37	6.60	6.53
K_2O	4.46	3.73	4.46	4.06	4.82	3.55	3.85	2.95	5.84	2.71	2.47	3.07	3.97	2.41	2.41
P_2O_5	–	–	0.01	1.01	0.11	–	–	–	–	–	–	–	–	–	–
H_2O	1.07	0.88	0.89	0.57	0.11	0.41	0.62	0.32	0.75	0.62	0.84	0.70	0.37	0.40	0.76
H_4O^-	0.20	0.25	0.13	0.12	0.07	0.03	0.04	0.03	0.07	0.07	0.06	0.08	0.06	0.02	0.03
P ppm	–	–	137	250	2522	–	–	–	50	50	–	–	250	98	98
Nb	–	–	–	–	–	100	100	200	100	200	200	300	300	100	100
Ta	–	–	–	–	–	150	200	500	200	1000	1000	1500	1500	500	500
Ti	3388	4006	–	–	6846	667	333	667	–	–	–	667	3672	–	–
Zr	100	–	200	80	200	100	100	100	300	100	100	300	1000	–	–
Sn	–	–	–	–	–	–	300	300	–	3000	3000	3000	2000	800	1000
V	–	–	16	12	84	56	–	–	–	–	56	–	100	–	–
Cr	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ga	–	–	–	–	–	300	300	200	300	300	500	500	100	–	–
Mo	–	–	–	–	–	–	–	––		–	–	–	–	–	–
Mn	387	516	646	387	646	1033	1550	1679	1033	1421	5555	8010	1808	516	258
Co	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ni	–	–	–	–	–	–	–	–	–	–	–	–	50	30	30
Cu	10	10	10	30	–	50	30	50	20	20	20	50	50	30	20
Zn	–	–	–	–	–	–	200	400	–	–	2000	1000	1000	–	–
Pb	–	–	–	–	–	200	200	100	200	–	100	100	50	20	40
Sr	100	100	100	50	–	50	100	50	100	50	100	100	50	100	100
Ba	300	300	200	100	–	400	300	300	200	300	300	300	200	100	100
Y	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Be	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 4
Chemical analyses of Younger Granites from other localities for comparison.

Reference	Average chemical compostion of the studied granites				Turekian and Wedepohl (1961)		Abu El Leil (1975)			Greenberg (1981)		
Rock Type / Oxides	Group 1	Group 2	Group 3	Apogranite	High-Ca granite	Low-Ca granite	Biotite granite Av	Granplhyric granite Av	Apogranite	Group III	Group II	roup I
SiO_2%	67.30	72.37	74.23	71.95	67.23	74.29	72.15	72.56	73.46	70.10	74.80	75.12
TiO_2	0.37	0.26	0.17	0.01	0.57	0.20	0.01	0.11	0.17	0.47	0.15	0.07
Al_2O_3	14.68	12.13	11.67	14.57	15.57	13.61	13.55	13.06	14.59	14.10	12.80	12.50
Fe_2O_3	1.36	1.45	0.93	1.04	4.23+	2.03	1.67	1.73	0.96	2.84*	1.09	0.86+
FeO	2.66	1.50	1.85	0.76	–	–	0.55	0.63	–	–	–	–
MnO	1.06	0.43	0.41	0.27	1.56	0.27	0.60	0.42	0.28	0.64	0.11	0.04
CaO	2.87	1.81	1.38	1.20	3.54	0.71	1.84	1.82	0.66	1.71	0.57	0.54
Na_2O	4.29	3.91	3.54	5.80	3.83	3.48	4.50	4.62	5.16	4.57	3.99	4.21
K_2O	3.48	4.09	4.46	3.44	3.04	5.06	4.00	4.02	3.10	3.64	4.62	4.43
H_2O_+	108	0.62	0.55	0.58	–	–	0.44	0.53	0.82	–	–	–
P_2O_5	0.07	0.03	0.04	–	0.21	0.14	0.07	0.06	–	0.15	0.05	0.05

* Total iron as Fe_2O_3

1. Group 1 granites have relatively high CaO (2.87%), FeO (3.88), MgO (1.06%), TiO_2 (0.37), P_2O_5 (0.07%), Al_2O_3 (14.68%) and MnO (0.08%), and relatively low SiO_2 (67.30%) and K_2O (3.48%). The Na_2O content exceeds that of K_2O. They also have relatively high Ba, Sr, V, Cr, Ni, P, Co, and Cu and relatively low, Y, Zn and Ta (Table 3).
2. Group 2 granites have intermediate values of both major and trace elements between Group 1 and group 3. They have intermediate values of CaO (1.81%), FeO+ (2.80%), MgO (0.43%), TiO_2 (0.26%), Al_2O_3 (12.13%), MnO (0.07%), SiO_2 (72.37%) and K_2O (4.05%). The K_2O contents exceeds that of Na_2O. They also have intermediate values of Ba, Sr, Cr, Ni, Y, Cu, Co, V and P.
3. Group 3 graites have relatively low CaO (1.38%), FeO+ (2.69), MgO (0.141%), TiO_2 (0.17%), Al_2O_3 (11.67%), MnO (0.04%) and relatively high SiO_2 (74.23%) and K_2O (4.46%). The content exceeds that of Na_2O. They have relatively low Ba, Sr, V, Cr, P, Co and Cu relatively high Y.
4. The apogranites contain relatively high MnO (0.16%), AL_2O_3 (14.57%) and Na_2O (5.80%) and low TiO_2 (0.03%), CaO (1.20%), FeO (0.76%), MgO (0.27%), P_2O_5 (0.002%) and K_2O (3.44%). They are also characterized by high values of Sn, Nb, Ta, Pb, Mn, Ga, and Cu and contain the lowest values of P and V. Cr, Co, Y and Be are not detectd.

The AFM diagram (Fig. 4) shows that the analysed granitic samples are pogressively richer in alkalies and poorer in Mg and Fe from Group 1 through Group 2 an Group 3 to the apogranites. The K, Na, Ca diagram (Fig. 5), including the suggested field for magmatic rocks after Raju and Rao (1974) which shows that : a) Group 1 granites are the most calcium rich and alkali poor whereas the apogranites and Group 3 granites are the most alkali rich

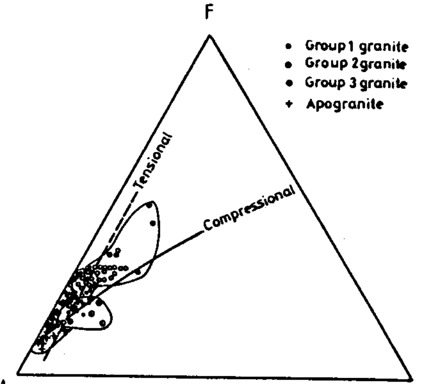

Fig. 4: AFM variation diagram.

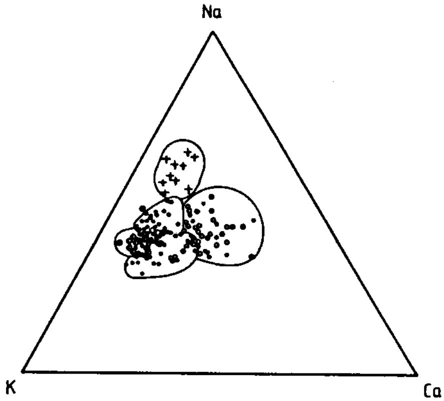

Fig. 5: K-Na-Ca variation diagram; symbols as in Fig. 4.

and calcium poor, b) the apogranites are apparently more sodic and less potassic whereas Group 3 more potassic and less sodic, c) Group 2 granites occupy an intermediate position between Group 1 and Group 3, d) the three granitic groups have their plots on the field representing granitic rocks of magmatic origin.

The Calc-alkaline/alkaline nature

The alkalinity ratios of the studied younger granites are calculated and plotted on Wright's (1969) alkalinity ratio variation diagram (Fig. 6). This shows that Group 1 granites are calc-alkaline to weakly alkaline, Group 2 granites and the apogranites are normal alkaline whereas Group 3 granites are strongly alkaline.

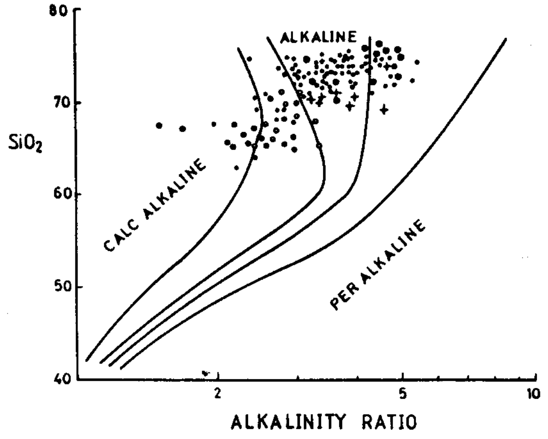

Fig. 6: Alkalinity variation diagram of Wright (1969) symbols as in Fig. 4.

Geochemistry of the Separated Minerals

Representative granitic samples of each of the four groups have been subjected to physical separation of their mineral components. These minerals include biotites, feldspars, muscovites, garnets and magnetites. The pure separated minerals were then chemically analysed to the same major and trace elements of the rocks using the same methods of analyses.

Major Elements

Biotite

Major and trace elements of 13 biotite analyses from the three granitic groups are given in Table 5. This table reveals that the separated biotites are rich in ferrous iron content which exceeds that of ferric iron. They are also characterized by high K_2O and Na_2O and low CaO. FeO content always exceeds that of MgO.

Table 5

Major and trace element analyses of the separated biotites, muscovites and garnets

	8'	11'	13'	16'	19'	28'	(1)	38'	58'	60'	69'	82'	110'	(2)	126'	134'	139'	Av.	N	50'	52'	Av.	C
SiO_2	39.14	39.60	43.80	30.90	38.19	34.75	37.72	34.65	31.00	32.25	35.35	31.35	40.00	34.13	31.90	46.70	49.89	48.30	51.22	34.50	33.70	34.10	37.23
TiO_2	3.96	2.70	3.99	3.60	5.60	2.80	3.77	2.00	0.30	1.90	1.08	2.50	3.40	1.98	3.00	1.20	–	0.60	0.53	1.06	–	0.80	0.00
Al_2O_3	14.64	12.98	15.92	15.57	12.98	16.87	14.83	12.98	19.47	18.67	16.87	15.83	14.36	16.36	16.09	21.61	25.40	23.51	25.91	17.65	20.77	19.21	20.66
Fe_2O_3	2.54	3.23	4.44	1.74	3.67	2.60	3.04	5.11	2.36	2.81	2.15	2.13	4.51	3.18	3.14	–	–	–	4.59	8.34	7.58	7.96	1.33
FeO	20.64	17.82	14.58	19.17	15.48	16.51	17.36	25.93	25.40	20.46	20.95	24.48	15.28	22.08	22.06	4.82	2.52	3.67	1.70	20.20	22.47	21.33	29.67
MnO	0.47	0.62	0.50	0.50	0.65	0.72	0.58	0.55	0.42	0.20	0.55	0.62	0.36	0.45	1.45	0.50	0.75	0.63	–	8.25	7.50	7.88	7.30
MgO	9.41	7.99	5.42	14.54	11.12	11.97	10.07	7.56	9.41	9.69	11.12	11.12	10.26	9.86	10.26	3.42	2.56	2.99	2.84	5.98	5.13	5.56	2.00
CaO	1.19	1.19	1.39	1.79	1.19	1.79	1.42	1.91	1.19	0.79	1.19	1.19	1.79	1.34	0.60	1.59	0.60	1.10	0.16	3.25	2.39	2.87	1.31
Na_2O	0.81	0.40	1.08	0.27	1.08	0.40	0.67	0.97	0.54	0.54	0.81	0.81	0.81	0.75	0.40	2.87	1.75	2.31	0.17	0.10	–	0.05	–
K_2O	3.97	6.38	5.82	6.60	6.84	7.08	6.11	5.14	6.44	9.33	6.63	4.34	5.54	6.24	6.41	8.85	8.85	8.85	6.09	0.58	0.48	0.53	–
H_2O^+	3.42	3.58	3.57	3.66	3.23	3.64	3.52	2.11	3.77	4.02	2.91	6.00	2.87	3.61	2.63	5.88	5.94	5.91	7.14	–	–	–	0.57
Nb ppm	30	30	–	–	30	30		100	–	–	100		–		30	200	300			–	–		
Ti	3000	10000	3000	8000	8000	8000		3000	100	8000	3000	10000	100		3000	8000	500			100	100		
Zr	200	300	200	200	200	300		300	–	200	200	300	100		200	200	300			100	30		
Sn	–	–	–	–	30	80		–	–	–	–	30	–		–	200	400			–	–		
V	100	200	–	200	200	200		–	–	30	30	100	–		–	100	–			–	–		
Cr	–	–	–	30	50	100		–	–	–	5	50	–		10	–	–			–	–		
Ca	30	30	–	50	50	200		30	–	–	30	100	30		10	10	10			30	–		
Mo	–	3	–	–	5	5		–	–	–	–	10	–		5	3	–			–	–		
Mn	1000	3000	800	2000	3000	3000		1000	100	300	1000	3000	3000		1000	1000	1000			3000	8000		
Co	–	30	20	30	50	50		30	–	–	–	30	–		–	–	10			–	–		
Ni	10	30	–	80	80	30		10	–	–	5	30	–		50	30	10			–	30		
Cu	30	20	10	30	30	30		3	10	2	10	30	10		30	500	100			10	5		
Zn	–	200	100	–	–	200		200	–	–	–	300	100		–	100	100			200	200		
Pb	–	–	–	–	–	80		–	–	–	–	30	–		–	100	100			–	–		
Sr	–	–	–	1000	1000	8000		–	300	500	300	–	–		500	–	–			–	–		
Ba	–	–	–	300	300	300		–	–	100	300	1000	–		100	–	–			–	–		
Y	50	50	–	50	80	80		300	–	–	100	200	100		30	–	–			300	300		
Be	–	–	–	–	8	6		3	–	–	–	8	–		–	–	3			–	–		

N = Hydrous muscovite (fine colloid fraction) Pennsylvanian Underclay, Vermilion Co., Illinds (Grim *et. al.*, 1973).
O = Garnet, granite, Chinkwell Tor, Dartmoor (Brammall and Harwood, 1932).

The chemical data of the biotite analyses were plotted on different types of variation diagrams to indicate the petrogenesis of the host granitic rocks. In the $(Fe_2O_3 + TiO_2)-MgO-(FeO + MnO)$ diagram (Fig. 7), the examined biotites fall within the field of plutonic biotites (Heinrich, 1946). Biotites from Group 1 and Group 2 lie within both fields of biotites of igneous rocks and biotites of metamorphic-metasomatic rocks (Gokhale, 1968), whereas that of Group 3 falls within the field of biotites of igneous rocks. in the $MgO-Al_2O_3$-FeO+ diagram (Fig. 8), the examined biotites (except for one anlysis from Group 1) fall within the zone for biotites of igneous rocks (Nockolds, 1947 and Gokhale, 1968). In the $MgO-(FeO + MnO)-(Fe_2O + TiO_2)$ diagram (described by Heinrich, 1947 and compiled by Engel and Engel, 1960; Fig. 9), the studied biotites fall within the field of biotites of granitic rocks.

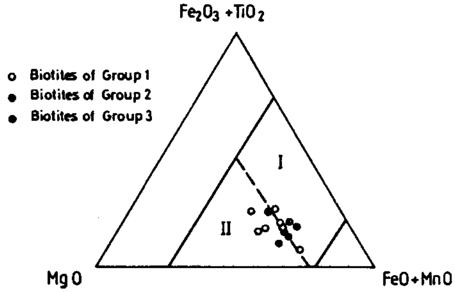

Fig. 7

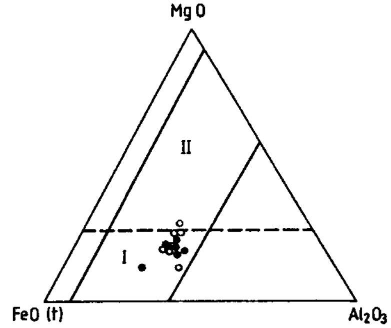

Fig. 8

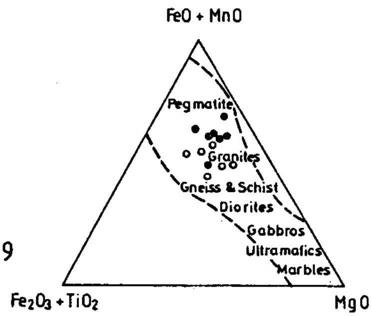

Fig. 9

Fig. 7: Plot of MgO, $(Fe_2O_3 + TiO_2)$ and $(FeO + MnO)$ in biotites separated from the Younger Granites.
zone drawn by Heinrich (1946)
line drawn by Gokhale (1968) separating biotites of magmatic rocks (I) from those of metamorphic-metasomatic rocks (II).

Fig. 8: Plot of FeO (total iron), MgO and Al_2O_3 in biotites separated from the Youner Granites; symbols as in Fig. 7. zone demarked by Nockolds (1947) for igneous rocks. line drawn by Gokhale (1968) separating biotites of magmatic rocks (I) from those of metamorphic-metasomatic rocks (II).

Fig. 9: Variation of chemical composition biotites with the rock type (After Engel and Engel, 1960); symbols as in Fig. 7.

The strcutural unit cell formula of the studied biotites were recalculated on the basis of 24(0.0H) to the general mica formula $[X_2Y_{4\text{-}6}Z_8O_{20}(OH,F,Cl)_4]$; Table 6. Figure 10 shows the relationship between the members of the Y-group (Fe^{+2}, Mg, Al^{vi}, Ti, Fe^{+3}). In this figure, all the samples of Groups 2 and 3 and four samples from Group 1 fall within the field of Mg-biotites defined by Foster (1960). In the $Fe^{+3}-Fe^{+2}-Mg$ diagram (Wones and Eugster, 1965, Fig. 11), the separated biotites fall between the Ni-NiO and $Fe_3O_4-Fe_2O_3$ buffer representing biotites coexisting with both potassium feldspar and magnetite.

Table 6

Structural unit cell formula of the separated biotites.

Rock Group	Group 1						
Locality	**Fawakhir**		**Atalla**	**Kib Absi**			
Sample No. Terms	8'	11'	13'	16	19'	28'	
Si	5.85	6.14	6.36	4.84	5.75	5.29	
Z	8.00	9.00	8.00	7.71	8.00	8.00	
Al^{vi}	2.15	1.86	1.64	2.87	2.25	2.71	
T_{vi}	0.45	0.32	0.44	0.42	0.63	0.32	
Al^{vi}	0.42	0.51	1.08	–	0.05	0.31	
Fe^{+3}	0.29	0.37	0.48	0.21	0.41	0.30	
Fe_{-3} Y	2.57 5.90	2.32 5.45	1.76 5.00	2.50 6.61	1.95 5.63	2.09 5.84	
Mn	0.06	0.08	0.06	0.07	0.08	0.09	
Mg	2.11	1.85	1.18	3.41	2.51	2.73	
Ca	0.19	0.19	0.22	0.30	0.19	0.29	
Na X	0.24 1.19	0.12 1.59	0.30 1.60	0.08 1.70	0.32 1.83	0.12 1.79	
K	0.76	1.28	1.08	1.32	1.32	1.38	

Rock Group	Group 2						Group 3
Locality	Kadabora	Um Hombos		Um Had	Eraddia	Ras Barud	South Eraddia
Sample Terms	38'	58'	60'	69'	82'	110'	126'
Si	5.64	4.84	4.97	5.45	4.73	6.01	5.14
Z	8.00	9.00	8.00	8.00	7.54	8.00	8.00
Al^{vi}	2.36	3.16	3.03	2.55	2.81	1.992.86	
Ti	0.245	0.44	0.21	0.20	0.28	0.39	0.37
Al^{vi}	0.13	0.42	0.35	0.49	–	0.56	0.19
Fe^{-3}	0.63	0.63	0.33	0.25	0.25	0.51	0.38
Fe^{-2} Y	3.51 .449	3.31 6.67	2.62 5.78	2.67 6.24	3.08 6.21	1.91 5.74	2.96 6.56
Mn	0.08	0.06	0.03	0.07	0.08	0.05	0.19
Mg	1.84	2.21	2.24	2.56	2.52	2.32	2.47
Ca	0.33	0.20	0.13	0.19	0.19	0.290.11	
Na X	0.30 1.69	0.16 1.64	0.16 2.13	0.24 1.73	0.24 1.27	0.24 1.59	0.12 1.55
K	1.06	1.28	1.84	1.30	0.84	1.06	1.32

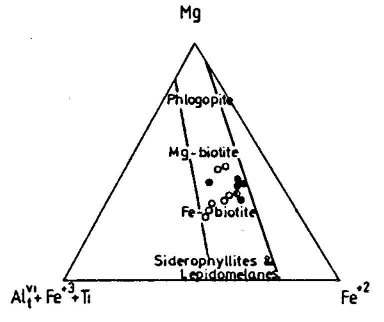

Fig. 10

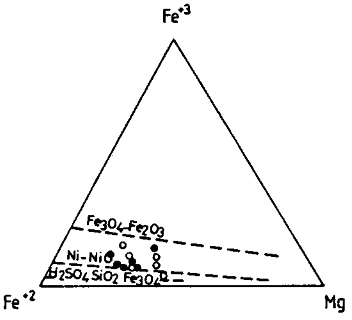

Fig. 11

Fig. 10: Relation between octahedral cations of the biotites separated from the studied Younger Granites; Symbols as in Fig. 7.

Fig. 11: Fe^{+3}-Fe^{+2} - Mg diagram of the separated biotites. Symbols as in Fig. 7. Dashed line = composition of biotites in the system. $KF^{3+}{}_3\ AlSi_3O_{12}(H_{-1})$ - $KFe^{2+}{}_3AlSi_3O_{10}(OH)_2$-$KMg_3AlSi_{10}(OH)_2$ (after Wones and Eugster, 1965).

Feldspars

Major and trace elements as well as the normative composition for 32 separated feldspars analyses from the studied granites are represented in Table 7. Considering the average contents, it is clear from table 7 and figure 12 that the separated feldspars are progressively richer in SiO_2 and K_2O and poorer in Na_2O, CaO and Al_2O_3 from Group 1 through Group 2 to Group 3. On the other hand, the feldspars of the apogranites show the highest contents of Na_2O, CaO and Al_2O_3 and the lowest K_2O content.

In table 7 and figure 13, the separated feldspars are characterized by the lowest value of "Or" mols. in Group (1) then increase gradually in Group (2) and Group(3) and then decrease again in the apogranite. The "Ab" mols show a reverse trend to that of the "Or" mols. The amount of "Ab" mols. increase to a maximum value in the apogranites due to the albitization processess.

The ratios of the three main mols. namely Or: Ab: An is 1.7:4.9:1 in Group (1), 7:8.8:1 in Group (2), 7:6:1 in Group (3) and in apogranite it is 4:10:1. The plagioclase type (Ab value) in the feldspar of Group (1) ranges from 77.01 (oligoclase type) to 87.39 (oligoclase type); in feldspars of Group (2) it ranges from 72.00 (oligoclase type) to 99.07 (albite type); in feldspars of Group (3) it ranges from 75.76 (oligoclase type) to 92.66 (albite type) and in the apogranites it ranges from 77.00 (oligoclase type) to 95.65 (albite type).

Table 7

Major and trace element analyses as well as normative composition of the separated feldspar.

	8′	11′	13′	16′	19′	28′		30′	36′	38′	50′	52′	54′	55′	58′	60′	69′	72	78′	82′	90′
SiO_2%	6550	65.20	64.00	62.95	65.25	64.60	64.53	64.30	62.05	63.60	65.05	64.35	64.70	63.30	66.80	62.20	67.10	63.40	66.05	63.00	69.25
TiO_2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Al_2O_3	18.54	19.65	18.84	18.35	18.87	18.09	18.72	19.35	18.62	19.13	18.65	18.97	20.69	17.58	18.36	20.17	17.50	20.25	18.32	18.22	16.10
Fe_2O_3	0.76	0.40	0.70	0.85	0.55	0.72	0.65	1.20	0.57	–	–	–	0.70	0.57	0.55	0.62	1.20	0.42	1.27	0.17	0.80
MnO	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MgO	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CaO	2.46	3.83	4.79	4.31	2.87	2.87	3.52	5.99	1.91	1.91	2.87	3.35	2.34	3.87	0.96	1.91	4.07	1.46	1.39	3.35	0.88
Na_2O	5.66	5.93	6.52	7.00	6.90	6.25	6.38	6.06	5.34	5.04	5.82	5.85	7.12	4.62	6.25	6.20	5.44	6.36	6.74	6.36	5.12
K_2O	4.58	3.70	2.41	3.23	2.99	3.66	3.44	2.05	7.96	7.32	5.16	5.69	1.83	7.82	4.96	5.69	3.66	6.26	6.41	6.99	5.25
H_2O	1.27	1.16	1.85	1.66	0.68	0.44	1.18	0.17	1.69	0.3	0.34	0.20	1.30	1.23	1.29	1.6	60.94	1.04	0.49	0.36	1.74
Nb ppm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ti	–	200	300	200	100	200		–	–	–	–	–	300	–	100	200	1000	100	50	200	100
Zr	–	50	100	–	–	30		–	–	50	–	–	30	–	50	–	300	–	–	–	–
Mo	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mn	–	–	300	200	100	100		–	–	–	–	–	–	–	20	80	100	20	–	200	50
Cu	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	3	–	3	–	–	–
Pb	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sr	–	500	–	1000	1000	500		–	–	–	–	100	500	50	100	300	300	–	–	200	200
Ba	–	–	200	–	200	200	100		–	–	–	–	–	50	–	50	100	30	200	30	30
Be	–	–	1	–	–	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–
Normative composition																					
Or	29.74	23.74	15.26	19.34	18.89	23.67	21.77	12.87	45.96	41.60	32.13	34.01	11.39	47.21	23.15	33.46	24.32	36.26	35.38	36.26	38.60
Ab	55.86	56.88	62.62	63.73	66.24	61.43	61.13	57.86	46.78	52.17	55.08	53.16	53.16	67.36	42.40	61.57	55.42	54.94	54.63	57.95	53.26
An	12.80	16.98	16.5	9.20	12.48	11.48	13.18	22.50	3.29	3.32	10.59	8.80	19.96	4.21	5.23	10.03	14.06	9.28	0.76	0.50	–
Wo	0.31	1.67	4.66	6.23	1.37	2.05	2.71	4.55	2.99	2.90	2.20	4.01	–	5.17	–	–	4.32	–	2.93	7.50	–
Mt	1.29	0.74	1.30	1.50	1.02	1.36	1.20	2.23	0.97	–	–	–	1.29	1.01	1.05	1.08	2.35	0.70	2.12	0.28	1.64
Plagioclase Type (Ab value)	81.36	77.01	79.50	87.39	84.15	84.25	82.28	72.00	93.43	94.02	83.87	85.80	77.14	90.97	92.17	84.68	79.62	85.48	98.71	99.07	87.86

	110′		118′	123′	126′	128′			130′	132′	135′	136′	138′	139′	
SiO_2%	64.65	61.55	64.46	68.30	66.85	69.20	70.00	68.59	65.00	67.45	67.40	60.10	66.80	66.80	65.99
TiO_2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Al_2O_3	17.92	19.65	18.71	16.90	18.97	15.24	16.28	16.85	18.06	17.58	18.00	19.10	19.62	19.62	18.66
Fe_2O_3	0.36	0.32	0.55	2.00	0.17	0.80	0.67	0.91	–	–	–	–	–	–	–
MnO	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MgO	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CaO	1.44	1.95	2.42	1.91	1.64	2.39	1.44	1.85	3.40	3.10	4.03	8.79	0.97	0.97	3.54
Na_2O	5.66	5.28	3.89	4.16	4.78	5.23	5.12	4.82	7.01	7.12	5.66	5.66	7.71	7.49	6.77
K_2O	6.65	9.64	5.83	6.82	5.96	4.87	5.82	5.86	4.43	4.43	3.47	3.90	2.65	2.84	3.62
H_2O	0.73	0.54	0.86	1.73	0.80	1.23	1.15	1.23	0.81	0.48	0.72	0.98	0.47	0.62	0.68
Nb ppm	–	–	–	–	–	–	–		100	80	80	30	30	30	
Ti	80	50		300	–	200	200		–	–	100	30	–	–	
Zr	–	30		100	30	–	–		100	30	30	–	30	20	
Mo	–	–	–	–	–	–	–	–	5	5	3	–	–	–	–
Mn	80	300		–	–	100	–		2000	1000	2000	2000	100	1000	
Cu	–	–	–	–	–	–	–	–	–	1	–	1	–	–	
Pb	–	–	–	–	–	–	–	–	100	100	–	–	–	–	
Sr	–	–		300	–	200	200		–	–	–	–	–	–	
Ba	1000	–	–	100	–				300	100	–	–	–	–	
Be	–	1		–	–	–	–		1	5	5	3	3	3	
Normative composition															
Or	40.84	51.55	34.07	35.04	34.20	33.84	36.38	34.87	26.19	26.36	23.28	22.30	16.68	17.98	19.14
Ab	52.83	42.91	53.91	45.97	50.12	55.34	54.85	51.57	63.01	64.41	57.73	49.22	73.75	72.08	63.37
An	1.75	3.73	2.63	–	–	4.79	–	1.20	4.7	2.93	15.27	14.70	9.59	9.94	9.52
Wo	1.75	3.73	2.63	–	–	4.78	–	1.20	6.09	6.28	3.72	13.77	–	–	4.98
Mt	0.50	0.99	4.29	0.55	1.65	1.39	1.97	–	–	–	–	–	–	–	–
Plagioclase Type (Ab value)	93.08	97.06	88.43	75.76	76.56	92.66	88.13	83.28	93.03	95.65	79.08	77.00	88.49	87.88	86.86

- = not determined   P, Ta, Sn, V, Cr, Ga, Co, Zn and Y are not detected.

Fig. 12

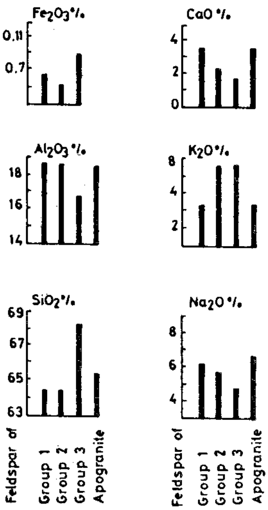

Fig. 13

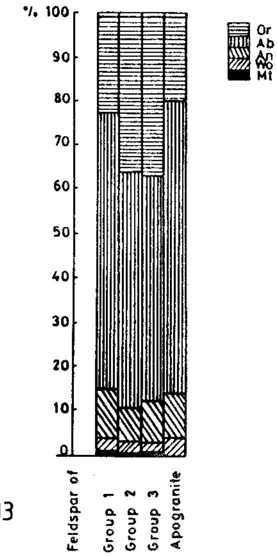

Fig. 12: Variation in the chemical composition of the feldspars separated from the studied Younger Granites.

Fig. 13: Graphic representation of the normative composition of the separated feldspars.

Muscovite

Major and trace elements of 2 muscovite analyses separated from the apogranite as well as one reference sample from Penssylvania (Grim *et al.,* 1937) are given in table 5. Comparison between the muscovite under consideration and the reference sample shows that the former is characterized by lower SiO_2, Al_2O_3 and relatively higher MgO, Na_2O, K_2O, CaO, TiO_2 and FeO.

The structural unit cell formula of the studied muscovite and the reference sample were calculated on the basis of 24(O.OH) and the results are shown in table 8. In the Z-site, Al^{iv} is more pronounced in the investigated samples while its Y-site is occupied by Al^{iv} (66.95%), Mg^{2+} (17.51%), Fe^{2+} (11.86%), Mn (1.98%) and Ti (1.69%). In X-site, K^+ ion is represented by 66.38%, Na^+ by 26.72% and Ca^{2+} by 6.90%. The studied muscovite is thus of subcalciferous type.

Garnet

Garnet occurs in some plutons of the Group 2 granites most probably due to the contamination of the granite materials by argillaceous impurities. Major and trace elements of 2 garnet analyses as well as one reference sample are given in table 5. Comparison between the studied garnet and the reference sample shows that the former is characterized by relatively higher Fe_2O_3, MgO, CaO, MnO, TiO_2, Na_2O and K_2O and lower SiO_2, Al_2O_3 and FeO.

Table 8

Structural unit cell formula of the studied muscovite as compared with hydrous muscovite (Grim *et al.*, 1973).

	134'	139'	Av	N
Si	6.49	6.70	6.60	6.75
Z	8.00	9.00	8.00	8.00
Al^{vi}	1.51	1.30	1.40	1.25
T^{vi}	0.12	–	0.06	0.05
Al^{vi}	2.03	2.70	2.37	2.77
Fe^{+3}	–	–	–	0.45
Fe^{+2} Y	0.56 3.49	0.28 3.58	0.42 3.54	0.19 4.02
Mn	0.06	0.08	0.07	–
Mg	0.72	0.52	0.62	0.56
Ca	0.23	0.09	0.16	0.02
Na X	0.78 2.57	0.46 2.07	0.62 2.32	– 1.04
K	0.56	1.52	1.54	1.02
OH	5.44	5.32	5.38	4.00

Sample No. Ions

The structural unit cell formula of the studied garnet and the reference sample were recalculated on the basis of 24(0.0H) and the results are given in Table 9. The formula shows that the Z-site is tetrahedrally occupied by 5.52 atoms Si and 0.48 atoms Al ^{vi}, whereas Si in the reference sample is occupied by 6.00 atoms. In the Y-site, the studied garnet has a total of 4.24 atoms where Fe^{+3} ion is represented by 22.88%, Al ^{vi} by 74.76% and Ti by 2.36%. The reference sample has 4.11 atoms distributed between 3.89% Fe^{3+} and 96.11% Al^{vi}. In X-site, Mg ion is represented by 22.77%, Fe $^{+2}$ by 48.57%, Mn by 18.21%, Ca by 8.43%, Na by 0.17% and K by 1.85% while in the reference sample Mg ion is represented by 8.36%, Fe^{+2} by 70.21%, Mn by 17.42% and Ca by 4.00%.

The chemical composition and the structural unit cell of both the studied garnet and the reference sample reveals that the Si, Al and Fe^{+2} which represent the main constituents are nearly equal in amount and represent the main constituents of both the reference sample and the separated garnet indicating that the stuied garnet is of almandine type. The relationship between the (CaO + MnO) and (FeO + MgO) is plotted on the parabolic curve (Nandi, 1967; Fig. 14). According to this diagram the content of (FeO + MgP) is less than 28% indicating no metamorphic grade of the studied garnet.

Table 9
Structural unit cell formula of the studied garnet as compared with other garnet (Brammall and Harwood, 1932).

Sample No. Ions		50'		52'		Av		O	
Si		5.57		5.46		5.52		6.00	
	Z		6.0		6.0		6.0		6.0
Al^{vi}		0.43		0.54		0.48		–	
T_{vi}		0.20		–		0.10		–	
Al^{vi}		2.92	4.13	3.41	4.33	3.17	4.24	3.95	4.11
Fe^{3+}		1.01		0.92		0.97		0.16	
Mg		1.45		1.24		1.35		0.48	
Fe^{2+}	Y	2.72		3.03		2.88		4.03	
Mn		1.12		1.03		1.08		1.00	
Ca	X	0.58	6.01	0.42	5.82	0.50	5.93	0.23	5.24
Na		0.02		–		0.01		–	
K		0.12		0.10		0.11		–	

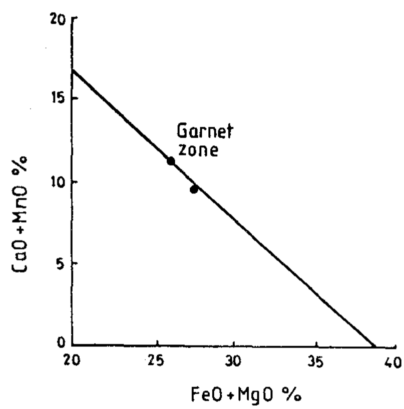

Fig. 14: The relationship between garnet composition weight % CaO + MnO versus FeO + MgO (After Nandi, 1967).

Magnetite

Major and trace elements of 4 magnetite analyses are given in table 10. The table reveals that the analysed magnetites are progressively richer in SiO_2 and Fe_2O_3 and poorer in FeO from Group 1 through Group 2 to Group 3,. TiO_2, Al_2O_3, MgO and CaO show no clear trend in the magnetites of the different types of granites.

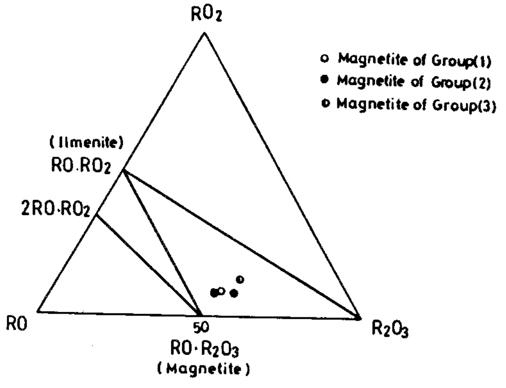

Fig. 15: Representation of magnetite fractions separated from Aswan granite in the molecular RO-RO_2-R_2O_3 traingular diagram.

The chemical composition of the separated magnetites are calculated to their molecular percentages and are plotted on the RO_2-RO-R_2O_3 triangular diagram (Vincent *et al.,* 1957; Fig. 15). The positions of the studied magnetites ar within the triangle cornered by $RO.R_2O_3$, R_2O_3, $RO.Ro_2$ but nearer to $RO.R_2O_3$-R_2O_3 base line. Through allotation of RO to their equivalent R_2 and R_2O_3, the normative composition shown in table 10. The magnetites of the studied granites are mostly composed of magnetite, Fe_2O_3 and some ilmenite. The component normative minerals of magnetite of the studied granite are distributed by the following ratio values: a) Group 1: 0.20 ilmenite, 0.56 magnetite and 0.24 Fe_2O_3, b) Group 2: 0.18 ilmenite, 0.56 magnetite and 0.26 Fe_2O_3, c) Group 3: 0.26 ilmenite, 0.36 magnetite and 0.38 Fe_2O_3. Kotb (1965) has proved (mineralographically) and by heating experiments) that the actual Fe_2O_3 calcualted in the normative formula is in -form (maghemite). Thus, the magnetite fractions of Group 1 and Group 2 are ilmenomaghemo-magnetite while in Group 3 it is ilmeno-maghemite.

Trace Elements

Tables 5, 7 and 10 indicate that: a) Sr is more concentrated in feldspars, biotite and magnetite, b) Ba is accomodated in magnetite and biotite rather than in feldspars, d) Y is enriched in biotite, magnetite and garnet, e) Zr is carried by magnetite, biotite, muscovite and feldspars, f) Mo is carried considerable amount of Ti, h) Muscovite, biotite and feldspars are the carrier of Sn, i) Ga and Cu are more concentrated in biotite, magnetite, muscovite and granet rather than in feldspars.

PETROGENESIS

The source and origin of the Younger Granites, is a major problem. The previously published Sr isotope data by Fullagar and Greenberg, 1978;

Table 10
Major and trace element analyses as well as normative composition of the separated magnetites.

Rock Group	Group 1	Group 2			Group 3
Locality	Kib Abasi	Um Had	Eraddia	Av.	El Sibai
Sample No. Terms	16'	69'	82'		123'
SiO_2%	0.40	2.10	2.99	2.55	2.80
TiO_2	6.00	2.20	3.00	2.60	5.20
Al_2O_3	1.25	1.81	3.46	2.64	1.03
Fe_2O_3	70.03	73.46	66.83	70.14	73.19
FeO	22.26	17.91	19.13	18.61	16.98
MnO	–	–	0.33	0.16	–
MgO	0.85	1.28	1.42	1.35	0.85
CaO	–	0.59	1.99	1.29	–
Ti ppm	1000	300	1000	650	3000
Zr	200	100	300	200	1000
V	300	100	200	150	30
Cr	80	–	50	25	80
Ga	30	–	30	15	80
Mo	10	–	3	1.5	20
Mn	200	300	300	300	1000
Co	–	30	–	15	–
Ni	30	–	10	5	20
Cu	20	3	20	11.5	30
Zn	300	200	–	100	800
Sr	1000	–	2000	1000	1000
Ba	300	–	200	100	300
		Normative composition			
$RO.RO_2$	0.20	0.16	0.20	0.18	0.26
$RO.R_2O_3$	0.56	0.54	0.58	0.56	0.36
R_2O_3	0.24	0.30	0.22	0.26	0.38

– = not detected
Nb, Sn, pb, Y and Be are not detected

Fullagar, 1980; Hashad, 1980; Meneisy and Lenz, 1982; Stern and Hedge, 1985 and Abdel-Rahman and Doig, 1987) indicate initial $^{87}Sr/^{86}Sr$ ratios in the range of 0.7016–0.7110. These ratios presumably result from deriviation of the melts from mantle, oceanic crust, or a new immature volcanic arc protolith of low Rb/Sr ratio and preclude the participation of much older sialic crust.

No simple model can account for the diversity and extremely variable major and minor element chemistry of the granitic magmas of the different groups of the Younger Granites. However, most of the geologic and chemical features observed in the Egyptian Younger Granites could be explained using a fusion-refusion model similar to that proposed by Collin *et al.,* (1982), in which an initial fusion event of the volcanic arc protolith produced wet high-Ca granites with I-type (Chappell and White, 1974; Pitcher, 1983) characteristics. These high-Ca granites with I-type characteristics are represented here by the less differentiated calc-alkaline to weakly alkaline granodiorite and monzogranite of Group (1). This fusion phase was followed by a later fusion of the same crust which produced progressively dry, low-Ca granites with A-type characteristics (Loiselle and Wones, 1979; Collins *et al.,* 1982). The progressively dry, low-Ca granites with A-type characteristics are represented here by the normal alkaline monzo and syenogranites of Group (2) and the highly differentiated strongly alkaline alkali feldspar granites of Group (3). The specific characteristics of each batch of I- of A-type granite magma would have been controlled by local compositional pecularities of the melt zone and fractional process during melting or after separation of the melted fraction. This petrogenetic model for the origin of the Egyptian Younger Granite had been previously suggested by Jackson *et al.,* (1984) for the Late Precambrian granitoid in Central Hijaz region of the Arabian Shield and is here found applicable to the Egyptian Shield.

The Pan-African Younger Granites of the Precambrian belt of the Eastern Desert of Egypt show a rapid transition from calc-alkaline I-type magmatism to normal alkaline and strongly alkaline A-type granitoid. Based on structural and tectonic evolution studies, Noweir (1989) shows that the calc-alkaline to weakly alkaline granitiods of Group (1) was contemporaneous with rapid uplift and erosion of the Precambrian belt of the Eastern Desert which marked the end of the orogeny. The granitoids of Group I, therefore strongly resemble the Caledonian type granitoids. The latter were intruded duing a phase of post collisional uplift, relaxation and decompression.

The sudden appearance of the normal alkaline and strongly alkaline A-type magmatism must be related to a significant structural event. Stern *et al.,* (1984) and Noweir (1989) believe that this episode of crust formation took place in an extensional tectonic setting analogous to that of the late Palaeozoic Oslo Rift of Norway. This extensional setting may be related to the transcurrent motion of the Najd fault system (Moore and Al Shanti, 1979 and Stern, 1985).

It is noted that the widespread and voluminous granitoids of the Egyptian Younger Granites are far more fractionated than the common plutonic products in most orogenic belts.

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جيولوجية ، بتروجرافية ، جيوكيميائية ونشأة
صخور الجرانيت الحديث بمصر

عبد الحميد محمد نوير و حمدان محمود السويفي

و عبد السلام محمد رشاد

يتضمن البحث نتائج تحاليل جديد لمائة وتسع وثلاثون عينة صخرية جمعت من ست وعشرون متداخلة جرانيتية وذلك لكل من العناصر الرئيسة والشحيحة اضافة إلى ثلاثة عشر تحليلاً لمعدن البيوتاتيت ، اثنان وثلاثون تحليلاً لمعادن الفلسبار وتحليلية لكل من الماسكوفيت والجارنت وأربع لمعدن المجنيتيت .

وقد أدت الدراسات الحقلية والبتروجرافية والجيوكيميائية إلى تقسيم متداخلات الجرانيت الحديث بمصر إلى أربع مجموعات متباينة تشمل :-

- مجموعة (١) الجرانودايورايت والمونزوجرانيت التي تنتمي إلى الـ I – type والأقل تفارق إلى ضعيفة القلية .
- مجموعة (٢) المونزوجرانيت والسيانوجرانيت التي تنتمي إلى الـ A – type والعادية القلية .
- مجموعة (٣) الجرانيت ذو الفلسبار القلي التي تنتمي إلى الـ A – type والشديدة القلية .
- مجموعة (٤) الابوجرانيت التي تتميز باثراء متميز في أكسيد الصوديوم .

ومن المعتقد أن الاصهرة المختلفة للمجموعات السابقة قد نشأت بالانصهار الجزئي واعادة الانصهار . كما تبين كذلك أن المجموعة (١) تشابه النموذج الكاليدوني الذي تداخل في اثناء عمليات النهوض البعد تصادمي والذي صاحبه عمليات استرخاء تكتوني اما المجموعتين (٢) ، (٣) فيبدو انها تداخلت في توضع يتسم بعمليات شد تكتوني .