Origin and Tectonic Setting of Granitoids from Eastern Desert of Egypt: Major Elements Constraints

M.E. Mostafa[*], M.A. Heikal[**] and A.H. Sabet[***]

[*]*Nuclear Materials Authority,*
[**]*Al Azhar University,*
[***]*Geological Survey of Egypt, Cairo, Egypt*

ABSTRACT. The complete chemical analyses of 118 granitic samples are compiled, of which 84 new analyses are presented. These granitic rocks belong to the Older Granitoids, Younger Granitoids and post-orogenic Alkali Granites. Among the Younger Granitoids, three granitic phases are distinguished, based on field relations.

The origin and tectonic setting of the granitoid rocks are discussed using field relations, multivariate statistics of the chemical data, and several major element parameters. The mineralogical and chemical similarities displayed by the Older and Younger Granitoids phase-I indicate that these two calc-alkaline rock suites probably evolved in the same tectonic environment, which is interpreted here as subduction related. On the other hand, it is argued that the Younger Granitoids phase-II (calc-alkaline to alkaline) evolved during the gradual stabilization of the area during Pan-African time. The alkaline granites of phase-III were possibly formed after the complete cratonization of the Arabian-Nubian Shield, probably associated with incipient rifting. The post-orogenic Alkali Granites were probably formed as intraplate anorogenic granites.

Introduction

The Eastern Desert of Egypt was apparently the site of extensive granitic plutonism during the period from about 900 to 570 Ma ago. Classifications of the basement rocks of Egypt and the granitic rocks in particular (El Shazly, 1964, 1980; Schurmann, 1966; El Ramly, 1972; Sabet, 1972; El-Gaby, 1975; Akaad and Noweir, 1980; Hussein *et al.*, 1982) have pointed out that the earliest granitic rocks in the Eastern Desert are the Older Granitoids (Grey and Shaitian types). The available ages on the

Older Granitoids, also referred to as synorogenic plutonites or syntectonic tonalites-granodiorites-monzonits, are in the range of 930 to 850 Ma ago (Meneisy, 1972; Hashad, 1980) and may possibly extend to 711 Ma (Dixon, 1979). The succeeding granitic cycle in the Eastern Desert is represented by the Younger Granitoids, also referred to as late orogenic plutonites or Pink-Red Granites. The ages obtained for these rocks range from 594 to 568 Ma ago (Fullagar and Greenberg, 1978; Fullagar, 1980; Hashad, 1980) and may possibly extend to 622 Ma ago (Meneisy and Lenz, 1982). Following the emplacement of the Younger Granitoids and up to the Late Mesozoic, postorogenic Alkali Granites represent the final stage of igneous activity in the Eastern Desert of Egypt. However, the major igneous activity ceased at the end of the Precambrian (550 Ma) (Engel et al., 1980).

Several authors attempted to characterize the granitic rocks of the Eastern Desert of Egypt on chemical bases, viz. El-Gaby, 1975; Kabesh et al., 1976, 1982; El-Sokary et al., 1978; Greenberg, 1981; Hussein et al., 1982. The latter separated the Alkali Granite and the albitized plutons from the younger granitoids and considered them as anorogenic intraplate melt of pre-existing crustal rocks. The rest of the younger granitoids were interpreted as having originated at plate boundaries during collision by partial melting of lower crust with additions from the mantle. On the other hand, El Gaby et al. (1988) grouped the younger granitoids with the older syntectonic to late tectonic granitoids mapped by El Ramly (1972) as one magmatic episode.

The present study deals with the chemical characteristics, statistical analysis, and origin of some granitic rocks which belong to the three main granitic cycles in the Eastern Desert of Egypt. The chemical data include a number of new chemical analyses (84) presented in the internal reports of the Geological Survey of Egypt (Sabet et al., 1973; Sabet et al., 1977, a,b,c; Sabet et al., 1978, a,b) and those of Abdel-Rahman (1979) and El-Gammal (1980) (9 analyses). In addition, 25 analyses previously published are also included (Schurmann, 1966; Sabet et al., 1976). The chemical analyses are held in a database and can be obtained from the authors on request.

Locations of the investigated samples are given in Fig. 1. To avoid confusion, the term "high-K granite" is used as a general chemical term for a granite that contains more alkali materials than is considered average for the group of rocks to which it belongs (Stoeser and Elliott, 1980). A "peralkaline granite" is one containing soda pyroxene and/or amphibole (Sorensen, 1974).

Geologic Setting

The Older Granitoids are of wide distribution in the Eastern Desert of Egypt, where they make up 26.7% of the basement outcrop (Stern, 1979). Exposures of these rocks seem to be due to deep level of erosion. Commonly, the Older Granitoids form massifs of a slightly elongated or, rarely, isometric form. Rarely they form typical composite batholiths (about 670 km^2 in surface exposure, e.g., Wadi El Miyah). The border zones of these granitoids contain abundant mafic inclu-
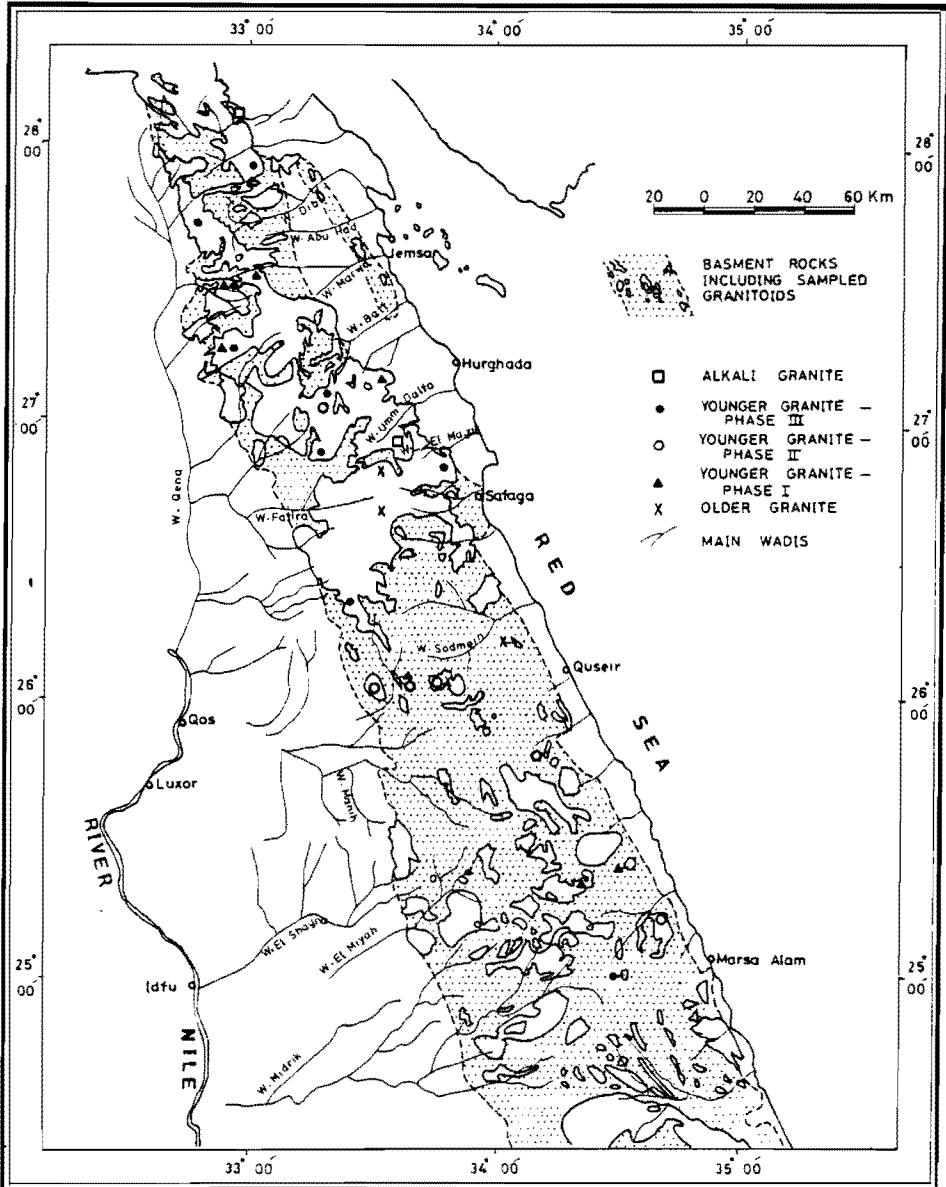
FIG. 1. Distribution of sampled granitoid phases over the granitic bodies in the Eastern Desert of Egypt.

sions and xenoliths of the country rocks. In composition, the Older Granitoids range in composition from diorite to granite, but are predominantly granodiorite. Amphibole is much more abundant than biotite. In contrast to the Younger Granitoids, the Older Granitoids show moderate to strong mineral foliation.

The Younger Granitoids constitute 16.2% of the basement outcrop in the Eastern Desert. Their distribution reveals a high concentration in the northern part of the basement. The age range (594 to 568 Ma) reported for these granitoids shows that they were developed within a restricted span of time during the Pan-African. However, the Younger Granitoids have been classified into three phases according to field relations (Sabet *et al.*, 1976; Abu Leil, 1980; Akaad and Noweir, 1980, Greenberg, 1981). According to Sabet *et al.* (1976) the following phases are recognized :

Phase –   I: Quartz diorites, tonalites, granodiorites and monzogranite

Phase – II: Medium-grained biotite and biotite-hornblende granites, granophyric granites, aplite granites and felsite porphyries

Phase – III: Coarse-grained biotite granites and leucocratic granites.

The morphology of the Younger Granitoid plutons differs according to their relations to the regional structures. Some of the studied plutons are elongated with their longer dimensions parallel to the strike of the regional structure (*e.g.*, Nugrus, Zabara), while others form large oval shaped plutons (*e.g.*, Abu Diab, El Ineigi) or nearly equidimensional ones (*e.g.*, Tweir, Umm Naggat). Some of the large plutons are characterized by zonal structure (*e.g.*, Umm Hammad). Contacts of the Younger Granitoids are generally sharp, non-reactive with country rocks and dip gently or steeply away from the plutons. Zones of migmatization have not been observed at the contacts of the studied plutons.

Only the granitoids of the first phase (*e.g.*, Fawakhir, W. Endiya plutons) are characterized by abundance of mafic inclusions, generally at their contacts. In addition, the granitoids of the second and third phases are not associated with pegmatites, suggesting emplacement probably at shallow levels which is confirmed by roof remnants (*e.g.*, metavolcanics and Dokhan Volcanics) observed on some of the studied granitoids (*e.g.*, G. Abu Had and Mesaid plutons) and by fluid inclusions in quartz in many Older and Younger Granitoids (El Shatoury *et al.*, 1975; El Shatoury, 1979). Dykes traversing Younger Granitoids are abundant in phases I and II, and scarce in phase III.

Petrographically, Younger Granitoids of phase I are mainly granodiorites of greyish pink color, sometimes grading into intrusive diorites and quartz diorites. Granodiorites are medium to coarse-grained, composed mainly of oligoclase, K-feldspar, quartz and hornblende. In the monzogranites, the hornblende amount decreases with the increase of the quartz. Biotite is commonly associated with hornblende. Apatite, sphene and iron oxides are the main accessories. Diorites are hypidiomorphic coarse-grained greyish green rocks , sometimes porphyritic. They are composed of andesine, hornblende and small amounts of quartz (3-5%). Biotite and iron oxides are accessories. Quartz diorites are petrographically similar but with higher contents of quartz (10-15%). Phase II are medium-grained pink or greyish pink, commonly porphyritic granites. They are composed mainly of quartz, microcline and/or orthoclase microperthites, and biotite. Hornblende, if present, occurs in small amounts (2-5%). Sphene, zircon, and apatite are the main accessory minerals. Phase III are commonly coarse-grained, reddish, leucocratic granites. They are com-

posed essentially of microcline microproperties, quartz, plagioclase (albite to acidic plagioclase). Biotite is observed in small amounts (3-5%), occasionally associated with muscovite. The accessory minerals are zircon, apatite, tantaloniobates, fluorite, magnetite and ilmenite.

The post-orogenic Alkali Granites represent the third granitic cycle. They have a limited distribution and form 0.2% of the basement outcrop in the Eastern Desert (Stern, 1979). These granites form small plutons of isometric circular or elongated outlines trending nearly NW-SE (G. Gharib) or may occur as lenticular dyke-like bodies (*e.g.*, Abu Aqarib) trending nearly N-S (El-Gaby and Habib, 1982). Field relations show that the examined alkali granite masses (*e.g.*, Gharib, El-Zeit) are not dissected by the post-granitic dykes (El Ramly, 1972). Contacts are sharp and chilled; outer margins are commonly observed. The studied alkali granites are mainly coarse grained, pink or red in color. They are composed essentially of quartz, perthites, riebeckite and barkevikite. Iron oxides occur in a small amount, associated with or without biotite.

Chemical Characteristics

Older and Younger Granitoids of phase I display a wide range of variations in contents of major elements as shown by the upper and lower confidence limits computed for these granitic rocks, beside the other measures of dispersion (Table 1). Younger

TABLE 1. Statistics of major oxides in the examined granitic rocks.

Variable	Range	$\bar{X}$	S	C.I.		Skw	kurt
				L.L.	U.L.		
O.G. (N = 19)							
SiO_2	54.72 – 74.42	67.82[a]	4.99	65.84 – 69.78		– 0.76	3.36
Al_2O_3	12.23 – 19.11	14.67[a]	1.65	14.03 – 15.31		0.81	3.92
Fe_2O_3	0.00 – 5.04	1.84[a]	1.43	1.28 – 2.38		0.83	2.68
FeO	0.06 – 4.15	2.06[a]	1.23	1.57 – 2.53		– 0.01	1.94
MgO	0.00 – 4.68	1.44[a]	1.13	1.01 – 1.87		1.02	4.18
CaO	0.88 – 9.83	3.51[a]	2.01	2.71 – 4.31		1.46	5.63
Na_2O	3.10 – 5.53	4.12[a]	0.58	3.90 – 4.34		0.89	3.78
K_2O	0.84 – 4.94	2.26[a]	0.98	1.87 – 2.63		1.00	3.84
TiO_2	0.17 – 1.33	0.50[a]	0.27	0.40 – 0.60		1.45	5.31
P_2O_5	0.00 – 0.26	0.07[a]	0.08	0.04 – 0.08		0.89	2.78
MnO	0.03 – 0.15	0.08[a]	0.03	0.08		0.17	2.27
S.I.	0.00 – 24.82	11.64[a]	7.56	7.99 – 15.28			
D.I.	48.23 – 91.97	73.42[a]	11.08	68.08 – 78.76			
Y.G. – I (N = 33)							
SiO_2	56.02 – 74.49	66.13[a]	4.29	64.88 – 67.38		– 0.56	3.30
Al_2O_3	12.78 – 19.42	15.01[a]	1.39	14.60 – 15.42		0.75	4.02
Fe_2O_3	0.00 – 4.99	1.76[a]	1.44	1.32 – 2.18		0.49	2.23
FeO	0.00 – 8.69	2.46[a]	1.98	1.87 – 3.03		0.97	4.26
MgO	0.09 – 4.89	1.39[a]	0.99	1.10 – 1.68		1.58	5.81
CaO	1.30 – 5.95	3.18[a]	1.10	2.85 – 3.49		0.50	3.04

TABLE 1. Contd.

Variable	Range	$\bar{X}$	S	C.I.		Skw	kurt
				L.L	U.L		
Na$_2$O	1.08 – 5.54	4.27[a]	0.71	4.07 – 4.47		– 2.50	12.73
K$_2$O	1.21 – 5.52	2.91[b]	0.83	2.67 – 3.15		0.60	4.58
TiO$_2$	0.23 – 2.21	0.68[a]	0.37	0.58 – 0.78		2.48	10.20
P$_2$O$_5$	0.00 – 0.23	0.05[a]	0.07	0.03 – 0.07		1.10	3.22
MnO	0.04 – 0.20	0.11[b]	0.03	0.08		0.62	4.15
S.I.	0.89 – 27.81	10.46[a]	5.98	6.33 – 12.58			
D.I.	48.50 – 91.66	73.90[a]	9.70	70.46 – 77.34			
Y.G. – II (N = 14)							
SiO$_2$	67.26 – 76.01	71.74[c]	2.58	70.54 – 72.92		0.04	1.86
Al$_2$O$_3$	12.19 – 16.75	14.22[c]	1.13	13.70 – 14.74		0.22	2.93
Fe$_2$O$_3$	0.51 – 2.16	1.30[a]	0.60	1.02 – 1.58		0.07	1.50
FeO	0.27 – 2.53	1.35[c]	0.65	1.05 – 1.65		0.18	2.05
MgO	0.00 – 0.96	0.45[c]	0.36	0.29 – 0.61		0.04	1.51
CaO	0.88 – 2.75	1.85[c]	0.51	1.61 – 2.07		– 0.27	2.38
Na$_2$O	1.75 – 4.72	3.81[c]	0.70	3.48 – 4.12		– 1.57	5.71
K$_2$O	1.14 – 4.90	3.50[c]	0.95	3.06 – 3.94		– 0.74	3.50
TiO$_2$	0.03 – 1.03	0.39[c]	0.27	0.26 – 0.50		1.04	3.34
P$_2$O$_5$	0.01 – 0.24	0.09[a]	0.06	0.06 – 0.10		1.31	3.58
MnO	0.03 – 0.14	0.07[c]	0.03	0.07		1.08	3.43
S.I.	0.00 – 8.99	4.06[c]	3.36	2.12 – 5.99			
D.I.	78.03 – 91.37	84.17[c]	3.93	81.90 – 86.44			
Y.G. (N = 44)							
SiO$_2$	70.13 – 77.40	74.67	1.65	74.27 – 75.07		– 0.73	3.51
Al$_2$O$_3$	11.03 – 13.94	12.37	0.69	12.19 – 12.53		0.12	2.05
Fe$_2$O$_3$	0.00 – 3.72	0.78	0.86	0.57 – 0.97		1.31	4.66
FeO	0.01 – 2.61	1.23	0.62	1.07 – 1.37		– 0.21	2.42
MgO	0.00 – 1.05	0.34	0.26	0.28 – 0.38		0.84	3.06
CaO	0.27 – 2.15	1.09	0.43	0.98 – 1.18		0.36	2.72
Na$_2$O	2.29 – 5.26	3.86	0.60	3.70 – 4.00		– 0.24	3.84
K$_2$O	2.11 – 6.03	4.28	0.71	4.11 – 4.45		– 0.19	3.79
TiO$_2$	0.03 – 0.70	0.23	0.15	0.20 – 0.26		1.14	4.20
P$_2$O$_5$	0.00 – 0.16	0.04	0.04	0.03		1.00	2.89
MnO	0.00 – 0.19	0.06	0.04	0.06		0.42	3.11
S.I.	0.00 – 8.51	3.10	2.33	2.39 – 3.80			
D.I.	84.74 – 95.02	90.55	2.27	89.86 – 91.24			
Alk. G. (N = 8)							
SiO$_2$	73.99 – 76.05	74.92	0.72	74.44 – 75.38		0.23	1.51
Al$_2$O$_3$	9.93 – 12.98	11.06	0.83	10.51 – 11.59		1.14	4.01
Fe$_2$O$_3$	0.50 – 2.31	1.30	0.55	0.94 – 3.64		0.63	2.40
FeO	0.00 – 3.82	1.85	1.02	1.17 – 2.51		0.15	3.14
MgO	0.00 – 0.43	0.20	0.14	0.11 – 0.29		0.41	1.93
CaO	0.30 – 1.39	0.98	0.39	0.73 – 1.21		– 0.81	2.04
Na$_2$O	3.51 – 5.18	4.46	0.58	4.08 – 4.82		– 0.40	1.74
K$_2$O	3.83 – 5.78	4.54	0.58	4.16 – 4.90		0.85	2.96
TiO$_2$	0.13 – 0.65	0.28	0.18	0.16 – 0.38		1.20	2.80

Table 1. Contd.

Variable	Range	$\bar{X}$	S	C.I.		Skw	kurt
				L.L.	U.L.		
P_2O_5	0.00 – 0.07	0.02	0.02	0.01		1.07	2.73
MnO	0.03 – 0.17	0.08	0.04	0.06 – 0.10		0.86	2.91
S.I.	0.00 – 3.51	1.63	1.21	0.61 – 2.64			
D.I.	86.70 – 94.80	89.81	2.50	87.72 – 91.90			

N = Total number of samples $\bar{X}$ = Arithmetic mean
S = Standard deviation   C.I. = Confidence intervals
L.L. = Lower limit   U.L. = Upper limit
Skw = Skewness   Kurt = Kurtosis

a,b,c = Suites with the same letter show no significant difference for that variable at 0.05 level of confidence.

Granitoids show variations in composition from phase II to phase III marked by increase in SiO_2 and K_2O, and a decrease in Al_2O_3, total FeO, MgO, CaO and TiO_2. The Alkali Granites nearly approach the Younger Granitoids phase III in composition, although their alumina content is lower. The linear correlations measure the elemental coherence between the different elements. Table 2 presents the correla-

Table 2. Correlation between major oxides in the examined granitic rocks.

Variable	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2
O.G.										
P_2O_5	0.04	– 0.24	– 0.07	0.06	– 0.19	– 0.05	0.24	– 0.02	– 0.19	0.07
TiO_2	– 0.19	0.37	0.42	– 0.27	0.08	– 0.25	0.25	0.08	– 0.44	
K_2O	0.30	– 0.21	– 0.09	– 0.24	– 0.45	– 0.25	– 0.48	0.02		
Na_2O	– 0.08	0.25	0.26	– 0.44	– 0.44	– 0.13	– 0.21			
CaO	– 0.83	0.21	0.29	0.61	0.46	0.71				
MgO	– 0.77	0.28	0.08	0.73	0.50					
MnO	– 0.46	0.22	0.12	0.48						
FeO	– 0.55	0.10	– 0.44							
Fe_2O_3	– 0.32	0.13								
Al_2O_3	– 0.61							critical r 0.05 = 0.46		
								N = 19		
Y.G. – I										
P_2O_5	0.07	– 0.09	0.03	– 0.03	– 0.16	0.06	– 0.04	0.08	– 0.05	– 0.04
TiO_2	– 0.81	0.15	0.01	0.73	0.50	0.69	0.68	– 0.21	– 0.44	
K_2O	0.51	– 0.08	0.20	– 0.57	– 0.43	– 0.48	– 0.56	– 0.31		
Na_2O	– 0.01	0.07	– 0.18	– 0.03	– 0.04	– 0.15	0.03			
CaO	– 0.94	0.41	– 0.04	0.67	0.45	0.69				
MgO	– 0.69	– 0.18	– 0.49	0.83	0.39					
MnO	– 0.48	0.14	– 0.21	0.56						
FeO	– 0.70	– 0.14	– 0.58							
Fe_2O_3	0.00	0.57								
Al_2O_3	– 0.49							critical r 0.05 = 0.35		
								N = 33		

TABLE 2. Contd.

Variable	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2
Y.G. – II										
P_2O_5	0.02	– 0.56	0.31	0.23	0.24	– 0.31	0.37	– 0.09	0.14	0.50
TiO_2	– 0.50	0.25	0.40	0.23	0.52	0.05	0.58	0.02	0.20	
K_2O	– 0.54	0.01	– 0.51	0.39	– 0.07	0.34	– 0.20	0.65		
Na_2O	– 0.54	0.14	– 0.53	0.33	– 0.14	0.51	– 0.35			
CaO	– 0.39	0.11	0.44	0.40	0.29	– 0.08				
MgO	– 0.56	0.50	– 0.53	0.63	– 0.32					
MnO	– 0.19	0.16	0.54	– 0.12						
FeO	– 0.68	0.05	– 0.28							
Fe_2O_3	0.12	– 0.17								
Al_2O_3	– 0.52							critical r 0.05 = 0.53		
								N = 14		
Y.G. – III										
P_2O_5	– 0.23	0.00	0.43	0.02	– 0.35	0.06	0.09	– 0.17	0.34	0.44
TiO_2	– 0.30	0.05	0.19	0.14	0.15	0.01	0.65	– 0.10	– 0.03	
K_2O	– 0.28	0.00	– 0.01	0.18	– 0.25	0.38	– 0.09	– 0.31		
Na_2O	– 0.34	0.38	0.06	– 0.14	0.22	0.07	– 0.21			
CaO	– 0.14	0.07	– 0.11	– 0.01	0.18	– 0.02				
MgO	– 0.37	0.35	0.10	– 0.03	– 0.04					
MnO	– 0.04	– 0.05	– 0.39	0.28						
FeO	– 0.14	– 0.29	– 0.43							
Fe_2O_3	– 0.46	0.40								
Al_2O_3	– 0.67							critical r 0.05 = 0.30		
								N = 44		
Alk. G.										
P_2O_5	0.16	– 0.14	0.06	0.01	– 0.70	0.36	– 0.38	– 0.80	0.57	0.82
TiO_2	0.41	– 0.15	0.32	– 0.27	– 0.58	0.13	– 0.49	– 0.51		
K_2O	– 0.27	0.44	– 0.41	– 0.13	– 0.62	0.49	0.24	– 0.71		
Na_2O	– 0.37	– 0.20	0.21	– 0.02	0.69	– 0.04	0.33			
CaO	– 0.49	0.52	– 0.08	– 0.49	0.28	0.13				
MgO	– 0.81	– 0.16	– 0.16	0.16	– 0.25					
MnO	– 0.12	– 0.40	0.49	0.15						
FeO	– 0.23	– 0.61	– 0.29							
Fe_2O_3	0.32	– 0.54								
Al_2O_3	0.05							critical r 0.05 = 0.71		
								N = 8		

tion between the major oxides of the examined granitic rocks. Significant positive correlation between FeO, MgO and CaO in the Older and Younger Granitoids of phase I are due to the abundance of biotite and hornblende in these rocks. Lack of correlation between these elements in the Younger Granitoids of phases II and III can be linked to the small amounts of ferromagnesian minerals, particularly hornblende. The negative correlation between SiO_2 and FeO, MgO, and CaO is in accordance with the marked inverse relation between quartz and ferromagnesian minerals in the Older and Younger Granitoids of phase I and for CaO with the abun-

dance and composition of the plagioclase. The range of differentiation index displayed by the Younger Granitoids of phases II and III is too narrow to display significant inter element correlations.
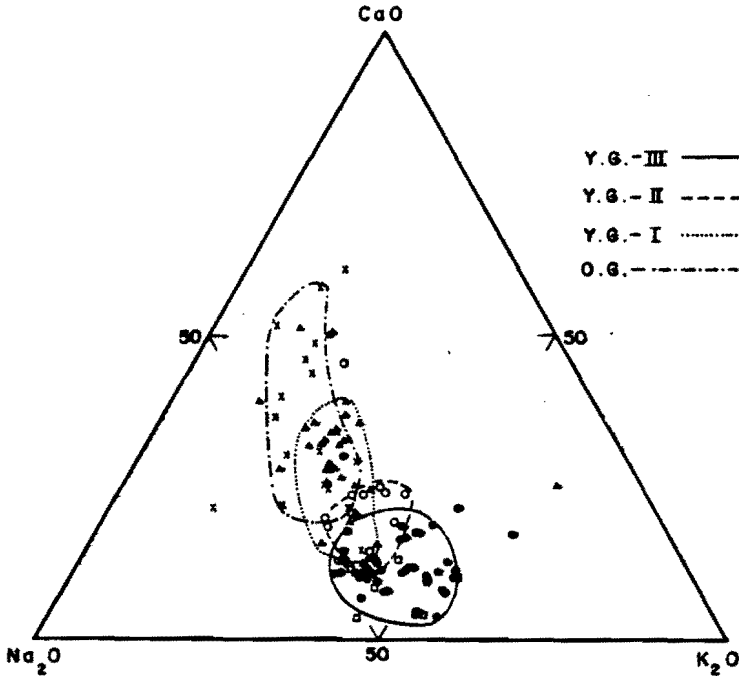

FIG. 2. Na$_2$O-CaO-K$_2$O diagram for the investigated rocks. Symbols as in Fig. 1.

Figure 2 shows the Na$_2$O-CaO-K$_2$O triangular variation diagram. Fields occupied by the Older and Younger Granitoids of phase I overlap and they also plot within the calc-alkaline field defined by Ramsay *et al.* (1986). A better separation between the fields occupied by the granitic rocks of phases I and III is noticed. The granitoids of phase II occupy an intermediate position. The alkali granites cannot be distinguished from the Younger Granites of phase III.

Older and Younger Granitoids are not peralkaline except for a few samples belonging to Younger Granites of phase III which contain slight acmite and/or sodium metasilicate in the CIPW norms. Alkali Granites plot in the peralkaline field. This finding is compatible with the results obtained on the basis of the amounts of alumina saturation calculated for the examined granitoids according to Shand's (1927) classification. The peraluminous and metaluminous types are common in the Older and Younger Granitoids.

The Wright's (1969) alkalinity ratio diagram (Fig. 3) shows conclusively the calc-alkaline character of the Older and the Younger Granitoids of Phase I. Granitoids of
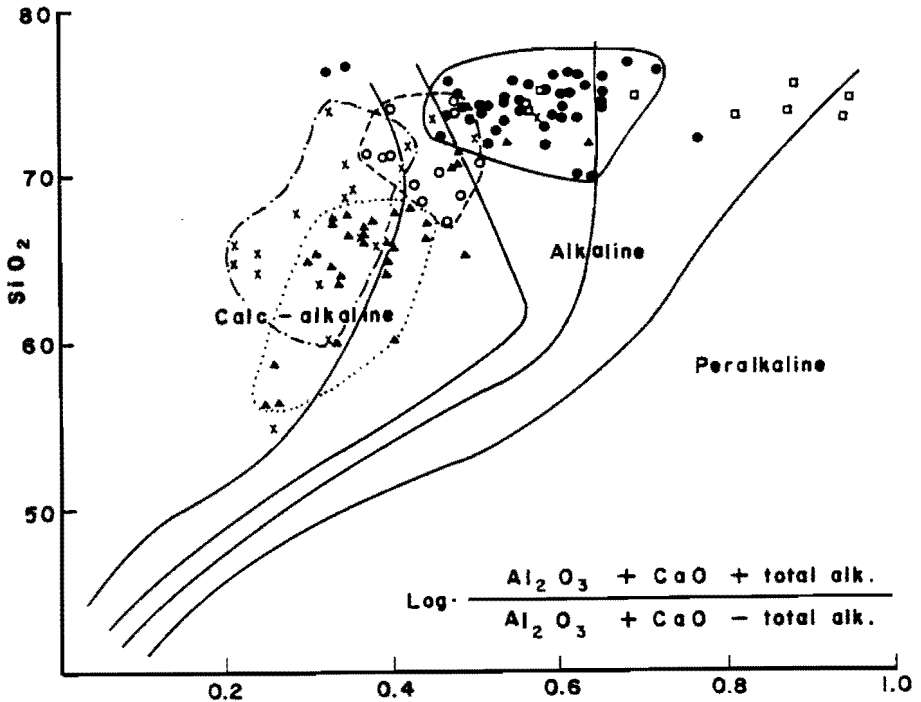
FIG. 3. Wright's (1969) alkalinity ratio versus SiO_2 diagram. Symbols as in Fig. 1.

the second phase extend from the calc-alkaline field into the alkaline one, whereas the third phase plot is in the alkaline field. The third phase granites, with few exceptions, are distinctly more alkaline than those of the second phase. The Alkali Granites are alkaline to peralkaline in character.

Chemical Classification

The chemical classification of the studied granitoids is intended to avoid the usage of different names coined in previous classifications. Figure 4 is the R_1-R_2 chemical variation diagram of De La Roche et al. (1980) which incorporates all the major elements, where $R_1 = 4 Si-11 (Na + K) - 2 (Fe + Ti)$ and $R_2 = 6 Ca + 2 Mg + Al$. On this diagram, two principal fields are outlined: a peridotitic field and an extensive felsic (granitic) field in the upper and lower parts of the diagram respectively. Most igneous series have their origins in either one or the other. Other rock types plot in successive belts about either the peridotitic or felsic centres with intermediate rocks occurring at the intersections of the belts. The classification scheme of De la Roche et al. (1980) defines a field of the alkali granite separated from that of the normal granite whereas other chemical classifications designate one field for both rock types. The Older Granitoids spread over the fields of tonalite, granodiorite and granite. The Younger Granitoids of Phase I show larger scatter and spread mainly over the
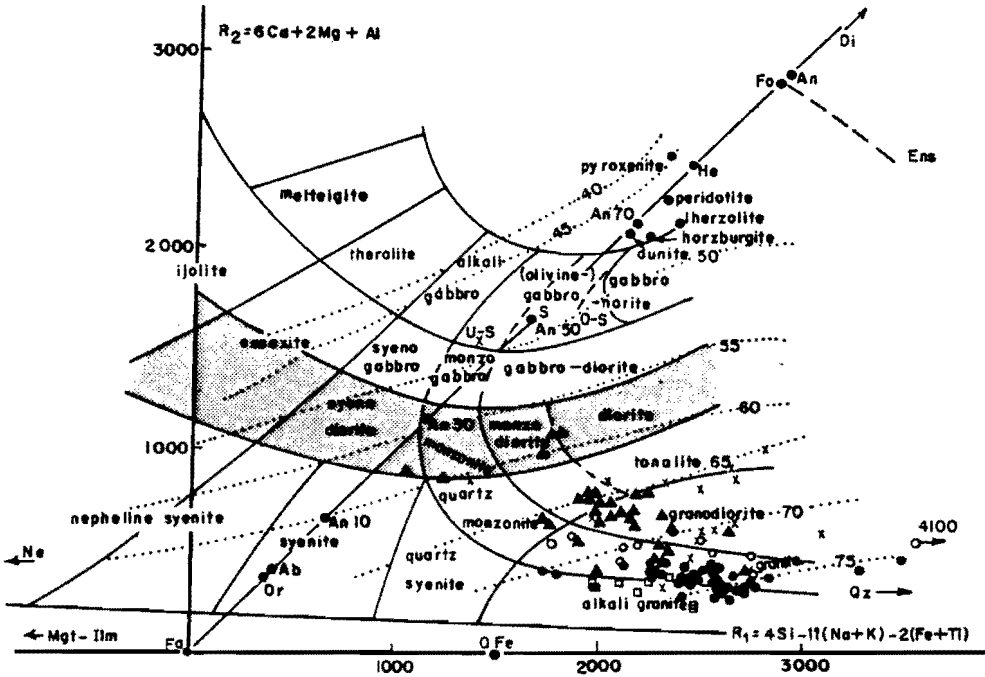
FIG. 4. Classification of the studied granitoids using R_1-R_2 diagram (De la Roche *et al.*, 1980). The diagram shows the critical plane of silica saturation together with the locations of the principal related minerals. The shaded zone corresponds to the "dioritic band". ......70......: Weight percent silica contours. Symbols as in Fig. 1.

fields of monzodiorite, quartz monzonite, granodiorite and granite overlapping greatly with the Older Granitoids. The Younger Granitoids of Phases II and III are restricted mainly to the field of granites with few plots in the granodiorite field. The Younger Granitoids of Phase III show some alkaline affinity. The Alkali Granites are well delineated within their field.

For comparison, the normative content of all the studied granitoids are plotted on the Ab-An-Or diagram of O'Connor (1965) which was later modified by Barker (1979). Figure 5 shows that the Older Granitoids and the Younger Granitoids of Phase I spread over the tonalite-granodiorite-granite fields in a well-defined path parallel to the An-Or side. Few exceptions plot in the trondhjemite field. The Younger Granitoids of Phases II and III are restricted to the granite field with few exceptions plotting in the granodiorite and quartz monzonite fields. The alkali granites plot on the Ab-Or join with one exception plotting within the normal granite field.

Major Oxides Statistics in Classification and Discrimination

Factor and discriminant analyses are among robust statistical tools which have sound application in rock classification and discrimination. Pearce (1976) applied
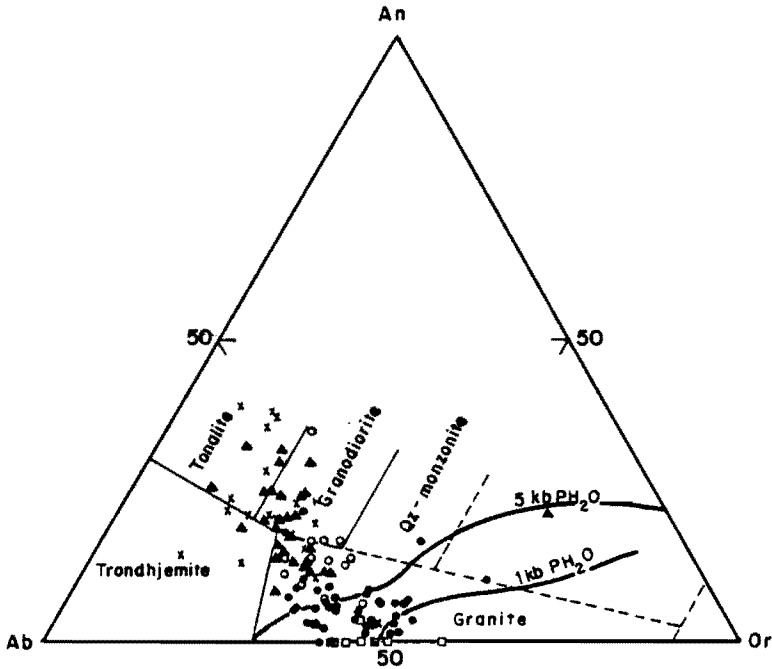
FIG. 5. Ab-An-Or ternary diagram. Classification boundaries from O'Connor (1965) and Barker (1979).
Symbols as in Fig. 1.

statistical discriminatory technique on major element patterns of basalts from eight
different tectonic settings and developed three discriminant functions. Function's
score diagrams enable distinguishing of six of these basalts and is considered useful in
allocating unknown samples. Recently, Abdel Meguid et al. (1990) extracted three
factors controlling major element pattern of only anorogenic younger granitoids.
Yet, the trend of evolution can be traced on the factor score diagrams. Factor
analysis on one hand can classify multivariate space data without a prior knowledge
of samples, according to their factor scores. On the other hand, discriminant analysis
is a complementary technique which can answer a question of the type: Is there a dif-
ference between the already classified samples that arises from factor analysis or
from any other prior knowledge? The difference between samples can be measured
by what is known in literature as "MAHALANOBIS" generalized distance "D^2". A
detailed discussion of factor analysis is given by Comrey (1973) and that of discrimin-
ant analysis by Rao (1952). The present calculation is referred to in the Integrated
Package in Computational Geology (IPCG) by Mostafa (1986).

 Factor Analysis is a technique by which variables measured on a set of samples are
linearly combined giving rise to a new set of fundamental quantities (factors) which
can be named and simply interpreted in the light of sound geologic reasoning. In
other words, one may say that the measured data along arbitrary axes is rotated to
occupy symmetric position with reference to a set of new axes which do have a mean-

ing. The principal factors are extracted from a correlation matrix. Through matrix manipulation, they are rotated to a position where each factor would have a large variance of the squared loading, thus the values are maximally spread out. Comrey (1973) also states that the most interpretable factor has high and low but few intermediate size loadings. Scores of the original data are calculated but related to the principal factors.

In multivariate space the discriminant analysis is based mainly on computing the pooled variance-covariance matrix from the var-covar matrix of each group of samples. The difference matrix between the means of all possible pairs of these group is computed. Thus, the measure of generalized distance D^2 between pairs of these group is calculated by relating the difference matrix of means to the pooled var-covar matrix. The calculation of t-value for group comparison in 2-dimensional space is a special case.

TABLE 3a. Statistics of major oxides, 118 samples of different granite phases, Eastern Desert of Egypt.

	Mean	St. dev.	Correlation matrix									
	$\bar{X}$	S	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2
SiO_2	70.80	5.02	1.00	− .77	− .35	− .61	− .43	− .79	− .86	− .25	.57	− .71
Al_2O_3	13.61	1.77	− .77	1.00	.43	.15	.28	.43	.60	.19	− .52	.50
Fe_2O_3	1.31	1.21	− .35	.43	1.00	− .28	.04	.04	.32	.05	− .24	.32
FeO	1.76	1.37	− .61	.15	− .28	1.00	.44	.72	.55	.04	.37	.53
MnO	.08	.04	− .43	.28	.04	.44	1.00	.36	.43	.16	− .41	.41
MgO	.82	.89	− .79	.43	.04	.72	.36	1.00	.76	.07	− .50	.52
CaO	2.13	1.49	− .86	.60	.32	.55	.43	.76	1.00	.06	− .67	.62
Na_2O	4.05	.68	− .25	.19	.05	.04	.16	.07	.06	1.00	− .18	.04
K_2O	3.50	1.15	.57	− .52	− .24	− .37	− .41	− .50	− .67	− .18	1.00	− .47
TiO_2	.42	.32	− .71	.50	.32	.53	.41	.52	.62	.04	− .47	1.00

Single variate statistics of the overall granites (Table 3a) shows that all major oxides excluding P_2O_5 possess coefficient of variation $(S/\bar{X})$ less than 100%. Thus, one can proceed computation on the original data with no need for any transformation. This also reflects the homogeneity of the dealt with granitic populations. Through factor analysis, the ten dimension space has been reduced into 3-D space giving rise to three fundamental factors accounting for about 75.19 of the total system information (TSI), Table 3b.

Table 3c shows that each of the designated factors may be worked at as an expression of different geochemical criteria that may reflect genesis and evolution of these rocks. The first factor (F_1) contributes for 49.42% of the TSI. It is negatively loaded with SiO_2 and K_2O and positively loaded with Al_2O_3, FeO, MnO, MgO, CaO and TiO_2, and can be correlated to the solidification process. The second factor (F^2) contributes for 15.38% of the TSI. It is loaded negatively with Al_2O_3, Fe_2O_3, CaO and TiO_2 and positively with SiO_2, FeO and K_2O and can be linked to mafic minerals. The third factor contributes for 10.39% of the TSI and is positively loaded mainly with Na_2O. It accounts for sodic enrichment in secondary processes.

TABLE 3b. Unrotated factor matrix.

Factor	1	2	3	4	5	6	7	8	9	10
eigenvalue	4.94	1.54	1.04	.73	.57	.45	.39	.17	.15	.02
percent	49.42	15.38	10.39	7.27	5.69	4.49	3.95	1.68	1.50	.24
cumulative %	49.42	64.80	75.19	82.46	88.15	92.64	96.58	98.26	99.76	100.00
SiO_2	− .95	.08	− .01	.18	− .14	.12	− .04	− .03	.06	.13
Al_2O_3	.72	− .46	.02	− .12	− .05	− .42	− .28	− .05	− .05	.05
Fe_2O_3	.31	− .84	− .18	.12	.15	.18	.29	− .09	− .11	.02
FeO_2	.67	.67	− .02	− .08	.13	.10	− .01	− .04	− .27	.04
MnO	.57	.21	.26	.70	.05	− .21	.13	− .02	.03	.00
MgO	.82	.31	−'.10	− .28	− .04	− .05	.24	− .21	.19	.02
CaO	.90	− .03	− .14	− .07	− .15	.02	.17	.32	.05	.04
Na_2O	.20	− .16	.93	− .20	.13	.13	.03	.02	.02	.02
K_2O	− .73	.11	− .10	− .13	.57	− .27	.15	.08	.03	.02
TiO_2	.77	− .03	− .18	.15	.38	.28	− .32	.01	.14	.01

TABLE 3c. Factors controlling granite evolution (Varimax rotated factors).

	Factor loads		
	F_1	F_2	F_3
SiO_2	− .822	.458	− .163
Al_2O_3	.450	− .696	.183
Fe_2O_3	− .060	− .907	− .030
FeO	.887	.323	− .007
MnO	.582	.006	.316
MgO	.879	− .074	− .017
CaO	.815	− .416	− .003
Na_2O	.030	− .061	.958
K_2O	− .605	.375	− .226
TiO_2	.701	− .373	− .061

The plot of sample scores of F_1 and F_2 (Fig. 6) has markedly scattered the different granitic phases. The Older Granite and phase I of the Younger Granite exhibit together wide scatter and occupy the lower right area. Younger phases closely scatter to each other and move toward the upper left. Thus, a trend of solidification is shown on the diagram with idealized zonation fronts. On the same plot some samples of the older phases scatter around younger phases; while the reserve is not true. Examining these samples show that they are rich in silica (more than 70%). This means that the diagram is very susceptible to the slight variation in composition. Meanwhile older phase samples might have undergone enrichment of silica in particular due to the contacts with younger phases. The present diagram shows marked resemblance with that of De La Roche (R_1-R_2 diagram, Fig. 4) but exhibits more sample dispersion and can consequently be used for classifying other unknown rock suites better than empirical indices.

It is possible to transform the major oxides data into standard scores using the formula: $Z = (x - \overline{X})/S$, where x = Input data, $\overline{X}$ = Arithmetic mean and S = Standard
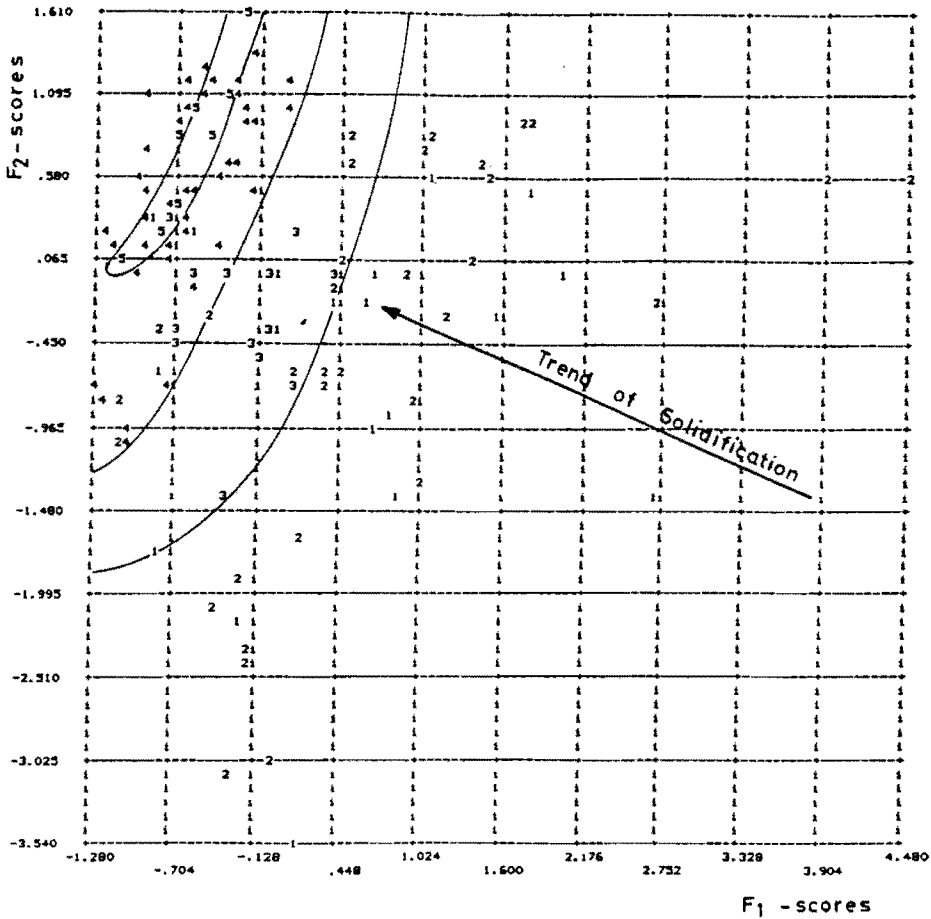
FIG. 6. Scatter diagram of factor scores controlling granite evolution with idealized zonation of differentiation front.

    1 = older granite

    2,3,4 = first, second and third phase of younger granites

    5 = alkali granite

deviation, and then calculate the scores as follows :

F_1-score = 0.31 FeO + 0.14 MnO + 0.24 MgO + 0.17 CaO + 0.15 TiO_2 –
        (0.15 SiO_2 + 0.16 Fe_2O_3 + 0.08 Na_2O + 0.10 K_2O)

F_2-score = 0.12 SiO_2 + 0.33 FeO + 0.12 MnO + 0.10 MgO + 0.05 Na_2O + 0.10 K_2O –
        (0.32 Al_2O_3 + 0.54 Fe_2O_3 + 0.11 CaO + 0.11 TiO_2)

Discriminant analysis is applied to verify the classification established by factor analysis. The generalized distances are calculated between the five different granite

phases (Table 4) and show that the Older Granite (OGE) is very close to phase I of the Younger Granite ($\rho = 1.95$; the least value among the different phases). The other phases are markedly separated from each other. Phase III of the Younger Granite (alkaline) and the Alkali Granite (ALKG) are very close to each other ($\rho = 3.73$).

TABLE 4. Mahalanobis generalized distance as major oxides discrimination between five groups of granites, Eastern Desert, Egypt.

	OGE	YGE_1	YGE_2	YGE_3	ALKG
OGE	0.00				
YGE_1	1.95	0.00			
YGE_2	9.18	18.59	0.00		
YGE_3	18.96	31.58	3.82	0.00	
ALKG	21.61	33.53	9.77	3.73	0.00

OGE   = Older granite
YGE_1 = First phase of younger granite
YGE_2 = Second phase of younger granite
YGE_3 = Third phase of younger granite
ALKG = Alkali granite.

Factor and discriminant analyses prove that the Older Granite and phase I of the Younger Granite can be regarded as if one rock unit and that phase III of the Younger Granite is closely associated with the Alkali Granite. This is in accordance with the field relations and previous characterization using the empirical and conventional indices.

The results discussed so far indicate that each phase has its own characters which have been reflected on every possible set of observations including field relations and pattern of major oxides.

Origin and Tectonic Setting

Figure 7 shows the log (K_2O/MgO) ratio plotted against SiO_2 for the studied granitoids. For comparison, the trends of evolution of the Older and Younger Granitoids in the Eastern Desert of Egypt as defined by Greenberg (1981) are shown on the same diagram. According to Ghuma and Rogers (1980), and Rogers and Greenberg (1981), the ratio K_2O/MgO provides the maximum separation between suites which are traditionally considered as anorogenic, generally silicic, alkali-rich granites; and those regarded to be orogenic and calc-alkaline. The alkali-rich suites rapidly lose MgO as they differentiate toward high-SiO_2 granites, thus giving the trend lines of the alkaline granites a much lower slope than the trend of the calc-alkaline assemblages. Figure 7 shows conclusively that the two parallel trends of the Older and Younger Granitoids of Phase I are similar to those of the calc-alkaline, orogenic suites. Phases II and III Younger granitoids and the Alkali Granites trend in a much lower slope than that of the calc-alkaline suites, and similar to that of the alkali-rich assemblages. This is in agreement with the recent findings in the Egyptian
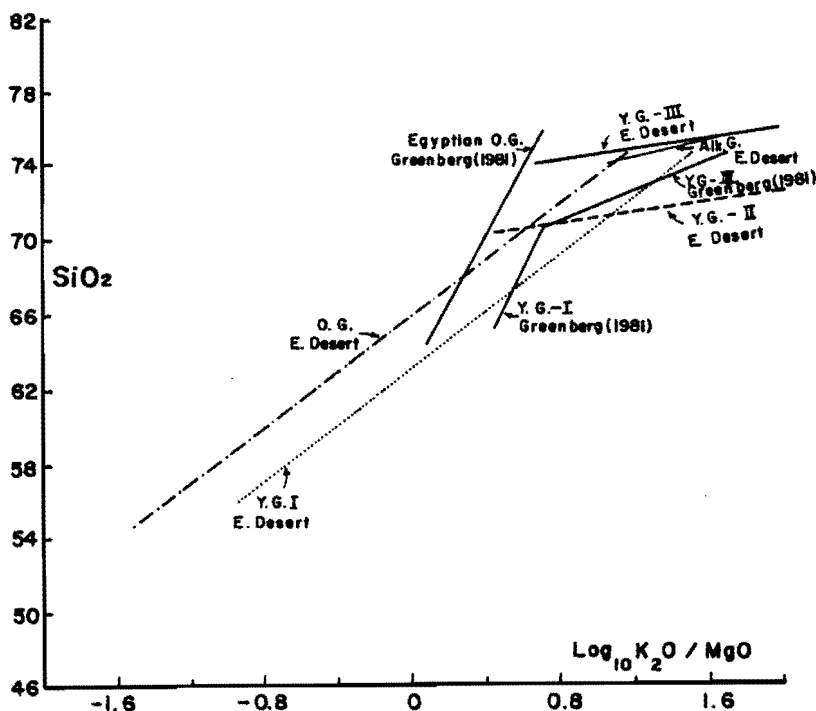
FIG. 7. Relationships between SiO_2 and $\log_{10} (K_2O/MgO)$. The trends of evolution of the Older and Younger Granitoids of the Eastern Desert of Egypt as defined by Greenberg (1981) are shown for comparison.

granites (Greenberg, 1981), and accordingly indicates a different origin for the Older and Younger Granitoids of Phase I on one hand and Phases II, III and the Alkali Granites on the other.

To account for the origin of the granitic rocks, De la Roche (1978) constructed a chemical variation diagram derived from a tetrahedron incorporating all the major cations distributed amongst its four apexes (Fig. 8). Within the tetrahedron, the plane P_3 is defined to include the main minerals of granitoid rocks-quartz (Qz), alkali feldspar (OR, AB), plagioclases (AB, AN), Fe-Ti oxides, magnetite (Mgt) and orthopyroxe (OPX). Biotites (M_3) are very close to P_3. Away from the plane P_3 are some typical minerals: on one side muscovite (M_2) and cordierite (CORD) characterizing the peraluminous rocks, and on the other side, hornblende (HB) and clinopyroxenes (CPX) characterizing the calc alkaline or the alkaline rocks. According to De la Roche (*op. cit*), the study of these minerals pattern leads to a specific function (F_3) which is used to construct a chemical variation diagram for the granitoid rocks with a precise significance to mineralogy and petrogenesis. Figure 8 shows the plane P_3 of the tetrahedron projected onto the bisecting line $2F_3 = 0$ which separates an aluminous or peraluminous field from a calc-alkaline field including most of the
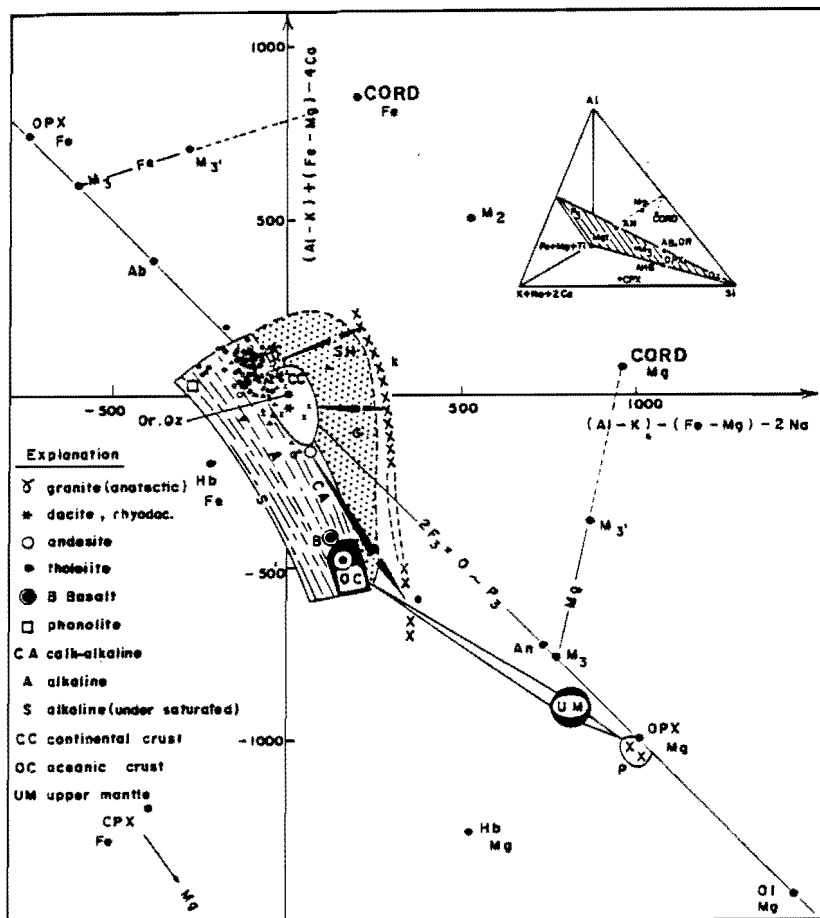
FIG. 8. A bivariant chemical diagram illustrating a partition of the function F_3, especially used for the granitoids rocks to account for their origin (De la Roche, 1978). Within the tetrahedron the plane P_3 is defined to include the main minerals of granitoid rocks. Symbols as in Fig. 1.

igneous series (dashed area). The widespread detrital sedimentary rocks-shales (SH) and greywackes (G) or their metamorphic derivatives are delineated towards the aluminous field (stippled area). On this diagram, the double arrows indicate the fractionation by partial melting in the upper mantle (white arrow) or in the crustal rocks (black arrows). The solid remnants of partial melting, peridotites (P), eclogites (e) and kinzigites (k), are in this manner connected to basalts, andesites, and anatectic granites.

The two parameters x-F_3 and Y-F_3 are calculated for the studied granitoids and plotted on Fig. 8. The data plots indicate that the Older and Younger Granitoids of Phase I are generated by partial melting of the continental crust with a contribution

of the oceanic crust, while the other granitic rocks are generated by partial melting of the continental crust. The origin suggested for the Older Granitoids according to De La Roche's (1978) diagram is consistent with other evidence, *e.g.*, low initial 87Sr/86Sr ratio (0.702-0.704) according to Hashad (1980). The low initial 87Sr/86Sr ratios indicate either upper mantle sources or lower crustal material with low Rb/Sr ratios and short time residence (Moorbath and Taylor, 1981). However, the initial ratio assigned to the Egyptian granitoids is in general low and can also be accounted for by the rapid recycling and immaturity of the crust (Stern and Hedge, 1985 and Ragab, 1987).

The mineralogical and chemical similarities displayed by the Older and Younger Granitoids of Phase I (calc-alkaline affinity, overlap on different chemical variation diagrams, similar and parallel crystallization paths in Fig. 7 and close relation of the chemical variables) indicate that these two rock suites have probably evolved in the same tectonic environment (subduction related). This is based on field relations, calc-alkaline affinity, trend on the AFM diagram which is nearly perpendicular to the FM-side (Petro *et al.*, 1979), trend on the K_2O/MgO-SiO_2 diagram nearly parallel to those of the calc-alkaline, orogenic granitic suites and on the fact that they are statistically related to each other.

On the other hand, the authors suggest that the Younger Granitoids of Phase II have evolved during the gradual stabilization of the area during Pan-African time (Rogers *et al.*, 1978; Ghuma and Rogers, 1980). The evolution of the Younger Granitoids of Phase III occurred probably after oceanic closure and was probably associated with incipient rifting and followed by the alkali phase of granite. This is based on field relations, alkaline affinity (Sillitoe, 1979), dispersion parallel to the AF side with noticeable cluster near the alkali apex (Petro *et al.*, 1979), trend of evolution on the K_2O/MgO-SiO_2 diagram and on the fact that they are statistically affine to each other.

Finally, the authors suggest that the post-orogenic Alkali Granites were formed after the complete cratonization of the Arabian-Nubian Shield as intraplate anorogenic granites. This is consistent with the study of Hussein *et al.* (1982) on this rock suite.

Acknowledgement

References

Abdel-Meguid, A.A., Mostafa, M.E. and **El Shatoury, H.M.** (1990) Factors controlling major element pattern of anorogenic younger granites of Egypt, *Egypt. Miner.*, **2**: 151-166.

Abdel-Rahman, A.M. (1979), *Geology of the Area around Gabal Abu Kharif, Eastern Desert – Egypt, with Special Emphasis on the Granitic Rocks*, M.Sc. Thesis, Cairo Univ., Egypt.

Abu Leil, I., (1980) *Geology, Petrography and Geochemistry of Some Granitic Rocks in the Northern Part of the Basement Complex, Egypt,* Ph.D. Thesis, Al-Azhar Univ., Egypt.

Akaad, M.K. and **Noweir, A.M.** (1980) Geology and lithostratigraphy of the Arabian Desert orogenic belt of Egypt between latitudes 25 35' and 26 30'N, *In:* **A.M.S. Al-Shanti** (ed.), *Evolution and Mineralization of the Arabian Nubian Shield, King Abdulaziz Univ. Bull., Jeddah,* **3,** part 4, Pergamon Press, Oxford, pp. 127-135.

Barker, F. (1979) Trondhjemite: Definition, environment and hypotheses of origin. *In:* **F. Barker** (ed.), *Trondhjemites, Dacites, and Related Rocks,* Elsevier, Amsterdam, pp. 1-12.

Comrey, A.L. (1973) *A First Course in Factor Analysis,* Academic Press, New York, 316 p.

De la Roche, H. (1978) La chimie des roches presentee et interpretee d àpres la structure de leur facies mineral dan l èspace des variables chimiques: fonctions specifiques et diagrammes qui s èn deduisent – application aux roches ignees, *Chem. Geol.,* **21:** 63-87.

————, **Leterrier, J., Grandclaude, P.** and **Marchal, M.** (1980) A classification of volcanic and plutonic rocks using R_1-R_2 diagram and major element analyses – Its relationships with current nomenclature. *Chem. Geol.,* **29:** 183-210.

Dixon, T.H. (1979) U-Pb ages and chemical characteristics of some pre-Pan-African plutonic rocks in the Egyptian shields. *5th Conference on African Geology, Cairo. Abstracts,* pp. 75-76.

El-Gaby, S. (1975) Petrochemistry and geochemistry of some granites from Egypt. *Neues Jahrb. Mineral. Abh.,* **124:** 147-189.

———— and **Habib, M.S.** (1982) Geology of the area south-west of port Safaga, with special emphasis on the granitic rocks, Eastern Desert, Egypt, *Annals Geol. Surv. Egypt,* **12:** 47-71.

————, **List, F.K.** and **Tehrani, R.** (1988) Geology, evolution and metallogenesis of the Pan-African Belt in Egypt, *In:* **El Gaby, S.** and **R.O. Greiling** (eds.), *The Pan-African Belt of Northeast of Africa and adjacent areas – Tectonic evolution and economic aspects of a late Proterozoic Orogen,* Friedr Viewey & Sohn, Braunschweig Wiesbaden, pp. 18-68.

El-Gammal, E.A. (1980) *Geological, Petrological and Geochemical Studies on the Basement Rocks of the Area South of Gabal El Shayib, Eastern Desert, Egypt,* M.Sc. Thesis, Al-Azhar Univ., Cairo-Egypt.

El Ramly, M.E. (1972) A new geological map for the basement rocks in the Eastern and Southwestern Deserts of Egypt, *Annals Geol. Surv. Egypt,* **2:** 1-18.

El Shatoury, H.M. (1979) Shallow intrusive granites from Egypt and their relation to mineralization. *In:* **A.M.S. Al Shanti** (ed.), *Evolution and mineralization of the Arabian-Nubian Shield, King Abdulaziz Univ., Jeddah, Bull.* **3:** part 2, Pergamon Press, Oxford, pp. 147-152.

————, **Takenouchi, S.** and **Imai, H.** (1975) A preliminary note on fluid inclusions in some granitic rocks from Egypt, *Min. Geol.,* **25:** 261-266.

El Shazly, E.M. (1964) On the classification of the Precambrian and other rocks of magmatic affiliation in Egypt, *22nd Int. Geol. Congr., India.*

———— (1980) Correlation and evolution of the Precambrian in Northeast Africa and Southwest Asia, *Earth-Science Reviews,* **16:** 103-312.

El Sokary, A.A., Sayah, T.A., El Shatoury, H.M., Attawya, M.Y. and **Assaf, H.S.** (1978) Contribution to the geochemistry of the granitoid rocks from Egypt, *Arab. J. Nuc. Sci. Applic.,* **11:** 127-150.

Engel, A.E., Dixon, T.H. and **Stern, R.J.** (1980) Late Precambrian evolution of Afro-Arabian crust from ocean arc to craton. *Geol. Soc. Am. Bull.,* **91,** 699-706.

Fullagar, P.D. (1980) Pan-African age granites of northeastern Africa: New or reworked sialic materials? *In:* **M.J. Salem** and **M.T.O. Busrewil** (ed.), *The Geology of Libya, v.* **III,** Academic Press, London, pp. 1051-1058.

————, and **Greenberg, J.K.** (1978) Egyptian Younger Granites. A single period of plutonism? (abs.). *Precamb. Res.,* **6:** A22.

Ghuma, M.A. and **Rogers, J.W.** (1980) Pan-African evolution in Jamahiriya and North Africa, *In:* **M.J. Salem** and **M.T. Busrewil** (ed.), *The Geology of Libya, v.* **III,** Academic Press, London, pp. 1059-1064.

Greenberg, J.K. (1981) Characteristics and origin of Egyptian Younger Granites. *Geol. Soc. Am. Bull.,* **92:** 749-840.

Hashad, A.H. (1980) Present status of geochronological data on the Egyptian basement complex, *In:* **A.M.S. Al-Shanti** (ed.), *Evolution and Mineralization of the Arabian-Nubian Shield, King Abdulaziz Univ., Jeddah, Bull.* **3:** part 3, Pergamon Press, Oxford, pp. 31-46.

Hussein, A.A., Ali, M.M. and **El Ramly, M.F.** (1982) A proposed new classification of the granites of Egypt, *J. Volcan. and Geother Research,* **14:** 187-198.

Kabesh, M.L., Hilmy, M.E. and **Ragab, A.G.** (1976) Some petrochemical characters of the granitic rocks of El Atawi stock, Eastern Desert, Egypt, *Chem. Erde-Bd.* **35:** 185-191.

————, **Salem, A.A., Heikal, M.A.** and **Salem, M.A.,** (1982) Petrochemistry and petrogenesis of the granitic rocks of Umm Samra pluton, Eastern Desert, *Egypt. J. Geol.,* **26:** 171-184.

Meneisy, M.Y. (1972) On the isotopic dating of the Egyptian basement rocks, *Annals. Geol. Surv. Egypt,* **2:** 103-109.

———— and **Lenz, H.** (1982) Isotopic ages of some Egyptian granites, *Annals. Geol. Surv. Egypt,* **12:** 7-14.

Moorbath, S. and **Taylor, P.N.** (1981) Isotopic evidence for continental growth in the Precambrian, *In:* **A. Kroner** (ed.), *Precambrian Plate Tectonics,* Elsevier, Amsterdam, 491-525.

Mostafa, M.E., (1986) *An Integrated Package for Computational Geology (IPCG),* Internal Report, Nuclear Materials Authority, Egypt.

O'Connor, J.T. (1965) A classification for quartz-rich igneous rocks based on feldspar ratios, *U.S. Geol. Surv. Prof. Paper* **525-B,** pp. 79-84.

Pearce, J.A. (1976) Statistical analysis of major element patterns in basalts, *J. Petrology,* **17** (Part 1): 15-43.

Petro, W.L., Vogel, T.A. and **Wilband, J.T.** (1979) Major element chemistry of plutonic rock suites from compressional and extensional plate boundaries, *Chem. Geol.,* **26:** 217-235.

Ragab, A.I. (1987) The Pan-African basement of the northern segment of the Eastern Desert of Egypt: A crustal evolution model and its implication on tectonostratigraphy and granite types, *M.E.R.C. Ain Shams Univ., Earth Sci. Ser.,* **1:** 1-18.

Ramsay, C.R., Drysdal, A.R. and **Clark, M.D.** (1986) Felsic plutonic rocks of the Medyan Region, Kingdom of Saudi Arabia. I. Distribution, Classification and Resource Potential, *J. Afr. Earth Sci.,* **4:** 63-77.

Rao, C.R. (1952) *Advanced Statistical Methods in Biometric Research,* John Wiley & Sons, New York, p. 355.

Rogers, J.W., Ghuma, M.A., Nagy, R.M., Greenberg, J.K. and **Fullagar, P.D.** (1978) Plutonism in Pan-African belts and the geologic evolution of north-eastern Africa, *Earth Planet Sci. Lett.,* **39:** 109-117.

———— and **Greenberg, J.K.** (1981) Trace elements in continental margin magmatism: part III. Alkali granites and their relationship to cratonization: Summary, *Geol. Soc. Amer. Bull,* **92:** 6-9.

Sabet, A.H. (1972) On the stratigraphy of the basement rock of Egypt, *Annals Geol. Surv. Egypt,* **2:** 79-101.

————, **Bessonenko, V.V.** and **Bykov, B.A.** (1976) The intrusive complexes of the Central Eastern Desert of Egypt, *Annals. Geol. Surv. Egypt,* **6:** 53-73.

————, **Chabanenko, V.** and **Tsogoev, V.** (1973) *Results of Prospecting for Rare Metals and Gold in El Sid-Semna Area in 1970-1971,* Internal report, 23, Geol. Surv. Egypt, Cairo.

————, **Shmelev, D.** and **Bordonosov, V.** (1977a) *Results of Prospecting for Gold, Rare and Nonferrous Metals Accomplished near Wadis Abu Ziran, Sodmein, Sagiya, Queih, Abu Shigeili in 1973-1974 (Quseir party 5/73),* Internal report, 23, Geol. Surv. Egypt, Cairo.

———— (1977b) *On the Results of Prospecting Work for Rare and Nonferrous Metals and Gold in the Area of Wadis Umm Gheig, Sitra, El Dabbah and Abu Tundub in 1973-1974* (Sibal party 4/73). Internal report, 26, Geol. Surv. Egypt, Cairo.

———— (1977c) *Results in Prospecting for Gold and Rare Metals in Wadi Safaga, El Barrud, El Marah and Hamama Area in 1974-1976.* Internal Report 24, Geol., Surv., Egypt, Cairo.

————, **Shmelev, D.** and **Shelekhov, B.** (1978a) *Results of Prospecting for Nonferrous, Rare Metals and Gold in the Area of Wadi Hammad, El Atrash, El Ghozah and Fatira El Beida in 1975/1977 (El Shayib parties 5/75 and 5/76),* Internal report, 5, Geol. Surv. Egypt, Cairo.

———— (1978b) *Results of Prospecting for Rare Metals, Nonferrous Metals and Gold in the Area of*

Wadis Dara, El Urf, Melaha, Abu Marwa, Hammad, Bali in 1976-1977 (Jemsa party 6/76), Internal report, 3, Geol. Surv. Egypt, Cairo.

Schurmann, H.M.E. (1966) *The Precambrian Along the Gulf of Suez and the Northern Part of the Red Sea*, E.J. Brill., Leiden.

Shand, S.J. (1927) *The Eruptive Rocks*, Wiley, New York.

Sillitoe, R. (1979) Metallogenic consequences of Late Precambrian suturing in Arabia, Egypt, Sudan and Iran, *In:* **A.M.S. Al-Shanti** (ed.), *Evolution and Mineralization of the Arabian-Nubian Shield*, vol. **3,** part 1, Pergamon Press, Oxford, pp. 109-120.

Sorensen, H. (1974) Classification and nomenclature of plutonic rocks. *In:* **H. Sorensen** (ed.), *The Alkaline Rocks*, John Wiley, New York, pp. 557-576.

Stern, R.J. (1979) *Late Precambrian Ensimatic Volcanism in the Central Eastern Desert of Egypt*, Ph.D. Thesis, Univ. California, San Diego, U.S.A., p. 210.

———— and **Hedge, C.E.** (1985) Geochronologic and isotopic constrains on Late Precambrian crustal evolution in the Eastern Desert of Egypt, *Am. J. Sci.*, **285:** 97-127.

————, **Gottfried, D.** and **Hedge, C.E.** (1984) Late Precambrian rifting and crustal evolution in the northeastern desert of Egypt, *Geology*, **12:** 168-172.

Stoeser, D.B. and **Elliott, J.E.** (1980) Post-orogenic Peralkaline and calc-alkaline granites and associated mineralization of the Arabian Shield, Kingdom of Saudi Arabia. *In:* **A.M.S. Al-Shanti** (ed.), *Evolution and Mineralization of the Arabian-Nubian Shields, King Abdulaziz Univ., Bull.*, vol. **3,** part 4, Pergamon Press, Oxford, 127-135.

Wright, J.B. (1969) A simple alkalinity ratio and its application to questions of non-orogenic granite genesis, *Geol. Mag.*, **106.** with current nomenclature, *Chem. Geol.*, **29:** 183-210.

تحكم نظام العناصر الأساسية في تحديد المنشأ والوضع التكتوني للصخور الجرانيتية بالصحراء الشرقية بمصر

مصطفى السيد مصطفى * ، محمد هيكل ** و عاطف ثابت ***

*هيئة المواد النووية ؛ **كلية العلوم ، جامعة الأزهر و ***هيئة المساحة الجيولوجية القاهــــــرة – جمهورية مصر العربية

المستخلص . جمعت في هذا البحث ١١٨ عينة من الصخور الجرانيتية من الصحراء الشرقية بمصر ، وذلك لإجراء التحليل الكيميائي الكامل . وقسمت هذه الصخور بناءً على نتيجة التحاليل إلى جرانيتات قديمة ، وجرانيتات حديثة ، وصخور جرانيتية قلوية متأخرة (بعد تكون الجبال) . كما أن العلاقة الحقلية لصخور الجرانيتات الحديثة أظهرت وجودها على ثلاثة أطوار . ويناقش البحث العلاقات الحقلية وإحصاءات للبيانات الكيميائية والعديد من دوال العناصر الأساسية لمعرفة المنشأ والوضع التكتوني لهذه الصخور الجرانيتية . واستنتج من هذه الدراسة أوجه التشابه المعدني والكيميائي لكل من الجرانيتات القديمة والطور الأول من الجرانيتات الحديثة ، وأن هذين النسقين من الصخور الكلسي قلوية ربما قد نشآ في نفس البيئة التكتونية والتي اعتبرت خندقية التكوين .

كما أوضحت الدراسة أن صخور الطور الثاني من الجرانيتات الحديثة (كلسية قلوية إلى قريبة من القلوية) قد نشأت في فترة الاستقرار التدريجي للمنطقة أثناء الحركة الأفريقية العامة ، بينما تكونت صخور الطور الثالث من الجرانيتات الحديثة (قريبة من القلوية) ، وذلك بعد اتمام تصلد صخور الدرع العربي النوبي . وربما صاحب ذلك بوادر تفلُّع . وتعتبر الجرانيتات القلوية فيما بعد تكون الجبال لا تكتونية النشأة والتي تكونت داخل اللوحة .