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NEW CONTRIBUTIONS TO THE GEOLOGY, GEOCHEMISTRY AND TECTONIC SETTING OF THE ASWAN GRANITES, SOUTHERN EGYPT

By

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ABSTRACT

The Aswan granitic rocks occupy a region in southern Egypt between the stable Archaean craton of the south Western Desert and the less stable Pan-African belt of the south Eastern Desert. They include light-grey medium grained granites, red coarse-grained granites and fine-grained granites.

The setup, field relations and petrography of the granitic rocks are discussed in detail. Seventeen new chemical analyses for both major and trace elements are presented. Also, the chemical analyses of four biotites, four feldspars and three magnetites separated from the granitic rocks are presented and three magnetites separated from the granitic rocks are presented and plotted on variation diagrams.

The field evidences indicate that the Aswan granites should be classed with the post-collisional granites, whereas the petrochemical and geochemical data suggest progressive differentiation from the granodiorite through monzogranite to syenogranite and that they are probably related to a single magmatic intrusive sequence. The Aswan granites have a related petrogenetic history with the calc-alkaline volcanic suites of the south Eastern Desert.

INTRODUCTION

The Aswan granitic rocks cover the central part of the area near Aswan city (Fig. 1) within latitudes 24° 5′, 18° 5′ N and longitudes 32° 53’, 26° 07’ E. These rocks have undergone field, petrographical, geochemical and geochronological studies since 1907. Geological maps of various scales have been given by many authors e.g., Ball, 1907; Hume, 1935, Little and Attia, 1943; El Shazly, 1954; Attia, 1955; Hunting, 1967 and others.

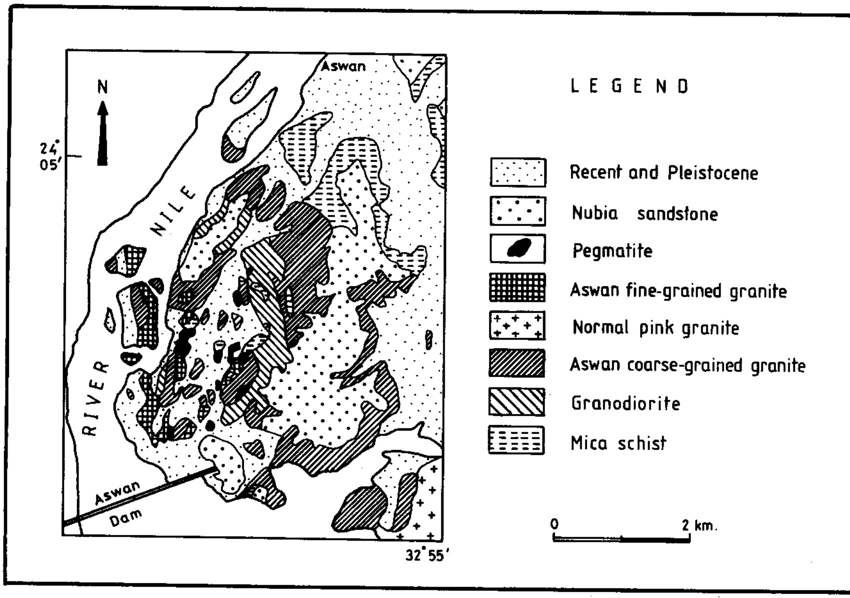


Fig. 1 : Geological map of Aswan area (after Attia, 1955).

The appropriate position for the Aswan granite in the stratigraphic sequence of Egypt is controversial. El-Shazly (1964) suggested a post-orogenic granite group for the coarse-grained granites of Aswan, much younger than the two main granitic groups of Egypt namely: (a) the older or synorogenic granite group and (b) the younger or late-orogenic granite group. El-Gaby (1975) considered the porphyritic Aswan granite as belonging to the synorogenic granite. Hussein *et al.* (1982) considered the Aswan granites very similar to the subduction-related granites of Group I (the older or synorogenic granites).

Regarding the mode of formation of the Aswan granitic rocks, Ball (1907), Barthoux (1922), Andrew (1934) and Hume (1935) all believed in the plutonic origin of these rocks. Rittmann (1953) believed that the coarse-grained granite of Aswan was formed by the granitization of pre-existing sedimentary rocks. He itemized this type as para-granite in contradistinction to the younger fine-grained granite which is of intrusive character. Gindy (1954, 1956 and 1957) considered the granitic rocks of Aswan to be product of metasomatic alteration and granitization of pelitic, psammitic and dioritic rocks. Higazy and Wasfy (1956) and Zaghloul and Khaffagy (1965) agree with Gindy's view. On the basis of observations on twelve chemical analyses for the Aswan basement rocks, Gindy (1974) believed that the coarse Aswan granite is of magmatic origin. El-Gaby (1975) considered the porphyritic granites of Aswan to be formed by granitization processes and partial mobilization under sustaining orogenic stresses. Ragab *et al.* (1978) concluded that the Aswan granitic rocks form a postorogenic, composite stock, its phases are intrusive and comagmatic.

The geochronologic investigations have not resulted in complete agreement regarding the age or the initial $^{87}Sr/^{86}Sr$ ratios of these granites. Schurmann (1966) reported 470 and 570 Ma K-Ar ages for feldspar and biotite separates, respectively. Based on five whole-rock samples, Leggo (1968) reported an age of 621±21 Ma and an initial $^{87}Sr/^{86}Sr$ of 0.704±0.0001. Hashad et al. (1972) presented a three point isochron from which an age of 578 Ma and an initial $^{87}Sr/^{86}Sr$ of 0.7092±0.0009. was deduced. Abdel Monem and Hurely (1980) analyzed six zircon fractions which did not define a chord but produced ages around an average of 565 Ma. These points define a chord that intercepts the upper Concordia at an age of 700 Ma. This is interpreted as the age of formation of the granite, whereas the previous Rb/Sr and K/Ar ages represent the age of emplacement or crustal rebound. Meneisy and Lenz (1982) and Stern and Hedge (1985) gave Rb/Sr ages for the Aswan coarse-grained granites in the range of 585 and 595 Ma and average initial $^{87}Sr/^{86}Sr$ of 0.703. Recent model Nd and Rb/Sr dating of the Aswan granites by Harris et al. (1984), gave ages of 950 and 680±10, respectively and initial $^{87}Sr/^{86}Sr$ of 0.7033.

The present study is concerned with the field observations, petrographic description, geochemical investigations and the chemistry of biotites, feldspars and magnetites separated from the Aswan granitic rocks in order to clarify the field, petrographic and geochemical characters of these granitic rocks, to present further data concerning their mode of formation and to throw some light on their tectonic setting

FIELD DESCRIPTION AND SETUP

The granite of the Aswan area has a roughly circular form, with a diameter of -5 kms. It forms many conspicuous hills which extend in a N-S direction. The granites are unconformably overlain by the Nubia Sandstone in many localites. The country rocks are mainly migmatites and consist of mica-and hornblende schists, augen gneisses and amphibolites with lit-par lit injection. The granitic rocks of Aswan area are not restricted to the studied area but extend further E and W beneath the Nubia Sandstone cover.

In this study the Aswan granitic rocks are represented by light grey medium-grained granites, red coarse-grained granites and fine-grained granites. The medium grainded granites form a number of sheet - like masses ovrlain in some localities by the Nubia Sandstone and grade into the coarse grained granite varieties. They range in composition from quartz diorites to granodiorites; the most abundant variety is the grey coloured granodiorite spotted with white and pinkish feldspar porphyroblasts which sometimes show linear arrangement. Gneissose granodiorite is often developed near contacts with the red coarse-grained granite. The granodiorites enclose big elongated xenoliths from the surrounding older metamorphites. The coarse-grained granites are widely distributed in the area and form most of the hills between Aswan and Shellal and underlies the Nubia Sandstone in many localities. They enclose angular and elongated xenoliths of granodiorite, gneisses, schists and other older metamorphic rocks. They are cut by sheets and dykes of fine-grained granite and pegmatites. This granite is normally pinkish in colour with abundant pink feldspar porphyroblasts up to 4 cm in length. The fine-grained Aswan granites, on the other hand, form sheets, dykes and irregular elongated masses cutting mainly the coarse-grained granite. These granites are homogeneous, non-porphyritic, fine-grained and show pinkish to greyish colours. Frequently, they show flow structure exhibited by the parallelism of the biotite flakes. Both the coarse-and fine-grained Aswan granites comprise monzogranite and syenogranite varieties. The preferred orientation of the potash feldspar porphyroblasts and the large elongated xenoliths is almost concordant with the foliation of the country rocks.

The Aswan granites are characterized by the presence of pegmatitic and aplitic veins. Two masses of leucogranites characterized by light colour and very little amounts of mafics are recognized south of the granodiorite quarry at Gebel Ibrahim Pasha and near the quarry of the fine-grained granites northeast of the Aswan Dam.

Aswan granitic rocks occupy a unique position between the Precambrian exposures of the south Eastern and south Western Deserts of Egypt. To the east, a basinal facies of metasedimentary and metavolcanic rocks together with batholithic older granites and younger granite plutons form extensive outcrops which represent the southern extension of the Pan-African Precambrian belt of the Eastern Desert. Samples from the metasedimentary succession from Abu Swayel mine gave a Rb/Sr age of 1160$\pm$144 Ma (El-Shazly et al., 1973). Metavolcanic rocks associated with the metasediments represented by rhyodacite from Abu Swayel define an isochrone of 768$\pm$31 Ma and an initial $^{87}Sr/^{88}Sr$ of 0.7019$\pm$3 (Stern and Hedge, 1985). An evolutionary model of Island arc formation and obduction-accretion tectonics is envisaged for this area.

To the west, on the other hand, there are many exposures of Archaean basement gneisses and schists which extend from Gabal Uweinat in the west to Bir Safsaf in the east. The Kurkur Murr charnokite from Gabal Uweinat form the oldest known basement in north-east Africa and two samples have model Nd ages of 3000 and 3200 Ma (Harris et al., 1984). This confirms their Archaean age and indicates that the event dated 2617$\pm$21 Ma by Rb/Sr whole rock analyses (Klerkx and Deutsch, 1977) involved crustal reworking. The rocks of the south Western Desert are characterized by three episodes of deformation and related metamorphism and anatexis until the final cratonization during the late Pan-African event was completed.

PETROGRAPHY

The Aswan granitic rocks are petrographically classified into granodiorites, monzogranites, syenogranites and minor quartz-diorites. These granites vary in grain size from fine to coarse-grained and frequently very coarse in size exhibiting pegmatitic appearance. They are characterized by equigranular hypidiomorphic and seriate porphyritic textures. Gneissose textures are sometimes present whereas the rapakivi texture is usually observed megascopically. They are composed mianly of potash feldspar, oligoclase and quartz together with variable proportions of biotite and hornblende. Sphene, allanite, apatite, zircon and magnetite are the accessories.

Potash feldspars are represented by microcline-microperthite, orthoclase-cryptoperthite and non-perthitic microcline. They vary considerably in abundance from one rock type to another. Phenocrysts are subhedral, sometimes enclose small quartz grains and are charged with hematitic inclusions along cleavage planes. The rapakivi texture is developed in all the granitic types where the phenocrysts of potash feldspars are surrounded by a thin envelope of fine-grained oligoclase and interstitial quartz aggregates. Myrmekitic texture is frequently observed at the alkali feldspar edges. *Oligoclase* (An_{12}) forms subhedral tabular crystals partly altered to sericite and replaced by quartz at the peripheries. *Quartz* commonly forms interstitial aggregates, but may also occur as phenocrysts. In rare cases quartz is intergrown with potash feldspars as micrographics texture. *Biotite* forms brown anhedral elongated flakes occasionally chloritized. In the gneissose varieties, the biotite flakes are arranged in parallel streaks giving rise to the gneissose texture. *Green hornblende* is common in quartz diorite and granodiorite and in some monozogranite varieties. In forms euhedral prismatic crystals which show fair pleochroism with X=yellow green, Y=olive green and Z=dark green.

CHEMISTRY OF THE GRANITIC ROCKS

Seventeen samples representing the different rock types and varieties of the Aswan granitic rocks were analysed for major and trace elements. These analyses together with three analyses of granites from other localites are shown in table 1. Rittmann norm, Niggli values, oxide ratios and various geochemical parameters for the analysed samples are given in table 2.

Comparison Between the Studied Aswan Granites and Granites of other Localities.

There is a close similarity between the average chemical composition of the Aswan

Table 1

Major and trace element analyses of the Aswan granitic

Rock type	Granodiorite			Monzogranite						Syenogranite													
Sample No. / Terms	200	201	Av.	202	203	204	205	206	Av.	207	208	209	210	211	212	213	214	215	216	Av.	A	B	C
SiO_2	67.94	67.10	67.52	66.68	70.01	72.52	70.93	68.68	69.76	70.44	70.04	70.40	67.07	70.04	72.06	73.44	71.85	70.53	67.10	70.30	67.23	74.29	71.21
TiO_2	0.66	0.40	0.53	0.72	0.44	0.10	–	0.26	0.30	0.44	0.56	0.40	0.60	0.46	0.20	0.06	0.10	0.18	0.34	0.30	0.57	0.20	0.65
Al_2O_3	13.60	16.36	14.98	14.28	13.40	12.46	13.91	14.54	13.72	12.93	13.34	13.45	14.54	12.77	13.08	13.34	13.50	13.76	13.50	13.42	15.50	13.61	12.09
Fe_2O_3	2.08	1.41	1.75	1.61	1.22	0.48	1.16	1.98	1.29	1.10	1.20	0.88	1.60	1.28	0.94	0.83	1.53	1.70	0.71	1.17			0.80
																					4.23*	2.03*	
FeO	3.86	3.07	3.46	4.02	2.94	3.54	2.39	3.18	3.21	2.99	2.76	2.72	3.20	3.13	1.81	1.16	1.84	1.91	3.56	2.41			3.39
MnO	0.10	0.05	0.07	0.06	0.07	0.09	0.10	0.12	0.09	0.07	0.05	0.04	0.06	0.06	0.03	0.06	0.03	0.06	0.08	0.05	0.07	0.05	0.08
MgO	0.94	1.37	1.15	0.49	1.10	1.18	0.81	1.06	0.93	1.02	1.00	0.59	0.64	0.59	0.21	0.57	0.97	1.01	0.85	0.74	1.56	0.27	0.12
CaO	3.10	2.53	2.82	2.93	2.67	2.11	2.45	2.62	2.55	2.74	2.26	3.04	2.63	2.74	2.38	1.87	1.76	1.71	2.56	2.37	3.54	0.71	1.61
Na_2O	3.10	4.06	3.58	3.23	3.37	3.10	3.50	3.77	3.39	2.69	2.69	2.65	3.23	2.96	3.10	2.83	3.10	2.83	3.50	2.96	3.83	3.48	3.39
K_2O	4.21	2.92	3.56	5.00	4.03	3.61	4.27	3.19	4.02	4.82	5.62	5.42	6.08	5.36	5.42	5.42	5.42	5.42	5.66	5.46	3.04	5.06	5.10
P_2O_5	0.19	0.02	0.10	0.03	0.06	0.04	0.05	0.05	0.04	0.06	0.07	0.05	0.08	0.04	0.02	0.03	0.01	0.06	0.04	0.04	0.21	0.14	0.24
H_2O^+	0.21	0.53	0.37	0.40	0.39	0.32	0.36	0.30	0.35	0.21	0.34	0.30	0.33	0.42	0.54	0.39	0.67	0.40	0.57	0.42	–	–	1.00
H_2O^-	0.15	0.20	0.15	0.20	0.18	0.15	0.10	0.01	0.13	0.17	0.15	0.10	0.13	0.19	0.17	0.03	0.06	0.08	0.09	0.12	–	–	–
Total	100.14	100.02	100.06	99.65	99.88	99.70	100.03	99.76	99.78	99.68	100.08	100.04	100.19	100.04	99.96	100.03	99.84	99.65	98.65	99.76	99.78	99.84	99.68
P ppm	4245	449	2347	649	1298	949	1004	4360	1000	1250	1500	1082	1788	873	474	750	250	1300	848	1011	NA	NA	
Nb	100	–	50	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	NA	NA	
Ti	11018	6677	8848	12020	7345	1669	–	4340	5008	7345	9348	6677	10016	7679	3338	1001	1669	3005	5676	5008	NA	NA	
Zr	1000	300	650	800	500	300	500	1000	620	1000	800	800	800	500	500	100	–	300	200	500	140	175	
V	140	140	140	112	84	112	140	112	112	56	140	112	140	118	80	84	84	140	116	107	88	44	
Cr	–	–	–	3	3	13	3	3	5	–	–	–	17	–	–	–	–	–	3	2	22	4.1	
Mn	1291	645	904	775	904	1162	1291	1612	1162	904	645	516	775	775	387	775	387	775	1033	645	NA	NA	
Ni	–	–	–	–	30	30	30	30	24	30	–	30	30	30	30	–	–	30	30	21	15	4.5	
Cu	20	20	20	20	30	50	20	20	28	10	30	30	30	10	50	10	20	10	20	22	30	10	
Zn	–	–	–	–	–	–	–	1000	200	1000	1000	–	–	1000	–	–	–	–	–	300	NA	NA	
Sr	300	200	250	240	210	200	300	300	250	200	200	300	100	200	300	100	200	500	300	240	440	100	
Ba	5000	5000	5000	3000	3000	1800	1600	3000	2480	3000	3200	3000	4000	3000	3000	100	1000	2000	2000	2430	420	40	
Y	100	100	100	100	100	50	80	100	86	100	–	100	100	100	–	200	–	–	100	70	35	40	
Be	30	20	25	10	10	10	10	10	10	10	10	10	10	10	3	10	3	10	10	8	2	3	
Ba/Sr	16	25	20	12	14	9	5	10	10	15	16	10	40	15	10	7	5	4	6	10	1	8	
(Sr/Ca) x 1000	14	11	12	11	11	13	17	16	14	10	12	14	5	10	17	7	15	40	16	14	17	20	

* = Total iron as Fe_2O_3 - = not detected NA = not analysed Pb, Co, Ga, Sn and Ta are not detected

A = High-calcium granite (Turekian and Wedepohl, 1961) B = Low calcium granite C = Rapakivi, Kustavi, south-western Finland (Sahama, 1945).

Table 2

Normative composition, Niggli values, various geochemical parameters and oxide ratios of the Aswan granitic rocks

Rock type	Granodiorite			Monzogranite						Syenogranite										
Terms / Sample No.	200	201	Av.	202	203	204	205	206	Av.	207	208	209	210	211	212	213	214	215	216	Av.
Normative composition of the studied Aswan Granites (Rittmann, 1973)																				
Quartz	26.46	25.46	25.96	21.06	27.94	36.26	27.59	29.58	28.49	28.94	26.97	27.16	17.93	26.07	28.58	31.28	28.19	30.02	19.03	26.42
Orthoclase	36.21	25.87	31.04	44.37	35.54	32.20	38.09	27.01	35.44	41.62	48.12	46.68	53.70	49.01	48.58	47.60	49.03	46.98	58.00	48.93
Plagioclase	20.01	39.85	33.93	25.70	28.62	25.93	28.29	38.29	29.37	21.18	17.69	18.91	19.74	16.28	17.86	17.50	18.02	19.03	13.71	17.99
Biotite	1.48	4.90	3.19	–	0.68	2.90	0.42	4.25	1.65	–	0.93	–	–	–	–	0.32	0.64	2.91	–	0.48
Amphibole	5.35	–	2.68	6.27	5.63	1.56	4.57	–	3.61	6.57	4.59	5.05	6.34	4.47	–	2.67	3.40	–	4.41	3.75
Sphene	0.50	–	0.25	1.00	0.37	0.02	–	–	0.28	0.49	0.46	0.68	0.96	0.70	0.05	0.04	0.06	–	0.51	0.40
Ilmenite	0.21	–	0.10	0.13	0.12	–	–	–	0.05	0.10	0.18	–	0.01	0.04	0.16	–	–	–	0.02	0.05
Magnetite	1.42	0.64	1.03	1.41	1.00	1.06	0.94	0.77	1.04	0.99	0.93	0.87	1.16	1.08	0.71	0.53	0.63	0.94	1.20	0.90
Apatite	0.36	0.04	0.20	0.06	0.11	0.08	0.09	0.09	0.09	0.11	0.13	0.17	0.15	0.19	0.04	0.06	0.06	0.11	0.07	0.11
Corderite	–	3.24	1.62	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Clinopyroxene	–	–	–	–	–	–	–	–	–	–	–	0.49	–	2.17	4.03	–	–	–	3.05	0.97
Niggli values																				
si	292	281	287	287	323	362	336	300	322	303	330	334	288	329	374	396	366	343	298	339
al	34.36	40.37	37.37	36.21	36.41	36.56	38.81	37.40	37.08	36.00	37.01	37.61	36.78	35.37	39.96	42.31	40.49	39.37	35.25	37.99
fm	26.94	23.96	25.45	23.03	23.44	25.71	19.74	25.47	23.48	23.22	22.37	18.28	20.97	21.21	13.26	13.46	16.96	21.56	21.50	19.28
c	14.27	11.37	12.82	13.53	13.21	11.28	12.45	12.27	12.55	13.90	11.42	15.48	12.12	13.82	13.24	10.80	9.61	8.92	12.18	12.15
alk	24.43	24.30	24.36	27.23	26.94	26.45	29.00	24.86	26.90	26.88	29.20	28.63	30.13	29.60	33.54	33.43	32.94	30.15	31.07	30.55
ti	2.12	1.26	1.69	2.33	1.52	0.37	---	0.85	1.01	1.56	1.98	1.42	1.94	1.62	0.78	0.24	0.38	0.66	1.13	1.17
P	0.33	0.04	0.19	0.05	0.11	0.09	0.09	0.08	0.08	0.11	0.13	0.17	0.14	0.19	0.05	0.07	0.24	0.12	0.07	0.13
k	0.47	0.32	0.40	0.51	0.44	0.43	0.45	0.36	0.44	0.54	0.57	0.57	0.55	0.54	0.54	0.56	0.54	0.56	0.52	0.55
mg	0.22	0.36	0.29	0.14	0.33	0.34	0.29	0.27	0.27	0.31	0.32	0.23	0.20	0.20	0.12	0.34	0.44	0.34	0.26	0.28
Various Geochemical Parameters and Oxide Ratios																				
Modified Larsen D.I.	11.29	10.23	10.76	12.14	11.66	12.06	12.33	10.82	11.80	12.39	13.34	12.93	13.22	13.04	13.88	14.24	13.84	13.64	12.80	13.33
Alkalinity ratio	2.55	2.17	2.36	2.83	2.71	2.71	2.81	2.36	2.68	2.84	3.28	2.92	3.37	3.31	3.45	3.37	3.53	3.29	3.66	3.30
Mafic Index	86.34	76.58	81.46	91.99	79.08	77.31	81.42	82.96	82.55	80.04	79.84	85.92	88.23	88.20	92.90	77.73	70.96	78.14	83.40	82.55
Felsic Index	70.22	73.40	71.81	73.74	73.48	76.08	76.03	72.65	74.40	73.27	78.62	72.64	77.97	75.22	78.16	81.52	82.88	82.83	78.16	78.13
FeO/MgO	4.10	2.24	3.01	8.20	2.67	3.00	2.95	3.00	3.45	2.93	2.76	4.61	5.00	5.30	8.62	2.03	0.87	1.89	4.18	3.26
K_2O/Na_2O	1.36	0.72	0.99	1.55	1.20	1.16	1.22	0.85	1.18	1.79	2.08	2.04	1.88	1.81	1.75	1.92	1.75	1.92	1.62	1.84
FeO/Fe_2O_3	1.85	2.17	1.98	2.50	2.41	3.37	2.06	1.60	2.48	2.72	2.30	3.09	2.00	2.44	1.92	1.40	0.55	1.12	4.01	2.06
Mol. Al_2O_3/Na_2O+K_2O+CaO	1.09	1.35	1.22	1.02	1.32	1.14	1.10	1.21	1.16	1.07	1.43	1.04	1.02	0.97	1.00	1.09	1.07	1.14	0.95	1.08

granodiorite and that of the high Ca granite of Turekian and Wedepohl (1961). Comparing the average Aswan monzogranite with the ideal high-Ca granite of Turekian and Wedepohl (op.cit.) indicates that the former are richer in SiO_2 and K_2O and poorer in TiO_2, Al_2O_3, CaO than the latter. The average composition of Aswan syenogranite has higher MgO, CaO and K_2O and lower SiO_2 and Na_2O than the low-Ca granite of Turekian and Wedepohl (op.cit.) On the other hand, there is a close similarity between the average chemical composition of the Aswan syenogranite and the analyses of the rapakivi granites of south western Finland (Sahama, 1945).

Chemical Classification.

The chemical analyses of the studied granitic rocks, calculated to Rittmann (1973) norm and plotted on the QAP diagram (Fig. 2) of Streckeisen (1976), show that the Aswan granitic rocks plot within the fields of granodiorite, monzogranite and syenogranite.

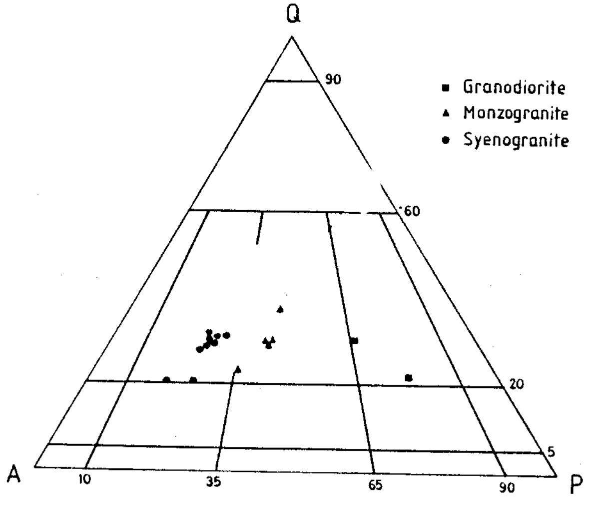


Fig. 2 : QAP diagram of Streckeisen (1976).

Variation in Chemical Composition and Magmatic Differentiation.

The calculated values of the modified Larsen differentiation index (MDI) are shown in table 2. the Aswan granitic rocks are arranged in a decreasing order of the average differentiation index into: granodiorite which has the lowest value of average MDI (10.76), monzogranite (11.80) and syenogranite which has the highest MDI (13.33). Figure 3 represents the plotting of the different major element concentrations and

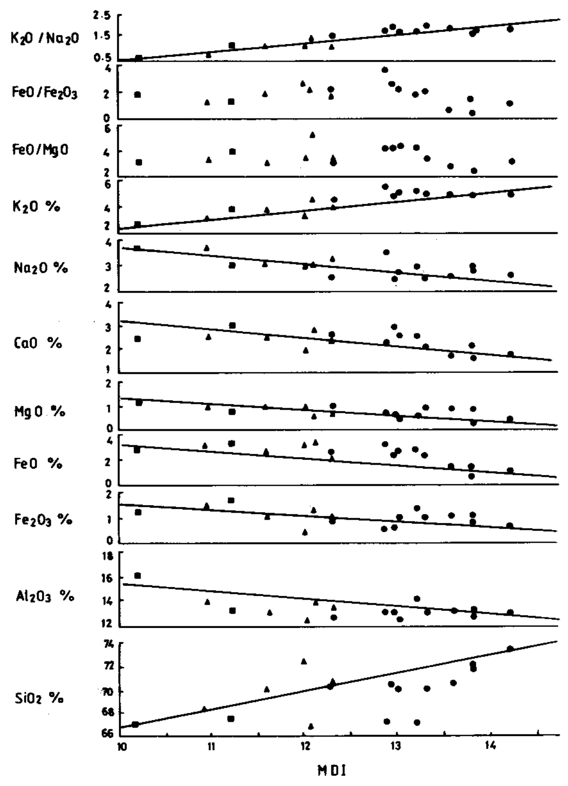


Fig. 3 : Plots of the contents of the major elements in the studied granites versus the modified Larsen factor (Nockolds and Allen, 1953) simply refered to as MDI in the present work; symbols as in Fig. 2.

element ratios of the investigated Aswan granites versus MDI of Nockolds and Allen (1953). It is clear from this figure that SiO_2 and K_2O increase with MDI whereas Al_2O_3, Fe_2O_3, FeO, MgO, CaO and Na_2O decrease. The reduction-oxidation scale (FeO/Fe_2O_3) and the ferriferous character of the mafic minerals (FeO/MgO) show no clear trend with MDI. On the other hand, the potassic affinity of feldspar (K_2O/Na_2O) shows positiv skewness with MDI. The spread of trace element concentrations as a function of the MDI is shown in Fig. 4. It is clear from this figure that P, V, Ti, Zr, Mn and Be decrease with MDI whereas Cr, Ba, Sr, Y, Ni and Cu remain approximately constant. As shown in table 1, the average Ba/Sr ratios decrease whereas the average Sr/Ca ratio increase from the granodiorite through the monzogranite to the syenogranite. All the above data suggest progressive differentiation from the granodiorite through monzogranite to syenogranite.

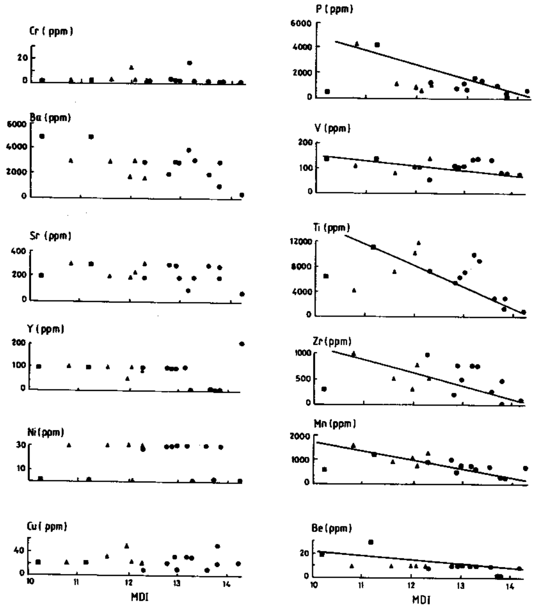


Fig. 4 : Plots of the contents of the trace elements versus MDI; symbols as in Fig. 2.

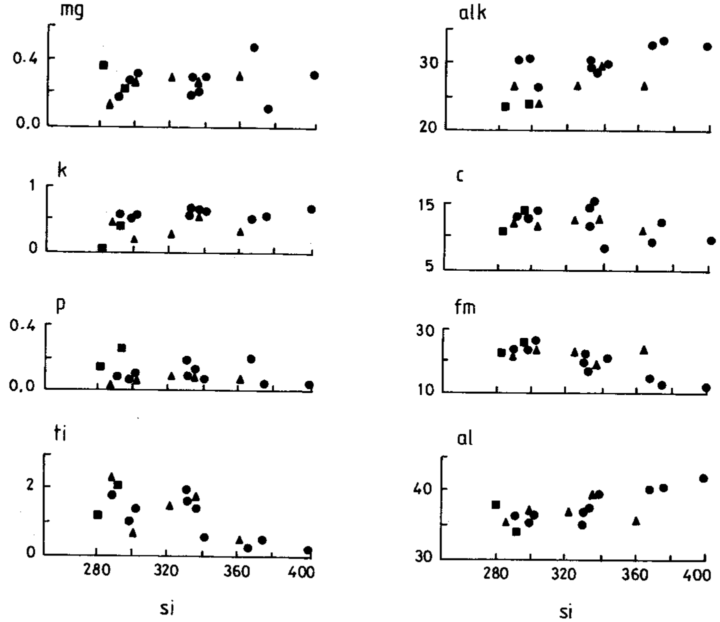


Fig. 5 : Variation diagrams of Niggli parameters against si values; symbols as in Fig. 2.

The calculated Niggli values are listed in table 2 and are plotted versus si in Fig. 5. The value si represents the degree of acidity of a rock which indicates its differentiation rate. Fig. 5 shows a relatively regular trend from the more basic granodiorite samples to the syenogranite samples. In general, the figure indicates a typical magmatic trend through enrichment of al, alk and k and depletion of fm, c, ti and p values during acidification of the magma.

The AFM diagram (Fig. 6) clearly illustrates that the analysed granitic samples lie closer to the alkali-total iron sideline. The figure shows a continuous variation in composition from the granodiorite through the monzogranite to the syenogranite. In K-Na-Ca diagram (Fig. 7), the trend of Aswan granites from Na to K began with granodiorite through monzogranite to syenogranite.

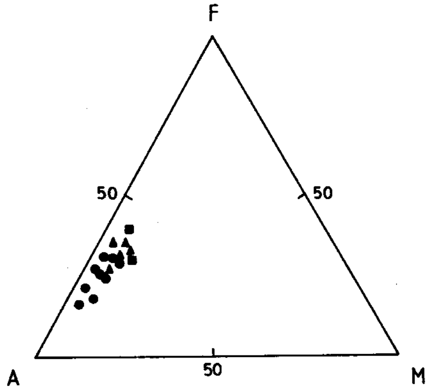


Fig. 6 : AFM variation diagram, symbols as in Fig. 2.

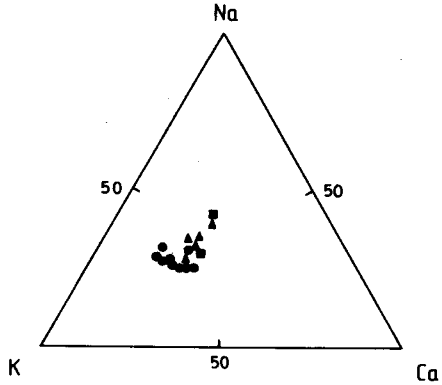


Fig. 7 : K-Na-Ca variation diagram; symbols as in Fig. 2.

K_2O/Na_2O Molecular Ratio

Figure 8 shows the relationship between K_2O and Na_2O where the majority of the investigated granites have K_2O/Na_2O ratio between 1-2 and are therefore of potassic character.

The Calc-Alkaline/Alkaline Nature

The alkalinity ratio calculated and plotted on Wright's (1969) alkalinity ratio variation diagram (Fig. 9), indicates that the granodiorite varieties of the Aswan granite have calc-alkaline affinities whereas the monzogranite and syenogranite varieties have alkaline affinities.

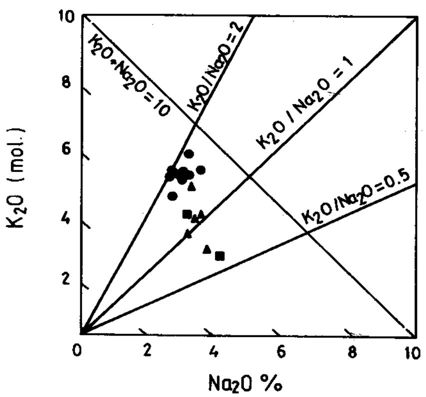


Fig. 8

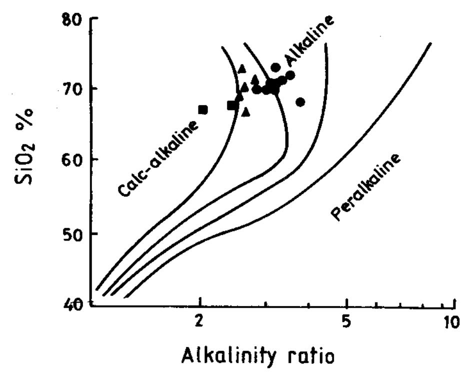


Fig. 9

Fig. 8 : Variation in alkalies of the studied granitic rocks; symbols as in Fig. 2.

Fig . 9 : Alkalinity varion diagram of wright (1969) ; simbols as in Fig. 2 .

The Granitic System

Normative proportions of Qz, Ab and Or are plotted on the Qz-Ab-Or-H_2O system at water-vapour pressures from 0.5 to 10 Kb (Tuttle & Bowen, 1958; Fig. 10). It is clear from this diagram that the fields of composition of the present rocks fall nearer to the high water-vapour pressure end of the minimum melting curve on the high orthoclase side. According to Tuttle and Bowen (1958), the concentration of the analyses near the centre of the diagram is readily explained if a magmatic history is involved in the origin of granites. As shown in Fig. 10, the analyses of Aswan granitic rocks concentrate near the centre of the diagram and hence are considered to possess a magmatic history.

The ternary diagram of the Ab-An-Or-H_2O system (Fig. 11) shows that the present analyses surround the low temperature minimum of the Ab-Or binary system which suggests that these rocks originate by fractional fusion of crustal rocks.

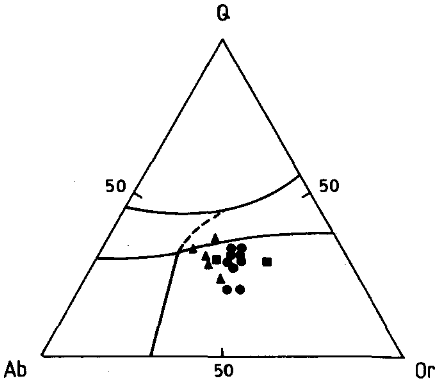


Fig. 10

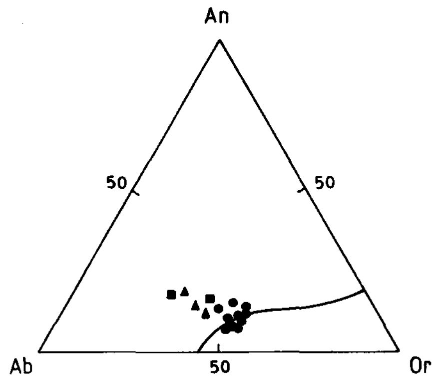


Fig. 11

Fig. 10 : Normative Qz-Ab-Or proportions for the analysed granitic rocks plotted on the Qz-Ab-Or-H_2O system at water-vapour pressures from 0.5to 10 Kb (Tuttle & Bowen, 1958). Symbols as in Fig. 2.

Fig. 11 : Normative Qz -An-Or proportions for the analysed granitic rocks; symbols as in Fig. 2. The solid line represents the feldspar boundary curve for the quartz-saturated ternary feldspar system at 1 Kb water-vapour pressure (James & Hamilton, 1972).

Chemistry of the separated minerals

Table 3 represents the chemical analyses of samples of pure minerals (4 biotites, 4 feldspars and 3 magnetites) separated from selected granitic samples using well established techniques.

Major Elements

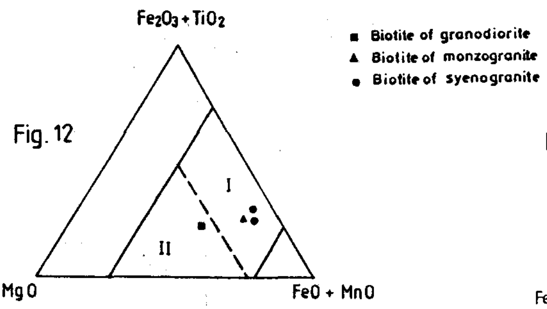
Biotite

The chemical composition of 4 separated biotites (table 3) are plotted on various variation diagrams to indicate the petrogenesis of the Aswan granites. Heinrich's (1946) variation diagram (Fig. 12) indicates that the biotite of the granodiorite fall within the field of metamorphic-metasomatic rocks, within the field of magmatic rocks. Nockold's (1947) variation diagram (Fig. 13) reached the same conclusion. The relationship between the weight percentage of MgO, (FeO+MnO) and (Fe_2O_3+TiO_2) are plotted on a ternary variation diagram (Fig. 14) described by

Table 3

Major and trace element analyses of biotites, feldspars and magnetite separated from the investigated Aswan granites

Mineral	Biotites				Feldspars				Magnetite		
Rock type	Grano-diorite	Monzo-granite	Syeno-granite		Grano-diorite	Monzo-granite	Syeno-granite		Grano-diorite	Monzo-granite	Syeno-granite
sample No	200	202	210	213	200	202	210	213	200	202	213
SiO_2	35.99	36.85	37.90	36.90	58.86	58.90	63.60	59.50	1.82	0.50	0.90
TiO_2	2.03	4.10	4.50	5.60	–	–	–	–	3.13	2.00	1.20
Al_2O_3	14.71	14.54	15.83	13.76	21.44	20.17	18.36	17.58	1.96	1.94	1.59
Fe_2O_3	4.29	4.94	3.35	4.78	0.48	0.20	–	0.10	71.98	79.12	77.36
FeO	16.30	22.31	22.37	23.68	–	–	–	–	19.47	15.07	16.47
MnO	0.37	1.15	0.67	0.70	–	–	–	–	0.44	–	0.35
MgO	11.47	5.61	5.13	5.42	–	–	–	–	1.27	1.06	0.42
CaO	1.54	0.90	0.70	1.10	4.79	6.45	5.45	8.79	–	–	1.79
Na_2O	1.36	0.81	0.81	0.81	7.82	5.82	4.96	4.96	–	–	–
K_2O	7.81	6.51	6.02	5.06	3.52	6.51	7.08	7.47	–	–	–
H_2O	2.93	2.65	1.53	1.83	1.34	0.27	0.52	0.65	–	–	–
Total	98.90	100.37	98.81	99.64	98.25	98.32	99.97	99.05	100.07	99.69	100.08
Ti ppm	10000	10000	10000	10000	100	200	200	200	3000	1000	800
Zr	300	300	300	200	–	30	100	100	300	300	100
V	100	30	30	30	–	–	–	–	200	100	100
Cr	10	–	–	–	–	–	–	–	50	30	30
Ga	20	10	30	30	–	–	–	–	30	10	50
Mo	3	–	–	–	–	–	2	3	3	3	10
Mn	1000	2000	2000	1000	80	200	30	300	2000	300	500
Co	–	–	–	–	–	–	–	–	10	–	–
Ni	30	20	10	–	–	–	–	–	30	10	10
Cu	20	15	30	10	–	–	–	1	20	20	30
Zn	100	300	100	–	–	–	–	–	800	–	1000
Sr	–	–	–	–	600	300	100	–	1000	1000	1000
Ba	100	–	–	–	200	300	300	1000	150	300	300
Y	30	200	200	300	–	–	–	–	–	–	–



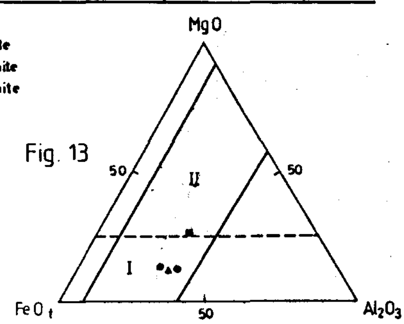


Fig. 12 : Plot of MgO, (Fe_2O_3+TiO_2) & (FeO+MnO) in biotites of Aswan granites. zone drawn by Heinrich.
line drawn by Gokhale (1968) separating biotites of magmatic rocks (I) from those of metamorphic-metasomatic rocks (II).

Fig. 13 : Plot of FeO (total iron), MgO and Al_2O_3in biotites of Aswan granites.
Zone demarked by Nockolds for igneous rocks.
line drawn by Gokhale (1968) separating biotites of magmatic rocks (I) from those of metamorphic-metasomatic rocks (II).

Heinrich (1946) and compiled by Engel and Engel (1960). This diagram indicates that all the biotites belong to granitic rocks.

Structural formula of biotites

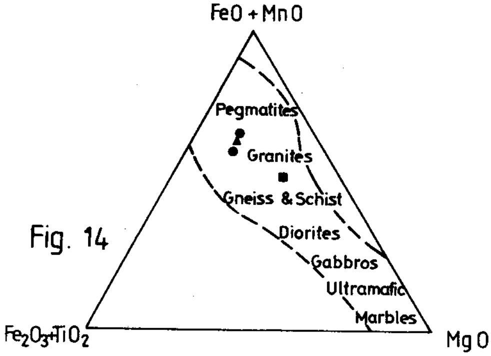
The analyses of the separated biotites were recalculated to give the structural formula on the basis of 24 (O, OH) to the general mica formula $X_2Y_{4-6}Z_8O_{20}(OH,F,Cl)_4$ (table 4). The X-group constitutes the co-ordinated large cations Ca, Na, and K, the Y-group cations are essentially Fe^2, Mg, Fe^{+3}, Al^{iv}, Ti with lesser amounts of Mn, whereas the Z-group are essentially Si and Al^{iv} which constitute the tetrahedral coordinates. The relationship between different members

Table 4

Structural unit cell formula of the separated biotites

Rock type		Granodiorite		Monzogranite		Syenogranite			
Terms		200		202		210		213	
Si	Z	5.59	8.0	5.75	8.0	6.01	8.0	5.84	8.0
Al^{iv}		2.41		2.25		1.99		2.16	
Ti	Y	0.24	5.83	0.48	5.84	0.53	6.13	0.67	6.15
Al^{vi}		0.27		0.42		0.96		0.41	
Fe^{+3}		0.50		0.58		0.40		0.57	
Fe^{+2}		2.10		2.90		2.94		3.12	
Mn		0.05		0.15		0.08		0.09	
Mg		2.67		1.31		1.22		1.29	
Ca	X	0.26	2.22	0.15	1.69	0.12	1.60	0.19	1.47
Na		0.42		0.26		0.24		0.24	
K		1.54		1.28		1.24		1.04	
OH		3.02		2.76		1.62		1.92	
$\frac{100xFe(t)}{Fe(t)+Mg}$		49.33		72.65		73.24		74.10	

of the Y-group (Fig. 15) indicates that the biotite separated from the granodiorite falls within the field of Fe^{2+}-biotite. It can be concluded that the principal variation in the Y-Group is between Fe and Mg as observed from the variation of the ratio 100xFe/Fe+Mg. This ratio is 49.33 in biotite separated from the granodiorite (Mg-rich biotite), 72.65 in biotite separated from monzogranite and 73.24 and 74.10 in biotites from the syenogranite (Fe-rich biotite). This reveals the trend of differentiation of the granitic rocks.



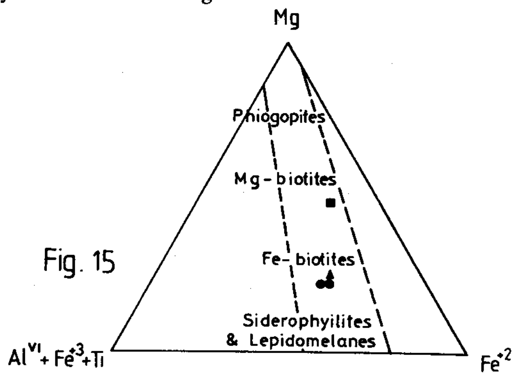


Fig. 14 : Variation of chemical composition of biotites with rock type. (After Engel and Engel, 1960).

Fig. 15 : Relation between octahedral cations of biotites of Aswan granites.

Feldspars

Tables 3 and 5 present the chemical and normative compositions respectively of the

Table 5

Normative compositions of the separated feldspars and magnetite.

Rock type	Granodiorite	Monzogranite	Syenogranite		
Terms \ Sample No	200	202	210	213	Av.
Feldspars					
Or	18.87	34.36	42.41	39.23	40.82
Ab	63.67	46.70	45.25	39.62	42.43
An	11.78	8.64	7.00	3.23	5.12
Wo	4.89	9.98	5.17	17.77	11.47
Mt	0.77	0.30	0.17	0.15	0.16
Magnetite					
Or:Ab:An	1.6:5.4:1	3.98:5.4:1	6.06:6.46:1	12.1:12.3:1	8:8.29:1
Ab value	84.39	84.39	86.60	92.46	89.23
$RO.RO_2$	0.16	0.08	–	0.08	–
$RO.R_2O_3$	0.58	0.52	–	0.60	–
R_2O_3	0.26	0.40	–	0.32	–

analysed feldspars. Variations in these chemical and normative compositions are illustrated in Figs. 16 and 17 respectively.

Table 3 and figure 16 indicate that in the feldspars separated from granodiorite through monzogranite to syenogranite, SiO_2, K_2O and CaO increase whereas Na_2O, Al_2O_3 and Fe_2O_3 decrease. Likewise, table 5 and figure 17 indicate an increase of Or mols. and a decrease of An mols. in the same direction. It is also noted that the amount of Or mols. predominate over An mols., and that the plagioclase (Ab value) ranges form 84.39 to 89.23 pointing to oligoclase type.

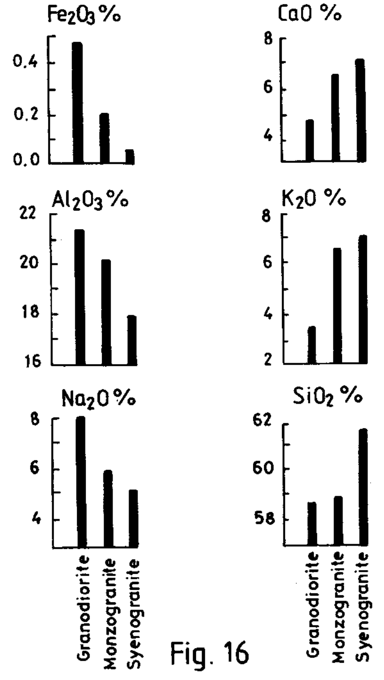


Fig. 16

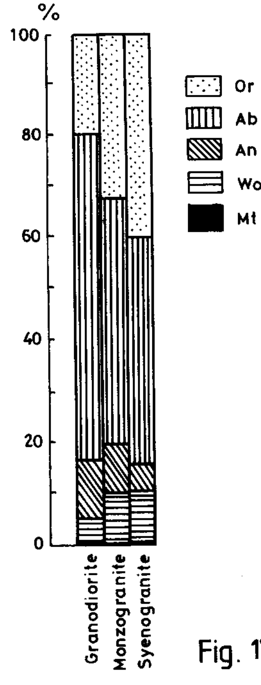


Fig. 17

Fig. 16 : Variation in the chemical composition of the feldspars separated from Aswan granites.

Fig. 17 : Graphic representation of the normative composition of the feldspars separated from Aswan granites.

Magnetite

The chemical composition of 3 separated samples of magnetite are presented in table 3 which shows that TiO_2, Al_2O_3, MgO and FeO decrease gradually from granodiorite through monzogranite to syenogranite. Generally the magnetite is of considerable ferric iron content over 70 % . The chemical analyses were subjected to calculations to reach their molecular percentage and are plotted on the triangular diagram (Vincent et al., 1957; Fig. 18) in terms of $R_2O_3(Fe_2O_3+Al_2O_3)$, RO_2 (SiO_2+TiO_2) and RO (FeO+MnO+MgO+CaO). The positions of the studied magnetite are within the triangle cornered by RO R_2O_3, R_2O_3, RO RO_2 but more nearer to RO R_2O_3-R_2O_3 base line.

The component normative minerals of the magnetite (table 5) are distributed by ratio 0.16 ilmenite, 0.58 magnetite and 0.26 Fe_2O_3 for magnetite of the granodiorite; 0.08 ilmenite, 0.52 magnetite and 0.40 Fe_2O_3 for the monzogranite and 0.08 ilmenite, 0.60 magnetite and 0.32 Fe_2O_3 for the syenogranite. Therefore the magnetite

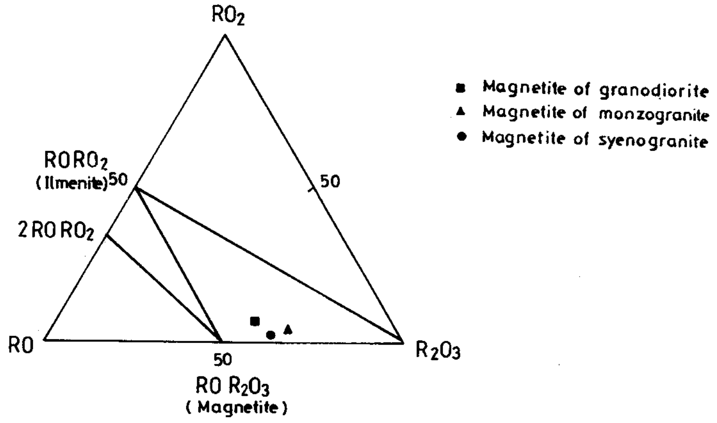


Fig. 18 : Representation of magnetite fractions separated from Aswan granite in the molecular RO-RO_2-R_2O_3 triangular diagram.

separated from the Aswan granites is mostly composed of magnetite and Fe_2O_3 with small amount of ilmenite. Kotb (1965) during his study on titaniferous ores of Egypt has proved (mineralographically and by heating experiments) that the actual Fe_2O_3 calculated in the normative formula is in γ - form (maghemite). Thus, the magnetite fractions of the Aswan granites are ilmeno-maghemo-magnetite.

Trace Elements

According to the distribution coefficient of the trace elements in the separated biotites, feldspars and magnetite from the Aswan granites (table 6), it is clear that: (a) V, Mn, Ni, Zr, Ti, Cu are accommodated mainly in magnetite and biotites, (b) Sr

Table 6

Distribution of trace elements in the component minerals of Aswan granites.

Element	Sample No.	Content of rock (ppm)	Feldspar content (ppm)	Feldspar coefficient	Biotite content (ppm)	Biotite coefficient	Magnetite content (ppm)	Magnetite coefficient
Ti	200	11018	100	0.009	10000	0.908	3000	0.272
	202	12020	200	0.017	10000	0.832	1000	0.083
	210	10016	200	0.019	10000	0.998		
	213	1001	200	0.199	10000	9.99	800	0.799
Zr	200	1000	-----	-----	300	0.30	300	0.30
	202	800	30	0.04	300	0.38	300	0.38
	210	800	100	0.13	300	0.38		
	213	100	100	1.00	200	2.00	1001	
V	200	140	-----	-----	100	0.71	200	1.43
	202	112	-----	-----	30	0.27	100	0.89
	210	140	-----	-----	30	0.21		
	213	84	-----	-----	30	0.36	100	1.19
Cr	200	-----	-----	-----	10	-----	50	-----
	202	3	-----	-----	-----	-----	30	10
	210	17	-----	-----	-----	-----		
	213	-----	-----	-----	-----	-----	10	-----
Mo	200	-----	-----	-----	-----	-----	3	-----
	202	-----	-----	-----	3	-----	3	-----
	210	-----	-----	-----	-----	-----		
	213	-----	2	-----	-----	-----	10	-----
Mn	200	1291	80	0.062	1000	0.774	2000	1.549
	202	775	200	0.258	2000	2.581	300	0.387
	210	775	30	0.039	2000	2.580		
	213	775	300	0.387	1000	1.290	500	0.645
Ni	200	-----	-----	-----	30	-----	30	-----
	202	-----	-----	-----	20	-----	10	-----
	210	30	-----	-----	10	0.33		
	213	-----	-----	-----	-----	-----	10	-----
Cu	200	20	-----	-----	20	1.00	201	
	202	20	-----	-----	3	0.15	201	
	210	30	-----	-----	30	1.00		
	213	10	1	0.10	10	1.00	30	3
Sr	200	300	600	2.00	-----	-----	1000	3.33
	202	240	300	1.25	-----	1000	1000	4.16
	210	100	100	1.00	-----	-----		
	213	100	-----	-----	-----	-----	1000	10.00
Ba	200	5000	200	0.04	100	0.02	150	0.03
	202	3000	300	0.10	-----	-----	300	0.10
	210	4000	300	0.08	-----	-----		
	213	100	1000	10.00	-----	-----	300	3.00
Y	200	100	-----	-----	30	0.3	-----	-----
	202	100	-----	-----	200	2.0	-----	-----
	210	100	-----	-----	200	2.0	-----	-----
	213	200	200	1.00	300	1.5	-----	-----

and Ba are more concentrated in magnetite and feldspars than in biotites, (c) Y is represented in biotites, (d) Cr and Mo are accommodated mainly in magnetite.

SUMMARY AND DISCUSSION

The Aswan granites form a roughly circular outcrop of 4-5 kms diameter, unconformably overlain by the Nubia sandstones in many localites. They are separated in the field into: (a) light grey medium-grained (b) red coarse-grained granites and (c) red fine-grained granites. These granites are cut by pegmatitic and aplitic veins and pockets. The medium-grained granites range in composition from quartz diorites to granodiorites whereas both the coarse and fine-grained granites comprise monzogranite and syenogranite. The granites are leucocratic and composed of oligoclase and quartz together with variable proportions of potash feldspars, biotite and hornblende; a rapakivi variety is also present. The Aswan granites enclose big elongated xenoliths from the surrounding country rocks. The latter are mainly migmatites and consist of schists, augen gneisses and amphibolites with lit-par-lit injection.

The average chemical composition of both granodiorite and monzogranite confirms with the high-Ca granite of Turekian and Wedepohl (1961), whereas the syenogranite confirms with the rapakivi granites (Sahama, 1945). The geochemical studies suggest a progressive differentiation within the granodiorite, monzogranite and syenogranite with a typical magmatic trend. The Aswan granites have potassic characters and calc-alkaline to alkaline affinities. The chemistry of the separated biotite reveals a magmatic crystallization for the host granites. The biotite separated from the granodiorite is a Mg-rich biotite whereas those separated from the monzogranite and syeno-granite are Fe-rich biotites. The separated plagioclase is of oligoclase type whereas the separated magnetite is an ilmeno-maghemo-magnetite.

Granites are the major magmatic products of most collision belts and may be subdivided tectonically according to the type of collision involved (continent-continent, continent-arc and arc-arc) and to the temporal relationship with the major deformation event into syn-collision or post-collision (Pearce et al., 1984).

The available field and chemical data as well as the tectonic setting of the Aswan granitic rocks suggest that they are post-collisional granites. These granitic rocks appear to have been produced as a result of arc-continent collision.

The syn-collisional granites typically plot within the granite (sinso stricto) field on Streckeisen (1976) diagram, are muscovite-bearing and peraluminous and exhibit most of the features associated with S-type granites. The post-tectonic granites most commonly contain biotite $\pm$hornblende as ferromagnesian minerals, plot in the same region as the volcanic arc granites (quartz monzonite, granodiorite and granite) on the Streckeisen diagram, belong to the calc-alkaline and K-rich calc alkaline suites and exhibit most of the characteristics of I-type granite.

The Aswan granitic rocks are muscovite-free and contain biotite and hornblende. Petrographically, they plot in the granodiorite, monzo-granite and syenogranite fields of the Streckeisen diagram and belong to K-rich calc-alkaline suites. Furthermore, the Aswan granites show the majority of the characteristics of I-type granites as they: a) form large complex plutons; b) contain mafic hornblende-bearing xenoliths; c) magnetite is the main iron oxide, d) the Na_2O content is higher than 3.2 in felsic varieties, decreasing to >2.2 in more mafic types and e) molecular Al_2O_3/Na_2O+K_2O+CaO is generally less than 1.1.

As already mentioned, the Aswan granitic rocks and their country rocks separate two contrasted tectonic terrains to the east and west. To the west, a cratonic domain, typified by the ≈ 3 Ga old granulites and gneisses of Gabal Uweinat forms the main Precambrian exposures of the south Western Desert. An accretionary juvenile arc terrain of Pan-African age forms the main exposures to the east. The relation between these two terrains and the Aswan area is central to understanding not only the tectonic evolution of the Aswan granitic rocks but also the tectonic evolution of the Precambrian of Egypt. This relation, however, remains equivocal but the tectonic pattern of nearly areas to the east suggests collisional tectonics between the two terrains. Habib *et al.* (1983) described an overthrust nappe at El Hudi area east of Aswan. The nappe lies on a substrate of an old cataclastic gneissose granite and is associated with syn- and post kinematic granites. It is suggested,therefore,that the region between the two terrains which contains the Aswan granites constitutes part of a foreland thrust and fold belt.

The source and origin of the Aswan granitic rocks is a major problem. As already mentioned, the initial $^{87}Sr/^{86}Sr$ of the Aswan granitic rocks range from 0.703 and 0.709 (Harris *et al.*, 1984 and Hashad *et al.*, 1972) and it seems very unlikely that these rocks were produced by remobilization or rejuvenation of sialic older crust. These granites must have been produced from a source with low $^{87}Sr/^{86}Sr$ ratio, such as mantle or oceanic crust and then contaminated by small quantities of older sialic crust. It is therefore not unreasonable to suggest that the granitic rocks of Aswan area have a related petrogenetic history with the calc-alkaline volcanic suites of the south Eastern Desert.

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إضافات جديدة إلى جيولوجية وجيوكيميائية والتوضع التكتوني لجرانيتات أسوان ـ جنوب مصر

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تحتل صخور أسوان الجرانيتية منطقة في جنوب مصر تقع بين راسخة الاركي الثابتة بجنوب الصحراء الغربية وحزام ألبان ـ افريقي Pan - African الأقل ثباتاً بجنوب الصحراء الشرقية وتشتمل على تنوع من الجرنيتات متوسطة التحبب الرمادية ـ الناتجة ، الجرانيتات خشنة التحبب الحمراء اضافة إلى الجرانيتيات دقيقة التحبب .

يناقش البحث بالتفصيل التوضع والعلاقات الحقلية لهذه الصخور الجرانيتية كما يقدم سبعة عشر تحليلاً كيميائياً جديداً للعناصر العظيمة والشحيحة اضافة إلى تحاليل لأربع من كل من البيوتايت والفلسبار اضافة إلى ثلاث من المجنيتيت .

وقد دلت الأدلة الحقلية على أن جرانيتات أسوان يجب أن تصنف ضمن الجرانيتات البعد تصادمية في حين دلت المعلومات الجيوكيميائية على عمليات تفارق متتالية من الجرانوديوريت عبر المونزوجرانيت إلى السيانوجرانيت والتي تنتمي على أغلب الظن تتابع تداخلي مجماتي واحد ويبدو كذلك أن جرانيتات أسوان تنتمي في أصولها إلى البركانيات الكلس ـ قلية بجنوب الصحراء الشرقية المصرية .