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Geochemistry of inhomogeneous rocks from Wadi Mubarak–Gabal Atud, metagabbro–diorite complex, Eastern Desert, Egypt

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ABSTRACT

Fifteen chemical analyses for both major and trace elements are given of inhomogeneous rocks of Wadi Mubarak–Gabal Atud, metagabbro–diorite complex in the central Eastern Desert of Egypt. The analyses show an oversaturated composition and a calc–alkaline character and provide evidence against the origin of the rocks from a differentiating basic magma. The hybrid origin of the investigated rocks appears unequivocal and is based on both field and chemical evidences. The hybrid rocks are believed to have been formed as a result of interaction between granitic and gabbroic components while the former was liquid and before the latter became completely solidified.

INTRODUCTION

The rocks are of an inhomogeneous and a predominantly hornblendic nature and belong to the metagabbro–diorite complex of the basement complex of the Eastern Desert of Egypt. The complex constituting the rocks outcrops from Wadi Mubarak in the north to Gabal Atud in the south, a distance of approximately 40 km, and from Gabal Igl El-Ahmar in the east to Gabal Homret Woggat about 34 km west (Fig. 1), and represents the most extensive mass of 'epidiorite' recorded as yet in the central Eastern Desert. The rocks of the complex were first referred to as epidiorites (Amin 1955) and were later called the metagabbro–diorite complex (Akaad & Essawy 1964). In view of the marked difference both in petrographic character and in geological setting between the so-called epidiorites of the Egyptian basement complex and the original epidiorites of the early British geologists, and also due to the absence of the term from American and strictly continental petrographical usage, Akaad & Essawy (1964) proposed the abandonment of the term epidiorite and the use of the more realistic terms instead, in order to depict the real nature of the rocks.

The southern periphery of the complex has been studied by Akaad & Essawy (1964) and was found to consist of a large variety of hornblendic rocks of original gabbroid parentage and including, principally, metagabbros, metadolerites, subordinate relics of the original gabbros, and hybrid diorites sometimes with appinitic tendencies. The appinitic rocks, which are unfailingly associated with localised patches of

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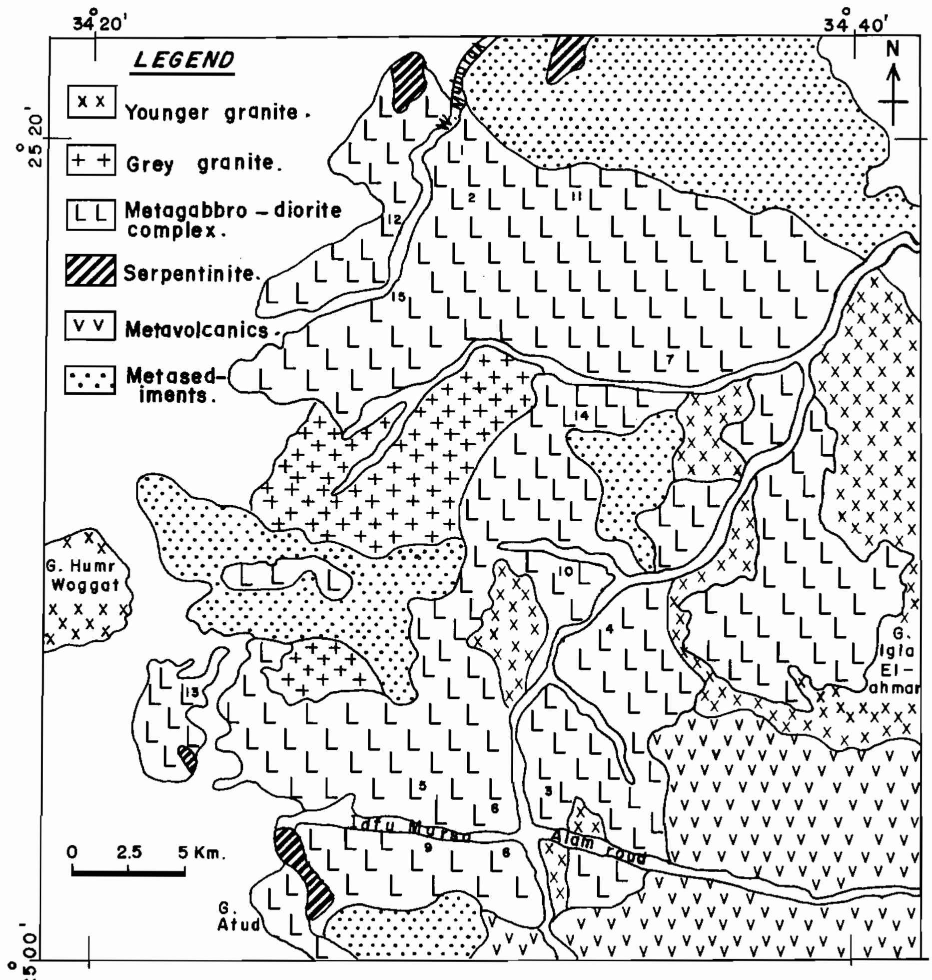

Fig. 1. Geological map of Wadi Mubarak–Gabal Atud metagabbro-diorite complex and surrounding rocks (after the geological map of the basement complex of the central Eastern Desert (El-Ramly & Akaad 1960) and based also on the geological map of the area around Bir Um Khariga (Essawy 1967)). Locality numbers of the analysed rocks are shown.

production of hybrid dioritic rocks, were also considered as clearly the product of hybridisation (Akaad & Essawy 1965).

No previous investigation has been undertaken of the geochemistry of the rocks of the complex. It is intended in the present paper to deal with the geochemistry of the inhomogeneous rocks, which constitute the principal component of the complex, in an attempt to clarify their petrogenesis.

FIELD DESCRIPTION

Field relations indicate that the rocks of the complex cut across metasediments, metavolcanics and serpentinites and are later dissected by grey granites and younger granites (Fig. 1). The contacts between the rocks of the complex and the enveloping metasediments, metavolcanics, serpentinites and younger granites are rather sharp and are not marked by any notable reaction. On the other hand, the grey granite sends a plexus of apophyses into the complex and shows considerable interaction with a notable addition of 'quartzo-feldspathic' components to the hornblendic rocks.

The complex consists of a vast array of intermingling of hornblende-rich rocks and leucocratic rocks and is crossed by quartzo-feldspathic veins. The rocks, in general, are of a markedly heterogeneous nature, characterised by distinct variation in grain size and in the proportion of the amphiboles to the felsic constituents. The variations may take place within small distances and sometimes a single outcrop can produce a large variety of hand specimens with appreciable differences. It is obvious in the outcrop that the principal component of the complex is a large assortment of inhomogeneous rocks, sometimes with appinitic tendencies. The appinitic rocks are characterised by giant idiomorphic crystals of hornblende simulating E.B. Bailey's original appinites of Appin (Scottish southwest Highlands) as well as other localities in Scotland and Donegal, Ireland (Akaad & Essawy 1965).

ANALYTICAL METHODS

Fifteen rocks from the complex were selected for chemical analyses for both major and minor elements. Silica, MgO and the R_2O_3 group (Al_2O_3, total iron oxides and TiO_2) were determined gravimetrically. Total iron oxides and TiO_2 were determined colorimetrically and, by their subtraction from the R_2O_3 group, Al_2O_3 was estimated. The value for FeO was obtained by titration against a standard solution of potassium permanganate and, by subtraction of FeO from total iron oxides, Fe_2O_3 was estimated. Na_2O and K_2O were determined by flame photometry and P_2O_5 and MnO colorimetrically. Chromium, nickel, cobalt, vanadium, strontium, barium and copper were determined spectrographically using a grating spectrograph (PG 5-2 Zeiss-Jena, DDR) in the wavelength range of 3800–2300 Å. A mixture of four parts of sample to one part buffer mixture (10 g C+2 g Ga_2O_3 +8 ml Au Cl_3 +3 ml Pd Cl_2) were arced to completion at 10 A (D.C.) with a gap of 5 mm. The internal standard lines were Pd 3421 and Au 3122 and the analysis lines were Cr 3015, Ni 3050 and 3414, Ba 3071, V 3185, Cu 3274, Co 3453 and Sr 3464.

CHEMISTRY

In Table 1 are given the analyses of selected inhomogeneous rocks of the complex, arranged in order of increasing silica content. Variation of the silica content is from 54·7 to 67·6%. Since silica is the dominent contributor to the chemical variance, Harker diagrams have accordingly been constructed (Fig. 2). The diagrams illustrate that alumina, magnesia, lime and total iron oxides, all show a negative correlation with silica. Soda and potash show considerable fluctuations but tend to increase in amount as the rocks become more siliceous. The rocks with the highest silica content (Nos. 9–15, Table 1) have an average composition which is closely comparable with Nockolds' (1954) average granodiorites (Table 2). The rocks are slightly richer in total iron oxides and poorer in alumina, soda and potash. The low silica and high alumina members of the series (Nos. 1–8, Table 1), on the other hand, are compared with Nockolds' average monzonites (Table 2) and are shown to be richer in silica and distinctly poorer in potash.

Table 1. Analyses and CIPW norms of the inhomogeneous rocks

	1	2	3	4	5	6	7	8
Major oxides								
SiO_2	54·7	55·3	57·3	57·7	57·9	58·1	58·9	62·9
TiO_2	0·8	0·8	0·7	0·7	0·1	0·8	0·6	0·6
Al_2O_3	17·3	17·1	16·6	16·4	16·3	16·4	16·9	16·2
Fe_2O_3	3·4	3·2	3·1	2·9	3·0	3·0	2·7	2·5
FeO	4·7	4·6	4·2	4·1	4·3	4·0	4·5	3·9
MnO	0·1	0·1	0·1	0·1	0·1	0·1	0·2	0·1
MgO	4·9	4·6	4·1	4·3	4·0	3·8	2·9	2·1
CaO	8·2	7·9	6·9	7·0	6·7	6·5	6·9	5·1
Na_2O	2·9	3·0	3·2	3·1	3·2	3·1	3·7	3·6
K_2O	1·5	1·6	1·9	1·9	1·8	1·7	1·6	2·1
P_2O_3	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2
Ign. loss	1·4	1·2	1·5	1·3	1·4	1·9	1·0	0·8
Total	100·1	99·6	99·8	99·7	99·7	99·6	100·1	100·1
CIPW norms								
Q	7·4	8·3	10·3	10·9	11·7	13·8	11·5	18·2
Or	9·0	9·5	11·5	11·5	11·0	10·0	9·5	12·5
Ab	26·5	27·5	29·5	28·5	29·2	28·5	33·5	33·0
An	30·3	29·0	25·8	25·8	25·3	27·0	25·3	22·3
En	14·0	13·2	11·8	12·2	11·4	10·8	8·2	6·0
Fs	3·8	3·6	3·4	3·4	3·4	3·0	4·8	3·2
Wo	3·8	3·8	3·0	3·2	3·0	1·8	3·2	0·6
Mt	3·6	3·5	3·3	3·0	3·2	3·3	2·9	2·7
Il	1·2	1·2	1·0	1·0	1·2	1·2	0·4	1·0
Ap	0·5	0·5	0·5	0·5	0·3	0·5	0·5	0·5
Cor	—	—	—	—	—	—	—	—
Total	100·1	100·1	100·1	100·0	99·7	99·9	99·8	100·0
Trace elements (ppm)								
Cr	38	86	240	260	42	42	215	78
V	130	115	210	140	160	~850	120	190
Ni	17	37	79	31	18	23	33	39
Co	17	23	26	24	25	27	21	27
Sr	350	270	280	250	340	340	360	225
Ba	350	260	310	230	430	< 50	340	200
Cu	16	15	58	17	1	25	19	22
Cr/V	0·3	0·7	0·1	1·9	0·3	< 0·1	1·8	0·4
Ni/Co	1·0	1·6	3·0	1·3	0·7	0·9	1·6	1·5
V/Ni	7·6	3·1	2·6	4·5	8·9	3·7	3·6	4·9

1, Monzonite along Wadi Mubarak; 2, monzonite N.W. of the complex; 3, monzonite S.E. of the complex; 4, monzonite from the central part of the complex; 5, monzonite S.W. of the complex; 6, appinitic monzonite along the Idfu–Marsa Alam Road; 7, monzonite N.E. of the complex; 8, monzonite along Idfu–Marsa Alam Road.

From the norms of Table 1, it is evident that all the analysed rocks are oversaturated (i.e. quartz normative). Corundum is entirely lacking from the norms of the monzonites and is only present in the norms of the acid end-members of the granodiorites.

Table 1 (*continued*)

	9	10	11	12	13	14	15
Major oxides							
SiO_2	66·0	66·2	66·4	66·8	66·9	67·1	67·6
TiO_2	0·5	0·5	0·7	0·5	0·5	0·5	0·8
Al_2O_3	14·8	15·3	14·6	15·6	15·8	15·4	15·2
Fe_2O_3	2·4	2·2	1·6	2·1	2·0	2·2	1·5
FeO	3·1	3·2	3·8	2·8	2·7	2·9	1·6
MnO	0·1	0·1	0·1	0·1	0·1	0·1	0·1
MgO	1·3	1·6	1·5	1·5	1·6	1·7	1·8
CaO	3·6	3·6	3·8	3·5	3·4	3·3	2·8
Na_2O	3·9	4·1	4·3	3·2	3·3	3·1	3·7
K_2O	3·1	2·3	2·1	2·6	2·4	2·5	3·3
P_2O_3	0·3	0·3	0·2	0·3	0·3	0·3	0·5
Ign. loss	1·1	0·9	0·8	0·8	1·0	0·9	1·3
Total	100·2	100·3	99·9	99·8	100·0	100·0	100·2
CIPW norms							
Q	21·0	21·1	21·0	27·1	27·1	27·7	24·9
Or	18·5	14·0	12·5	15·5	14·5	15·0	20·0
Ab	35·5	37·0	39·5	29·0	30·0	28·5	33·5
An	14·0	16·5	14·5	16·0	15·5	15·5	10·5
En	3·8	4·6	4·2	4·2	4·6	5·0	5·0
Fs	2·4	2·8	3·8	2·2	2·4	2·4	—
Wo	0·6	—	1·2	—	—	—	—
Mt	2·6	2·4	1·7	2·1	2·1	2·4	1·7
Il	0·6	0·6	1·0	0·6	0·6	0·6	1·2
Ap	0·8	0·5	0·5	0·5	0·5	0·5	1·1
Cor	—	—	—	2·1	2·6	2·3	2·0
Total	99·8	100·0	99·9	99·3	99·9	99·9	99·9
Trace elements (ppm)							
Cr	31	24	100	98	115	92	19
V	62	300	135	130	220	200	74
Ni	16	18	22	39	29	38	13
Co	16	27	24	25	24	29	13
Sr	390	355	475	360	430	325	365
Ba	410	350	320	240	210	170	500
Cu	21	8	15	22	19	44	8
Cr/V	0·5	0·1	0·8	0·8	0·5	0·5	0·3
Ni/Co	1·0	0·7	0·9	1·6	1·2	1·3	1·0
V/Ni	3·9	16·6	6·1	3·3	7·6	5·3	5·7

9, Appinitic (pegmatitic) granodiorite along Idfu–Marsa Alam road; 10, appinitic (pegmatitic) granodiorite from central part; 11, granodiorite from the northern periphery; 12, granodiorite N.W. of the complex; 13, appinitic granodiorite east of Gabal Homret Woggat; 14, granodiorite N.W. Gabal Igl El-Ahmar; 15, granodiorite along Wadi Mubarak.

The analyses have been plotted on the triangular diagrams (Na_2O+K_2O)–($FeO+Fe_2O_3$)–MgO, and K_2O–CaO–Na_2O (Figs, 3, 4) and they follow a typically calc–alkaline trend (cf. Nockolds & Allen 1953). The plots of the normative Q–Ab–Or

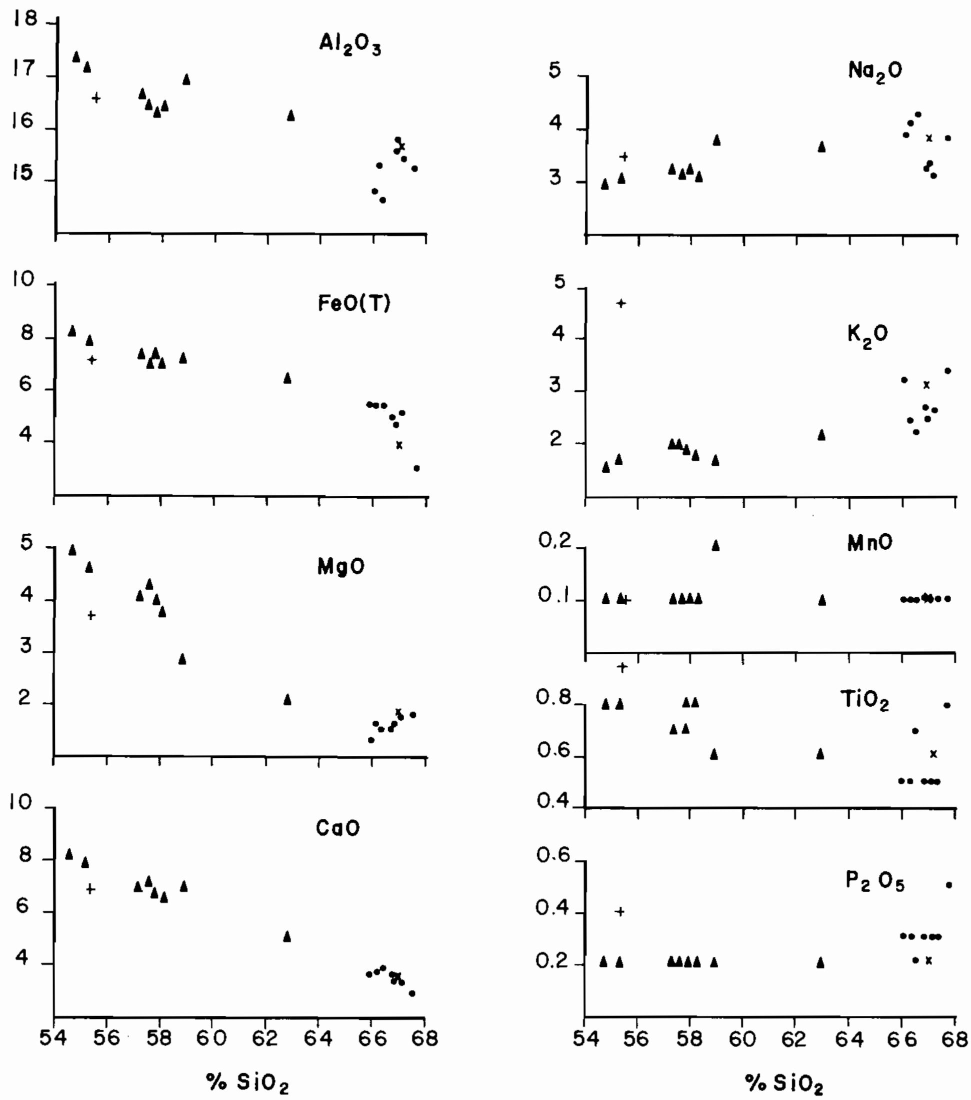

Fig. 2. Variation diagrams of major oxides vs. silica. ▲, monzonites, ●, granodiorites, + Nockold's average monzonite, × Nockold's average granodiorites.

of the rocks, correlated with the synthetic system Na Al Si_3O_8–K Al Si_3O_8–SiO_2–H_2O (Luth *et al.* 1964), are also shown in Fig. 5. The granodiorites fall in a region corresponding to the liquidus minimum in the system Ab–Or–Q–H_2O at relatively low water vapour pressures and the monzonites fall in a region corresponding to the liquidus minimum at relatively higher water pressures.

DISTRIBUTION OF ELEMENTS

As already noted above, the rocks under consideration have granodioritic to monzon-

Table 2. Average composition of the granodiorites and monzonites of Wadi Mubarak, with comparisons

	I	II	A	B
SiO_2	66·7	57·8	66·9	55·4
TiO_2	0·6	0·7	0·6	1·1
Al_2O_3	15·2	16·7	15·7	16·6
Fe_2O_3	2	3	1·3	2·6
FeO	2·9	4·3	2·6	4·6
MnO	0·1	0·1	0·1	0·1
MgO	1·6	3·8	1·6	3·7
CaO	3·4	6·9	3·6	6·8
Na_2O	3·6	3·2	3·8	3·5
K_2O	2·6	1·8	3·1	4·7
P_2O_5	0·3	0·2	0·2	0·4

I, Average composition of analyses Nos. 9–15, Table 1.
II, Average composition of analyses Nos. 1–8, Table 1.
A, Average granodiorite (Nockolds 1954, Table 2, column IV).
B, Average monzonite (Nockolds 1954, Table 4, column I).

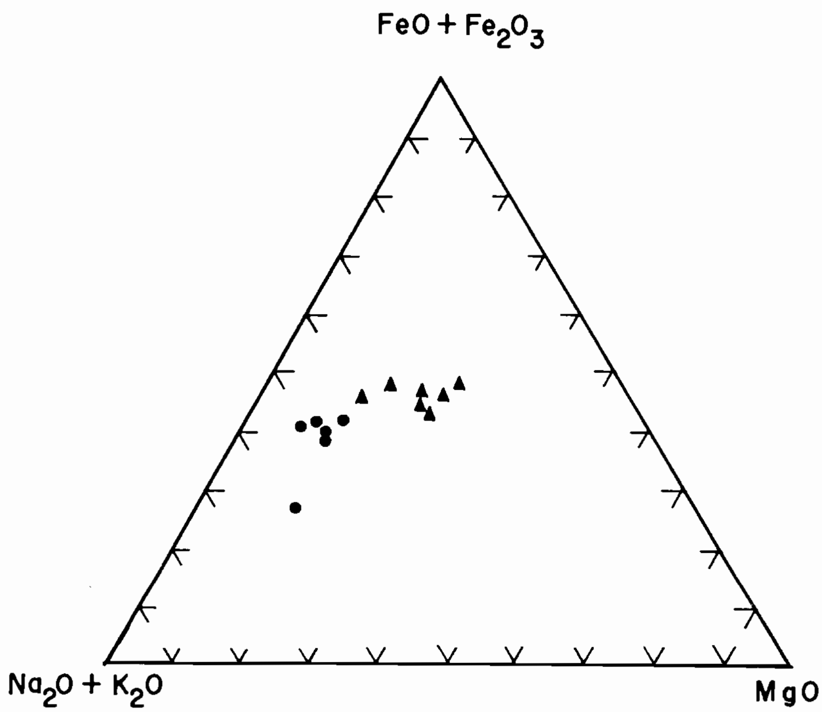

Fig. 3. FMA diagram of the inhomogeneous rocks. ▲, monzonites, ●, granodiorites.

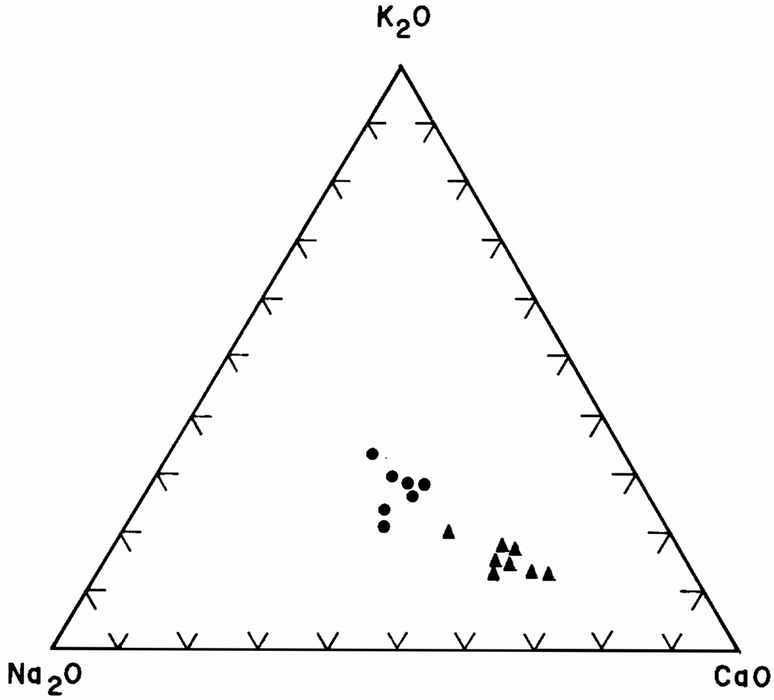

Fig. 4. K_2O–Na_2O–CaO diagram of the inhomogeneous rocks. ▲, monzonites, ●, granodiorites.

itic compositions. The trace element variation is shown in Table 1 and as with the major elements, SiO_2 has been used as an index of variation (Fig. 6). The distribution of certain trace elements in the analysed rocks could be summarized as follows. Chromium varies from 19 to 115 ppm in the granodiorites (average 68 ppm) and from 38 to 260 ppm in the monzonites (average 125 ppm). The average vanadium contents of the granodiorites and monzonites are 160 and 239 ppm, respectively. Fig. 5 shows that apart from sample No. 6 (which distorts the average of the monzonites), the V values for the granodiorites and monzonites are similar within experimental error. Sample No. 6 is unusually rich in vanadium ($\sim$ 850 ppm) which might be attributed to the presence of clinopyroxene. The average Ni content is 20 ppm in the granodiorites and 35 ppm in the monzonites. There is no marked difference in Co content in the various rocks studied. It varies from 13 to 29 ppm with an average value of 22 ppm in the granodiorites and 24 ppm in the monzonites. The rocks generally have $Cr > Ni > Co$. The strontium content of the granodiorites is slightly higher than that of monzonites, the average content of granodiorites being 386 ppm compared with 302 ppm in the monzonites. Barium varies from <50 to 430 ppm. The averages of Ba in the granodiorites and monzonites are 314 and 271 ppm, respectively. Copper ranges between 8 and 44 ppm in the granodiorites (average 20 ppm) and between 1 and 58 ppm in the monzonites (average 22 ppm).

In Table 3, the average abundance of trace elements in the granodioritic and monzonitic rocks of the complex are compared with the averages for high-calcium granites or granodiorites (Turekian & Wedepohl 1961) and diorites (Goldschmidt 1954). It can

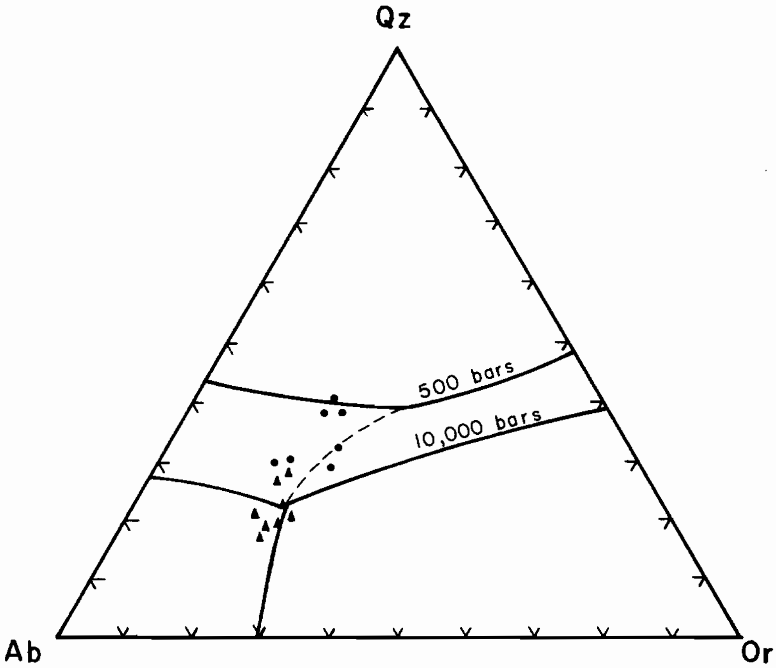

Fig. 5. Normative albite–orthoclase–quartz of the inhomogeneous rocks, plotted in the system Na Al Si_3O_8–K Al Si_3O_8–SiO_2–H_2O. Field boundaries at 0·5 and 10 K bars are shown. A dotted line represents the trace of the isobaric minimum or eutectic point at intermediate water pressures (after Luth *et al.* 1964). ▲, monzonites, ●, granodiorites.

be inferred from this table that the rocks under consideration are unusually rich in Cr. The granodiorites are richer in V, Ni, and Co than those of Turekian & Wedepohl. V and Co in the monzonites are within Goldschmidt diorite range, whereas Ni is at the lower end of diorite mean. As monzonite values are expected to be lower than diorite values, the monzonites are considered accordingly as being rich in V, Ni and Co.

The Cr/V ratio has an average value of 0·6 in the granodiorites and 0·8 in the monzonites. The Ni/Co ratio varies from 0·9 to 1·6 in the granodiorites and from 0·7 to 3·0 in the monzonites, the average ratio being 1·2 and 1·5 for the granodiorites and monzonites, respectively. The average V/Ni ratio is 5·3 for the granodiorites and 9·0 for the monzonites. Taylor (1969) showed that the calc–alkaline andesites of circum-Pacific type typically contain low Ni/Co ratios (<1) and high V/Ni ratios (>8), whereas the alkalic and tholeiitic basalts show Ni/Co >2 and V/Ni <2. It might be deduced from these ratios that the Ni/Co and V/Ni ratios of the present rocks are not consistent with expectations from their major element compositions.

PETROGENESIS

There is ample evidence that the inhomogeneous rocks of the complex are hybrid in nature and appear to have been formed as a result of interaction between basic rocks and 'quartzo-feldspathic' granitic material during intrusion of the latter. The compositions of the analysed rocks accord reasonably well with the compositions of

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جيوكيميائية الصخور غير المتجانسة بمعقدة الميتاجابرو ـ دايواريت ، منطقة جبل عتود ـ وادى مبارك الصحراء الشرقية المصرية

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خلاصـــــة

يمثل هذا البحث دراسة جيوكيميائية على صخور غير متجانسة تنتمى إلى معقدة الميتاجابرو ـ دايورايت وتقع بين جبل عتود جنوبا ووادى مبارك شمالا بالصحراء الشرقية المصرية .

وقد أوضحت الدراسة الحالية أن الصخور غير المتجانسة هى صخور هجينية يتراوح تركيبها بين الجرانودايورايت والمونزونايت ، وأنها لم تنتج على التبلور التجزيئى لصهير البازلت بل تكونت نتيجة لتفاعل بين صهير حامضى (جرانيتى) وصخور قاعدية لدنة .

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