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Trace Element Distribution in Relation to Post-magmatic Alteration in the Gabal Mueilha Granites, Southeastern Desert, Egypt

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ABSTRACT. The Gabal Mueilha area consists of high-level granites with high content of volatiles and associated pegmatites and greisen, emplaced in a deep-seated tectonic zone. Geochemical bed-rock sampling was carried out in order to assess the mineralization potential of the district and to study the distribution and interelement relationships of Sn, Nb, Mo, Bi, Be, Pb, Y, Zr, Cu and Ti during magmatic and post-magmatic processes. Results indicated that anomalous concentrations of Sn, Nb, Be, Mo and Bi are associated with the most intensively albitized and greisenized zones in the apical parts of the granites, probably due to their emanation transportation under the effect of degassing processes during magmatic and post-magmatic stages. Ti, Y and Zr are partially leached away during post-magmatic processes. There are marked differences in the behaviour between Sn, Nb, Y, Zr, Cu, Pb and Ti during magmatic and post-magmatic processes. This is probably because they tend to form complexes that differ in mobility and stability under different geological environments.

The Gabal Mueilha area is located in the northern part of the Southeastern Desert of Egypt (Fig. 1). It is formed of low hills of low grade metasediments intruded by the younger granite boss of Gabal Mueilha. The latter is the most conspiceous topographic feature of the district with its oval shape and its summit rising about 707 m above Sea level and 350 m above the wadi. The general altitude of the country rocks is between 400 and 500 m above Sea level. The rocks are well exposed. Soils are absent. Poorly sorted sands, gravel and boulders are the main constituents of the stream sediments filling the dry wadis.

During an airborne radiometric reconnaissance survey for some parts of the Southeastern Desert of Egypt carried out by Lockwood Geophysical Corporation in 1968, a circular radiometric anomaly of 1000 c.p.s. was located on Gabal

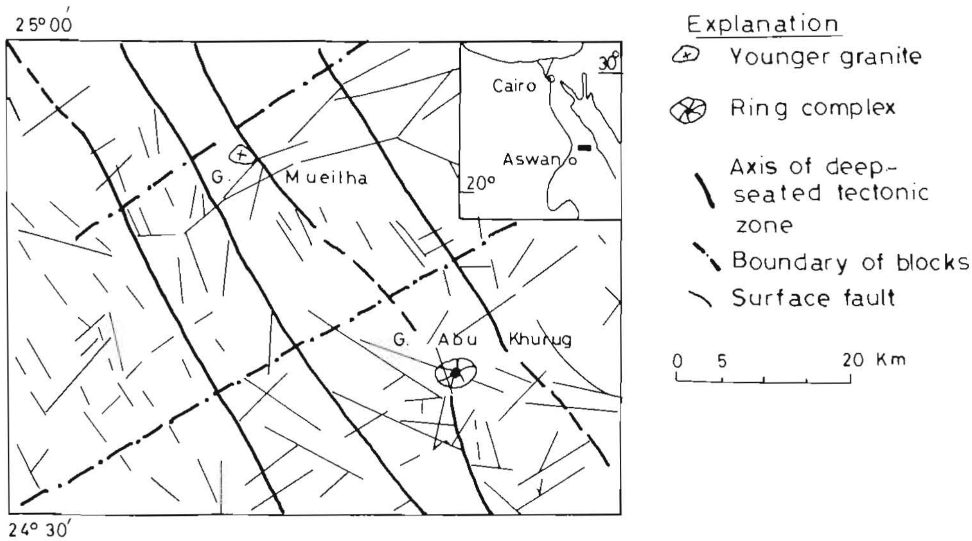

Fig. 1. Tectonic map of the northern part of the Southeastern Desert of Egypt showing the location of Gabal Mueilha area (after Hunting 1967 and Lockwood 1968).

Mueilha granites. On ground verification, it was found that the granite is cut by a number of tectonic zones along which greisenization and/or albitization took place. Panning of few samples from the alluvium filling the dry streams draining the granite revealed the presence of cassiterite in them (Soliman 1971, 1975, United Nations 1974). According, bed-rock sampling was carried out on the granites as part of an exploration program initiated by the Regional Planning Authority of Aswan with the assistance of the United Nations Development Program (UNDP).

The aim of this survey is the assessment of the mineralization potentials of the district and to elucidate the trace element characteristics of the granites which may be useful in further exploration purposes as well as to reveal the role-played, if present, by greisenization and albitization processes in the concentration of the ore-forming elements. The choice of the bed-rock as a sampling medium is attributed to the fact that the rocks are well exposed, soils are absent and the stream sediments are limited and restricted mainly in the few wadis in the district.

General Geology and Tectonics

The aeromagnetic survey carried out by Lockwood Geophysical Corporation (1968) in some parts of the Southeastern Desert of Egypt, including the Gabal Mueilha area, revealed the presence of some linear magnetic anomalies with pronounced amplitude with normal or reversal polarities, running at a constant strike of N 30°W to N 35°W (parallel to the lenght of the Red Sea) for more than 120 km. These linear anomalies are related to deep-seated tholeiitic dykes rich in titano-magnetite minerals and pyrite and are interpreted as representing deep-seated tectonic zones associated with the rift development of the Red Sea. Similar phenomena have also been noted on the airborne maps in the Saudi Arabia (Krs *et al.* 1973, Garson and Krs 1976, Krs 1977). These deep-seated tectonic zones are traversed by some block faults striking in a N 60°E direction (Fig. 1). These are the main rifts and regional systems of faults, folds, intrusive contacts and dykes and veins in the district. The term 'deep-seated tectonic zones' refers to zones of primary disjunction structures running deep through the Earth's crust which behave as channel ways for ascending magmatic products. On the surface, they are characterized by almost linear trends and run to a distance of several hundreds of kilometres. Their width is measured in hundreds of meters and they have possibly survived several geologic epochs (Stovickova 1973 *in* Garson and Krs 1976). These zones being prominent structural features in the crust, are associated by various geologic processes among which post-magmatic alterations and mineralization. Two distinctive types of such zones are recognized in the Southeastern Desert of Egypt (United Nations 1973, Garson and Krs 1976, Krs 1977). The most characteristic features of the first type is the introduction of huge tholeiitic dykes with anomalous magnetic and electrical properties along the whole zone. The second type is characterized by anomalous radioactivity, intense metamorphism and frequent granitic and alkaline ring complexes intrusions and metasomatic alterations including greisenization, albitization, silicification, tourmalinization, propelitization and similar hydrothermal and autometamorphic alterations as well as the acid type mineralization namely Sn, Nb, Ta, Be, Mo, Bi and F. The Gabal Mueilha granite is situated on the border of one of the second type near its intersection with a block fault and is probably structurally controlled or somehow related to these tectonic zones.

The Gabal Mueilha area is built up of Precambrian metasediments intruded by the granite mass of Gabal Mueilha and a group of dykes and veins including quartz, dolerite, porphyrite, felsite, aplite and pegmatite (Fig. 2). The metasediments are the oldest rocks in the district and are formed of fine to coarse grained, greenish black to greyish colour schists, grewackes, mudstones and hornfels, which were formed by low to moderate regional metamorphism of psammopelitic geosynclinal sediments. The schists and grewackes are highly foliated. The banding and schistosity of these rocks are parallel and have a NW-SE direction. The direction of dip is always to the north with angles varying from 50° to 70°. The mudstones and hornfels are hard and nonfoliated rocks. They are jointed in various directions and have brownish weathering colour.

The Mueilha area is strongly folded, primarily along NW-SE axes, and secondarily NE-SW (Hunting 1967). The area is cut by several faults and instrusive contacts striking in different directions. The NE-SW and NW-SE trends are rather predominant, and dividing the Gabal Mueiha mass into separate blocks. The fault

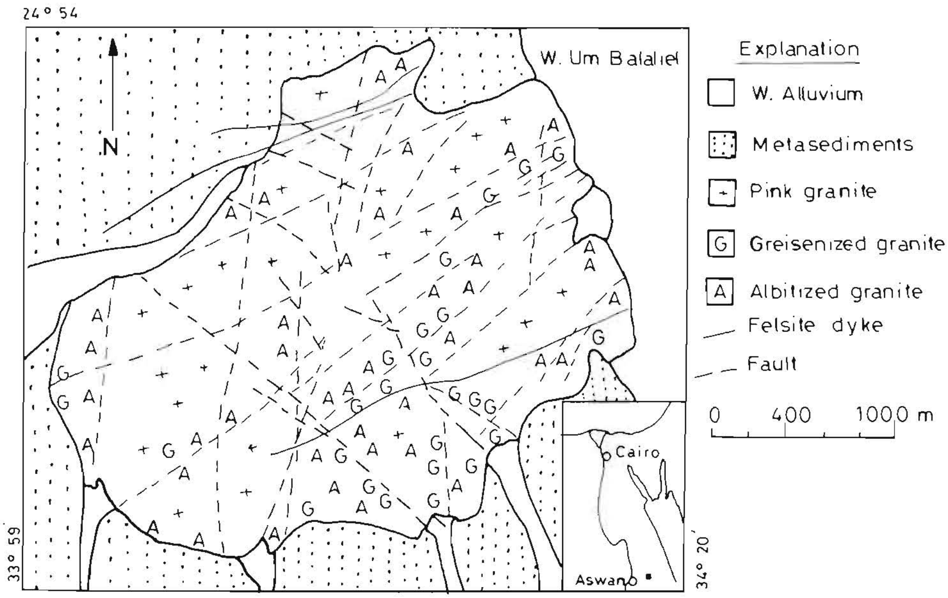

Fig. 2. Geological map of Gabal Mueilha area (after Soliman 1975).

planes in the granites are usually occupied by basic dykes. These faults and their intersections are considered as suitable channel-ways for the post-magmatic solutions and gases responsible for greisenization and albitization processes in the district.

The granite is medium to coarse grained, composed of about 30% quartz, 40-50% orthoclase-microcline perthite, 10-15% oligoclase-albite and 3-4% biotite and muscovite with accessory cassiterite, fluorite, xenotime, topaz and zircon. Foliation and lineation were not observed. The granite is devoid of xenoliths. Few small pegmatite veins (5-20 m long and 10-20 cm thick) and small pockets of pegmatites (30-50 cm in diameter) are observed inside the granite and around it. They are composed of quartz, albite, microcline, muscovite and lepidolite with accessory topaz and fluorite grains. Felsite dykes, quartz veins, dolerite, porphyrite and aplite dykes of variable lengths cutting the granite and the country rocks are recorded. They are usually barren.

A thin strip (2-5 m) of biotite-hornblende-quartz hornfelsic rocks of greenish black colour is developed along the contact of the granite and the country rocks. No skarn was found in the district, probably due to the absence of carbonate rocks in the geosynclinal sediments. The Gabal Mueilha granite is characterized by steep contacts. This is probably due to its emplacement as a dome-like offshoot of a much larger intrusion which is not yet exposed.

Wall-rock Alteration

Greisenization and albitization are recognized in few zones of the granites of Gabal Mueilha. Greisenization is exhibited by the partial to complete alteration of zones of the pink granite into yellowish-green rock composed of quartz, yellowish-green muscovite (probably fluoro-muscovite), canary yellow lepidolite with topaz and fluorite (greisen), Fig. 3. All stages of alteration of the pink granite to greisenized granite and greisen are present. In the early stage, the mica of the granite are slightly replaced by yellowish-green mica, but the original texture of the granite is well preserved. In an advanced stage, the rock-forming minerals are largely replaced by quartz and muscovite and the original texture is obliterated. The main mineralogical changes that occurred during greisenization were the destruction of the feldspars of the granite and the formation of quartz, muscovite, lepidolite, topaz and fluorite. The main chemical changes were the migration of sodium and iron and the addition of silicon, fluorine and water (Zaghloul *et al.* 1978).

Fig. 3. Photomicrograph of greisen from Gabal Mueilha, showing abundant muscovite flakes and quartz. C.P. × 75.

Albitization is manifested by the growth of fine-to-medium-grained albite accompanied by the bleaching of the colour of the rock. All stages of alteration of the pink granite to albitized granite and albitites are present. In the early stage, the original minerals of the granite are partially replaced by fine to medium grained albite, but the original texture is well preserved. In an advanced stage, the rock-forming minerals are largely replaced by albite and the original texture is obliterated (Fig. 4). The albitized granites generally show porphyroblasts of K-feldspar and quartz embedded in the newly developed albite aggregates. The albitites are, on the other hand, fine-grained leucocratic rocks with aplitoidal appearance and are composed almost entirely of albite and show distinct cataclastic texture. The main chemical changes that occurred during albitization were the partial migration of iron and the addition of sodium (Soliman 1975, Zaghloul *et al.* 1978).

The greisenization and albitization processes are structurally controlled since they are confined mainly to the fault planes and contact zones. The most intensively altered zones are usually observed along the intersection of major faults, and usually form isolated patches. No alterations were observed in the country rocks.

Fig. 4. Photomicrograph of albitized granite from Gabal Mueilha, showing abundant albite and quartz and rare k-feldspar and mica. C.P. × 75.

Sampling and Analytical Methods

A few bed-rock samples were collected from the unaltered granite, greisenized and albitized granites. When these samples were analysed, abnormal amounts of Sn were obtained. Consequently, detailed bed-rock sampling was carried out on the granite on a regular, stacked 200 × 40 m network with profiles at right angles to the strike of the altered zones and main tectonic lines. A total of 1000 rockchip samples were collected from an area of about 9 km^2 (765 samples from the granites and 234 samples from the country rocks and pegmatite, felsite and basic dykes). Rock samples comprised of 7-8 pieces of unweathered rock collected from an area of 5-7 m^2 around a central sampling point. In cases where more than one rock type occur around the sampling station, each rock type is sampled separately. The analyses of these samples were semiquantitative for Sn, W, Nb, Pb, Y, Mo, Bi, Be, Zr, Cu and Ti using Hilger and Watts large quartz and glass emission spectrograph by the method of anode excitation in the laboratories of the 'Assessment of the Mineral Potentials of the Aswan Region Project'. The results of these analyses are discussed below.

Trace Element Distribution in the Granites

Mean, range and coefficient of variance of the analysed trace elements in the unaltered granites, greisenized granites and albitized granites of Gabal Mueilha compared with the mineralized granites of northern Nigeria of Olade (1980) as well as the average world-wide low-Ca granites of Turekian and Wedepohl (1961), are given in Table 1 and the interelement relationships, in the form of coefficient of correlation, of these elements are shown in Table 2.

Concentrations of Sn in the unaltered granites (pink granites) range from 10 to 80 ppm and average 38 ppm (Table 1). This average value is more than twelve times the clarke of 3 ppm for the world-wide average of low-Ca granites (ideal granites) of Turekian and Wedepohl (1961) and about twice the mean value for the Nigerian mineralized granites of Olade (1980) and reflects the high background content of Sn in Gabal Mueilha granites, suggesting that these granites were derived from a speciallized magma enriched in Sn. On the other hand, the unaltered granites of Gabal Mueilha are considerably depleted in Nb, Y and Zr and contain about equal amounts of Cu and Pb relative to the Nigerian granites. The albitized granites and greisenized granites show much higher concentrations, with average values more than 7 and 11 times the average for the unaltered granites (Table 1). All these rocks show high degree of variability in their Sn contents. This is probably attributed to the uneven distribution of cassiterite in these rocks.

Frequency distribution of Sn, Nb, Pb, Y, Zr, Cu, and Ti, in the different varieties of Gabal Mueilha granitic mass is log normal and shows large positive skewness (Fig. 5).

Table 1. Mean values and standard deviation of trace elements (ppm) in the granitic rocks of the Gabal Mueilha, compared with Nigerian granites.

	Unaltered granites (n = 240)			**Greisenized granites (n = 170)**			**Albitized granites (n = 347)**			**Nigerian(+) granites**	**Average(++) world-wide granites**
	X	**S**	**C.V.**	**X**	**S**	**C.V.**	**X**	**S**	**C.V.**		
Sn	38 (10-80)	11	29	146 (10-4000)	341	233	220 (10-4000)	573	260	22	3
Nb	48 (30-200)	31	64	51 (30-200)	39	76	65 (30-800)	129	198	22	3
Pb	78 (20-300)	37	47	66 (20-300)	35	53	83 (20-300)	32	38	156	21
Y	46 (10-100)	17	36	22 (10-100)	11	50	26 (10-100)	13	50	56	19
Cu	14 (10-100)	27	192	10 (5-100)	6	60	10 (5-50)	10	100	211	40
Zr	39 (10-100)	6	15	23 (10-100)	16	29	27 (10-100)	16	59	16	10
Ti	62 (20-200)	114	183	35 (10-100)	9	26	37 (10-100)	7	19	262	175

X = mean and range; S = Standard deviation; C.V. = Variation coefficient; n = number of samples
(+) Olade (1980)
(++) Turekian and Wedepohl (1961).

Table 2. Interelement correlations in Gabal Mueilha granitic rocks (values in coefficient of correlation).

	Unaltered granites	Greisenized granites	Albitized granites
Sn – Pb	+0.002	+0.033	+0.069
Sn – Nb	+0.209	+0.102	+0.095
Sn – Y	+0.061	−0.052	−0.116
Sn – Zr	+0.027	−0.014	−0.165
Sn – Ti	−0.027	−0.030	−0.119
Sn – Cu	−0.028	−0.036	+0.013
Nb – Pb	+0.012	+0.052	+0.104
Nb – Y	−0.034	−0.040	−0.124
Nb – Zr	−0.134	−0.099	−0.105
Nb – Ti	−0.032	−0.177	−0.084
Nb – Cu	−0.007	+0.015	−0.024
Y – Pb	+0.101	+0.081	+0.047
Y – Zr	+0.286	+0.678	+0.416
Y – Ti	−0.151	+0.314	+0.439
Y – Cu	−0.051	−0.223	+0.141
Zr – Pb	−0.008	+0.077	−0.117
Zr – Ti	+0.055	+0.442	+0.454
Zr – Cu	−0.088	−0.195	+0.122
Ti – Pb	−0.107	−0.053	+0.138
Ti – Cu	−0.014	−0.030	+0.206
Cu – Pb	−0.023	+0.120	+0.063

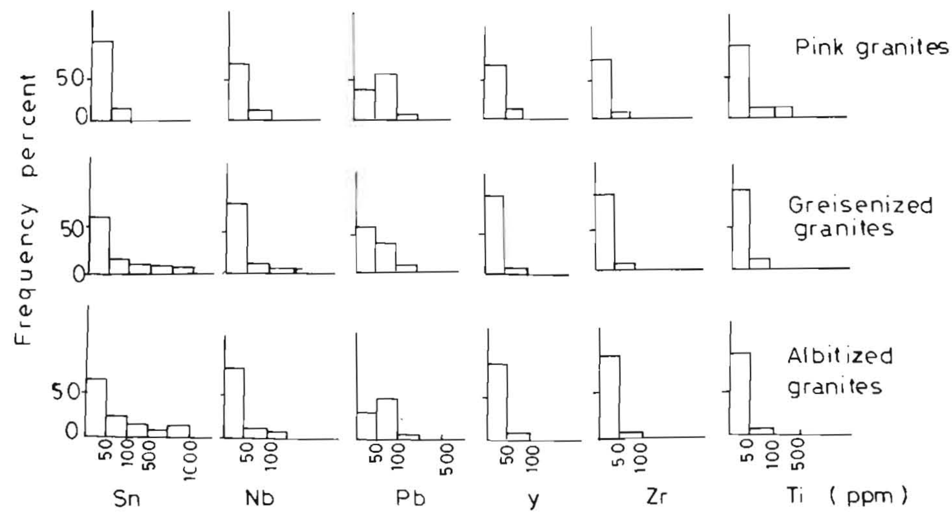

Fig. 5. Frequency distribution of Sn, Nb, Pb, Y, Zr and Ti in Gabal Mueilha granites.

A visual examination of the distributions shows that about 43% of the sample population in the albitized granites compared with about 35% in the greisenized granites exceed the provisional cut-off value of 60 ppm Sn (mean + 2 s.d. of the unaltered granites, Olade 1980). The higher anomalous values (> 60 ppm) in the albitized and greisenized samples indicate that Sn is concentrated by greisenization and albitization processes in these rocks.

The distribution of Sn in Gabal Mueilha granites is shown in Fig. 6, which shows that anomalous concentrations of this element (> 100 ppm) occur in isolated, small zones tending to be associated with fractures and the highest concentrations of Sn (> 1000 ppm) are associated with the most intensively albitized and greisenized zones of the granite at the intersection of main fractures.

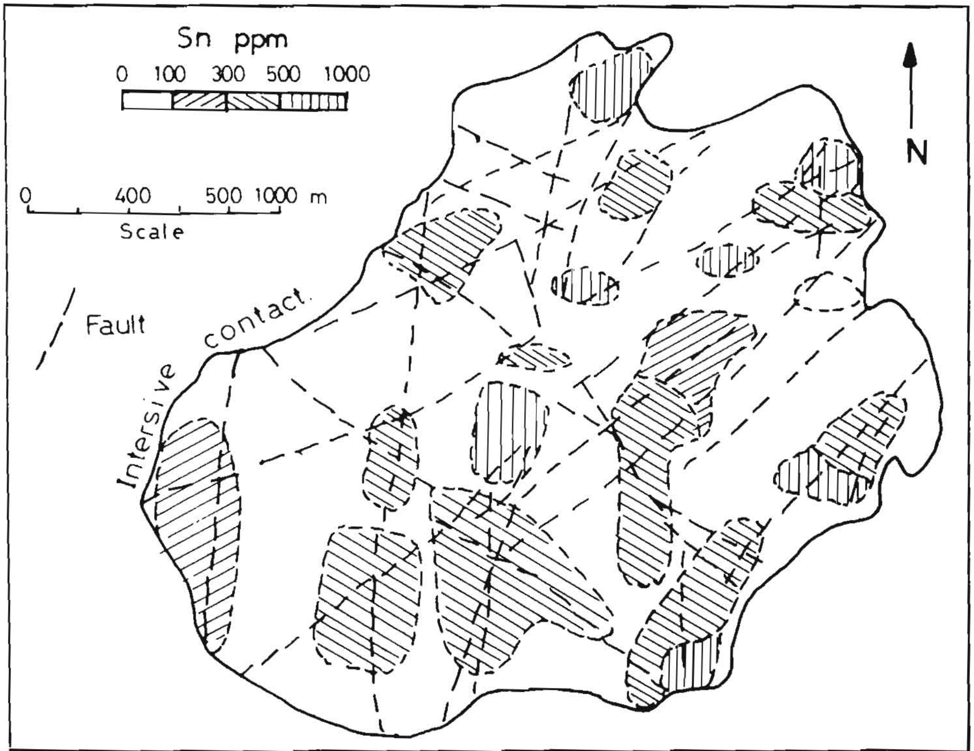

Fig. 6. Distribution of Sn in Gabal Mueilha.

The spatial connection between the tin anomalies and the fractures and their intersections, suggest the development of the tin anomalies by Sn-bearing solutions ascending along these fractures. Field verification showed that these zones usually occur in isolated patches at the elevated parts of the present-day erosion level in the granite mass which probably coincides with the apical parts of the Gabal

Mueilha granite. The limited albitized and greisenized zones and associated geochemical anomalies in the Gabal Mueilha granites is probably attributed to its dome-like shape with steep contacts which could not hinder the upcoming post-magmatic solutions responsible for greisenization, albitization and Sn anomalies as shown in Fig. 7.

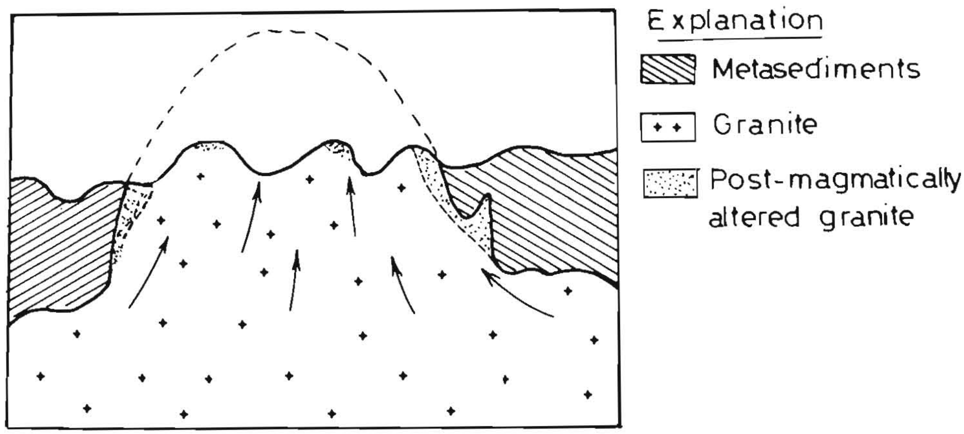

Fig. 7. Morphological sketch showing the steep contacts of the Gabal Mueilha granites. Arrows show the probable paths of the post-magmatic solutions.

The anomalous Sn distribution reflect the occurrence of some discrete accessory minerals of Sn in the granite with relatively high concentrations of these minerals in the albitized and greisenized zones. Traces of cassiterite and columbite associated with topaz and fluorite were identified in the heavy concentrates of these rocks separated by heavy liquids. Some samples of greisen contain up to 30% by weight topaz.

Niubium and Pb show slight higher values in both the albitized and greisenized granites relative to the unaltered pink granites (Table 1) and show weak positive correlations with Sn during magmatic and postmagmatic processes (Table 2). The enrichment of these elements in the Mueilha granites relative to the world-wide granites of Turekian and Wedepohl (1961) (Table 1) probably due to the occurrence of columbite and the relatively high concentration of these elements in some rock-forming minerals particularly micas.

Zirconium, Y and Ti are strongly depleted in both the greisenized and albitized granites relative to the unaltered granites (Table 1) and show negative correlations with Sn in the greisenized and albitized granites (Table 2). The depletion of these elements are probably attributed to their leaching away during greisenization and albitization and the destruction of the rock-forming minerals in which these elements are concentrated, especially micas and feldspars. Similar results were recorded by Bowden (1966) and Bowden *et al.* (1976) in some Nigerian granites.

Anomalous Be, Bi and Mo values (> 3000, 300, 2000 ppm, respectively) are detected in few erratic samples and are usually associated with high Sn concentrations in the albitized and greisenized granites.

The presence of fluorite and topaz in the unaltered granites, greisenized granites and albitized granites indicate the enrichment of these rocks in volatile components. Soliman (1975) and Zaghloul *et al.* (1976) showed, on geochemical basis, that the Gabal Mueilha granite was emplaced at lower water vapour pressures and shallow depths in the crust (*i.e.*, high-level or hypabyssal granite). Tauson (1967), Tauson and Kozlov (1972), Kosals and Mazurov (1970) showed that in high-level intrusions with high content of volatiles, ore-elements associated with volatiles such as Sn, Nb, Be, Bi, Y, Mo, ... etc., are usually concentrated in the apical parts of the intrusion due to their emanation transportation under the effect of degassing processes during magmatic and postmagmatic stages (greisenization and albitization).

Trace element distribution in the country rocks

Tin, Nb, Pb, Mo, Bi and Be were not detected in the metasediments. Cu and Zr were recorded in normal values (Table 3).

Table 3. Mean values of trace elements (ppm) and radioactivity (μR/hr) in country rocks.

Rock type	Sn	Nb	Pb	Y	Cu	Zr	Ti	Radio-activity	Number of samples
Metasediments	–	–	–	–	35	37	3000	15	195
Pegmatites	14	59	87	18	20	10	42	20	8
Felsite dykes	15	36	68	14	13	24	84	20	13
Basic dykes	–	–	–	17	14	60	3000	15	18

Radioactivity

Detailed radiometric survey for the granites and the country rocks was carried out using ascintillation founters measuring in μR/hr. The highest radioactivity recorded was 50 μR/hr in the albitized and greisenized granites, showing a close relationship between radioactivity and greisenization and albitization processes.

The average radioactivity is 25, 45 and 45 μR/hr for the unaltered granites, greisenized granites and albitized granites, respectively, indicating that the postmagmatically altered granites are distinctly more radiogenic than the unaltered rocks. The country rocks always show readings less than 20 μR/hr.

Conclusion

The data presented in this paper suggest the emplacement of the Gabal Mueilha granites along the intersection of a deep-seated tectonic zone and a block fault. The granites are considerably rich in Sn and depleted in Zr relative to the average world-wide low-Ca granites as well as the mineralized Nigerian granites. The Gabal Mueilha granites can, then, be considered as rich Sn granites probably derived from a speciallized magma enriched in Sn and depleted in Zr. Greisenization and albitization processes induced some mineralogical and chemical changes in the granite. Frequency distribution of Sn in the unaltered granites, greisenized and albitized granites are positively skewed with a relatively large proportion of values exceeding 60 ppm. The higher anomalous values of Sn are usually associated with the most intensively albitized and greisenized zones near the intersection of main fractures. Tin is concentrated in the granites while Ti, Zr and Y are leached away during greisenization and albitization processes. The leachment of Ti, Y and Zr is probably ascribed to the destruction of the rock-forming minerals in which these elements are mainly concentrated, especially mica and feldspars. There are marked differences in the behaviour between Sn, Nb, Y, Zr, Cu and Ti during magmatic and post-magmatic processes. This is probably because they tend to form complexes that differ in mobility and stability under different geologic environments.

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توزيــع العنــاصــر الشحيحـة وعـلاقـاتهـا بالعمليـات الصهـيريـة الـلاحقة في الصخور الجـرانيتيـة في منطقـة جبـل المـويلحة بجنوب الصحراء الشرقية بمصر

مصطفى محمود سليمان

قسم الجيولوجيا ـ كلية العلوم ـ جامعة الزقازيق ـ مصر

تتكـون منطقـة جبـل المويلحة من جرانيت غني بالمواد المتطايرة ويصاحبه بجماتيت وجرايزن تداخلت في منطقة بنائية عميقة . وقـد تم المسح الجيـوكيميـائي في المنطقة بهدف تقدير جهدها المعـدني وكـذلـك دراسـة توزيـع عنـاصر القصدير والنيوبيوم والمـوليبـدنـوم والبـزمـوت والـبر يليـوم والـرصـاص واليتر يوم والـزركـونيـوم والنحـاس والتيتـانيوم وعلاقاتها أثناء العمليات الصهير ية وما بعدها .

أثبتت الـدراسـة وجود تركيزات عالية لعناصر القصدير والنيـوبيـوم والـبر يليـوم والمـوليبدنوم والبزموت في المناطق التي تأثـرت بعمليـات ألبتـة وجرزنة . وقد عُزى ذلك إلى انتقالها الانبعـاثي تحت تأثـير عمليـات انطـلاق وتحـر ر الغـازات من الصهير أثناء العمليات الصهير ية واللاحقة .

كذلـك بينت الـدراسـة انتقـاص عنـاصـر الـزركونيوم واليـتر يـوم والتيتـانيـوم في الجـرانيت نتيجـة عمليات الجرزنة والألبتــة . كذلـك أثبت البحث وجـود اختـلاف في السلوك

الجيوكيميائي لعناصر القصدير والنيوبيوم والتريوم والزركونيوم والنحاس والرصاص والتيتانيوم أثناء العمليات الصهيرية واللاحقة وذلك بسبب تكوينها لمركبات معدنية مختلفة في سيولتها وثباتها في البيئات الجيولوجية المختلفة .