# Mineralogical and Chemical Changes Accompanying Greisenization and Albitization of Egyptian Granites

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ABSTRACT. Albitization and greisenization processes are recognized in certain zones in the tin-bearing granites of the Southeastern Desert of Egypt. These alteration processes are usually followed by hydrothermal activities and are not observed in the non-stanniferous granites. Albitization is of magmatic and/or post-magmatic processes, whereas greisenization is formed by post-magmatic. Greisenization resulted in the destruction of the feldspars of the granites and the formation of quartz, muscovite, lepidolite, topaz, fluorite and cassiterite. This is accompanied by partial migration of Na, K, Ca, Fe, Ti, Y, Zr, Be and Pb and the addition of Si, F, H<sub>2</sub>O, Sn and Nb. Albitization is manifested by the growth of fine to medium-grained albite, sometimes with beryl. This is accompanied by the addition of Na, Be, Sn, Nb, Cu, Mo and Bi and partial migration of Si, Fe, Ti, Y and Zr. Fluoride complexing is an important factor in element mobility and transportation during greisenization and albitization. Carbonate and fluoride complexing are the most plausible cause of element mobility in hydrothermal processes giving rise to quartz veins.

Two types of granitic rocks are exposed in the Eastern Desert of Egypt. These are the syn-tectonic to late-tectonic granites (987-830 my.; El-Ramly 1972) and the post-tectonic granites (640-480 my.; El Shazly 1964). The former group comprises rocks of granitic to granodioritic composition and usually forms batholithic masses covering substantial areas with broad sandy plains and scattered accumulations of boulders of tor-like outcrops. They are previously mapped as 'grey granites', 'older granites' and 'shaitian granites'. These rocks were emplaced at higher water vapour pressures and deep levels in the crust (deep-level granites). The post-tectonic granites represent the younger group and are generally referred to as the 'younger granites' and are previously mapped as 'pink', 'red' or 'gattarian'. They are characterized by their pronounced pink or red colour, essentially unfoliated and forming small masses sometimes with isometric outlines. They show rugged reliefs with

high peaks sometimes in excess of 1000 m and are mostly affected by similar diagonal system of faults having NE-SW and NW-SE directions with a well defined vertical joint system. Some masses are remarkably radioactive. Geochemically, the majority of the younger granites are peraluminous rocks having Al > (Na + K + 2 Ca) and low Ca and Mg, high F and absence of B. The crystallization of the younger granites was at low to moderate water vapour pressure and consequently at shallow to moderate depths in the crust (high-level granites; El-Gaby 1975, Zaghloul *et al.* 1976, Soliman 1980, 1983a). Based on the abundance of tin, the younger granites were divided into three groups: 1) the tin-mineralized, 2) the stanniferous and 3) the tin-barren granites (Soliman, in press).

Amazonitization, albitization and greisenization processes have been recognized in some Egyptian younger granites (Soliman 1971, 1975, United Nations 1974, Bugrov *et al.* 1973, Hussein 1973, Zaghloul *et al.* 1978). These alteration processes are usually associated with tin and beryllium mineralization (Soliman 1982a). This investigation deals with the mineralogical and chemical changes accompanying greisenization and albitization of the Gabal Mueilha, Mueilha tin mine, Homrit Mikpid, Homr Akarim and Um Shilman granites in the Southeastern Desert of Egypt (Fig. 1).



Fig. 1. Location map showing the investigated granite masses.

# **Geology and Petrographical Characteristic**

The general geology of Gabal Mueilha, Mueilha tin mine, Homrit Mikpid, Homr Akarim and Um Shilman have been described by El-Ramly and Al-Far (1955), El-Ramly *et al.* (1959, 1970), El-Shazly *et al.* (1965), Soliman (1971, 1975, 1982a and b, 1983a and b, 1984a, b and c), and Hassan and El-Shatoury (1976). These granites form small masses intruding igneous and metamorphic basement complex and usually having sharp contacts with the development of thin strips (2-5 m) of hornfelsic rocks with the absence of skarns (due to the absence of calcareous rocks). The granites have many features in common. They are all fine to mediumgrained, locally porphyritic, suggesting shallow deroofing of the granites. They are made up essentially of different proportions of orthoclase, microcline, perthite, plagioclase (An<sub>10-25</sub>), quartz and subordinate biotite and/or muscovite. The accessory phase includes zircon, monazite, xenotime and fluorite. They show granular to hypidiomorphic textures usually cataclastic. Myrmekitic, perthitic and graphic intergrowths are common in these granites.

The results of point-counting (modal) analyses of the unaltered granites, albitized granites and greisenized granites of the studied areas are summarized in Table 1 and plotted in Fig. 2, which shows that the unaltered (pink) granites fall in the syenogranite field and the albitized granites and greisenized granites fall in the monzogranite and quartz-rich granite fields respectively of Streckeisen (1967). (Some greisen samples contain up to 80% by volume muscovite, 20% quartz with variable amounts of fluorite, topaz and cassiterite, other griesen samples contain

	Unaltered granites		Albitized granites		Greisenized granites	
	Range	Average	Range	Average	Range	Average
K-feldspar Quartz Plagioclase Biotite Muscovite Topaz Fluorite Others	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	37.8 35.0 18.0 4.1 3.4 - 0.5 1.2	22 -35 21 -45 33 -48 1.5- 8 0.0- 0.5 0.0- 1.5 0.0- 1.5 0.0- 2	25.0 27.0 42.0 3.4 0.1 0.5 0.5 1.5	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$     18.0 \\     48.0 \\     8.3 \\     0.2 \\     22.0 \\     1.5 \\     0.8 \\     1.2   $
Total		100		100		100

 Table 1. Modal composition (volume %) of the studied unaltered granites, albitized granites and greisenized granites.



Fig. 2. Egyptian granitic rocks plotted according to the classification scheme of Streckeisen (1967).

up to 70% quartz, 20% muscovite, 10% topaz with variable amounts of fluorite and cassiterite. These samples are devoid of feldspars and are not plotted in Fig. 2).

The petrographic, mineralogical and geochemical characteristics of the studied granites (Table 2) suggest that they were formed by crystallization of magmas formed by partial melting of crustal materials, *i.e.*, S-type granites (Chappell and White 1974). Similar observation was recorded by Hussein *et al.* (1982).

Amazonitization, in the form of amazonite-rich rocks, albitization in the form of albite-rich rocks and greisenization in the form of quartz-mica rocks are recognized in certain zones in the studied granites. Greisenization is usually structurally controlled and occurs along the granite-country rocks contact zones as well as along the main fault planes cutting the granites. This mode of occurrence as well as the replacement nature of greisenization indicate a post-magmatic origin for this process.

Amazonitization and albitization processes are sometimes structurally controlled. In other cases, they show weak relations with the main fractures and occur in zones and patches showing gradational and/or sharp contacts with the unaltered granites. These features suggest the occurrence of more than one phase of each of amazonitization and albitization processes in the studied granites (some phases are probably formed by magmatic processes, others are of post-magmatic origin). Pollard (1983) believes that post-magmatic K-feldspathization (amazonitization) results from early aqueous phase saturation and albitization may be produced during late-stage aqueous phase saturation in association with the breakdown of sodiumflour-rare element complex and the magmatic and/or post-magmatic nature of these processes depends largely on the timing of late-stage intrusion, the degree of crystallization, the volatile content and the timing of aqueous phase saturation

	S-type characteristics, Chappell and White (1974)	Egyptian younger granites, Soliman (1975)
1)	Na <sub>2</sub> O may be low, normally 3.2% in rocks with approx. 5% $K_2O$ , decreas- ing to 2.2% in rocks with approx. 2% $K_2O$ .	Na <sub>2</sub> O ranges from 2.29% to 4.31% in samples containing from 2.77% to 3.25% K <sub>2</sub> O.
2)	Mol. $Al_2O_3/(Na_2O + K_2O + CaO)$ 1.1	Mol. $Al_2O_3/(Na_2O + K_2O + CaO)$ ranges from 1.36 to 1.94.
3)	SiO <sub>2</sub> 65%	SiO <sub>2</sub> ranges from approx. 72.26% to $77.80\%$
4)	1% CIPW normative corundum	CIPW normative curundum ranges from 1.02 to 2.50.
5)	Initial Sr <sup>87</sup> /Sr <sup>86</sup> 0.708	Initial Sr <sup>87</sup> /Sr <sup>86</sup> ranges from 0.7171 to 0.7597 (El-Shazly <i>et al.</i> 1972).
6)	Biotite abundant in more mafic S-type granite and muscovite is common in more felsic types.	Biotite is frequent among them. Mus- covite and two mica (biotite and muscovite) granites are present.
7)	Accessory minerals include monazite and cassiterite, cordierite, garnet, andalusite and sillimanite may be present.	Accessory minerals are zircon, monazi- te, xenotime, cassiterite and fluorite.
8)	Hornblende-bearing xenoliths are rare and metasedimentary xenoliths are common	No hornblende-bearing xenoliths found and metasedimentary xenoliths are rare.

Table 2.	Chemical and mineralogical	characteristics	of typical	S-type	granites	compared
	to those of the studied your	iger granites.				

in the solidifying amazonitization may occur first, followed by albitization and then greisenization (Pollard 1983). Post-greisen phase (second phase) of microclinization and albitization is recorded in some rare-metal granites (Beus and Zalashkova 1964, Syritso and Chernik 1967, Zalashkova and Sitnin 1967). These alteration processes are usually followed by high temperature hydrothermal activities resulting in the development of mineralized quartz veins as the final stage in the sequence of events controlling the solidification of rare-metal granitic magma and ore-formation (Fig. 3). Similar models were proposed by Beus and Zalashkova (1964), Shcherba (1970), Stemprok (1979) and Pollard (1983).

Albitization (Na-feldspathization) of Egyptian granites is manifested by the growth of fine to medium-grained albite. This is accompanied by the bleaching of the colour of the rock. Different stages of alteration of the biotite or muscovite granite to albitized granite and albitites are recognized. In the early stages, the original minerals of the granite are slightly replaced by fine to medium-grained albite, but the original texture is well preserved. In an advanced stage, the rock-



Fig. 3. Model showing possible succession of microclinization, albitization, greisenization and hydrothermal processes in Egyptian granites. Arrows show the probable paths of post-magmatic fluids.

forming minerals are largely replaced by albite resulting in the development of albitite composed mainly of albite and quartz (Fig. 4).

Megascopic grains of bluish-green beryl, up to 2 mm in length, are disseminated in the albitized granites and albitites of Homrit Mikpid and Homr Akarim areas (Soliman 1971, 1975, United Nations 1974, Hassan and El-Shatoury 1976). Beryl replaces feldspars in these rocks (Fig. 5, 6 and 7).

Cassiterite, topaz and fluorite are recorded in the heavy concentration of albitized granites and albitites from Homrit Mikpid, Homr Akarim and Um Shilman after treatment with heavy liquids. Soliman (1982b) showed that the beryl of Homrit Mikpid and Homr Akarim is a sodium variety. Beus (1962) believes that the sodium variety of beryl is formed metasomatically by replacement of K-feldspar by Be-bearing fluids. The occurrence of beryl, cassiterite, topaz and fluorite in the albitized granites and albitites suggests the introduction of Be, Sn and F during albitization in the form of several complexes. Possible complexes include: Sn H<sub>4</sub> (Rankama and Sahama 1968), NaBeF<sub>3</sub>, BeF(OH)<sub>3</sub><sup>3-</sup>, BeF(H<sub>2</sub>O)<sub>3</sub><sup>+</sup> and Sn (OH<sub>2</sub>,F)<sub>6</sub><sup>2-</sup> (Smirnov 1968). The role of fluorine and other volatile components in magmatic, post-magmatic and mineralization of Egyptian granites is not yet studied. However, until additional geochemical data are available, it seems possible that the deposition of beryl, cassiterite, topaz and fluorite in the albitized granites is related to the following reactions:

190



Fig. 4. Photomicrograph of albitite from Gabal Mueilha, consisting mainly of albite and quartz. C.P.  $\times$  75



Fig. 5. Photomicrograph of beryliferous albitized granite from Homrit Mikpid area, showing beryl (B) grown in the granite enclosing relics of feldspars (F) and muscovite (M) in a poikilitic texture. C.P. × 75.

191



Fig. 6. Photomicrograph of beryliferous granite from Homr Akarim area, showing beryl (B) grown in the granite enclosing relics of feldspars (F) and mica (M) in a poikilitic texture. C.P. × 75.



Fig. 7. Photomicrograph of beryliferous albitized granite from Homr Akarim, showing beryl crystals (B), oligoclase (O) and quartz (Q). C.P. × 75.

 $\begin{array}{ll} SnF_4 & + H_2O \rightarrow SnO_2 + HF \\ (Tin tetrafluoride) & (Cassiterite) \\ (CaAl_2Si_2O_8-NaAlSi_3O_8) + HF \rightarrow Al_2(SiO_4)(OHF) + \\ (Plagioclase) & (Topaz) \\ & + CaF_2 + SiO_2 + Na^+ + H_2O \\ (Fluorite) & (Quartz) \\ \end{array}$   $\begin{array}{ll} KAlSi_3O_8 + Be^{2+} + Na^+ + F^- + H_2O \rightarrow \\ & NaAlSi_3O_8 + KAl_2(AlSi_2O_{10}) (OHF) + Al_2Be_2(Si_6O_{18}) + SiO_2 \\ (Albite) & (Muscovite) & (Beryl) & (Quartz) \end{array}$ 

It seems possible that the intensity of albitization depends mainly on the concentration of sodium resulted from the breakdown of the early formed plagioclase of the granite and the breakdown of sodium-flour-rare element complexes, and the deposition of beryllium minerals in the albitized granites is controlled in part by the concentration of beryllium in the mineralizing aqueous fluids and the interaction between the granite and these fluids.

Greisenization of the granite is exhibited by partial to complete alteration of sheets of the pink or red granites into yellowish-green rock (*e.g.*, Gabal Mueilha, Homrit Mikpid and Homr Akarim) or brown (*e.g.*, Mueilha tin mine), composed mainly of quartz, yellowish-green muscovite (or brown muscovite), topaz, canary yellow lepidolite, fluorite and sometimes cassiterite. Biotite is the first mineral replaced by yellowish-green muscovite, and relicts of biotite were recorded in the yellowish-green flakes of muscovite in the Gabal Mueilha area. The main mineralogical changes that occurred during greisenization were the replacement of both biotite and feldspars of the granite and the formation of quartz, muscovite, lepidolite, topaz, fluorite and cassiterite. Topaz is usually dominant in amount relative to fluorite in the heavy concentrates of the greisenized granites and greisens obtained by treatment with heavy liquids. Some greisen samples (500 g each) from Gabal Mueilha were found to contain from 10 to 30% by weight topaz.

Megascopic grains of pitch-black to brown cassiterite up to 2 mm in diameter are disseminated in the greisenized granites and greisen of Gabal Mueilha and Mueilha tin mine areas (Fig. 8). The occurrence of cassiterite, topaz and fluorite in the greisenized granites and greisens suggest that Sn and F were added to the granite during greisenization as complexes. Possible complexes include:  $SnF_4$  (Rankama and Sahama 1968), Sn (OH<sub>2</sub>F)<sub>6</sub><sup>2-</sup>, AlF(H<sub>2</sub>O)<sup>4</sup>, AlF(H<sub>2</sub>O)<sub>5</sub><sup>2+</sup>, SiF<sub>6</sub><sup>2-</sup> (Smirnov 1968); HF, FeF<sub>2</sub><sup>+</sup>, FeF<sup>2-</sup> (Roberson and Barnes 1978, Richardson and Holland 1979a and b). The deposition of cassiterite, topaz and fluorite and the formation of muscovite and quartz during greisenization may be ascribed to the hydrolysis of SnF<sub>4</sub> (or the breakdown of tin-flour-rare element complexes) and the destruction of the feldspars of the granite under the influence of HF; that is:

 $\begin{array}{rl} SnF_4 & + H_2O \rightarrow & SnO_2 & + HF \\ (Tin tetrafluoride) & (Cassiterite) \\ K & AlSi_3O_8 & + (CaAl_2Si_2O_8 - NaAlSi_3O_8) & + HF + H_2O \rightarrow \\ (K-feldspar) & (Plagioclase) \\ & KAl_2(Si_2AlO_{10})(OHF) & + Al_2SiO_4(OHF) & CaF_2 & + \\ (Muscovite) & (Topaz) & (Fluorite) \\ & + & SiO_2 & + Na^+ + K^+ + H^+ \\ & (Quartz) \end{array}$ 

It seems possible that the fluorite content of the greisenized granites and greisens depends mainly on the calcium content of the plagioclase, whereas the deposition of topaz is influenced mainly by the concentration of Al, Si and F in the ore fluids. This may explain the high concentration of topaz relative to fluorite in these rocks.

The resulted potassium and sodium in these reactions may increase the alkalinity of the post-magmatic fluids resulting in a second phase of microclinization and albitization (Fig. 3).



Fig. 8. Photomicrograph of greisen form Mueilha tin mine area, showing zoned cassiterite embedded in muscovite flakes. C.P. × 75.

Lode and Fissure filling quartz veins containing cassiterite (Fig. 9) occur along the margins of the greisenized and albitized granites of the Mueilha tin mine and Homr Akarim masses. The veins are confined to fractures and shear zones. They are well defined having clear and direct contacts with the host rocks, and consist mainly of quartz associated with varying amounts of cassiterite and mica. Topaz, fluorite and calcite are common accessory minerals. Topaz is crystallized before quartz (different generations) and fluorite and calcite were crystallized after quartz (El-Ramly et al. 1970). These may indicate that fluorite was active before and during the formation of quartz and CO<sub>2</sub>, and some fluorite have left the system after the formation of quartz, and fluoride and carbonate complexing occurred during the hydrothermal processes giving rise to quartz veins. The quartz veins of the Mueilha tin mine are enriched in Al, Ca, Fe, Be, Nb, Sn, W, Mo, Cu, Zn, Pb, Bi, Ga, Zr, Y and Yb and are strongly depleted in alkalis (El-Ramly et al. 1970). The enrichment of these veins in Al and their depletion in alkalis is probably due to the action of CO<sub>2</sub>-rich volatile phase coexisting with siliceous melt as shown by Burnham (1967). The high concentration of the ore elements in the Mueilha quartz veins is probably a result of their mobility as fluoride and carbonate complexing. It is interesting to mention that carbonate complexing is considered as the most plausible cause of element mobility in siliceous veins derived from peralkaline granite magma in Saudi Arabia by Harris (1981) and these veins are enriched in CO<sub>2</sub> and have low F and alkalis content.



Fig. 9. Photomicrograph of mineralized quartz vein from Homr Akarim area, showing zoned and cracked cassiterite. The cracks are filled by quartz. C.P.  $\times$  75.

## Chemistry

Forty five samples of unaltered granites (pink granites), greisenized granites and albitized granites from Gabal Mueilha, Mueilha tin mine, Homrit Mikpid and Homr Akarim were analysed for both major and trace elements by Soliman (1975) and Zaghloul et al. (1978). In the present study, 15 samples from the unaltered granites (pink granites), greisenized granites and albitized granites from Um Shilman area were analysed for both major and trace elements. Major elements were determined by wet chemistry and trace elements by emission spectrograph in the laboratories of the Geological Survey of Egypt. Table 3 shows the average chemical composition of the unaltered granites (pink granites), greisenized granites and albitized granites from Gabal Mueilha, Mueilha tin mine, Homrit Mikpid, Homr Akarim and Um Shilman granitic masses, compared with the average chemical composition of the greisenized granites of Alaska reported by Siansbury (1964, 1969) as well as the tin-bearing anorogenic, peraluminious younger granites of Nigeria (Olade 1980). The correlation co-efficients between every pair of elements in the unaltered granites, greisenized granites and albitized granites are calculated by computer and are presented in Table 4.

Table 3 confirms the peraluminous nature of the Egyptian unaltered granites (agpaitic index 0.76) and shows a general parallelism between the Egyptian younger granites and the Nigerian younger granites (biotite granites that are genetically related to Sn and Nb mineralization) in their major oxides. However, the Egyptian granites are slightly enriched in Al<sub>2</sub>O<sub>3</sub> and CaO and depleted in Na<sub>2</sub>O and  $K_2O$  with respect to the Nigerian granites. On comparing their trace elements, it is revealed that the Egyptian granites are considerably rich in Sn and Pb and depleted in Nb, Y and Zr relative to the Nigerian granites, suggesting that the Egyptian granites were derived from highly differentiated magmas rich in Sn and Pb and depleted in Nb, Y and Zr. The high differentiation nature of the Egyptian granites is indicated by their low Sr content (10 ppm Sr, von Knorring and Rooke 1973). Hildreth (1981) believes that chlorine-rich magmas are usually enriched in Zr, Y and Nb, whereas magmas in which fluorine is the dominant halogen exhibit more pronounced enrichment of Sn and Be. The common occurrence of accessory fluorite in the stanniferous Egyptian granites and the development of fluorite veins (the thickness of these veins ranges from 30 to 50 cm and their length varies from 30 to 80 m) in the Sn and Be-mineralized granites, e.g., Homrit Mikpid and Homr Akarim areas, suggest that these granites were derived from fluorine-rich magmas. This may explain the enrichment of our granites in Sn and their depletion in Nb, Y and Zr relative to the Nigerian granites.

The greisenized and albitized zones of the Egyptian granites are abnormally rich in Sn relative to the unaltered granites and the albitized granites contain enhanced values of Be and reflecting Sn mineralization in both the greisenized and albitized granites and Be mineralization in the albitized granites.

	Unaltered granites	Albitized granites	Greisenized granites	Alaskan <sup>(+)</sup> greisenized	Nigerian <sup>(++)</sup> granites
	(n = 20)	(n = 20)	(n = 20)	graintes	
SiO <sub>2</sub>	75.29	74.36	78.84	72.80	75.49
$Al_2O_3$	13.81	13.96	13.69	14.90	12.62
Fe <sub>2</sub> O <sub>3</sub>	0.92	0.65	0.63	0.02	0.62
FeO	0.40	0.32	0.30	0.50	1.02
TiO <sub>2</sub>	0.09	0.07	0.05	1.60	0.12
CaO	1.09	0.82	0.58	0.57	0.54
MgO	0.26	0.24	0.21	0.95	0.16
Na <sub>2</sub> O	3.81	4.89	0.73	0.58	4.18
K <sub>2</sub> O	3.27	3.22	2.98	2.35	4.63
MnO	0.03	0.03	0.02	0.93	0.02
$P_2O_5$	0.04	0.04	0.06	0.01	0.03
$H_2O^-$	0.08	0.06	0.12	-	-
$H_2O^+$	0.48	0.52	1.95	2.90	-
Total	99.57	99.18	100.16	98.11	99.43
C.I.P.W. nor	rms				
Q	38.40	31.96	62.12	61.96	32.29
Or	19.32	19.02	17.59	13.86	27.27
Ab	32.22	41.35	6.18	4.72	29.57
An	5.15	3.80	2.50	0.28	2.48
С	2.14	1.06	8.37	11.34	-
Trace elemen	nts (ppm)				
Sn	110	311	240		30
Nb	57	68	54	-	130
Be	52	456	46	-	-
Y	61	56	40		200
Zr	114	82	73	-	260
Pb	86	81	68	_	30
Cu	16	54	44	-	-
Мо	9	39	11	·—	-
Bi	8	25	11	_	_

 Table 3. Average chemical composition of unaltered granites, greisenized granites and albitized granites.

(+) Siansbury (1964, 1969); (++)Olade (1980) n = number of samples; (-) not determined.

$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		Unaltered granites	Albitized granites	Greisenized granites
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -Al <sub>2</sub> O <sub>3</sub>	-0.57	-0.82	-0.37
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -Fe <sub>2</sub> O <sub>3</sub>	-0.49	+0.36	+0.04
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -FeO	-0.04	+0.36	+0.52
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -TiO <sub>2</sub>	-0.16	-0.39	+0.29
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -CaO	-0.10	+0.27	-0.43
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -MgO	-0.05	-0.16	-0.30
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -Na <sub>2</sub> O	-0.44	-0.60	-0.89
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -K <sub>2</sub> O	0.06	-0.62	-0.15
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -MnO	+0.02	+0.24	-0.19
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -P <sub>2</sub> O <sub>5</sub>	+0.54	+0.23	-0.12
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -Sn	+0.18	-0.15	+0.32
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -Nb	+0.33	+0.12	-0.23
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -Be	-0.18	-0.20	+0.14
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	SiO <sub>2</sub> -Y	-0.26	+0.00	+0.22
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	SiO <sub>2</sub> -Zr	-0.14	-0.46	-0.11
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	SiO <sub>2</sub> -Pb	-0.05	+0.29	-0.20
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	SiO <sub>2</sub> -Cu	-0.28	+0.25	+0.38
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	SiO <sub>2</sub> -Mo	-0.07	+0.08	-0.37
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	SiO <sub>2</sub> -Bi	+0.20	+0.39	-0.08
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -Fe <sub>2</sub> O <sub>3</sub>	-0.12	-0.52	-0.06
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -FeO	+0.32	-0.39	-0.22
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -TiO <sub>2</sub>	+0.41	-0.19	-0.17
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -CaO	+0.05	-0.31	+0.47
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -MgO	-0.05	+0.07	-0.02
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -Na <sub>2</sub> O	-0.04	+0.12	+0.03
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -K <sub>2</sub> O	-0.36	+0.50	-0.23
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -MnO	+0.13	+0.19	+0.00
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -Pb	-0.33	+0.11	+0.05
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -Sn	-0.28	+0.32	-0.30
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -Nb	-0.48	+0.05	-0.11
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Al <sub>2</sub> O <sub>3</sub> -Be	+0.25	+0.31	-0.12
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	$Al_2O_3$ -Y	+0.16	+0.03	+0.51
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	$AI_2O_3$ -Zr	+0.27	+0.18	-0.26
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Al <sub>2</sub> O <sub>3</sub> -Pb	-0.41	-0.40	-0.02
$Al_2O_3$ -Mo+0.16+0.18+0.38 $Al_2O_3$ -Bi-0.34-0.27-0.22 $Fe_2O_3$ -FeO-0.18+0.36-0.48 $Fe_2O_3$ -TiO2-0.15-0.06-0.47	Al <sub>2</sub> O <sub>3</sub> -Cu	-0.10	-0.20	+0.54
$AI_2O_3$ -B1 $-0.34$ $-0.27$ $-0.22$ $Fe_2O_3$ -FeO $-0.18$ $+0.36$ $-0.48$ $Fe_2O_3$ -TiO2 $-0.15$ $-0.06$ $-0.47$	$Al_2O_3$ -Mo	+0.16	+0.18	+0.38
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	$A_{1_2}O_3 - B_1$	-0.34	-0.27	-0.22
$re_2 O_3 - 11 O_2 = -0.15 = -0.06 = -0.47$	$Fe_2O_3$ -FeO	-0.18	+0.30	-0.48
	$Fe_2O_3 - FIO_2$	-0.15	-0.06	-0.47
$Fe_2O_3$ -CaO +0.30 +0.34 +0.09	$Fe_2O_3$ -CaO	+0.30	+0.54	+0.09

Table 4.	Pair correlation coefficients between elements in unaltered gra	-
	nites, albitized granites and greisenized granites.	

# Table 4. (Cont.)

	Unaltered granites	Albitized granites	Greisenized granites
Fe <sub>2</sub> O <sub>3</sub> -Na <sub>2</sub> O	+0.19	-0.13	-0.13
Fe <sub>2</sub> O <sub>3</sub> -K <sub>2</sub> O	-0.03	-0.30	+0.23
Fe <sub>2</sub> O <sub>3</sub> -MnO	+0.23	-0.39	+0.50
Fe <sub>2</sub> O <sub>3</sub> -P <sub>2</sub> O <sub>5</sub>	+0.02	-0.43	+0.64
Fe <sub>2</sub> O <sub>3</sub> -Sn	+0.40	+0.03	+0.61
Fe <sub>2</sub> O <sub>3</sub> -Nb	+0.26	-0.10	+0.14
Fe <sub>2</sub> O <sub>3</sub> -Be	+0.26	-0.40	-0.64
Fe <sub>2</sub> O <sub>3</sub> -Y	+0.21	-0.55	-0.25
Fe <sub>2</sub> O <sub>3</sub> -Zr	+0.00	-0.37	-0.42
Fe <sub>2</sub> O <sub>3</sub> -Pb	+0.38	+0.25	+0.77
Fe <sub>2</sub> O <sub>3</sub> -Cu	+0.60	+0.04	-0.26
Fe <sub>2</sub> O <sub>3</sub> -Mo	-0.10	+0.13	+0.30
Fe <sub>2</sub> O <sub>3</sub> -Bi	-0.27	-0.22	+0.74
FeO-TiO <sub>2</sub>	-0.17	-0.20	+0.93
FeO-CaO	+0.19	+0.26	-0.52
FeO-MgO	+0.09	+0.22	-0.57
FeO-Na <sub>2</sub> O	-0.23	-0.16	-0.50
FeO-K <sub>2</sub> O	-0.57	-0.68	-0.10
FeO-MnO	+0.36	-0.25	-0.34
FeO-P <sub>2</sub> O <sub>5</sub>	+0.03	-0.42	-0.23
FeO-Sn	-0.21	+0.12	-0.33
FeO-Nb	-0.28	+0.29	-0.62
FeO-Be	-0.24	-0.14	+0.51
FeO-Y	+0.04	-0.50	+0.08
FeO-Zr	+0.08	-0.19	+0.38
FeO-Pb	-0.56	-0.06	-0.61
FeO-Cu	-0.03	+0.20	+0.27
FeO-Mo	-0.29	+0.30	-0.56
FeO-Bi	+0.11	+0.00	-0.25
TiO <sub>2</sub> -CaO	-0.12	-0.09	-0.32
TiO <sub>2</sub> -MgO	-0.34	+0.29	-0.47
TiO <sub>2</sub> -Na <sub>2</sub> O	+0.00	+0.47	-0.32
$TiO_2$ - $K_2O$	+0.01	+0.21	-0.23
TiO <sub>2</sub> -MnO	-0.47	-0.23	-0.26
$TiO_2 - P_2O_5$	+0.17	-0.42	-0.20
TiO <sub>2</sub> -Sn	+0.10	-0.58	-0.34
TiO <sub>2</sub> -Nb	+0.24	-0.63	-0.56
TiO <sub>2</sub> -Be	+0.35	+0.33	+0.44
TiO <sub>2</sub> -Y	-0.07	-0.05	+0.00
TiO <sub>2</sub> -Zr	+0.15	+0.63	+0.30
TiO <sub>2</sub> -Pb	-0.15	-0.06	-0.47
TiO <sub>2</sub> -Cu	+0.15	+0.00	+0.19

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Tab	le 4.	(Cont.)	
		(/	

	Unaltered granites	Albitized granites	Greisenized granites
TiO <sub>2</sub> -Mo	-0.14	+0.11	-0.50
TiO <sub>2</sub> -Bi	-0.44	-0.15	-0.28
CaO-MgO	+0.67	+0.39	+0.33
CaO-Na <sub>2</sub> O	-0.39	-0.35	+0.26
CaO-K <sub>2</sub> O	+0.00	-0.36	-0.23
CaO-MnO	+0.28	-0.32	-0.17
CaO-P2O5	+0.20	-0.10	-0.09
CaO-Sn	+0.24	-0.35	-0.30
CaO-Nb	+0.03	-0.55	+0.40
CaO-Be	+0.44	-0.19	-0.47
CaO-Y	-0.31	-0.44	+0.00
CaO-Zr	-0.49	-0.63	-0.22
CaO-Pb	-0.10	+0.07	+0.26
CaO-Cu	+0.13	+0.45	+0.00
CaO-Mo	+0.21	+0.13	+0.42
CaO-Bi	+0.60	-0.50	-0.31
MgO-Na <sub>2</sub> O	-0.08	-0.04	+0.30
MgO-K <sub>2</sub> O	-0.03	+0.10	-0.53
MgO-MnO	+0.59	-0.06	-0.03
MgO-P <sub>2</sub> O <sub>5</sub>	+0.17	-0.28	-0.43
MgO-Sn	+0.10	-0.49	+0.30
MgO-Nb	+0.23	-0.46	+0.60
MgO-Be	-0.03	+0.30	+0.21
MgO-Y	-0.28	+0.02	-0.03
MgO-Zr	-0.39	-0.04	-0.40
MgO-Pb	-0.27	+0.01	+0.20
MgO-Cu	-0.29	+0.43	-0.07
MgO-Mo	-0.16	-0.02	-0.05
MgO-Bi	+0.18	-0.44	+0.11
Na <sub>2</sub> O-K <sub>2</sub> O	+0.21	+0.38	+0.37
Na <sub>2</sub> O-MnO	+0.00	-0.02	+0.26
$Na_2O-P_2O_5$	-0.27	-0.50	+0.14
Na <sub>2</sub> O-Sn	-0.23	-0.16	-0.17
Na <sub>2</sub> O-Nb	-0.07	-0.09	+0.33
Na <sub>2</sub> O-Be	-0.34	+0.05	-0.14
Na <sub>2</sub> O-Y	+0.49	+0.12	-0.30
Na <sub>2</sub> O-Zr	+0.39	+0.78	+0.26
Na <sub>2</sub> O-Pb	+0.02	-0.06	+0.16
Na <sub>2</sub> O-Cu	+0.03	-0.25	-0.55
Na <sub>2</sub> O-Mo	-0.33	-0.32	+0.38
Na <sub>2</sub> O-Bi	-0.58	-0.15	-0.16
K <sub>2</sub> O-MnO	-0.37	-0.03	+0.32

# Table 4. (Cont.)

	Unaltered granites	Albitized granites	Greisenized granites
K <sub>2</sub> O-P <sub>2</sub> O <sub>5</sub>	-0.27	+0.00	+0.60
K <sub>2</sub> O-Sn	+0.19	+0.05	-0.12
K <sub>2</sub> O-Nb	+0.00	-0.08	+0.02
K <sub>2</sub> O-Be	+0.00	+0.20	-0.29
K <sub>2</sub> O-Y	-0.34	+0.24	-0.29
K <sub>2</sub> O-Zr	-0.49	+0.26	+0.42
K <sub>2</sub> O-Pb	+0.48	+0.04	+0.11
K <sub>2</sub> O-Cu	-0.05	-0.13	-0.52
K <sub>2</sub> O-Mo	+0.13	-0.28	+0.37
K <sub>2</sub> O-Bi	-0.04	-0.28	-0.03
MnO-P <sub>2</sub> O <sub>5</sub>	+0.11	+0.38	+0.82
MnO-Sn	+0.04	-0.06	+0.57
MnO-Nb	+0.02	+0.17	+0.20
MnO-Be	-0.22	-0.10	-0.43
MnO-Y	-0.13	+0.81	+0.33
MnO-Zr	-0.12	+0.09	-0.48
MnO-Pb	-0.18	-0.02	+0.73
MnO-Cu	-0.30	-0.08	+0.00
MnO-Mo	-0.24	-0.37	+0.64
MnO-Bi	+0.02	+0.24	+0.28
$P_2O_5$ -Sn	+0.62	+0.10	+0.40
P <sub>2</sub> O <sub>5</sub> -Nb	+0.49	+0.00	+0.03
P <sub>2</sub> O <sub>5</sub> -Be	-0.02	-0.01	-0.60
$P_2O_5$ -Y	-0.19	+0.40	-0.03
$P_2O_5$ -Zr	-0.21	-0.28	-0.23
$P_2O_5Pb$	-0.12	+0.12	+0.64
P <sub>2</sub> O <sub>5</sub> -Cu	+0.25	-0.17	-0.18
$P_2O_5$ -Mo	-0.22	-0.22	+0.54
P <sub>2</sub> O <sub>5</sub> -Bi	+0.32	+0.33	+0.21
Sn-Nb	-0.33	+0.78	+0.03
Sn-Be	+0.19	-0.22	-0.37
Sn-Y	-0.18	-0.21	+0.04
Sn-Zr	-0.29	-0.27	-0.41
Sn-Pb	+0.22	-0.20	+0.50
Sn-Cu	+0.42	-0.24	+0.03
Sn-Mo	-0.03	+0.31	-0.02
Sn-Bi	+0.41	+0.20	+0.60
Nb-Be	-0.08	-0.13	+0.00
Nb-Y	-0.25	+0.01	-0.21
Nb-Zr	-0.06	-0.08	-0.54
Nb-Pb	+0.05	-0.18	+0.59
Nb-Cu	-0.05	-0.16	-0.38

	Unaltered granites	Albitized granites	Greisenized granites
Nb-Mo	-0.52	+0.13	+0.42
Nb-Bi	+0.00	+0.35	-0.16
Be-Y	-0.03	+0.28	-0.04
Be-Zr	-0.10	+0.17	+0.09
Be-Pb	+0.35	-0.12	-0.49
Be-Cu	+0.25	-0.37	+0.05
Be-Mo	+0.43	+0.29	-0.54
Be-Bi	+0.30	-0.08	-0.22
Y-Zr	+0.87	+0.32	-0.33
Y-Pb	-0.17	+0.23	-0.11
Y-Cu	+0.33	-0.37	+0.92
Y-Mo	-0.13	-0.47	+0.39
Y-Bi	-0.22	+0.22	-0.22
Zr-Pb	-0.34	+0.11	-0.73
Zr-Cu	+0.08	-0.31	-0.32
Zr-Mo	-0.23	-0.34	-0.40
Zr-Bi	-0.45	+0.14	-0.21
Pb-Cu	+0.33	-0.13	-0.25
Pb-Mo	+0.35	-0.35	+0.61
Pb-Bi	+0.28	+0.06	+0.41
Cu-Mo	+0.09	+0.12	+0.09
Cu-Bi	+0.35	-0.24	-0.17
Mo-Bi	+0.46	+0.04	-0.13

Table 4.(Cont.)

As shown by Table 3, there are significant differences between the unaltered granites and those were subjected to greisenization and albitization processes in their major and trace elements. Greisenization enhanced the Al/Na+K ratio making the greisenized granites more corundum-normative than its parent magma (represented by unaltered granites, Table 3). The main chemical changes that accompanied greisenization were the migration of Na, K, Ca, Be, Y, Zr, Pb and Fe and the addition of Si, Sn and H<sub>2</sub>O. The loss of Na is greater than that of K because K has probably participated in the formation of greisen mica (muscovite and lepidolite). The loss of Fe, Na, K and Ca during greisenization is attributed to the migration of these elements during the replacement of the feldspars and biotite of the granites under the influence of high-temperature fluorine-rich fluids responsible for greisenization. Negative correlation coefficient values are recorded between SiO<sub>2</sub> and each of Na<sub>2</sub>O, K<sub>2</sub>O, CaO, MgO, MnO, P<sub>2</sub>O<sub>5</sub>, Zr, Nb, Pb, Mo and Bi during greisenization (Table 4). It is interesting to note that Na<sub>2</sub>O has strong negative correlation with SiO<sub>2</sub> relative to that between K<sub>2</sub>O and SiO<sub>2</sub> (Table 4).

Albitization decreased the Al/K + Na ratio making the albitized granites less corundum-normative than its parent magma (represented by the unaltered granites) (Table 3). The main chemical changes during albitization were the addition of Na (some of which is probably derived from greisenized granites and greisens), Be, Sn, Nb, Cu, Mo and Bi and the partial migration of Fe, Ca, Si, Ti, Y and Zr (Table 3). Significant negative correlation coefficients are noted for Na<sub>2</sub>O with SiO<sub>2</sub> and P<sub>2</sub>O<sub>5</sub> and non-significant correlation coefficients are noted for Na<sub>2</sub>O with CaO, Fe<sub>2</sub>O<sub>3</sub>, FeO, Be, Sn, Cu, Mo and Bi in the albitized granites (Table 4).

Similar major and trace elements, but with different concentrations, are recorded in the unaltered granites, greisenized granites and albitized granites in each individual locality under investigation. This may suggest that the post-magmatic fluids responsible for greisenization and albitization are derived from the same magma chamber gave rise to the granitic mass in each locality, *i.e.*, greisenization and albitization processes are of autopneumatolytic nature. More trace element and isotopic data are needed to test this hypothesis.

On comparing the chemical composition of the Egyptian and Alaskan greisenized granites (Table 3), it is revealed that, apart from some minor differences in Si,  $Fe^{3+}$ , Ti, Mg and Mn, there is a general parallelism between the two sets of data particularly in their Na values, suggesting that Na is an index element for greisenization of granitic rocks, and the intensity of depletion or leaching of this element is an indication of the intensity of greisenization and the replacement of the feldspars of the granites during this process. Similar observation was recorded by Soliman (1975) and Zaghloul *et al.* (1978).

#### Conclusion

The tin-bearing granite rocks of Gabal Mueilha, Mueilha tin mine, Homrit Mikpid, Homr Akarim and Um Shilman are abnormally rich in Sn and Pb and depleted in Nb, Y and Zr relative to the Nigerian younger granites. The formation of tin and beryllium deposits in the Mueilha, Homrit Mikpid and Homr Akarim can be explained as a direct result of the high content of Sn and Be in these rocks. Greisenization and albitization processes induced some mineralogical and chemical changes in the granites. Greisenization enhanced the Al/Na+K ratio making the greisenized granites more corundum-normative than its parent magma. The main mineralogical changes that occurred during greisenization were the replacement of the feldspars of the granite and the formation of muscovite, quartz, lepidolite, topaz, fluoride and cassiterite. This is accompanied by partial migration of Na, K, Ca, Be, Y, Zr, Fe and Pb and the addition of Si, F, Sn and H<sub>2</sub>O. Albitization decreased the Al/Na+K ratio making the albitized granites less corundum-normative than its parent magma. Albitization is manifested by the growth of fine to medium-grained albite sometimes with beryl. This is accompanied by partial addition of Na, Be, Sn, Nb, Cu, Mo and Bi and partial migration of Fe, Ca, Si, Ti, Y

and Zr. Fluoride complexing is an important factor in element mobility during greisenization and albitization. Carbonate and fluoride complexing are the most plausible cause of element mobility in hydrothermal processes giving rise to the quartz-cassiterite veins. There are marked differences in the behaviour between Si, Fe, Ti, Ca, Al, Mg, Na, K, P, Mn, Sn, Nb, Be, Pb, Y, Zr, Cu, Mo and Bi during magmatic and post-magmatic processs. This is probably because they form complexes that differ in mobility under different geochemical conditions.

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التغيرات المعدنية والكيميائية المصاحبة لعمليات جرزنة وألبتة صخور الجرانيت بمصر

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يختص هذا البحث بدراسة التغيرات المعدنية والكيميائية المصاحبة لعمليات جرزنة وألبتة صخور الجرانيت بمصر. بينت الدراسة أن عمليات الجرزنة والألبتة محصورة فقط فى صخور الجرانيت الحاملة للقصدير، وأن عمليات الجرزنة تؤدى إلى ذوبان الفلسبار ليحل محله معادن المسكوفيت والكوارتز والتوباز والفلوريت وأحياناً الكاسيتيرايت. وقد صاحب ذلك نقص فى عناصر الصوديوم والبوتاسيوم والكالسيوم والحديد والتيتانيوم واليتريوم والبركونيوم والبريليوم والرصاص وإضافة عناصر السيليكون والفلور والماء والقصدير. يصاحب عملية الألبتة نمو معدن الألبيت مع إضافة عناصر الصوديوم والبريليوم والنيوبيوم والنحاس والموليبدنوم مع نقص فى عناصر السيليكون والنيوبيوم