Research Article

Rare metals mineralization in altered granites at Nusab El Balgum Area, Southwestern Desert, Egypt

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Abstract

Nusab El Balgum area southwestern Desert, Egypt, is consists mainly of sandstone (Devonian), volcanic rocks (Permo-Triassic), altered granitic rocks and post granitic dykes. The altered granitic rocks are classified microscopically to silicified granite and kaolinized granite. The most important types of wall rock alteration are sericitization, silicification, carbonization, hematization chloritization and kaolinization). The recorded gold contents in Nusab El Balgum area, southwestern Desert of Egypt in the silicified granite (9 to 0.3 g/t) is more than kaolinized granite (0.3 g/t) , pyroclastics (0.3g/t)and post granitic dykes(0.5g/t) and considered as first record in association with rare metals(Ni, Ag, Zn, Pb ,Th , U ,Ga ,W and Mo). The mineralogical studies confirm the presence of three mineralization stages, the earliest mineralization stage (high temperature stage) is characterized by the formation of native Au associated with hypogene rare metals (pyrite, galena, sphalerite and native Ni). The second stage (lower-temperature) is characterized by the formation of supergene secondary minerals; uranium, barite and atacamite. Third stage is related to carbonate facies formed after the oxide (supergene alteration). The rare metals enrichment in the study area are formed due to the subsequent processes; including the ascending hydrothermal solutions (alkaline followed by acidic hydrothermal solutions), with further contribution of the descending acidic meteoric water; supergene enrichment processes. The origin of uranium appears to be closely associated with the rare metals mineralization and may be reflects readily their intimate coherence.

Keywords: Hydrothermal solutions, Nusab El Balgum, auriferous, rare metals, thorite, gold.

INTRODUCTION

Nusab El Balgum area is bounded by latitudes 23° $15^/$ to 23° $20^/$ N and longitudes 29° $15^/$ to 29° $20^/$ E, southwestern Desert, Egypt .Nusab El Balgum is located North of Bir Safsaf Precambrian basement rocks, about 600 km south west of Aswan City near Kurkur and Dungul Oases. It forms an elongated body trending in the ENE-WSW direction.

The granitoids rocks are a major source of economically important metals such as Cu, Mo, Sn, W, and Au (Kesler, 1994).The magmatic-hydrothermal ore deposits form by a complex sequence of events starting with the generation of hydrous melts in the crust and ending with the precipitation of ore metals from hydrothermal fluids (e.g., Burnham and Ohmoto, 1980; Ishihara and Takenouchi, 1980; Stein and Hannah, 1990; Barnes, 1997).

The granites are enriched in lithophile elements and considered as important economic resources for Ta, Nb, Sn, Li, Be, Cs, Rb, Y, U, Th, Ga, P, Zr, F, B, and rare-earth elements (REE). The term`` rare elements'' or ``rare metals'' are generally used to encompass a variety of elements such as tantalum, niobium, beryllium, lithium, zirconium, and rare-earth elements (REE) concentrated in acidic magmatic rocks. Granite-hosted rare-element deposits are formed both within the evolved facies of granite and during the hydrothermal alteration processes of magmatic units.

The Mo–F–U association is recorded in many localities worldwide (Aleshin et al., 2007; Chabiron et al., 2003). Genetically related Au, Mo, and U are also common (Ciobanu et al., 2013a, b; Newberry, 1979). The presence of precious metals (Au and Ag) in Mo–Bi ores is attributed to the Bi-chalcogenides which act as scavengers and hosts for Au and Ag (Ciobanu et al., 2009).

As discussed above, the Mo–Bi–Ag and U–F mineralizing fluids were probably extracted from the same granitic magma. Anomalous amounts of Ag, Cu, Pb, Zn and Bi are characteristic of the late fractionate, especially upward in the magmatic system (Smith, 1979). The hydrothermal metal-bearing fluids moved along micro-fractures and faults, precipitated the metals and caused wall rock alteration.

The mineralogy and geochemistry of the rare metals Au, Ag, Mo, W, as well as Cu, Ga, Zn, Pb and U in the altered granites are the main target of this paper.

Field geology

The Nusab El Balgum area is consists mainly of sandstone (Devonian), volcanic rocks (Permo-Triassic, Schandelmeier and Derbyshire 1984), altered granitic rocks and post granitic dykes (Figure 1).

The altered granitic rocks form irregular low lying surface, usually rising less than 2m above ground level in the southern part and southeastern part of the mapped area. Some of these rocks occur as small isolated bodies and intruded, up doming the volcanic rocks where some xenoliths of latter engulfed in the granitic rocks.

In general the altered granitic rocks are subdivided into two types, silicified and kaolinized granite, they are medium in grain size and characterized by their weathered surface, their texture being affected by extensive alteration along joints. The contact between these granites and the volcanic is sharp.

Silicified granite is located in the south and southeastern part of the study area, forming nearly rounded shape of low lying surface relative to volcanic rocks covering an area of about 3km^2. Hematitization, kaolinization, sericitization and silicification are the main alteration processes. Petrographically, this rock is characterized by complete absence of plagioclase where the potash feldspar (perthite) and quartz are the main constituents. Mafic minerals are mainly alkaline pyroxenes that intensively altered or metasomatized by meteoric or hydrothermal solutions. Quartz comprises primary and reworked quartz. Quartz is clearly affected by the processes of metasomatism and corroded by the potash feldspar (Fig.2a) or spatially dissolved by the hydrothermal solution and left as skeletal crystals. Rare crystals of the primary quartz enclose minute crystals of secondary rebeckite (Figure 2b). Pyroxene occurs as aegirine-augite which characterized by very low extinction angle and third order interference colors (Figure 2c). Most of the alkaline minerals are idiomorphic occur as pseudomorphs occupied by quartz and iron oxides (Kerr, 1959**)** as result of migration of the alkali elements during the process of metasomatism (Figure2d).
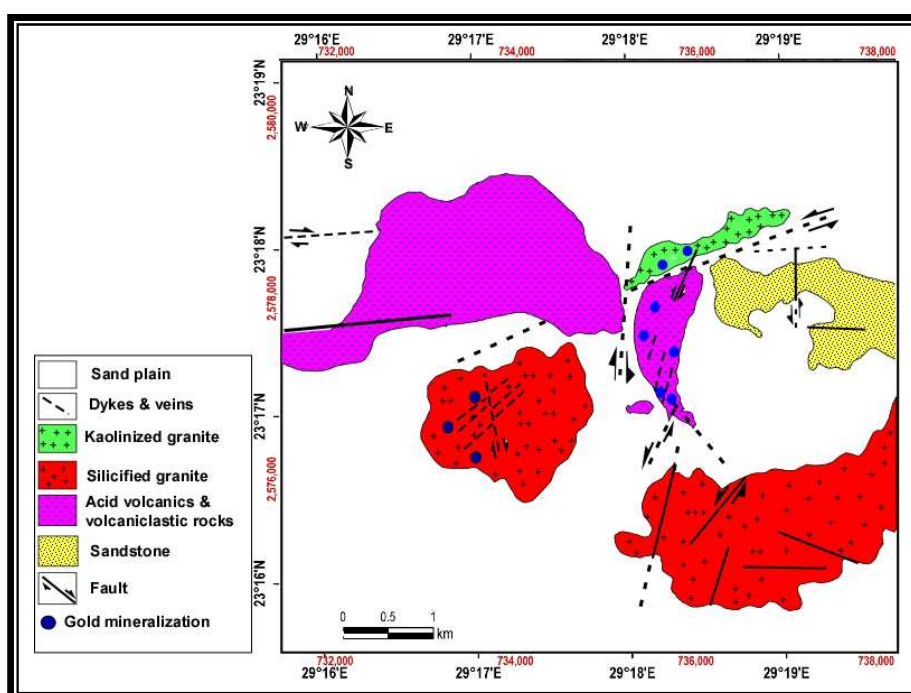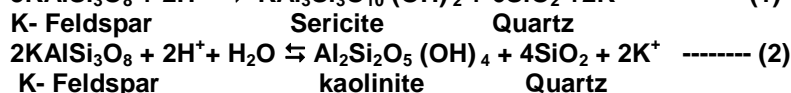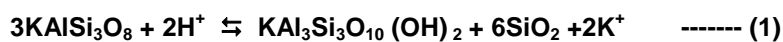

Figure 1. Geologic map of the Nusab El Balgum area, southwestern Desert, Egypt

Accessory minerals are mainly zircon, iron oxides and uranium minerals**.** Zircon of Nusab El Balgum silicified granite is noncrystalline zirconosilicate arranged in chain-like aggregate with truncated forms. (Figure 2e). Iron oxides adsorb uranium ions and play an important role in the formation of the secondary uranium minerals. The later may crystallize directly from the hydrothermal solutions as autunite mineral occurring as rose-like crystals on the fractures of quartz (Figure 2f).

kaolinized granite is located in the northern part of the study area intruding the volcanics, having elongated shape with 2Km in length and 150m in width (Fig.3). Kaolinization, sericitization and carbonitization are the main processes alteration.
In this portion the feldspars are completely altered to sericite and kaolin according these equations (Walther, 2005).

$$3KAlSi_3O_8 + 2H^+ \leftrightarrows KAl_3Si_3O_{10} (OH)_2 + 6SiO_2 + 2K^+ \quad \text{------- (1)}$$
K- Feldspar   Sericite   Quartz
$$2KAlSi_3O_8 + 2H^+ + H_2O \leftrightarrows Al_2Si_2O_5 (OH)_4 + 4SiO_2 + 2K^+ \quad \text{-------- (2)}$$
 K- Feldspar   kaolinite   Quartz

Accordingly, the potash feldspars in reducing conditions are transformed to sericite (equation 1) (Figure 4a) and when water is added to the system, kaolin is produced (equation 2) liberating amorphous silica (silicification) (Figure 4b) and free potash ions.

Microscopic investigation of the kaolinized granite revealed that perthite crystals are characterized by patches of secondary carbonate. Zircon represents the main accessory mineral occurring as aggregates of immature crystals showing its characteristic interference colors and high relief (Figure 4c).

Hydrothermal solutions also plays an important role in enriching the rock by uranium and forming of secondary uranium autunite which occurs in the form of rose-like crystals associating the iron oxides that stained the amorphous silica (Figure 4d).
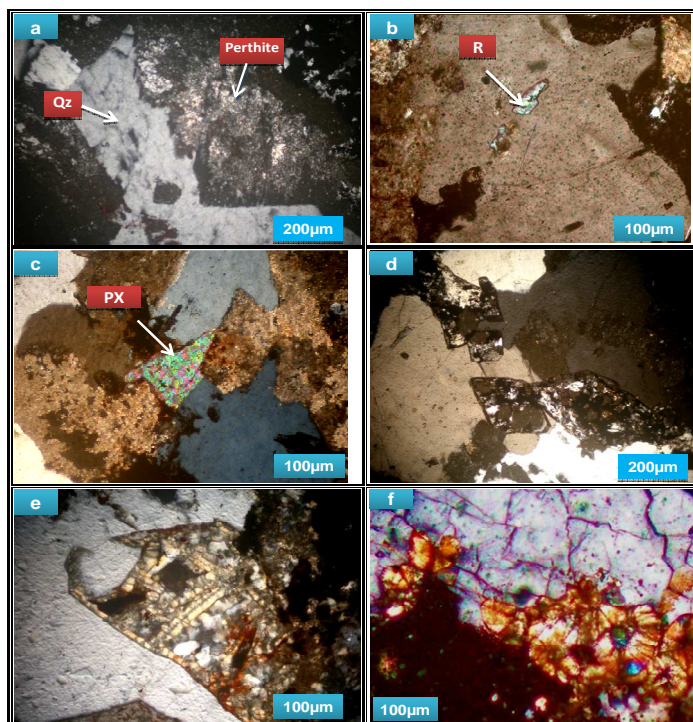
Figure 2. Photomicrographs of Nusab El Balgum silicified granite showing
a) Quartz corroded by the potash feldspar. C.N.20.
b) Minute crystals of secondary rebeckite(R) .C.N.40
c) Euhedral crystal of aegirine-augite (PX). C.N.40
d) Pseudomorphs alkaline minerals. C.N.20
e) Zircon forms chain-like aggregate. C.N.40
f) Rose-like crystals of autunite mineral. C.N.40
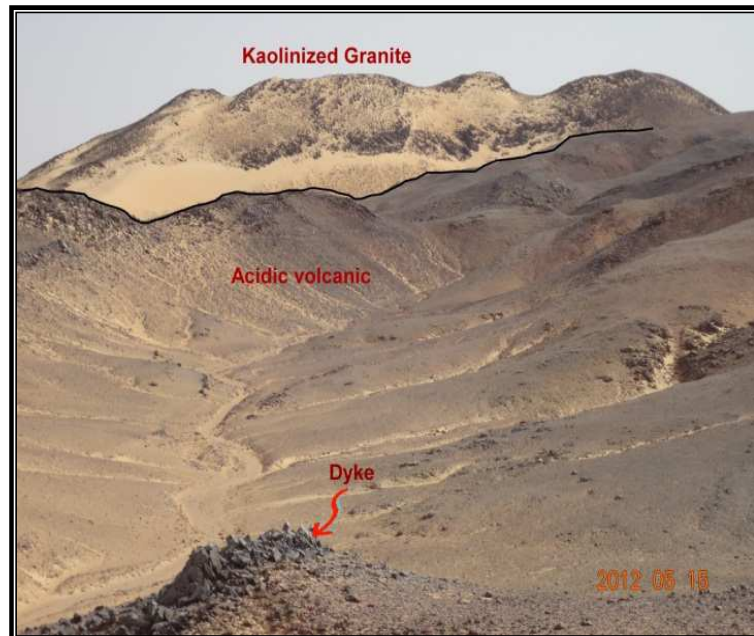
Figure 3. Photomicrograph showing volcanic rocks intruded by kaolinized granite
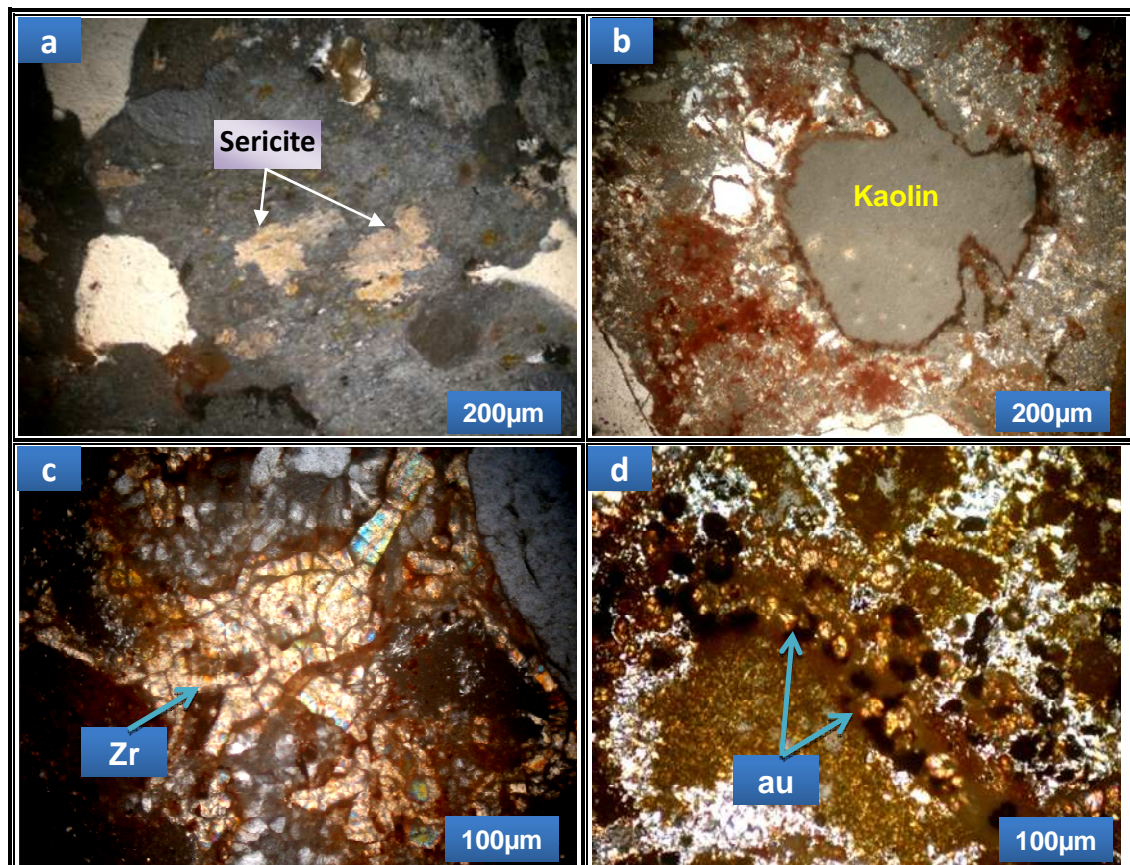
Figures 4. Photomicrographs of Nusab El Balgum kaolinized granite showing:
a)The alteration of potash feldspars to sericite. CN.20
b)Kaolin mineral as alteration product. CN.20
c)Aggregates of immature zircon. C.N40
d)Rose-shape of autunite(au). C.N.40

Mineralogical results

The obtained data from both X-ray diffraction and ESEM analyses (Table1) revealed the presence of the following mineral groups: 1- Radioactive minerals, 2- rare metals and 3-Accessory minerals.

Table 1. Results of the identified minerals in the altered granites

Rock type	Radioactive minerals	Rare Metals		Accessory Minerals
		Primary	Secondary	
Silicified Granite	Uranophane, Autunite Thorite	Gold Pyrite, Galena, Sphalerite, Nickel	Atacamite Barite	Hydrothermal Zircon, Xenotime, Apatite ,Ilmenite, Hematite
Kaolinized Granite	Thorite Autunite	Pyrite, Galena, Sphalerite	Atacamite	Hydrothermal Zircon, Xenotime, Apatite, Ilmenite ,Hematite

RADIOACTIVE MINERALS

Uranium mierals

Most uranophane appears to be of supergene origin where it can be noticed in the oxidized parts of deposits. Uranophane **[Ca (UO$_2$) (SiO$_2$)$_2$(OH)$_2$.5H$_2$O] and autunite** are present as small aggregates on quartz surface in silicified granite of Gabel Nusab El Balgum area**,** (Figures 5a and 2f and 4d). The grains are very soft with different grades of yellow to waxy dull color. The U contents range from 35 to 180 ppm in silicified granite (table 2). The EDX analysis gives a Ca: U: Si ratio equal 1:5:1.5, however the analyses were considered as semi-quantitative.

Thorite, (Th, U) SiO$_4$

Thorite was rarely found as individual crystals and frequently as fine laths or rose shape associated with quartz. Thorite grains are composed mainly of Th (71.7 wt. %), U (9.7wt. %), Si (7.8 wt. %) and REEs (6wt. %) with considerable amounts of P (Fig.5b). Thorite occurs mainly as laths shape associated with rare earths and composed of Th (60 wt. %), REEs (13 wt. %) with considerable minor amounts of U (Fig.5c).

RARE METALS

Native gold (Au)

Gold nugget is usually 35 to 60 percent gold, and the remainder mostly silver. The native gold occurs as bright spots with traces of copper coating on quartz grains in the silicified granite (Figure 5d). Au contains (from 9 to 0.35 g/t) in silicified granite, (0.3 g/t) in kaolinized granite, (0.3 g/t) in volcaniclastic rocks and (0.5 g/t) in post-granitic dykes by using fire assay technique.

As compared, gold and silver in silicified granite with the average gold content of igneous rocks 0.005 ppm (Rankama and Sahama, 1950), or its crustal abundance 0.004 ppm (Govett 1983), and the average silver content of igneous rocks is 0.1 ppm (Goldschmidt, 1937a; Rankama and Sahama, 1950) and the crustal abundance is estimated to be 0.08 ppm (Hamaguchi and Kuroda, 1959), the silicified granite is enriched in Au (9g/t) and Ag (7ppm).

Nickel (Ni)

Native nickel is extremely rare in nature, as it is almost always alloyed with iron . Iron meteorites , for example, are typically 6% to 20% nickel. It is a silvery-white lustrous metal with a slight golden tinge. Nickel was found in silicified granite of the study area and confirmed by ESEM technique (Figure 5e). The analyses show that Ni about 73wt. % with traces of Fe.

Pyrite (FeS$_2$)

Pyrite is the main sulphide mineral encountered in the study area. During the oxidation of pyrite, oxygen is consumed, resulting in a reducing environment at the zone of the reaction.

$$4FeS_2 + 15 O_2 + 10H_2O \rightarrow 4FeO (OH) + 8H_2SO_4$$
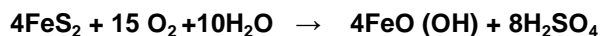
The above equation also indicates how an acidic environment is generated during the oxidation of pyrite. ESEM analysis shows the Fe: S ratio equal 1:1.5 (Figure 5f), with small amounts of Si. Another type of pyrite was recorded called oxidized pyrite where Fe increases and S disappear, Fe: S ratio equal 6.5:1 with traces of Cu, Ni, Cl and Mn (Figure 5g).

Galena (PbS)

Galena occurs most frequently together with sphalerite .Occurrence of lead and zinc sulphide may be of low-, intermediate- or high temperature origin (Deer et al., 1992). Galena was found in granites in two shapes as flacks with Pb: S ratio equal 1.1:1 and traces of Ba (Fig.5h), or as cubic-octahedral crystals where Pb: S ratio equal 1:1(Figure 5i).

Sphalerite (Zn, Fe) S

Sphalerite is found in association with galena, pyrite, and other sulfides. Its color is usually gray to gray-black. Its luster is sub metallic for high iron varieties. Sphalerite, also known as blende or zinc blende, is the major ore of zinc when pure (with little or no iron). The mineral was recorded in the study area in granitic rocks where Zn: S ratio equal 4.4:1 with some traces of Fe (Figure 5j).

Atacamite $Cu_2Cl (OH)_3$

Atacamite is a copper halide mineral , formed from primary copper minerals in the oxidation or weathering zone of arid climates. The chemical compositions of atacamite are relatively rich in Cu and Cl about over 90% with minor traces of Zn and S (Fig.5k).

Barite ($BaSO_4$)

Barium contents in the silicified granite range from 53 to 426 ppm (table 2). Barite is secondary base metals. Barite was recorded in silicified granite showing Ba: S ratio equal 1.1:1, with traces of Si in silicified granite (Figure 5l).

ACCESSORY MINERALS

Zircon ($ZrSiO_4$)

Magmatic zircon was recorded in different rock types in the study area, but the hydrothermal type was concentrated in altered granites only. Red and black hydrothermal zircon was common. Hydrothermal zircon varies in shapes; cylinder, botryoidal and rounded zircon (Fig.5m). In hydrothermal worm zircon, adsorb concentration of LREEs (50 wt. %) on its surface, and cotunite mineral ($PbCl_2$) (Fig.5n).

Xenotime (YPO_4)

Xenotime was found in silicified and kaolinized granite in Nusab El Balgum area coating on iron oxides on its surface and not found as individual grains. The EDEX analyses gave, P (14 wt. %), Y (17.6 wt. %) and Fe (56 wt. %)(Figure 5o).

Apatite (Ca PO_4)

Apatite is the most common phosphate mineral, and is the main source of the phosphorus. Apatite was recorded in the study area in kaolinized and silicified granite with Ca: P ratio equal 2:1and contains cerite mineral on its surface (Figure 5p).
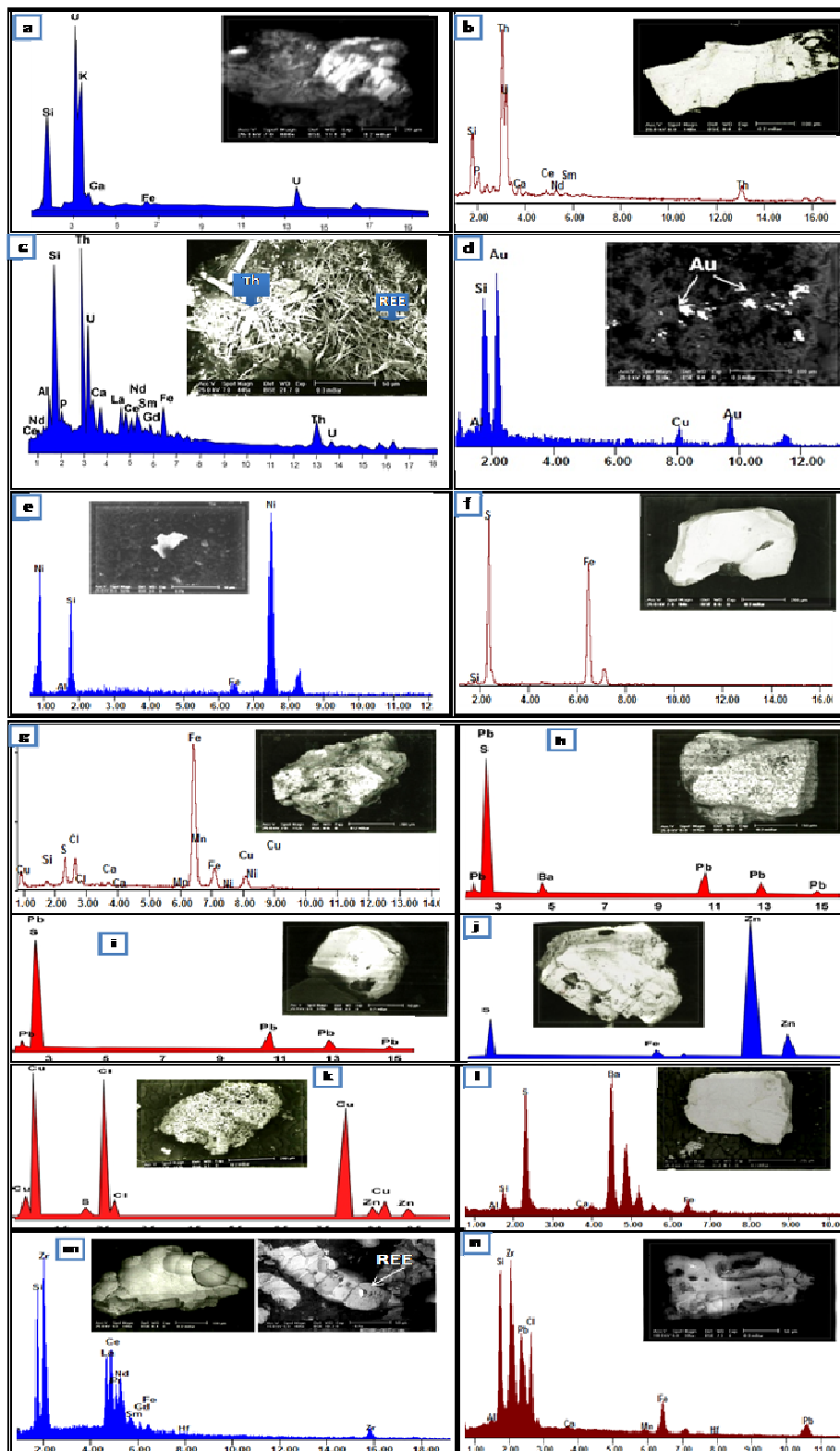
Figure 5. EDX and BSE images showing: a) uranophane b and c)variable shapes of thorite d)native gold e)native nickel f)pyrite g) oxidized pyrite h and i) galena j) sphalerite k) atacamite l) barite m and n) different types of zircon mineral o) xenotime p)cerite on the surface of apatite

Trace element geochemistry

The studied samples were analyzed in the laboratories of the Egyptian Nuclear Materials Authority and faculty of engineering, Kyushu University, Japan by X-ray Fluorescence technique for major oxides and some trace elements. Generally, the rocks are subjected to various degrees of alteration, accompanied by changes in the original mineral and redistribution of some mobile elements. The mobility of the major elements during the alteration processes results from the dissolution and the destruction of the pyrogenic phases hold these elements. The trace element analyses of samples from the alteration zones observed in Nusab El Balgum silicified and kaolinized granite are listed in Tables (2 and 3). Igneous rocks contain 80 ppm Zn on average (Sandell and Goldich, 1943), and lead has an estimated average crustal abundance of 16 ppm (Govett, 1983), average As content of igneous rocks is 5ppm (Goldschmidt and Peters, 1934) and the crustal abundance is 2ppm (Govett, 1983).

In general, all studied rocks show enrichment of most large ion lithophile elements (LILE) and (HFSE) elements and depletion of Sr, V, Cr and Ni. The averages for all the samples in the study silicified granite are 327 ppm Zn, 124 ppm Pb and 45 ppm. As, so that lead may be said to be enriched in relation to their crustal abundances or average contents in igneous rocks. The abundance of barium and strontium in felsic rocks is 830 ppm and 33ppm, respectively (Govett 1983).The low strontium content is due to the destruction of K-feldspar and plagioclase. Barium was principally bound to K-feldspar, and its fluctuation within the alteration is due to the variation in the amount of sericite in the whole rock samples.

Table 2. Chemical analysis of some trace elements (ppm) for silicified granite

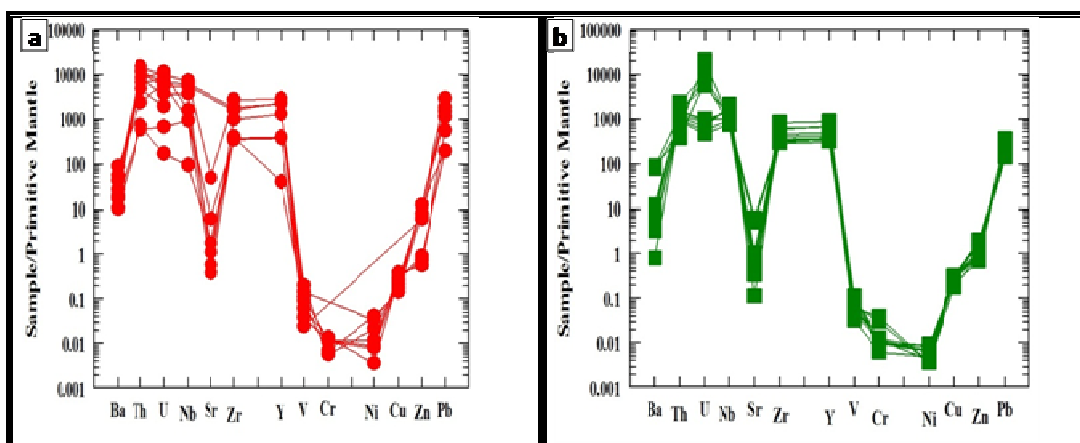|				Silicified granite					
				Trace Elements(ppm)					
	1	2	3	4	5	6	7	8	Av.
V	26	3	14	12	5	18	8	5	11
Cr	21	u.d	36	17	33	u.d	40	35	26
Co	35	--	14	21	12	30	u.d	14	21
Ni	81	18	18	42	16	68	7	23	36
Cu	4	11	11	6	7	5	8	8	7
Zn	405	301	28	601	592	610	45	36	327
Pb	133	215	64	177	23	331	22	23	124
Ag	12	15	6	8	4	12	--	2	7
Hg	u.d	u.d	u.d	u.d	u.d	u.d	--	u.d	u.d
Cd	1	0	u.d	8	7	9	--	u.d	4
As	80	80	13	55	23	86	--	12	45
Sb	10	9	13	5	6	3	--	4	7
Sn	69	65	7	45	30	60	--	19	38
Bl	2	1	3	0	0	0	--	4	2
Mo	285	250	6	156	60	251	--	32	132
W	191	150	31	128	110	146	--	46	109
Rb	10	103	7	25	40	9	u.d	1	28
Sr	u.d	817	32	10	20	0	112	7	125
Ga	54	99	24	50	15	85	12	16	44
Ba	95	207	82	208	135	280	426	53	186
Y	7323	9528	134	4490	1285	7694	1254	1332	4130
Zr	14743	22400	3209	8024	2848	13200	2856	2989	8784
Nb	3467	3945	51	1994	900	3088	507	521	1809
Th	792	954	5	529	321	737	152	37	441
U	112	180	3	68	35	100	110	12	77
S	u.d	0	7045	791	1540	41	--	479	1649
Cl	155	0	226	346	492	200	--	134	259

Unmeasured elements   U.d: under detection limit

Table 3. Chemical analysis of some trace elements (ppm) for kaolinized granite

Trace Elements(ppm)											
	1	2	3	4	5	6	7	8	9	10	AV.
V	11	13	14	7	8	6	8	9	4	9	9
Cr	28	29	34	37	116	30	36	89	18	29	45
Co	u.d	9	u.d	1	u.d	u.d	u.d	u.d	u.d	10	3
Ni	13	13	13	10	7	14	8	7	10	18	11.3
Cu	8	8	6	9	7	9	7	5	9	8	7.6
Zn	48	55	35	60	46	103	49	47	88	83	61
Pb	23	40	32	16	21	18	22	23	20	17	23
Ag	5	8	0.0	2	--	2	--	--	2	4	3.3
Hg	u.d	u.d	4	u.d	--	u.d	--	--	u.d	u.d	0.6
Cd	u.d	u.d	10	u.d	--	u.d	--	--	2	2	2
As	13	18	22	12	--	11	--	--	7	14	14
Sb	5	11	7	6	--	6	--	--	9	7	7.3
Sn	12	41	38	36	--	24	--	--	26	20	28
BI	2	4	4	3	--	3	--	--	2	0.0	206
Mo	50	62	75	41	--	27	--	--	36	33	46
W	100	68	36	26	--	51	--	--	40	46	52
Rb	50	158	162	2	3	9	u.d	86	130	8	68
Sr	2	12	18	14	88	6	99	110	9	14	37
Ga	14	22	14	17	11	14	15	9	13	15	14
Ba	17	60	31	40	424	16	375	409	4	36	141
Y	2222	2853	2193	1618	1009	1170	1125	1237	1427	1447	1630
Zr	5025	6476	4968	3641	2286	2620	2520	2825	3209	3243	3681
Nb	875	1129	867	634	406	457	449	503	559	567	645
Th	74	72	95	92	23	59	37.5	75	61	96	69
U	15	12	17	100	120	8	360	160	10	18	82
S	13	1623	1700	4878	--	188	--	--	534	2066	1571
Cl	86	262	282	131	--	250	--	--	260	266	220

Unmeasured elements   U.d: under detection limit

Figures 6. Normalized multi-element patterns for the studied a) silicified and b) kaolinized granitic rocks using the primitive mantle values of Sun and McDonough (1989)

Table 4. Results of fire assay analyses for the altered granites, volcanic rocks and post granitic dykes

	silicified granite			Kaolinized granite		Volcanic rocks			Dykes	
Sample No	1	2	3	4	5	6	7	8	9	10
Au(g/t)	9	1.24	0.35	0.3	0. 3	0.32	0.4	0.3	0.36	0.5

Table 4 shows the results of fire assay analyses for 10 samples from the altered granites, volcanic rocks and post granitic dykes. The silicified granite samples have higher content of gold (ranges from 9 to 0.35 g/t) than the kaolinized granite samples (0.3 g/t).

Table 5. Correlation matrix between some major elements and rare metals in altered granites

	Au	SiO₂	Al₂O₃	FeOᵗ	As	Ag	Ni	Cu	Zn	Pb	Y	Zr	Nb	Th	U	Mo	W	Sn	Ga
Au	1																		
SiO₂	-0.07	1																	
Al₂O₃	-0.13	-0.5	1																
FeOᵗ	0.57	-0.2	-0.3	1															
As	0.5	0.2	-0.9	0.5	1														
Ag	0.72	0.3	-0.8	0.46	0.9	1													
Ni	-0.3	0.35	-0.9	0.2	0.7	0.4	1												
Cu	0.7	-0.3	0.6	0.18	-0.3	0.06	-0.8	1											
Zn	0.14	0.02	-0.8	0.3	0.9	0.7	0.83	-0.3	1										
Pb	0.4	-0.2	-0.6	0.33	0.87	0.75	0.6	-0.2	0.92	1									
Y	0.7	0.2	-0.8	0.6	0.96	0.98	0.5	-0.03	0.8	0.8	1								
Zr	0.84	0.21	-0.6	0.65	0.84	0.96	0.28	0.23	0.5	0.65	0.96	1							
Nb	0.63	0.3	-0.8	0.61	0.96	0.96	0.56	-0.08	0.7	0.75	0.99	0.95	1						
Th	0.63	0.2	-0.8	0.65	0.97	0.95	0.57	-0.09	0.8	0.8	0.99	0.94	1	1					
U	0.8	0.16	-0.7	0.71	0.88	0.95	0.4	0.1	0.63	0.7	0.98	0.9	0.97	0.96	1				
Mo	0.4	-0.2	0.1	0.3	0.99	0.92	0.3	-0.3	0.86	0.5	0.9	0.83	0.96	0.66	0.87	1			
W	0.3	-0.01	-0.4	0.41	0.93	0.9	0.7	-0.4	0.7	0.6	0.85	0.75	0.91	0.6	0.7	0.9	1		
Sn	0.4	0.1	-0.1	0.3	0.8	0.8	0.6	-0.2	0.87	0.68	0.88	0.6	0.8	0.8	0.8	0.9	0.7	1	
Ga	0.72	0.2	-0.01	0.4	0.9	0.9	0.4	-0.3	0.7	0.89	0.93	0.9	0.87	0.91	0.92	0.8	0.8	0.8	1

In general gold have strong positive correlation with Ag, Cu, Y, Zr, Nb, Th and U, moderately positive correlation with As and FeOᵗ and weakly negative correlation with Ni Table (5). Uranium have very strong positive correlation with Th, Nb, Zr, Y, Ag, As, Au, strong positive with Pb and Zn and moderately positive with Ni. As have strong positive correlation with Zn, Ag, Pb, Y, Zr, Th, Nb and U, weakly negative with Cu.

R-mode factor analysis

R-mode factor analysis is concerned with interrelation between variables; each variable attributes a certain loading to each of the extracted factors, which is expressed in the matrix of factor loading. The initial step in calculating R-mode factor analysis is to compute a correlation matrix. The latter was calculated using log-transformed values (Table 6).

Table 6. Factor correlation values (r) for the altered granites

	Factor (1)	Factor (2)	Factor (3)
Au	0.88	-0.73	0.05
V	0.01	0.98	-0.05
Cr	-0.77	0.17	-0.51
Co	0.34	0.93	0.09
Ni	0.46	0.85	0.24
Cu	0.02	-0.98	-0.15
Zn	0.68	0.50	0.49
Pb	0.70	0.17	0.55
Ag	0.99	-0.03	0.02
As	0.92	0.27	0.30
Sb	0.21	-0.09	-0.96
Sn	0.94	0.30	-0.14
BI	-0.52	-0.02	-0.85
Mo	0.92	0.32	0.21
W	0.77	0.38	0.27
Y	0.98	-0.01	0.22
Zr	0.97	-0.23	0.08
Nb	0.98	0.08	0.15
Th	0.97	0.07	0.23
U	0.96	-0.18	0.18
S	-0.40	0.00	-0.74
Cl	-0.37	0.68	-0.33
Ga	0.91	-0.12	0.33

Factor 1 (Au–Pb-Ag–As–Sn-Mo- W- Y– Zr– Nb–Th-U-Ga)

Factor 1 explains 61.2% of the total variance, and has high loading values of (0.8, 0.7, 0.99 0.92, 0.94, 0.92, 0.77, 0.98, 0.97, 0.98, 0.97, 0.96 and 0.91) for the variables of Au, Pb, Ag, As, Sn, Mo, W, Y, Zr, Nb, Th, U and Ga respectively. This factor is therefore composed of these variables; it can be termed a rare metals factor.

The association of Mo, Sn, W and Pb is typically of felsic rocks and is, therefore, considered as lithologically controlled. Moreover, specks of gold and sulfide disseminations were observed in quartz surface. As value is usually pathfinder for Au (Tables 2 and 3) and agree with Hale (1981) and Samal et al. (2008).

Factor 2 (Ni–Co–V)

Factor 2 accounts for –22.7% of the data variability of this model and reflects, essentially, a mafic lithological control and has high loading values of (0.98, 0.93 and 0.85) for V, Co and Ni respectively. This factor has negative relation with Au, which mean that the source of gold wasn't mafic rocks.

Radioactivity of the granitic rocks

The results of the radiometric studies are shown in Table (6). From this table, it is clear that, the silicified granite is more radioactive than the kaolinized granite.

The eU and eTh contents in the silicified granite range from 5- 275 ppm and from 7-1395 ppm respectively. The eU and eTh content in the kaolinized granite (10 44 ppm) respectively and (36-235 ppm) respectively in kaolinized granite. D-Factor for silicified granite (av.3.7) is lower than that of kaolinized granite (av.4.1). The high anomalous in the silicified granite (1- 3-4-5-10) are strongly affected by hydrothermal alteration, that revealed by the ferrugenation processes. The supergene uranium mineralization in the silicified granites is related to hydrothermal solutions transported along a channel ways (faults).The main alterations comprise intense red hematization, kaolinization and silicification processes.

Hematization is the most common alteration feature in the form of abundant dark red to blackish brown hematitic dusts as nests or staining fracture surfaces around the uranium minerals. There is a +ve correlation between the degree of hematization in silicified granite and the intensity of uranium mineralization (av.69).

This may be due to the high ability of iron oxides for absorbing uranium minerals from its bearing solution (Hussein et al., 1965) or due to the prevalence of oxidation conditions and complexing ions, that cause the precipitation of uranium as complex uranyle ions. The intense hematization of the silicified granitic rocks (Fe^t = 10%) indicates the presence of alkaline hydrothermal solutions possessing temperature varying between 300^0C and 350^0C (Sweenwald and Sayfried, 1990; Attawiya et al., 1999).

The higher values of eTh/eU ratios suggest that uranium loss is manifested than thorium gain. Steenflet (1982) stated that an eTh/eU ratio greater than six may indicate loss of uranium. On the other hand, the range of eTh/eU ratio in granite commonly lies between 2-6 (Rogers and Adams, 1969). All samples lies between lines eTh/eU (0.1-10) (Figure 7). Average U chemically in silicified and kaolinized granites (107-91) is higher than eU (69-24) respectively; indicate addition (gain) of uranium.

Table 6. Showing the radiometric results for granitic rocks

	Sample No	eU(ppm)	eTh(ppm)	Ra(ppm)	K%	U_{ch}	Th_{ch}	P –factor eU/Ra	D-factor U_{ch}/eU	U/Th
Silicified granite	1	275	1395	167	UDL	180	954	1.6	0.7	0.19
	2	1	7	2	0.78	3	5	0.5	3	0.6
	3	5	496	83	0.6	60	0	0.1	12	0
	4	34	178	32	0.7	200	262	1.1	6	0.76
	5	44	244	33	0.8	200	516	1.3	4.5	0.39
	6	29	297	77	0.5	35	312	0.4	1.2	0.11
	7	52	500	83	UDL	100	737	0.6	2	0.14
	8	83	507	98	UDL	130	727.5	0.8	1.6	0.18
	9	70	275	149	UDL	140	433	0.5	2	0.32
	10	188	573	102	0.62	112	792	1.8	0.6	0.14
	11	33	34	18	0.54	12	37	1.8	0.4	0.32
	12	10	52	10	0.26	110	151.5	1	11	0.73
	Average	69	380	71.2	0.6	107	410.6	1	3.7	0.3
Kaolinized Granite	13	21	74	20	1.5	180	152	1.1	8.6	1.2
	14	23	57	15	0.9	15	75	1.5	0.7	0.2
	15	36	68	18	3.8	17	95	2	0.5	0.2
	16	44	57	18	3.41	12	72	2.4	0.3	0.2
	17	10	37	14	0.12	100	92	0.7	10	1.1
	18	23	54	13	0.54	120	23	1.8	5.2	5.2
	19	10	50	11	0.91	8	59	0.9	0.8	0.1
	20	40	235	12	0.17	360	37.5	3.3	9	9.6
	21	18	36	12	2.04	160	75	1.5	9	2.1
	22	16	47	13	2.74	10	61	1.2	0.6	0.2
	23	20	68	16	0.26	18	96	1.3	0.9	0.2
	Average	24	71	15	1.5	91	76	1.6	4.1	1.8

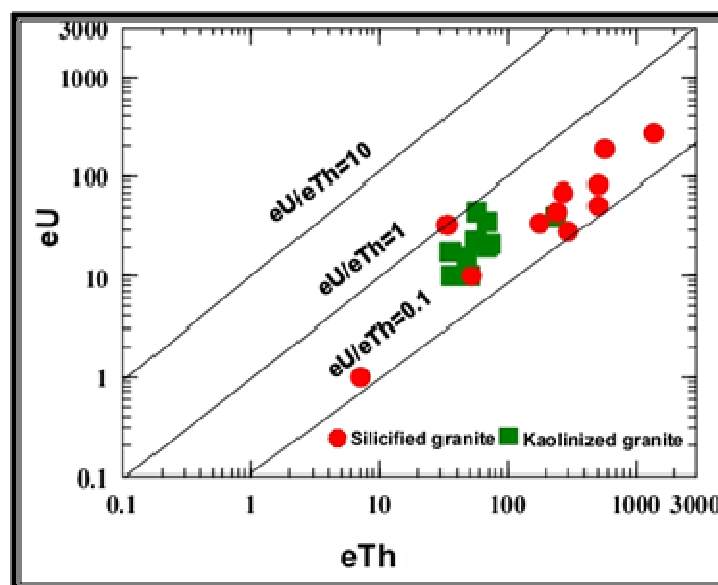*Not chemically analyzed.   UDL: under detection limit

Figure 7. Variation diagrams between eU and eTh

SUMMARY AND CONCLUSIONS

The mineralogical studies confirm the presence of three mineralization stages, the earliest mineralization stage (high temperature stage) which is characterized by the formation of native Au associated with primary sulfide minerals such as pyrite, galena, sphalerite and native Ni. The presence of second stage (lower-temperature) is characterized by the formation of secondary minerals; barite and atacamite. Third stage is related to carbonate facies formed after the oxide (supergene alteration).

   In Nusab El Balgum area, southwestern Desert of Egypt the recorded gold contents in the silicified granite (0.3 - 9 g/t) is more than kaolinized granite (0.3 g/t) , pyroclastics(0.3g/t) and post granitic dykes(0.5g/t) and considered as a first record. The silicified granite is also higher than kaolinized granite in HFSE.
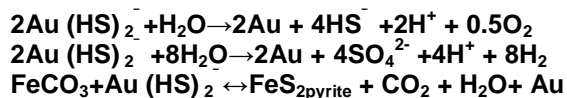
   Botros (2004) classified gold deposits of Egypt into three groups. These are strata bound deposits and non-stratabound deposits hosted in igneous and metamorphic rocks, as well as placer gold deposits. The most important one is non-stratabound gold deposits, which are divided into –a-vein type mineralization, which has constituted the main target for gold in Egypt since Pharaonic times, and –b-disseminated-type mineralization hosted in hydrothermally altered rocks (alteration zones) which have recently been recognized as a new target for gold in Egypt. Gold always occurs as inclusions or associated with sulfide minerals, while gold in the study granite occurs as nuggets disseminated in quartz surface and not associated with sulfide minerals. The source of gold with its native nuggets is mostly hydrothermal solutions

   Merton (in EGSMA, 1912) mentioned that the gold grade increases with depth. In hydrothermal deposits, gold is most commonly associated with silver and the rare metals; copper, lead and zinc. The rare-metal values are generally high as pyrite, native Ni, sphalerite and galena. Gold mineralization in the study area is auriferous and of disseminated-type in agrees with Botros (2004).The gold is transported up through faults by hydrothermal waters and deposited at temperatures of 300°C to 400°C and pressures of 1 to 2 kbars(Klemm et al. , 2001)when the water cools too much to retain gold in.

   Mineral assemblages formed during hydrothermal alteration reflect the geochemical composition of ore-forming fluids. Gold is mainly transported in solution as Au-Cl and Au-S complexes. The change of physicochemical conditions such as temperature, pressure, oxygen fugacity, and sulfur fugacity are effective mechanisms for gold precipitation. Gold tends to be concentrated in the vapor phase of fluids at high temperatures and pressures. Au-As and Au-Sb associations are common in gold deposit. Hydrothermal fluids forming epithermal gold deposits are Au-saturated in most cases, whereas fluids of Carlin-type are Au-under saturated.

   The occurrence of gold mainly depends on temperature, pressure, pH values, Cl^- concentration, and fugacity of H_2S in a hydrothermal system. Gold mostly occurs as $AuCl_2$ in a system with temperature higher than 400^0C(Gammons and Williams-Jones,1997), and with decreasing temperature being the primary mechanism causing gold deposition. $Au(HS)_2^-$ is the dominant phase at lower temperature, and the maximum solubility exists in the vicinity of the

$H_2S-HS^- -SO_4^{2-}$equilibrium point; then, with the decline of oxygen fugacity, the Au-S complex breaks down, leading to gold precipitation (Cooke and Simmons, 2000; Robb,2005).

2Au (HS)$_2^-$ +H$_2$O→2Au + 4HS$^-$ +2H$^+$ + 0.5O$_2$
2Au (HS)$_2^-$ +8H$_2$O→2Au + 4SO$_4^{2-}$ +4H$^+$ + 8H$_2$
FeCO$_3$+Au (HS)$_2^-$ ↔FeS$_{2pyrite}$ + CO$_2$ + H$_2$O+ Au

Six stages of alteration assemblages have been identified (Figure 8) based on field and microscopic investigations(sericitization, silicification, carbonization, hematization chloritization and kaolinization).Activities of the tectonic movements created channel ways which allows hydrothermal fluids to infiltrate wall rocks, leading to diffusive alteration processes on the two types of granites. Sericitization followed and overprinted K-feldspar alteration. Subsequently silicification followed by carbonization has occurred. Gold mineralization was closely related to silicification alteration.

The rare metals enrichment in the study area are formed due to the subsequent processes; including the ascending hydrothermal solution (alkaline and acidic hydrothermal solutions), with further contribution of the descending acidic meteoric water; supergene enrichment processes. The alkaline hydrothermal solution in silicified granite was under PH more than 7and T. (300^{0}C to 350^{0}C) where total FeO^t (Av.6.5 in silicified and 4.3 in kaolinized). The acidic solution was under PH ranges from 2 to 3 with low temperature varying between 200^{0}C to 250^{0}C (Helgeson,1969).

Figure 8. Paragenetic sequence for the minerals in the altered granites, Nusab El Balgum area

Stage / Mineral	K-feldspar alteration	Sericitization	Silicification	Hematization	Kaolinization	Carbonitization
Qz	————————	————————	————————	————————	——————	
K-feldspar	——————					
Albite	————	———				
Sericite		————		————————	———	
Kaolin					————————	———
Pyrite		———————	————————	———		
Sphalerite		———————	————————	———		
Galena		—————	————————	——		
Atacamite		———————	————————	———		
Barite			————————	———		
Zircon	————————	————————	————————	————————	———	
Thorite		———————	————————	————————	————————	—
Uranophane		———	————————	——		
Native Ni		———————	————————			
Gold			————————	———		

Precipitation of hematite is due to extensive alteration of pyrite and probably decreased the pH of the alkaline solution and rising acidic fluids. The presence of clay minerals (related to alteration of feldspars) indicates a high temperature environment (higher than 200ºC). The mixing of volatile fluids with meteoric water and fluid- wall rock interaction result in changes in pH and oxygen activity and deposition of hypogene rare metals (nickel, gold, galena and sphalerite) and supergene ones (atacamite, barite and secondary uranium) in fractures filling of altered granites**.**

The sudden change in the pH and temperature of the fluids will lead to destabilization of rare metal complexes favoring their deposition (Alexandrov et al., 1985).The rare metals mineralization are accumulate in the residual melt of the late fractionate (Bright, 1974) especially upward in the magmatic system (Smith, 1979). During the emplacement of the post granitic dykes, the rare metals were precipitated from saline and reduced fluids as sulfides due to cooling, fluid mixing and wall rock reaction.

Depending on Oxygen fugacity (fO$_2$) in the final magmatic fractionation, uranium tend to form the relatively soluble uranyle ion (UO$_2$) $^{+2}$, hence, hydrothermal processes during final stages of crystallization of the granitic magma are important in controlling the later redistribution of uranium within the rocks (O'Connor et al., 1982).The origin of uranium appears to be closely associated with the rare metals mineralization and may be reflects readily their intimate coherence.

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